NBS BUILDING SCIENCE SERIES 125

An Economic Model for Passive Solar Designs in Commercial Environments

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An Economic Model for Passive Solar Designs in Commercial Environments

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PREFACE

This report was prepared by the Applied Economics Group, Building Economics and Regulatory Technology Division, Center for Building Technology, National Engineering Laboratory, National Bureau of Standards (NBS) for the Department of Energy, Office of Solar Applications for Buildings, under Interagency Agreement EA-77-A-01-6010.

The work is in support of the Solar Cities Program, whose broad objective is to increase the application of solar technology in cities and towns by developing methodologies, guidelines, and examples specific to the urban environment. This report provides a method for the economic evaluation of passive solar designs for commercial buildings, as well as illustrative case examples. The case examples are based on solar designs and thermal performance characteristics described in "Design and Analysis of Passive Solar Heating Solutions for Neighborhood Commercial Strip Settings" [1], a separate paper by the Environmental Design Research Division, Center for Building Technology, National Bureau of Standards.

A number of other NBS reports in support of the Solar Cities Program also complement the economic research described in this publication. These separate reports document research in the following areas: the use of solar energy in commercial environments [2], computer modeling of solar gain through various types of glazings in urban environments [3], and the effects of climatological factors on window-shopping and other pedestrian behaviors in retail environments [4, 5].

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The author wishes to thank all those persons in the Applied Economics Group and Architectural Research Group, Center for Building Technology, National Bureau of Standards, who contributed to the preparation of this report. Rosalie T. Ruegg provided direction to this economics project and invaluable editorial and technical assistance. S. Robert Hastings, project leader of the NBS component of the Solar Cities Program, organized and managed the research effort at NBS. Kalev Ruberg provided the solar designs and thermal analyses for the case examples included in this report. Dr. Harold E. Marshall, Chief of the Applied Economics Group, and Dr. Carol Chapman Rawie also deserve special thanks for the time they spent in discussing and reviewing this report. Appreciation is extended to Colonel Denver Lovett, Center for Consumer Product Technology, National Bureau of Standards, for assisting in the identification and evaluation of real estate investment factors important to solar energy investment decisions for commercial buildings. Thanks are also due to the other NBS reviewers, Heinz R. Trechsel, Mark L. McKinstry, and Dr. Justin Kim, for their comments and suggestions. The author wishes to acknowledge Mr. Frank deSerio of the Department of Energy, Program Manager of the Solar Cities Program, for providing financial support and general guidance to this project.

Photograph Credits: Pages viii, 1/Kalev Ruberg and S. Robert Hastings; page 5/Table Mountain Architects and Engineers; pages 10, 11, 45/ Kalev Ruberg; pages 17, 125/John Holton, page 97/Kalwall Corporation.

ABSTRACT

This report presents an economic model for evaluating passive solar designs in commercial environments. It discusses the literature on this topic and draws upon this literature to develop a general methodological framework. The model incorporates a life-cycle costing approach that focuses on the costs of purchase, installation, maintenance, repairs, replacement, and energy. It includes a detailed analysis of tax laws affecting the use of solar energy in commercial buildings. Possible methods of treating difficult-to-measure benefits and costs, such as effects of the passive solar design on resale value of the building and on lighting costs, rental income from the building, and the use of commercial space, are presented. The model is illustrated in two case examples of prototypical solar designs for low-rise commercial buildings in an urban setting. These designs were developed at NBS under the Solar Cities Program. The two designs, a wall collector system and a street canopy, are evaluated for a neighborhood in Baltimore undergoing urban renewal. Results of the analyses indicate these designs may be economically feasible under a realistic range of economic conditions. Topics requiring further research are identified.

KEY WORDS: Benefit-cost analysis; building economics; commercial buildings; investment analysis; life-cycle cost analysis; passive solar energy; retrofit; revitalization; solar energy systems.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

Page

LIST OF FIGURES AND TABLES

Above and facing page: A *series of "greenhouses" adjoin the exterior walls of the First Wisconsin National Bank Building, Madison, Wis.*

EXECUTIVE SUMMARY

Widespread use of passive solar energy systems in commercial buildings depends upon the economic feasibility of such systems. Because active and passive solar energy systems for commercial and residential buildings have significantly different characteristics, they require separate study. Different assumptions and data are required for the evaluation of passive solar designs for commercial buildings than for the evaluation of active systems for commercial buildings or the evaluation of residential passive systems. Corporate tax laws alone have a major impact on the economic feasibility of capital investments by businesses. In addition, some passive solar designs for commercial

settings have significantly different cost and benefit profiles than those typical of active systems or residential passive systems. Furthermore, commercial investors tend to use shorter investment study periods than have been used typically in evaluating residential solar energy systems, periods considerably shorter than the service lives of most passive solar components. Consequently, passive system components of commercial buildings can be expected to have significantly greater resale value at the end of the investment study period than is typically assumed in evaluating residential passive systems, or even commercial active systems.

The purpose of this report is to develop a model that provides a comprehensive assessment of an investment in passive solar energy for a commercial building and that is sufficiently flexible to be useful to a variety of types of commercial investors for evaluating different kinds of buildings and passive systems. Using a benefit-cost approach, the model presented in the report incorporates the costs of purchase, installation, maintenance, replacement, and energy, including the effects of income, property, and sales taxes and of tax incentives for utilization of solar energy at the Federal, State, and local levels. It evaluates effects of the investment on energy costs for both heating and lighting, rental income, space utilization, and resale value of the building. It allows for comparison of the passive solar design with a conventional building design that differs substantially in architectural and thermal characteristics from the passive solar design. The model provides several measures of economic efficiency of passive solar investments.

The report has six sections. Sections 1 and 2 provide background to the issues in passive solar economics explored in the report. Section 3 describes the benefit-cost model in algebraic detail. Section 4 provides a verbal description and discussion of the variables included in the economic model. It suggests different values for key variables such as the discount rate, borrowing rate, investment study period, and tax rates in different investment situations. It provides procedures for estimating values for purchase costs, annual repair and replacement costs, annual operation and maintenance costs, annual energy savings for heating and lighting, annual rental income attributable to the passive solar energy system, and resale value of the system. It also surveys tax incentives currently in effect at the State, local, and Federal levels. By providing an overview of the key variables affecting the economic feasibility of passive solar energy in commercial buildings, this section of the report can be useful to investors and policy makers in identifying situations where passive solar energy is likely to be most cost effective given current conditions. Implications can be drawn regarding the formulation of new policies to encourage increased use of passive solar energy.

The two case examples presented in section 5 of the report evaluate hypothetical designs for retrofitting passive systems to buildings in a neighborhood in Baltimore undergoing urban renewal. These examples serve to illustrate the application of the model. In addition, they demonstrate that passive solar energy may be a promising approach to building rehabilitation in urban areas. The analyses show that the two passive solar designs may be economically feasible over a range of economic conditions and assumptions representative of urban commercial settings. The last section of the report summarizes the key features of the economic model and conclusions of the case studies. Issues requiring further research are identified.

Facing page: *The design for the permanent facilities of the Solar Energy Research Institute makes use of passive solar energy for heating in winter and cooling in summer. Placement of the building in a natural "sun-bowl" on Table Mountain, Golden, Colo., affords the north and west facades shelter from the winter winds while protecting the east and west facades against the summer sun. Solar courts act as thermal buffers to the workspaces while collecting solar energy and light. South wall mass absorbs and stores solar energy for heating. Operable sash and louvers and low-speed fans encourage natural ventilation and cooling.*

1. INTRODUCTION

1.1 BACKGROUND

Energy consumption has become a high priority concern to commercial building owners [6]. Energy is a major portion of the costs of operating office buildings, industrial facilities, and shopping centers, as well as individual shops and stores. Moreover, most commercial buildings are strongly affected by short supplies as well as the high cost of energy. In increasing numbers, commercial building owners are looking for ways to improve the economic efficiency with which they use energy, as well as the reliability of energy supplies.

Passive solar energy is one approach to alleviating the dependence on non-renewable energy sources for heating commercial buildings and industrial facilities. Unlike active solar energy systems, passive systems collect and transport heat by non-mechanical means and usually are integral elements of a building structure. Passive solar energy systems use south-facing glass or plastic for solar collection and thermal mass for heat absorption, storage, and distribution.*

Passive solar energy systems can be incorporated into a new building design, e.g., a building can be built with south-facing windows and massive masonry walls and floors. They can be added (retrofitted) to an existing building, e.g., glazing panels can be added over the south side of an existing wall. They can also be designed to function outside of, but in conjunction with, a group of new or existing buildings, e.g., the space adjacent to buildings along a city block might be enclosed with a glazed canopy.

As is true of most energy technologies, however, the widespread use of passive solar energy systems in commercial buildings is strongly dependent on the economic feasibility of such systems. Experience with commercial building systems as well as methods for evaluating these systems have been limited. Most experience and research in passive solar energy has been in houses, leaving unaddressed many issues unique to commercial applications. Furthermore, because the characteristics of active and passive solar energy systems differ, existing studies of active solar energy systems in commercial environments are not substitutes for the specific economic analysis of passive solar energy systems. Little about the economic feasibility of passive systems can be deduced from the literature on active systems.

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* For a description of the fundamentals of solar energy, heat theory, and basic types of passive systems, see Edward Mazria, The Passive Solar Energy Book [7].

In a recent report of the American Institute of Architects (AIA), the following observation was made:

> "While there is much activity underway throughout the United States in passive solar heating and cooling, these techniques are still not generally incorporated into most new and existing buildings. This lack of passive buildings may be generally traced to . . . [among other factors] . . . a lack of quantitative basis for evaluating design decisions such as estimating cost and performance."*

It is evident that, in order to facilitate the application of passive solar technology in commercial buildings, there is a need for economic procedures, assumptions, and data which comprehensively address both the commercial real estate investment environment and the special technical characteristics of passive solar energy systems.

1.2 PURPOSE

The purposes of this report are 1) to develop a comprehensive method of economic evaluation for appraising the economic feasibility of passive solar designs in commercial settings; 2) to examine the key variables affecting the economic feasibility of passive solar investments in commercial environments; and 3) to determine the economic feasibility of selected passive solar designs under specified conditions.

This report is primarily an analytical tool for the building community and policy makers. It also is intended as a guide to financiers and investors in evaluating the costs and benefits of passive solar energy systems in commercial buildings.

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* AIA Research Corporation, Passive Solar Design: A Short Bibliography for Practioners [8].

1.3 ORGANIZATION AND APPROACH

The report is organized into six major sections. Section 1 is introductory. Section 2 describes major previous work in passive solar economics. Section 3 describes algebraically a benefit-cost economic evaluation model which provides for a comprehensive assessment of the costs and benefits of passive solar designs over the "life-cycle" of the investment. Costs and benefits are evaluated from the point of view of the commercial real estate investor whose decisions are critical to the widespread use of passive solar energy. Several alternative measures of economic performance are provided by the model to establish a basis for comparison against various investment criteria.

Section 4 examines in detail the variables included in the economic evaluation model. It provides suggestions for estimating values for variables in the economic model and for making the appropriate economic assumptions for a given investment situation. The variables considered include 1) costs of passive solar energy systems; 2) benefits of passive solar designs; 3) real estate investment management considerations; and 4) higher property values and extended property lives due to the long service lives of many passive solar components. This section provides guidance to investors and policy makers seeking to understand the key factors affecting the economic feasibility of passive solar designs for commercial buildings.

Section 5 provides case examples which illustrate the application of the economic evaluation model to two specific passive solar designs in realistic urban commercial settings and demonstrate the economic feasibility of these particular designs.

The last section provides a brief summary of the report and descibes future research required to make the proposed methodology a more useful evaluation tool.

Present worth discount formulas and definitions of key symbols used throughout the economic evaluation model are provided in an Appendix to assist the user in applying the model.

Above and facing page: The south-facing masonry wall of this building is being converted to an indirect gain passive solar heating system. Above, the wall is being prepared to receive the solar collector. Facing page, a portion of the glazing is in place.

2. SURVEY OF THE LITERATURE

The major work in passive solar economics has been that conducted jointly by the University of New Mexico's (UNM) Resource Economics Group and the Los Alamos Scientific Laboratory's (LASL) Energy Systems and Economic Analysis Group under sponsorship of the Department of Energy, Office of Conservation and Solar Applications.* This work represents the state-of-the-art in passive solar economic modeling and thus

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* A series of related studies has resulted from this research effort. Those released by LASL/UNM for citation are listed in [9-16].

provides an important reference point for defining some unresolved issues in passive solar economics and for expanding existing evaluation methodologies.

A brief overview of the results of the LASL/UNM model and anlyses is presented below, followed by a discussion of key unresolved issues.

2.1 THE LASL/UNM MODEL

Utilizing procedures for estimating the performance of passive solar heating systems developed by solar engineering research groups at LASL, LASL/UNM developed an economic model for evaluating the costs and energy saving benefits of four passive designs for residential buildings: thermal storage wall, thermal storage roof, direct gain, and attached sunspace. The model allows for variation in the number and type of glazings, storage type and volume, night insulation options, glazing area, glazing to storage ratios, interior temperature swings, and selective coatings.

Each of four passive designs has been integrated into a design specification for a prototypical conventional single-family, single-story, 135 m^2 (1500 ft^2) residence to facilitate consistent comparisons of passive and conventional buildings and energy costs. For each design, the model computes life-cycle energy savings and other measures of economic feasibility for a given location and type of fuel.

The model's subroutines determine for the standard building in different locations the various combinations and sizes of features which yield identical solar contributions to heating the building as well as the unique minimum-cost combination for each solar heating contribution. The locus of all minimum-cost points for all solar heating contributions forms an expansion path for optimizing solar design. In a separate portion of the model, this locus of minimum-cost points is considered in combination with conventional fuel costs. The output portion of the model records the minimum-cost combination of passive features and conventional fuel and thus the optimal solar design and maximum life-cycle savings for a given set of assumptions and conditions. Budget constraints, maximum and minimum sizing constraints such as required to maintain a minimum comfort level, and architectural constraints can be added to the optimal sizing portions of the model.

The economic evaluation methodology can be used for conducting sensitivity studies such as evaluating the effects of various incentives and for making regional comparisons. The number of prototype conventional designs used in the studies is currently being expanded to include two-story homes with heated as well as unheated basements, in addition to the single-story home with no basement [14].

2.2 RESULTS OF LASL/UNM ANALYSES

The LASL/UNM researchers have developed cost data and conducted economic performance and optimization analyses for selected solar energy designs, both active and passive, for their prototypical single-family residential buildings in a number of locations and with various back-up heat sources and incentive conditions.

Some of the major conclusions* of this work are the following:

a) passive system designs offer more economic promise than the active systems considered;

b) night insulation improves economic performance significantly, and the performance increases with the severity of the climate;

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* These conclusions are taken primarily from [16], the most comprehensive of the reports to date.

c) the passive designs currently offer net savings in all but a few states when used to displace electric resistance heating;

d) in cases where solar energy is cost effective, the economically optimal solar contribution (i.e., solar fraction) tends to be lower for passive systems than for active systems, largely because the fixed part of system costs is negligible for passive heating systems, but large for active systems;*

e) low interest loans and tax credit incentives enhance the economic feasibility of active and passive solar energy systems and raise the optimal solar fraction.

2.3 UNRESOLVED ISSUES

The research efforts at LASL/UNM are notably confined to the analyses of hypothetical suburban residential solar buildings. Economic assumptions are not discussed in detail in the studies surveyed. Tax considerations other than special tax incentives are not discussed and do not appear to be included in the major studies [16].** Furthermore, the LASL/UNM methodology fails to encompass possible non-energy benefits of the passive designs.

Although the economic analysis method developed by LASL/UNM can be applied to other residential buildings, the LASL/UNM model is not appropriate for commercial buildings. Tax laws alone have a major

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* For an explanation of this relationship, see Ruegg, Rosalie T., et al., Economic Feasibility of Solar Space and Water Heating Systems in Commercial Buildings [17].

** The LASL/UNM model currently has the capability for including taxes affecting residential systems. However, the computer program contains a single set of tax parameters. The user of the program must override the parameters specified by LASL/UNM to use values appropriate to different investment situations [14].

impact on life-cycle economic feasibility, and they are significantly different for business than for residential investments.* Moreover, specialized passive solar designs are evolving for commercial buildings. These designs tend to have different performance and cost profiles than those for extant residential systems. Furthermore, commercial and non-commercial investors use different investment study periods. Such differences make it necessary to develop a distinctly different model, assumptions, and data base for evaluating commercial passive solar applications.

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* For discussion and illustration of the effects of corporate tax laws on investment costs and energy savings, see Economic Feasibility of Solar Space and Water Heating Systems in Commercial Buildings [17].

Facing page: *This solar canopy over a sidewalk in Toronto, Canada, protects pedestrians from inclement weather and provides passive solar heating to adjacent buildings.*

3. MODEL FOR EVALUATING THE ECONOMIC FEASIBILITY OF PASSIVE SOLAR DESIGNS

This section of the report presents a benefit-cost model for evaluating the economic feasibility of passive solar designs for commercial buildings. It incorporates the costs of purchase, installation, maintenance, repair, replacement, and energy over the life-cycle of the passive solar investment project. It considers effects on energy costs for heating and lighting and on rental income, space utilization, and resale value of the building. The model includes income, property, and sales taxes and tax incentives for utilization of solar energy at the Federal, State, and local levels. It provides measures for determining the economic efficiency of passive solar investments and for comparing investment alternatives.

3.1 MODEL SELECTION

Life-cycle benefit-cost analysis techniques consider all costs and benefits to be derived from a project over its life.* Thus, they are particularly useful for evaluating solar and energy conservation projects. In these types of projects, a large portion of investment costs occur initially, while the benefits occur over the entire life of the project. A life-cycle economic model for evaluating solar energy projects can be expanded to include any number of costs, different types of energy savings, and other effects of the investment. It enables detailed analysis of the effects of taxes, financing projects with borrowed funds, and government incentives. Another important feature of this type of model is that it can be used in conjunction with systems analysis models which simulate the thermal and lighting performance of the building.

The financial, commercial, and industrial communities have used certain life-cycle cost approaches for years. The internal rate of return measure is one life-cycle cost approach used frequently in evaluating capital investments. It is becoming increasingly important in real estate investment analysis [19]. Payback is another widely used measure of feasibility that conceptualizes the flow of costs and

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* The project life is the time horizon, or study period, used by the investor in evaluating the project. Depending upon the personal perspective of the investor, the time horizon might be the depreciation period, the financing period, the period for maximum speculative profits, the economic life, or the useful life of the building or related system. See [18] and section 4.3.3.

benefits over time. (However, the payback measure is not a full life-cycle measure because it does not include costs and benefits that occur after the payback period.)

The benefit-cost model presented in this report provides for a number of life-cycle measures of feasibility. While these measures enable consideration of costs and benefits of the investment in passive solar energy over the entire useful life of the project, a period somewhat shorter than the useful life, the expected holding period of the investment, is used as the study period. The value of solar components at the end of the study period is estimated and deducted from the costs of the system.

3.2 OVERVIEW OF BENEFIT-COST PROCEDURES

The basic steps in the benefit-cost evaluation are as follows: 1) Expected cash flows, including costs, benefits, taxes, and special government subsidies, are estimated based on a comparison of the proposed investment with its alternative, and the approximate timing of each cash flow is determined. 2) All cash flows are converted to a common time basis using discounting procedures. 3) The elements of benefits and costs, in time equivalent form, are used to compute various measures of economic feasibility.

3.2.1 Comparing Investment Alternatives

Each type of cost and benefit cash flow for a proposed passive solar investment building must be compared with the counterpart cash flow for a non-solar building alternative. Estimates of the differences in cost and benefit cash flows for the two buildings are required before applying the life-cycle evaluation model.* (Guidelines for estimating

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* In determining which of two solar designs (active and/or passive) is more cost effective, generally one should first determine the economic feasibility of each solar building relative to the non-solar building and then compare the economic feasibility results for the two solar buildings.

these cost and benefit cash flows and for making the necessary comparisons are provided in section 4.)

3.2.2 Discounting and Adjusting for Inflation

Discounting is the economic tool used in life-cycle economic analysis to adjust for the time value of money. It involves the application of interest, or discount, formulas to time-dependent cash flows to convert them to a common point in time.* The time value of money, apart from inflation, reflects an investor's preference for money in hand over money expected in the future. This preference can be explained by the ability of money in hand to earn a return through investment, i.e., by the "opportunity cost of capital."

The discount formulas referred to in this report are provided in the Appendix. The algebraic equation, notation, and intended use are given for each formula. Discount factors are constructed by evaluating the formula appropriate to the type of cash flow, time period, and assumptions about inflation. The economic model presented in this report converts each cost and benefit to its present value.**

Expected inflation is included in all elements of the model representing future cash flows. Thus, the discount rate used in the model represents a nominal discount rate, i.e., one that includes the expected annual rate of inflation over the analysis period. This

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* Business analysts commonly use other terminology and slightly different mechanisms for adjusting cash flows for the time value of money, such as "capitalizing annual income." However, the discounting procedures described in this report are widely used and provide a comprehensive framework for evaluating many types of investment projects.

** An equally valid, alternative approach would be to convert all cash flows to their annual values before combining them into measures of economic feasibility.

procedure adjusts cash flows to constant dollars, in addition to adjusting for the opportunity cost of capital over and above inflation.

The effects of income taxes are also specified for each element of the model, i.e., all costs and benefits are adjusted to an after-tax basis. Thus, the discount rate represents an after-tax return on alternative uses of funds (see section 4.3.1).

3.2.3 Determining Economic Feasibility

Once adjusted to a common time basis, the cost and benefit elements of the model can be combined in different ways to calculate a variety of measures of economic feasibility. These measures enable comparison of the benefits and costs of the solar investment. Three present value measures of economic feasibility are included in this report: net benefits; benefit-cost ratio; and savings-to-investment ratio. The internal rate of return measure is also provided.

3.3 ELEMENTS OF THE ECONOMIC MODEL

This section defines the cost and benefit elements of the economic model. The cost elements are specified in section 3.3.1, the benefit elements in 3.3.2. A summary of key symbols used throughout in the model is provided in the Appendix.

3.3.1 Solar Energy Costs

The following general equation shows the elements of solar energy costs that are estimated within the evaluation model and the relationships among costs, taxes owed, and tax deductions:

$$TC = C + M + R - S - I - D - C_r + P - M_v - G + C_g + O_c \, , \qquad (1)$$

where

TC = total present value cost of the solar energy system over the investment analysis period;

C = present value of initial capital costs of the investment, including design, materials, labor, sales tax, and financing;

M = present value of operation and maintenance costs after allowing for tax deductions at the State and Federal levels;

R = present value of repair and replacement costs incurred during the study period;

S = present value of deduction from taxable income for sales tax;

I = present value of deductions from taxable income for interest;

D = present value of deductions from taxable income for depreciation;

C_r = present value of tax credits against the State and Federal tax liability;

P = present value of property tax payments after allowing for tax deductions at the State and Federal levels;

M_v = present value of the estimated selling price at the end of the investment analysis period;

G = any grant obtained for the solar energy system;

C_g = present value of capital gains and depreciation recapture taxes due at the end of the holding period if the building and solar energy system are sold; and

O_c = other costs indirectly related to the solar energy system.

Each element in the equation will be specified in turn.

Capital Cost. The capital cost of a passive solar energy system financed with equity funds is the difference in initial purchase costs for the solar building and a non-solar counterpart building. The purchase costs represent the total purchase price for the passive solar energy system, including design and engineering costs as well as installation and materials costs.* To determine the purchase costs of the passive solar energy system, one should compare the total costs of labor and materials for the proposed solar-equipped building with the costs for a counterpart building without solar features. It is advantageous to estimate labor and materials costs separately if sales taxes are different for the two types of costs.** Items eligible for tax credits and other incentives should be separate from those not eligible.*** In the following equation, each purchase cost element should represent the difference in cost for the two buildings, subtracting the cost for the non-solar building from the cost for the passive solar building:

$$C_a = C_m \cdot (1 + s) + C_\ell \cdot (1 + s) + C_{sm} \cdot (1 + s) + C_{s\ell} \cdot (1 + s), \quad (2)$$

where

C_a = initial purchase costs of the passive solar energy system (the difference in purchase costs for the solar and non-solar alternative buildings);

C_m = estimated initial purchase cost of materials not eligible for special incentives;

s = sales tax rate/100 ($s = 0$ for cost elements not subject to sales tax);

C_ℓ = estimated initial purchase cost of labor not eligible for special incentives;

C_{sm} = estimated initial cost of materials eligible for special incentives;

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* Costs of financing the system with borrowed funds are discussed in section 4.3.2.

** The sales tax may not apply to both material and labor costs, or solar components may be exempt from sales tax (see section 4.3.4).

*** In sizing systems, a separate estimate of fixed and variable costs of solar components is also advantageous (see [17]).

$C_{s\ell}$ = estimated initial labor cost eligible for special incentives.

Initial purchase costs, C_a, represent the present value of initial capital costs, C, for an investment financed entirely with equity funds.

For investments financed with borrowed funds, capital costs include the initial down payment, the mortgage payments over the study period, and the principal of the loan remaining at the end of the study period. In cases where a portion of the passive solar investment is financed with borrowed funds, the present value of initial capital costs, exclusive of tax effects and special incentives, is represented by the following general equation:

$$C = D_p + M_p + R_p \ , \qquad (3)$$

where

D_p = down payment;

$$D_p = f_d \cdot C_a \ , \qquad (4)$$

for

f_d = fraction of purchase cost paid as a down payment, and C_a is as defined above. For a project totally financed from equity funds, $f_d = 1.0$.

M_p = present value of mortgage payments made as of the end of the investment analysis period;

$$M_p = (1 - f_d) \cdot CRF_{\frac{i}{12},\ 12m} \cdot UPW_{d,h} \cdot C_a \ , \qquad (5)$$

for

$CRF_{\frac{i}{12},\ 12m}$ = capital recovery discount factor for monthly payments at annual interest rate of i percent over loan period of m years;

$$CRF_{\frac{i}{12},12m} = \frac{\frac{i}{12}\left(1 + \frac{i}{12}\right)^{12m}}{\left(1 + \frac{i}{12}\right)^{12m} - 1} \quad . \tag{6}$$

$UPW_{d,h}$ = uniform present worth factor for discount rate, d, and investment analysis period, h, $h \leq m$ (for $h > m$, use $UPW_{d,m}$); and other terms are as defined above.

R_p = remaining principal at the end of the investment analysis period, for $n < m$;

$$R_p = (1 - f_d) \cdot C_a \cdot \left[1 - \frac{12CRF_{\frac{i}{12},12m} - i}{12CRF_{\frac{i}{12},12h} - i} \right] \cdot SPW_{d,h} \quad , \tag{7}$$

for

$SPW_{d,h}$ = single present worth discount factor for discount rate, d, and investment analysis period, h; and other terms are as defined above.

Equations (3) to (7) allow the investment analysis period to be different from the financing period. The analysis assumes that if the investment analysis period is shorter than the loan term, i.e., the building is to be sold before the loan is paid off, the investor pays the principal remaining on the loan out of proceeds from liquidation of the investment. Otherwise, all initial capital costs are assumed to have been paid as of the end of the loan period.

Annually Recurring Operation and Maintenance Costs. The next element in the total costs equation, M, represents annually recurring operation and maintenance (O&M) costs of the passive solar energy system over the investment analysis period, discounted to present value dollars. These costs are represented by the following equation:

$$M = (1 - t_c) \cdot L \cdot UPW_{d,\rho,h} \quad , \tag{8}$$

where

M = present value of annually recurring operation and maintenance costs, after allowing for tax deductions;

t_c = combined State and Federal marginal income tax rate/100 (see section 4.3.5);

L = annually recurring cost for operation and maintenance of the passive solar system, defined as the difference in annual non-fuel O&M costs for the solar and non-solar buildings and expressed in base-year prices, i.e., prices in the year the building (system) is purchased;*

$UPW_{d,\rho,h}$ = modified uniform present worth discount factor for discount rate, d, annual inflation rate, ρ, and investment analysis period, h.

This equation models the recurring O&M costs of the solar energy system as a constant amount, L. The modified uniform present worth factor allows the future value of these costs to increase yearly with expected inflation while discounting these future values to a single present value equivalent. (See section 4.1.2 for further discussion of components of operation and maintenance costs.)

Repair and Replacement Costs. Future building costs which cannot be represented with reasonable accuracy as annually recurring costs, and are expected to differ for the proposed solar and non-solar alternative buildings, should be estimated as to size and timing and discounted separately (see section 4.1.3). For tax-deductible repair and replacement costs of R_t anticipated in year t, the present value of the net solar repair and replacement cost is represented by the following:

$$R = (1 - t_c) \sum_{t}^{h} = R_t \cdot SPW_{d,\rho,t} , \qquad (9)$$

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* See section 4.1.2. All fuel costs are excluded except for electricity required to operate components of the passive solar energy system.

where

R = present value of repair and replacement costs after allowing for tax deductions;

R_t = repair and replacement cost in year t, $t = 1, \ldots, h$; defined as the difference in repair and replacement costs in year t for the solar and non-solar buildings and expressed in base-year prices;

$SPW_{d,\rho,t}$ = modified single present worth discount factor for discount rate, d, annual inflation rate, ρ, and time period, t, $t = 1, \ldots, h$; and other terms are as defined above.

The next four elements of the total cost equation, S, I, D, and C_r, represent deductions from taxable income.

Sales Tax Deduction. The value of the sales tax deduction is represented by the following equation:*

$$S = t_c \cdot SPW_{d,1} \cdot s \cdot (C_m + C_\ell + C_{sm} + C_{s\ell}) , \qquad (10)$$

where

$SPW_{d,1}$ = single present worth factor for discount rate, d, and period of 1 year, and other terms are as defined above.

This equation assumes sales taxes on material and labor are deducted from gross taxable income for the tax year in which the purchase is made, the value of this deduction being realized approximately one year after the purchase.

Mortgage Interest Deduction. The following equation represents the value of the tax savings for the interest portion of mortgage or loan payments for the solar energy system over the investment analysis period:

$$I = C_a \cdot t_c \cdot (1 - f_d) \cdot d_s , \qquad (11)$$

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* Only costs subject to sales taxes should be included. Other cost elements should be given a value of 0 in this equation.

where all terms are as defined above except for d_s, a complex discount factor used to determine the present value of the interest portion of mortgage payments over the investment analysis period. The discount formula is the following:

$$d_s = \sum_{t=1}^{h} \frac{12CRF + (1 - CRF \frac{12}{i}) \left[(1 + \frac{i}{12})^{12t} - (1 + \frac{i}{12})^{12(t-1)} \right]}{(1 + d)^t}, \qquad (12)$$

where

h = investment analysis period and is less than or equal to m (for an investment analysis period equal to or longer than the loan term, h = m);

m = mortgage or loan term;

i = annual interest rate on loan;

d = discount rate;

CRF = capital recovery factor which determines monthly loan payment based on annual interest rate, i, and loan term of m years (see equation (6)).

Depreciation Deductions. The straight-line method of depreciation is most generally applicable to solar energy components of commercial properties (see section 4.3.4). The present value of taxes saved due to depreciation deductions is expressed by the following equation:

$$D_{SL} = (C_{\ell} + C_m + C_{s\ell} + C_{sm} - S_a) \cdot t_c \cdot \frac{1}{N} \cdot UPW_{d,h}, \qquad (13)$$

where

D_{SL} = present value of tax savings from straight-line depreciation deductions;

S_a = salvage value expected at end of depreciation period;

N = allowed depreciation period;

$UPW_{d,h}$ = uniform present worth factor for discount rate, d, and period of investment analysis, h;

h = investment analysis period and is less than or equal to N (for an investment analysis period equal to or longer than the depreciation period, h = N); and

t_c = combined State and Federal tax rate/100.

Note that the purchase costs in equation (13) are exclusive of sales taxes. It is assumed that sales taxes are deducted in the year the purchase is made and thus are not part of the depreciable base costs.

In cases where the solar energy system is an integral part of a new building, and the declining balance method is used to depreciate the entire building,* the appropriate equation to use in estimating the value of depreciation deductions is the following:

$$D_b = t_c \cdot (C_\ell + C_m + C_{s\ell} + C_{sm} - S_a) \sum_{t=1}^{h} \frac{\frac{b}{N}\left(1 - \frac{b}{N}\right)^{t-1}}{(1 + d)^t}, \quad (14)$$

where

b = declining balance rate, e.g., b = 1.5 for 150%;

h = investment analysis period; and other terms are as defined above.

In cases where depreciation rules differ at the State and Federal levels, the depreciation equation of the appropriate type must be applied separately for depreciation at the Federal and State levels and the results summed. The present value of tax savings due to depreciation deductions from taxable income at the Federal level would be determined with either equation (13) or (14), depending upon whether the straight-line or declining balance method is used at the Federal level. The Federal tax rate, t, would be used in

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* See section 4.3.4 for discussion of eligibility for depreciation.

place of the combined rate, t_c. The present value of tax savings at the State level would be determined separately with the straight-line equation, letting t_c equal the State marginal tax rate and N, the amortization period specified in the State legislation (see section 4.3.4).

Tax Credits. A tax credit is a reduction in the actual tax liability of the investor and is usually specified as a percentage of investment costs. The present value of tax credits at the State and Federal level is expressed by the following equation:

$$C_r = C_f + C_s , \quad (15)$$

where

C_r = present value of State and Federal tax credits;

C_f = Federal tax credits;

$$C_f = (1 + s)\,(C_{sm} + C_{s\ell}) \cdot F_c \cdot SPW_{d,1} , \quad (16)$$

for

F_c = tax credit rate as percentage of investment cost/100; and

$SPW_{d,1}$ = single present worth factor for discount rate, d, and 1 year, and

C_s = effective state tax credit (see section 4.3.4);

$$C_s = (1 + s)\,(C_{sm} + C_{s\ell}) \cdot S_c\,(1 - t_f) \cdot UPW_{d,n} , \quad (17)$$

for

S_c = State tax credit rate/100, as stated in legislation;

t_f = Federal marginal income tax rate/100;

$UPW_{d,n}$ = uniform present worth factor for discount rate, d, and period, n, where n equals the number of years the tax credit is allowed (if n = 1, as is usually the case, $UPW_{d,n} = SPW_{d,1}$); and all other terms are as defined above.

It is assumed that the investment is made at the beginning of the tax year but that the tax credits are not realized until the end of the tax year in which the investment is made. It is also assumed that tax credits at the State and Federal levels have the same eligibility requirements.

<u>Property Tax Payments</u>. This element in the solar energy cost equation represents an increase in solar costs. In addition to the nominal property tax rate and rate of assessment, the value of this tax payment depends on: 1) the portion of solar energy purchase costs captured in the assessed market value of the building at any given point in time (as measured by the difference in market value of the solar and alternative buildings); and 2) the changes in market value of the building over the analysis period.

The following equation for the present value of property tax payments allows the assumptions about market value to be tailored to the specific case examined:

$$P = C_a \cdot t_p \cdot (1 - t_c) \cdot \left[\sum_{t=\ell}^{h} \left(\frac{h-x}{h}\right)^t \left(\frac{1+\gamma}{1+d}\right)^t \right] , \qquad (18)$$

where

P = present value of property tax payments over the investment analysis period;

t_p = effective property tax rate on commercial buildings/100 (see section 4.3.4);

t_c = combined Federal and State marginal income tax rate;

ℓ = year property tax begins (some States exempt solar energy systems from property taxes for a specified number of years);

h = investment analysis period;

$x = h(1 - v)^{\frac{1}{h}}$, where v is the fraction of the initial purchase costs of the solar energy system that is reflected in the market value of the building at the end of the investment analysis period, appreciation excluded;*

γ = expected annual rate of appreciation (including general inflation) in the market value of the solar energy system (the actual assessment level is incorporated in the effective tax rate, t_p); and other terms are as defined above.

In this equation, the factor $(\frac{h-x}{h})^t$ is a decay factor such that the value of the factor at time t = h is equal to v. The factor $(1 + \gamma)^t$ allows the portion of the solar energy system that has not decayed in each year to appreciate in market value at rate γ which which may be less than, equal to, or greater than the annual change in market value of the rest of the building or general rate of inflation. The factor $(1 - t_c)$ accounts for the fact that property taxes are an allowed deduction from taxable income at the Federal and State levels.

Resale Value. The estimated sales price or market value of the solar energy system at the end of the investment analysis period is represented in the economic evaluation model as resale value. The resale value in present value dollars is described by the following equation:

$$M_v = (C_\ell + C_m + C_{s\ell} + C_{sm}) \cdot v \cdot SPW_{h,\gamma,d} , \qquad (19)$$

where

M_v = present value of expected sales price of the solar energy system (or, equivalently, the difference in sales price

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* This fraction, v, is represented best by the following ratio:

$v = \Delta R_e / C_a$,

where ΔR_e is the estimated difference in resale value of the solar and non-solar alternative buildings, appreciation excluded, and C_a is the purchase cost of the solar energy system (as defined in equation (2)). The value of v should take into account decay due to physical deterioration and any anticipated failure of the real estate market to fully value the services of the system, or both factors (see section 4.3.3).

of the solar and alternative investment buildings) at the end of the holding period;

v = portion of initial solar energy purchase costs captured in sales price of the solar building at the time of resale (same as for property tax equation), appreciation excluded;

$SPW_{h,\gamma,d}$ = modified single present worth formula for investment analysis period, h, appreciation rate, γ, discount rate, d; and other terms are as defined above.

<u>Capital Gains and Depreciation Recapture Taxes</u>. Sale proceeds in excess of undepreciated costs of the solar system are subject to a capital gains tax. Depreciation in excess of straight-line depreciation at the time of sale is subject to an additional depreciation recapture tax (see section 4.3.4). The combined value of these taxes is described by the following equation:

$$C_g = t_{cg} \cdot SPW_{d,h} \left[P_r - \frac{N-h}{N} (C_\ell + C_m + C_{s\ell} + C_{sm} - S_a)\right] + D_r , \qquad (20)$$

where

t_{cg} = combined State and Federal corporate capital gains tax rate;

P_r = expected sale price at end of investment period, i.e.,

$$P_r = v \cdot (C_\ell + C_m + C_{s\ell} + C_{sm}) (1 + \gamma)^h;$$

D_r = present value of depreciation recapture tax. $D_r = 0$ if straight-line depreciation is used or if declining balance depreciation taken up to the time of resale is less than or equal to straight-line depreciation. Where declining balance depreciation exceeds the straight-line amount, i.e., where

$$\left[1 - \left(\frac{N-b}{N}\right)^h\right] > \frac{h}{N}:$$

$$D_r = t_c \cdot SPW_{d,h} \cdot (C_\ell + C_m + C_{s\ell} + C_{sm} - S_a) \left[\left(1 - \left(\frac{N-b}{N}\right)^h\right) - \frac{h}{N}\right]. \qquad (21)$$

All terms are as defined for equations (13, 14, and 20).

Grants. Grants are assumed to occur at the time of purchase. Thus the value of the grant is deducted directly from other system costs in the total cost equation.

Other Costs. Other costs directly or indirectly attributable to the solar energy system may arise with some passive designs and, if sizable, should be added to the total cost equation. Some examples are costs of obtaining solar access rights and solar easements, costs of securing approval of "non-conventional" building designs from community planning boards, costs of obtaining building rights for solar canopies, and costs for interior design of the passive solar building in excess of interior design costs for the non-solar building. These "other costs" are generally design specific and are not included in the mathematical model presented in this report.

Consideration of the alternatives to the passive solar design will determine which costs should be attributed to the solar energy investment. Costs that are unchanged by the solar investment are usually not relevant to the investment decision and can be omitted from the cost comparison since they would cancel out of the equation.

3.3.2 Solar Energy Benefits

Most economic studies of solar energy have considered only savings in conventional heating costs in evaluating the benefits of the solar investment. Many passive solar designs offer additional benefits that may significantly improve the economic feasibility of the investment in solar energy. Included in the economic evaluation model presented in this report are: 1) reduced energy costs for heating, 2) reduced energy costs for lighting, and 3) increases in rental income from commercial space due to the passive solar design.

It is possible, of course, that the passive solar design will adversely affect lighting costs or the income-producing quality of commercial space. Consideration of these "negative benefits" may show the investment should not be undertaken even if the passive solar energy system appears to be cost effective when evaluated on the basis of energy savings for heating alone.

The benefits of the solar energy system are represented by the following equation:

$$TB = B_H + B_L + B_I \ , \qquad (22)$$

where

TB = present value of total benefits attributable to the solar energy system;

B_H = present value of savings in heating costs;

B_L = present value of savings in lighting costs; and

B_I = present value of increased (decreased) net rental income due to the passive solar energy system.

An algebraic model will be specified for each element in the equation.

Savings in Heating. Using estimates of the quantity of fuel saved annually and energy price data,* the total present value savings in heating costs over the investment analysis period is determined as follows:

$$B_H = (1 + s)\ (1 - t_c)\ [P_{fc} \cdot F_c \cdot D_{fc} - P_{fs} \cdot F_s \cdot D_{fs}] \ , \qquad (23)$$

where

B_H = present value of conventional fuel savings;

s = sales tax rate for fuel/100;

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* An overview of procedures available for estimating the thermal performance of a passive solar building and for estimating the quantity of heating fuel saved is provided in section 4.2.1.

t_c = combined State and Federal marginal income tax rate/100;

P_{fc} = price per sales unit of fuel used in the non-solar building alternative;

F_c = quantity of fuel required annually in the non-solar building, in sales units (see equation (40));

D_{fc} = compound discount factor that accounts for expected price escalation for fuel used in the non-solar building over the investment period;

P_{fs} = price per sales unit of fuel used in the solar building;

F_s = quantity of fuel required annually in the solar building (see equation (40)); and

D_{fs} = a compound discount factor that accounts for expected price escalation for fuel used in the solar building.

When there are three escalation rates, the following algebraic formula can be used to calculate D_{fs} and D_{fc}:*

$$D_f = \left(\frac{1+e_1}{d-e_1}\right)\cdot\left[1-\left(\frac{1+e_1}{1+d}\right)^{n_1}\right] + \left(\frac{1+e_2}{d-e_2}\right)\cdot\left[1-\left(\frac{1+e_2}{1+d}\right)^{n_2}\right]\cdot\left(\frac{1\div e_1}{1+d}\right)^{n_1} + \left(\frac{1+e_3}{d-e_3}\right)\cdot\left[1-\left(\frac{1+e_3}{1+d}\right)^{n_3}\right]\cdot\left(\frac{1+e_2}{1+d}\right)^{n_2}\cdot\left(\frac{1+e_1}{1+d}\right)^{n_1} \qquad (24)$$

where e_1, e_2, and e_3 are expected fuel price escalation rates, including inflation, that hold for n_1, n_2, and n_3 years respectively; $(n_1 + n_2 + n_3)$ is the investment analysis period; and d, the nominal discount rate.

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* For the period of 1980-95, the Energy Information Administration, Department of Energy, has published three projected escalation rates for each of three use sectors - residential, commercial, and industrial - ten regions, and four types of fuel (see Energy Costs, section 4.2.1). The equation for D_f can, of course, be extended to allow for additional time periods and escalation rates.

Savings in Lighting. Artifical lighting costs average about 25 percent of the total energy costs for conventional commercial buildings [20], as compared with about 45 percent for residential buildings [21]. In office buildings, artificial lighting costs average about 48 percent of total energy costs [22]. The use of daylighting as a substitute for artificial lighting can have a major impact on energy costs in office buildings and other buildings with a high proportion of lighting costs.

A passive solar building may enable more or less use of daylighting than an alternative non-solar design. For example, it may provide greater window area than would otherwise be used, or it may use less and/or concentrate the window area in the south-facing portion of the building, thereby reducing daylighting in the remainder of the building. Furthermore, mass storage walls of the trombe type may block a large portion of the light from south-facing windows. Large direct gain systems with substantial glazing areas may cause substantial glare in work areas of office buildings during major portions of the work-day, necessitating moving work areas away from windows. Installing shading devices to reduce glare may decrease the thermal performance of the passive solar heating system, thereby reducing savings in heating costs. The importance of artificial lighting relative to total energy use in commercial buildings makes daylighting an important area of passive solar architectural research and an important factor to consider in determining the economic feasibility of passive solar energy for commercial buildings.

The present value of the change in lighting costs due to increased (decreased) use of daylighting, B_L, is determined using the same discounting formula, D_f, used for evaluating heating costs, as follows:

$$B_L = P_e \cdot Q_e \cdot (1 + s)\ (1 - t_c) \cdot D_f \ , \qquad (25)$$

where

B_L = present value of savings in lighting costs;

P_e = price of electricity/sales unit;

Q_e = quantity of electric power saved annually, in sales unit, calculated by subtracting power usage in the solar building from usage in the non-solar building; and all other terms are as defined above.

Differences in Space Rental Income. The last type of benefit included in the economic evaluation model represents a difference in the income-producing potential of the proposed solar building and the alternative non-solar building. It requires estimates of the differences in rental rates* for space in the passive solar building and the counterpart non-solar building and of the quantity of space to which these differences apply.

Differences in rental income could result from adding passive solar components such as an attached sunspace or mass storage wall to an otherwise conventional building or from fundamental differences in architectural design for the two buildings which change the use of the space and its ability to earn income. Market preferences for commercial space in the passive solar building could cause differences in rental rates. For example, anticipated shortages of conventional energy supplies might increase demand for space in solar buildings relative to non-solar buildings. Furthermore, sales revenue per square meter of leased space might be higher or lower in the passive solar building than the conventional building depending on its attractiveness to shoppers in terms of design, convenience of shopping,

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* This effect is discussed in terms of rental income because rental income is most generally useful in valuing commercial space. For guidelines in using this and other measures such as sales revenue, see section 4.2.3.

and comfort. If this effect is anticipated, rental rates may be higher or lower for the solar building.

The present value of a change in net rental income from commercial space due to the passive solar design may be described by the following equation:

$$B_I = (1 - t_c) \cdot I_c \cdot A_e \cdot UPW_{d,\rho,h} , \qquad (26)$$

where

t_c = combined Federal and State marginal income tax rate/100;

I_c = estimated difference in annual income, after all expenses, per m^2 of commercial space in the passive solar building compared with the alternative non-solar building (may be positive of negative);

A_e = m^2 of commercial space to which the difference in net income rate (per m^2) applies;

$UPW_{h,\rho,d}$ = modified uniform present worth factor for investment analysis period, h, expected annual inflation rate, ρ, and nominal discount rate, d.

If rental rates in various sections of the building are affected differently by the passive solar design, the annual change in income, I_{c_i}, for each affected area, A_{e_i}, i = 1, ..., q, can be determined and results over all areas summed:

$$B_I = (1 - t_c) \cdot \left(\sum_{i=1}^{q} I_{c_i} \cdot A_{e_i} \right) \cdot UPW_{d,\rho,h} , \qquad (27)$$

3.4 ECONOMIC FEASIBILITY MEASURES

The economic feasibility measures provided by the economic model and utilized in the case studies are: 1) net benefits, 2) benefit-cost ratio (B/C), 3) savings-to-investment ratio (SIR), and 4) internal rate of return (IRR). Once each cost and benefit element has been identified and evaluated quantitatively using equations (1) through

(27), the first three measures can be calculated readily. The fourth measure, the IRR, is calculated as an integral part of the discounting process as is explained below.*

3.4.1 Net Benefits

The net benefits method computes the net present value of all costs and benefits expected to occur over the life-cycle or investment planning period; i.e.,

$$NB = TB - TC \; , \tag{28}$$

where

NB = net benefits or net present value of investment; and TB and TC are as defined in sections 3.3.1 and 3.3.2.

A net benefits value of 0 means that the investment just recovers all costs, including the cost of money, but no more, while a value above 0 means that the investment results in positive savings over and above costs.

Determining the optimal design and size of an investment is generally best accomplished with the net benefits measure. The project design and size with the largest net benefits is the economically efficient choice apart from budget limitations.

3.4.2 Benefit-Cost Ratio (B/C)

The benefit-cost ratio is represented by the following equation:

$$B/C = \frac{TB}{TC} \; , \tag{29}$$

where all terms are as defined in sections 3.3.1 and 3.3.2.

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* The advantages and disadvantages of each method for particular applications are discussed in further detail in <u>Microeconomics of Solar Energy</u> [23].

The B/C describes the gross return on an investment project, above the cost of money, per average investment dollar. A B/C value of 1 means the project just recovers costs; a value greater than 1 means the project more than recovers costs. This measure is particularly good for ranking independent projects competing for a limited budget. If projects are selected in descending order of their B/C, the net savings from the total budget will be maximized.

In evaluating energy-related projects, where the major benefits are reductions in energy costs, the composition of "benefits" and "costs" is somewhat arbitrary. For example, tax savings are a type of cost savings just as are energy savings. Furthermore, including all tax savings in the denominator with investment capital costs and resale value may cause the denominator to become negative, rendering the B/C ratio meaningless.

3.4.3 Savings-to-Investment Ratio (SIR)

An alternative measure of the return per average investment dollar that has been particularly useful for evaluating energy conservation projects is the savings-to-investment ratio:

$$SIR = \frac{TB + S + I + D + C_r + G - M - R - P - C_q - O_c}{C - M_v}, \qquad (30)$$

where all terms are as defined in sections 3.3.1 and 3.3.2.

According to this measure all elements but initial capital costs and resale value (or salvage value) are placed in the numerator. This measure enables the investor to focus on total savings relative to the capital investment minus resale value.

A further modification in the SIR measure is to include all costs and savings except for the initial downpayment in the numerator. Businesses sometimes prefer this version of the SIR since it focuses on total savings relative to the original equity capital outlay.

A negative result is less likely with the savings-to-investment ratio measure than with the B/C ratio. The SIR is subject to essentially the same interpretation and use as the B/C ratio.

3.4.4 Internal Rate of Return (IRR)

The internal rate of return (IRR) is the calculated interest rate which, when used in place of the discount rate in equations (1) to (27), equates the discounted value of costs of an investment over the analysis period with the discounted value of the benefits that occur over that time; i.e., the internal rate of return is the solution rate for which

$$TB_i - TC_i = 0 , \quad (31)$$

where i is the interest rate used to discount benefits and costs according to equations (1) to (27). The investment is economically efficient if this calculated rate of return is equal to or greater than the rate of return required by the investor.

The IRR is important in evaluating solar energy systems in commercial buildings for several reasons: 1) it is widely used in the business and financial communities; 2) investors with different discount rates have flexibility in comparing calculated IRR's on projects against their minimum acceptable rates of return, which may change over time; and 3) it is a measure for ranking competing independent projects on the basis of investment yield.

Unfortunately, the IRR is cumbersome to compute manually. It is generally calculated by trial and error whereby different interest rates are used to discount cost and benefit cash flows until a rate is found that equates total costs and benefits.*

The procedure is to compute the net present value using a low interest rate that gives a present value greater than zero, then with a high discount rate that gives a present value less than zero. By interpolation between the low and high discount rates, one can determine the approximate interest rate that equates savings and costs, i.e., the internal rate of return.

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* There may be multiple solution interest rates in certain circumstances depending on the direction of cash flows in different periods.

Facing page: *This shopping center in Toronto, Canada, is fully enclosed by a solar canopy. Note the extensive venting system.*

4. ESTABLISHING DATA AND ASSUMPTIONS

This section examines in detail the data and assumptions required to apply the economic evaluation model presented in section 3. The following types of data and assumptions are described: 1) costs of the passive solar energy system; 2) benefits of the passive solar energy system, and 3) investment management considerations, such as discount rates, borrowing rates, investment study periods, taxes, and government incentives.

Guidelines for determining values for the cost, benefit, and financial variables in the economic model are provided. Accurate estimates of the investment costs and energy savings attributable to the proposed project are, of course, essential to the economic evaluation. In addition, the following considerations should influence values assigned to variables in the evaluation model:

1) What kind of building is involved (e.g., new, existing, retail store, office building)?
2) In what type of commercial setting is the building located (e.g., shopping center, central business district of large city of small city, satellite commercial neighborhood of large city, highway commercial strip)?
3) What are the long-term investment objectives of the owner?
4) Who pays the utility costs?
5) Might a passive solar design offer the building owner additional benefits beyond savings in heating costs?
6) What rate of return is required by the owner on an investment in this building?

4.1 ESTIMATING SOLAR ENERGY COSTS

The costs of a passive solar energy system may be divided into three major categories: 1) purchase costs; 2) annual costs for operation and maintenance, and 3) replacement costs. The size and timing of each cost affects the life-cycle cost of the investment. Both must be determined before conducting a life-cycle economic evaluation of the proposed investment.

4.1.1 Purchase Costs

New Construction. In evaluating a new passive solar building, it is important that a comparison of the total costs of alternative buildings be made. For one thing, architectural and construction costs, even apart from specific solar components, may be different for the solar than the alternative building. This is partly because there is little standardization in the design and construction of components for commercial building systems. The design of each passive solar component tends to be unique to the specific building. For example, most mass storage walls must be built to the architect's specification on the building site, using labor intensive types of construction such as masonry and concrete. Most architects have very limited experience in designing passive solar buildings, and there are very few existing passive solar buildings to draw upon for guidance. Cost differences attributable to these differences in design characteristics should be included in the estimate of solar purchase costs.

Furthermore, it is likely that the passive solar features will be structurally integrated with the rest of the building and thus multi-functional. For example, thermal storage walls, including extra-thick masonry partition walls, may provide structural support to the building, a thermal energy storage medium, and possibly even aesthetic value. Glazing likewise may have architectural and aesthetic value as well as thermal qualities. Determining what portions of the costs of these components should be attributed to the solar energy system would be very difficult without a comparison of the total costs of two alternative buildings. The key to the comparison of costs of the two buildings is in defining solar and non-solar buildings that represent realistic counterparts. Note that if the buildings differ in the type or quality of space available for commercial use as well as in cost these differences should be measured if possible and included in the economic evaluation along with differences in purchase costs (see section 4.2.3).

<u>Systems Retrofit to Existing Buildings</u>. In estimating the purchase costs of a retrofit passive solar energy system, one need consider only the building costs that will differ if the solar energy system is added to the building. The estimate of purchase costs should include all costs incurred in designing, purchasing, and installing the passive

solar energy system, as well as costs for modifications in the building required to install the solar components. Any reduction in the capital costs of conventional equipment or building components attributable to the solar investment, and incurred at the time of the initial solar investment, should be subtracted from the estimate of initial solar costs. For example, if a back-up conventional furnace purchased at the time of the solar installation is smaller than would be required without the solar energy system, the difference in the two furnace costs would be subtracted from the initial costs of the solar energy components.

Retrofit passive solar systems frequently have higher initial costs than new building systems because of the structural modifications required to install them. This is particularly true of designs involving extensive changes in the thermal mass and glazing characteristics of the building. In addition, tax laws and financial arrangements are frequently less favorable to retrofit systems. Where these conditions exist, retrofit systems are less cost effective than systems in new buildings.

An investigation of incentives available for building improvements and rehabilitation, however, showed that some special subsidies are applicable to retrofit projects, but not new buildings. These incentives effectively lower the cost of retrofit heating systems relative to new building systems.* Furthermore, new retrofit designs are emerging, such as those developed for the Solar Cities Program, which combine hybrid and passive components in simple, low-cost modifications to existing buildings.

Regional Variation. There is substantial regional variation in passive solar energy costs. Although most components for active systems in commercial buildings are produced by national firms, passive systems are generally constructed on the building site by local builders and

* A discussion of these programs appears in sections 4.3.4 and 4.3.5.

subcontractors from materials obtained locally. Costs of materials and labor for these systems are closely tied to overall building construction costs in the region.* A few passive components are manufactured by national firms, for example, special glazing materials and trademarked products for shading and night insulation.

Energy Conservation Features. Most passive solar buildings are being built with thermally sound, well insulated envelopes. The question arises as to whether these energy-conserving elements should be considered part of the passive solar energy system. They can make a tremendous difference both in the amount of thermal energy required for heating annually and in initial solar costs. The same issue arises with draperies, awnings, shades, shutters, and other features that may be found in any energy conserving building but may be more critical to the thermal performance of the passive solar building.

The essential rule in evaluating these and other costs of solar energy systems is consistency. If particular energy-conserving modifications are to be made in any case, they should be considered sunk costs. In this case, the costs of these modifications would not be included in the estimates of initial solar costs, and energy savings due to solar would exclude energy savings due to energy conservation. If the energy-conserving modifications are to be made only in conjunction with solar energy, both the modifications and their effects should be included in the solar evaluation.

Other Acquisition Costs. Additional acquistion costs may arise with particular solar designs and settings. For example, significant costs may be incurred in obtaining solar access rights or solar easements

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* The Dodge Manual, Means Building and Construction Cost Data, and other cost-estimating manuals provide detailed regional price adjustment factors which can be applied to cost estimates based on national averages [24, 25].

in congested urban environments. In general, existing common laws do not guarantee access to the sun. Since the owner of a solar building must be concerned with preventing shading of certain portions of the building over its entire life, it may be necessary to negotiate a legally binding, transferable easement over the solar access space, with a clear description of the space and with title insurance. Where applicable, the costs of obtaining the solar access, i.e., of obtaining agreement among adjacent property owners and compensation for removing vegetation or making structural changes, should be included with other solar costs.*

4.1.2 Operation and Maintenance Costs

Costs for operating and maintaining a passive solar energy system include costs related to the system that recur every year over the investment analysis period. As with purchase costs, estimating operation and maintenance (O&M) costs is dependent upon a thorough comparison of costs for the proposed solar building and a counterpart non-solar building. All significant recurring costs for either building that occur after installation and are expected to differ for the two buildings should be identified. The estimated annual operation and maintenance cost for the solar energy system is found by subtracting the sum of the annual operation and maintenance costs for the non-solar building from the sum of annual costs for the solar building.** All costs should be expressed in base-year prices, i.e., prices at the beginning of the study period, before applying the model in section 3.

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* Several states have passed legislation guaranteeing solar access to various degrees. As of late 1977 these states included Maryland, New Mexico, Kansas, Colorado, and Oregon.

** An annual operation and maintenance cost of one percent of initial acquisition costs, plus adjustments for inflation, is sometimes assumed in economic studies of passive solar energy systems [14, 17].

Recurring costs for cleaning south-facing windows, insuring the passive solar components, and maintaining non-solar heating equipment should be among the O&M costs considered. Insurance premiums for a building reflect the replacement value of the building components. To the extent that the solar-equipped building has a higher replacement cost than the conventional building, insurance costs will be higher for the solar building.*

Although fuel costs are a major recurring O&M cost for solar and non-solar buildings, fuel costs for heating and lighting should not be included among O&M costs in using the economic model in section 3. These costs are accounted for in the benefits portion of the model. Costs for electricity required to operate hybrid passive components (e.g., mechanical fan systems, night insulation equipment, shades, and other system components) can be included either in O&M costs or in heating costs (in the benefits portion of the model).

4.1.3 Repair and Replacement Costs

Repair and replacement costs are costs that occur on an irregular basis during the investment analysis period. All such costs that differ for the solar and non-solar counterpart building affect the economic feasibility of the passive solar investment.

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* The National Solar Heating and Cooling Center has recently surveyed major insurance companies and associations for the history of insurability of solar energy systems. It was found that the companies do not differentiate between buildings with solar and those with conventional heating systems for insurance purposes [26]. However, most research related to the insurance issue has been limited to residential properties. In commercial neighborhoods with high rates of vandalism and other crimes, a building owner may have difficulty obtaining insurance for a building with large glass windows or other glazed areas. There are durable glazing materials that may be acceptable to insurance companies.

Since repair and replacement costs vary in size from year to year, these costs must be estimated for each year, subtracting the estimated cost for the non-solar building from the cost for the solar building. The resulting cost for each year is entered into the evaluation model. All repair and replacement costs should be expressed in prices of the base year.

Uninsured damage to solar energy components, uninsured damage caused by these components (e.g., water damage from a water storage wall or roof pond), and repair and replacement of solar and non-solar heating system components should be among the costs included. Keep in mind that major repairs and replacements to non-solar heating equipment may be expected to occur at different times in the solar and non-solar buildings and to be more extensive for one building than the other.

To simplify the analysis, frequently the future capital costs of the alternative building are disregarded, and only solar-specific costs for operating, maintaining, and replacing solar energy components are included in the analysis. This approach presumes other non-energy costs are the same for the two buildings and is a reasonable approach where the back-up heating system for the solar building is of the same type and efficiency as the heating system in the alternative building. In new passive solar construction this is likely not to be the case. Particularly in regions of the country where large fractions of the annual energy requirement can be provided with passive solar heating, the efficient back-up system is likely to differ substantially, in non-energy as well as energy costs, from the energy system used in the non-solar building. These differences should, of course, be reflected in the economic evaluation.

4.2 ESTIMATING SOLAR ENERGY BENEFITS

This section provides guidance in estimating the annual fuel savings from an investment in passive solar energy for a commercial building and identifies possible effects of passive solar designs on income from rental of space in the building. The non-energy effects of passive solar designs for commercial buildings, such as changes in space rental income, are generally difficult to measure and specific to the building design and use. This section suggests some possible sources of data for estimating values for key variables in the economic model that account for these effects.

4.2.1 Savings in Heating Fuel Costs

In this section, the procedures for estimating annual heating fuel consumption for a solar and a non-solar building will be outlined and the energy cost data required to perform the life-cycle evaluation described. An overview of the solar load ratio method is provided. This method is described in detail in the Passive Solar Design Handbook [27].

Predicting the Solar Heating Contribution. Estimating physical energy savings of passive solar buildings requires a measure of performance of the solar energy components. Several simulation methods are currently being developed for passive systems. The most thoroughly documented are a series of methods developed by Los Alamos Scientific Laboratory. The PASOLE program developed at LASL provides a detailed, hourly thermal network analysis of a building with passive components [28]. Two additional methods have been derived from results of PASOLE simulations for a large number of cities: the load collector ratio method, which provides a "quick and dirty" approximation of solar performance suitable for the early phase of system design, and the solar load ratio method, which provides a somewhat more detailed analysis suitable for the final system design phase.

The solar load ratio method was developed by applying ordinary least squares regression analysis to results for a large number of runs of the PASOLE program. LASL estimated functions that relate solar performance (actual contribution of solar energy in meeting the building's energy requirement expressed as a percentage of the total reference energy load) to the solar load ratio (solar radiation absorbed/total reference energy requirement). These estimated equations are considerably easier to use than the PASOLE program or other computer simulation programs.

Researchers at Los Alamos have recently modified their solar load ratio method of estimating the performance of passive solar buildings. The revised method (that adopted in this report) is to relate the non-solar heating fraction (NSHF), i.e., the actual quantity of auxiliary energy required divided by the total reference energy requirement of the building, to the solar load ratio and to a load modifier, K. Comparing the solar building with a building that is thermally identical except for passive components, the net solar savings fraction (SSF) is then defined as follows:

$$SSF = 1 - NSHF ,$$

where NSHF is a function of the solar load ratio and load modifier (as specified in equations (36) and (37)).

Based on extensive testing at LASL, it is believed that the SSF provides an improved estimate of the actual energy savings due to solar. This is to be compared with past approaches used by LASL and others which defined solar performance and energy savings in terms of the solar heating fraction, i.e., the gross solar contribution in providing energy to the building relative to the total reference energy requirement. By separating out the solar energy actually used from the gross solar contribution, the SSF approach removes a bias (generally upward) inherent in the earlier solar heating fraction (SHF) approaches.

Since the LASL model is based on a comparison of the solar building envelope with a building envelope physically identical to it except for south-facing walls, the procedures recommended by LASL have been extended somewhat in this report to allow comprehensive assessment of the energy savings for a proposed solar building which differs in architectural design from the alternative building investment. A passive solar building may differ substantially in construction, in insulation quality, in architectural design, and in type and efficiency of the conventional or back-up heating system from an alternative conventional commercial building. Differences in heating costs caused by these different characteristics or other factors should be included in the economic evaluation. It is proposed that the investor consider the total fuel consumption annually in both the solar and alternative buildings and perform a life-cycle evaluation of energy costs for each.

It should be recognized that passive solar simulation programs for commercial building systems are in a very early stage of development. Substantial research is required to validate existing analysis tools for small commercial buildings and to develop new tools for large commercial buildings with interior heating zones and complex ventilation systems.

Energy Consumption in the Solar Building. Adopting the LASL procedures for calculating energy consumption in the solar building, a three-step approach is used: 1) estimation of the monthly reference energy requirement (energy required annually to maintain the designated thermal comfort level in a reference non-solar building which is thermally identical to the passive solar building except for solar components); 2) calculation of solar radiation absorbed by the building; and 3) calculation of monthly auxiliary (non-solar) heating profiles for the solar building.

Step 1. Compute the monthly reference energy requirement for space heating using the following equation*:

$$HL = DD \cdot \underbrace{\left(\sum_{j=1}^{n} U_j A_j + L_i \right)}_{\text{Building Load Coefficient}} , \tag{32}$$

where

HL = reference energy requirement;

DD = number of degree days, Celsius (Fahrenheit), in month;

$U = \frac{1}{R}$ = rate of heat loss through building component, $kJ/m^2 \cdot$ degree day, C (Btu/$ft^2 \cdot$ degree day, F);

A = $m^2(ft^2)$ of conducting surface, excluding south-facing solar wall;

n = number of conducting surfaces;

L_i = infiltration component. This is based on an estimate of the number of air changes in the building each hour:

$$L_i = 1.207 \cdot 24 \cdot a_c \cdot r^3 \cdot a_d , \tag{33}$$

where

1.207 = specific heat of air, $kJ/m^3 \cdot °C$;

24 = hours/day;

a_c = air changes/hr;

r^3 = m^3 of building space; and

a_d = air density ratio.

As defined in equation (32), the reference energy load is the thermal energy required to maintain a designated comfort level in a non-solar reference building. The reference building envelope is assumed to be identical to that of the passive solar building except for the south-

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* This is based on the method of heat-loss calculations suggested by ASHRAE. For a more detailed description of this method, see ASHRAE Handbook of Fundamentals [29].

facing wall. By excluding the south-facing wall from the thermal analysis, one assumes this wall is perfectly "neutral," i.e., it has no monthly net gains or losses or is perfectly insulated.* The gains and losses through the south glazing of the solar building are accounted for in the next step.

Step 2. Determine the solar radiation absorbed by the building by first obtaining monthly data for solar energy incident on a horizontal surface in the given location and then multiplying these values by a series of factors that account for the building orientation, window tilt, ground reflectivity, reflectors, overhangs or shading (if any), absorptance characteristics of the solar storage walls, and collector area:*

$$I_A = I_i \cdot t_t \cdot r \cdot s \cdot t_r \cdot a_b \cdot A_c \,, \tag{34}$$

where

- I_A = solar radiation absorbed/mo.;
- I_i = solar radiation on a horizontal surface in a given location, $kJ/m^2 \cdot mo.$ ($Btu/ft^2 \cdot mo.$);
- t_t = correction for tilt and orientation of solar aperture;
- r = ground reflectance factor (generally about .3);
- s = window reflector, overhang, and shading factor;
- t_r = window transmittance factor;
- a_b = absorptance of solar wall (generally .85-.95 for trombe and water walls, .9 to 1.0 for direct gain walls); and
- A_c = solar window area, m^2 (ft^2).

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* See [27]. LASL states that these simplifying assumptions have a negligible effect on the results. The reference building here is a hypothetical building used to determine the performance of a solar building. It is expected to differ from the actual "alternative to solar" building investment.

** For procedures for calculating these factors, see [27]. Note that data for solar radiation incident on a vertical south-facing surface for 219 cities appear in Appendix C of [27].

Step 3. Compute the solar load ratio (SLR) by dividing solar radiation absorbed monthly (computed in step 2) by the monthly reference energy requirement (computed in step 1). Then modify the calculated SLR with a factor 1/K:

$$K = 1 + (A_c \cdot G) / BLC , \qquad (35)$$

where

A_c = solar glazing area;

G is determined from table 4.1; and

BLC = Building Load Coefficient (see equation (32)).

TABLE 4.1: LOAD ADJUSTMENT FACTOR, G[a]

System	DG	DGNI	TW	TWNI	WW	WWNI
G	10.6	2.4	3.6	0.5	5.0	0.7

Source: Passive Solar Design Handbook [27].

[a]DG = direct gain system; DGNI = direct gain system with night insulation;
TW = trombe wall system; TWNI = trombe wall system with night insulation;
WW = water wall system; WWNI = water wall system with night insulation.

Calculate the value of the modified non-solar heating fraction, NHSF/K, by substituting both the calculated SLR/K values and the values of constants in table 4.2 corresponding to the appropriate solar design type into equation (36) or (37) [27].

$$\text{For } SLR/K < R \qquad NSHF/K = 1 - A\ SLR/K , \qquad (36)$$

$$\text{For } SLR/K > R \qquad NSHF/K = B + C \exp(-D\ SLR/K) , \qquad (37)$$

where R, A, B, C, and D are constants defined in table 4.2.

TABLE 4.2: SOLAR LOAD RATIO EQUATION COEFFICIENTS[a]

System	R	A	B	C	D
DG	0.5	0.5213	-0.0133	1.0642	0.6927
DGNI	0.7	0.5420	0.0134	1.1479	0.9097
TW	0.6	0.3698	-0.0408	1.0797	0.4607
TWNI	1.0	0.4556	0.0231	1.2159	0.8469
WW	1.3	0.4025	0.0128	1.5053	0.9054
WWNI	1.2	0.4846	0.0201	1.8495	1.2795

Source: Passive Solar Design Handbook [27].

[a] A, B, C, and D are coefficients relating the non-solar heating fraction to the solar load ratio.

To obtain the non-solar heating fraction, NSHF, multiply the calculated $\frac{NSHF}{K}$ by the calculated K. Then, to determine the non-solar monthly heating requirement, multiply the NSHF by the reference energy requirement found in step 1. The resulting value is the non-solar energy required monthly, Q_i, to maintain the solar building at the designated comfort level:

$$Q_i = NSHF \cdot HL \, , \qquad (38)$$

where all terms are as defined above.

The annual non-solar energy requirement is, of course, the sum of the monthly requirements:

$$Q_s = \sum_{i=1}^{n} Q_i \, , \qquad (39)$$

where

Q_s = total annual non-solar energy requirement; and

Q_i = monthly non-solar energy requirement, for

i = 1, January,

i = 2, February, etc.

The quantity of fuel actually consumed depends additionally on the type and efficiency of the furnace or other non-solar heating plant. The following equation converts the quantity of energy to the equivalent quantity of fuel:

$$F_s = \frac{Q_s}{e_s \cdot b_s} \tag{40}$$

where

F_s = quantity of conventional fuel required annually, in sales unit (e.g., gal, or liters of oil);

Q_s = annual non-solar energy requirement, kJ (Btu);

e_s = combustion efficiency of furnace, generally .6 to .75 for natural gas and oil, 1.0 for electricity; and

b_s = energy content per sales unit of fuel, kJ/liter (Btu/gal.).

Energy Consumption in the Non-Solar Building. The procedures described in step 1 for determining the monthly reference energy requirement of the solar building should be reapplied to the non-solar alternative building (the actual non-solar building alternative, which may be different from the "reference" building), again excluding the south-facing wall. The calculated monthly energy requirements for this building are then summed and converted to the equivalent quantity of fuel by the procedures given in equation (39), i.e.,

$$F_c = \frac{Q_c}{e_c \cdot b_c} , \tag{41}$$

where

F_c = quantity of fuel required annually for non-solar building, in sales unit;

Q_c = quantity of energy required to maintain the building at the designated comfort level, calculated using equation (32) and summing over all months;

e_c = combustion efficiency of furnace in non-solar building (see equation (40)); and

b_c = energy content per sales unit of fuel.

Extensions to the General Procedures. A few extensions of the procedures described above should be noted:*

1) The energy savings of mixed systems (for example, a building combining a trombe wall and direct gain) can be calculated by a) determining the absorption of solar radiation for the two systems separately, b) calculating the non-solar heating fraction for each, and c) finding a weighted average of the performance of the two systems, using the glazing area for each as the weighting factor.

2) According to LASL, the trombe wall estimating equations should be used in evaluating attached sunspace designs. This procedure presumably is predicated upon the building wall adjacent to the sunspace serving as a mass thermal storage medium, i.e., it is comparable to a trombe wall. If the adjacent wall lacks sufficient mass for thermal storage, a more suitable approach might be to treat the sunspace merely as a thermal buffer to the adjacent building in computing the energy requirement of the solar building. This procedure is followed in the solar canopy case example examined in section 5 of this report.

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* All are described in greater detail in the Passive Solar Design Handbook [27].

3) The solar load ratio estimating equations have been tested for changes in underlying design assumptions, such as wall thickness, types and layers of glazing, interior mass, and the addition of rock storage beds. Sensitivity results appear in the Passive Solar Design Handbook, and the calculation of energy savings can be modified to account for these design differences.

4) Both internal energy gains from people, appliances, and artificial lighting and solar gains through windows not in south-facing walls have been disregarded in the procedures outlined above. Frequently, these energy gains can be expected to be approximately the same for the solar and alternative buildings and can be disregarded without affecting the comparison of energy costs of the two buildings. This greatly reduces the computational burden. Keep in mind, however, that if either the fuels used in the alternative buildings differ, *or* furnace efficiencies differ, the dollar value of energy gains from these sources will also differ. If the differences in energy gains, or in the price or efficiency of usage of fuel in the alternative buildings are major,* both internal gains and solar gains should be calculated for both buildings and subtracted from the energy requirements of both buildings. For the solar building, LASL suggests that this be done after calculating the non-solar heating fraction, i.e., internal gains would be subtracted from the calculated values of Q_s and Q_c (see equations (33), (39), and (41)).

The equations for estimating the solar savings fraction were developed primarily from calculations involving standard passive solar designs for residential buildings. Tests of small commercial buildings show the equations to be equally satisfactory for estimating solar performance in these buildings. Performance results have been relatively insensitive to differences in load usage profiles over a daily period.

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* Substantially different use of daylighting in the two buildings could cause a major difference in internal energy gains.

The LASL solar load ratio method is comparable in analytic detail and accuracy to alternative computer-based passive solar performance models currently available, providing assumptions used in the LASL analyses correspond to the operation of the proposed building. LASL notes that a thermostat setting of 65°F (in the absence of internal heat) and a maximum air temperature of 75°F (at which point heat is presumed to be vented to maintain this temperature) are particularly important assumptions. The solar load ratio method has the advantage of greater simplicity of calculation. LASL is preparing detailed instructions and worksheets enabling calculation by simple hand methods. A computer or programmable calculator and printer is not required. The method is limited in application to buildings whose energy requirements are dominated by thermal losses through the building envelope and infiltration.

Buildings of substantial size, including most commercial buildings, depend directly on mechanical air handling systems, not infiltration, for inflow of outside air and air circulation. Much of the heat required is generated internally, and cooling is the major comfort consideration. A static thermal analysis method such as that described in step 1 does not provide adequate estimates of the energy requirements of these buildings. It is necessary to use a computer simulation program that models the thermal dynamics of the building to perform a thermal analysis. A number of these programs exist, including DoE-2 developed by DoE and the University of California, BLAST developed by the Construction Engineering and Research Laboratory (CERL), and NBSLD developed by NBS.

Some of these transient load models have been used successfully to estimate energy requirements in the evaluation of active systems,* but there are substantial difficulties in using these models to

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* See [17] for a discussion of the use of BLAST in evaluating commercial building solar energy systems.

analyze large, multi-zone passive solar buildings with complex HVAC systems. The energy requirements of these buildings cannot be calculated in isolation of the solar components. The thermal characteristics of mass storage walls must be represented in the computer model along with those of conventional walls. Existing thermal analysis programs for large commercial buildings do not allow for thermal storage walls.

Work is underway at LASL, NBS, and LBL (Lawrence Berkeley Laboratories) to adapt DoE-2 to passive solar buildings. The resulting program will be applicable to multi-zone commercial buildings.

A number of other computer-based methods for evaluating the performance of passive solar energy systems are available. Like the solar load ratio method, these methods are limited to relatively small buildings, but, unlike the solar load ratio method, they provide for an hourly thermal analysis. DEROB and TEANET are computer simulation models developed by the University of Texas and by Total Environmental Action (Harrisville, N.H.) specifically for passive solar energy systems. TEANET can be used on a hand-held programmable calculator. As part of the Solar Cities Program, NBS also is developing single-zone, dynamic analysis methods for analyzing passive solar buildings [3].

Energy Costs. The dollar value of the quantity of fuel consumed annually in each building is evaluated first for the base year and then for the life-cycle of the investment period. The life-cycle evaluation requires that values be specified for both present and future fuel prices. Establishing values to use for future energy costs mean projecting prices in an uncertain future.

The Energy Information Administration (EIA), Department of Energy, has developed a comprehensive computer model, the Mid-Term Energy Forecasting System (MEFS),* for generating fuel price projections. The DoE fuel price model divides the nation into 10 geographical regions. Fuel prices are provided by fuel type, by building type, and also by region, for three future periods - to mid 1985; to mid 1990; and to mid 1995 - and for three price scenarios--"low;" "medium;" and "high." Escalation rates for each time interval can be derived from the bench-mark price projections. EIA updates base-year fuel prices and projected future prices periodically and is in the process of developing marginal price projections in order to provide an improved measure of the benefits to society of saving fuel.

The most recent published MEFS forecasts are based on actual 1979 prices expressed in 1980 dollars and real escalation rates.** For the case studies in this report, EIA projections based on actual 1978 prices, the "high" price scenario, were used.*** Projected real escalation rates were adjusted for an annual expected inflation rate of 6 percent over the investment analysis period.****

Combined discount-escalation factors for converting annual energy costs for the base year to present value life-cycle costs can be constructed for each set of escalation rates and a given discount

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* MEFS is a later version of a model called the Project Independence Evaluation System, published originally in September 1976. All Federal agencies are required to use these EIA prices in evaluating energy conservation and solar projects in Federal buildings.

** The prices and escalation rates for the "high" price scenario appear in [30].

*** These prices and escalation rates appear in [31].

**** This estimate of annual inflation is based on econometric forecasts for the next 20 years published in late 1978 by Data Resources, Inc.

rate. The formula for constructing these factors appears in equation (24).

Who Pays Utility Costs. Implicit in the procedures for estimating energy savings described in this section is that the investor in solar energy, generally the building owner, obtains all the benefits in fuel savings. Either the building owner pays all the fuel bills for the solar building, or, if the tenant does, the tenant pays a higher rental rate that offsets his or her lower utility costs. This is apart from higher rent related to non-energy effects of the passive solar building design described in section 4.2.3. The tenant is assumed to be equally well off, and indifferent to, paying fuel costs as part of rent or separately.

These are powerful and possibly optimistic assumptions considering the trend to tenant-paid utility costs in recent years.* In some cases different assumptions may be merited, and estimates of energy savings adjusted to reflect the portion actually obtained by the owner of the passive system.

Note, however, that the trend to charging tenants for utility costs has been due in large part to the unpredictability of fuel prices over the lease period. Interrupted supply and general shortages of conventional fuel have been additional causes for concern. As solar energy becomes widely used and understood, tenants should be willing to pay a higher rent commensurate with their reduced utility costs.

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* As energy prices have escalated unpredictably in recent years, it has become increasingly common for office building leases to revert energy costs in excess of a certain monthly charge per square foot of leased space to the tenant. Utility usage in space leased for retail sales or warehousing or other light industrial uses is usually metered and tenants charged for all utilities.

4.2.2 Effects on Lighting Costs

Typically, only the energy loss and solar gain characteristics and the costs of windows are included in the analysis of window components of solar buildings.* Windows frequently have the additional characteristics of providing daylighting for interior spaces and visual communication with the outdoor environment. If designed and managed effectively, windows can substitute daylighting for artificial lighting and thereby serve to reduce electricity costs. Moreover, studies have shown that daylighting, if properly utilized, can reduce cooling loads generated by electric lighting [32] and be more effective in illuminating tasks than equivalent artificial lighting [33]. On the other hand, poorly designed windows can cause heating and cooling loads to increase with increased use of daylighting. They can also interfere with visual performance by providing uncontrolled brightness and glare.

Since passive solar buildings depend upon windows for collecting solar energy to heat the building, the effects of these windows on lighting needs should be considered. Estimating the potential savings in artificial lighting costs from use of daylighting requires: 1) an estimate of the daylighting available to each lighted area or workspace in the proposed passive solar building as compared with that available in the alternative non-solar building; 2) an estimate of the actual minimum requirements for lighting in each area; 3) an estimate of the artificial lighting used in the non-solar building; and 4) the price schedule for electricity, including seasonal variations and time-of-day charges.

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* An exception is [34]. Ruegg and Chapman include an evaluation of daylighting in their economic analysis of windows. However, their study examined windows in a conventional building with no provision for thermal storage.

Daylighting Potential. To determine the quantity of daylighting available, it is necessary to develop detailed specifications of the architectural and interior design of the proposed building, including the size, position, and physical characteristics of the windows; the size of rooms; the layout and surface characteristics of workspaces; the shading characteristics of nearby buildings and landscaping; and the use of shades, draperies, and shutters.

In addition, it is necessary to make assumptions about the behavior of building occupants, for example, their willingness to reduce artificial lighting and to manage window shading features effectively.

Once these characteristics and assumptions have been specified, a daylighting analysis can be conducted. A number of methods have been developed for estimating available daylighting. The most comprehensive tools are complex hourly simulation computer models. Simpler and less costly methods, involving short computer algorithms, exist for making rough estimates. One is the daylight factor method used by Kusuda and Collins [32]. As defined by these NBS researchers, the daylight factor is the "ratio between illumination on a horizontal plane at a reference point in the room and illumination on a horizontal plane under the open sky, both without direct sun."*

Lighting Needs. It is necessary to establish a minimum level of illumination for each room or work area. By comparing the minimum required level with the daylighting available, one can establish the quantity of artificial lighting required for the space.**

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* The daylight factor calculation procedures are provided in detail in [32]. In [35], Kusuda and Bean compare the results of using the daylight factor method with those obtained with a rigorous interreflection model GLIM (General Light Interreflection Model) for a sample office module.

** In their economic evaluation of windows, researchers at NBS assumed a minimum illumination level of 6.7 fc for residential buildings and 50 fc for commercial buildings [32, 34].

Obviously, the greatest savings in electricity occurs when artificial lighting is reduced to the minimum required for the specific daylight conditions and for the activity occurring within the space.*

Savings in Electric Power. To determine the annual power savings, first, subtract the quantity of daylighting available to the investment building over the year from the minimum requirement over the yearly period. The difference is the quantity of artificial lighting required for the investment building. Second, determine the amount of artificial lighting required in the non-solar building. (This can be done in either of two ways: 1) repeat the calculations used for the proposed passive solar building, with appropriate assumptions as to the use of daylighting in the non-solar building or 2) assume a constant hourly electric power usage during occupied periods throughout the year.) Lastly, find the differences in artificial lighting required for the two buildings, subtracting the quantity for the proposed investment building from the quantity for the non-solar building. A positive value reflects a savings in electricity for the passive solar building, a negative value, an increase in the electricity requirement for the passive solar building.

The dollar value of the savings in electric power, considered over the study period, is then found by applying the same procedures used in evaluating savings in heating costs. Note that if a significant portion of savings in electric power occurs during peak load periods, where electricity is subject to extra demand charges, the peak load price should be used in evaluating energy savings that occur during those periods.

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* Automatic sensor controls can be installed to dim lights to the minimum required level and to shut off lights during periods when daylight illumination is sufficient or the room is not occupied. If such systems are to be included in the proposed investment building but not the alternative non-solar building, the costs as well as energy savings from use of these controls should be included in the analysis.

4.2.3 Changes in Income from Commercial Space

Passive solar designs for commercial buildings may significantly affect the quality of life and use of space in commercial settings. These changes should be considered and valued if possible along with other costs and benefits of the solar investment.

The economic model evaluates these effects by defining them in terms of changes in net rental income. The general procedures for estimating the change in income due to the passive solar design are as follows:

1) Compare the quantity of space available for commercial use in the proposed solar building with that in the non-solar building;
2) Establish ownership of the space. (Some of the passive solar designs developed for the Solar Cities Program affect space beyond the standard building lot, i.e., they enclose pedestrian sidewalks and/or the street, or a vacant lot adjacent to a building. In evaluating these designs, it must be determined whether rights to build over the space and subsequently to use or rent the space can be acquired and if so at what costs.)
3) Examine the alternative uses for all the space included in the proposed solar design and a counterpart, non-solar alternative design.
4) Estimate the difference in net income per square meter of affected area for the solar and non-solar buildings. If various areas of the building are affected differently, find the difference in net income for each separate affected area. (In some cases, income from one portion of a building may be lower than for a counterpart non-solar building and income from other portions higher. Each portion of the building should be treated separately if variations occur throughout the building.)

Values for the quantity of space affected and for the expected income from each unit of space, net of all operating costs, are entered into the life-cycle evaluation model, equation (26) or (27).

Income from rent, net of income taxes and operation and maintenance expenses, is a comprehensive measure of income from commercial space. For an owner-occupied space or building, income may be computed from estimated sales revenue net of all operating, personnel, and merchandise costs. Since the variables affecting net sales revenue are numerous and consistent data difficult to obtain, it is often useful to impute a rental value proxy for net income when analyzing owner-occupied properties.

The Urban Land Institute publication Dollars and Cents of Shopping Centers [36] and the 1978 Experience Report for Downtown and Suburban Office Buildings [37] provide extensive data for rental and sales income and operation expenses for a large number of commercial retail and office building classes and for diverse tenant classifications. These sources provide broad data bases for estimating the benefits and costs of changing the use of commercial space. Table 4.3 provides some examples of this data for selected tenant classes in two types of shopping centers: neighborhood and regional. These examples provide a range of possible rents that can be imputed to commercial space.

In using rental income data such as that in table 4.3 to estimate the net income from commercial space, expected operation and maintenance costs per square meter of area should be subtracted from gross rental receipts. In retail or light industrial leased buildings, these costs (exclusive of utility costs) are generally expected to be 20-25 percent of rental income. The net income is taxable at the ordinary income tax rate applicable to the leasor.

TABLE 4.3: ANNUAL RENTAL INCOME--TWO CLASSES OF SHOPPING CENTERS, SELECTED TENANTS, 1978

Tenant	Rent	
	Neighborhood $\$/m^2$ ($\$/ft^2$)	Regional $\$/m^2$ ($\$/ft^2$)
Supermarket	25.62 (2.38)	22.82 (2.12)
Doughnut Shop	52.74 (4.90)	98.81 (9.18)
Ladies' Apparel	43.06 (4.00)	58.56 (5.44)
Family Shoe Store	32.30 (3.00)	63.62 (5.91)
Ice Cream Parlor	50.60 (4.71)	86.11 (8.00)
Plant Store	48.98 (4.55)	103.55 (9.62)
Flower Shop	44.90 (4.17)	107.64(10.00)

Source: Dollars and Cents of Shopping Centers, 1978 [30].

Another type of information that may be useful in evaluating passive solar designs for retail stores and shopping centers is data describing the difference in income for enclosed and non-enclosed retailing areas. For example, enclosing pedestrian areas with a solar canopy may improve the profitability of adjacent retailing operations relative to the situation with no enclosure.*

Unfortunately, estimating the improved income potential of a shopping center due to enclosure is a task filled with uncertainties. Ideally, one wishes to obtain data on the preferences and habits of shoppers in different commercial environments. However, behavioral research in these issues is in an early stage, and existing research provides

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* This effect is considered further in the solar street canopy case example in section 5.

little data directly useful in assessing the impacts of climatological factors on shopping habits and on pedestrian traffic.*

The income data on enclosed versus non-enclosed malls gathered by the shopping center industry provides an alternative measure of these effects. Data on sales revenue, expenses, and rental receipts for existing enclosed versus non-enclosed malls is available for two classes of shopping areas: super-regional and regional. A portion of this data appears in table 4.4.

The table shows that both operating receipts and net operating income per square meter of leased area are substantially higher for enclosed than non-enclosed malls in both types of centers. The difference in net operating income for enclosed versus non-enclosed malls, subtracting the value for the non-enclosed mall from the value for the enclosed mall, provides an estimate of the increased annual income per square meter of affected area from enclosing a shopping mall. However, these data can be considered only very rough measures of the effects of enclosing malls. Income results vary substantially with the age of shopping centers and with other factors besides enclosure. The Urban Land Institute is currently collecting data on the results of enclosing non-enclosed malls that should give additional insight to the profitability of enclosure.

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* Two recent studies examined climatological effects on pedestrian behavior in shopping areas. A study conducted jointly by the Institute for Man and Environment at the University of Massachusetts and Weather Dynamics, Inc., showed high winds affect pedestrian behavior. Cash register receipt data was found to be negatively correlated with average wind speeds in the most severe wind sites [38].

A separate study conducted at NBS as part of the Solar Cities Program considered window-shopping behavior on retail streets in different sun/shade and temperature conditions. The results of the NBS study failed to show a significant relationship between sun and shade conditions and pedestrian behavior in shopping areas. However, the study was limited to temperate conditions and to two locations [4, 5].

TABLE 4.4: ANNUAL INCOME--ENCLOSED VS. NON-ENCLOSED MALLS, MEDIAN VALUES, 1978

	Regional		Super Regional	
	Enclosed $\$/m^2$ ($\$/ft^2$)	Non-enclosed $\$/m^2$ ($\$/ft^2$)	Enclosed $\$/m^2$ ($\$/ft^2$)	Non-enclosed $\$/m^2$ ($\$/ft^2$)
Operating Receipts (Primarily Rental Income)	56.51 (5.25)	39.40 (3.66)	78.25 (7.27)	48.44 (4.50)
Operating Expenses	18.08 (1.68)	13.13 (1.22)	19.59 (1.82)	22.93 (2.13)
Operating Balance (Net Income Before Debt Service)	39.61 (3.68)	27.13 (2.52)	57.48 (5.34)	32.83 (3.05)

Source: Dollars and Cents of Shopping Centers, 1978 [36].

4.2.4 Other Benefits

The possibility that passive solar designs will affect the quality of life of occupants of the building should also be considered. Depending on the specific architectural design, passive features can potentially: 1) increase or reduce noise levels by changing acoustical isolation from street noise; 2) provide a more or less aesthetically appealing environment than conventional commercial building designs; 3) increase the use of interior landscaping, with effects on comfort and health; and 4) increase or decrease the thermal comfort of occupants. The measurement of acoustical, aesthetic, comfort, and health effects of passive solar designs and interior landscaping is an important area for further passive solar research.

4.3 FINANCIAL VARIABLES*

A number of financial variables in addition to the direct costs and income potential of an investment in solar energy for a commercial building affect its economic feasibility. These variables include: 1) the discount rate which reflects the investor's opportunity cost of receiving and spending money over time; 2) the interest rate and other terms for financing a system with borrowed funds; 3) the length of time the investment is "held" before resale or other disposal; 4) the value of the property at the time of resale or disposal, net of disposal or resale costs; 5) the rate of taxation on property, sales, and income; 6) depreciation and other expense allowances against taxable income; and 7) tax credits, grants, and other governmental incentives. Following is a discussion of each of these variables, including guidelines for determining their appropriate values in different investment situations. A number of special subsidy programs are described.

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* This section is based on interviews with actual investors in commercial real estate and an extensive survey of existing legislation and programs of public assistance which affect the use of passive solar energy in commercial buildings.

4.3.1 Discount Rate

The discount rate is a key variable in the interest, or discount, formulas used in life-cycle economic analysis to adjust for the time value of money. The selection of an appropriate discount rate to be used in the discount formulas is critical to describing accurately the value of costs and benefits that occur at different times over the life-cycle of a proposed investment. Ideally, this discount rate should represent the best return available on alternative uses of funds by the investing firm. It may also be expressed as a minimum acceptable rate of return on an investment. In using an economic evaluation model that specifies costs and benefits in terms of after-income-tax discounted values (as this report does), one should use a discount rate that represents after-tax rates of return.

In the model presented in this report, inflation is included in estimates of future cash amounts, and the effects of inflation are removed by including the expected rate of inflation in the discount rate used to adjust for time differences, i.e., a "nominal" rate is used. Alternatively, all cash amounts may be expressed in constant dollars (without inflation) before being discounted. In this case, a "real" discount rate, one that does not include inflation, should be used for discounting.

The relationship between a real and nominal discount or interest rate is the following:

$$d_n = (1 + d_r)(1 + \rho) - 1 = d_r + \rho + d_r\rho \qquad (42)$$

where

d_n = nominal discount rate

d_r = real discount rate, and

ρ = expected rate of inflation.

Although the portion of a market interest rate that is attributable to expected inflation is seldom specified, some expectation about inflation is generally built into these rates, and higher rates are associated with periods of expected higher inflation.

In addition to components for inflation and compensation to investors for postponing consumption, discount rates may reflect a compensation for risk. There is some dispute 1) whether this risk compensation should be reflected in the discount rate or handled separately in the estimation of expected costs and benefits, and 2) whether the compensation for risk should vary with the overall riskiness of the firm or with expectations about a particular investment.

Frequently, there is an element of both situations. Stockholders in firms with poor stock ratings will demand higher rates of return, and firms will require higher returns on more risky investments than less risky investments.

A wide range of discount rates are used in actual practice depending on the type of investment, the type of firm, prevailing economic conditions, and the method chosen for treating inflation and taxes. Some investors focus on the long-term potential of their projects and are satisfied with a good but not exceptional annual return over a large number of years. A representative example of this type of investor is an institutional investor such as a bank or insurance company with a large quantity of internal company funds available for financing investment projects. Such investors tend to seek a moderate annual return on a few large building projects and to use a moderate discount rate, such as an after-tax rate of 5-7 percent plus annual inflation.

Speculative investors, on the other hand, will typically finance an investment with borrowed funds at a market rate and seek investment projects which earn a high rate of return on a small amount of equity in each of numerous projects. These investors will tend to use a high discount rate in evaluating a high-risk building investment, as high as 15 percent above expected inflation.*

Small, non-speculative investors who plan to occupy the investment buildings may use lower discount rates in evaluating a solar building, for example, 3-5 percent above expected annual inflation, depending on their alternative investment opportunities.

Using a high discount rate in evaluating an investment in solar energy reduces the value of future benefits and costs relative to the initial investment cost. Since the benefits of a passive solar energy system occur over the entire life of the project while a large portion of the costs tend to occur initially, solar energy systems will generally not be as attractive to investors who use high discount rates as to those who use lower rates. An important exception is situations where investors obtain loans at low interest rates to finance a major portion of the passive solar project.

4.3.2 Borrowing Rate

Financing a portion of a solar energy system with borrowed funds has two major impacts: 1) It defers payment of the financed portion of the capital costs of the system. Equity funds not invested in the solar energy system can be used for additional projects. 2) It adds to the capital costs of the investment, but because financing costs are tax deductible, the effective interest rate is lower than the borrowing rate upon which loan payments are based. Moreover, the

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* The treatment of taxes, inflation, and risk in evaluating real estate investments varies considerably among actual investors. The discount rates cited serve to illustrate the range of discount rates used in actual practice. They are not intended as recommended values.

effective cost of the system may be reduced still further by financing it with borrowed funds if the projected rate of inflation reflected in the loan interest rate fails to cover the actual rate of inflation in the income of the borrower.

Heavy use of financing leverage is more typical of some types of investors than others. Large institutional firms with a large supply of internal funds may prefer to use equity funds for nearly all capital investments, while smaller, more speculative firms may continually seek the leverage advantages of borrowing.

Conventional Loans. Financing arrangements for solar buildings, as for conventional buildings, are determined by individual lenders operating within the prevailing conditions of local and national money markets. However, conditions vary with the credit worthiness of the firm. Long-term mortgage financing of a new solar-heated commercial building would generally be obtained from large nation-wide insurance companies at interest rates somewhat lower than the prime rate, depending on the relationships between the lender and borrower. Although lenders are sometimes willing to make a 30-year mortgage loan for new construction, they often require that the loan be paid off or refinanced after 15 years.

For solar retrofit or rehabilitation projects, financing terms are usually less favorable than for new construction. Unless the borrower is eligible for a special government subsidized loan or grant, he or she usually must obtain a commercial bank loan. These loans generally are 3-5 year uncollateralized loans with interest rates somewhat above the prime rate. Downpayment requirements are typically 25 percent for large mortgage loans, possibly less for a small commercial bank loan.

Many passive solar retrofit projects undertaken in combination with other building improvements should be eligible for government insured and subsidized building improvement loans. These loan programs provide more favorable financing arrangements than are typically available from commercial banks.

HUD loan programs of interest to solar investors are the Title 1 Property Improvement Loans and Section 312 Rehabilitation Loans.

Title 1 Property Improvement Loans.* Title 1 loans are obtained from private FHA-approved financial institutions. HUD provides loan insurance to the lender and specifies major loan conditions and eligibility requirements. Currently, the maximum loan is $15,000 for a non-residential structure. The structure to be improved must be a completed building occupied for a minimum of 90 days before application for the loan. ("Shell houses" are excluded as "not completed.") The current maximum interest rate allowed of 13 percent is somewhat below current market rates for business loans, and the maximum loan term of 15 years substantially longer than the term of a standard commercial bank loan, which is typically 3-5 years. The FHA loan insurance premium, 1/2 percent per annum of loan proceeds, is paid by the lender.

Heating systems are specifically eligible for these loans. Thus, most passive and active system components are eligible. This government-insured loan program is particularly important to small firms and to firms undertaking projects in neighborhoods where property insurance is difficult to obtain.

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* This loan program is described in detail in [39].

Section 312 Loans.* Through the Section 312 program, HUD makes available to private building owners government loan funds. These funds may be used to rehabilitate, improve, or repair property, but are limited to buildings either in Federally funded urban renewal areas or part of a Community Development Block Grant project. The funds are disbursed through city and county governments and public agencies. "Shell buildings," such as those obtained by cities under tax sales and then sold to private individuals for a nominal sum, are eligible. The maximum loan for one building is $100,000; the current interest rate, 3 percent; and the maximum loan term, 20 years. Rehabilitation undertaken with the loan funds must bring the property into compliance with minimum standards of local building codes.

Although these low-cost loans have strict eligibility requirements, they are of considerable importance to major urban revitalization projects. Either in combination with, or as an alternative to re-development grants and tax credits for building rehabilitation and energy conservation, they substantially reduce the cost barriers to using solar designs in urban rehabilitation projects.

Other Loan Programs. Some local governments have sponsored special loan programs for building rehabilitation to supplement funds from the Federal programs. In many cities, these funds are widely available, typically at interest rates below market rates. As of January 1978, Massachusetts, Minnesota, and Oregon had passed legislation relating to loans for solar energy systems, but these programs were limited.

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* This section is based primarily on telephone interviews with officials at HUD and the Department of Housing and Community Development, Baltimore, MD. For further information, contact HUD, local community development associations, and the Catalogue for Federal Domestic Assistance [40].

4.3.3 Study Period and Market Value

The study period is the length of time over which an investment is evaluated. Obviously, the cumulative economic benefits over the study period will be greater the longer the period of expected service, and the proposed investment will appear more cost effective with a longer study period, providing other conditions are the same.

In analyzing solar energy systems, a typical approach has been to use a study period equal to the expected service life of the system, for example, 20-25 years for an active system [17], or 30 years for a passive system [14]. By using this approach, energy savings and other economic benefits occurring over the entire useful life of the project are included in the economic evaluation. In addition, an expected salvage value of the solar components for scrap, net of disposal costs, can be specified.

An alternative approach is to use a study period shorter than the anticipated service life of the project but to include an estimate of the market value of the investment at the end of the study period in the investment analysis. The market value at the end of the study period represents the potential resale value of the system at the time of resale. By including the resale value in the analysis, the service life of the investment beyond the study period is accounted for.

It is proposed in this report that the latter approach to selecting investment analysis periods be used in evaluating passive solar commercial buildings. Although passive solar energy systems tend to be durable, structural components of the building with service lives comparable to the building as a whole (building lives of 30-50 years are assumed for depreciation purposes), investors in commercial real estate typically use relatively short investment analysis periods. Some investors plan to sell or refinance their properties after a period considerably shorter than the mortgage term or service life. These investors tend to select investment analysis periods corresponding to the anticipated holding period of the investment.

Estimating Holding Periods. The tax shelter concept is frequently cited in real estate investment literature as a major criterion for setting holding periods [41, 42]. According to the tax shelter concept, a project should be sold when the annual payment on the principal of a loan becomes larger than annual depreciation [42]. By selling or refinancing and using cash received to start new projects, the investor can often return to a position of greater return on equity. For an investment financed at market lending rates of 10-12 percent, and depreciated according to the declining balance method, annual principal payments become equal to annual depreciation in 12-15 years. This criterion is likely to be particularly important to a cash-poor young firm seeking rapid expansion and to speculative investors seeking rapid recovery of investment costs and subsequent reinvestment in new projects.

Another firm may select a holding period that maximizes the return on an investment according to a more comprehensive set of criteria. For example, the investor might wish to compare the net present value of all cash flows from the investment, or, alternatively, its internal rate of return, for different holding periods and to select the holding period for which the rate of return or net present value is greatest.*

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* Cooper and Pyhrr discuss a rate of return model for evaluating real estate investments and selecting optimal holding periods [19].

To a firm using equity financing, the tax shelter criterion tends not to be relevant to establishing a holding period. Large institutional firms which fund projects entirely from equity appear commonly to use 15-20 year investment analysis periods, although they do not necessarily sell or replace the investment at the end of this period. For many investors, including lenders, the future beyond 15 years is too uncertain to be represented in investment planning.

Estimating Resale Value. Passive solar energy systems should have considerable remaining service life at the end of a short holding period. Thus, many investors should expect to recover a significant portion of their original capital investment at the time of sale of the building. Increases in conventional fuel prices and shortages of conventional energy supplies over the study period should contribute to high resale values for passive solar buildings. It is important to the assessment of feasibility of the system that this resale value be included in the economic evaluation.

Unfortunately, estimating the market value of a passive solar energy system at the future time of resale is a difficult task. Ideally, one wishes to predict the difference in selling price for the passive solar building and an alternative, comparable conventional building. In order to derive an estimate of resale value, these questions must be addressed: 1) What proportion of the total building value is reflected in the solar energy investment at the time the solar investment is made? (Does the solar investment over-improve the building?) 2) How will buyers, financiers, and appraisers respond to solar-heated buildings at the time of resale? 3) What is the history of commercial property values in the neighborhood of the solar building? 4) What is the expected service life of the solar components of the building? Of the building itself? and 5) Apart from energy savings, what economic benefits from the solar energy system might affect its resale value?

The approach for determining resale market value suggested in this report is to estimate the fraction of the original passive solar energy system in service at the end of the study period (measured as a fraction of the original purchase and installation costs). This can be done by estimating the fraction of initial investment costs that covers durable, long-lived building components with service lives commensurate with the building as a whole. One then assumes that the remaining portion of the system deteriorates over the study period and has no economic value at the end of the study period. In addition, the system components that do not deteriorate may be assumed to appreciate in market value at a specified annual rate, which may be equal to, less than, or greater than the general rate of inflation assumed in the analysis, depending on an overall assessment of the real estate market conditions for passive solar buildings and the anticipated economic benefits of the system. This annual appreciation rate should cover both the effects of general inflation and trends in real estate market evaluation of passive solar buildings relative to conventional buildings.*

An alternative approach to determining resale value is to estimate the economic benefits from the passive solar energy system during the remainder of its service life beyond the study period. This approach requires not only an estimate of energy prices and non-energy benefits

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* Some mechanical "hybrid solar" components, for example, fan systems, might have a service life equal to or less than the study period. On the other hand, south-facing windows and structural components like thermal storage walls might be expected to have long service lives and to increase in market value over some portion of their service lives due to inflation in general or to other market supply and demand and replacement cost factors. Note that if the resale price of the passive solar building is expected to be the same as the resale price of an alternative non-solar building, the resale value of the solar energy system must be assumed to be zero.

during the period beyond the study period but also an assessment of the cost and efficiency characteristics of alternative, conventional heating systems during that period.*

Given the degree of uncertainty about economic and technological conditions beyond the study period, this alternative approach is not recommended. Estimating resale value as a function of the original purchase costs, the procedure suggested in this report, tends to represent more closely the operation of the actual real estate market and does not require economic data for the remainder of the building life beyond the study period. This procedure could be extended to allow some passive solar energy components to deteriorate at different rates and others to appreciate at different rates depending on the particular system design and the market conditions assumed.

4.3.4 Taxes and Tax Incentives

Government tax policies can be expected to have a major influence on the economic feasibility of commercial investments in solar energy. The combination of high corporate marginal tax rates and of tax deductions for business expenses, plus the special incentives provided by the Federal government and local governments for solar energy through the tax mechanism, effectively reduce the investment costs of commercial building systems to a small fraction of what they would be otherwise.** Property taxes, sales taxes, and capital gains taxes raise the effective capital costs of the solar investment,

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* Presumably, the conventional heating systems in the solar and alternative buildings would be replaced one or more times during the service life of the solar energy system.

** See figure 5.2 in this report and the results reported in The Economic Feasibility of Solar Space and Water Heating Systems in Commercial Buildings [17].

but since the first two are allowed tax deductions, and the third occurs only in the distant future, if at all, the effect of these taxes is generally small relative to the tax deductions for interest and depreciation and the tax credits. Since conventional fuel costs are also tax deductible, the effective savings in fuel costs due to the solar energy system are also reduced.

Income Tax Rates. Because the value of a tax deduction is directly related to the rate at which the investor's income is taxed, it is important to select a tax rate to use in the economic evaluation of these tax effects appropriate to the particular investor. The appropriate rate to use in evaluating the solar investment is generally the marginal rate at which the last dollar of taxable income is taxed. The specific rate used will depend upon assumptions as to the total taxable income characteristics of the particular investor.

Starting with the 1979 tax year, a new schedule of Federal corporate tax rates went into effect. The 1978 Revenue Act reduced the maximum tax rate from 48 percent to 46 percent, cut the lowest rates to 17 percent and 22 percent, and added two new tax brackets. The resulting corporate income tax rate schedule is as follows:**

For income -

not greater than $25,000	17%
greater than $25,000 but not exceeding $50,000	22%
greater than $50,000 but not exceeding $75,000	30%
greater than $75,000 but not exceeding $100,000	40%
greater than $100,000	46%

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* See figure 5.2 in this report and the results reported in The Economic Feasibility of Solar Space and Water Heating Systems in Commercial Buildings [17].

** Revenue Act of 1978, PL 95-600, Sec. 301 [43].

In order to account simultaneously for the State and Federal laws in evaluating deductions allowed by both tax authorities, a combined State and Federal income tax rate can be applied within the economic evaluation model. The following equation describes this combined rate:*

$$t_c = t_s + (1 - t_s)t_f , \tag{43}$$

where

t_c = combined Federal and State tax rate/100;

t_s = State corporate income tax rate/100; and

t_f = Federal corporate tax rate/100.

Captial Gains and Depreciation Recapture Taxes. If the solar energy system has a market value above the undepreciated costs remaining at the time of sale of the building, the seller must pay a capital gains tax** on the difference between the selling price of the system and its undepreciated costs.*** If the seller has used a depreciation method other than straight line, he must pay, in addition, depreciation

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* This equation assumes that State income taxes are an allowed tax deduction at the Federal level but Federal taxes are not deductible in computing State taxes, the assumption made throughout the report. A few States allow a tax deduction for Federal taxes. In those cases, the appropriate equation for the combined tax rate is the following:

$$t_c = t_s + \frac{t_f (1-t_s)^2}{1 - t_f t_s} . \tag{44}$$

See Engineering Economics, A Manager's Guide to Economic Decision Making [44].

** Beginning with the 1979 tax year, the Federal corporate capital gains tax rate was reduced from 30 percent to 28 percent. State governments also tax capital gains, often at the ordinary income rate. Non-corporate investors are subject to different capital gains laws. Only 40 percent of the capital gains of individuals is taxed, but at the ordinary income tax rate.

*** The undepreciated value consists of the remaining depreciable base plus salvage value.

recapture taxes on depreciation taken in excess of the straight-line amount at the time of sale. Depreciation recapture is taxed at the ordinary income tax rate.

The combined State and Federal corporate capital gains tax rate is described by the following equation:*

$$t_{cg} = t_{sc} + (1 - t_{sc})t_{fc} , \tag{45}$$

where

t_{cg} = combined capital gains tax rate/100;
t_{sc} = State capital gains tax rate/100; and
t_{fc} = Federal capital gains tax rate/100.

Sales Taxes. Unless exempted by special legislation, solar energy systems are subject to State and local sales taxes. As of late 1977, the following States had passed special legislation exempting solar energy systems from sales taxes: Arizona, Connecticut, Georgia, Maine, Michigan, and Texas [46].

Property Taxes. A solar-equipped building may have a higher market or assessed value than a similar building without solar equipment if the initial cost of the solar building is higher. Property taxes owed on the portion of the assessed value attributable to the solar energy system are an added cost of the solar energy system. The effective tax rate equals the overall assessment rate used by the taxing authority (generally a fraction of the market value) times the official property tax rate. A number of States have passed legislation exempting solar energy systems from property taxes (see table 4.5 and [45]).

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* This assumes State taxes are deductible in determining the Federal tax liability, but Federal taxes are not deductible in determining the State tax liability. See Income Tax Rates above.

Depreciation. Passive solar building components may be depreciated either in composite with the commercial building envelope or separately. If component depreciation is taken, the solar energy system may be depreciated over a shorter period than the rest of the building, a period of 15-20 years being typical for mechanical heating system components. The Internal Revenue Service (IRS) will require that a longer period be used for durable, non-mechanical passive features integral to the building, unless conditions suggest otherwise. In a new building, the period might be 30-50 years; in an existing building, 20 years.*

The depreciation method allowed for heating and cooling system components depends on whether the building is new or existing when purchased and whether it is a residential building. The straight-line method of depreciation must be used for existing non-residential buildings and their components, while either a declining balance (150 percent maximum) or straight-line method may be used for an existing residential or new building.**

The entire initial purchase costs of the system, including design work, engineering, and installation, minus the expected salvage value of materials for scrap, are depreciated. Sales taxes most likely would be deducted in the tax year the system was purchased and thus would not be included in depreciation expenses.

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* In accordance with section 167 of the Internal Revenue Code of 1954 [46], the IRS defines the useful lives of real estate properties on the basis of individual "facts and circumstances." According to the IRS, periods of 30-50 years are typically used for depreciating structural components of new buildings, 20 years, for existing buildings.

** Currently component depreciation is not allowed on a retrofit solar energy system if the building owner previously used composite depreciation. In that case, the retrofit system must be depreciated over the depreciation period used for the building as a whole.

The investor selects a depreciation period and salvage value based on general nationwide IRS standards and criteria. At any given time, the actual market value of the investment property may differ substantially from the undepreciated system costs. However, if the investment is sold, the resale value in excess of undepreciated system costs is taxed at the capital gains or ordinary income rate.*

Some states allow a short period amortization of all or a portion of solar energy costs in lieu of a tax credit or normal depreciation. These deductions are equivalent to straight-line depreciation of the system over the period specified.**

Operation and Maintenance Costs. Costs for operation and maintenance of a passive solar energy system or conventional system for a commercial building are allowable tax deductions. This includes the cost of fuel used in the back-up conventional heating system. The tax deduction for fuel costs greatly reduces conventional energy costs for those in high income brackets and thereby greatly reduces after-tax fuel savings, i.e., the benefits, of solar energy systems.

Interest Payments. Tax deductions for interest payments are a major source of tax savings to firms in high marginal tax brackets which use debt financing for a significant portion of a capital investment. These tax effects are discussed further in section 4.3.2.

Tax Incentives. Two Federal tax laws provide important incentives for the utilization of passive solar energy in commercial buildings.

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* See Capital Gains and Depreciation Recapture Taxes above.

** See Depreciation Deductions in section 3.3.1.

1) The Energy Tax Act of 1978 provides a business investment tax credit of 10 percent for energy conservation, solar, or wind property acquired after September 30, 1978 [47]. It is limited to depreciable equipment with a useful life of 3 years or more. The eligibility rules for this tax credit have not been firmly established. At the current time, the definition of solar energy systems in commercial or other business property appears to be broader than for residential systems, in that it includes passive components with structural as well as heating functions. Components with significant structural characteristics are currently not eligible for the residential tax credit. The Internal Revenue Service is expected to publish further definitions and eligibility rules for the business investment credit for energy conservation.

2) The Revenue Act of 1978 provides a 10 percent investment tax credit to encourage the rehabilitation of older commercial buildings. To be eligible, the building must have been in use for 20 years, and 75 percent or more of the existing external walls must remain in place after the rehabilitation [48]. Many passive solar energy systems installed at the time of other rehabilitation improvements in commercial buildings should be eligible for both the energy tax credit and rehabilitation tax credit.

Existing State tax incentives include exemptions of solar energy systems from property taxes and sales taxes and reductions in State income taxes. Table 4.5 shows the State tax incentives in effect as of January 1978.*

Tax credits are generally expressed as a percentage of investment costs and deducted directly from the tax liability. Like a Federal tax credit, a State tax credit for solar energy is deducted directly

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* For further information as to the provisions of the State legislation, the reader is referred to the State energy offices.

TABLE 4.5: STATE TAX INCENTIVES FOR SOLAR ENERGY

	Real Property	Income	Sales
Alabama			
Alaska		*	
Arizona	*	*	
Arkansas		*	*
California	*	*	
Colorado	*	*	
Connecticut	*		*
Delaware			
Florida			
Georgia	*		*
Hawaii	*	*	
Idaho		*	
Illinois	*		
Indiana	*		
Iowa			
Kansas	*	*	
Kentucky			
Louisiana			
Maine	*		*
Maryland	*		
Massachusetts	*	*	
Michigan	*		*
Minnesota			
Mississippi			
Missouri			
Montana	*	*	
Nebraska			
Nevada	*		
New Hampshire	*		
New Jersey	*		
New Mexico		*	
New York	*		
North Carolina	*	*	
North Dakota	*	*	
Ohio			
Oklahoma		*	
Oregon	*	*	
Pennsylvania			
Rhode Island	*		
South Carolina			
South Dakota	*		
Tennessee			
Texas	*		*
Utah			
Vermont	*		
Virginia	*		
Washington	*		
West Virginia			
Wisconsin		*	
Wyoming			
Totals	27	16	6

Source: State Solar Energy Legislation of 1977: A Review of Statutes Related to Buildings [46].

from State income taxes owed. However, a State income tax credit for solar energy is not equivalent to a Federal tax credit of the same percentage of system cost, because State taxes are an allowed tax deduction in determining taxable income for Federal tax purposes.*

4.3.5 Grant Programs

The one Federal grant program directed specifically at commercial building solar energy systems is the National Solar Heating and Cooling Commercial Demonstration Program.** Under this program, the Department of Energy provides grants for systems selected by the agency on a case-by-case basis. Demonstration projects must meet specific requirements for solar energy system design as well as for operation and data collection.*** These grants are not included in the economic evaluations of solar energy designs conducted for this report because eligibility is limited to a relatively small number of buildings.

Grant programs for community assistance are possible additional sources of government grant funds for solar energy systems. The Block Grant and Action Grant programs sponsored by HUD provide funds for urban redevelopment projects. Energy conservation measures and solar designs utilized in conjunction with these projects are covered by these grants.

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* See Income Tax Rates above, equation (17).

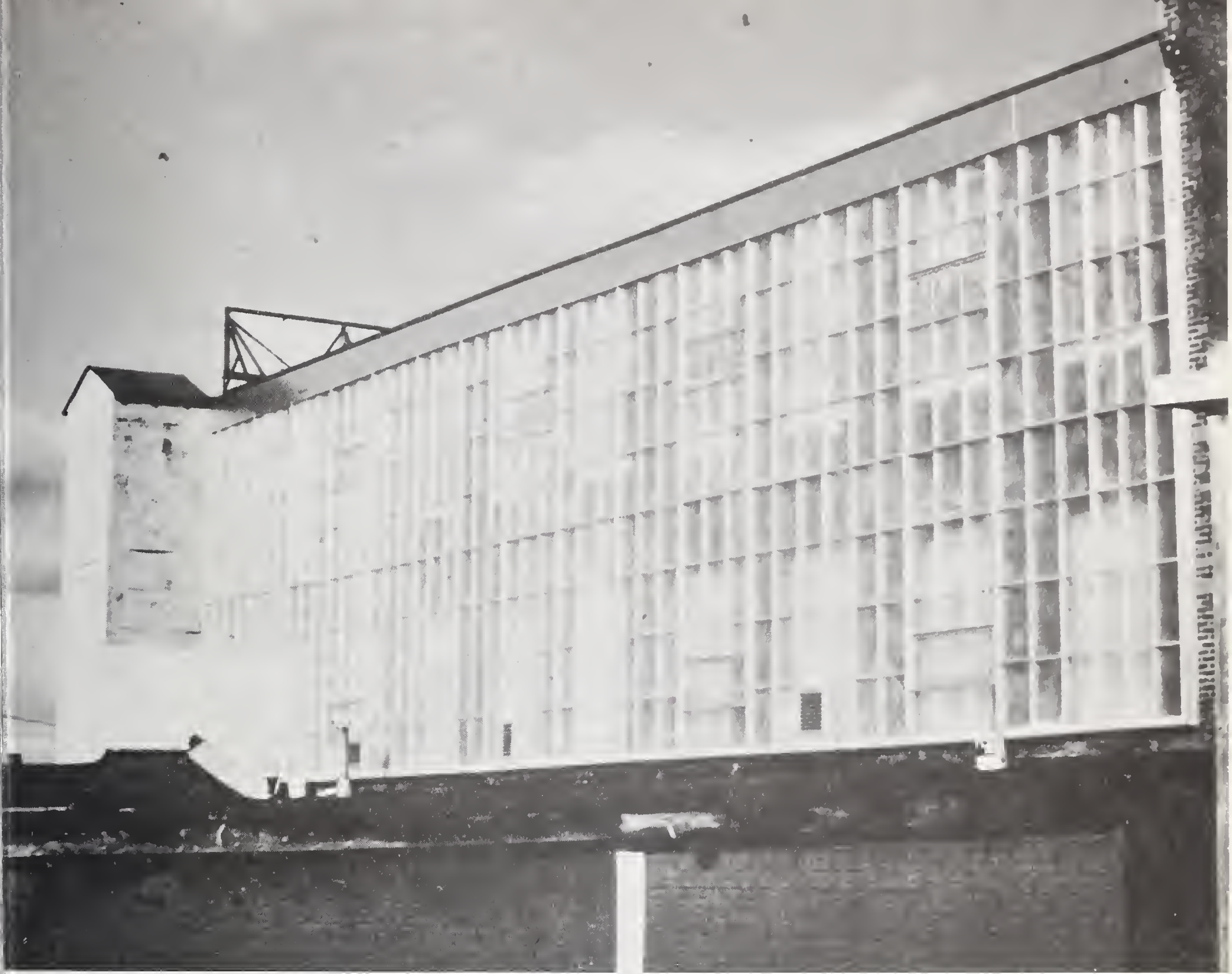
** Project reports are issued by the National Solar Data Program. These reports detailing project descriptions and costs are a good source of data for estimating costs of solar investments.

*** For further information about the commercial building demonstration program, contact the National Solar Heating and Cooling Information Center, P.O. Box 1607, Rockville, MD. 20840, (800) 523-2929.

The objective of these HUD programs is to support projects that address the problems of distressed urban areas by expanding job and business opportunities and by improving housing. Only public entities, at the State, county, or local level, are eligible for Block Grant assistance funds. The Action Grants generally involve cost sharing among private investors and local and Federal governments. Because these grants are generally substantial in size,* they have a potentially important impact on the economic feasibility of using solar energy in rehabilitation projects.

* In 1978, Action Grants ranged from $77,700 (for a small-city project) to $14 million (for a large-city revitalization project) [40].

Facing page: *Rehabilitation of this turn-of-the-century mill building in Manchester, N.H., included retrofitting the building with a wall collector passive solar energy system.*



5. CASE EXAMPLES

In the case examples selected for study in this report, the economic evaluation model described in section 3 is applied to designs for retrofitting passive systems to buildings in a neighborhood of commercial establishments designated for urban renewal in South Baltimore, Maryland. The case examples were developed at the National Bureau of Standards to investigate the passive use of solar energy in urban commercial environments. They represent "laboratory studies" of hypothetical designs for buildings in Baltimore's Cross Street revitalization area. This neighborhood was selected as prototypical of two types of "neighborhood commercial strip" environments: small areas of grocery stores, drug stores, restaurants, and other retail stores distributed throughout the residential zones of large cities, and the downtown area of small cities and towns [2].

The buildings in the neighborhood are similar in that most have one attached exterior wall and alleys bordering the other side wall and the rear wall. The buildings range in height from one to three stories, with a commercial area located on the ground floor. Typically the upper stories are unoccupied storage areas. In areas already renovated, residential use of the upper stories is increasing.

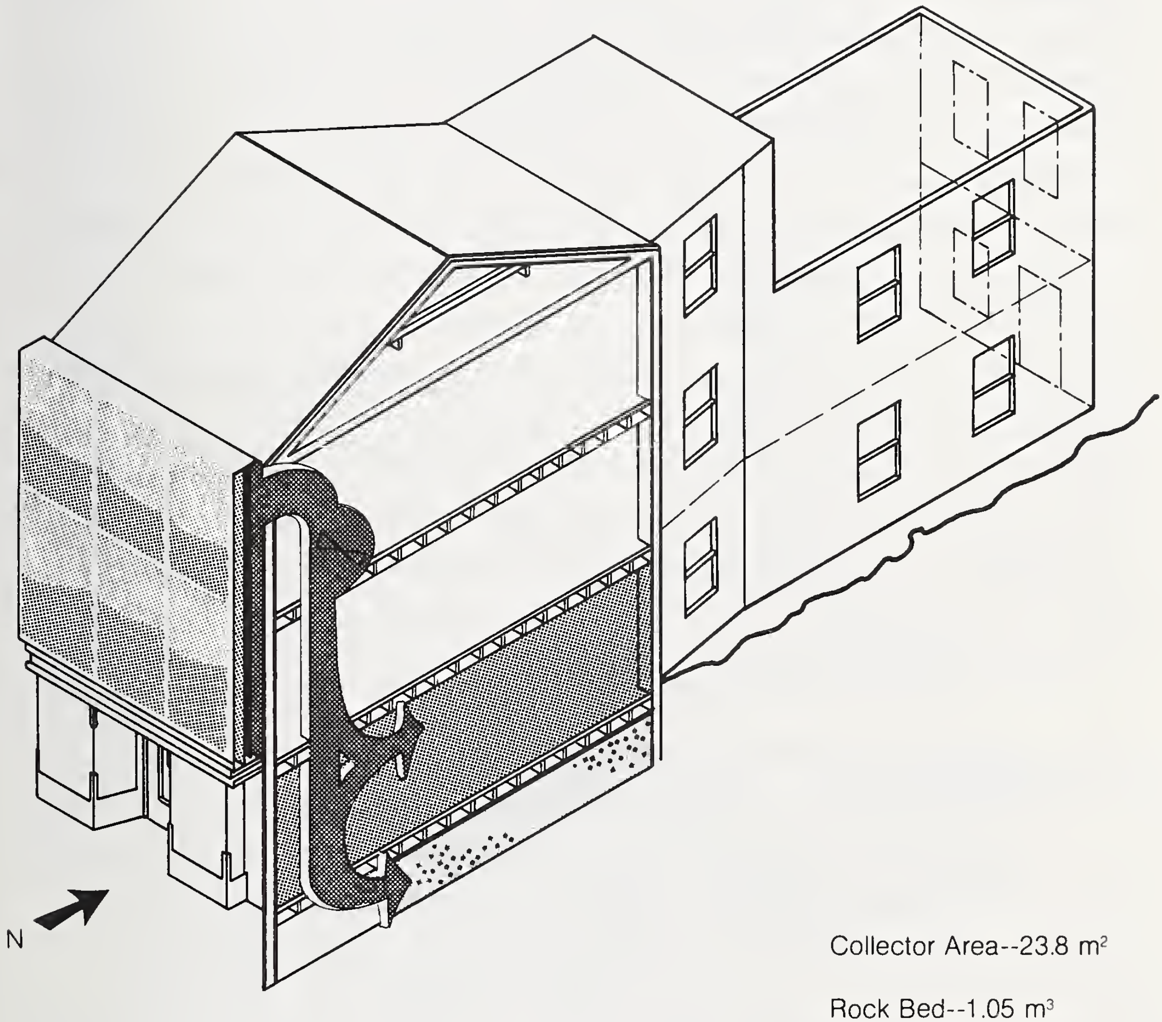
Public subsidy programs for improvements in individual buildings as well as for large-scale community revitalization projects provide major incentives for solar as well as conventional rehabilitation. These programs are taken into account in the case examples.

5.1 WALL COLLECTOR FOR A NEIGHBORHOOD RETAIL STORE

The first solar design examined was a wall air collector system for a three-story south-facing building. The ground floor is currently occupied by a shoe store, and the upper floors are vacant. The occupied area comprises 73.2 square meters: 57.1 square meters of sales area and 16.1 square meters of office and stockroom space.

The proposed solar wall collector is illustrated in figure 5.1 The solar collector covers the south-facing wall of the upper stories. It is composed of a sheet of corrugated tin roofing overlaid with a double glazing of Kalwall acrylic. A simple hot air circulation system and a rock bed for thermal storage are included in the design. The wall collector could be mounted on either the street or rear facade of similar buildings on parallel streets, depending on the building orientation.

FIGURE 5.1: SOLAR WALL COLLECTOR



Collector Area--23.8 m^2

Rock Bed--1.05 m^3

The economic feasibility of the solar wall collector was assessed first for the "most likely" set of conditions, assuming the investor takes advantage of tax incentives and loan programs available.

5.1.1 Data and Assumptions

Costs. The breakdown of component costs of the solar wall collector system appears in table 5.1. Estimated costs of labor and materials for this system in the Baltimore area, including overhead, profit, and sales taxes, were $4873. Modifications to the existing structure preparatory to retrofitting the solar energy components were expected to be insignificant. An annual operation and maintenance cost of 1 percent of the original purchase price, plus inflation, was assumed to cover insurance premiums, cleaning, repair, and replacement of worn parts over the investment analysis period. System costs were based on U.S. average data obtained from Means Building Construction Cost Data 1978 and were converted to an estimated 1979 price in Baltimore by applying an inflation factor and location cost modifier. Current energy prices and future escalation rates were based on DoE data published in the Federal Register, April 30, 1979 (see Energy Costs, section 4.2.1). A Maryland sales tax of 5 percent was added to fuel and materials costs.

Economic Assumptions. In the base-case scenario, the building owner was assumed to be a small corporate investor who would use the building for his own business and would finance 75 percent of the solar energy system with borrowed funds at the most favorable financing terms available. Currently the best financing arrangements are available under the HUD Section 312 Program, which provides 3 percent loans for 20 years. A nominal discount rate of 12 percent, including inflation, a 30 percent Federal marginal income tax bracket (combined State and Federal tax rate of 34.9 percent), and a 15-year investment analysis period represented "middle-of-the-road" assumptions about the annual income and required rate of return for this investor.

TABLE 5.1: ESTIMATED COSTS FOR WALL COLLECTOR

Item	Materials	Labor
Kalwall-Sunwall 1	$2329.60	$998.40
Tin sheathing	242.76	46.24
Variable Volume Damper	151.36	20.64
Thermostat	30.55	16.45
Air extractor	30.60	5.40
Insulated ducting	116.60	95.40
Fan, 1/4 HP	252.00	98.00
Gravel and treatment[a]	7.80	1.29
Rock bed insulation	21.45	9.19
Rock bed lining	141.75	173.25
	3324.46	1464.26
Adjustment for inflation, mid-1978 - mid-1979	x 1.10	x 1.10
	3325.56	1610.68
Regional adjustment factors (Baltimore)	x .97	x .92
	3232.44	1478.60
Sales tax	x 1.05	x 1.00
	$3394.06	$1478.60
Total, Materials and Labor	$4872.66	

Source: <u>Means Building and Construction Cost Data 1978</u> [25].

[a] Cost estimates for gravel and treatment are based on the unit cost (per ton), including delivery. The estimates are lower than typical minimum charges for gravel and hauling. It is assumed for the purposes of analysis that the collector system will be installed in a number of buildings in the neighborhood. The total cost of gravel and hauling for the group of neighboring buildings will exceed the minimum charge.

The property tax rate was set at zero because solar energy systems in Maryland are exempt from local property taxes. The solar investment was assumed to be eligible for both the Federal solar energy business tax credit of 10 percent and the building rehabilitation tax credit (see section 4.3.4), an additional 10 percent.

Special grant funds were not included in the analysis. Although Baltimore has received Block Grant funds for urban renewal projects, these funds are currently being used only for large commercial revitalization projects.

The base-case scenario also presumed the entire neighborhood undergoes extensive revitalization during the investment analysis period, with the solar investment a part of larger improvements. It was further assumed that the real estate resale market fully values solar heated buildings; more specifically, it was assumed that the resale price of the solar energy system at the end of the 15-year holding period recovered 90 percent of the initial purchase costs plus 9 percent annual inflation. This is based on the expectation that 90 percent of the passive system will have considerable remaining service life at the end of the holding period. (Experience in similar neighborhoods has often been that commercial activity increased and property values rose faster than the rate of general price inflation following revitalization efforts.) Since the market valuation assumptions were the most tenuous, they were examined most extensively in the sensitivity analysis.

A summary of all economic assumptions used in the base case appears in table 5.2 Sensitivity of results to these assumptions is examined in section 5.1.3.

Benefits. The economic benefits of the wall collector solar energy system were assumed to be limited to savings in fuel costs. (The appreciation in market value is treated in the cost portion of the evaluation.) Estimates of the quantity of energy saved by the wall

TABLE 5.2: ECONOMIC ASSUMPTIONS FOR THE WALL COLLECTOR BASE CASE

Item	
Solar materials cost, 1979 Prices	$3232
Solar labor cost, 1979 Prices	$1479
Sales tax, materials and fuel	5%
Total system cost	$4873
1979 price of fuel/GJ	
Oil	$3.56
Electricity	$13.65
Fuel escalation rates (nominal)	
Oil	
1979-1985	11.1%
1985-1990	8%
1990-1994	11.2%
Electricity	
1979-1985	6.7%
1985-1990	6.8%
1990-1994	8.6%
Discount rate (nominal)	12%
Expected annual rate of inflation	6%
Loan interest rate	3%
Down payment	25%
Years financed	20
Investment analysis period, years	15
Depreciation	Straight line - 20 years
Recurring cost, % of purchase cost	1%
Property tax rate	0
Value of system at end of investment period, % of purchase cost	90%
Annual rate of appreciation including general inflation	9%
Combined Federal and State income tax rate	34.9%
Tax credits	
Energy	10%
Rehabilitation	10%
Combined State and Federal capital gains tax rate	33%
Grant	0

collector design were derived using thermal analysis and solar performance data generated by Ruberg at the National Bureau of Standards.*

The annual total energy requirement of the building prior to installation of the Kalwall was estimated to be 65.4 x 10^6 kJ, and after the Kalwall, 62.88 x 10^6 kJ.** The wall collector solar design was assumed to function comparably to an active system. Solar performance was computed with the solar load ratio procedure for active systems, using the following equation:***

$$f_s = 1 - 1.173e^{-0.0609SLR} , \qquad (45)$$

where

f_s = monthly fraction of energy requirement, HL, that can be provided by the solar energy system;

SLR = solar load ratio, $\frac{H_B A_c}{HL}$:

H_B = monthly insolation per unit area on a collector tilted at angle B from horizontal;

A_c = collector area; and

HL = monthly energy requirement.

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* For detailed thermal and solar analysis, see reference [1]. The thermal analysis of the building with and without the solar components was performed using a model developed at NBS from existing static thermal analysis programs, primarily TEANET, with BIN weather data, and with solar data reported by Kusuda and Ishii [49].

** By installing the wall collector, thermal energy losses through the upper-story windows were reduced by 2.53 x 10^6 kJ annually.

*** A number of solar load ratio estimation equations were tested. Solar fraction results were not very sensitive to the equation used. The equation used for this case example was developed for active systems and appears in the DoE Facilities Solar Design Handbook [50]. The solar load ratio method for active systems is parallel to that for passive systems described in section 4.2.1. Of course, the equations and assumptions are entirely different from those developed for passive systems.

The quantity of energy savings consisted of two components: 1) reduction in the total energy requirements of the building for space heating by 2.53×10^6 kJ due to reducing energy losses through the south-facing wall; and 2) the solar contribution to meeting the energy requirement, amounting to 24.6 percent of the total after installing the Kalwall, or 15.47×10^6 kJ. The total benefits of the solar energy system were the sum of these two effects, each evaluated over the analysis period; and the net benefits, the difference between total benefits and total costs. An oil furnace efficiency of 60 percent was assumed in calculating energy savings for the oil case. Electric resistance heating was assumed to be 100 percent efficient.

5.1.2 Results - Base Case

Given the estimated costs and base-case assumptions, the solar wall collector appears very cost effective. The results summarized in table 5.3 show that net life-cycle savings were $1,262 when the alternative to solar was an oil-fired furnace and $2,037 when electric resistance was the alternative. Internal rates of return were 21 percent and 29 percent, respectively, depending on whether the fuel was oil or electricity. The benefit-cost ratios could not be computed because total life-cycle costs were negative. The savings-to-investment ratios proved to be 10 and 16 for the oil and electricity cases, respectively. The substantial difference in results for the two alternative fuels is explained by the vastly different current prices per GJ (10^6 kJ) of the two types of energy.*

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* The MEFS estimates of oil prices were prepared before the huge OPEC increases in the summer of 1979. As oil prices increase, the solar feasibility results for oil will approach those for electricity.

TABLE 5.3: RESULTS FOR THE WALL COLLECTOR BASE CASE[a]

	Total Life-Cycle Costs	Total Life-Cycle Benefits	Net Life-Cycle Savings	Savings to Investment Ratio	Internal Rate of Return, %
Oil	$-295	$967	$1262	10	21
Electricity	$-295	$1742	$2037	15.7	29

[a] All terms are as defined in section 3. See table 5.2 for economic assumptions upon which analysis was based.

Note that positive net benefits resulted from a reduction in total costs as well as from energy savings. Life-cycle costs were negative because of the high estimated resale value of the solar property at the end of the investment analysis period and the substantial tax credits and tax deductions. Of course, it must be assumed that the resale value reflects energy savings anticipated by the purchaser of the resale property.

Figure 5.2 illustrates for the oil case the breakdown of financing, resale value, and tax effects on total life-cycle costs and savings. The first and second columns illustrate costs, the third column, benefits (fuel savings). The height of the first column represents the total purchase costs of the solar energy system. The impact of discounting mortgage payments, of tax deductions, and of resale value is represented in the first column by successive reductions in total costs. Increases in the total costs due to annually recurring costs and capital gains taxes are shown in the second column (see upward pointing arrows). These costs are not sufficient to bring total costs above zero. The dark shaded portion, representing -$295, is the total life-cycle costs after all taxes, deductions, tax credits, and liquidation of the investment at the end of the analysis period.

The benefits (fuel savings) column shows the effects of the tax deductions for energy costs, the dark shaded portion being total fuel savings after the tax deductions. The sum of the two dark shaded areas in columns two and three is the net benefits from the investment.*

5.1.3 Sensitivity to Economic Assumptions

The sensitivity of net benefits to changes in the following assumptions was tested: borrowing rate; percent market valuation at the time of

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* If total costs were positive, these costs would, of course, be subtracted from total savings in determining net savings.

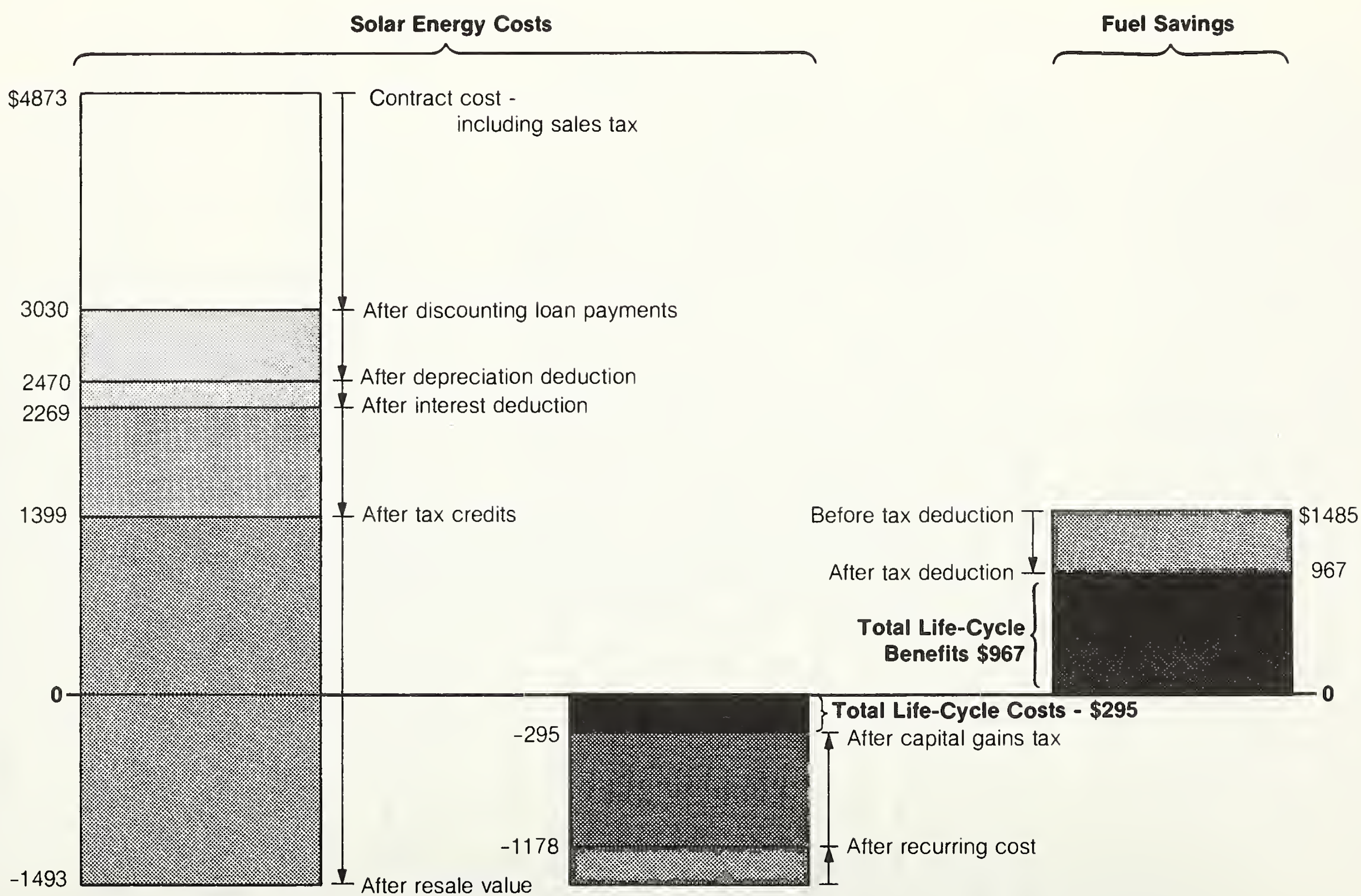

FIGURE 5.2: BREAKDOWN OF COSTS AND BENEFITS FOR WALL COLLECTOR

resale; annual appreciation of solar property value; investment analysis period; discount rate; and tax credits. Oil was assumed to be the energy alternative to solar in all the sensitivity analyses. Since oil currently costs considerably less than electricity, but more than natural gas, the solar feasibility and sensitivity results for oil can be interpreted as a "middle" energy case.

Results of the sensitivity analysis are summarized in figure 5.3 and explained below.

Interest on Borrowed Funds. Borrowing rates of 7, 10, and 12 percent were considered in addition to the base-case assumption of 3 percent, keeping all other assumptions as for the base case. The rate of 7 percent represents rates available from the City of Baltimore for building improvement loans; 10 percent, a minimum commercial mortgage loan rate at the current time; and 12 percent, the maximum rate allowed on HUD Title 1 government insured building improvement loans in mid 1979 (see section 4.3.2). In all cases, net life-cycle savings (benefits) were positive.

Resale Value. Resale values of 25, 50, 75, and 90 percent of initial system costs (plus 9 percent annual appreciation, the base-case appreciation assumption), were tested in conjunction with borrowing rates of 3 percent and 12 percent, keeping all other assumptions the same as for the base case. Given the 3 percent loan, the wall collector system was cost effective for all resale values tested above 25 percent of initial system cost. When a 12 percent borrowing rate was used, however, the wall collector was cost effective only for the 90 percent market valuation case. Results appeared to be more sensitive to the market value assumption than to other assumptions tested.

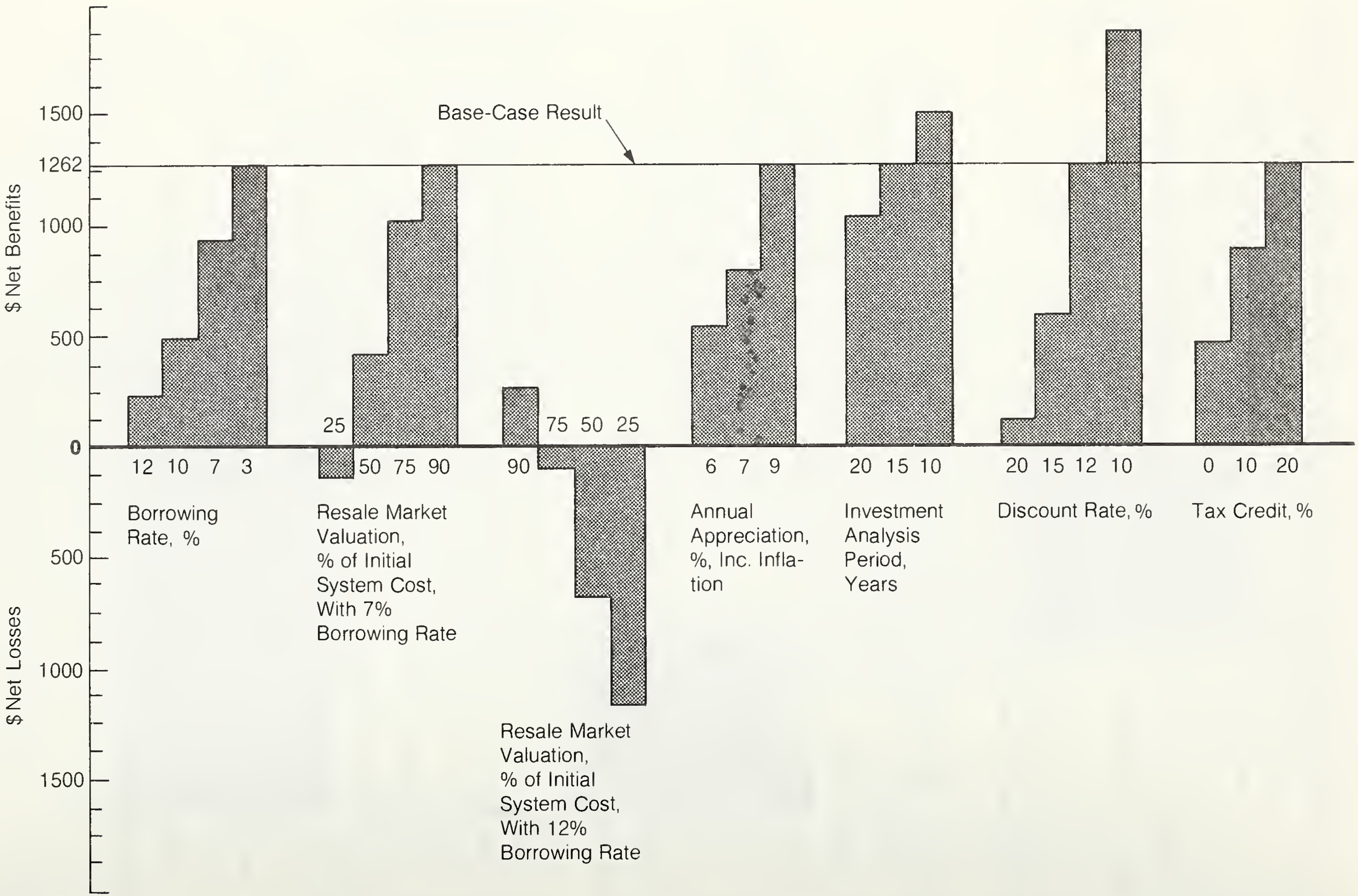

FIGURE 5.3: SENSITIVITY OF NET BENEFITS TO ECONOMIC ASSUMPTIONS FOR WALL COLLECTOR

Appreciation. Annual appreciation rates of 6 and 7 percent, as well as the 9 percent rate used in the base case, were considered, keeping all other assumptions the same as for the base case. Net benefits were positive in all cases, but were reduced by more than 50 percent by changing the appreciation rate from 9 to 6 percent.

Investment Analysis Period. Holding periods of 20 and 10 years were examined, in addition to the base-case 15-year period. Net savings were positive in all cases, and results appeared to be less sensitive to holding period than to other assumptions. The notable result was that net benefits (savings) were higher the shorter the holding period for those periods examined.

Discount Rate. Discount rates higher and lower than the 12 percent rate used in the base case example were examined. Net savings (benefits) were positive in all cases; the lower the rate, the higher the net savings.

Tax Credit. In the base case, it was assumed the solar energy system was eligible for a 10 percent rehabilitation tax credit as well as for the 10 percent Federal energy credit. Net savings were reduced by 30 percent when the rehabilitation credit was left out of the analysis. Tax credits and grants that directly offset investment costs were thus shown to be extremely important investment incentives.

5.1.4 Conclusions of the Wall Collector Case

In conclusion, the wall collector was cost effective given the assumptions considered to be most realistic for the Baltimore neighborhood under study. It also was cost effective for a considerable range of values for the borrowing rate, study period, discount rate, tax credits, and resale value. However, results were highly sensitive to resale value given the other conditions assumed. Since the resale price of a building or building component is one of the most difficult values to estimate, as well as a key factor in the cost effectiveness of the project, tests of sensitivity of results to this variable proved to be an important consideration when using a relatively short study period relative to the useful life of the project.

5.2 SOLAR STREET CANOPY

The second case example was a glazed canopy for enclosing the street and pedestrian areas among 48 buildings located along a street running north to south in South Baltimore (see figure 5.4). By providing a thermal buffer to the street-facing walls of the adjacent buildings, the canopy would reduce thermal energy losses through the street-facing walls of the buildings and thus reduce the annual thermal energy requirements for space heating.

Temperature swings within the large "attached sunspace" enclosed by the canopy would be modified sufficiently* for the space to be used year-round for a wide variety of income-producing activities, for example, a roller skating rink, restaurants, garden shops, and other small retailing activities.** Agriculture also merits mention as a possible use for this space because it is becoming important in some urban neighborhoods similar to that described in this case example. Food crops are becoming familiar in unlikely urban locations, for example, vacant lots in urban renewal areas [51]. Although this urban movement is unlikely to make a dent in the overall food supply in cities (and may be expected to occur only in situations unsuited

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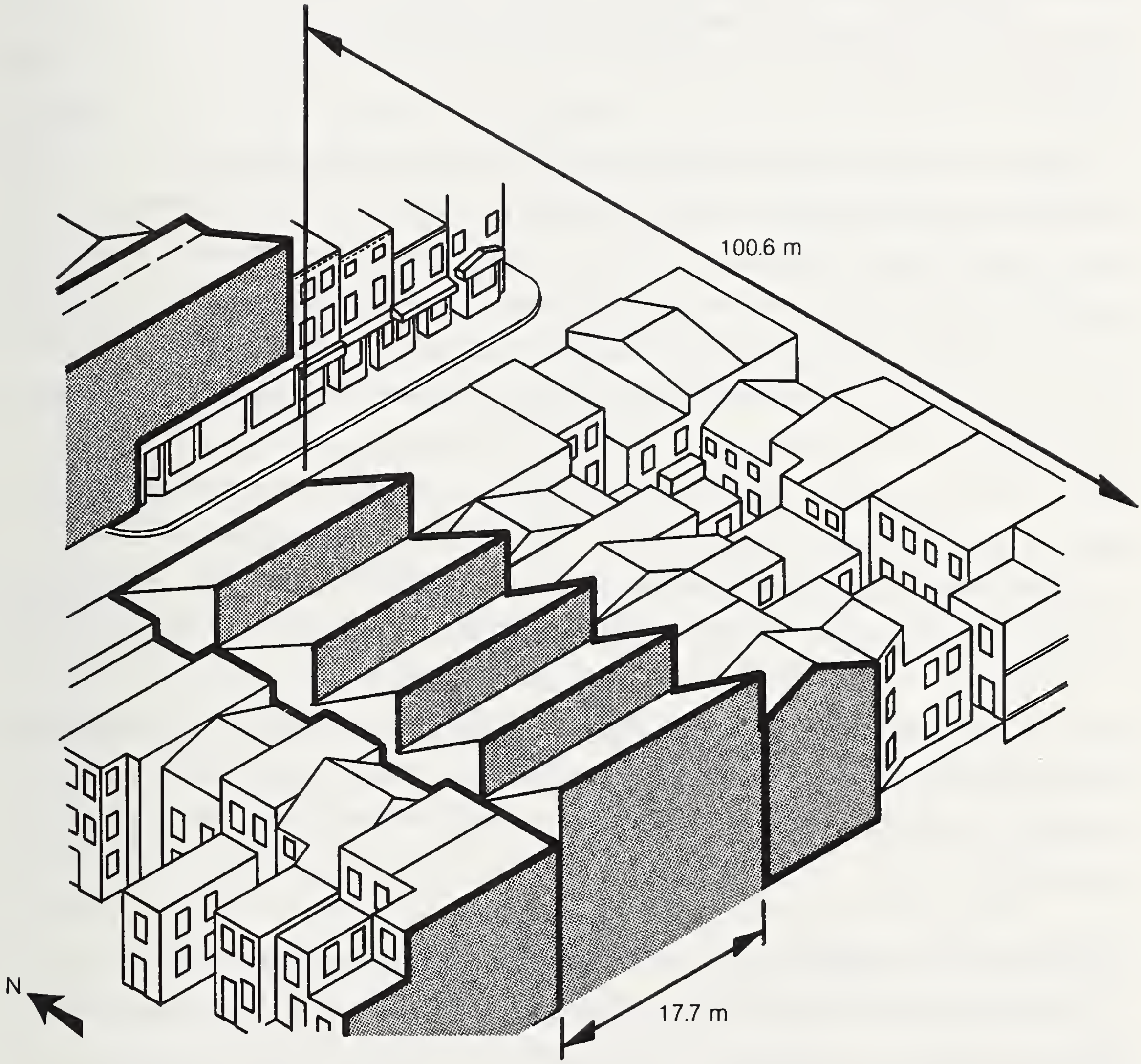
* According to Ruberg, temperature swings would be bounded to the range 12° to 20° C.

** Some of these activities would be suitable for many types of commercial settings, downtown business districts, satellite commercial centers, large or small cities, and office as well as retailing areas.

FIGURE 5.4: SOLAR STREET CANOPY



Collector--Double-glazed
Fiberglass, 700 m²

Covered Street Area--1780.6 m²

to higher income-yield activities), Olkowski and Olkowski report that a substantial amount of food can be produced in a small urban area with very low costs for capital, fossil fuels, and transportation, compared with rural large-scale agriculture [52]. The semi-conditioned greenhouse atmosphere provided by a solar canopy would increase significantly the quantity and diversity of food crops that could be grown annually [52, 53].

In order to realize this economic benefit from agriculture, the investors responsible for the solar canopy would presumably rent the enclosed area, perhaps to an independent urban farmer who wished to grow crops and sell directly to consumers, or even to a group of tenants of nearby buildings (perhaps a group of senior citizens) who wished to establish an agricultural cooperative, or possibly to an educational facility for horticultural use. The agriculture would then provide sales and rental income to the owner and operators, respectively. The consumer would benefit in lower food cost, in less exposure to dangerous pesticides, and possibly in a greater variety of food year-round.*

Some of these agricultural and retailing activities could occur whether or not the solar canopy exists. However, each activity might be limited to a portion of the year and then limited further by weather conditions.

An additional consideration in evaluating the solar street canopy is the impact of enclosing window-shopping and pedestrian areas on rental rates for space in adjacent retail stores. This potential change in income to building owners is parallel to changes which might be

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* Olkowski and Olkowski [52] note the possibilities of recycling urban food wastes for low-cost, "healthful" fertilizer in urban agriculture. Additionally, they note pest control should be more effective at considerably lower expense than in large agri-business farming.

expected from enclosing a conventional shopping mall. Presumably the dramatic increase in the percentage of conventional enclosed malls during the last 10 years is due in part to the anticipation of higher profits throughout the retailing areas of the mall from improving the comfort and aesthetic quality of the pedestrian areas and window-shopping environment. Since the solar enclosure should be able to provide an improved shopping environment similar to that of the conventional enclosed mall, the potentially higher profits to be obtained by adjacent retailing operations should be considered in evaluating the solar canopy investment, just as with a conventional shopping mall investment. This income benefit is apart from income obtained from leasing portions of the area enclosed by the canopy, and from reducing the heating bills for the adjacent buildings.

5.2.1 Data and Assumptions

Ownership. The solar street canopy is a large project which extends beyond existing building lots to sidewalks and streets. Presumably, the city owns the space enclosed by the canopy initially. The city might install the canopy itself or grant building privileges to a group of private investors. Alternatively, private investors might purchase the land directly, lease it, or merely obtain formal permission to build over the space and to lease enclosed space out to others. For the purpose of this case study evaluation the solar canopy was assumed to be a private investment undertaken by an individual developer or group of building owners, possibly in conjunction with redeveloping the entire neighborhood of buildings. This assumption is in keeping with the focus of public assistance programs on private investment for revitalizing urban areas and with current requirements of both local and Federal grant programs. These programs often require substantial private funding as a condition for public aid (see section 4.3.4).

Note that evaluations of public investments differ in key respects from evaluations of private investments, such as in the treatment of taxes, grants, and externalities (e.g., social costs and benefits of these projects that are not reflected in market prices).

A further important assumption to the economic evaluation of the solar canopy was that the owners of the solar canopy had rights to income produced in the space enclosed by the canopy. If these rights did not exist, owners of the solar canopy could not reap the benefits of the solar investment and, hence, would have less incentive to make the investment. In order to illustrate the effect of the solar canopy on income from this space and to include this effect among the benefits of the investment, it was assumed that the owners of the canopy had acquired the right to income from the enclosed space through purchase of the land or other formal agreement and that this right existed whether or not the solar canopy was constructed over the space. The investment decision was whether to construct the solar canopy or to have an open "street mall."* Costs of acquiring the land or rights to use it for income-producing purposes were sunk costs, i.e., they were inherent in both investment alternatives and therefore could be disregarded in the economic evaluation of the solar canopy.

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* Although the alternative to the solar canopy considered in the case study in this report was an open street mall, the economic model can also be used to compare a solar canopy with a conventional shopping mall enclosure. This comparison would require detailed cost and energy analyses for both shopping mall designs in addition to the analysis of income differences. Costs for the solar canopy would reflect the differences in cost for the solar and conventional enclosure, and the benefits, the differences in energy costs and income for the two types of enclosures. If non-energy benefits were expected to be approximately the same for the solar as for the conventional enclosure, the solar enclosure could be expected to have the higher benefits when energy benefits were included, and could be assumed to be the more cost effective choice provided it did not entail higher construction and other costs.

Solar Canopy Costs. The cost in Baltimore in 1979 for materials and installation costs, including overhead and profit, was estimated to be $472,000. This estimate was based on Means Building Construction Cost Data 1978 and adjusted for regional pricing factors, inflation, and sales taxes on materials. Annual operation and maintenance costs were assumed to be 2 percent of initial purchase costs, plus inflation. This is a somewhat higher rate than that assumed for the wall collector system because cleaning costs are expected to be higher for this type of collector system.*

Financial Variables. Most financial variables and energy price variables were given the same values as in the wall collector base case. The following were noteworthy exceptions. The minimum borrowing rate was assumed to be 7-12 percent, instead of 3 percent. (HUD 312 loans are unlikely to be available for this type of project. The investors are more likely to obtain a subsidized loan from the city at a minimum of 7 percent annually, a group of Title 1 building improvement loans at 12 percent interest,** or conventional financing at a rate comparable to the Title 1 loans or slightly higher.)

Rather than the 30 percent tax rate used in the first example, a Federal marginal tax rate of 40 percent was assumed. This 40 percent rate would presumably fit more closely that of a group of somewhat larger corporate investors required of this project as compared with the wall collector. Furthermore, the street canopy was assumed eligible for the 10 percent energy tax credit, but not the 10 percent rehabilitation tax credit. (The solar canopy would presumably be considered an "enlargement" of

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* The architectural design includes walkways in the canopy structure for access to glazing for maintenance and repairs.

** These are limited to $15,000 per building. A group of investors (corporate or non-corporate) could obtain separate loans. Section 4.3.2 describes eligibility requirements for these loans. (In late 1979, after the analysis was completed, the interest rate on Title 1 loans was raised to 13 percent.)

existing buildings. "Enlargements" are specifically excluded from eligibility for the rehabilitation investment tax credit.)* Table 5.4 summarizes the economic data and assumptions used in the economic analysis of the street canopy.

The solar canopy project would be a possible candidate for Block Grant funds (see section 4.3.5). Grant funds were not specifically included in the analysis, but, as is noted among the results of the case example, their impact can be inferred.

Energy and Other Benefits. Three economic benefits were examined for the solar canopy system: 1) savings in fuel costs for heating adjacent buildings; 2) increased income from the enclosed mall area; and 3) increased income from the 48 adjacent buildings.

The analyses of thermal performance showed the annual heating requirement of the adjacent 48 buildings could be reduced by 57 percent by installing the attached sunspace solar energy system, i.e., from an average of 65.4×10^6 kJ per building to an average of 28.1×10^6 kJ per building, for a saving on the average of 37.3×10^6 kJ per building [1]. This was due largely to the reduced temperature gradient through the street-facing walls of the 48 buildings. To avoid over-heating, heat gains would be vented when the air temperature of the canopy enclosed area exceeded 20°C. The brick walls of the buildings and street and sidewalks would provide some thermal mass. As for the wall collector case, an oil furnace efficiency of 60 percent was assumed in estimating energy savings due to the canopy.

To estimate the increased income generated by the solar canopy, rental income values net of all operating expenses were imputed to the street mall areas and to the adjacent buildings. These values were based on

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* See [48] and section 4.3.4.

TABLE 5.4: ECONOMIC ASSUMPTIONS FOR SOLAR STREET CANOPY

Item	
Solar materials cost, 1979 prices	\$312,985
Solar labor cost, 1979 prices	\$159,168
Sales tax rate, materials and fuel	5%
Total cost of canopy	\$472,000
1979 price of oil, per GJ	\$3.56
Fuel escalation rates (nominal)	
1979-1985	11.1%
1985-1990	8%
1990-1994	11.2%
Discount rate (nominal)	13%
Expected annual rate of inflation	6%
Loan interest rate	7%, 12%
Down payment	25%
Years financed	20
Investment analysis period, years	15
Depreciation	Straight line, 20 years
Recurring cost, % of purchase cost	2%
Property tax rate	0
Value of system at end of investment analysis period, % of purchase cost	90%
Annual rate of appreciation, including general inflation	9%
Combined Federal and State income tax rate	44.2%
Tax credits: energy	10%
Combined State and Federal capital gains tax rate	33%
Grant	0
Space enclosed by canopy	1722.6 m^2 (11,484 ft^2)
Net annual income, before taxes,	
from leasable space enclosed by canopy	\$18.80/m^2 (\$1.75/ft^2)
from leasable portion of open street mall	\$4.73/m^2 (\$0.44/ft^2)
Increased income, before taxes, attached buildings, with canopy	\$2.70/m^2 (\$0.25/ft^2)

data published by the Urban Land Institute [36].* In evaluating income from the mall area, it was assumed that with the solar canopy 60 percent of the area was leasable year around for garden shops and other retailing activities and for growing plants, and that an annual rental income of \$18.80 per m^2 (\$1.75 per ft^2) of leased area, net of operating expenses and before taxes,** could be obtained from this area. This resulted in a net rental income of \$20,097 annually from this space. It was assumed that without the canopy, rental income would be only 25 percent of that with the canopy, or \$5,024, due to seasonal limitations and periodic inclement weather. The difference of \$15,073 represented the increase in annual income due to the canopy.

To estimate the value of increased rental income from the 48 adjacent buildings, it was assumed that sales revenue would increase for these buildings due to improvement in the window-shopping environment and that the building owners would capture this benefit in higher rent. (The weather-controlled atmosphere would attract a greater number of shoppers to the area, and doors to individual stores could remain open without substantial heat loss as an invitation to shoppers.) An increase in net rental income of \$2.70 per m^2 (\$0.25 per ft^2) of leased area, before taxes, was assumed. This value was intended to

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* See section 4.2.3 regarding the use of rental income versus net income from sales as a measure of income from commercial space.

** This estimate is based on reported average rental income for food markets in neighborhood shopping centers. (See table 4.3, section 4.2.3. Note that food markets are a low-rent tenant class compared with other candidates for this space and thus the rental values used in the evaluation represent a low estimate of potential income from commercial space.) An expense ratio of 1 to 4, i.e., 25 percent, was applied to estimated gross rental income of \$25.00/m^2 to determine net income. This expense ratio was cited by actual investors as typical for shopping centers.

represent the increase in rental income per m^2 of leased area for the buildings adjacent to the solar canopy.* This increase of $2.70 per m^2 results in a total difference in annual net income of $9,456, or $197 for each building.**

5.2.2 Results

The economic feasibility results for the closed canopy design are summarized in table 5.5. Two cases were considered: 1) the financing of 75 percent of the investment with a 7 percent loan, and 2) the financing of 75 percent of the investment with a 12 percent loan. Other assumptions were the same for both cases. The back-up fuel was assumed to be oil.

The results show that net benefits (column 6) were positive in both cases. The internal rate of return was 23 percent and 20 percent, respectively, for the 7 percent and 12 percent loan cases.

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* This value is considerably lower than differences in rental rates for enclosed versus non-enclosed malls reported by the Urban Land Institute for regional and super-regional centers. It is intended to provide a conservative estimate of differences that could be expected from enclosing a neighborhood shopping center. The Urban Land Institute data (reported in table 4.5, section 4.2.3) showed net income (before debt service) per m^2 of leased area was $24.65 higher for enclosed super-regional centers than for non-enclosed centers of that class, and net income (before debt service) per m^2 was $12.50 higher for enclosed regional centers than for non-enclosed regional centers. The Urban Land Institute does not report data for other types of centers. See section 4.2.3 for further discussion of the data limitations in valuing effects of enclosing a shopping center.

** Possible effects of the solar canopy on lighting costs and cooling costs were not considered in the evaluation because the two effects were expected to offset one another. The canopy should serve to reduce cooling costs for the adjacent buildings by reducing the temperature gradient through street-facing walls of the buildings. On the other hand, lighting costs might increase for the adjacent buildings due to the shading provided by the canopy. The net effect was assumed to be relatively small.

TABLE 5.5: ECONOMIC EVALUATION OF THE SOLAR STREET CANOPY[a]

Loan	TOTAL LIFE-CYCLE COSTS	LIFE-CYCLE BENEFITS			TOTAL LIFE-CYCLE BENEFITS	ECONOMIC FEASIBILITY	
		Conventional Fuel Savings	Increased Income from Enclosed Space	Increased Income from Attached Buildings	(Savings) (2)+(3)+(4) = (5)	Net Life-Cycle Benefits (5)-(1) = (6)	Internal Rate of Return
	(1)	(2)	(3)	(4)			(7)
7% Loan	$ 61,820	$77,080	$78,560[b]	$49,280[c]	$204,920	$143,100	23%
12% Loan	110,130	77,080	78,560[b]	49,280[c]	204,920	94,790	20%

[a] All terms are as defined in section 3. See table 5.4 for economic assumptions upon which analysis was based.

[b] The annual increase in net income from the space of $15,073 resulted in a life-cycle benefit of $78,560.

[c] The annual increase in income from the attached buildings of $9,456 resulted in a life-cycle benefit of $49,280.

Note that fuel savings alone were sufficient to offset costs in the 7 percent loan case (net benefits would be approximately $15,000 considering only fuel savings benefits) but not in the 12 percent loan case. Supplementary benefits from increased use of the enclosed space and increased income from the attached buildings (columns 3 and 4) of about $30,000 were required in the 12 percent loan case for the passive solar canopy to be cost effective according to the net benefits measure. Alternatively, a HUD Block Grant of $30,000 would be sufficient for the solar canopy to be cost effective in the 12 percent loan case. Given a 7 percent loan, the solar canopy is cost effective without considering non-fuel benefits or potential grant funds.

5.3 IMPLICATIONS

The two case examples in this study show that the selected passive solar designs for retrofit to commercial buildings may be economically feasible under a realistic range of assumptions. The resale value of the solar energy system was shown to be a major factor in the cost effectiveness of the solar designs considered when the investment analysis period corresponds to the relatively short holding period that business investors tend to adopt.

The importance of variables affecting the resale value suggests that the promising results obtained in the base-case analyses are dependent on a general rehabilitation of the entire community and on a real estate resale market that is fully responsive to the benefits of solar-equipped buildings. This further suggests that an independent building owner considering the use of solar energy in renovating an individual building in a neighborhood where property values are low and expected to remain so should evaluate the cost effectiveness of the project based on energy savings alone. In these cases, the length of the investment study period may be a decisive factor in the economic feasibility of the investment.

Since resale values are always difficult to predict, the sensitivity of economic feasibility results to different resale values should be examined in conducting an economic evaluation of an investment in solar.

Even under relatively conservative assumptions, the potential non-energy benefits of a large street-scale passive solar project were shown to be comparable in size to the energy benefits. Where measurable, and particularly in the absence of subsidized loans and other substantial incentives, non-energy benefits of passive solar designs may be critical to the investment decision.

The special tax incentives and loan programs available to investors in solar energy and building rehabilitation also were shown to have a major impact on the feasibility of solar energy systems eligible for these programs. The special public subsidy programs available in urban renewal areas, combined with the multi-faceted benefits of solar energy, make solar designs a promising approach to real estate investors planning revitalization projects in designated urban renewal areas.

The solar designs examined in this report did not require that portions of the original building structure be torn down in order to retrofit the passive solar components. Passive solar designs which require major changes in the wall structure or window area in order to obtain the same energy savings as those examined are likely to be less cost effective. An important exception is situations where the existing walls are being demolished and rebuilt whether or not solar energy is used.

Facing page: *Properly designed venting systems are essential to maintaining desired comfort levels in areas enclosed by solar canopies.*

6. CONCLUSIONS

In this report, a comprehensive life-cycle costing model for evaluating passive solar designs for commercial buildings has been developed and applied to two case examples of specific solar designs for a neighborhood commercial strip setting. Although the use of life-cycle investment analysis is relatively new to the commercial real estate investment community, it is becoming more widely recognized as a necessary tool for evaluating certain kinds of investments. By accounting more fully for possible energy and non-energy benefits of passive solar designs than has been typical in existing methodologies, and by incorporating investment variables and criteria of specific interest to the commercial real estate community, the life-cycle costing model proposed in this report should be useful both to the solar research community and to actual real estate investors and financiers.

The report has examined in detail the key variables affecting the economic feasibility of passive solar designs for commercial buildings. It has provided substantial guidelines for estimating values for the variables in the economic model according to different investment situations and a survey of major government incentives for which passive solar components of commercial buildings are eligible. This analysis should aid potential investors and policy makers in identifying where use of passive solar energy is likely to be most cost effective.

Anticipated furture research includes evaluation of additional passive solar designs for neighborhood commercial strip settings and for other commercial environments designated by the Solar Cities Program. In addition, it is anticipated that the proposed investments in solar energy for different types of buildings and locations will be compared with alternative kinds of investments in energy conservation for the same buildings.

Improved and expanded data bases are critical to the full assessment of benefits of solar energy in commercial buildings. Existing thermal analysis procedures suitable for estimating the energy requirements of large buildings, solar or conventional, are difficult to use at best and inadequate for many situations, making energy savings from solar designs for commercial buildings difficult to estimate. Behavioral research into real estate market valuation of solar buildings and user response issues is also in a preliminary stage. Issues identified in this report as requiring further research include real estate market preferences for solar versus conventional buildings, shoppers' preferences for enclosed versus non-enclosed malls; the willingness of building occupants to substitute daylighting for artificial lighting; the valuation of conditioned space in commercial areas, and the effects of solar designs on building acoustics and human comfort.

Given existing data and tools of analysis, rough estimates of energy and non-energy benefits can be derived and compared with solar energy costs, and the sensitivity of the economic feasibility results to particular assumptions and conditions can be tested. With expanded and more reliable data, more comprehensive and accurate economic evaluations should be possible. These improvements should lead to better energy decisions among investors and to improved decision making on energy-related spending in both the public and private sectors.

REFERENCES

1. Ruberg, Kalev, "Design and Analysis of Passive Solar Heating Solutions for Neighborhood Commercial Strip Settings," Proceedings of the Fourth National Passive Solar Conference (Newark, Del.: American Section of the International Solar Energy Society, 1979).
2. Hastings, S. Robert, "Passive Solar Design for Urban Commercial Environments," Proceedings of the Fourth National Passive Solar Conference (Newark, Del.: American Section of the International Solar Energy Society, 1979).
3. Ruberg, Kalev, A Computer Model for Quantifying Solar Gain Through Various Types of Glazings in Any Given Urban Geometry and Climate (Washington, D.C.: National Bureau of Standards, 1980), NBS Interagency Report, In Press.
4. Stahl, Fred I.; Conway, Don; and Goglia, Margaret R.; "Human Behavioral Considerations in the Planning and Design of Passive Solar Systems for Commercial Facilities: An Exploratory Study of the Effects of Sun and Shade," Proceedings of the Fourth National Passive Solar Conference (Newark, Del.: American Section of the International Solar Energy Society, 1979).
5. Conway, Don; Goglia, Margaret R.; and Stahl, Fred I.; A Pilot Study to Predict the Effects of Shadows from Passive Solar Configurations on Pedestrians' Behavior (Washington, D.C.: National Bureau of Standards), In Press.
6. International Council of Shopping Centers, "Shopping Centers and the Energy Crisis," Shopping Center Report (New York: International Council of Shopping Centers, 1977).
7. Mazria, Edward, The Passive Solar Energy Book (Emmaus, Pa.: Rodale Press, 1979).
8. AIA Research Corporation, Passive Solar Design: A Short Bibliography For Practitioners (prepared for the U.S. Department of Energy under Contract No. EG-77-C-01-4113, October 1978, p. iii).

9. Noll, Scott A., "Economics and the Design Process," Proceedings of the Third National Passive Solar Energy Conference, San Jose, California, Jan. 11-13, 1979 (Newark, Del.: American Section of the International Solar Energy Society, 1979).

10. Noll, Scott A.; Roach, J. Fred; and Ben-David, Shaul; "Trombe Walls and Direct Gain: Patterns of Nationwide Applicability," Proceedings of the Third National Passive Solar Energy Conference, San Jose, California, Jan. 11-13, 1979 (Newark, Del.: American Section of the International Solar Energy Society, 1979).

11. Noll, Scott A., "Thermal Mass Storage and Glazings Show Effectiveness in New Modeling," Solar Engineering Magazine (January, 1979).

12. Noll, Scott A., and Thayer, Mark A., "Trombe Wall vs. Direct Gain: A Microeconomic Analysis for Albuquerque and Madison," Proceedings of the Third National Passive Solar Energy Conference, San Jose, California, Jan. 11-13, 1979 (Newark, Del.: American Section of the International Solar Energy Society, 1979).

13. Noll, Scott A., and Wray, William O., "A Microeconomic Approach to Passive Solar Design: Performance, Cost, Optimal Sizing, and Comfort Analysis," Energy The International Journal (London: Pergamon Press, August, 1979).

14. Roach, Fred; Ben-David, Shaul; and Kirchner, Christina; "The LASL/UNM Solar Performance Code: A Basic Primer," Proceedings of the Fourth National Passive Solar Energy Conference, October 3-5, 1979 (Newark, Del.: American Section of the International Solar Energy Society, 1979).

15. Roach, Fred; Noll, Scott; and Ben-David, Shaul; "The Comparative Economics of Passive and Active Systems: Residential Space Heating Applications," Proceedings of the 1978 Annual Meeting of the International Solar Energy Society, August 28-31, Denver, Colorado (Newark, Del.: American Section of the International Solar Energy Society, 1978).

16. Roach, Fred; Noll, Scott; and Ben-David, Shaul, "Passive and Active Residential Solar Heating: A Comparative Economic Analysis of Select Designs," Energy The International Journal (London: The Pergamon Press, August, 1979).

17. Ruegg, Rosalie T.; Sav, G. Thomas; Powell, Jeanne W.; and Pierce, E. Thomas; Economic Evaluation of Solar Space and Water Heating Systems in Commercial Buildings (Washington, D.C.: National Bureau of Standards, 1980), In Press.

18. Ruegg, Rosalie T.; Petersen, Stephen R.; and Marshall, Harold E.; Recommended Practice for Measuring Life-Cycle Costs of Buildings and Building Systems (Washington, D.C.: National Bureau of Standards, 1980), In Press.

19. Cooper, James R., and Pyhrr, Stephen A., "Forecasting the Rates of Return on an Apartment Investment: A Case Study," Readings in Real Estate Investment Analysis, Vol. 1 (Cambridge, MA.: Ballinger Publishing Company, 1977).

20. Isakson, H. R., Making the Most of Energy in Real Estate, (Washington, D.C.: U.S. Department of Energy, 1978).

21. Clark, Roy E., and Hastings, S. Robert, Quantified Occupant-Use Factors Affecting Energy Consumption in Residences (Washington, D.C.: National Bureau of Standards, 1979), NBS Interagency Report 78-1501.

22. Pike, Tyrone, and Golubov, Michael, "Daylight Design Options - Cost-Benefit Analysis," Proceedings of the Fourth National Passive Solar Conference (Newark, Del.: American Section of the International Solar Energy Society, 1979).

23. Ruegg, Rosalie T., and Sav, G. Thomas, Microeconomics of Solar Energy (Washington, D.C.: National Bureau of Standards, 1980), In Press.

24. McGraw-Hill's 1980 Dodge Manual (New York: McGraw-Hill Cost Information Systems Company, 1979).

25. Means Building Construction Cost Data, 1979 (Kingston, Mass.: Robert Snow Means Company, 1978).
26. National Solar Heating and Cooling Information Center, "Solar Accepted by Nation's Insurers," Solar Status (Washington, D.C.: U.S. Department of Housing and Urban Development, 1979).
27. Balcomb, J. Douglas, and Anderson, Bruce, Passive Solar Design Handbook, Draft Report, April 6, 1979, DOE/CS-0090-D.
28. McFarland, Robert D., "PASOLE A General Simulation Program for Passive Solar Energy," October 1978. LASL Informal Report, LA-7433-MS.
29. American Society of Heating, Refrigeration, and Air-Conditioning Engineers, ASHRAE Handbook & Product Directory: 1977 Fundamentals (New York: American Society of Heating, Refrigeration, and Air-Conditioning Engineers, 1977).
30. Federal Register, Monday, April 30, 1979, Vol. 44, No. 84.
31. Federal Register, Wednesday, January 23, 1980, Vol. 45, No. 16.
32. Kusuda, Tamami, and Collins, Belinda L., Simplified Analyses of Thermal and Lighting Characteristics of Windows: Two Case Studies (Washington, D.C.: National Bureau of Standards, 1978), NBS Building Science Series 109.
33. Griffith, James W., "Benefits of Daylighting--Cost and Energy Savings," ASHRAE Journal (New York: American Society of Heating, Refrigeration, and Air Conditioning Engineers, January 1978), pp. 53-56.
34. Ruegg, Rosalie T., and Chapman, Robert E., Economic Evaluation of Windows in Buildings: Methodology (Washington, D.C.: National Bureau of Standards, 1979), NBS Building Science Series 119.
35. Kusuda, Tamami, and Bean, J.W., "Comparison Between a Simplified Daylighting Calculation Procedure and a Comprehensive Interreflection Model Calculation Procedure," Proceedings of the 3rd International Symposium on Use of Computers for Environmental Engineering Related to Buildings, Banff, Alberta, Canada, May 10-12, 1978 (Ottawa: National Research Council).

36. Urban Land Institute, Dollars and Cents of Shopping Centers (Washington, D.C.: Urban Land Institute, 1975, 1978).

37. Building Owners and Managers Association International, The 1978 Experience Exchange Report for Downtown and Suburban Office Buildings (Washington, D.C.: Building Owners and Managers Association International, 1979).

38. Cohen, Howard; McLaren, T. Ian; Moss, Stanley M.; Petyk, Roman; and Zuke, Ervin H.; Pedestrians and Wind in the Urban Environment (Massachusetts: Institute for Man and Environment and Weather Dynamics, Inc., December 1977).

39. U.S. Department of Housing and Urban Development, Title 1 Property Improvement Loan Operating Handbook (Washington, D.C.: U.S. Department of Housing and Urban Development, June 1973).

40. Executive Office of the President, Office of Management and Budget, 1979 Catalogue of Federal Domestic Assistance. Available from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

41. Stauss, George, "The Effect of Tax on Yield and Value," Readings in Real Estate Investment Analysis, Volume I (Cambridge, Mass.: Ballinger Publishing Company, 1977).

42. Thorne, Oakleigh J., "Real Estate Financial Analysis," Readings in Real Estate Investment Analysis, Volume I (Cambridge, Mass.: Ballinger Publishing Company, 1977).

43. Revenue Act of 1978, Sec. 301, Public Law 95-600, 95th Cong., 92 Stat. 2820.

44. American Telephone and Telegraph Company, Engineering Economics, A Manager's Guide to Economic Decision Making, Third Edition (New York: McGraw-Hill Book Company, 1977).

45. Eisenhard, Robert M., State Solar Energy Legislation of 1977: A Review of Statutes Relating to Buildings (Washington, D.C.: National Bureau of Standards, 1979), NBS Interagency Report 79-1705.

46. Internal Revenue Code of 1954, U.S. Code, Title 26, Sec 167 (d).

47. Energy Tax Act of 1978, Public Law 95-618, 95th Cong., 92 Stat. 3194.

48. Revenue Act of 1978, Sec. 315, Public Law 95-600, 95th Cong., 92 Stat. 2824.

49. Kusuda, T., and Ishii, K., "Hourly Solar Radiation Data for Vertical and Horizontal Surfaces on Average Days in the United States and Canada" (Washington, D.C.: National Bureau of Standards, 1977), NBS Building Science Series 96.

50. U.S. Department of Energy, DOE Facilities Solar Design Handbook, (Washington, D.C.: U.S. Department of Energy, 1978). DOE/AD-0006/1.

51. Pierce, Neal R., "Gardens in the City," The Washington Post, August 28, 1979.

52. Olkowski, Helga, and Olkowski, William, "Bio-Solar Systems in Urban Areas," Proceedings of the Second National Passive Solar Conference, Passive Solar State of the Art, Volume 3 (Newark, Del.: American Section of the International Solar Energy Society, 1978).

53. Kolstad, Charles D., "The Economics of the Attached Solar Greenhouse for Home Heating--A Preliminary Assessment," Proceedings of the Second National Passive Solar Conference, Passive Solar State of the Art, Volume 3 (Newark, Del.: American Section of the International Solar Energy Society, 1978).

54. Yanda, William F., "Solar Sustenance Project, Phase II, Final Report," (Santa Fe, New Mexico: New Mexico Energy Resources Board, 1977).

APPENDIX

SUMMARY OF KEY SYMBOLS AND DISCOUNT FORMULAS

A. KEY SYMBOLS*

C_a = initial purchase costs of the passive solar energy system, including labor, materials, and sales taxes;

C_ℓ = estimated initial cost of labor required to install the passive solar energy system, including only those labor costs not eligible for special solar incentives;

C_m = estimated initial purchase cost of materials, including only those materials not eligible for special incentives;

$C_{s\ell}$ = estimated initial labor cost eligible for special solar incentives;

C_{sm} = estimated initial cost of materials eligible for special incentives;

d = nominal (including inflation), after-tax discount rate;

γ = annual rate of appreciation in market value of solar energy system, including general inflation;

h = investment analysis period (study period);

ρ = annual rate of general price inflation;

s = sales tax rate/100;

t_c = combined State and Federal corporate income tax rate;

* All other symbols are defined with each use.

B. DISCOUNT FORMULAS*

Nomenclature	Use When	Algebraic Form
Single Present Worth ($SPW_{d,n}$)	Given a future sum of money expressed in current (future year) dollars; to find a present sum of money	$SPW_{d,n} = \frac{1}{(1 + d)^n}$
Modified Single Present Worth ($SPW_{d,\rho,n}$)	Given a future sum of money, expressed in base-year dollars; to find a present sum of money	$SPW_{d,\rho,n} = \left(\frac{1 + \rho}{1 + d}\right)^n$
Uniform Present Worth ($UPW_{d,n}$)	Given a uniform annual, end-of-period payment; to find a present sum of money	$UPW_{d,n} = \frac{(1 + d)^n - 1}{d\,(1 + d)^n}$
Modified Uniform Present Worth ($UPW_{d,\rho,n}$)	Given a uniform annual end-of-period payment, escalating at an annual rate, ρ; to find a present sum of money	$UPW_{d,\rho,n} = \left(\frac{1 + \rho}{d - \rho}\right)\left(1 - \left(\frac{1 + \rho}{1 + d}\right)^n\right)$

* All terms are as defined in Appendix A, except for n, a number of years, which varies with different elements in the economic evaluation model and is specified with each use of the formula.

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

This report presents an economic model for evaluating passive solar designs in commercial environments. It discusses the literature on this topic and draws upon this literature to develop a general methodological framework. The model incorporates a life-cycle costing approach that focuses on the costs of purchase, installation, maintenance, repairs, replacement, and energy. It includes a detailed analysis of tax laws affecting the use of solar energy in commercial buildings. Possible methods of treating difficult-to-measure benefits and costs, such as effects of the passive solar design on resale value of the building and on lighting costs, rental income from the building, and on the use of commercial space are presented. The model is illustrated in two case examples of prototypical solar designs for low-rise commercial buildings in an urban setting. These designs were developed at NBS under the Solar Cities project. The two designs, a wall collector system and a street canopy, are evaluated for a neighborhood in Baltimore undergoing urban renewal. Results of the analyses indicate these designs may be economically feasible under a realistic range of economic conditions. Topics requiring further research are identified.

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)*

Benefit-cost analysis; building economics; commercial buildings; investment analysis; life-cycle cost analysis; passive solar energy; retrofit; revitalization; solar energy systems

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