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***An Economic Analysis of a Passive Solar
Multiple-Family Dwelling for Upstate New York***

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An Economic Analysis of a Passive Solar Multiple-Family Dwelling for Upstate New York

Joseph Laquatra, Jr.*

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* Department of Consumer Economics and Housing, Cornell University, Martha Van Rensselaer Hall, Ithaca, NY 14853.

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ABSTRACT

Energy use in the residential sector has been the focus of considerable analytical and experimental research, particularly since the Arab oil embargo of 1973, which heralded the end of an era of inexpensive fossil fuels. There has been widespread acceptance of energy conservation technology and the enactment of Federal and state legislation that mandates specific levels of thermal integrity in new and rehabilitated structures.

As a complement to finite resource conservation measures, technologies involving the use of alternative energy sources can have a substantial impact on the reduction of fossil fuel dependency in the residential sector. Space conditioning represents the single largest end-use of energy in this market and is a significant component of total energy demand. As a source of energy supply for space conditioning, the potential of solar energy is proving to be effective and reliable.

The northeastern region of the U.S. is heavily dependent on fossil fuels for space conditioning, particularly for space heating. It is also a locale that is widely perceived as being unsuitable for solar energy use because of the extent and severity of its cold, cloudy weather.

The objective of this study was to examine the economic feasibility of passive solar energy as applied to a multiple-family dwelling in three upstate New York cities: Buffalo, Rochester, and Syracuse. Specifically, two passive solar applications--a Trombe wall and a direct-gain system--for a nine-unit structure designed by Total Environmental Action, Inc. were analyzed through the use of a solar economic performance code developed by the Los Alamos National Laboratory and the University of New Mexico. City-specific data, including climatological information,

building construction costs, utility rates, and property taxes were used, as were various economic parameters to reflect economic conditions in general and specifically those of the solar systems' owners.

The study was divided into two sections: (1) an owner-occupied analysis, which treated the multiunit structure as a condominium development, and (2) a renter-occupied analysis, which treated the units within the building as apartments. In the owner-occupied section, the performance code was used to evaluate the economic viability of the solar systems through the calculation of life-cycle cost analyses and payback times. Other data generated by the code were used in the renter-occupied analysis to examine the effect of an investment in passive solar energy on a developer's rate of return and on an investor's cash distribution and tax shelter benefits.

One major finding of the study was that even in the cold and cloudy cities of Buffalo, Rochester, and Syracuse, investing in a passive solar heating system can be economically preferable to constructing buildings that rely solely on conventional heating systems. This was seen in both the owner-occupied and renter-occupied analyses.

Other observations included the beneficial effects of income tax credits on a solar system's economic feasibility, and the sensitivity of analyses of this type to economic parameters that are used. In addition, the Trombe wall system performed better than the direct-gain strategy because of lower system costs and higher solar energy contributions to the building's annual heating load.

AN ECONOMIC ANALYSIS OF A PASSIVE SOLAR
MULTIPLE-FAMILY DWELLING FOR UPSTATE NEW YORK

by

Joseph Laquatra, Jr.

I. INTRODUCTION

Structural Design and Energy Use

The key role that energy plays in an economic system has been noticeably highlighted since the early 1970s. Prices of fossil fuels have risen dramatically, partially because of sporadic supply shortages. This continual price rise has led to the development of alternative resources and technological innovations in all sectors of the economy, with perceptible effects on energy end-uses. In the residential and commercial sectors, wherein exists the single largest end-use of energy in the U.S., space conditioning (12, p. 1), these efforts are resulting in structures with high degrees of thermal integrity, as well as designs that take advantage of renewable resources.

Residential structures long have been built with little regard to their energy use. Studies of this issue fault government policies for encouraging fossil fuel prices below their replacement costs, and consumer and producer behavior, which placed a strong emphasis on minimizing a dwelling's initial construction costs with little concern about future operating expenses. The Arab oil embargo of 1973, however, was instrumental in bringing about a change in these attitudes; now the housing industry is gradually becoming attentive to the benefits of increased levels of thermal insulation and dwelling designs that take "... advantage of the exterior environment to create the desired interior environment." (24, p. 180) Most designs that make use of this advantage do so through the use of solar energy.

The simplest application of solar technology to a dwelling is through the use of passive solar space conditioning. Whereas an active solar system relies on collectors, fans, pumps, and coils, a passive system takes advantage of the natural forces of conduction, convection, and radiation to collect and distribute the sun's energy. Use of passive solar technology is characterized by careful consideration of a building's orientation on its lot and the selection of construction materials that allow the building itself to act as both a solar collection and a heat storage distribution system.

In a practical sense, the passive solar advantage adds functions to a building's structural members (load-bearing walls, beams, etc.), which must exist whether or not the solar system does. The only qualification is that if a building's floor, walls, and/or roof are designed as components of its heating system, the materials used to build them must be capable of performing as such. For example, a direct-gain, passive solar home is oriented so that its largest wall faces south. This wall consists of enough windows to admit sunshine, which is absorbed as heat in the masonry north, east, and west walls and floor. At night, the south-facing glass is covered with insulated panels and absorbed heat is reradiated from the masonry walls and floor into the house. Mazria (46, p. 29) and Teller (88, p. 225) related that this type of passive solar system is always working, because all sunlight--direct or diffuse--that passes through the southern glazing is absorbed as heat by the thermal mass. For this reason, such a system is well suited for cloudy climates. Passive solar dwellings are protected from summer overheating by roof overhangs, which function in accordance with the sun's position in the sky and admit sunlight in the winter but shade it in the summer.

The use of house orientation and design to accept warmth from the sun in the winter and block excessive sunshine in the summer is an ancient concept that was used by Egyptians, Greeks, Persians, Hindus, and pre-Columbian North and South American Indians. Passive solar techniques began to appear in American residential architecture in the late 1930s and early 1940s, with the advent of large hermetically sealed windows. Early tests of the practicality of such applications found merit but noted that the low cost and ready availability of fossil fuels at that time could not justify the higher initial cost of a system with storage capacity (60).

The solar dwelling recently has become a popular alternative, and has been the subject of much academic and professional research and experimentation. However, widespread acceptance by builders and buyers has not yet been achieved, particularly in the colder climates of the U.S., where pessimistic attitudes about solar potential and producers' perceptions of inadequate demand pose formidable barriers to its rapid development. This is true particularly with the housing industry within the northeastern region, which was described by O'Riordan and Migani (58) as more conservative than in other parts of the country. Until consumers become more educated about energy-conscious design, conventional, energy-inefficient building forms will prevail in new construction.

One reason cited for slow acceptance of solar designs is the risk involved in solar investments. Risk was identified by Margolin and Misch (43) as one of several psycho-economic factors that also act as barriers to solar energy incentives in the housing market. That risk is a probabilistic notion of what may happen in the future, acting as an impediment to solar development because of attitudes held both by home builders and

buyers. Both have expectations about the future and reveal these anticipations in different ways. Builders may be excessively risk-averse; they are likely to avoid ventures they consider overly speculative by continuing to construct homes with proved sales potential. Home buyers' expectations are revealed in concerns over the length of payback time of a solar investment and in the chance of new technology replacing obsolete systems.

On the supply side, Reiger (64) noted that the housing market's fragmentation impeded more widespread use of solar energy for space heating in single-family dwellings. He reported that 56 percent of the estimated 2 million housing starts in the U.S. in 1977 were single-family dwellings constructed by small builders on speculation. The localized nature of this market necessitates buyer awareness of life-cycle cost advantages of solar homes, particularly when the purchase price of such homes is higher than their conventional counterparts. He cautioned, however, that energy is only one of the many serious issues facing the housing industry and that favorable life-cycle cost analyses alone do not sell solar homes. A study by the Real Estate Research Corporation (62) led to the conclusion that builders still have to be concerned primarily with local design preferences. The inclusion of a solar heating system in a new home will attract buyers to look and possibly buy, but not at the expense of amenities such as space, which the buyers expect.

Life-cycle cost analysis methods now show that passive solar heating compares favorably with conventional heating systems in most parts of the U.S. (1, p. iii). In spite of this, passive solar techniques are not generally incorporated into most new and existing buildings because, as Böer (9) noted, the building industry is marked by a lack of awareness

and understanding of solar applications from the perspectives of both producers and consumers. The producers are unwilling to compound the risk of their speculative ventures by increasing their costs through features that have yet to be proved effective on a large scale. Moreover, these producers, who are builders and developers, often are unable to adopt certain construction techniques because of constraints imposed by building codes and zoning ordinances. Consumers, on the other hand, are interested in a variety of factors when the home purchase decision is considered; energy costs represent only one of these factors. If savings are possible in this area through alternative construction methods that increase a home's initial cost, these increased costs are likely to be viewed with respect to the resultant energy savings. But because the average length of home ownership in the U.S. is 7 years, any additional investment in a home that cannot be recovered within that timeframe may not be made.

According to the National Research Council (52, p. 359), much of the stock of existing structures is likely to be replaced between the years 1985 and 2010. If these replacements are designed for energy conservation and passive solar potential where it is practical, energy requirements for space conditioning can be reduced from a major to a minor part of the nation's energy demand.

During the past several years, much research has concerned the application of passive solar technology to residential construction, particularly with regard to economic performance of such units. The majority of this research has focused on single-family dwellings and, until recently, little attention has been paid to the potential of passive solar multiple-family structures. Notable exceptions to this can be seen in California, Massachusetts, and Vermont, which are now providing incentives in the

forms of grants and low-interest loans to encourage the inclusion of passive solar concepts at the design stage of multiunit projects. Because one impediment to more widespread use of solar energy is skepticism regarding its potential, such incentives can be helpful in overcoming this barrier by providing working examples of its capability. Eventually, this could result in an understanding of the technology to a point where its inclusion in all new construction is considered routine.

The potential contribution by passive solar heating to energy demand for space conditioning was shown to be substantial by those researchers who examined its applications in multiple-family dwellings. Johnson (32) calculated a 70-percent reduction in conventional fuel use by a housing project for the elderly in Paducah, Kentucky, that was designed with this solar advantage. Schneider-Criezis (75) demonstrated a 65-percent solar contribution to the annual heating load of a typical unit of a passive solar high-rise dwelling designed for Boston. The Executive Office of Energy Resources in the Commonwealth of Massachusetts is currently involved in a program that ultimately will construct 800 passive solar-heated apartments that will consume only 25 percent of the energy required to heat similar units of conventional design. The California Energy Commission sponsored a passive solar design competition that resulted in multifamily designs capable of impressive reductions in conventional energy use for both heating and cooling.

Purpose of Study

The importance of using alternative energy resource technologies is underscored by current events. Continued dependence on fossil fuels in the face of finite supplies, political problems, and adverse environmental

consequences may be unnecessary if the full potential of renewable, nonpolluting means to the same ends is explored. The purpose of this study is to contribute to this exploration through an economic analysis of a passive solar, multiple-family dwelling design, for three locations in upstate New York that typically experience severe winters: Buffalo, Rochester, and Syracuse.

Upstate New York is part of this country's northeastern region, an area heavily dependent on fossil fuels for primary heating sources. As documented by the Annual Housing Survey (95), over 54 percent of all occupied housing units in this region are heated with fuel oil. Utility gas is the second most common heating source, 37 percent, followed by electricity, 6 percent. Twenty-two percent of the total occupied housing units in this region are in structures designed for 5 or more units.

This category of structures should not be overlooked in analyses of potential energy savings through passive solar technology. Multifamily structures are characterized by a steadily decreasing supply and increasing conversion to condominiums and cooperatives (38, p. 3). The existing supply of multifamily structures, regardless of tenure, is typified by rising operating costs, with space heating fuel exhibiting the largest rise of any single item. Studies of the Northeast (90, p. 345) have linked rising heating costs with landlord abandonment of buildings vulnerable to such rises: older, poorly insulated properties inhabited by tenants with incomes too low to tolerate rent increases. In other properties, landlords face decreasing operating returns if fuel adjustment clauses are not included in leases. In the past, short-run solutions, such as Federal and state fuel assistance payment programs, were responses to this problem. A long-run solution is the adaption of passive solar

heating technology to multiple-family housing through both the retrofit of existing buildings and the inclusion of the solar advantage at the design stage of new structures. This study will examine the potential of one such design.

Objectives of Study

The credibility of passive solar dwellings in a localized housing market can be established by economic analyses that justify the higher initial costs of such units with savings in energy expenditures over time. Present value calculations are useful in observing the relationship between a solar system's combined initial and operating costs and the resultant total savings in energy expenditures. Parameters for analyses of this type include solar system and dwelling unit specifications, known thermal properties of building materials, and site-specific climatological data. These studies are sensitive to choices made regarding price escalation projections of conventional fuels and discount rate selection, but are nonetheless valuable tools for facilitating rational decisions with respect to capital investment.

The premise of this thesis is that an economic analysis of a passive solar multiple-family dwelling design can be used to evaluate investments in this technology in the northeastern cities of Buffalo, Rochester, and Syracuse. To this end, a design responsive to this region's climate will be examined in three separate sites using city-specific climatological data. Because of differences in tax advantages and development incentives, the choice of tenure within a multiunit structure is a relevant

concern and, accordingly, the study will consist of analyses for owner-occupied units (condominiums) and renter-occupied units (apartments), using techniques of payback time and life-cycle cost analyses.

Scope of Study

Chapter II deals with some of the multifamily housing market issues that have implications on the routine inclusion of passive solar space conditioning in the design and construction process.

Chapter III is a review of pertinent literature on passive solar technology, which includes a historical chronology of site-sensitive architecture from the days of ancient Rome to the present, a discussion of generic barriers in today's housing industry that effectively inhibit widespread use of climate-responsive building forms, and an overview of current economic research dealing with this subject.

Chapter IV details the analytical framework of this thesis, reviewing the climate of upstate New York and the design chosen for this analysis. Use of the economic performance model--Economic Assessment of Solar Energy (EASE)--developed by the Los Alamos National Laboratory and the University of New Mexico, and its adaption to multiunit dwellings are reviewed in this section.

In Chapter V, the information generated by the model is used to analyze the economic feasibility of the structure design for the multifamily structures in the three New York cities.

Finally, the project's findings are summarized in Chapter VI, and conclusions regarding passive solar construction techniques in upstate New York's multifamily housing market are drawn.

II. JUSTIFICATION

Introduction

The use of site-sensitive design can decrease residential use of fossil fuels, yet most buildings are still designed and constructed ignoring this possibility. The routine inclusion of this technology faces substantial institutional and economic hurdles in both the single-family and multiple-family housing markets. Although some advances have been made in single-family housing, only minor research has been undertaken in multiple-family dwellings.

Multiple-Family Dwellings and the Development Process

Passive solar design concepts can be applied effectively to multiple-family housing, but the nature of the development process inhibits dispersion of the techniques. Even though increasing numbers of designers and consumers of housing have a working knowledge of energy-efficient applications, there is still no significant movement in this direction on the part of developers (50, p. 2-2). To understand why this is the case, it is necessary to review the process through which multiple-family dwellings are developed.

The production of a multifamily housing unit involves more people, institutions, time, and money than does an addition to the stock of single-family dwellings. In addition, because of the nature of the marketing and financing system for multifamily housing, there is no connection made between the architect and developer, who set the level of energy consumption, and the tenant, who is the ultimate consumer of the energy (50, p. 2-3).

Because inhabitants of a multifamily housing project are not involved in its development, the necessity of additional capital funds for energy-efficient design requires that information be available regarding the effect that this incremental cost has on an investor's rate of return and tax benefits. In the owner-occupied market, Federal and state tax incentives facilitate this investment. But it is not yet clear that tenants in the rental market are willing to exchange higher monthly rent payments for lower monthly utility bills.

Some working examples do exist, however, such as Strawberry Fields West, a passive solar apartment project in Springfield, Missouri. Muller (51, p. 90) reported that the inclusion of the solar advantage in this project allowed its owner to charge higher-than-market-level rents for the units. The young professional tenants in this development are willing to make the trade-off between these higher rents and their lower utility bills; the project's owner credits the site-sensitive design with his positive cash flow and higher-than-average return on his investment. The solar design factors increased the cost of this development by 7-8 percent and, thus, the rents, but tenants are currently saving \$10 to \$15 per month in utility costs.

Strawberry Fields West may owe its success to the sophistication of its tenants if, as MASEC (50, p. 6-60) reported:

Most tenants of rental housing view their dwelling units as short-term living arrangements and consider the amount of the monthly housing cost (which is primarily rent) as one of the key criteria in selecting a temporary dwelling. Accordingly, it is unlikely in the near future that an owner of rental housing

would be able to "pass through" to his tenants, in the form of increased rents, any additional upfront costs associated with passive solar design.

Although the preceding quotation suggests that tenants are ignorant of fuel costs, that may not be the case because corner apartments in some complexes rent for less than interior apartments. Landlords who are responsible for utility costs have been receiving increased rent payments from their tenants through fuel price escalation clauses in lease agreements (90, p. 345) and schemes such as the "Resident Utility Billing System," in which tenants in master-metered properties receive utility bills from their landlords based on apartment size (13, pp. 204-205).

It may be that tenants will be unwilling to pay higher rents that are calculated from projections of probable energy savings. Renters may be skeptical of solar potential in a given area, particularly if no empirical data exist on that potential. Or they may be unwilling to accept higher rents simply because tenants move more often than owners and the short-term nature of their tenure choice prompts selection of units with lower rent charges.

It should be understood at this point that whether passive solar technology is accepted for widespread use in the multiple-family dwelling market depends in the long run on consumer demand for energy-conscious design in these units. Until developers, architects, builders, and lenders perceive that expenditures in this technology will not negatively impact an investment in a multiple-unit structure, conventional buildings are likely to be built.

The Multifamily Dwelling Market Today

The current state of the multiple-family housing market--as discussed by Sternlieb and Hughes (83, 84), Lowry (40), Hendershott (27), and the U.S. Comptroller General (93)--indicates that the rental housing market is characterized by both decreasing supply and decreasing demand.

The decline in renter-occupied units is not equivalent to a decreasing stock of multiple-family dwellings because condominiums and cooperatives also comprise the latter. However, multifamily starts have also fallen relative to single-family starts (10, p. 1). Condominium and cooperative conversion represent one factor contributing to the decrease in rental units. In addition, landlords who face declining operating returns from their rental properties are responding with abandonment; investors are now reluctant to develop new rental properties. The rise in rents throughout the 1970s did not occur rapidly enough to keep pace with inflation or offset rising operating costs (40, p. 20). Changes in the characteristics of demand also have contributed to the decline in renter households, as tax and investment advantages of home ownership have significantly affected American tenure choice (28, p. 2).

The aforementioned researchers in this area of the rental housing market consistently refer to rising operating costs as one of the most troublesome problems in rental property ownership. This is particularly a problem in master-metered buildings, where tenants, paying a fixed charge for rent and utilities, have no incentive to conserve energy because the cost of using each additional unit is zero. In addition, these rising operating costs are increasing faster than rents, as demonstrated by Lowry's 20-year index of net operating returns from rental property (36, p. 26). Note that under perfect market conditions, however,

short-run prices do not rise relative to costs unless demand is perfectly inelastic. Furthermore, a given percentage increase in fuel costs would not necessarily imply a matching long-run percentage increase in rents for two reasons: (1) utilities are only one component of total costs, and (2) landlords have some flexibility in their production functions. As energy prices rise, landlords can substitute energy inputs with applications of conservation technology. To some extent, one fuel can substitute for another as their relative prices change. However, substitution hinges on the extent to which consumers prefer certain fuels for particular qualities, such as cleanliness and security of supply, as well as any capital cost associated with alternative energy sources (89).

Rent-control programs operate effectively for the short-run benefit of tenants who live in regulated units. But this benefit is at the long-run expense of future apartment seekers who find deteriorating units in a shrinking market because project income becomes too low to warrant new investment. But even in the absence of rent controls, a phenomenon Lowry (40) defines as rent restraint exists; that is, for reasons not fully understood, rents do not rise relative to costs. Part of the explanation may be that 60 percent of all rentals are in buildings of fewer than five units. These are owned by small investors who avoid the cost of move-outs and become "turnover minimizers" instead of "rent maximizers."

Switching to individual metering of utilities reduces operating costs in existing buildings so that tenants will be responsible for the amount of energy they actually use. Walker (97) reported on a study by the Midwest Research Institute of master-metered and individually-metered apartments in 10 large cities. The report, showing that master-metered apartment buildings use 35 percent more electricity than individually-

metered buildings, suggests that energy use decreases as tenants become responsible for its cost. This may have implications for a long-term solution to the energy-use problems of the rental market.

Passive Solar Design: An Alternative

It is possible that if passive solar technology for space heating is applied to multiple-family dwellings, a significant portion of total energy demand for fossil fuels in the U.S. can be reduced. As noted above, most buildings, particularly multifamily structures, are designed and constructed without consideration of environmental advantages.

Sternlieb and Burchell (82, p. 21) noted differences in reactions to operating cost increases in owner- and renter-occupied dwellings and reported more innovation in reducing operating costs in the former category. In the area of multiple-family housing, there has not been much investment in innovative technologies to reduce operating costs.

The economic cost of maintaining an inefficient building is eventually passed along to the consumers of the building. ... This overhead expense in no way improves the quality of our lives ... but does limit our economic choices. [81, p. 112]

The preceding quotation from Carl Stein should be clarified to distinguish between buildings that house their owners and buildings inhabited by tenants. It is not always true that tenants will pay the price of increased fuel costs, as previously noted. It can be argued, however, that even if fuel price increases are paid by landlords and are not passed

along to tenants, tenants may still bear the cost through a decrease in services. The landlord may use minimal building rehabilitation and maintenance to offset rising costs and still maintain a positive cash flow.

From the broader perspective, other characteristics of passive solar design contribute to its attractiveness as an energy source.

Solar energy is an income energy resource rather than a depletable capital resource. It is widely available, and is not subject to foreign control (except, perhaps, in a theological sense). Direct conversion of sunlight into heat and electricity has no repercussions in terms of land destruction, air pollution, or other types of environmental degradation often associated with more traditional forms of energy. [76,.p. 2]

Passive solar heating may prove to be an integral part of the solution to the economic problems of rising operating costs and decreasing capital returns in the multifamily housing market. Intrinsic to its appeal are matters relating to energy supply and technological simplicity. Widespread use, however, is restricted by several considerations, such as the capital-intensive nature of this method. The continued development of passive solar technology may depend upon microeconomic analyses, which negate the impact of high initial costs with low life-cycle costs, as well as the macroeconomic perspective, which recognizes the value of declining dependence on nonrenewable resources.

III. REVIEW OF LITERATURE

Introduction

Energy-conscious design in residential construction has been the focus of much attention in recent years, as prices of fuels conventionally used for space conditioning have increased steadily and dramatically. These increases have provided the first incentives to examine the efficiency of this energy end-use and the extent to which it can be affected through structure design.

Space heating and cooling represents the single largest end-use of energy in the U.S. today. It has been identified as a major component of the nation's total energy demand, at or near 25 percent of total demand (59, p. 116; 52, p. 359). Of the total energy consumption in the residential sector, 68 percent is used for space heating (39, p. 162). These figures are substantial, particularly when viewed in light of the statement by Stein (81, p. 166) that more than one-third of this energy consumption is affected by architectural decisions.

The structures that now exist, built with little regard for their operating expenses, best characterize the era during which fossil fuels were thought of as cheap and plentiful. Examples range from the post-World War II, detached single-family dwelling with little or no insulating features and large single-pane windows facing north and west, to the glass-skinned urban high-rise that is completely dependent upon mechanical systems for thermal comfort. Buildings such as these were designed and constructed without consideration of ecological moderating forces that can naturally influence the interior temperature of a dwelling.

Investments in renewable energy resources available through site-sensitive designs were neglected because they were not cost effective.

Historical Review of Site Sensitivity in the Built Environment

Before the onset of cheap fossil fuels, the built environment was more likely to take into consideration the use of renewable resources. Early civilizations recognized the potential contributions to interior space conditioning realizable through climate-adaptive architecture.

Primitive cultures had an understanding of their link with nature, and they sought to maintain that balance in the structures they constructed. They understood that the moderation of climate was the essence of shelter design. The sun was used to temper the indoor climate, and designs, materials, and orientations were chosen to maximize this energy source. Climate was the context within which the building functioned.

[74, p. 7]

Evidence of man's early understanding of architecture harmonious with the environment is provided by Noll (56, p. 166) in a citation from the written work of Roman architect Marcus Vitruvius Pollio from the first century B.C. Recommendations for the building and designing of a community during that age focused on an assessment of the characteristics of a site before the planning of a structure, including the incorporation of earth sheltering and southern exposure in cold northern climates and passive solar cooling techniques in hot southern regions. Kennedy's documentation of early European architecture (33, pp. 17-30) illustrates that the use of passive solar energy in shelter design was common during

the turn of the first millenium in Italy, France, and Spain. North America's Pueblo Indians of Arizona and New Mexico oriented and designed their dwellings to take advantage of their sunny climate. In fact, as early as 1100 A.D., a passive solar multiple-family structure was built in the Pueblo Bonito of Chaco Canyon, New Mexico. This 5-story building, constructed as a huge semicircle, housed nearly 1,000 people in 800 rooms. In addition to its southeastern orientation, it used a solid rock north wall and adobe as thermal mass (81, p. 115). The houses of the New England pioneers were well-suited for that region's harsh winters. Solar heat gain through southern exposures, masonry-filled walls, and wood stoves located on north ends were all components of our early American indigenous architecture (74, p. 8). As illustrated in this discussion, the concepts of passive solar space conditioning certainly do not compose a new technology developed in response to the 1973 Arab oil embargo.

Energy-Conscious Design: An Alternative With Potential

The gradual realization of adverse environmental consequences of fossil fuel use combined with soaring prices and dwindling supplies have contributed to a growing awareness of the potential of nonpolluting, renewable resources.

While it is reasonable to question why the society as a whole was so short sighted, buildings of the mid-60s represented the general social concerns of the time. It is appropriate to consider the best of them as being representative relics of a by-gone era, an era tragically naive about energy resources. It is the height of irresponsibility to carry forward concepts which

evolved in this naive era into the late 1970s, when we have been forced to be acutely aware of the impact of energy resource consumption. [81, p. 107]

Even though the preceding citation by Stein may have overstated the issue, when viewed from an economic perspective, it is at the least impractical to continue building practices that disregard renewable and virtually inexhaustible energy resources in an era marked by declining supplies and increasing prices of conventional fuels. Significant reductions in energy demand are possible through energy-conscious design.

Energy Conscious Design (ECD) can be defined as a combination of energy conservation measures and solar tempering which, when optimized within a specific microclimate, dramatically decreases the total generated energy requirements of a building or group of buildings. ... It achieves this by paying close attention to building orientation, proportion, form and shape, landscaping, spatial organization, envelope characteristics, space conditioning and HVAC equipment efficiency. [58, p. 11]

According to Devo1 (16, p. 9), of the one-third of all energy consumed by buildings in the U.S., one-half is wasted through thoughtless building design. Stated more specifically, 17 percent of the power that is presently used in the U.S. would be available for other purposes if the existing stock of buildings had been designed with the capacity to use passive solar energy. A recent Worldwatch Institute study on new construction and rehabilitation reported that the combined technologies of conservation and passive solar can reduce by 25 percent the amount of

energy used in the buildings of the world by the end of this century (79, p. 8). Energy use per square foot of building space is subject to significant reductions through renewable resource technologies, so that the incorporation of these technologies into existing construction methods can have important ramifications at both the macro- and micro-levels of an economic system. A decrease in the aggregate use of fossil fuels lessens the national dependence on foreign supply sources or at least makes these fuels available for other purposes. A reduction in a building's operating expenses can make a substantial contribution to a project's feasibility. Some benefits, such as long-term improvements in environmental quality and increased levels of natural daylighting within a structure, do not lend themselves as readily to quantification, but are positive contributions to an ecosystem attributable to energy-efficient architecture.

Innovation and the Building Industry

The provision of residential shelter in the U.S. constitutes an industry with a vast number of participants, including landowners, developers, architects, government officials, laborers, lenders, realtors, tenants, and owners. The construction industry can be characterized as a highly fractionalized activity that involves many small producers and consumers. It operates in a powerful and often difficult labor environment and does not undertake much research and development in comparison with other industries of its size. In addition, problems with capitalization make the industry a captive of national economic cycles. All of these attributes contribute to the composition of a sector in the U.S. economy that is extremely risky (76, p. 38).

Schoen, Hirshberg, and Weingart (76, pp. 49-63) examined the process of change in the housing industry and grouped its barriers into three categories: technological, economic, and institutional. In any industry, an innovation must first be proved to work before it will achieve widespread acceptance. In the owner-occupied housing market, the buyers must be convinced that passive solar heating is technologically feasible.

In the renter-occupied market, the "buyers" are actually the investors in this type of housing and make decisions that will affect the users--the future tenants. In the long-run, if passive solar technology is widely accepted in the rental housing market, renters may express a preference for units built with this feature. However, these units would already have to exist on a scale large enough to have such an effect. The demonstration of an innovation's economic feasibility is another condition to its successful implementation.

Owner-occupants must be convinced that despite high initial cost, the advantages of a passive solar system in terms of life-cycle costs and payback time merit investment. In the rental market, developers' concerns range from the effect of the incremental cost of a solar system on the investment's rate of return to its consequences on a project's cash-flow and tax-shelter benefits. Both the owner-occupied and rental markets are highly susceptible to interest rate fluctuations because of the large sums of capital needed to finance the construction of a project. Changes in the costs of capital that add to the financial burden of an undertaking are likely to impact negatively on energy technologies that increase construction time and cost. This "first cost sensitivity" hinders the use of passive solar systems that result in higher initial costs than conventional structures but make possible lower operating costs.

As previous innovations in the construction industry have shown, proof of technological and economic feasibility alone does not guarantee market acceptance of new methods. Established building techniques are not only guarded by the interests of those for whom they create jobs but also are mandated by building codes that often impede change. Ironically, energy conservation codes also can pose barriers to the use of passive solar energy when provisions that specify a maximum allowable glazing-to-floor-area ratio are violated by a direct-gain system that relies on relatively large areas of southern glazing.

Closely linked to organizational and institutional characteristics that inhibit solar energy use are important cultural factors. The construction industry is based on crafts, not science. The building process itself relies on the use of a series of trade unions, all of which make separate contributions to a project. This craft orientation results in reliance on previous methods and resistance to the use of new techniques, skewing the industry to a traditional orientation.

O'Riordan and Migani (58) analyzed the housing industry in the northeastern U.S., identifying factors that impede widespread use of climate responsive design in this region. Among these factors are a lack of awareness of the technology's principles, higher initial costs, and a lack of credibility for the capabilities of solar energy in this colder, cloudy area (58, p. 12).

One can see, then, that both institutional barriers and the perceptions of producers and consumers act as impediments to the development of solar energy in the building industry. In fact, it may be the case that there is some interaction among these factors so that one may influence another. This point in itself would be an interesting issue for further

research; for the purposes of this thesis, however, it is sufficient to note that the retarded development of solar energy in this sector of the economy is the apparent result of market failure.

Incentives for Solar Energy Use

Government incentives, originating at both the Federal and state levels, have been addressing this problem of market failure through loan and grant programs and tax credits. The National Energy Act of 1978 and the Crude Oil Windfall Profits Tax Act of 1980 (50, pp. 6-27 through 6-30) established Federal income tax credits for investments in energy conservation and renewable resource technologies. Within the latter category, passive solar systems, by their very nature, have not always been able to qualify for tax credits. Because systems of this type are incorporated into a building's structural members, issues regarding use of the credit at first centered on methods for isolating the incremental cost of construction features solely attributable to passive solar technology. Instead of developing a uniform formula for achieving this, however, the Internal Revenue Service issued rules specifying that only materials and components, the sole purpose of which is to transmit or use solar radiation, could be included under the tax credit. So most passive solar measures are excluded by virtue of definition with the explicit citation that windows, load-bearing walls, and greenhouses do not qualify.

The importance of federally assisted housing programs in the market is likely to diminish during the near term; nevertheless, note that recent changes in these programs have removed barriers that once inhibited the inclusion of solar systems in subsidized and insured multifamily projects. Mortgage insurance programs within the Department of Housing and Urban

Development (HUD) regulate capital costs of multiunit projects by limiting their amounts. The Housing and Community Development Act of 1980 (50, p. 6-17) increased these mortgage insurance limitations for multifamily programs by up to 20 percent, provided such increases are made necessary by increased project costs resulting from solar energy systems. This change affects virtually every HUD multifamily housing insurance program, including Sec. 221(d)(4), the most frequently used program in this category.

Also affected by the 1980 Housing and Community Development Act is the prototype cost limitation provision of HUD's public housing programs, from which the cost of a passive or active solar heating system is now exempted. In addition, the act requires that solar systems be installed in all new projects and in those involving substantial rehabilitation, where such systems are found to be feasible through life-cycle cost analyses. Increases in Fair Market Rent levels of the Housing Assistance Payments Program (HUD Sec. 8) are now authorized for projects that use active or passive solar space and/or domestic water heating systems.

The Energy Security Act of 1980 (50, p. 6-36), signed into law by President Carter on June 30, 1980, created the Solar Energy and Energy Conservation Bank, which is operated under HUD's jurisdiction. Although the future activities of the bank are highly speculative, its history is interesting. The bank was mandated to facilitate the secondary financing of residential energy conserving improvements and solar energy systems by purchasing loans made for such purposes; it took over this authority from the Government National Mortgage Association (GNMA). In addition to

purchasing loans, the bank also could offer direct loans with either reduced principal obligations or subsidized interest to low- and moderate-income people.

At the time of this writing, the bank is operating without a budget under directives to halt all loan activities (98). The Reagan Administration has proposed rescission of the \$121 million appropriation for the bank's operations in 1981 and no funding for 1982. Budget reduction plans of this administration do not include elimination of tax credits for solar energy use (22, p. 2) but are expected to affect solar programs administered by the Department of Energy (19, p. 1).

Recently another agency of the Federal government, the Department of Agriculture's Farmers Home Administration, officially recognized passive solar design advantages and adapted its guidelines for its assisted housing programs to make minimum levels of passive solar benefits mandatory in its subsidized units (3, p. 607).

States also have encouraged the use of solar energy in residential heating systems through the provision of low-interest loans from housing finance agencies, direct loan and grant programs from state energy offices, and amendments to real property laws that exempt from local property taxes the increased value of units attributable to solar systems. The legality of solar easements, which guarantees continued access to sunlight for owners of solar systems, also has been recognized at the state level. Hendrickson (29, p. 97) discussed elements making state incentives preferable to Federal incentives. State incentives provide a basis for meaningful policy development for local governments and allow closer relationships with end-users of solar technology.

Disincentives for Solar Energy Use

It is worth noting at this point that disincentives for energy-conscious design also have been created by the government as a result of intervention in the oil and natural gas industries. In the oil industry, the percentage depletion allowance, introduced by Congress over 50 years ago to stimulate production of energy reserves, and subsequent provisions for expensive drilling costs had an initial effect of increasing the after-tax rate of return on investments in the exploration and production of oil, which led to increased capital flows into each of those areas. New reserves were found subsequently and production was stimulated and greatly increased, leading to lower prices. Further intervention in the natural gas industry resulted in regulated prices that are considerably lower than competitive market prices. In this manner, the historic U.S. low-price policy for energy was established, which led consumers to treat oil and gas as cheap commodities and to consume these nonrenewable resources excessively. Mead (48, p. 352) stated that in the absence of these artificial stimulants, the market would have delayed production and energy's price would have been more representative of its replacement cost. Consequently, consumers would have been more likely to use these resources efficiently because they would have been paying prices more reflective of energy's true marginal cost.

These Federal policies effectively acted as a subsidy to conventional energy industries, the results of which are illustrated in Fig. 3.1. The initial energy supply curve before the tax deductions were permitted is represented by ss' . Price and output at this level are shown by P_0 and Q_0 . With an effective subsidy of AB per unit of output, the supply curve shifted to SS' , with corresponding changes in price and output to

Fig. 3.1. Effect of government intervention in the energy industries.

P_1 and Q_1 . The loss in government revenue, or the cost to taxpayers, is depicted by the rectangle $CFEP_1$. This amount is greater than that gained by consumers, P_0AEP_1 , and the gain to producers, $CFAP_0$. The net loss, therefore, is represented by the area of FEA (15, p. 767). This distortion to the market resulted in the delivery of excessive energy supplies to far too many users at too low a price, contributing to the shortages of the 70s, which were exacerbated by the Arab oil embargo.

Rising energy costs compel consumers to examine the effectiveness with which this resource is being used; in the residential sector, because some building practices allow inefficient energy use, a continually increasing emphasis is being placed on finite resource conservation technology. Generally, this can be defined as a substitution of less costly resources or production factors for energy. It is indicated in the short run by changes in consumer behavior towards key energy-intensive activities with the use of existing capital. A rational consumer response to rising

Fig. 3.2. Marginal costs and marginal benefits of energy conservation.

energy prices is an investment in conventional energy-conserving equipment, materials, and devices until the marginal savings generated equal the marginal costs of the investment (30).

Figure 3.2 illustrates the costs versus the benefits of increments in energy savings resulting from increments in energy resource conservation measures. The optimal investment is indicated by the point of intersection between the marginal-cost and marginal-benefit curves. Marginal costs are equal to the incremental dollars invested in energy conservation; the incremental values of energy savings represent marginal benefits.

Marginal costs and benefits associated with investments in conservation are again depicted in Fig. 3.3. Efficiency in resource use at present prices entails a conservation or renewable resource investment level of P_0 resulting in savings of Q_0 . Cheap and plentiful supplies of energy 30 years ago were responsible for the lower marginal benefits

Fig. 3.3. Changes in marginal benefits of energy conservation following changing energy prices.

possible through conservation (MB') and the consequent lower levels of investment in such an effort. MB'' represents a reversal of this scenario, in which deregulation, decontrol, and further internalization of environmental and other social costs cause more increases in energy prices, thus increasing the marginal benefits of conservation measures (96, p. 1). When prices eventually do reach these levels, marginal benefits associated with conservation expenditures will increase further. These price changes represent only one factor responsible for changing marginal benefits, but these benefits can be affected by other things, such as changes in technology. Figure 3.3 considers only private costs associated with energy conservation. Note that social costs are important in discussions of this topic and would have to be considered as producers become required to capture externalities, such as pollution, involved with production.

Cost Effectiveness of Passive Solar Designs

Although the concepts of passive solar space conditioning are simple, decisions regarding its use are not. Balcomb (7, pp. v-19) discussed the complexity of incorporating energy-conscious design in the building process because use of this strategy necessitates consideration of numerous factors in addition to thermal performance. As an integral part of the design process, an economic analysis can facilitate informed decision-making. Duffield (17, p. 688) posed the question of whether a passive solar system represents the least costly method of residential space heating.

The quick answer is that it depends, it depends [sic] on how well the solar system converts sunlight into usable heat, how much the system costs, the alternatives available and their costs, and on a number of site-specific parameters such as the amount of sunlight available over the course of the year, the severity of the climate, and the thermal characteristics of the building itself.

In economic evaluations of passive solar designs, numerous analytical techniques have been applied. These studies contribute to the body of knowledge in this field, specifically with regard to the cost effectiveness of the technology, which must be demonstrated before successful commercialization of this technology can occur (76, p. 51). With regard to cost effectiveness, it is a complex technical and economic issue that requires accurate information about incremental costs and energy savings for its calculation. This information relies on, and is highly sensitive to, certain basic assumptions, including rates of interest and inflation,

and cost-escalation projections of conventional fuels. The issue is complicated further by values such as structural aesthetics, natural daylighting, and spatial amenities, all of which complicate the task of assigning incremental costs. The method under which a project is financed will affect noticeably the determination of cost effectiveness (67, p. 697).

Discussing key factors in a solar system's economic analysis, Noll and Barley (57, pp. 207-236) identify the two fundamental elements of space conditioning costs in a dwelling as fuel and energy conservation expenditures. If a solar and an auxiliary heating system are included in a structure, then the principal components of the total heating costs are

- (1) investment for solar heating system,
 - (2) investment for energy conservation, and
 - (3) recurring cost of auxiliary heating.
- [57, p. 207]

The relationships among the three variables are such that manipulation of any one of them leads to changes in the other two. Cost optimization is a term used to describe the process by which the values assigned to each of the variables result in the minimum total cost. An evaluation is performed to determine the economic merit of a particular design.

Economic Evaluation Techniques

Analytical tools that are useful for conducting evaluations of solar energy systems were detailed by Marshall and Ruegg (44) and include life-cycle costing, net benefits or savings, savings-to-investment ratio, and the payback time analysis.

The life-cycle costing technique involves a comparison of two energy systems--a solar and a conventional system. The cost of each system is summed separately and includes net costs of purchase (less any salvage value), maintenance, repair, replacement, and all other costs attributed to the investment, including the cost of money over the investment's economic life. The system having the lower total life-cycle cost while meeting the investor's constraints is the preferred investment.

A general formula for calculating the total life-cycle costs of an energy system investment is

$$LCC = P - S + M + R + E, \quad (III-1)$$

where LCC = life-cycle costs,

P = purchase and installation costs,

S = salvage value,

M = maintenance and repair costs,

R = replacement costs, and

E = energy costs.

In this and in the following two equations, all costs are in either present value or annual value dollars and are adjusted for taxes and incentives.

The net benefits or savings method calculates the difference between the economic lifetime dollar energy savings and economic lifetime dollar costs of an investment in a solar energy system by applying the following formula to the difference between two alternative investments being compared.

$$(B - C) = E^* - (P^* - S^* + M^* + R^*), \quad (\text{III-2})$$

where $(B - C)$ = net benefits or savings; and the values of E, P, S, M , and R in this and subsequent equations, where accompanied by an asterisk, represent the difference between present value or annual value costs for an investment in a solar energy system and the conventional system under comparison.

Like the two preceding techniques, the savings-to-investment ratio, often referred to as the benefit/cost analysis, is based on cash flows.¹ Unlike the life-cycle costing and the net benefits or savings techniques, savings and investment costs are expressed as a ratio rather than as a dollar amount. This ratio must be greater than 1 for positive net savings to be realized. The higher this ratio is, the greater the dollar savings realized per dollar of investment. Following is the general formula used in the calculation of the savings-to-investment ratio.

$$\text{SIR} = (E^* - M^*) \div (P^* - S^* + R^*), \quad (\text{III-3})$$

where SIR = savings-to-investment ratio.

A commonly used technique in the evaluation of solar energy investments is the payback time analysis, which measures the elapsed time between the point of initial investment and the point at which accumulated savings, net of accumulated costs, are sufficient to offset the initial

¹The time value of money is considered in these equations through the application of a discounting factor to each of the costs presented. This point will be discussed in Chapter IV.

investment cost. If costs and savings are adjusted to account for the changing value of money over time, this tool is referred to as "discounted payback." If a time adjustment is omitted, it is termed "simple payback."

If an investor's objective is to achieve a rapid turnover of investment funds, the investment increases in desirability as the payback period decreases. It should be noted, however, that a shorter payback time does not necessarily indicate the most economically efficient investment because any savings realized after the payback period are ignored.

The following formula shows how to find the discounted payback period, Y .

$$P^* = \sum_{j=1}^Y (E^*_j - M^*_j - R^*_j + S^*_j) . \quad (\text{III-4})$$

The simple payback period, Y_s , can be calculated as

$$Y_s = \frac{T}{A} , \quad (\text{III-5})$$

where T = total system costs, and

A = anticipated annual savings.

One can see that there are many ways to evaluate an investment in a solar energy system. Each method has its own strengths and weaknesses, and, based on these points, will be the preferred method given the circumstances of the investment under analysis. Both the life-cycle costing technique and the net benefits or savings method are useful in a determination of whether total building costs are higher with an investment in a

solar energy system. However, neither of these methods is effective for comparing projects that have different purposes but that compete for a limited budget.² Under a condition such as this, the savings-to-investment ratio is recommended for determining the ranking to be given to competing investments that are not direct substitutes for each other (44, p. 14). This ratio reflects the return on an investment, and can be used to rank investment projects to determine which will result in the largest total return for a given budget.

The payback time analysis measures the period necessary to recover investment funds, which is often a critical factor to speculative investors and homeowners, who require a fast turnaround of these funds. This feature of rapid recovery, however, may be overemphasized, with the result that less efficient, short-term ventures can be favored over more efficient, long-term investments. This technique does not provide a full measure of an investment's profitability because benefits and costs occurring after payback time has been reached are ignored. This problem can be overcome by supplementing the payback time analysis with the life-cycle cost analysis, which will be the procedure followed in this thesis.

Economic Analysis Through Computer Modeling

Complex calculations to determine cost effectiveness and the trade-offs inherent in choices about the discount rate, fuel cost escalation rates, operating and maintenance costs, depreciation, resale value, financial incentives, and projections of system economic life make

²An example of such a circumstance would be the decision to increase the thermal mass of building walls instead of using exterior shading devices for south-facing windows.

computer modeling a necessity (67, p. 698). Accordingly, numerous computer programs for passive solar design analysis were developed during the past several years; the one chosen for this study is reviewed here.

A joint initiative of the University of New Mexico's (UNM) Resource Economics Program and the Economics Group of the Los Alamos National Laboratory during 1975 and 1976 led to the development of the Los Alamos/UNM Solar Economic Performance Code (EASE) "... to assist in the evaluation of market potential for residential passive solar heating systems on a nationwide basis." (34, p. 1) The code was designed to evaluate seven general passive solar strategies through the use of life-cycle cost and payback time analyses. User-specified inputs allow flexibility in choosing unit design, location, financial parameters, and government incentive options. Fixed inputs include load collector ratios (LCR) that estimate the thermal performance of a given climate-responsive design from hourly thermal network models of the seven passive solar designs, a 65° Fahrenheit heating degree-day base as an interior design temperature, and localized fuel prices and construction costs.

The program's output includes a life-cycle cost analysis based on

- (1) conventional fuel prices;
- (2) total solar cost;
- (3) interest, discount, and inflation rates;
- (4) operating, maintenance, and property tax rates;
- (5) downpayment and resale rates;
- (6) Federal, state, and local tax brackets; and
- (7) government incentives.

Results of the analysis are expressed in dollars per million Btu (65, p. 28).

The code's economic evaluation includes a solar cost optimization, which expresses maximum solar savings as a function of the minimum delivered cost of heat. Available restrictions to this optimization include specified payback and downpayment recovery periods (65, p. 29). System cost recovery and downpayment recovery are variants of the payback time analysis, which also can be included as part of the EASE routine.

IV. ANALYTICAL FRAMEWORK

Objective

This study examines the economic feasibility of a multiple-family dwelling design with alternative passive solar applications for three locations in upstate New York. Economic feasibility, a complex issue, can be defined in different ways. For the purposes of this study, the term will be used in the context of payback time and life-cycle cost analyses compatible with conventional alternatives given current market conditions pertinent to owner-occupants.

In the rental market, issues pertinent to the evaluation include the effects of an investment in passive solar technology on a developer's rate of return, and project cash-flow and tax-shelter effects during the building's operating phase. The developer is the person or firm who initiates and often builds a rental project. Before the project enters the operating phase, the developer often sells a large portion of its ownership (usually 95 percent) to outside investors. This is known as the syndication process. At this point the developer realizes a profit on the investment that was required for project construction. The analysis will examine the effect of a passive solar investment on this item.

The most widely used ownership mechanism for multifamily rental projects is the limited partnership (38, p. 22). Investors in such agreements treat all income or losses from the projects as additions to or deductions from personal income. Because operating expenses--including property taxes, interest and mortgage insurance premiums, and depreciation --can be deducted as business expenses, it is possible to have a negative project income and a positive cash flow at the same time. In this way,

cash that investors receive from a rental project can be tax free and, if "paper losses" are large enough, income received from other sources can be "sheltered" from income taxes. In a review of a rental housing investment possibility, then, projections that show a wide gap between cash flow and project income are preferable to those that do not. The study will illustrate the effect of a passive solar investment on this gap.

Upstate New York: The Climate

Relative to the rest of the U.S., New York has a high incidence of cloudiness because of its location within the prevailing cross-country path of low-pressure systems in the meteorologically active midlatitudes and the proximity of the Great Lakes as sources of moisture (6, p. 4). The section of upstate New York that is of interest for this thesis is known as the Lake-Effect Region (5, p. 4), an area which receives considerable lake-induced cloud cover during the winter months and, consequently, low amounts of solar radiation. In addition, this region is subject to cold winters with occasionally very cold periods and the most frequent, longest cloudy spells of any other area in the state (5, pp. 4-5).

The Structure

The building chosen for this analysis has not been constructed. It is a three-story, nine-unit dwelling designed by Total Environmental Action (TEA), Inc. (92), and is depicted in Fig. 4.1. The figure is an illustration of what will hereinafter be referred to as the "basic structure," that is, the building without distinct passive solar applications. It houses nine single-level units of 1,270 square feet each. Living,

Fig. 4.1. The basic structure.

dining, and kitchen areas are located on the south end of the units; bedrooms and baths are on the north. In addition, each unit has a south-facing deck. Built on a concrete slab, the walls consist of 2 x 4 framing, fiberglass insulation, styrofoam sheathing, and wood siding. Party walls are of masonry block and intermediate floors are trussed. The roof is insulated with 12 inches of fiberglass and all windows are double-glazed casements. The basic structure's north elevation, sectional view, and floor and roof plans are illustrated in Appendix A.

The two passive solar building applications being analyzed are a vented Trombe wall and a direct-gain system with storage. A Trombe wall consists of a solid masonry panel that serves as all or part of a building's south-facing wall. Its exterior surface, painted black, is glazed with glass or plastic. The glazing is separated from the wall by an air space of at least 4 inches. Solar heat gain is delivered to the building by conduction through the mass. As an alternative heat-delivery method, the Trombe wall can be vented at both the floor and ceiling levels of the building to create a convective loop.

A direct-gain system was explained in Chapter I, but it will be reviewed here. Large amounts of southern glazing admit sunlight, which is then stored as heat in thermal mass located within the structural interior. In the application analyzed in this thesis, the party walls serve as the thermal mass.

The changes to the south wall of the building to accommodate the systems are shown in Figs. 4.2 and 4.3. No other changes are made to the basic structure, except for filling the party walls with grout in the direct-gain building.

Fig. 4.2. South wall, direct-gain building.

Fig. 4.3. South wall, Trombe wall building.

Building costs were calculated for the basic structure and the solar applications by TEA on a regional basis. During the analysis of the solar economic performance code, these costs were adjusted with city-specific cost adjustment factors calculated from local cost indices (34, p. 3). Costs are presented in Appendix A.

Heating Load Calculations

To quantify the performance of these passive solar energy systems, it is first necessary to determine the amount of heat with which each unit in the basic structure must be supplied during the heating season. This figure, known as the annual heating load, was calculated for each unit with the methods described by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (2) and by Leckie et al. (37). Calculations are presented in Appendix A.

Performance Evaluation and Organization of the Analysis

The structure of the solar economic performance code is illustrated in Fig. 4.4. The first portion of the code is concerned with the specification of inputs and the calculation of certain economic parameters. After all economic parameters are defined, the solar collector area is calculated from the LCR, the chief determinant of overall performance. This is the ratio of the building's heating load to collector area, and is based on hourly thermal network models developed for different passive solar designs. Also calculated is the solar load ratio (SLR), the ratio of available solar radiation to each unit's annual heating load. Solar system costs are then calculated with this information and with the relevant variable costs. The life-cycle cost analysis then is carried

Fig. 4.4. Structure of the Los Alamos/UNM Solar Economic Performance Code.

out, leading to cash-flow tables and the calculation of simple payback. Computed for each unit with each solar application were payback time and net present value in comparisons with the following conventional heating systems: oil, natural gas, electrical resistance, and heat pumps. The payback time is the length (in years) of the period required for energy savings to equal the solar investment. The net present value represents the difference between life-cycle costs of the solar system and a specified conventional alternative. If this figure is positive, it represents cash savings attributable to the solar system; if negative, it represents losses.

Analyses were conducted for each unit, with each of the passive solar applications for each of the three cities. The units in the building were assigned numerical identifiers as per the illustration in Fig. 4.5. Because of identical annual heating loads for units 1 and 3, 4 and 6, and 7 and 9, each of these pairs was treated as one unit in the analysis.

Owner-Occupied Versus Renter-Occupied Analyses

Owners of units that they occupy and owners of units that are rented approach investment decisions in different ways. Because owner-occupants --whether they own detached single-family dwellings or condominium units-- are responsible for their utility bills, they are the beneficiaries of investments in alternative energy systems. Analyses that are relevant to these owners include the payback time and life-cycle cost analyses, among others. Rental housing owners, on the other hand, are in most cases not responsible for their buildings' utility bills because of separate metering (38, p. 1), which may be mandated for new construction, as is the case in New York State, through the Energy Conservation Construction Code.

Fig. 4.5. Numerical identification of the structure's units.

Although conventional fuel savings may not motivate rental housing owners to invest in alternative energy systems, other factors may induce such a course of action.

The criteria for investment decisions in rental housing are based on the different types of profit generated by this kind of venture. These include the developer's after-tax rate of return, positive cash-flow and tax-shelter benefits during the building's operating phase, and capital gains at the time of the building's sale. Therefore, an analysis of the economic feasibility of an investment in a passive solar heating system should focus on the effect of that system's incremental cost on these different indications of profit.

Economic Parameters for the Owner-Occupied Analysis

Financial parameters used in the present value calculations of the life-cycle cost analysis reflect conditions of both the economy in general and those of the solar system owner (61, p. 7). Parameters selected for this study and used in the calculations of what is termed the "base case," are presented in Table 4.1. These parameters reflect the user-specified inputs of the solar economic performance code. Ten sets of calculations followed from the base case, each with a variation in one user-specified parameter. These variations are presented in Table 4.2. The model's fixed inputs for this analysis are presented in Table 4.3.

Analytical Techniques for the Owner-Occupied Analysis

Payback Time Analysis

As described in Chapter III, the payback time analysis is an analytical technique useful in evaluating solar energy systems. Its use is advocated by Böer (9), who defined the payback period as the time at

TABLE 4.1

USER-SPECIFIED FINANCIAL PARAMETERS FOR THE BASE CASE

<u>User-Specified Input</u>	<u>Justification</u>
30-Year Period of Analysis	A mortgage with a 30-year term was assumed for the base case and this was chosen as the solar system ownership period.
20-Percent Downpayment	Assumed as a representative figure for a conventional mortgage.
8-Percent Annual Inflation Rate	Assumed as a representative figure for a long-term inflation rate.
3.5-Percent Real Discount Rate	Chosen to represent a conservative estimate of a real long-term discount rate (77).
7.5-Percent Real Mortgage Interest Rate	Chosen as a representative figure of the current conventional mortgage interest rate. (This is a real rate. The nominal rate is equal to this figure plus the inflation rate, or 15.5 percent.)
150-Percent Resale Rate	Chosen to reflect appreciation in the solar system's value beyond that caused by inflation.
Local Property Tax Rates	Obtained from Real Property Tax Service in each of the three cities. See Appendix A.
30-Percent Federal and State Marginal Tax Brackets	Chosen as a midrange value, representative for condominium unit buyers (14).

TABLE 4.2

VARIATIONS IN USER-SPECIFIED FINANCIAL PARAMETERS

<u>Variation to Base Case</u>	<u>Justification</u>
7-Year Period of Analysis	Chosen as representative of the average period of home ownership in the U.S.
15-Year Period of Analysis	Used as a potential average period of condominium ownership (14).
25-Percent Downpayment	Assumed as an alternative to the original 20-percent figure.
7.5-Percent Real Discount Rate	Used to test the sensitivity of the analysis to a change in the discounting factor.
11-Percent Annual Inflation Rate	Assumed as a representative long-term value for continued high inflation.
20-Percent Federal and State Marginal Tax Brackets	Chosen as a low-range value, representative for condominium unit buyers (14).
40-Percent Federal and State Marginal Tax Brackets	Chosen as a high-range value, representative for condominium unit buyers (14).
1.5-Percent Real Mortgage Interest Rate	Chosen as a representative figure of lower interest rates, to test the sensitivity of the analysis to such a change (9.5-percent nominal rate).
100-Percent Resale Rate	Chosen as a conservative estimate indicating that the value of each solar system keeps pace with inflation.
12-Percent State Tax Credit	Chosen to reflect current proposals before the New York State Senate and Assembly (53). (This set of calculations makes an addition to the financial parameters used in the base case.)

TABLE 4.3

FIXED INPUTS USED IN THE SOLAR ECONOMIC PERFORMANCE CODE

Fixed Input	Justification
Load Collector Ratio	Correlation between heating load and southern glazing. Used to estimate thermal performance of a given solar design. SOURCE: J.D. Balcomb and R.D. McFarland, "A Simple Technique of Estimating the Performance of Passive Solar Heating Systems," <u>Proceedings of the 1978 Annual Meeting of AS/ISES</u> , Denver, Colorado, August 23-31, 1978.
Degree Days	SOURCE: U.S. Department of Commerce, "Monthly Normals of Temperature, Precipitation and Heating and Cooling Degree Days, 1941-1970," Oceanic and Atmospheric Administration Environmental Data Service (1973).
Fuel Prices	SOURCE: F. Roach and M. Yeaman, "Residential Conventional Fuel Prices and Future Projections: Data Inputs for the Los Alamos/UNM EASE III Model," Los Alamos Scientific Laboratory Report (September 1980). <u>Escalation Rate Calculation:</u> $x_t = x_0(1 + r)^t$ $\frac{x_t}{x_0} = (1 + r)^t$ $\frac{x_t}{x_0} = 1 + r$ $r = \frac{x_t}{x_0} - 1$ x_t and x_0 from Annual Real Fuel Escalation Rates, US Department of Energy Midrange Trend Scenario--1985, 1990, and 1995. x_0 is the price of fuel in year 1; x_t is the price in year t.
Construction Cost Adjustments	City-specific cost indices. SOURCE: <u>R. S. Means Construction, Building Construction Cost Data, 1979</u> (January 1980).

which initial cost and operating expenses with compounded interest equal the total savings in energy expenditures with compounded interest. The condition for payback time is therefore represented by

$$A + B = D , \quad (IV-1)$$

where A is equal to the future value of the initial cost at the end of the payback period; B represents annual expenses associated with the solar system, such as taxes, insurance, maintenance, and repairs, and is calculated with an annual fixed charge rate that accumulates as an annuity; and D represents the system's income or energy savings in the form of an accumulated annuity of the dollar value of the annually displaced conventional energy. A, B, and D are calculated as follows.

$$A = C(r + 1)^n , \quad (IV-2)$$

where C = initial cost of the solar investment,
 r = annual real interest rate, and
 n = length of payback time.

$$B = mC \frac{(1 + r)^n - 1}{r} , \quad (IV-3)$$

where m = fixed rate of annual expenses.

$$D = E \frac{(1 + r)^n - 1}{r}, \quad (\text{IV-4})$$

where E = dollar value of annually displaced conventional energy.

From the conditional equation, $A + B = D$, Böer derived an expression for the ratio of annually displaced energy cost to the initial cost.

$$\frac{E}{C} = m + \frac{r}{1 - (1 + r)^{-n}}. \quad (\text{IV-5})$$

This ratio, calculated with different payback periods, decreased with longer payback terms and increased with shorter ones.

As applied to passive solar design, the payback time analysis can be of value once the increased initial cost attributable to the solar system is isolated from the total cost of the structure. In an analysis of an active system, the task is simple. A summation of all equipment costs associated with the collection, storage, and distribution of solar energy is necessary. This equipment will be in the form of constructed solar collectors, fluid transport pipes, pumps, water tanks, radiators, and fans. Critical elements of a passive solar system, on the other hand, also serve dual functions as walls and floors of the units they heat. So it is necessary to compare the cost of the dwelling as built using the solar technology with the cost of the same dwelling as built using

conventional construction techniques. In other words, what is being calculated is what Saunders (73) identified as the incremental cost of a solar system, which is the system's initial cost less the cost of the conventional system it replaces. Because most passive solar buildings also require a conventional heating system to function during protracted periods without sunlight, it is also necessary to include the incremental cost of the auxiliary heating system as part of the solar strategy. In other words, it is the difference in the cost of the conventional heating system under a nonsolar versus a solar system that is relevant.

In addition to calculating the initial cost of the system, it is necessary to estimate the sum of all annually recurring costs associated with it throughout the payback time, and to determine from this amount an average annual rate of the system's initial cost that is equal to these expenditures. Finally, one must determine the amount of conventional fuel conserved or the energy expenditures that would be necessary if heating were to be accomplished solely with conventional techniques. This quantity, measured in British Thermal Units (Btu), can be estimated through heat-loss and heat-gain calculations performed with desk calculators or packaged computer programs. The conversion to dollars can be achieved through a separate analysis of energy cost per Btu, as demonstrated by Hellenbrand (26).

Although the payback time analysis offers an understandable assessment of the additional investment necessary with a passive solar heating system, it is not without weaknesses that might prompt consideration of alternative evaluation methods. The determination of the additional initial cost, for example, cannot be made without a theoretical comparison between solar technique and conventional technique. The performance

standards approach taken by most building codes has encouraged the development of variable construction methods for achieving stated levels of structural and thermal response in buildings. The conventional technique chosen, therefore, may affect significantly the payback calculation because the cost of the technique depends upon the method selected. This situation may induce an analyst to conduct several payback analyses, comparing the proposed passive solar system with a number of conventional alternatives. Note that the alternatives considered may be limited to a determinable range, so one may prefer to compute the mean of the two construction cost limits, using this as a basis for comparison.

The calculation of expenses associated with the system throughout its economic life necessitates that an assumption be made regarding this timespan. The length of time associated with financing arrangements may be designated as the economic life of the structure. A drawback to this approach is that any expenses incurred after the mortgage period are ignored, which may lead to an understatement of the payback period. The 40-year useful life measure of the Internal Revenue Service may be practical in an analysis of a multiunit structure; or, if an investment is made for a specific timeframe in a project, then that term may be relevant for the evaluation. Because state bonds with 25-year terms are used to finance the projects within the Massachusetts Multi-Family Passive Solar Program, payback time analyses of those structures recognize that figure as economic lifetime (69, p. 1).

Once the solar system's economic life is determined, it is necessary to ascertain the expenses attributable to it. At this step, consideration should be given to increasing fuel rates for comparative purposes and for computation of the auxiliary system cost. Hellenbrand (26) determined

accelerating fuel cost rates for various fuels based on rates of increase during the past 10 years. MacArthur et al. (42, p. 5), call this variable the "Fuel Cost Growth Rate" and define it as the effective rate at which the price of fuel escalates when the time value of money is considered. Given this definition, the fuel cost growth rate can be expressed as follows.

$$\sum_{j=1}^n (1 + F)^j = n \left[\frac{r(1 + r)^n}{(1 + r)^n - 1} \right] \sum_{j=1}^n \left(\frac{1 + f}{1 + r} \right)^j, \quad (\text{IV-6})$$

where F = fuel cost growth rate,
 n = period of interest,
 r = discount or mortgage rate, and
 f = actual fuel escalation rate (42, p. 5).

The inclusion of the system's remaining costs requires a tabulation of all projected maintenance, repair, and insurance costs of the system over its lifetime. In addition, a proportion of property tax payments may be a relevant consideration because some states have passed legislation exempting solar heating systems from the property tax.

Life-Cycle Cost Analysis

As an alternative to the payback time method, a life-cycle cost analysis computes one cost number from expenses that occur throughout a system's economic life. Two primary schemes for grouping these costs are the present-value method, which treats all costs associated with a system throughout its lifetime as if they could be paid at the present, and the

annual-cost method, which treats costs as if they occurred in equal annual payments during a system's lifetime. Either approach is considered appropriate by McGarity (47) and Ruegg (70), as long as annual costs such as insurance and maintenance remain constant. When annual costs are expected to change from year to year because of changing prices, the present value of these costs must be calculated before a constant annual cost figure can be computed.

Both the present-value and annual-cost methods place greater value on expenditures made in the present than on those planned for the future. This time value of money shows that one dollar received now is worth more than one dollar received one year from now, because the dollar received today can be invested to collect interest.

In the present-value method, the time value of money is considered by multiplying costs occurring in future years by an annually decreasing fractional discounting factor. In other words, the sum of the reduced annual costs is equal to the present value of future annual expenditures. The factor used to reduce these annual costs is known as the discount rate, which both McGarity and Ruegg agree should be a relative interest rate reflecting the system owner's time preference for money. In a passive solar design evaluation, the selection of the appropriate rate may be based on current rates of return in other investment possibilities or on the mortgage interest rate.

A discount rate can be expressed as either a nominal rate, which includes an inflation factor, or a real rate, which does not. Either expression can be used as long as the costs analyzed correspond to the term used. That is, if a nominal discount rate is used, estimated future costs should include inflationary price changes; if costs are discounted

using a real rate of interest, costs should be estimated without consideration of inflationary factors.

The Single Present Worth Formula is used in the present-value method as follows.

$$\text{First Year: Annual Cost} \times 1/(d+1) = \text{Present Value} \quad (\text{IV-7})$$

$$\text{Second Year: Annual Cost} \times 1/(d+1)^2 = \text{Present Value} \quad (\text{IV-8})$$

$$\text{Third Year: Annual Cost} \times 1/(d+1)^3 = \text{Present Value} \quad (\text{IV-9})$$

Thus, with constant annual costs,¹

$$\text{Present Value} = \left(\begin{array}{c} \text{Constant} \\ \text{Annual} \\ \text{Costs} \end{array} \right) \times \left(\sum_{j=1}^n \frac{1}{(1+d)^j} \right), \quad (\text{IV-10})$$

where d = discount rate, and

n = economic life of system (47, p. 12).

¹When costs are not constant, but increase with time, this fractional annual increase must be accounted for in the present-value computation by an additional factor of $(1+e)$ in the first year, $(1+e)^2$ in the second year, $(1+e)^3$ in the third year and so on, assuming a constant rate of increase in costs (47).

Under these conditions, the present-value formula becomes:

$$\begin{aligned} PV' &= \left(\begin{array}{c} \text{Initial} \\ \text{Annual} \\ \text{Costs} \end{array} \right) \times \left[\sum_{j=1}^n \left(\frac{1+e}{1+d} \right)^j \right] \\ &= \left(\begin{array}{c} \text{Initial} \\ \text{Annual} \\ \text{Costs} \end{array} \right) \times \left\{ \frac{1+e}{d-e} \left[1 - \left(\frac{1+e}{1+d} \right)^n \right] \right\} \end{aligned} \quad (47, \text{ p. } 12)$$

The present value of the entire investment then can be determined by adding the appropriate present value of the sum of annual costs to the sum of the initial costs.

$$\begin{array}{l} \text{Present Value} \\ \text{Entire Investment} \end{array} = \begin{array}{l} \text{Initial} \\ \text{Expense} \end{array} + \begin{array}{l} \text{Present Value} \\ \text{Annual Costs} \end{array} \quad (\text{IV-11})$$

The annual-cost method considers the time value of money in a different way, treating the present value of an entire investment as financed by a loan with no compound interest and no downpayment. The constant annual payment is calculated with the Uniform Capital Recovery Formula, which computes a payment in a uniform series of payments, over n periods at an interest rate of r .

$$\begin{array}{l} \text{Uniform} \\ \text{Annual} \\ \text{Cost} \end{array} = \begin{array}{l} \text{Present Value} \\ \text{Entire Investment} \end{array} \times \frac{r(1+r)^n}{(1+r)^n - 1}, \quad (\text{IV-12})$$

where r = interest rate and n = lifetime of system (78, p. 47).

This formula is simplified by McGarity (47) from the present-value analysis to

$$\begin{array}{l} \text{Uniform} \\ \text{Annual} \\ \text{Cost} \end{array} = \left[\begin{array}{l} \text{Initial} \\ \text{Expense} \end{array} \times \frac{r(1+r)^n}{(1+r)^n - 1} \right] + \begin{array}{l} \text{Constant} \\ \text{Annual} \\ \text{Costs} \end{array} \quad (\text{IV-13})$$

Thus, the uniform annual cost can be considered as the amortized amount paid each year for the solar system plus maintenance, insurance, and any other operational costs for one year.

If annual costs are expected to increase by a fractional amount each year, this increase must be reflected in the annual cost calculation.

$$\text{Uniform Annual Cost} = \left[\text{Initial Expenses} \times \frac{r(1+r)^n}{(1+r)^n - 1} \right] + \left[\text{Constant Annual Costs} \times D \right], \quad (\text{IV-14})$$

$$\text{where } D = \left[\frac{r(1+e)}{r-e} \right] \left[\frac{(1+r)^n - (1+e)^n}{(1+r)^n - 1} \right]. \quad (47, \text{ p. } 13)$$

In a life-cycle cost analysis of a passive solar system, either the present-value or the annual-cost model will yield results that can be used to determine the least-cost alternative. The present-value model forecasts all costs over the period of the analysis and then discounts them to an equivalent single cost today; the annual-cost model forecasts all costs over the period of the analysis and then divides them into uniform annual costs by discounting. Because several alternative measures of a discount rate can be applied to costs, it may be useful to evaluate alternatives with several discount rates, to check the sensitivity of the analysis to these rates. Selecting a reasonable range of rates and conducting an analysis with both the low-range rate and the high-range rate provides a thorough sensitivity check (71, p. 4).

Procedure for the Owner-Occupied Analysis

Life-Cycle Cost Analysis

Given the financial parameters chosen for the analysis, present values are calculated to determine the life-cycle costs of the passive solar system. A present-value function is used to determine the present

worth of an annual expenditure that escalates at a fixed rate each year and is then discounted over a period of years (61, p. 11). As per the description by Kirschner et al. (35, p. 12), the four present-worth factors relevant to the analysis are those concerning the downpayment and mortgage payments (PWF1), mortgage interest deductions (PWF2), resale profit (PWF3), and the sum of operation, maintenance, and property expenses (PWF4). The present-worth factors are summed as

$$\Sigma PWF = (PWF1 - PWF2 - PWF3 + PWF4). \quad (IV-15)$$

The present value of the incremental solar system cost is determined by multiplying this summation by the system's cost. A capital recovery factor then is used to convert the total present value into annualized dollars.

The four present-worth factors are calculated as

$$PWF1 = DPR + [(1 - DPR) \times CRF1N/CRF2N], \quad (IV-16)$$

$$PWF2 = (1 - DPR) \times FSLTXR \times (CRF1N/CRF2N + \{(R + AIR) - CRF1N\} \times DSPTIR}), \quad (IV-17)$$

$$PWF3 = PWFPTR \times \{FWFPTD \times RESR - [(1 - DPR) \times RBTIPT]\}, \quad (IV-18)$$

$$PWF4 = [DSPTDR \times PTXR \times (1 - FSLTXR)] + [(DSPTGR \times OPR)], \quad (IV-19)$$

where DPR = downpayment as a proportion of total system cost,
 CRF1N = nominal capital recovery factor for period of analysis,
 CRF2N = nominal capital recovery factor for system life,

FSLTXR = Federal, state, and local tax bracket,

R = interest rate,

AIR = annual inflation rate,

DSPTIR = differential series present-worth factor applied to mortgage interest deductions,²

PWFPTR = present-worth factor applied to resale value and remaining loan balance,

FWFPTD = future-worth factor applied to resale value rate,

RESR = resale rate applied to solar system at the end of the period of analysis,

RBTIPT = remaining loan balance factor,

DSPTDR = differential series present-worth factor applied to property value,

PTXR = property tax rate,

DSPTGR = differential series present-worth factor applied to property tax and operation, maintenance, and insurance rates, and

OPR = recurring operation and maintenance costs of the design.
(OPR is expressed as a fixed proportion of total system cost.) (35, p. 31)

Simple Payback Time Analysis

A simple payback is calculated within a subroutine of EASE. The dollar value of the displaced conventional fuel is summed one year at a time until the value of the fuel savings exceeds the total system cost. The resulting count of years represents the time it takes for system savings to exceed system costs (35, p. 49).

²The differential series represents a method of translating a sequence of varying payments into a constant value and equating them to present values.

Procedure for the Renter-Occupied Analysis

Discussing investment decision criteria in the rental housing market, Levine and Raab (38, pp. 21-28) list three types of profit that are used as measures of economic viability: a positive cash flow that provides operating revenues to the owners, tax effects that reduce overall income tax liability, and appreciation in property value that results in capital gains at the time of sale. An addition to this list could be the developer's after-tax rate of return following a project's syndication to outside investors. These items are analyzed in this study by applying information on energy savings generated by EASE to their calculations. As in the owner-occupied section, the three buildings compared are the basic structure and the Trombe wall and direct-gain solar applications.

Developer's Rate of Return

The production of a multifamily rental project originates with the activities of a developer or a builder-developer team. The initial stage of the development process involves market surveys; site selection; negotiations with local, state, and Federal agencies; and preliminary discussions with architects. These activities are undertaken at some degree of risk in anticipation of a profit, which can be calculated as an after-tax rate of return on the investment in development and construction costs. Based on an approach detailed by the Mid-American Solar Energy Complex (50, p. 6-3), the developer's investment--the cost of constructing each of the three buildings in each of the three cities--is analyzed by examining this after-tax rate of return.

Tax Benefits and Cash Flow

Twenty-year projections of each building's income and cash flow were calculated under two sets of assumptions: (1) debt service based on a 0.70 loan-to-value ratio, 30-year term, 14-percent interest and 0.005 mortgage insurance premium; and (2) debt service based on a 0.90 loan-to-value ratio, 30-year term, 9.5-percent interest and 0.005 mortgage insurance premium. Both sets used New York's 15-year property tax exemption of value attributable to a solar system's incremental cost and the double-declining-balance method for calculating depreciation.

Capital Gains

An increase in a building's value from the time it is constructed to the time it is sold will result in a profit, or capital gain, at the time of sale. One method of determining value for an apartment building is to divide the project's annual income by a capitalization rate. This rate is usually equal to the current rate of interest with a premium added for risk. The capitalization rate also can be subjectively determined and will be relatively low if a particular rental investment is considered safe, so that a building's value will be high. If a rental property investment is considered risky, the capitalization rate will be high and, consequently, the building's value will be low (38, p. 26).

At this time, empirical data regarding the effect of a passive solar investment on capital gains in a rental project do not exist. It is not yet clear how such an investment will affect an apartment building's resale value. If value is determined by dividing income by a capitalization rate, certain assumptions must be made regarding both income and the capitalization rate. For example, if rental income is calculated by

adding the value of solar energy savings to the rents that would be charged for similar apartments of conventional construction, a basic assumption regarding tenant behavior is being made. That is, tenants are indifferent to paying higher rents for passive solar apartments if those higher rents are exactly offset by energy savings. This assumption may be conservative, if factors other than energy savings contribute to the decision to rent a solar unit, so that capital gains will be understated. On the other hand, if tenants are skeptical about potential savings in energy expenditures possible through solar energy, they may be unwilling to pay the higher rents; consequently, capital gains will be overstated.

The uncertainty that exists in this area, then, makes it particularly difficult to ascertain the level of risk associated with solar investment in rental housing and to determine the effect of such an investment on a project's capital gain. This subject presents an interesting area for further research; further discussion of it in this thesis would be of a highly speculative nature.

V. ANALYSIS OF THE DATA

Owner-Occupied Analysis

Life-Cycle Cost Analysis

Net present value, as used in this analysis, represents the difference in life-cycle costs between the solar heating system and its conventional alternative. The calculation of the solar investment's net present value against each conventional alternative is based on two cases: (1) the unit with the conventional heating system only, and (2) the unit with the conventional system and the passive solar system. In this way, the initial cost of the conventional system is not considered in the analysis. The factor that is important is the coefficient of performance, which is representative of the cost of one unit of fuel and how much of that unit is used as heat. The efficiency of a heat pump is such that, relative to other conventional systems, little fuel (in this case, electricity) is required for delivered heat, so the annual fuel cost is small relative to other systems. But heat pumps have high initial costs; so high, in fact, that it is unlikely that a developer would consider their use in a multi-family project. The effective cancellation of these costs in the analysis, however, and the resulting comparison with the solar investment make a unit with a heat pump appear to be economically preferable to one with a heat pump and a passive solar system. The passive solar system's net present values are positive in the gas, oil, and electrical resistance comparisons because of the high annual costs of energy for those systems.

Results of the net present value equations for the base case in life-cycle cost comparisons with natural gas, oil, electrical resistance, and

heat pump systems are presented in Table 5.1 and graphed in Figs. 5.1 and 5.2. Table 5.1 illustrates that, for each city, the building's units fall into two groups: (1) the first floor units (1,2,3), and (2) the units of the upper floors (4 through 9). Heat-loss factors were higher for the units on the first floor because these were the only units for which conductive losses through the concrete slab were calculated (see Appendix A). These units, therefore, had higher annual heating loads; consequently, the values of the energy savings computed from the solar savings fractions were higher. This pattern was consistent throughout the analysis and hereinafter, the first floor units will be referred to as Unit Group 1 and the units on the upper floors as Unit Group 2.

It can be observed readily from Table 5.1 that in all the Trombe wall comparisons, except for the heat pump comparison, the passive solar investment has a positive net present value. The direct-gain comparisons show mostly negative net present values for the solar investment. Two factors can be isolated for this effect: (1) The investment required for the Trombe wall, \$21 per square foot, was less than that required for the direct-gain system, \$34 per square foot (see Appendix A); (2) The solar savings fractions resulting from the Trombe wall system were higher than corresponding values for the direct-gain system.¹ Note that, except for

¹Regarding the magnitude of this cost differential, personnel in the Solar Energy Group of the Los Alamos Lab suggested that the interior mass of the direct-gain system may have been oversized in terms of volume necessary for performance modeling. Accordingly, an alternative direct-gain system for the basic structure, designed by TEA with less interior mass and a cost of \$25 per square foot, was analyzed using the base case parameters only. As could be expected, the resulting net present values for this less expensive system improved in all cases and were positive in the gas, oil, and electrical resistance comparisons. Because of time constraints, this less expensive system was not analyzed with any of the base case variations.

Fig. 5.1. Base case, unit group 1: net present value.

Fig. 5.2. Base case, unit group 2: net present value.

the heat pump comparisons, the absolute values of these negative numbers are small. Changes in one of the sets of the financial parameters used, the fuel cost escalation rates, could substantially affect these values. As noted in Chapter IV, these rates are based on a midrange trend of price escalation. This trend assumes uniform annual rates of increase from 1978 to 1995. Recent changes made in oil and natural gas deregulation schedules are likely to cause cost increases at rates that are higher and less uniform than this scenario predicts. Results of this analysis, then, should be reviewed with this point in mind.

Figure 5.1 also depicts the base case net present values for the direct-gain comparisons. Again, in the heat pump comparison the solar system has the lowest values. Small negative values also can be attributed to the solar system in both the gas comparisons and electrical resistance comparisons of Buffalo and Syracuse. In the gas comparison, the initial cost of fuel (cost of fuel in the first year of the analysis) is higher in Rochester than in either Buffalo or Syracuse. The same is true in the electrical resistance comparison. These differences are substantial enough to cause the effects shown.

Figure 5.2 examines Unit Group 2 of the Trombe wall and direct-gain buildings. Net present values for the solar investments of these units are not as high as the values for Unit Group 1. The lower annual heating loads of these units result in lower values of absolute savings.

Variations to the base case were described in Chapter IV. The effects of these variations on the net present value calculations are presented graphically in Figs. 5.3-5.11. In addition, the general direction of these changes is summarized in Table 5.2. For the purposes of this thesis, changes are observed for Unit Group 1.

TABLE 5.1

BASE CASE, NET PRESENT VALUE (DIFFERENCES IN LIFE-CYCLE COSTS BETWEEN THE SOLAR
AND CONVENTIONAL HEATING SYSTEMS)

System Type	Unit #	Gas			Oil			Electrical Resistance			Heat Pump		
		BUF	ROCH	SYR	BUF	ROCH	SYR	BUF	ROCH	SYR	BUF	ROCH	SYR
Trombe Wall	1,3	710	1224	858	1067	996	1023	763	1256	722	-350	-195	-386
	2	709	1224	857	1065	995	1022	762	1255	722	-351	-195	-386
	4,6	523	928	615	844	727	760	571	955	496	-429	-318	-478
	5	522	922	611	842	722	756	570	950	492	-430	-320	-479
	7,9	524	932	619	845	731	764	572	950	499	-429	-316	-476
	8	523	927	615	843	726	760	571	955	495	-429	-318	-478
Direct Gain	1,3	-92	319	-3	245	105	151	-41	349	-129	-1091	-1010	-1161
	2	-93	318	-4	243	103	149	-42	347	-130	-1092	-1011	-1161
	4,6	-344	-51	-297	-57	-230	-168	-301	-25	-404	-1198	-1163	-1273
	5	-347	-57	-301	-60	-235	-172	-304	-32	-408	-1199	-1165	-1274
	7,9	-342	-47	-293	-54	-226	-164	-299	-22	-400	-1197	-1161	-1271
	8	-344	-52	-298	-57	-231	-168	-301	-27	-404	-1198	-1163	-1273

BUF = Buffalo
ROCH = Rochester
SYR = Syracuse

Fig. 5.3. 7-year owner: net present value.

Fig. 5.4. 15-year owner: net present value.

Fig. 5.5. 7.5-percent real discount rate: net present value.

Fig. 5.6. 11-percent annual inflation rate: net present value.

Fig. 5.7. 20-percent marginal tax bracket: net present value.

Fig. 5.8. 40-percent marginal tax bracket: net present value.

Fig. 5.9. 1.5-percent real mortgage interest rate: net present value.

Fig. 5.10. 100-percent resale rate: net present value.

Fig. 5.11. 12-percent state income tax credit: net present value.

TABLE 5.2

GENERAL DIRECTION OF CHANGES IN NET PRESENT VALUES CAUSED BY
VARIATIONS TO THE BASE CASE PARAMETERS^a

<u>Variation</u>	<u>Trombe Wall</u>	<u>Direct Gain</u>
(1) 7-Year Analysis Period	Positive ^b	Positive
-----	-----	-----
(2) 15-Year Analysis Period	Positive ^b	Positive
-----	-----	-----
(3) 7.5-Percent Real Discount Rate	Negative	Negative
-----	-----	-----
(4) 11-Percent Annual Inflation Rate	Positive	Positive
-----	-----	-----
(5) 20-Percent Marginal Tax Bracket	Negative	Negative
-----	-----	-----
(6) 40-Percent Marginal Tax Bracket	Positive	Positive
-----	-----	-----
(7) 1.5-Percent Real Mortgage Interest Rate	Positive	Positive
-----	-----	-----
(8) 100-Percent Resale Rate	Negative	Negative
-----	-----	-----
(9) 25-Percent Downpayment	No Change	No Change
-----	-----	-----
(10) 12-Percent State Income Tax Credit	Positive	Positive

^aThe Base Case Parameters: (1) 30-Year Period of Analysis, (2) 20-Percent Downpayment, (3) 8-Percent Annual Inflation Rate, (4) 3.5-Percent Real Discount Rate, (5) 7.5-Percent Real Mortgage Interest Rate, (6) 150-Percent Resale Rate, (7) Local Property Tax Rates, (8) 30-Percent Marginal Tax Bracket.

^bSome negative changes were noted as a result of city-specific differences in conventional fuel prices.

(1) 7-Year Period of Analysis. Results of this change are illustrated in Fig. 5.3. This graph shows that for the Trombe wall, a change in the ownership period of this magnitude resulted in decreasing the net present values for all cases in the gas and oil comparisons; in the electrical resistance comparisons, no change for Buffalo or Syracuse, and a negative change of 25 percent for Rochester; and all positive changes in the heat pump comparisons. The direct-gain investment's net present value increased in all cases.

In every comparison, for both solar systems, the net present value was positive with this decrease in the ownership period. The improvements in the direct-gain system's values resulted from a change in the capital recovery factor, CRF2N. Lowering the period of analysis increased the value of CRF2N in Eqs. (IV-16) and (IV-17). In effect, the higher mortgage payments of this more expensive system were truncated because of the shorter timeframe. Also affected were the present values of the conventional system operating costs, which decreased, thus improving in performance comparisons with the solar systems. These effects varied from city to city because of differences in city-specific fuel prices.

(2) 15-Year Period of Analysis. Figure 5.4 illustrates the results of changing the period of analysis by a lesser degree than that of the preceding case. As in this prior example, negative impacts on the Trombe wall investment were seen in each of the three cities for both the gas and oil comparisons. Very slight improvements were seen in the electrical resistance comparisons of Buffalo and Syracuse; a decrease was noted in the Rochester case. There were increases in the net present values in the

heat pump comparisons. In the direct-gain comparisons, positive changes were noted in all cases for each heating system compared. In all cases, for both systems, net present values were positive.

As in the previous base case variation, the effects noted were a result of system costs that were spread over a longer period than the period of analysis. In this case, 15 more years of mortgage payments were ignored, which generally resulted in higher net present values.

In the case of Rochester, the higher cost per unit of electricity resulted in a lower benefit/cost ratio over the shorter analysis, in which the savings attributable to mortgage interest and offset fuel were greatly decreased.

(3) 7.5-Percent Real Discount Rate. A change in this factor affected the calculation of future benefit streams (see Fig. 5.5). All comparisons were affected negatively by this four-point increase. The discount rate was used in the calculation of all present-worth factors as in the computation of the following elements from Eqs. (IV-16) through (IV-19).

$$CRF2N = \frac{DR + AIR}{1 - \left(\frac{1}{1 + AIR + DR} \right)^N} \quad (V-1)$$

(35, p. 30)

One can see that an increase in DR will result in an increased value of CRF2N, which, in turn, decreases the value of PWF1 in Eq. (IV-16). This same capital recovery factor is affected in the calculation of PWF2 in Eq. (IV-17), as is DSPTIR, which is the present-worth factor applied to mortgage interest deductions.

$$DSPTIR = \left\{ 1 + AIR + R \times \left[1 - \frac{(1 + AIR + R)}{(1 + AIR + DR)} \right] \right\}^N (DR - R). \quad (V-2)$$

(35, p. 29)

When DR is increased in this equation, the present value of the mortgage interest deductions is decreased.

The present-worth factors applied to the remaining loan balance (PWFPTR), property value (DSPTDR), and operating costs (DSPTGR) are similarly affected in Eqs. (IV-18) and (IV-19).

The rate of decrease in net present values is not constant across all cases because of effects attributable to different fuel rates and property tax rates in each of the cities.

(4) 11-Percent Annual Inflation Rate. The 3-point increase in this rate caused small increases in the net present values in all cases, as seen in Fig. 5.6. The annual inflation rate affects the present-worth and capital-recovery factors and, in turn, the values of cost and benefit streams. Although all changes were positive, they varied from system to system within a small range. These effects were caused by changes in the fuel cost growth rate, which consists of two additive components: a real rate and the annual rate of inflation. A summation of the two produces the nominal rate used in the analysis. This procedure is responsible for the differences observed by heating system comparison because adding the different inflation rate to each real cost growth rate, which is different for each fuel, causes varying percentage changes. Overall, each case showed positive changes because of the positive change in the inflation rate from the base case. If this parameter were changed to a value of less than 8 percent, negative changes would be observed.

(5) 20- and 40-Percent Marginal Tax Brackets. Figures 5.7 and 5.8 depict the value of the solar investment when the marginal tax brackets are changed by a 10-percent decrease or increase, respectively. Results were uniform in all cases. Decreasing this parameter to 20 percent caused decreases in the net present values, which remained positive in gas, oil, and electrical resistance comparisons for the Trombe wall. Increasing it to 40 percent caused increases in the values, which were seen as positive in both the Trombe wall and direct-gain gas, oil, and electrical resistance comparisons.

The significance of including Federal and state marginal tax brackets in the owner-occupied analysis is that the rates at which income is taxed affects the value of taxable deductions. Mortgage interest and property taxes are deductible items over the zero bracket amount in this analysis; these deductions increase income as follows.

$$\Sigma \text{ Deductions} \times (1 - \text{FSLTXR}) = \text{Reduction in Tax Payments.} \quad (\text{V-3})$$

Because this parameter reflects the value of each dollar of additional income, it is evident that an increase in a solar system owner's marginal tax bracket leads to an increase in the net present value of that system, and vice versa.

(6) 1.5-Percent Real Mortgage Interest Rate. If expressed nominally, this rate would be 9.5 percent. It is a decrease of six points from the base case rate and increased, in all cases, the net present values, as illustrated in Fig. 5.9. A decrease in this factor lowered both the annual interest and principal payments, so that whereas there was a

reduction in total costs, there was also a reduction in the benefits. Net present values did improve, however, and were positive for all cases in both systems, except in the heat pump comparisons.

Equations (IV-16) and (IV-17) calculated the present-worth factors of the downpayment, principal, and interest payments. In these calculations, the interest rate affects the capital recovery factor for the analysis period as follows.

$$CRF1N = \left(\frac{R + AIR}{1 - \frac{1}{1 + AIR + R}} \right)^N \cdot \quad (V-4)$$

(35, p. 30)

Decreasing the interest rate increases the value of CRF1N, which, in turn, increases PWF1. This increased value of CRF1N is also a factor in the calculation of PWF2 [see Eq. (IV-17)], as is the present-worth factor that is applied to mortgage interest deductions [see Eq. (V-2)]. A decrease in the interest rate, then, increases the value of PWF1 and PWF2 but not to the same degree, resulting in an increased total present value.

(7) 100-Percent Resale Rate. Figure 5.10 shows that a 50-percent decrease in this parameter resulted in a decrease in the solar investment's net present value for all cases. The only positive net present values for the solar systems with this change were noted in the gas, oil, and electrical resistance comparisons of the Trombe wall system. The resale rate enters the calculation of only the present worth factor for resale profit, PWF3 see Eq. (IV-18) . The change in net present value is not equal to the change in the resale rate because the latter is subject to the future-worth factor of the resale profit, FWFPTD.

$$\text{FWFPTD} = (1 + \text{AIR})^N . \quad (\text{V-5})$$

One can see that a decrease in the resale rate decreases the present worth of the resale profit. Intuitively, one realizes that a decrease in the resale rate results in fewer benefits, whereas none of the costs change.

(8) 25-Percent Downpayment. An increase of 5 percentage points in this parameter had little effect on the present values of the solar investments. Very slight changes were noted and were not graphed. A larger change in this parameter would have better illustrated the effect of increasing or decreasing the downpayment rate.

(9) 12-Percent State Income Tax Credit. The state tax credit effectively works as a cash rebate based on the solar system's initial cost, which, consequently, increases the investment's net present value. EASE treats the rebate as a cash inflow item in year 1 of the analysis, so that the total benefits of the solar investment are increased without a corresponding increase in costs. The effect of this government incentive is illustrated in Fig. 5.11. An increase in the net present value of the solar investment can be seen in all cases.

Payback Time Analysis

Results of the simple payback calculations for the base case are presented in Table 5.3 and graphed in Figs. 5.12 and 5.13. Table 5.3 illustrates that, as in the life-cycle cost analysis, the building's units fall into two groups: (1) Unit Group 1, and (2) Unit Group 2.

In every case, as shown in Table 5.3, the payback time for the Trombe wall investment is shorter than that for the direct-gain system. The same factors that were isolated for differences in the net present values

TABLE 5.3

BASE CASE, PAYBACK TIME (IN YEARS)

System Type	Unit #	Gas			Oil			Electrical Resistance			Heat Pump		
		BUF	ROCH	SYR	BUF	ROCH	SYR	BUF	ROCH	SYR	BUF	ROCH	SYR
Trombe Wall	1,3	15	13	14	12	12	12	12	10	12	21	18	21
	2	15	13	14	12	12	12	12	10	12	21	18	21
	4,6	16	14	15	13	13	13	13	11	13	23	19	23
	5	16	14	15	13	13	13	13	11	13	23	19	23
	7,9	16	14	15	13	13	13	13	11	13	23	19	23
	8	16	14	15	13	13	13	13	11	13	23	19	23
Direct Gain	1,3	19	17	18	16	16	16	17	14	17	30	25	30
	2	19	17	18	16	16	16	17	14	17	30	25	30
	4,6	20	18	20	18	18	18	19	16	19	30	28	30
	5	20	18	20	18	18	18	19	16	19	30	28	30
	7,9	20	18	20	18	18	18	19	16	19	30	28	30
	8	20	18	20	18	18	18	19	16	19	30	28	30

BUF = Buffalo
 ROCH = Rochester
 SYR = Syracuse

Fig. 5.12. Base case, unit group 1: payback time.

Fig. 5.13. Base case, unit group 2: payback time.

can be cited here, but simply stated, it takes longer for the energy savings resulting from the more expensive solar system with lower solar savings fractions to equal the system's investment.

The effects of the changes in the base case parameters on payback times are illustrated in Figs. 5.14 and 5.15. Some variations to the base case parameters caused no changes in the payback times. These variations were not graphed. The effects of adding the 12-percent state tax credit are shown in Fig. 5.16. In addition, the general direction of these changes is summarized in Table 5.4.

New York State's Home Insulation and Energy Conservation Act mandates utility company financing of conventional energy conservation improvements if such improvements have a payback period of 7 years or less. Using this timeframe as a basis for comparison of what may be considered a reasonable payback time, one can see that most of the payback times calculated in this study are long. Whether condominium unit owners would accept these payback times is an issue that deserves further study but is beyond the scope of this thesis.

(1) Base Case. As expected from the life-cycle cost analysis, variations in payback times occurred from city to city and by heating system comparison. Generally, in both the direct-gain and Trombe wall comparisons, solar systems for Unit Group 2 had long payback times. This is due to the lower annual heating loads and, consequently, annual fuel savings with lower values that take longer to equal system investment. All solar comparisons with the heat pump system had the longest payback times between 20 and 30 years. Once again, note that the comparison in this case was between a passive solar unit with a heat pump and a conventional unit with a heat pump. No consideration was given to the heat

Fig. 5.14. 7-year owner: payback time.

Fig. 5.15. 11-percent annual inflation rate: payback time.

Fig. 5.16. 12-percent state income tax credit: payback time.

TABLE 5.4

GENERAL DIRECTION OF CHANGES IN PAYBACK TIME CAUSED BY
VARIATIONS TO THE BASE CASE PARAMETERS^a

<u>Variation</u>	<u>Trombe Wall</u>	<u>Direct Gain</u>
(1) 7-Year Analysis Period	Lengthen	Lengthen

(2) 15-Year Analysis Period	No Change	No Change

(3) 7.5-Percent Real Discount Rate	No Change	No Change

(4) 11-Percent Annual Inflation Rate	Shorten	Shorten

(5) 20-Percent Marginal Tax Bracket	No Change	No Change

(6) 40-Percent Marginal Tax Bracket	No Change	No Change

(7) 1.5-Percent Real Mortgage Interest Rate	No Change	No Change

(8) 100-Percent Resale Rate	No Change	No Change

(9) 25-Percent Downpayment	No Change	No Change

(10) 12-Percent State Income Tax Credit	Shorten	Shorten

^aThe Base Case Parameters: (1) 30-Year Period of Analysis, (2) 20-Percent Downpayment, (3) 8-Percent Annual Inflation Rate, (4) 3.5-Percent Real Discount Rate, (5) 7.5-Percent Real Mortgage Interest Rate, (6) 150-Percent Resale Rate, (7) Local Property Tax Rates, (8) 30-Percent Marginal Tax Bracket.

pump's high initial cost. Its efficient operation, however, results in small annual expenditures for fuel, so that the time necessary to recover the solar investment is extended.

(2) 7-Year Owner. Figure 5.14 shows the changes resulting from a shorter period of analysis. Decreasing this time from 30 to 7 years caused both positive and negative changes in the Trombe wall comparisons. In the gas comparison, slight increases in the payback time in Buffalo and Syracuse resulted, with no change for Rochester. No changes were noted in the oil and electrical resistance comparisons; increases resulted in each city in the heat pump comparison. The direct-gain comparisons show either no change or increases in payback times.

In the life-cycle cost analysis, the period of analysis enters the capital recovery factor as an exponent, so, in most cases, lowering that exponent results in lower system resale profits and lower annual fuel savings, resulting in longer payback times. But this change in the period of analysis did not affect the payback times in the oil and electrical resistance comparisons with the Trombe wall, though it did affect the net present values in those cases. In these cases, the cost of fuel is high enough to result in high annual fuel savings that are not offset by the change.

The direct-gain comparisons showed longer payback times than the base case in all cases except Buffalo and Syracuse in the heat pump comparison, where no change was noted. In this instance the annual fuel savings were so low in contrast with other fuels, that the effect of a change in the analysis period was slight.

(3) 15-Year Owner. Changes in the payback time were small for both the Trombe wall and direct-gain comparisons when the period of analysis was changed to 15 years. As in the preceding discussion, the present values of benefits and costs were affected, but not to the same degree so that the payback time was affected little with a change in the analysis period by a lesser degree.

(4) 7.5-Percent Real Discount Rate. Even though the life-cycle cost analysis showed negative changes in net present value when the discount rate was increased by 4 percentage points, no change was effected in the payback times of any of the cases. Because everything in the net present value calculations was affected by the same rate, changes were relative, not absolute. So the payback times remained unchanged.

(5) 11-Percent Annual Inflation Rate. As a result of this change, very small (1-2 year) negative changes can be seen in Fig. 5.15 for both the Trombe wall and direct-gain comparisons with gas, oil and electrical resistance. Small changes (3-5 years) also were seen in the heat pump comparisons. In all cases, the time period necessary for system payback was shortened because, as in the life-cycle cost analysis, the addition of a higher annual inflation rate to the fuel cost growth rate increased the value of energy savings and resulted in shorter payback times.

(6) 20- and 40-Percent Marginal Tax Brackets. Changing this parameter relating to the solar system owner's economic condition had no effect on payback time. As described in the life-cycle cost analysis, this parameter reflects the value of income tax deductions. The EASE analysis treats housing-related tax deductions as after-tax cost savings. The higher the tax bracket, the higher is the value of these savings. But a change in tax brackets of 10 percent in either direction did not affect

tax savings enough to change the payback time, as it is calculated by the code. It is likely that payback was affected by several months, but because EASE deals with yearly increments in computing this measure, no changes were indicated. If marginal tax brackets that were substantially different from the base case parameter had been selected, changes would have been evident in the payback periods.

(7) 1.5-Percent Real Mortgage Interest Rate. No change occurred in the payback time when the interest rate was decreased by 6 points. The increased net present values that were described in this section of the life-cycle cost analysis were not enough to affect the payback measures. Total benefits as well as total costs decreased with this change, but only regarding mortgage-related items. Fuel savings remained the same and, in this example, the decreased system costs were offset by the decreased benefits to an extent that did not affect the time period required for savings to equal costs.

(8) 100-Percent Resale Rate. No change was noted from the base case with a variation in this parameter. The resale rate affects a cash inflow item in the final year of the analysis, so it is not a factor pertinent to the calculation of annual benefits used in the simple payback procedure and, therefore, causes no change.

(9) 25-Percent Down Payment. As in the life-cycle cost example, this change from the base case downpayment rate had no effect on the outcome of the analysis. A larger downpayment rate would have resulted in higher first costs and lower mortgage costs as well as lower deductions, so that solar savings may not have offset costs as in the base case.

(10) 12-Percent State Tax Credit. Figure 5.16 shows that this government incentive had a more noticeable effect on the payback times than did any of the previously discussed changes to the base case parameters. Because this credit effectively works as a cash rebate to the solar system owner at the end of year 1, it increases the value of the solar benefits without any corresponding increase in system costs. The value of the mortgage interest deductions is unaffected even though system cost is effectively decreased. Of particular interest are the payback times of between 6 and 9 years for all cities in the oil and electrical resistance comparisons. The higher prices of these fuels result in savings that are higher than those attributable to the gas or heat pump systems. The addition of the tax credit as an additional benefit in a comparison with these higher-priced fuels resulted in the shortest payback periods of the analysis.

Renter-Occupied Analysis

Developer's Rate of Return

Following is an examination of typical development costs for a rental project and a comparison of these costs for the basic structure and the two solar applications. Also calculated for each case is the developer's after-tax rate of return.

If the developer were to take out a 1-year loan at 20-percent interest for 70 percent of the project's development costs (50, p. 6-3), excluding land costs, investment by the lending institution and the developer would be as follows in Tables 5.5-5.7.

TABLE 5.5

TOTAL DEVELOPER INVESTMENT,
BASIC STRUCTURE

	<u>Buffalo</u>	<u>Rochester</u>	<u>Syracuse</u>
Project Costs	\$322,806	\$314,241	\$314,209
Less: Borrowed Funds	225,964	219,969	219,946
Developer's Equity Requirement	<u>\$ 96,842</u>	<u>\$ 94,272</u>	<u>\$ 94,263</u>
Plus: Cost of Financing (@ 20% interest on an average of half the funds owed)	<u>22,596</u>	<u>21,977</u>	<u>21,995</u>
Total Developer's Investment	\$119,438	\$116,269	\$116,258

TABLE 5.6

TOTAL DEVELOPER INVESTMENT,
TROMBE WALL

	<u>Buffalo</u>	<u>Rochester</u>	<u>Syracuse</u>
Project Costs	\$336,960	\$328,019	\$327,806
Less: Borrowed Funds	235,872	229,613	229,464
Developer's Equity Requirement	<u>\$101,088</u>	<u>\$ 98,406</u>	<u>\$ 98,342</u>
Plus: Cost of Financing (@ 20% interest on an average of half the funds owed)	<u>23,587</u>	<u>22,961</u>	<u>22,946</u>
Total Developer's Investment	\$124,675	\$121,367	\$121,288

TABLE 5.7

TOTAL DEVELOPER INVESTMENT,
DIRECT GAIN

	<u>Buffalo</u>	<u>Rochester</u>	<u>Syracuse</u>
Project Costs	\$345,737	\$336,685	\$336,666
Less: Borrowed Funds	242,016	235,680	235,666
Developer's Equity Requirement	<u>\$103,721</u>	<u>\$101,005</u>	<u>\$101,000</u>
Plus: Cost of Financing (@ 20% interest on an average of half the funds owed)	<u>24,202</u>	<u>23,568</u>	<u>23,567</u>
Total Developer's Investment	\$127,923	\$124,573	\$124,567

Assuming a building sale price of one dollar over its cost (4, p. 46), a syndication value of 95 percent of the mortgage and a 40-percent marginal tax bracket for the developer, the calculation of the after-tax rate of return is as presented in Table 5.8. One can see that unless specific effects are applied to the solar applications, there is no difference in the rate of return calculated for the passive solar structures and the basic structure. The developer's after-tax rate of return also is dependent on projections of rental income streams. If it could be determined that passive solar apartments could indeed command higher rents than conventional apartments, then developers would be able to recoup their higher investments through higher sale prices. Accordingly, after-tax rates of return would increase. On the other hand, if investors are skeptical of the potential for higher rental income streams in passive solar apartments and are not willing to pay higher sale prices for such apartments, developers could face rates of return that are lower than those realized from conventional buildings. They would be investing more for passive solar features and not recouping this increased investment. This represents yet another area for further research because empirical data are necessary to avoid highly speculative projections.

It is possible to determine the effect of an income tax credit for a passive solar investment on a developer's rate of return. As an illustration of this, Table 5.9 lists the developer's rate of return when New York's proposed 12-percent income tax credit is treated as an addition to the gross profit before taxes. This change increased the after-tax rate of return by one percentage point.

TABLE 5.8

COMPARISON OF DEVELOPER'S RATE OF RETURN

	Basic Structure			Trombe Wall			Direct Gain		
	BUF	ROCH	SYR	BUF	ROCH	SYR	BUF	ROCH	SYR
Sale Price	322,807	314,242	314,210	336,961	328,020	327,807	345,738	336,686	336,667
Less Borrowed Funds	225,964	219,969	219,946	235,872	229,613	229,464	242,016	235,680	235,666
Less Interest	22,596	21,997	21,995	23,587	22,961	22,964	24,202	23,568	23,567
Plus Syndication	214,666	208,971	208,949	224,078	218,132	217,991	229,915	223,896	223,883
Gross Profit Before Taxes	288,913	281,247	281,218	301,580	293,578	293,388	309,438	301,334	301,317
Less Income Tax	115,565	112,499	112,487	120,632	117,431	117,355	123,775	120,534	120,527
Gross Profit After Taxes	173,348	168,748	168,731	180,948	176,147	176,033	185,663	180,800	180,790
Rate of Return	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45

TABLE 5.9
DEVELOPER'S RATE OF RETURN WITH TAX CREDIT

<u>System</u>	<u>City</u>	<u>Rate of Return</u>
Trombe Wall	Buffalo	0.46
	Rochester	0.46
	Syracuse	0.46
Direct Gain	Buffalo	0.46
	Rochester	0.46
	Syracuse	0.46

Tax Benefits and Cash Flow

Project income streams as well as cash distributions were projected in 20-year analyses for the basic structure and the two passive solar buildings in each city under the two sets of assumptions described in Chapter IV. Presented in Tables 5.10 and 5.11 are illustrations of the format used. Depicted are the projections for the basic structure in Buffalo, financed at 14-percent interest and 0.005 mortgage insurance premium for 30 years with a 0.70 loan-to-value ratio. Figures 5.17 through 5.19 illustrate the projections for the Rochester cases.² Procedures used to calculate these figures are presented in Appendix B.

In all cases, the 0.70 loan-to-value ratio at 14-percent interest produced lower cash flows and greater losses in the early years of operation and an overall larger gap between cash flow and project

²The projections for the three cities did not differ substantially from each other. For this reason, the projections are illustrated for one city only. The graphic projections for Buffalo and Syracuse are available from the author on request.

TABLE 5.10
BASIC STRUCTURE, INCOME AND EXPENSE (BUFFALO, 0.70
LOAN-TO-VALUE RATIO)

<u>Year</u>	<u>Project Income</u>	<u>Operating Expenses</u>	<u>Interest and M.I.P.^a</u>	<u>Depreciation</u>	<u>Total Deductions</u>	<u>Loss (Income)</u>	<u>95-Percent Allocations</u>
1	67,716	24,378	32,765	16,140	73,283	5,567	5,289
2	"	"	32,673	15,333	72,384	4,668	4,435
3	"	"	32,568	14,567	71,618	3,902	3,707
4	"	"	32,449	13,838	70,665	2,949	2,802
5	"	"	32,313	13,146	69,837	2,121	2,015
6	"	"	32,158	12,489	69,025	1,309	1,244
7	"	"	31,981	11,865	68,224	508	483
8	"	"	31,779	11,271	67,428	(288)	(274)
9	"	"	31,549	10,708	66,635	(1,081)	(1,027)
10	"	"	31,288	10,172	65,838	(1,878)	(1,784)
11	"	"	30,989	9,664	65,031	(2,685)	(2,551)
12	"	"	30,648	9,181	64,207	(3,509)	(3,334)
13	"	"	30,260	8,722	63,360	(4,356)	(4,138)
14	"	"	29,818	8,285	62,481	(5,235)	(4,973)
15	"	"	29,313	7,871	61,562	(6,154)	(5,846)
16	"	"	28,738	7,478	60,594	(7,122)	(6,766)
17	"	"	28,083	7,104	59,565	(8,151)	(7,743)
18	"	"	27,335	6,749	58,462	(9,254)	(8,791)
19	"	"	26,484	6,411	57,273	(10,443)	(9,921)
20	"	"	25,512	6,091	55,981	(11,735)	(11,148)

^aM.I.P. = mortgage insurance premium.

TABLE 5.11
BASIC STRUCTURE, CASH FLOW (BUFFALO, 0.07
LOAN-TO-VALUE RATIO)

<u>Year</u>	<u>Total Income</u>	<u>Operating Expenses</u>	<u>Interest and M.I.P.^a</u>	<u>Amortization</u>	<u>Total Applications</u>	<u>Cash Distributions</u>	<u>95-Percent Allocations</u>
1	67,716	24,378	32,765	633	57,776	9,940	9,443
2	"	"	32,673	722	57,773	9,943	9,446
3	"	"	32,568	823	57,769	9,947	9,450
4	"	"	32,449	938	57,765	9,951	9,453
5	"	"	32,313	1,070	57,761	9,955	9,457
6	"	"	32,158	1,219	57,755	9,961	9,463
7	"	"	31,981	1,390	57,749	9,967	9,469
8	"	"	31,779	1,585	57,742	9,974	9,475
9	"	"	31,549	1,807	57,734	9,982	9,483
10	"	"	31,288	2,060	57,726	9,990	9,491
11	"	"	30,989	2,348	57,715	10,001	9,501
12	"	"	30,648	2,677	57,703	10,013	9,512
13	"	"	30,260	3,051	57,689	10,077	9,526
14	"	"	29,818	3,479	57,675	10,041	9,539
15	"	"	29,313	3,966	57,657	10,059	9,556
16	"	"	28,738	4,521	57,637	10,079	9,575
17	"	"	28,083	5,154	57,615	10,101	9,596
18	"	"	27,335	5,875	57,588	10,128	9,627
19	"	"	26,484	6,698	57,560	10,156	9,648
20	"	"	25,512	7,636	57,256	10,190	9,680

^aM.I.P. = mortgage insurance premium.

Fig. 5.17. Cash distributions and income streams, basic structure.

Fig. 5.18. Cash distributions and income streams, Trombe wall building.

Fig. 5.19. Cash distributions and income streams, direct-gain building.

income. Responsible for this difference were the lower principal amounts deducted from cash flow and larger interest payments deducted from project income.

In the basic structure cases, the cash flow and income lines are smooth. This is not so with the passive solar buildings because of the 15-year exemption from the property tax of the increased value attributable to the solar system. Because property tax payments increase in the 16th year, changes can be seen in both income and cash distributions. Cash flows decrease slightly and the rate of increase in income changes. Income does not decrease as a result of the decreasing rate of payments to interest, which offsets the larger property taxes.

In each of the three cities, one can see that the Trombe wall investment widens the gap between cash distributions and project income in comparisons with the basic structure and the direct-gain investments. Reasons for these improvements include the following: in both cases involving the solar buildings, rent changes were calculated at the basic structure rate plus the dollar value of energy savings attributable to the passive solar systems in year 1 of the EASE analysis. In this way, tenants were assumed to be indifferent to the trade-off between higher rent payments and lower utility bills. (This is likely to be a conservative assumption if factors other than energy savings contribute to the attractiveness of a solar-heated apartment.) Project income increased as did interest and depreciation charges, so that the overall effect was a decrease in project income throughout the 20-year period and a decrease in cash distributions, but not to the same extent. With the Trombe wall investment, more income was sheltered from taxes.

If the assumption that rental income will be increased exactly by the amount of energy savings is indeed conservative, then tenants may be willing to pay rents that are higher than those projected in this study. If this is the case, cash distributions and project income would increase to the same extent, with no effect on the tax shelter benefits. The building's value would increase, however, so capital gains would likely increase. On the other hand, if the assumption used is not conservative; that is, if higher rents could not be realized, the effect would be to decrease project income and cash distributions, and to decrease the building's value. This would lead to lower capital gains.

Owner-Occupied Versus Renter-Occupied Analyses

In an analysis of a passive solar multiple-family dwelling, the tenure of the building's inhabitants is an important consideration. Because investment concerns in the owner-occupied market are different from those in the renter-occupied market, the analysis should proceed from two separate points that reflect the relevant concerns of each sector. Because of these differences, it would not be relevant to draw any comparisons between the two sections of this study other than to point out that in the cities selected for this thesis, the Trombe wall system at \$21 per square foot was shown to be a more economical investment than the \$34 per square foot direct-gain system. This was true in both the owner-occupied and renter-occupied buildings, not only because of the lower cost involved but also because of the higher solar savings fractions.

VI. SUMMARY AND CONCLUSIONS

This study assessed the economic implications of adapting elements of passive solar technology to a multiple-family dwelling in each of three upstate New York cities--Buffalo, Rochester, and Syracuse. Additions of Trombe wall and direct-gain systems to nine-unit dwellings were analyzed as investments in both the owner-occupied and renter-occupied markets. Net present values and payback times of solar investments in the owner-occupied category were calculated from life-cycle cost comparisons of conventional heating alternatives. In the renter-occupied analysis, effects on the developer's after-tax rate of return and the investors' tax benefits and cash distributions were observed through 20-year projections of income and cash flow.

The most interesting finding of this thesis is that even in three cloudy, cold cities of upstate New York an investment in a passive solar heating system can be cost-effective in a multiple-family dwelling. Many questions remain, however, and represent areas for further research. These include considerations of tenant acceptance of higher monthly rental payments in exchange for lower utility bills and the effects of a passive solar investment on an apartment building's capital gains.

Of the two solar systems studied in this thesis, the Trombe wall performed better than the direct-gain system through higher net present values and shorter payback times in the owner-occupied analysis. In the renter-occupied study, the Trombe wall building increased tax shelter benefits more than did the direct-gain building. In both sections of the analysis, the reasons for the Trombe wall's better performance were its lower initial cost and higher solar savings fractions.

Of the conventional heating system alternatives considered, the solar systems had the lowest net present values and longest payback times when compared with heat pumps. This analysis made no distinction among initial costs of any of the conventional systems because each comparison involved a unit with a conventional system only and a unit with that same conventional system and a solar system. The low annual fuel use of heat pumps resulted in low solar savings and, thus, low net present values and long payback times. It is likely that a comparison involving a solar/gas-heated unit and a heat-pump-heated unit would show lower life-cycle costs for the solar/gas comparison, so that the solar investment would have a higher net present value and a shorter payback time. In addition, the high initial costs of heat pumps make their use by developers unlikely in multifamily projects.

Analyses of this type are sensitive to financial parameters used. In the owner-occupied analysis, this was evident from the changes observed in the variations to the base case. Changing some parameters, such as the system owner's marginal tax bracket or the mortgage interest rate, affected the net present values by a uniform rate in all cases. The negative changes in net present values caused by an increase in the discount rate were not uniform in all cases; they varied by city and by the heating system compared. These cases illustrated effects of property taxes and conventional fuel prices that did not escalate at the same rate as the discounting factor. However, the changes that did occur to the net present values and payback times, in most cases, were not substantial. One notable exception to this was the addition to the base case parameters of New York's proposed income tax credit for solar systems, which substantially increased the passive solar investment's net present value.

Sensitivity of the analysis to chosen financial parameters also was demonstrated in the renter-occupied study. In this section of the analysis, the proposed 12-percent state tax credit also was seen to positively affect the solar investment by increasing the developer's rate of return.

What is the proper role of government in solar energy development? In the past, both the Federal and state governments have developed low-interest loan, loan guarantee, and grant programs for demonstrations of solar viability. These programs have been effective in reducing initial system costs for owners but have been criticized for their complexity. Levine and Raab (38, p. 27) reported that it is for this latter reason that rental housing owners have a strong preference for tax credits.

It is unfortunate that, given a tax credit's effectiveness for improving a solar system's economic feasibility, the Internal Revenue Service has excluded passive systems from the Federal credit. For this reason, the Federal tax credit was not used in the analysis. If it were applicable, its effect would be similar to that of the state credit. Federal tax credit could be an effective incentive for more widespread use.

One ineffective government incentive is the exemption from property taxes of the increased value of a building that is attributable to a solar system. Because property taxes are deductible from Federal income taxes, use of this exemption reduces the amount of property taxes paid and income tax deductions. From another perspective, use of this incentive reduces local government revenues while it increases payments to the Federal treasury.

Government involvement in the development of solar energy can be justified by the existence of market failures that intervention can overcome. The effect of risk on solar technology was discussed as an impediment to solar development from the perspectives of both producers and consumers. Through the provision of financial incentives, Federal and state governments can work effectively as educators, increasing the numbers of economically feasible solar energy systems and gradually changing the perceptions of builders and buyers that now act as barriers to widespread use of solar technology.

The high social costs of fossil fuel use also should be recognized. Fossil fuels have been subsidized heavily in the past; had these subsidies not existed, it is likely that the economic feasibility of solar energy would have surpassed that of oil, gas, and coal long ago. This same argument can be applied to nuclear technology, which has benefited from Federal subsidies since its inception. Nuclear energy is likely to continue receiving subsidies in the future, as the needs for waste storage and fission reactor decommissioning increase. In part, then, government subsidies for solar energy development should continue simply because other energy sources have received and are likely to continue receiving them. In fact, because these subsidies have not been evenly applied to all types of energy, market distortions now exist that have made solar energy appear to be more expensive than it actually is.

Regarding the fuel cost escalation rates, it was noted in Chapter V that the rates used in the EASE analysis are based on a Department of Energy midrange trend scenario that assumes uniform annual rates of increase in conventional fuel costs. Recent changes made in price deregulation schedules could render this scenario inaccurate. If this

proves to be the case, the net present values and the payback times in the owner-occupied analysis and, consequently, the assumptions underlying the renter-occupied analysis will be conservative. One must realize that this item is only one of many speculative parameters, and that results of the study should be reviewed with this in mind.

In the rental analysis, increases in the total tax shelter benefits were seen in the Trombe wall applications, with wider gaps between cash distributions and project income than either the basic structure or the direct-gain building. Whereas the Trombe wall building had higher mortgage-related costs and operating costs than the basic structure, the high solar savings fractions allowed for increases to the basic structure rents, which offset these costs in the calculation of cash distributions. Income, however, decreased because of higher depreciation deductions in addition to the higher mortgage and operating costs. Note that rents may have been calculated at lower values than could actually be received for passive solar apartments. The model used in this study assumed that tenants would accept rents that are higher than conventional units by the amount of their units' fuel savings. Effectively, this states that a tenant is concerned only with a passive solar unit's energy savings when other factors may influence the decision to rent such a unit. It may be that tenants are unwilling to make such a trade-off. Data were not available on this issue, which represents another area for further study.

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APPENDIX A

Fig. A.1. Basic structure, north elevation.

Fig. A.2. Basic structure, sectional view.

Fig. A.3. Basic structure, unit floor plan.

Fig. A.4. Basic structure, roof plan.

BUILDING COSTS

Basic Structure: \$117,561/3 units (92, p. 32)

Regional Cost Adjustment Factor = 0.88 (92, p. 35)

9-unit cost: $\$117,561 \times 3 \times 0.88 = \$310,361$

City-specific cost adjustments:

Buffalo: $\$310,361 \times 1.0401 = \$322,806$

Rochester: $\$310,361 \times 1.0125 = \$314,241$

Syracuse: $\$310,361 \times 1.0124 = \$314,209$

Incremental Solar Costs:

	<u>Unit Cost</u>	<u>Total Cost</u>
	<u>Trombe Wall</u>	
Buffalo	\$1,573	\$14,154
Rochester	1,531	13,778
Syracuse	1,531	13,778

	<u>Direct Gain</u>	
Buffalo	\$2,548	\$22,931
Rochester	2,494	22,444
Syracuse	2,495	22,457

Building Total Costs:

	<u>Trombe Wall</u>	<u>Direct Gain</u>
Buffalo	\$336,960	\$345,737
Rochester	328,019	336,685
Syracuse	327,806	336,666

HEAT-LOSS CALCULATIONS

Adjustment Factors:

Walls To correct for effect of framing members:
2 x 4, 16" on center; walls = 20% framing

$$U_{av} = S/100(U_s) + (1 - S/100) (U_i),$$

where

U_{av} = average U value for building section,

U_i = U value for area between framing members,

U_s = U value for area backed by framing members,

S = percentage of area backed by framing members,

$$U_{av} = 0.20(0.228) + 0.80(0.054), \text{ and}$$

$$U_{av} = 0.089.$$

(2, p. 22.5)

Windows To correct for effect of casements:

$$U_{adj} = U + Adj,$$

where

U_{adj} = adjusted U value, and

Adj = adjustment factor.

All windows in casements @ 60% glass:

$$U_{adj} = 0.58 \times 0.85$$

$$= 0.493$$

Sliding glass @ 80% glass:

$$U_{adj} = 0.58 \times 0.95$$

$$= 0.551$$

(37, p. 99)

Roof No adjustment necessary.

2 x 4 ceiling rafters. Insulation placed on top of rafters.

U-Value Calculations:

$$U = 1/R$$

Walls

<u>Construction</u>	<u>Resistance (R)</u>
1. Exterior Surface	0.17
2. Wood Siding	0.85
3. 1" T&G Total Wall	5.40
4. 3-1/2" Fiberglass	11.00
5. 6 mil polyethylene	Negligible
6. 1/2" gypsum board	0.45
7. Interior Surface	<u>0.68</u>
Total Resistance	18.55
U-value	0.054
Adjusted U-value	0.089

Windows

<u>Construction</u>	<u>U</u> <u>Value</u>	<u>U_{adj}</u> <u>Windows</u>	<u>U_{adj}</u> <u>Glass Door</u>
Double-glazed, 1/2" air space	0.58	0.493	0.551

Roof

<u>Construction</u>	<u>Resistance (R)</u>
1. Exterior Surface	0.17
2. 235# asphalt shingle	0.44
3. 15# felt	0.06
4. 5/8" CDX plywood	0.78
5. 1" air channel	0.90
6. 12" Fiberglass	38.00
7. 6 mil polyethylene	Negligible
8. 1/2" gypsum board	0.45
9. Interior Surface	<u>0.68</u>
Total Resistance	41.48
U-value	0.024

Doors

<u>Construction</u>	<u>U-value</u>
Solid urethane foam core with thermal break	0.19

Floor (Heat Loss)

<u>Unit</u>	<u>Exposed Perimeter</u>	<u>Heat Loss/ ft. Exposure (Btu/hr.)</u>	<u>Heat Loss (Btu/hr.)</u>	
1	121.08 ft.	40	4,843.2	
2	70.25 ft.	40	2,810.0	
3	121.08 ft.	40	4,843.2	(2, p. 24.5)

Ventilation (Heat Loss)

$$H = 0.018 (T_i - T_o)nV, \quad (37, p. 102)$$

where

H = heat loss (Btu/hr.) due to infiltration,

n = # air changes per hour,

V = volume of dwelling (ft.³),

T_i = inside temperature (°F), and

T_o = Outside temperature (°F).

$$V = 1,270 \text{ sq. ft.} \times 8 \text{ ft.} = 10,160 \text{ ft.}^3$$

$$n = 0.5 \quad (87, p. 12)$$

$$\begin{aligned} \text{Buffalo and Rochester: } H &= 0.018 (65) [0.5(10,160)] \\ &= \underline{5,943.6} \end{aligned}$$

$$\begin{aligned} \text{Syracuse: } H &= 0.018 (70) [0.5(10,160)] \\ &= \underline{6,400.8} \end{aligned}$$

Heat-Loss Rate Per Unit:

Units 1 & 3

<u>Component</u>	<u>Area</u>	<u>U-Value</u>	<u>Heat-Loss Rate (Btu/hr.)</u>
Windows	98.12	0.493	48.37
Walls	863.46	0.089	76.85
Roof	-	-	0.00
Metal Door	18.00	0.190	3.42
Sliding Glass Door	40.20	0.551	22.15
Floor	1,270.00	-	4,843.20
Ventilation	-	-	<u>5,943.60</u>
Total Heat Loss Per Hour			10,937.59

Unit 2

<u>Component</u>	<u>Area</u>	<u>U-Value</u>	<u>Heat-Loss Rate (Btu/hr.)</u>
Windows	98.12	0.493	48.37
Walls	456.79	0.089	40.65
Roof	-	-	0.00
Metal Door	18.00	0.190	3.42
Sliding Glass Door	40.20	0.551	22.15
Floor	1,270.00	-	4,843.20
Ventilation	-	-	<u>5,943.60</u>
Total Heat Loss Per Hour			10,901.75

Units 4 & 6

<u>Component</u>	<u>Area</u>	<u>U-Value</u>	<u>Heat-Loss Rate (Btu/hr.)</u>
Windows	98.12	0.493	48.37
Walls	863.46	0.089	76.85
Roof	-	-	0.00
Metal Door	18.00	0.190	3.42
Sliding Glass Door	40.20	0.551	22.15
Floor	-	-	0.00
Ventilation	-	-	<u>5,943.60</u>
Total Heat Loss Per Hour			6,094.39

Unit 5

<u>Component</u>	<u>Area</u>	<u>U-Value</u>	<u>Heat-Loss Rate (Btu/hr.)</u>
Windows	98.12	0.493	48.37
Walls	456.79	0.089	40.65
Roof	-	-	0.00
Metal Door	18.00	0.190	3.42
Sliding Glass Door	40.20	0.551	22.15
Floor	-	-	0.00
Ventilation	-	-	<u>5,943.60</u>
Total Heat Loss Per Hour			6,058.19

Units 7 & 9

<u>Component</u>	<u>Area</u>	<u>U-Value</u>	<u>Heat-Loss Rate (Btu/hr.)</u>
Windows	98.12	0.493	48.37
Walls	863.46	0.089	76.85
Roof	1,388.00	0.024	33.31
Metal Door	18.00	0.190	3.42
Sliding Glass Door	40.20	0.551	22.15
Floor	-	-	0.00
Ventilation	-	-	<u>5,943.60</u>
Total Heat Loss Per Hour			6,127.70

Unit 8

<u>Component</u>	<u>Area</u>	<u>U-Value</u>	<u>Heat-Loss Rate (Btu/hr.)</u>
Windows	98.12	0.493	48.37
Walls	456.79	0.089	40.65
Roof	1,388.00	0.024	33.31
Metal Door	18.00	0.190	3.42
Sliding Glass Door	40.20	0.551	22.15
Floor	-	-	0.00
Ventilation	-	-	<u>5,943.60</u>
Total Heat Loss Per Hour			6,091.50

HEAT-LOSS FACTORS

$$Q = \frac{\text{Heat-Loss Rate}}{T_i - T_o},$$

where Q = heat loss per degree of temperature difference per hour,

T_i = inside design temperature (65°F), and

T_o = outside design temperature: Buffalo = 0°F

Rochester = 0°F

Syracuse = -5°F

(37, pp. 151-152)

Units 1 & 3

Buffalo & Rochester:	$Q = 10,937.59/65$ $= 168.27$	$168.27 \times 24 = 4,038.48$ $4,038.48/1,270 = \underline{3.179} \text{ Btu/DD/ft.}^2$
Syracuse ^a :	$Q = 11,394.79/70$ $= 162.78$	$162.78 \times 24 = 3,906.72$ $3,906.72/1,270 = \underline{3.076} \text{ Btu/DD/ft.}^2$

Unit 2

Buffalo & Rochester:	$Q = 10,901.75/65$ $= 167.72$	$167.72 \times 24 = 4,025.28$ $4,025.28/1,270 = \underline{3.169} \text{ Btu/DD/ft.}^2$
Syracuse:	$Q = 11,358.95/70$ $= 162.27$	$162.27 \times 24 = 3,894.48$ $3,894.28/1,270 = \underline{3.067} \text{ Btu/DD/ft.}^2$

Units 4 & 6

Buffalo & Rochester:	$Q = 6,094.39/65$ $= 93.76$	$93.76 \times 24 = 2,250.24$ $2,250.24/1,270 = \underline{1.772} \text{ Btu/DD/ft.}^2$
Syracuse:	$Q = 6,551.59/70$ $= 93.59$	$93.59 \times 24 = 2,246.16$ $2,246.16/1,270 = \underline{1.769} \text{ Btu/DD/ft.}^2$

^a457.2 Btu/hr. added for Syracuse ventilation adjustment
(see ventilation calculations).

Unit 5

Buffalo &
Rochester:

$$Q = 6,058.19/65 \\ = 93.20$$

$$93.20 \times 24 = 2,236.8$$

$$2,236.8/1,270 = \underline{1.761} \text{ Btu/DD/ft.}^2$$

Syracuse: $Q = 6,515.39/70$
 $= 93.08$

$$93.08 \times 24 = 2,233.92$$

$$2,233.92/1,270 = \underline{1.759} \text{ Btu/DD/ft.}^2$$

Units 7 & 9

Buffalo &
Rochester:

$$Q = 6,127.7/65 \\ = 94.27$$

$$94.27 \times 24 = 2,262.48$$

$$2,262.48/1,270 = \underline{1.781} \text{ Btu/DD/ft.}^2$$

Syracuse: $Q = 6,584.9/70$
 $= 94.07$

$$94.07 \times 24 = 2,257.68$$

$$2,257.68/1,270 = \underline{1.778} \text{ Btu/DD/ft.}^2$$

Unit 8

Buffalo &
Rochester:

$$Q = 6,091.5/65 \\ = 93.72$$

$$93.72 \times 24 = 2,249.28$$

$$2,249.28/1,270 = \underline{1.771} \text{ Btu/DD/ft.}^2$$

Syracuse: $Q = 6,548.7/70$
 $= 93.55$

$$93.55 \times 24 = 2,245.2$$

$$2,245.2/1,270 = \underline{1.768} \text{ Btu/DD/ft.}^2$$

LOCAL PROPERTY TAX RATES

<u>City</u>	<u>Nominal Rate</u>	x	<u>Equalization Rate</u>	=	<u>Effective Rate</u>
Buffalo	115.52		0.2345		27.09
Rochester	172.01		0.2345		40.34
Syracuse	147.44		0.2345		34.57

SOLAR SAVINGS FRACTIONS

<u>Units</u>	<u>Trombe Wall</u>			<u>Direct Gain</u>		
	<u>BUF</u>	<u>ROCH</u>	<u>SYR</u>	<u>BUF</u>	<u>ROCH</u>	<u>SYR</u>
1,3	0.23	0.24	0.25	0.21	0.22	0.23
2	0.23	0.24	0.25	0.21	0.22	0.23
4,6	0.43	0.44	0.44	0.38	0.39	0.39
5	0.43	0.44	0.44	0.39	0.39	0.39
7,9	0.43	0.43	0.44	0.38	0.39	0.39
8	0.43	0.44	0.44	0.38	0.39	0.39

APPENDIX B

Project Income, Basic Structure:

Market rent for Upstate New York = 0.50/sq. ft./month (72)

Adjustments:

Buffalo: $0.50(1.0401) = 0.52$
Rochester: $0.50(1.0125) = 0.51$
Syracuse: $0.50(1.0124) = 0.51$

Buffalo: 1,270 sq. ft. x 0.52/sq. ft. = \$660

$660 \times 9 \times 12 = \underline{\$71,280}$

Rochester & 1,270 sq. ft. x 0.51/sq. ft. = \$648
Syracuse: $648 \times 9 \times 12 = \underline{\$69,984}$

	<u>Buffalo</u>	<u>Rochester & Syracuse</u>
Gross Rent	\$71,280	\$69,984
Less 5% Vacancy	<u>3,564</u>	<u>3,499</u>
Effective Gross Rent	\$67,716	\$66,485

Operating Expenses, Basic Structure (including real estate taxes):

Effective Gross Rent x 0.36 = Operating Expenses (72)

Buffalo: $\$67,716 \times 0.36 = \$24,378$

Rochester,
Syracuse: $\$66,485 \times 0.36 = \$23,935$

Project Income, Solar Buildings:

Conventional Fuel (electrical resistance) Savings in Year 1:

<u>Unit</u>	<u>Trombe Wall</u>			<u>Direct Gain</u>		
	<u>BUF</u>	<u>ROCH</u>	<u>SYR</u>	<u>BUF</u>	<u>ROCH</u>	<u>SYR</u>
1	84	109	83	79	102	77
2	84	109	83	79	102	77
3	84	109	83	79	102	77
4	75	95	73	67	85	65
5	75	95	73	67	85	65
6	75	95	73	67	85	65
7	75	96	73	67	85	65
8	75	95	73	67	85	65
9	75	96	73	67	85	65
Totals	702	899	687	639	816	621

Trombe Wall

Buffalo: $71,280 + 702 = \$71,782$

Rochester: $69,984 + 899 = \$70,883$

Syracuse: $69,984 + 687 = \$70,671$

Direct Gain

Buffalo: $71,280 + 639 = \$71,919$

Rochester: $69,984 + 816 = \$70,800$

Syracuse: $69,984 + 621 = \$70,605$

	<u>Trombe Wall</u>			<u>Direct Gain</u>		
	<u>BUF</u>	<u>ROCH</u>	<u>SYR</u>	<u>BUF</u>	<u>ROCH</u>	<u>SYR</u>
Gross Rent	71,982	70,883	70,671	71,919	70,800	70,605
Less 5% Vacancy	3,599	3,544	3,534	3,596	3,540	3,530
Effective Gross Rent	68,383	67,339	67,137	68,323	67,260	67,075

Operating Expenses, Solar Buildings:

Operating expenses without tax component = Effective Gross Rent x 0.24
(72)

Trombe Wall

Buffalo: $68,383 - 67,716 = 667$
 $67,716 \times 0.36 = 24,378$
 $667 \times 0.24 = \underline{160}$
24,538

Rochester: $67,339 - 66,485 = 854$
 $66,485 \times 0.36 = 23,935$
 $854 \times 0.24 = \underline{205}$
24,140

Syracuse: $67,137 - 66,485 = 652$
 $66,485 \times 0.36 = 23,935$
 $652 \times 0.24 = \underline{156}$
24,091

Direct Gain

Buffalo: $68,323 - 67,716 = 607$
 $66,485 \times 0.36 = 23,935$
 $607 \times 0.24 = \underline{146}$
24,524

Rochester: $67,260 - 66,485 = 775$
 $66,485 \times 0.36 = 23,935$
 $775 \times 0.24 = \underline{186}$
24,121

Syracuse: $67,075 - 66,485 = 590$
 $66,485 \times 0.36 = 23,935$
 $590 \times 0.24 = \underline{142}$
24,077

Depreciation:

Method Used: Double-declining balance
= 2 x straight-line rate
 $SL = (DB - S)/L,$

where

SL = straight-line amount,

DB = depreciable basis,

S = salvage value, and

L = useful life.

(4, p. 42)

Assumptions: DB = cost

S = 0

L = 40

(4, pp. 41-42)

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