MASTER

The Impact of Federal Tax Policy and
Electric Utility Rate Schedules Upon the
Solar Building/Electric Utility Interface

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EXECUTIVE SUMMARY

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TABLE OF CONTENTS

Executive Summary

The Study

Section I. Introduction

- A. Background
- B. Research Scope
- C. Research Objectives
- D. Notes on Scope of Study

Section II. Methodology

- A. The Systems Model
- B. Overall Building Design
- C. Building Cost Determination
- D. TRNSYS Description

Section III. Case Study: Colorado Springs, Colorado

- A. Utility Selection
- B. KW Demand of Buildings at Utility Peak
- C. Annual Consumption (kwh) of Electricity
- D. Load Factors
- E. Financial Impact on Consumer
- F. The Impact of Tax Credits
- G. The Impact on the Electric Utility
- H. Societal Impact

Section IV. Other Case Studies

- A. New England Electric System - Worcester, MA.
- B. Public Service of New Mexico - Albuquerque, NM.
- C. Pacific Gas and Electric - Sacramento, CA.
- D. Georgia Power - Atlanta, GA.

Section V. Summary and Conclusions

- A. Weather: Insulation and Temperature
- B. Building Configurations
- C. Building Costs
- D. Utility Costs
- E. Financial Parameters
- F. The Appropriateness of Solar Tax Credit Policies

Appendices

- A. The Impact of State and Federal Legislation
- B. The Impact of Building Codes
- C. TRNSYS Unit Descriptions
- D. Utility Weather, Loads and Rate Data

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MAJOR FINDINGS

IMPACT ON UTILITIES

Peak Demands

Energy conservation measures and active and passive solar energy investment, as examined herein, reduce the demand of buildings at times of peak in the winter peaking utilities studied. Active solar hot water heating, passive solar and energy conservation measures reduced the demand of buildings at times of peak in the summer peaking utilities studied.

In both winter and summer, the incremental investments in insulations to at least 2 x 4 insulated stud wall are clearly the most effective peak load reducer. Building orientation and the degree of building fenestration treatment were as significant as most solar investment.

Load Factors

Non-load managed active solar space heating systems have a negative effect on utility load factors in all the utilities examined. Energy conservation, passive solar and active solar hot water have varied impacts on load factors depending on utility and weather characteristics. Solar hot water heating was particularly effective in improving load factors in summer peaking utilities.

Load Management

Several load management opportunities exist for electric utility investment in alternative technologies. Interruptable service contracts are particularly attractive.

CONSUMER COST EFFECTIVENESS

A number of buildings, differently constructed, were analyzed. The Base Building, consisting of an all-electric heating, cooling, and hot water system, with "2x4" fully insulated stud wall construction, 16% south glazing, and 6" attic insulation is the most economical building in several cost scenarios. Other investments that appeared to be cost effective under certain conditions include:

- 1) additional energy conservation to, at least, "2x6" insulated stud walls and insulation, and 6" additional attic insulation;
- 2) masonry building 8" concrete block with 4" external Styrofoam[®] insulation;
- 3) solar hot water system with 5.6m^2 collector area;
- 4) solar space heating and hot water system with 17.5m^2 collector and 1.23m^3 storage;
- 5) solar space heating and hot water system with 35m^2 collector and 2.65m^3 storage;
- 6) thermal shutters, particularly ones that had different winter/summer operation modes;
- 7) 80% south facing glass - either double glazing and shutters or triple glazing;
- 8) south orientation.

Several practices were found to be particularly not cost-effective by comparison to other options available and include:

- 1) minimally insulated buildings; (below ASHRAE 90-75)

- 2) north orientation of major window expanse;
- 3) 80% south facing glass without either thermal shutters or triple glazing;
- 4) an overhanging shade, particularly on small glass expanses and areas with low cooling loads;
- 5) active solar heating systems on the masonry buildings or the minimally insulated building.

The actual economic trade-offs that exist between different building configurations are not as much dependent on differences in absolute savings of energy consumption as they are on the relationship of these energy savings to building costs, utility costs, and financial assumptions.

SOCIETY - THE FEDERAL GOVERNMENT PERSPECTIVE

The greatest benefits to society are realized by the insulation of the existing underinsulated building stock and the prohibition of further similar construction. In addition, benefits are realized from investment in additional energy conservation in most cases. Active and passive energy systems may also be warranted depending upon financial analysis, utility costs and climate. The exclusion of all external societal costs from this analysis, particularly effects on balance of trade and pollution, underestimates the value of all these investments.

The tax policies favor solar investment at the expense of energy conservation. This has been found to be an inefficient allocation of resources given the results of the analysis.

RESEARCH SCOPE

The present concern over seeking non-conventional methods of the heating and cooling of residences has resulted in numerous claims regarding the efficacy of each of these methods. The dimensions posed by heating of spaces and hot water and air conditioning command approximately fifteen percent of total energy usage in the United States. Solar heating and cooling is regarded by many as representing a cost competitive mode, which, combined with auxiliary back-up, can perform these household functions. Indeed, recently passed federal legislation and the tax provisions enacted in numerous states are attempting, in their objectives, to make this energy form competitive with gas, oil and electrical means of heating and cooling.

It is the intent of this analysis to show that a utility solar-passive strategy can be used rather effectively in aiding the utility to obtain more efficient load factors and lower costs. Given this claim, and the accompanying analysis, it will become obvious that any legislation enacted should be mindful of the sensitivity of this interface to the promotion of any one technological input to energy conservation and building design. That is, it will be shown that legislation favoring active solar system strategies, with the exception of domestic hot water heating, over that of passive designs and energy conservation may not be a preferred strategy.

RESEARCH OBJECTIVES

Two primary research objectives are pursued in this analysis.

1. Determine the impact of active and passive solar energy designs for space conditioning and hot water heating for the residential sector upon the diurnal and annual load curves for

for several utilities.

2. Assess the effect of present utility pricing policies and examine alternative pricing schemes, as well as federal and state tax credits, as they may affect the optimal sizing and configuration of active solar and passive solar building components.

The tasks used to achieve the first research objective are:

- 1a. Using a systems analysis approach, simulate the performance of a conventional and solar space and water heating for relevant building designs representing existing and future housing stock. Performance will be obtained for annual peak utility periods and representative off-peak utility periods.
- 1b. Juxtapose the performance of the buildings with various solar component sizing and control (for peak consumption constraints) against the diurnal and annual load curves for five electric utilities.
- 1c. Determine the impact of the solar buildings on utility energy and generating capacity design and usage criteria.
- 1d. Using utility forecasting scenarios and market penetration assumptions, forecast the impact of solar for those future years.

The tasks of the second objective follow as given Objective One's results:

- IIa. Analyze the impact of utility pricing, as it presently exists, upon solar users, the utility, and non-solar users.
- IIb. Analyze the impact of different electric rate structures upon solar users, the utility, and non-solar users.
- IIc. Cost the solar buildings and compare these costs with a conventionally space conditioned and water heated

building. Compare these costs with utility bills and cost parameters for both buildings under different pricing and tax credit scenarios.

RESEARCH RESULTS

For purposes of this discussion, the major parameters that distinguish variation in the cost-effectiveness of particular building design fall into five categories:

- A. The Weather: Primarily Solar Insulation and Temperature;
- B. Building Configurations;
- C. Building Costs;
- D. Utility Costs and Rates;
- E. Financial Parameters (inclusive of tax credits for solar and energy conservation investment).

Each of these parameters will affect the determination of the least cost alternative. The importance of each parameter, particularly the sensitivity, will be highlighted. Five utilities were studied: Colorado Springs Department of Public Utilities, (Colorado Springs, Colorado); Public Service Co. of New Mexico (Albuquerque, New Mexico); New England Electric System (Worcester, Massachusetts); Pacific Gas and Electric (San Francisco, California); and Georgia Power Co. (Atlanta, Georgia).

A. WEATHER: INSOLATION AND TEMPERATURE

The importance of weather (solar insolation, temperature, and to a lesser extent wind speed and relative humidity) in determining the optimal building configuration is well understood. Weather and climate have traditionally played a significant role in building design. However, the impact of variations in solar radiation availability is not as well understood.

It was shown that Colorado Springs experiences a high number of degree days and high amount of solar radiation. The importance of weather conditions as to the cost feasibility of solar heating and hot water systems is not paramount. Comparisons with Worcester indicate little variance in relative cost-effectiveness of the designs studied were due to climatic variation.

The weather at the time of utility peak also varies between regions and between utilities. Colorado Springs experiences its peaks during the winter. A recent trend, probably due to a higher saturation of electric resistance heating, has caused a shift in the utility peak demand from periods of cloudy low insolation and Christmas lighting around the winter solstice, to periods of extreme cold. This shift has significant impact on solar performance due to the necessary poor performance of the solar system during periods of low insolation. Worcester peak weather conditions appear to be similar to Colorado Springs, although the insolation available may be even higher.

Summer peaking utilities have different concerns as solar heating capabilities do not significantly reduce electricity demand at the time of system peak. Hot water demand can be lowered in summer peaking utilities depending on the weather. In Atlanta, the hot water demands were lowered by .46 kw out of about .75 kw demand for hot water at the time of system peak. The weather in Albuquerque is more favorable at system peak as almost all of the hot water demand (.64 kw out of .73 kw) for hot water was provided by solar.

Investments in energy conservation will reduce heating or air conditioning loads at time of utility peak. The more extreme the temperature, the greater the savings in peak demands as a

result of energy conservation investment.

B. BUILDING CONFIGURATIONS

Changes in the building configurations (including the design, floor plan, insulation, solar energy system, and passive solar energy system) impact on the kwh consumption, the kw demand at the time of utility peak and subsequently the economics. In every location, of those buildings examined*, the most significant reductions in kwh, kw and costs were realized by bringing an underinsulated residence up to ASHRAE 90-75 standards. The underinsulated home contained 6" of attic insulation, but contained no wall insulation. The inclusion of 3-1/2 inches of wall insulation in Colorado Springs created the largest reduction in energy usage--greater than the energy reduction from a 70 m² solar energy liquid collector.

The Base Building consisting of an all-electric heating, cooling and hot water system, with "2x4" full insulated stud wall, 16% south glazing, and 6" attic insulation was the most economical building in several cost scenarios. Other investments that appeared to be cost-effective under certain conditions (not listed in order of cost effectiveness) included:

1. additional energy conservation to "2x6" insulated stud walls and 12" (6" additional) attic insulation;
2. masonry Building of 8" concrete block with 4" external Styrofoam[®] insulation;
3. solar hot water system with 5.6 m² collector area;
4. solar heating and hot water system with 35 m² collector and 2.65 m³ storage;

* The buildings examined in this study do not necessarily represent optimal configurations. Optimality would have to be determined through an optimization process. The results of this study are preliminary and should not be used for decision making without further study.

5. thermal shutters particularly ones that had different winter/summer operation modes;
6. 80% south facing glass--either double glazing and shutters or triple glazing;
7. South orientation vs. north orientation.

Several practices were found to be particularly not cost-effective by comparison to other options available and (not listed in order of cost effectiveness) include:

1. minimally Insulated Buildings (no wall insulation, 6" attic insulation);
2. north orientation of major window expanse;
3. 80% south facing glass without either thermal shutters or triple glazing;
4. an overhanging shade, particularly on small glass expanses and areas with low cooling loads;
5. active solar heating systems on the Masonry Buildings or the Minimally Insulated Building.

The actual economic trade-offs that exist between different building configurations are not as much dependent on differences in absolute savings of energy consumption as they are on the relationship of these energy savings to building costs, utility costs, and financial assumptions.

C. BUILDINGS COSTS

One of the largest variations among the previous studies of solar heating cost-effectiveness is the construction/installation costs for the solar heating system. Variations in variable costs per square foot of collector range from \$2 to \$30/sq. ft. of

* For a complete list and description of buildings simulated, see Appendix A.

collector. The sensitivity of variations in the cost of solar has been indirectly examined in this study when the efficacy of tax credits were examined. Tax credit policies, both Federal and California, favor solar energy investment over other alternatives. For instance, the California tax credit lowers the cost of a 35 m² active solar collection system by \$3,000 from \$8,254 to \$5,254 or a 35% reduction. A re-evaluation in Colorado Springs of the cost-effectiveness to the consumer utilizing this lower cost for the solar system, reveals an uneconomic assessment for the solar system. Only in the "high future"* lifecycle scenario does the solar heating building utilizing these reduced costs values have a lower cost to consumer than the all-electric version of the same building (Base Building #1). The situation in Albuquerque and Worcester, reveals a more favorable response of solar heating cost-effectiveness to a 35% reduction in the cost of the solar system. The response is due more to the presence of higher fuel costs than to the cost reduction itself.

Other building practices that are not widely employed also initiate debate as to appropriate costs. The costs of utilizing masonry construction varies between regions and with familiarity of usage. The \$3,600 incremental costs for the masonry structure over the Base Building may be excessive in many cases. The price of shades and shutters is also subject to variations in cost depending on which of a variety of systems is utilized.

D. UTILITY COSTS AND RATES

The variation in utility costs accounts for most of the variations in results between locations. The exceptionally low cost of fuel and capacity for Colorado Springs, clearly favor the

consumption of electricity as compared to either Worcester or Albuquerque. This phenomenon is best illustrated by examining the impact of higher electric rates on building cost-effectiveness in Colorado Springs. The "appropriate block" electric rate for Colorado Springs was changed from the original 0.025 \$/kwh to 0.045 \$/kwh, the latter which closely represents the value for Worcester and Albuquerque. The results are shown in Table I.

Recalling the results, utilizing the original electric rates (0.025 \$/kwh), the all-electric Base Building 1C is the lowest cost alternative in both the first year and "medium" lifecycle scenarios. When costs are raised by one cent to 0.035 \$/kwh the least cost alternative shifts. In the first year analysis, the all-electric Energy Conservation Building 6C with 80% glass and a winter/summer differentiating shutter, was the least cost alternative to the consumer.

Utilizing the rate 0.045 \$/kwh, that was similar to the rate for Albuquerque and Worcester, produces significant changes. In the first year analysis, the same Energy Conservation Building 6C was still the least cost alternative. In the "medium future" lifecycle scenario sixteen buildings had lower costs than the all-electric Base Building. The least cost alternative was 14B, the Masonry Building with 80% glass, thermal shutters and a solar hot water system. If cost in Colorado Springs were as high as they are in Worcester, it is not surprising (because of the higher solar radiation levels) to find that the cost effectiveness of solar heating systems would be more favorable in Colorado Springs. This is illustrated by the large number of "A" type buildings that have costs lower than Base Building 1C in the lifecycle analysis with 0.045 \$/kwh as the electric rate.

TABLE I
THE SENSITIVITY OF ELECTRIC RATES TO
CONSUMER COST-EFFECTIVENESS*
COLORADO SPRINGS

First Year Cost Analysis

RATE	LEAST COST ALTERNATIVE	OTHER BUILDINGS WITH COSTS LOWER THAN BASE BUILDING 1C***
0.025 \$/kwh	All-electric Base Building-No shade (1C)	—
0.035 \$/kwh	All-electric Energy Conservation #2, with shade, 80% glass, thermal shutters, (6C)	None
0.045 \$/kwh	All-electric Energy Conservation #2, with shade, 80% glass, thermal shutters, (6C)	None

Medium Future Lifecycle Analysis**

RATE	LEAST COST ALTERNATIVE	OTHER BUILDINGS WITH COSTS LOWER THAN BASE BUILDING 1C
0.025 \$/kwh	All-electric Base Building-No shade, (1C)	—
0.035 \$/kwh	All-electric Masonry Building, 80% glass. w/s shutters (14C)	6C, 14B
0.045 \$/kwh	Solar hot water Masonry Building, 80% glass, w/s shutters (14B)	1A, 2A, 3AC, 4AC, 6BC, 9A, 13BC, 14C, 15BC

* No tax credits applicable.

** DR = .08 IR = .085 Electric Rate Increase .07 per year, Fuel Cost Increase = .10 per year.

*** See Appendix A for the key to building numbers.

E. FINANCIAL PARAMETERS

The sensitivity of final results to changes in financial parameters such as the discount rate is acknowledged throughout the literature. In this report, a variety of different values were utilized ranging from a first year analysis to a "high future" lifecycle analysis. The results were indeed sensitive to changes in discount rate and the rate of increase in electric rates.

The critical problem with this sensitivity is the lack of consensus as to the appropriate values to use in an analysis. These financial parameters analyze the impact of unknown future prices. Concomitantly, there exists debate as to which scenario best reflects the interest of a particular individual, or society as a whole. These researchers feel that the appropriate set of parameters for the consumer lie somewhere between the first year cost analysis which generally favors the Base Building in Colorado Springs and the Energy Conservation Buildings in Albuquerque and Worcester; and, the lifecycle analysis which favors more energy conservation, passive and active solar investment. On the other hand, national well-being may not be expressed sufficiently by even the most generous lifecycle cost analysis if the basis is a twenty year lifecycle. The application of public policy with such a short lifetime is probably inappropriate. This is particularly important when significant external social costs are ignored as they have been here.

F. IMPACTS ON UTILITY

One factor virtually ignored in most assessments of solar energy is the impacts on the utility companies which supply auxiliary energy. The principal concern in this report is to examine the

impacts of alternative technologies upon electric utilities both because electricity's low capital costs make it a convenient back-up source and because electric utilities' load management concerns portend significant interface problems.

Clearly the most significant findings is the extremely low individual load factors* for the buildings with combined solar space and water heating systems. In Colorado Springs, the load factors for the buildings with combined space and hot water systems were less than 10% as compared to 36% for the all-electric Base Building. It appears that in Colorado Springs and Worcester a large amount of auxiliary energy required by the buildings with active systems is actually demanded at times of utility peaks. The larger the active systems, the truer this is. Counterbalancing the trend of low load factors for solar buildings are the improved load factors of energy conserving buildings.

In summer peaking utilities such as Georgia Power Co. and Public Service Company of New Mexico solar heating and hot water systems lower annual consumption to a greater extent than they lower energy demand during summer peak loads. The load factors are necessarily poorer for these systems. Solar hot water systems alone and some energy conserving techniques do improve load factors in these locations.

These variations in load factors produce variations in costs of service. In several cases wide differences exist between the

*Individual load factor is the average kilowatt demand for space conditioning and hot water divided by the kilowatt demand for space conditioning and hot water at the time of utility peak load demand.

cost of service and the revenues received by utilities from solar buildings. This has prompted interest in higher rates for solar users.

The importance of the electric rate in the building/utility interface cannot be overestimated. The rate affects the cost effectiveness to the consumer. The rate must also, however, reflect the cost of service to utility and the impact on society.

Electric utility rate schedules are developed to recover costs over a broad range of users. Variations in cost of service between a solar and non-solar home are less than the variations in cost of service between an underinsulated and insulated home. Refinement of rate design to better reflect costs of service will provide a better signal to all consumers with regard to utility impact. Rate designs which differentiate by time-of-use and/or weather sensitivity will better reflect the true cost of service and should yield greater economically efficient consumer response.

One potentially attractive rate schedule may be the use of an interruptable service contract. The electric utility can curtail the need for expansion by rolling out service to prearranged solar buildings; with the incentive to the customer being a lower charge. The infrequency of peak electricity demand by solar buildings may make interruptable service contracts ideal. An indirect benefit of these types of rates may be the increased use of building thermal mass. Results show that large amounts of building thermal mass dampen heat flows to such a degree that the exclusion of on-peak electrical heating in the Masonry Buildings does not appreciably alter internal room temperature or comfort even at

design conditions. Under present rates that do not differentiate between time-of-day or weather sensitivity, no incentive to the consumer to invest in thermal mass exists despite great societal benefits.

G. THE APPROPRIATENESS OF SOLAR TAX CREDITS

A significant barrier to the development of alternative energy sources and energy conservation is the present cost of existing fuel sources. Subsidies to these existing fuel sources and the exclusion from the price the consumer pays of some social costs including pollution costs and foreign trade deficit impacts have kept the price of these existing fuel sources artificially low. Development of alternative investments which reduce the consumption of these scarce fuel sources is retarded. The high initial investment in solar and energy conservation has also hampered its development.

The President and Congress, realizing the societal benefits that will result from investment in energy conservation and solar, enacted tax credits. California has also initiated a tax credit policy which provides greater tax relief and extends benefits to passive solar energy. These tax credits are developed as a promotional incentive for solar energy investment. Energy Conservation investment is not afforded the same level of tax reduction as it is felt that these investments may not require as much assistance to be cost-effective.

From examination of the results of this survey, it appears that the U.S. tax credits do provide an improved economic picture for active solar investment relative to all alternatives. However,

the benefits do not appear to be sufficient to make active solar investment cost-effective against all these alternatives. The tax credits for California do appear to more favorably promote the development of solar energy, particularly passive solar energy. One finding of note is the trade-off that exists as a result of the tax credits. The investment in solar energy is often times enhanced at the expense of investment in energy conservation, which does not receive equivalent tax relief.

The crucial issue revealed here is that while these tax credits may promote the development of solar energy, rapid commercialization of solar energy in itself does not maximize societal benefits and may be an inefficient allocation of resources. The desire of energy legislation is principally to lower dependence on foreign sources of fuel, and to lower the need for expensive utility generation capacity, and not solely to promote development of solar energy. This is particularly true if investment in energy conservation may meet these requirements at less cost. It was found in this report to be particularly true of energy conservation with at least up to 6" attic insulation and wall insulation of 2x4 stud walls. It is shown in Albuquerque that for every \$10,000 investment in a 35 m² solar energy collector the returns to society, excluding social costs, are \$9305 in present value savings. For the same amount of investment in wall insulation in Minimally Insulated Buildings the returns to society, not including social costs, are \$192,645 or 2100% greater. For a further investment in insulation to 12" attic and 2 x 6 fully insulated stud wall, the return to society is \$16,283. An inconsistency exists in the U.S.

tax credits which provide \$300 of tax credit to the above energy conservation investments, and \$2200 to the above solar building, despite greater benefits from energy conservation. The inconsistency is harder to comprehend in the California tax policy where \$3000 worth of incentives are provided for the solar investment and no incentives are provided for the energy conservation investments alone.

Part of the reluctance to promote energy conservation results from a belief that energy conservation alone cannot solve this nation's future energy needs. The point is, however, that these energy conservation investments represent at present, using the accounting presented herein, the least cost alternatives to society. Society's inaction in developing them may be a gross misallocation of resources. The unequal tax credit policy which favors solar over energy conservation investment provides and unjustified advantage to solar from the point of view of national well being. Other barriers to energy conservation do exist such as tenant/landlord responsibility which may not fully be relieved by equal tax credit policy. The relevant point, however, is that if waste could be controlled easily, societal benefits justify the providing of nearly free energy conservation to any home similar to the Minimally Insulated Building.

Finally, the above analysis reveals the need to treat solar energy and energy conservation economics together. Trade-offs exist between the two investments and centralized electric energy. Cost effectiveness to the consumer is not necessarily consistent with maximized national well-being. Public policy that addresses itself

to the consumer and fails to consider societal impacts is not appropriate. To the degree that this is explicit in this study and accepted by the policy community, redirection of the tax policies should be warranted.

APPENDIX A

Key to Building Numbers and Descriptions

Generic Building Types:

Base Building--2" x 4" insulated stud wall, 6" attic insulation

Energy Conservation Building--2" x 6" insulated stud wall,
12" attic insulation

Masonry Building--8" Concrete Block, 4" exterior styrofoam,
12" attic insulation

Minimally Insulated Building--2" x 4" uninsulated wall,
6" attic insulation.

Generic System Types:

A. Combined 35 m² Solar Heating and Hot Water, Electric
Back-up and cooling

B. 5.6 m² Solar Hot Water System, Electric heating, cooling
and auxiliary.

C. All-Electric heating, cooling and hot water.

Building Simulations*:

Building

- 1 - Base Building.
- 2 - Base Building - with overhanging shade.
- 3 - Energy Conservation Building - with shade.
- 4 - Energy Conservation Building - with 1" styrofoam, w/shade.
- 5 - Energy Conservation Building - with 1" styrofoam, 80% south windows, w/shade.
- 6 - Energy Conservation Building -w/styrofoam, 80% south windows, thermal shutters, w/shade.
- 7 - Energy Conservation Building - with triple storage size in active system 7.95 m³.
- 8 - Energy Conservation Building - with one-third storage size in active system 0.88m³.
- 9 - Energy Conservation Building - with 17.5 m² collector, 1.32 m³ storage, w/shade.
- 10 - Energy Conservation Building - with 70 m² collector, 5.30 m³ storage, w/shade.
- 11 - Masonry Building - w/shade.
- 12 - Masonry Building - 80% south windows, w/shade.
- 13 - Masonry Building - 80% south windows, thermal shutters, w/shade.
- 14 - Masonry Building - 80% south windows, winter/summer shutters, no shade.
- 15 - Masonry Building - 80% south windows, triple glazing, w/shade.
- 16 - Minimally Insulated Building - w/shade

SECTION I

INTRODUCTION

A. BACKGROUND

Fuel supply interruptions and rapidly increasing energy costs have focused increasing attention on solar heating and cooling of buildings (SHACOB). A rapidly developing manufacturing and service industry are ready to satisfy the growing enthusiasm for solar energy. With recent passage of the National Energy Plan, the potential impacts of solar market penetration are large. The President has set the goal of 2.5 million installations by 1985.

There are, however, significant technical, economic and institutional barriers which must be overcome before significant commercialization can become a reality. These significant barriers include:

- high construction cost of SHACOB;
- identification of cost-effective applications;
- average cost pricing of alternative competing energy sources;
- impact of SHACOB on utilities supplying auxiliary energy, particularly upon the generating capacity requirement and rate structures of electric utilities.

Although all of the above are part of the commercialization calculus and are addressed herein, it is the last barrier to which this study is specifically addressed. In the past it has been largely the responsibility of the Barriers and Incentives Branch, and the Solar Heating and Cooling Division, Department of Energy, to suggest which, if any, of the above barriers warrant legislative or regulatory remedy, as well as assessing the incentives that are provided for commercialization of solar energy.

Many researchers have postulated that SHACOB will impact negatively on electric utilities which supply back-up energy. Feldman, et.al. (1976), in some cases, found that solar buildings adversely affect load factor and cause a net revenue loss for the utility. Lorsch (1976) found that SHACOB worsened load factors and exacerbated peak demands for two Pennsylvania electric utilities. Asbury and Mueller (1976) postulate that SHACOB can only displace off-peak fuel and, therefore, must compete not only with alternative fuels like natural gas and electricity, but also with thermal energy storage (TES) applications "fueled" by inexpensive off-peak electricity. The research conducted by Southern California Edison with the Jet Propulsion Lab., (Braun et.al. (1975)) supports these other research findings. The Puerto Rico Water Resources Authority (Llavina (1976)) on the other hand has concluded that solar hot water commercialization in Puerto Rico will have beneficial effects on the utility's load factor and peaking requirements.

The failure of these studies has been in not examining alternative technical configurations with regard to the solar appliances, the building characteristics, and the potential for integrated SHACOB/load management. In addition, passive solar buildings until very recently did not receive the attention they deserve with regard to mitigating the negative impacts at the solar energy utility interface.

Efficient allocation of resources must be examined from the perspective of the consumer and the utility. Consideration of the peak demands placed on the utility by individual consumers is required for electric utility capacity expansion planning. Auxiliary loads for alternative technologies, including HVAC,

passive and energy conservation systems, must, therefore, be examined. Furthermore, present average cost pricing policies for energy deviate from a true price signal of the cost of energy, resulting in inequity and inefficiency in allocation of energy resources. The pricing of energy at its true cost may not accelerate the commercialization of SHACOB but will, at least, represent a better allocation of resources. In addition, more direct means of load management must be examined so as to determine those policies most beneficial to both consumer and utility. Finally, those configurations defined as preferred under the above criteria should serve as input to national policy, and should be promoted insofar as they coincide with overall energy policy.

These problems have been directed more often to gas utilities rather than electric utilities, since natural gas presently provides by far the greatest share of energy for space and water heating. There are, however, several important reasons why an analysis of the solar/electric utility interface is salient:

- the long-run national availability of natural gas is unclear;
- electric utilities experience peaking problems;
- construction cost is normally lower for SHACOB applications with electric auxiliary, which reduces the first-cost barrier.

B. THE SCOPE OF THE RESEARCH

The primary objective of this study is to examine the impact of a number of technical configurations which will affect the economic and physical efficiency of the solar building and the

electric utility supplying auxiliary energy to that building. Definition of an optimal configuration among those systems to be examined is a secondary but significant objective. These results should serve as a salient input to implementation of energy policies.

The present state of the art of the solar building utility interface has been extensively reviewed by Dickson, Eichen, and Feldman (1977). The review indicates that solar building design should include utility consideration in the sizing and use of storage, controls and collector and should be integrated with utility load management. Most previous studies have focused on the "optimal" sizing of solar systems accounting for minimum cost per BTU input for the solar system without regard as to when utility auxiliary energy and capacity are needed. Since temporal variations in utility usage will affect utility costs and service reliability factors, these studies are not reflective of a more accurate accounting of the true costs to society of implementing solar systems.

Feldman, et. al. (1976) have shown that optimal sizing of solar components will vary with the type of rate structure employed and whether the sizing is performed according to the criteria of the utility, the building owner or society in general. The same tendency has been shown by Feldman et.al. (1977) with regard to other non-solar design considerations such as amount of insulation, glazing, etc., and, also, with respect to passive solar building technical specification. There also exists trade-offs in configurations between the solar and non-solar components within a building, as well as their joint effect upon utility energy and capacity.

C. RESEARCH OBJECTIVES

The specific objectives are:

- I. Determine the impact of solar energy collector and storage size on temporally variant electric energy use and energy system economics in several regional scenarios.
- II. Identify and assess solar energy system control and energy storage schemes for utility peak load mitigation and energy system economics for each regional scenario.
- III. Determine the impact of building design elements on temporally variant building electric energy use and building system economics for each regional scenario.
- IV. Using those relationships developed in objectives I-III, recommend and assess peak mitigating residential solar building designs for each regional scenario.

D. NOTES ON SCOPE OF THE STUDY

Electric utilities are complex systems which are not easily simplified nor modeled. They encompass a wide diversity of characteristics geographically, in climate, in life-style, in socio-economic characteristics, and in other factors which affect utility operations. For these reasons, what may be true in one part of a utility's service area may not hold for another part, nor can generalizations to an entire service area always be made.

One of the limitations of this study is that the building performance simulations are done for a single site in each of the utilities. The unavailability of long-term and reliable weather

data, particularly hourly solar radiation, makes it difficult, if not impossible, to model the climatic diversity represented in each utility service area. Therefore, the results of this study are generalizable only to the extent that these sites are representative of overall climate in the service area. Weather data from National Climatic Center stations on these sites was used to "drive" the simulation model. One of the criteria used to select these sites was their representativeness of the entire service area in terms of climate. An additional consideration in site selection was to choose that site which best coincided with the locus of expected solar market penetration.

This study does not attempt to model the intricate working of each utility. Instead, it focuses on the incremental costs and loads imposed on the utilities by a single user, which can be analyzed somewhat independently of day-to-day operations. The incremental load of a single residential user certainly has no impact on a large utility; but, to the extent that a single user with a given technical configuration and load pattern is representative of a larger group of users, knowledge of the impacts on utility fuel costs, capacity requirement, and system reliability is important.

This study utilizes the principles of microeconomics in focusing on marginal costs to the utility and marginal impacts on economic efficiency. There is still, however, debate in professional circles on how to calculate marginal costs. Many methods have been proposed, and there is no widely recognized "correct" method. The

* See Section III of this report for a discussion of the criteria used for site selection, and the use of weather data.

methodology developed by Cicchetti et. al. (1976) is used in this study because we feel it best adheres to the conceptual framework for calculation of marginal costs; and, because some of the utilities involved have used the methodology in the past in their own load and rate research studies. This allows comparisons to be made between the utilities based on uniformity of approach.

A further objective of this study is to determine the cost-effectiveness of various solar technical configurations to the consumer. Both life-cycle and first-year cost analyses are performed, using financial and economic assumptions which could be open to some debate.

SECTION II

METHODOLOGY

A. THE SYSTEMS MODEL

In order to satisfy the objectives of this study, a model is used which examines the interface between solar energy buildings and electric utilities. Simply stated, the model operates in the following fashion. The performance of a building, that is, the amount of electricity demanded, is calculated under average and extreme weather conditions (peak period) for one location in the utility. The impact of these demands on the electric utility is measured, and the long and short run costs incurred as the result of the addition of one building in the service area are determined. Economic efficiency comparisons are made between buildings of different designs from the point of view of the utility, the building owner, and national economic efficiency. Figure II-1 is a flow chart of the model. The detailed analytical stepwise procedure is as follows:

Step I. Site/Utility Selection

Five geographically dispersed utility service areas were selected for study. For each, a specific site has been selected which serves as the building location and as the source for weather. The five utilities are:

- The City of Colorado Springs, Colorado
- Georgia Power Company, Georgia
- New England Electric System, Massachusetts
- Pacific Gas & Electric, California
- Public Service Company of New Mexico, New Mexico

FIGURE II-1
FLOW CHART OF THE MODEL

Step II. Building Selection

The development of a well defined building model is one of the prerequisites of this methodology. Special care has been taken to account for many factors which effect building loads.

The National Association of Home Builders Research Foundation, Inc., in Westinghouse (1973) has specified building parameters typical of new building construction. Conformity to these values has been attempted as much as possible with only slight modification to aid in ease of modeling, adaptation to solar and representation of future building stock. The building modeled is a 140 m^2 (1500 sq. ft.), single story ranch, 18m (58ft.) long, 8m (26ft.) wide, with 2.4 m (8 ft.) high walls. The building is oriented with the major dimension south. The building has a basement in Colorado and Worcester and an insulated slab in Atlanta, Albuquerque, and Sacramento. Beyond these specifications, many other factors which affect the energy consumption of a typical residence are specified: insulation, wall structure, active solar, passive solar, thermal mass, fenestration, control devices, and human behavior. The detailed description of each building modeled is described under Building Descriptions, Section II,B.

BUILDING PERFORMANCE SECTOR

Step III. Building Performance Simulation

The performance of each building within the utility service area is modeled using a modified version of TRNSYS (1978), a transient computer simulation model developed at the University of Wisconsin Solar Energy Laboratory, Madison. (See TRNSYS Description. Section II,D.)

Step IV. Specify Typical Weather Year

The thermal performance of a residential building is largely a function of weather. In order to simulate performance using TRNSYS, hourly weather data is needed. The selection of specific weather years is limited to those sites with hourly readings of dry bulb and wet bulb temperature, insolation and wind speed. The specific locations for calculating yearly building performance are:

The City of Colorado, Colorado	Boulder, Colorado (1956)
Georgia Power Company, Georgia	Atlanta, Georgia (1960)
New England Electric System, MA	Blue Hills, Massachusetts (1958)
Pacific Gas & Electric Company, CA	Fresno, California (1951-58)
Public Service Company of New Mexico	Albuquerque, New Mexico (1959)

Step V. Average Annual Electric Consumption

The results of the TRNSYS simulation, using the appropriate annual weather sequence, yields the average yearly performance of each building. Performance of a building is measured by the amount of electricity that is consumed. Because this electricity is supplied by the electric utility, it is important to gauge the performance of a building by its effect on the utility's load curves. The above performance calculation is the hour by hour consumption of that type of building. This consumption represents the hourly demand for electricity for space conditioning and hot water by each building. It should not be thought of, however, as a complete account of the building's performance or

the complete effect on the utility since the values are representative of space conditioning and hot water heating only. It is assumed that the remainder of a household's electric load, for lighting, for example, is the same in all buildings and can, therefore, be ignored in the analysis.

Step VI. Peak Weather Sequences

Average electric consumption provides an incomplete analysis of building performance because extreme weather conditions are not emphasized. This is important since extreme weather conditions are responsible for the utility's peak loads. The peak loads determine the capacity requirement and subsequent capital costs to the electric utility. For this reason, it is necessary to include the performance of the building under the peak load conditions as part of the overall performance of each building. In order to test the performance of a building under peak load conditions, five day (minimum) weather sequences were compiled. These weather sequences coincide with the historic times that the utility experiences its peak load. The last day of these sequences is in fact the peak load day for a given year. It is assumed that a minimum of five days is sufficient to mitigate the influence of initial starting conditions (e.g. storage tank temperature) in the simulation of solar building performance. The critical factor is the performance of each building during the peak period on the peak load day. It is during this period that incremental electricity demand causes the need for additional capacity for the utility. Local Climatological Data sheets (LCD) for each of the following cities (years 1970-1975) provided the

necessary data.

The City of Colorado Springs, Colorado	Colorado Springs, Colorado
Georgia Power Company, Georgia	Atlanta, Georgia
New England Electric System, MA	Worcester, Massachusetts
Pacific Gas & Electric Company, CA	Sacramento, California
Public Service Company of New Mexico,	Albuquerque, New Mexico

Weather sequences of a minimum of five days, corresponding to the peak period of the above data, were used in the building performance simulation.

Step VII. Peak Electric Consumption

The performance of each building at the times when the utility experiences peak demands can be compared, and the capacity requirement (in kw) of each building can be determined.

UTILITY FINANCE SECTOR

Step VIII. Short Run Cost

The performance of each building has been determined as above. The impact of each building on the electric utility can be analyzed by examining expenses incurred by the utility and broken down into three components. The components reflect the three separate areas into which costs can be categorized: energy costs, capacity costs, and customer costs. Marginal cost programs determine the utility's long and short run incremental costs by examining separately the contributions of each component. The model examines the effect of an additional building upon the load of the utility. This direct analysis permits one to ignore any common expenses between different building configurations, other than for heating and cooling. In this manner the direct

contribution of space conditioning to the expenses of the electric utility are calculated. The first component of an electric utility's costs is its energy costs or short run costs. Short run costs include all costs that vary with the amount of energy produced - the cost of fuel, and operation and maintenance costs that vary with output. The short run costs per kwh increases as output increases because higher output normally requires use of less efficient generating plants. This means a greater use of fuel and higher cost per kwh. Should output drop to zero, however, there would be no short run costs. The primary component of short run marginal costs is the energy or fuel costs. The demand in kilowatts of an electric utility is met at any time by a group of generating plants whose total capacity is sufficient to meet demands. Each of the generation units making up this capacity has a fuel requirement per kwh, determined by the plant's thermal efficiency. The cost of that fuel - gas, oil, coal or nuclear, is the incremental fuel cost of that plant. The utility operates a system of economy dispatch where available plants with the lowest incremental fuel costs provide the necessary capacity, so as to minimize total costs.

Some utilities have developed sophisticated cost programs to derive the short run marginal costs for each hour of the year. However, generalization of plant efficiencies into broad categories provides a good representation of short run marginal costs. In this study, incremental fuel costs are derived from the weighted average of historic fuel costs over time-of-use demand periods as calculated by the utility. The demand period segregates groups of hours which normally have peak loads from those which experience lower levels of load. In addition, a shorter period, or partial

peak may also be specified. The incremental fuel cost for each period is adjusted by the appropriate calculated loss multiplier for energy, to account for losses between the point of generation and the point of use. Variable operation and maintenance costs per kwh are added to calculate the short run marginal costs, which are multiplied by the number of annual kwh in each of the demand periods to derive the annual short run cost to the utility. This process is repeated for each building.

The calculation of average short run costs is considerably complicated where a significant portion of a utility's capacity is derived from hydropower. Supplied hydropower has short run marginal costs near zero, but since it is far less reliable (not always available) compared to other types of plant, annual fuel cost is closely related to hydro availability. Incremental fuel cost is, therefore, normally based on some average hydro availability.

Step IX. Long Run Costs

The second aspect of utility's costs and the effect of solar buildings on those costs is the demand or capacity cost. This cost is a result of the demand for additional generating capacity and subsequent transmission and distribution needed to service the new growth. The costs are most appropriately the opportunity costs which arise from an unexpected increase in demand (Berlin et.al., 1976). Using the marginal cost theory, the cost of meeting this demand should be paid by those users who instigated the need for additional facilities, i.e., as a function of the load placed on the system by each at the time that the system has the least reserve capacity. The long run cost of the utility is the amortized cost of the capacity required by each of the buildings. The costs are based on utility supplied data on marginal capacity costs.

The model calculates the effect of one additional building on the utility peak loads. What is determined is the increment to utility load of the building at the time the utility has experienced its peak demands in the past. The increment to the existing load from each of the buildings can be costed out using data from the utility on its incremental generation costs, derived, for example, from Cicchetti et.al. (1976). The effect on the capacity requirements of the utility of each of the buildings can, therefore, be compared, where the cost in dollars for new capacity required is the common denominator.

Using TRNSYS, each building is simulated for a minimum of five days prior to each of the past five historic annual peak load days. The performance of the building on the peak days of the utility is obtained. The desired result of the simulation is the diversified electric demand for the peak period (the hours for which there is probability of loss of load) on the peak load day. The demand is considered diversified over time, since electric draw for space conditioning and water heating occurs in short bursts. When this demand, however, is integrated over a 1-hour period, the load profile is smooth and reflects the heating or cooling load of the buildings. The model uses the average demand of the building during the peak period of the peak load day for each of five years as a surrogate for capacity requirement. It is not useful to specify the demand of the building during the instant of system peak both because load diversity is not represented by a single building and due to the lack of precision of the building model and utility forecasting.

The long run cost to the utility for each building is derived by calculating the marginal annual generation capacity cost, and the marginal annual transmission and distribution (T&D) related capacity cost for the utility, and multiplying the total annual capacity cost by the kw requirement of each building at time of system peak. The methodology used for calculating marginal capacity costs is explained in detail in Cicchetti et.al. (1976). Though this is not the only methodology which could be employed, it does provide theoretically justifiable cost allocations which are useful in bracketing marginal costs.

Step X. Rate Schedule of Utility

Electric utilities often have a number of rate schedules, which apply to different classes of customers. As a result, the selection of the proper rate for the heating and cooling portion of the electric bill is a complicated process. Under average cost pricing, most utilities utilize a declining block rate. As consumption increases, the unit price per kilowatt hour decreases. Because heating and cooling consumption may be viewed as an increment to other uses of electricity and since it is desired to isolate the marginal effects of various configurations, the appropriate block to bill for the heating and cooling kwh demand is at the marginal rate for average monthly use. It is assumed that a typical household uses approximately 500 kilowatt hours per month for lighting, etc., exclusive of electricity for space conditioning and hot water heating.

It is further assumed that an appropriate rate for billing incremental kwh is the price of the 501st kilowatt-hours (P_{501}) for the existing declining block rates, the customer's bill is

computed from: $(\text{kwh} \times P_{501})$. The time-of-use rates were either supplied by the participating utilities or calculated from the marginal cost values and represent potential short term implementable tariffs.

Step XI. Electric Bill

The calculation of the electric bill is simply a matter of multiplying the appropriate rate times the amount of consumption. In the case of time of use rates, the hour by hour consumption of electricity for each building is aggregated into the specified demand periods.

Step XII. Revenue to Utility

The revenue to the utility is specified as the amount equivalent to the electric bill of the building owner. This represents only the revenue from heating/cooling uses of electricity.

Step XIII. Total Incremental Cost to Utility

The total costs are merely the sum of the short run costs and the long run costs. As in the case of revenues, this value is not meant as the total costs but as a mode of comparison between buildings. Since other costs and revenues are ignored, it is not possible to derive to what extent revenues and costs are out of balance.

BUILDING OWNER SECTOR

Step XIV. Incremental Construction Cost

The costs of all building options have been costed out using Means Building Construction Cost Data (1976). The relevant value is the additional cost of each building over the base, "2 x 4" standard building meeting ASHRAE 90-75 standards. Comparisons of

the cost-effectiveness of each building can be made under life-cycle or first year cost analysis. The effects of tax credits can also be evaluated.

Step. XV. Economic Efficiency Sector

The determination of the economic efficiency of solar energy construction must take into consideration the effects on three different sectors: the solar building owner, the utility, and national economic efficiency. For the solar building owner, the important economic consideration is whether the amortized cost of the solar building is exceeded by the average annual savings in the heating/cooling bill within a specified payback period. For the utility, the total costs incurred to supply energy to any customer should be recouped by the revenues from sales to that customer. If this is not the case, then either other utility customers must subsidize that customer, or the utility must devise a rate which puts costs and revenues in balance. In practice, the pursuit of equity is such a difficult process that rates are derived to balance costs and revenues over broad classes of users. National economic efficiency will be served if the total costs to society of the solar construction are less than those of substituting electrical energy for solar energy. These total costs must include the incremental costs for the solar energy systems and the potential savings from delayed utility capacity.

B. OVERALL BUILDING DESIGN

Building Structure

All buildings are single story ranch-style houses. Dimensions and orientation are held constant, and no structures are attached to the outside. Infiltration is constant at $\frac{1}{2}$ air change per hour.

There is a basement on each building. Windows comprise 7.7% of the east-and west-facing walls. (See Table II-1); Building Configuration Constants). A floor plan is presented in Figure III-1.

SOLAR AND SPACE HEATING SYSTEMS

Each of the buildings is modeled with electric cooling and electric auxiliary heating. Passive systems including high thermal mass, large window areas, and fenestrations options are included in some buildings; the impacts of variation in passive aspects are reflected more accurately because of modifications made to TRNSYS (See Section II-D). Each building is modeled with and without an active solar space conditioning and domestic hot water system; each building is also modeled with a separate domestic hot water system only.

1. Cooling

The sensible cooling demands (latent loads are not considered) of each building are met by use of a three ton conventional compression cycle air conditioner with a COP of 2.4.

2. Auxiliary Heating

Auxiliary heating is provided by electrical forced air heating. Auxiliary heating comes on whenever room temperature drops below 18.4°C.

3. Passive Solar

Large window areas, high thermal mass, shading, triple glazing, and winter or summer shutters are used for control of internal temperature; a count is kept of how often windows could have been opened to provide cooling.

FIGURE II-1

FLOOR PLAN

TABLE II-1

BUILDING CONFIGURATION CONSTANTS

Type: Single story ranch house
 Dimensions: 58' long x 26' wide x 8' high (walls).
 Volume: 12,000 ft.³
 Floor Area: 1,500 ft.²
 Orientation: Long axis east-west
 Basement: Yes
 Attached Structures: None
 Wall Construction: Variable.
 Ceiling Insulation: Variable.
 Thermal Mass: Variable.
 Effective Capacitance: Variable.
 Window Area: Variable % of south-facing wall.
 7.7% of east-and west-facing walls.
 Variable % of north-facing wall.
 Glazings: Variable
 Infiltration: 1/2 air change per hour.

Space Conditioning Systems

Active Solar System:

Collector Area: Variable (combines dystem with hot water).
 Collector Tilt: 60°
 Number of Glass Covers: 2 panes.
 Collector Efficiency Factor: .9
 Collector Plate Absorptance: .9
 Collector Plate Emmitance: .9
 Fluid Thermal Capacitance: 3.56 kg/kg°C.
 Loss Coefficient for Bottom and Edge: 1.63
 Extinction Coefficient X Thickness of each glass cover: .037
 Flowrate: 879 kg/hr.
 Heat Exchanger Mode: Counter flow.
 Overall Heat Transfer Coefficient of Exchanger: 11,870 kj/hr°C.
 Tank Volume: Variable.
 Loss Coefficient for Tank: 1.021 kj/hr°C.
 Pump On/Off Temperatures: 5.6°C/1.7°C.

Auxiliary Heating System: Electric Forced Air.

Air Conditioning System: 3 ton conventional compression cycle air conditioner. COP 2.4.

Interior Thermostat: 3 Stage.

Minimum Utilized Solar Storage Temperature: 25.55°C.

"Cooling On" Temperature: T interior $\geq$ 25°C.

"Solar Heating On" Temperature: T interior $\leq$ 20.00°C.

"Auxiliary Heating On" Temperature: T interior $\leq$ 18.4°C.

TABLE II-1 (cont'd)

Passive Solar Systems (may or may not be present in buildings):

Shading: Horizontal overhang shade on south wall.

Shutters: Insulating shutters on windows.

Energy Control Routines:

Count kept of number of times windows could have been opened to provide needed cooling.

Shutters opened at night in summer for cooling by convection of windows, closed during day to reduce direct heat gain.

Shutters closed at night in winter to reduce heat loss, open during day to maximize direct heat gain.

Interior Heat Generation

Energy Transfer into Room from People: 1100 kJ/hr.

Energy Transfer into Room from Appliances & Lighting Fixtures: 1800 kJ/hr.

Domestic Hot Water System

Collector Area: 5.6m^2 .

Collector Tilt: 60°

Number of Glass Covers: 2

Collector Efficiency Factor: .9

Collector Plate Absorptance: .9

Collector Plate Emittance: .9

Fluid Thermal Capacitance: 3.56.

Loss Coefficient for Bottom and Edge: $1.63\text{ kJ/hr}^\circ\text{C.m}^2$.

Extinction Coefficient x Thickness of Each Glass Cover: .037

Flowrate: 281.0 kg/hr.

Pump On/Off Temperatures: $5.6^\circ\text{C}/1.7^\circ\text{C}$.

Effectiveness of Heat Exchanger: 0.7.

Volume of Preheat Storage Tank: $.303\text{m}^3$

Loss Coefficient of Preheat Tank: $1.80\text{ kJ/hr}^\circ\text{C}$.

Usage Profile: Typical Daily Mass Flow Profile (Mutch, 1974).

Total Daily Mass Demand: 300 liters.

Delivery Temperature: 48.9°C .

4. Active Solar

An active solar space heating system combined with a domestic hot water system is modeled. Collector and storage sizing is variable; collector tilt is 60° or 45° . A double-loop liquid heat transfer system using a counter flow heat exchanger is simulated. A dead band controller, activated by a 5.6° difference between collector temperature and storage temperature, is used; the pumps switch off when the temperature difference drops to 1.7°C . The room thermostat provides for utilization of stored solar heat when the room temperature drops below 20°C , bringing on auxiliary energy when the solar storage is not sufficient to keep the room temperature above 18.4°C .

5. Domestic Hot Water

A domestic hot water system may be utilized with no associated space heating system. A preheat tank is used to heat water entering the domestic hot water tank. Cold water is mixed in if necessary to insure that the water will be delivered to the house at 48.9°C ; an electric element is used if necessary to raise water temperature to 48.9°C .

Building Variables

The buildings modeled reflect present construction practices, standard energy conservation practices, or common passive solar systems combined with energy conservation; each building is modeled with active solar space heating and hot water systems, solar hot water only, and with no solar systems. Thirteen energy conservation and passive buildings are modeled in an effort to determine which configurations are most cost-effective. Active system sizing

is also varied to determine the most cost-effective system, as well as the building configurations most compatible with active solar. (See Table II-2, Building Numbers and Descriptions).

TABLE II-2

BUILDING NUMBERS AND DESCRIPTIONS

Generic Building Types:

Base Building -- 2"x 4" insulated stud wall, 6" attic insulation

Energy Conservation Building -- 2" x 6" insulated stud wall,
12" attic insulation

Masonry Building -- 8" Concrete Block, 4" exterior styrofoam,
12" attic insulation

Minimally Insulated Building -- 2" x 4" uninsulated wall, 6" attic
insulation.

Generic System Types:

A. Combined 35 m² Solar Heating and Hot Water, Electric Back-up
and cooling.

B. 5.6 m² Solar Hot Water System, Electric heating, cooling
and auxiliary.

C. All-Electric heating, cooling and hot water.

Building Simulations*: Colorado Springs

Building

- 1 - Base Building. 16% south windows.
- 2 - Base Building - with overhanging shade. 16% south windows.
- 3 - Energy Conservation Building - with shade. 16% south windows.
- 4 - Energy Conservation Building - with 1" styrofoam, w/shade.
16% south windows.
- 5 - Energy Conservation Building - with 1" styrofoam, 80% south
windows, w/shade.
- 6 - Energy Conservation Building - with styrofoam, 80% south windows,
thermal shutters, w/shade.
- 7 - Energy Conservation Building - with triple storage size in
active system 7.95 m³.
- 8 - Energy Conservation Building - with one-third storage size in
active system 0.88 m³.
- 9 - Energy Conservation Building - with 17.5 m² collector, 1.32 m³
storage, w/shade.
- 10 - Energy Conservation Building - with 70 m² collector, 5.30 m³
storage, w/shade.
- 11 - Masonry Building - w/shade. 16% south windows.
- 12 - Masonry Building - 80% south windows, w/shade.
- 13 - Masonry Building - 80% south windows, thermal shutters, w/shade.
- 14 - Masonry Building - 80% south windows, winter/summer shutters, no shade.
- 15 - Masonry Building - 80% south windows, triple glazing, w/shade.
- 16 - Minimally Insulated Building - w/shade.

*All 16 Buildings modeled with A, B, and C system types.

Four different wall construction types have been utilized and include:

1. Base Building
2. Energy Conservation Building
3. Masonry Building
4. Minimally Insulated Building

(See also Table II-3 Building Structure)

1. Base Building

A base building has been specified in order to provide a basis of comparison for subsequent building modifications. The base building is a single story ranch house with "2 x 4" insulated stud wall (R-11) and 6" of insulation in the roof (R-19). The building does not contain any other significant energy conservation, active solar, or passive solar additions. The benefits of improvements in these areas can then be evaluated by comparison with this base building. This building conforms very closely to the new building conservation standards. All new residential construction will be required to have this amount of insulation.

2. Energy Conservation Building

Minimum building standards in no way represent the optimal amount of insulation and are not necessarily the most cost-effective alternative to the homeowner. A building designed for energy conservation was modeled to determine if such improvements are justified in Colorado Springs.

In the energy conservation building, the "2 x 4" stud wall is replaced by a fully insulated 2" x 6" stud wall. As a second option, a one inch sheet of total wall (styrofoam) is nailed to the exterior. The application of styrofoam not only increases

the R value of the wall to 24, but, also, reduces conduction losses through the studs themselves. The use of 12" of ceiling insulation increases the ceiling R value to 38.

3. Masonry Building

Materials other than wood are often used for building construction in Colorado Springs. Buildings utilizing masonry have different energy consumption patterns than do wood buildings because large amounts of building thermal mass lower temperature fluctuations. At the same time, these materials have been used in buildings which utilize solar radiation and fenestration to control interior temperatures. These elements of building design, labelled direct gain passive solar, have been shown to be effective means of utilizing solar energy through building design.

A heavy thermal mass passive building has been modeled using TRNSYS with modifications outlined in Modification to TRNSYS. The building construction consists of 8" concrete block wall with 4" of total wall sheeting on the external surface resulting in a R value of 20. It is important that the insulation be put on the outside of the masonry so as to allow the heat stored in the masonry to be re-radiated into the living space. The heat transmission properties (UA) of the passive building are very similar to those of the energy conservation building. The difference in the performance of the two buildings can be attributed, in large part, to fenestration and building thermal mass.

4. Minimally Insulated Building

This minimally insulated building represents the building stock build prior to the 1970's. This building has "2 x 4"

uninsulated stud walls (R-4) and 6" of insulation (R-19) in the ceiling. This category of building construction is included in an effort to explore retrofitting both of energy conservation and solar energy systems.

TABLE II-3

BUILDING STRUCTURE

Base Building

Type: Single story ranch house.
 Dimensions: 58' long x 26' wide x 8' high (walls).
 Volume: 12,000 ft.³
 Floor Area: 1,500 ft.²
 Orientation: Long axis east-west.
 Basement: Yes.
 Attached Structures: None.
 Wall Construction 2" x 4" insulated stud wall; R-11.
 Ceiling Insulation: 6" insulation; R-19.
 Thermal Mass: Light, 30 lbs. building material/ ft.² floor area.
 Effective Capacitance: 13,920 K_j/°C.
 Window Area: 16% of south-facing wall.
 7.7% of east-and west-facing walls.
 10% of north-facing wall.
 Glazings: 2 panes.
 Infiltration: 1/2 air change per hour.

Energy Conservation Building

Type: Single story ranch house.
 Dimensions: 58' long x 26' wide x 8' high (walls).
 Volume: 12,000 ft.³
 Floor Area: 1,500 ft.².
 Orientation: Long axis east-west.
 Basement: Yes.
 Attached Structures: None.
 Wall Construction: 2" x 6" insulated stud wall with 1" total wall
 (Styrofoam insulation) on outside; R-24.
 Ceiling Insulation: 12" insulation; R-38.
 Thermal Mass: Light, 30 lbs. building material/ft.² floor area.
 Effective capacitance: 13,920 K_j/°C.
 Window Area: 16% of south-facing wall.
 7.7% of east- and west-facing walls.
 10% of north-facing wall.
 Glazings: 2 panes.
 Infiltration: 1/2 air change per hour.

TABLE II-3

BUILDING STRUCTURE (cont'd.)

Masonry Building

Type: Single story ranch house.
 Dimensions: 58' long x 26' wide x 8' high (walls).
 Volume: 12,000 ft.³
 Floor Area: 1,500 ft.².
 Orientation: Long axis east-west.
 Basement: Yes.
 Attached Structures: None.
 Wall Construction: 8" masonry with 4" total wall (styrofoam insulation) on outside; R-20.
 Ceiling Insulation: 12" insulation; R-38.
 Thermal Mass: Heavy, 130 lbs. building material/ft.² floor area.
 Effective Capacitance: 40,000 K_j/°C.
 Window Area: 16% or 40% of south-facing wall.
 7.7% of east- and west-facing walls.
 10% of north-facing wall.
 Glazing: 2 panes.
 Infiltration: 1/2 air change per hour.

Uninsulated Wall Building

Type: Single story ranch house.
 Dimensions: 58' long x 26' wide x 8' high (walls).
 Volume: 12,000 ft.³
 Floor Area: 1,500 ft.².
 Orientation: Long axis east-west.
 Basement: Yes.
 Attached Structures: None.
 Wall Construction: 2" x 4" uninsulated stud wall; R-4.
 Ceiling Insulation: 6" insulation; R-19.
 Thermal Mass: Light, 30 lbs. building material/ ft.² floor area.
 Effective Capacitance: 13,920 K_j/°C.
 Window Area: 16% of south-facing wall.
 7.7% of east- and west-facing walls.
 10% of north-facing wall.
 Glazings: 2 panes.
 Infiltration: 1/2 air change per hour.

C. BUILDING COST DETERMINATION

The determination of economic efficiency for the solar building studied, from consumer, utility and national welfare perspectives, relies on the calculation of building impact on energy use and demand and the cost of the building configuration producing that impact. This chapter discusses the methodology used for costing specific building components and presents incremental cost data for the building configurations studied.

The selection of the particular construction types used in this study represents a balance between actual construction practice for "conventional" single-family residential buildings and the project team's expectations of what construction practices may be for mass produced solar and energy conservation single family residential buildings. For example, the base (2 x 4 stud wall) building reflects" standard industry practice and was modeled and costed accordingly. However, in selecting a "heavy mass, well insulated" building, no "standard industry practice" exists for residential buildings -- especially a standard practice that would typify industry practice 10 to 15 years from now when such buildings may impact on utility loads. It was, therefore, necessary to select specific construction details that balanced the desired thermal performance characteristics, realistic construction practice and installation costs. While this balancing of objectives is addressed in the discussion of each building component, it is best exemplified by the selection of the "high mass" building envelope. In providing a high thermal mass building, it was decided to use masonry exterior wall construction.

The final selection of solid concrete block represents a balance between thermal performance (where poured in place or precast concrete may be best) and residential building practice (where conventional non-solid concrete block may represent the current industry approach in conventional buildings).

For final cost determination for each building component option, a published architectural cost handbook--Means Building Construction Cost Data--was employed. It is important to understand that the costs available from Means represent costs applicable to larger commercial structures and not specifically to residential buildings. While labor rates are for union trades and, therefore, represent labor costs higher than what would be expected for residential construction, the material costs are for large commercial projects where volume buying allows a lower material cost than would be available to the typical residential builder. The final cost determination is, therefore, believed representative of residential construction practice, but is subject to considerable variation for a specific component. The variation in building component cost is somewhat moderated by the selection of building components that, in balancing thermal performance and residential building practice, usually result in a moderate cost option and not necessarily in an option at either end of the cost range.

Costing Methodology

The costing procedure utilized here is similar to that used by many architects in arriving at preliminary cost estimates. The primary difference is that the methodology allows for the cost

determination of insulated building components in order to facilitate the aggregation of these components into a number of different scenarios.

The various tasks associated with the costing methodology are:

- 1) Disaggregate buildings into components to be costed
- 2) Select an appropriate architectural treatment for each component
- 3) Prepare architectural drawings and specifications in sufficient detail to cost components
- 4) Determine component costs and, where appropriate, determine incremental costs over specified base cost
- 5) Adjust component costs for selected cities
- 6) Aggregate building component costs for specified buildings

Tasks 1-3 associated with costing methodology are discussed in conjunction with the following section on "Building Components". The four primary energy conservation and solar energy parameters (insulation, thermal mass, fenestration treatment and active solar energy system designs) are characterized by specific building components. Where there exists a range of architectural options for a building component that accomplishes the same objective (e.g. three ways of providing window shading are covered), one option is selected based on thermal performance, standard construction practice, probable consumer acceptance and cost. The selected building component options are then characterized by architectural drawings and specifications in sufficient detail to permit costing.

The building component costs are determined through the use of a published construction cost guide - Means Building Cost Data.

In order to have a consistent cost base with the utility data, all construction costs are reported in 1976 dollars, using the 1976 edition of Means. As discussed in the opening paragraphs of this chapter on Costs, Means is specifically developed for commercial construction and not directly applicable to the residential construction considered here. In any case, the costs are determined on a consistent basis, and, while the reported costs may not be directly applicable to residential construction, the relative cost are believed accurate.

Component costs calculated with the use of Means include material, labor, overhead and profit on a standardized basis. These standardized costs are then adjusted for specific localities using city cost indices in Means. These cost indices reflect the relative building cost differences for specific locations around the United States.

Once all component costs are determined, overall building designs are specified. The specified buildings are costed by aggregating the proper building components and summing the costs. Incremental costs of specific buildings over the cost of the base case, conventional ranch style building then serve as inputs to the financial analysis from consumer, utility and national welfare perspectives. Actual building costs are aggregated as part of the financial analysis.

Building Components

The building components selected for study reflect those components that might be included as part of energy conservation or solar heating packages. An attempt is made to exclude or hold constant those components which would not be a direct part

of such packages. (See Table II-1 "Building Configuration Constants"). For example, while solar buildings, especially passive solar buildings, may have non-conventional floor plans to facilitate natural air circulation, the selected buildings have the same floor plan; one that is amenable to conventional and solar building design alike. Interior construction (partitions, conventional plumbing, appliances, furnishings, etc.) is assumed constant. Building components beyond the building proper (garages, patios, vegetation, etc.) are excluded. While both interior structure and components beyond the building proper offer significant opportunity for impacting on consumer, utilities and national welfare, they are beyond the scope of this study.

The four parameters most affecting auxiliary energy consumption are insulation level, building thermal mass, fenestration treatment and active solar energy system sizes. Insulation and building thermal mass are characterized by building envelope specification. Fenestration treatment involves window orientation and area, window shading and shuttering devices and the number of glazing layers. The active solar energy system is specified as a "conventional" liquid system of various collector sizes and collector area/storage volume ratios. Roof structures are modified as necessary to accomodate varying collector sizes. In that there is significant overlap in building cost elements between the four energy conservation-solar energy parameters, it is necessary to individually cost the building elements affected by each parameter and then aggregate the building elements so as to represent a specific combination of energy conservation-solar energy paramters. The

building elements selected for costing are:

ceiling insulation

window overhang (window shading device)

roof structure

wall structure including insulation and fenestration

fenestration treatment

active solar energy system costs

A discussion of each building element follows.

Ceiling Insulation

All buildings modeled have a minimum of 15 cm of fiberglass ceiling insulation. It is recognized that a large fraction of new and a larger fraction of existing single family dwellings do not have the equivalent of 15 cm of fiberglass ceiling insulation (R19). However, the 1985-1990 time period should see the adoption of R19 ceiling insulation as an absolute minimum and, therefore, 15 cm was selected as the base cost.

The ceiling insulation was increased for more energy conserving buildings to a level of 30 cm. Ceiling insulation levels in the range of 15-30 cm may be changed without materially changing other building elements.

Window Overhang

In passive solar buildings, a stationary projection or overhang is placed above windows to allow the low altitude winter sun to enter but to block the high summer sun. Such window shades may be provided by attached horizontal trellises, offset roofs or ceiling joist extensions. Any of the three approaches to providing window shading may be selected depending on the architectural requirements of the building. A 1.42 m overhang, rather than the

present typical overhang of .36m, provides the desired shading effect. All three approaches were costed, and the approach using ceiling joist extensions was selected due to its low cost and its minimal impact on other architectural elements (such as roof structure).

Roof Structure

The roof structure for a roof mounted solar energy system differs from a conventional roof. This difference results from the collector's need to be at some optimal angle for collecting the winter sun. A standard roof was assumed to have a minimum 4/12 pitch, (to accommodate snow build up in some study locations) to be built from prefabricated roof trusses (typical of production ranch style homes) and to have asphalt roofing. This roof structure was modified to accept space heating collectors (17.5 m^2 and 35 m^2) by maintaining the 4/12 north roof pitch but increasing the south pitch to 19/12 (60°). In order to accommodate the larger 70 m^2 collector, the south roof surface was increased which increases the slope (and surface area) of the north roof. The incremental costs of the modified roof structures were calculated as the additional cost of lumber for larger roof trusses, additional sheathing, building paper, trim and rake edges for the roof and the additional area of the end walls. Incremental costs for asphalt roofing, excluding shingles from under collectors, were calculated. The standard roof structure was used for the 5.6 m^2 solar domestic hot water system by providing for a support frame in the cost of that system.

Wall Structure

Costs for the various wall structures were complicated by the interdependence of structural type (2"x4", 2"x6", masonry),

insulation amount and type, and fenestration considerations.

Seven structural/insulation configurations were initially selected for costing. These were:

"2x4" stud wall without insulation

"2x4" stud wall with R11 insulation

"2x4" stud wall, R11 insulation, 1" Styrofoam[®]

"2x6" stud wall, R19 insulation

"2x6" stud wall, R19 insulation, 1" Styrofoam[®]

8" solid concrete block with 2" externally applied Styrofoam[®]

8" solid concrete block with 4" externally applied Styrofoam[®]

The "2x4" stud wall, with studs 16" on center is typical of the vast majority of residential construction. The "2x6" stud wall with studs 24" on center is gaining rapid acceptance as an incrementally low cost method for allowing thicker insulation to be installed in wall cavities. Styrofoam[®] ("Total Wall") is gaining rapid acceptance as an insulating, nonstructural sheathing and was considered as an addition to both wood frame wall constructions. As discussed earlier, the selection of solid concrete block as the structural component for a high mass wall is based on balancing thermal performance, standard construction practice and cost. In both masonry wall scenarios, insulation (2" & 4") is applied to the outside surface of the masonry.

After initial costing, it was possible to eliminate 2 wall types--

"2x4" stud wall, R11 insulation, 1" Styrofoam[®]

8" solid concrete block with 2" Styrofoam[®]

The "2x4" stud wall, R11 insulation, 1" styrofoam was eliminated because it offered slightly less insulating value at a higher cost than the "2x6" stud wall with R19 insulation. Although a

number of builders now offer "2x4" with total wall construction, it is assumed that buildings with this construction will become less frequent as more builders become aware of the benefit of "2x6" stud walls. The 8" concrete block with 2" styrofoam was eliminated due to minor cost differences with the 8" concrete block with 4" styrofoam and while offering significantly less thermal performance.

Three fenestration scenerios were applied to all wall types. East and west wall glass areas were held constant at 8% for all cases. South and north window areas were varied as follows:

16% south glass, 10% with glass (Figure III-2)

40% south glass, 4% north glass (Figure III-3)

80% south glass, 4% north glass (Figure III-4)

The 16% south glass is typical of ranch style homes with a sliding glass door. The 40% and 80% south glass cases provide significantly more window for passive gains and, therefore, the north side windows were reduced to reflect a desire to reduce losses out those windows. Standard window sites were used throughout.

Since increasing the glass area reduces the wall area, costs for the three window configurations and the five different wall types were done as a matrix. Costs of the windows were figured to include interior trim, flashing, cauking and exterior painting, as well as the cost of the window units themselves. The remaining area of the wall for each elevation was multiplied by a cost per unit area calculated for each wall type. The masonry wall costs also include an additional cost per linear foot of window opening for concrete lintels and sills. The cost for the 80% glass, south

FIGURE III-2 BASE BUILDING WITH 16% SOUTH GLASS

FIGURE III-3 BUILDING WITH 40% SOUTH GLASS

FIGURE III-4 BUILDING WITH 80% SOUTH GLASS

wall elevation was calculated once and kept constant because the remaining 20% consists of framing and trim and, therefore, the cost did not vary with wall type.

Fenestration Treatment

With the heat loss/gain through glass representing such a large percentage of the building load for the 80% glass south elevation cases, two energy conservation scenarios were applied to the windows. The base case window system utilized double pane wood frame windows. The first energy conservation scenario utilizes a third layer of glass. This cost was calculated on a unit area basis and applied to all windows. The second window energy conservation scenario involves the selection of insulating shutters and an appropriate operating scheme. Three shutter options all providing R11 insulating capability were designed and costed. They were:

Styrofoam window inserts

Multilayer, insulating roller shades

Sliding, solid shutters.

The multilayer, insulating roller shades were selected based on moderate cost and probable consumer acceptance.

Although specific operating routines were used in modeling the performance of the shutters, they were assumed to be manually operated and no costs were included for automation.

Active Solar Energy Systems

The collector system selected is a typical liquid flat plate system. Collector areas and storage volume are varied under various scenarios. Costs were derived per unit collector area, per unit storage volume and for fixed costs, so as to give reasonable cost when aggregated into a system. These costs are

\$160/m² of collector, \$256/m³ of storage and \$1500 for fixed aspects of components such as pumps, piping and controllers. For the base 35 m² system, the cost is \$7842 or \$224/m².

The installed cost of a solar domestic hot water system, including a collector support frame for the roof was assumed a constant \$2500 over a conventional electric hot water system.

Operating and Maintenance Expenses

In addition to installed capital costs for the various solar buildings, operating and maintenance expenses play an important role in the economic analysis. Operating costs for the active collector systems are primarily pump running costs. Pump energy is assumed to be 3.5% of the collected energy and is included in the cost analysis along with the auxiliary energy consumption. Incremental maintenance expenses were calculated for all solar building designs. However, the only significant incremental maintenance costs were found to be for the collector system, window overhang and shutters.

D. TRNSYS DESCRIPTION

TRNSYS is by far the most widely known and used transient simulation program for solar energy systems. Klein (1976) reports that TRNSYS has been distributed to approximately 150 companies, universities, and government agencies both in the United States and abroad. It is also the simulation model which is most often cited in the literature, and for which there has been the greatest amount of verification of results. It was developed by the University of Wisconsin-Madison Solar Energy Laboratory under dual funding by NSF/RANN and ERDA. The most useful reference to this program in the TRNSYS manual by Klein et. al., (1978).

TRNSYS may be used to evaluate the thermal performance of a nearly infinite number of configurations of SHACOB systems. This capability is due to the structure of the program which allows the specification and connection of component models to solve a set of simultaneous algebraic and differential equations which describe the system. TRNSYS may be useful in the specification of any thermal transient system, but has special application to solar energy systems because of the availability of a library of component models which are most often associated with solar energy systems.

Some of these components include: flat plate solar collector, stratified fluid storage tank, heat exchanger, on/off auxiliary heater, space cooling load and air conditioning, with rock bed thermal storage, liquid collector-storage subsystem, air collector-storage subsystem, and domestic water heating subsystems.

Each of the component models in the library is formulated as a separate FORTRAN subroutine. New component models are periodically added by the authors and are included in the library. In addition, the user may specify his own component model (e.g., for novel equipment) which can be easily added to the program.

TRNSYS is adaptable to modeling direct gain passive solar systems because of its use of the heat transfer methodology developed by Mitalas and Stephenson (1967). This method simulates the movement of heat through the building, and allows for a time lag in heat transfer, thus simulating the effect of heavy thermal

mass in damping interior temperature fluctuations. This heat transfer method is a practical method for accurate calculation of building loads.

The output from TRNSYS is user specified, and may range from simple longterm estimates of solar contribution to extremely detailed analysis of the thermal performance of the system in one-hour time steps or less. Most often, the detailed output just described is only used for verification of the results of the simulation, or in tracing logic or specification errors in the description of the system. The output does not include any economic analysis.

TRNSYS Modification

Modifications have been made to TRNSYS in an effort to more accurately model passive solar systems (Abrash, Wirtshafter, Sullivan, and Kohler, (1978)).

a) Solar Heat Gain Through Windows

On the standard version of TRNSYS, solar heat gain through windows is calculated in the wall model (type 17). There is no provision for shading, which is necessary in most passive buildings to avoid overheating. In addition, the model uses a constant value for the transmittance of the glazing, instead of calculating it as a function of incident angle. Although this may be sufficient for conventional buildings where solar gain through windows is relatively small, it could introduce significant error in the dynamic simulation of passive buildings.

A new subroutine was written to calculate solar heat gain through windows which includes provisions for shading and variable transmittance. The transmittance of windows to beam and diffuse

radiation is calculated for north, east, south and west windows following the procedure used to calculate transmittance of cover glazing in the TRNSYS collector model (type 2). The transmittance of beam radiation is calculated as the product of the transmittance due to reflection and the transmittance due to absorption, using the angle of incidence from the modified radiation processor. The transmittance of diffuse radiation is calculated in a similar manner, using an incident angle of 60° .

The overhanging shade is modeled as a horizontal roof overhang on the south side of the building. The distance that the overhang projects from the building, and the distance from the shade to the top of each window, as well as the window dimensions are specified as parameters by the user. The radiation processor is modified to output the solar profile angle, which is used to determine the fraction of each window shaded to beam radiation. The fraction of each window shaded to diffuse radiation is calculated as the fraction of sky view blocked by the shade. In order that solar heat gain and shading may be modeled in this component, the shading factor in the wall model is set to 100% and the heat gained through windows in the solar heat gain component is made an input to the room.

b) Shutter Routines

Type 15 Algebraic Operator Routines were used to model both summer and winter shutter performance. In the winter, the UA of an insulated shuttered window is outputted at night, while the UA of a double-glazed window is outputted during the day. This allows for maximum direct heat gain with minimal convective losses. In the summer, the UA of an insulated shuttered window is outputted

in the day, and no direct heat gain is made through the windows. At night, the UA of a double-glazed window is outputted, resulting in convective cooling. See Appendix C for TRNSYS unit description.

SECTION III

CASE STUDY - COLORADO SPRINGS

A. UTILITY SELECTION

The choice of the city of Colorado Springs, Department of Public Utilities, as the test case is due to several factors. Colorado, the site of the Solar Energy Research Institute, is a prime area for solar energy adoption. Prima facie, the climate is favorable to solar energy, and the attitude of policy makers towards solar energy is very positive. The selection of Colorado Springs is predicated on the acquisition of utility data including marginal costs and weather data from a previous study by the investigators.

The results of the case study are divided into seven parts. The first three parts examine different thermal aspects of the building performance; the kw demand of the building at utility peak, the annual kwh consumption of electricity, and the individual building load factor. The next four parts examine financial aspects of the different thermal loads including: the financial impact on the consumer, the impact of tax credits, the impact on the electric utility, and the overall societal impact.

B. THE KILOWATT DEMAND OF BUILDINGS AT UTILITY PEAK

The evaluation of the sensitivity of the thermal performance of a building to changes in active, passive, and energy conservation building features is essential to determination of the cost-effectiveness of such energy-related modifications. Such an analysis

involves evaluation of both the annual kilowatt hour (kwh) consumption of electricity and the building kilowatt (kw) demand at the time the utility is experiencing its annual peak demand (time of coincident peak).

A preliminary investigation by Feldman and Anderson (1976) has indicated that active solar systems may impact negatively on utility loads and finances. The impact of passive solar and energy conservation in buildings must also be ascertained. The critical variable in assessing the utility impact is the amount of electricity demanded by the buildings at the time the utility experiences system peak demand. It is at this point that the need for more generation capacity, one of the largest utility expenses, is realized. The utility companies through a number of new tariff designs will be attempting to pass these capacity costs back to customers who are responsible for peak demands.

The peak demands (in kw) for the representative buildings in Colorado Springs have been calculated in accord with Step IX in Chapter II, Section I. The peak demands are displayed in Table III-1 and are differentiated by building type and configuration (A,B or C).

For each building, the inclusion of a solar energy system reduces peak kw demand. Type A, with collector sized for heating and hot water, has a lower kw demand than Type B, with collector sized for hot water only. Type C, an all-electric version, has the highest kw demand of the three. Comparison of some of the different building types and solar equipment sizing provides an indication of kw capacity requirements. It is possible to isolate certain changes in building design such that all other design characteristics except one are held constant. In the following discussion, the impact of changes in active systems, building

envelopes, and fenestration are evaluated as to the impact on peak kw demand.

The Effect of Active Systems

In Table III-2, the kw demand of a 2"x6" building with varying collector sizes are shown. A comparison of the building with no collector and 35m² of collector reveals a one third reduction in capacity requirement from 4.5 kw to 3.2 kw as a result of the active system. A problem arises in that the annual reduction in kwh of energy from this building is 90%, and thus the reduction in revenues to the utility under the present pricing tariff is significantly greater. The full extent of this phenomena will be addressed in the sections on load factors and utility impact below.

The cause of these higher peak demands in relation to average demands is partly due to the weather conditions associated with peak conditions in Colorado Springs. The average sky cover factor during the peak days is less than fifty percent clear. Benefits from increases in collector size are constrained by lack of solar radiation during these critical times. This is evident from the building performance of the other collector sizes. Doubling the size of the collector to 70m² does not result in a 50 percent reduction in capacity requirement, but only a 25 percent (.8kw) reduction to 2.4 kw. A 17.5m² collector increases the kw demand to 3.9 kw.

One often suggested solution to the problem if inadequate solar collection potential may be to increase the size of the storage. The sensitivity of variation in storage size on peak loads is not clearly demonstrated. Tripling of storage size from

TABLE III-1

DEMANDS OF BUILDINGS IN KW DURING UTILITY PEAK

Colorado Springs

<u>Building #</u>	<u>Solar Heating & Hot Water -(A)</u>	<u>Solar Hot Water Electric Heating-(B)</u>	<u>All Electric Heating & Hot Water- (C)</u>
1	4.6	5.5	5.8
2	4.6	5.5	5.8
3	3.5	4.4	4.7
4	3.2	4.2	4.5
5	4.2	5.6	5.9
6	2.9	3.8	4.0
7	3.1	4.5	4.8
8	3.5	4.3	4.5
9	3.9	4.2	4.4
10	2.4	4.7	5.0
11	2.8	3.6	3.9
12	4.1	5.8	6.1
13	2.7	4.2	4.4
14	1.9	2.3	2.6
15	3.1	4.4	4.7
16	9.2	9.9	10.2

TABLE III-2

VARIATION IN COLLECTOR SIZE ON KW DEMAND*

Colorado Springs

<u>BUILDING</u>	<u>DESCRIPTION</u>	<u>KW DEMAND</u>
Collector = 70m^2 , Storage = 5.3m^3		2.4
Collector = 35m^2 , Storage = 2.65m^2		3.2
Collector = 17.5m^2 , Storage = 1.32m^2		3.9
Collector - 5.6m^2 (Hot Water only)		4.2
No Active System		4.5

*Energy Conservation 2 with 16% south glass and overhang shade.

TABLE III-3

VARIATION IN INSULATION LEVELS ON KW DEMAND*

Colorado Springs

<u>BUILDING</u>	<u>DESCRIPTION</u>	<u>KW DEMAND</u>
Base Building	(R11, R19)	5.8
Energy Conservation 1	(R19, R38)	4.7
Energy Conservation 2	(R24, R38)	4.5
Minimally Insulated	(R4, R19)	10.2
Masonry Heavy Mass Building	(R20, R38)	3.9

*All Buildings are all electric with 16% south glass with overhang shade.

building 4 to building 7, has little effect on kw demand. To our knowledge, simulation of buildings with storage sizes approaching seasonal storage has not been performed, but may result in a cost-effective reduction of peak kw demands.

The Effect of Building Envelope

The impact of solar buildings on utility peak loads in Colorado Springs is not only a function of low levels of radiation, but also a function of extreme ambient temperature. Changes in building envelope design may be more critical to the amount of capacity demanded than is solar equipment sizing. Different building configurations of energy conservation and passive designs have been simulated to examine this hypothesis.

In Table III-3, a number of different building types have been modeled to determine the peak capacity requirements. The importance of insulation as a method of reducing kw demands* is quite evident. An all-electric Base Building requires 5.8 kw of electricity capacity. By adding 6 inches of insulation to the ceiling and utilizing a fully insulated 2"x6" stud wall, the capacity requirement was reduced 19% (1.1 kw) to 4.7 kw. This finding is significant in that given the proper incentives, it could be less expensive for the utility to meet anticipated growth in peak demands by insulating homes in their service area rather than by constructing new generation facilities. This fact is evidence of the importance of conservation as the major source of energy available to this nation. The savings in capacity costs to the utility are in addition to consumer and utility savings in energy consumption.

*The term demand as used in this chapter is an engineering term referring to kilowatts required, and should not be confused with economic demand.

Another finding of note is the peak demand of the Minimally Insulated Building. The peak demand of 10.2 kw for the all electric Minimally Insulated Building with no wall insulation and a window shade is nearly twice the demand of the equivalent Base Building. The only change between the two buildings is the inclusion of 3½ inches of wall insulation in the latter building.

As expected by the diminishing return nature of insulation, the increase in insulation beyond R19 walls, R38 ceiling does not result in as drastic a reduction of utility loads. It is unclear whether the inclusion of an extra inch of Total Wall [®] (Styrofoam [®]) is justifiable. The determination of the optimal amount of insulation cannot be determined by examining the peak capacity effects alone, but must include consideration of annual consumption and costs as well.

Another factor affecting the peak demand of a building is the thermal mass of the building. A masonry structure retains more heat energy collected from the sun radiation during periods of low temperature. The more mass the greater is this potential. In Table III-4 the effects of thermal mass have been isolated. It can be seen that the higher mass Masonry Buildings almost always has a lower demand than the better insulated wood frame building. In the first set of comparisons for the 16% south glass buildings, the heavy mass Masonry Buildings No.11 performs considerably better than the Energy Conservation Building #1 (the 2x6 wood frame light mass Building No.3) (3.9 kw to 4.6 kw). Even Building #4 which is better insulated than the Masonry Building has a higher peak demand. In the other cases, the differences between the wood frame with 80% glass and masonry demands are less significant. This is mostly due to the inclusion of additional thermal mass (water tube storage) into the wood building, doubling its mass.

TABLE III-4

VARIATIONS IN BUILDING THERMAL MASS ON KW DEMAND

Colorado Springs

	<u>All-Electric Configuration</u>
16% glass, with shade	
Building 4 (R24,R38, light mass)	4.5
Building 11 (R20,R38, heavy mass)	3.9
80% glass, with shade, no shutters	
Building 5 (R24, R38, medium mass)	5.9
Building 12 (R20,R38, heavy mass)	6.1
80% glass, with shade, with shutters	
Building 6 (R24,R38, medium mass)	4.0
Building 13 (R20, R38, heavy mass)	4.4

It is clear from Table III-4 that the Masonry Building does reduce capacity requirements significantly. Building No. 11 performs better than the other buildings listed in the previous Table. The only difference between this building and the others is the inclusion of masonry walls and heavy building thermal mass. Building No. 11 performs so well that the capacity demand of the all electric version of Building No. 11 had a capacity demand equivalent of building No. 9 (a 2x6 building with total wall (R24)) with a 17.5m^2 collector. This is in spite of the fact that the costs for the Masonry Building are \$1800 less. The positive effects of heavy building mass are reflected in these results.

The Effects of Fenestration

One of the particularly interesting results of the analysis was the impact of fenestration on capacity demands. The lowered capacity demands of many of the Masonry Buildings were even further reduced through utilization of south facing glass and thermal shutters.

The first entry in Table III-5 shows the effect of adding thermal shutters (R11) to the Energy Conservation Building #1 (a 2x6 with total wall building) with 80% south glass. The reduction in kw demand is 1.3 kw for the active buildings and even higher for the all electric version.

The benefits of shutters are more clearly shown for the Masonry Building in Table III-5. The additional investment in shutters lowered demand by 1.4 kw in the building with an active system, and lowered demand by 1.7 kw in the building with all-electric heating and hot water. Triple glazing and a shade in the same Masonry Building with 80% south glass was almost as effective as the thermal shutters. It is concluded that use of large expanses of south facing glass without the use of thermal shutters and/or triple glazing, tends to

TABLE III-5

THE EFFECT OF THERMAL SHUTTERS ON KW DEMAND

Colorado Springs

<u>Energy Conservation Bldg.2, 80% south glass</u>	<u>35m²Collector</u>	<u>All Electric</u>
without thermal shutter	4.2	5.9
with thermal shutter	2.9	4.0
<u>Masonry Building, 80% south glass</u>		
without thermal shutter	4.1	6.1
with thermal shutter	2.7	4.4
with triple glazing	3.1	4.7

significantly increase coincident peak demand. The benefits of large glass expanses with thermal shutters in reducing kw demand is not assured, however, as the kw demand of buildings with these features were not significantly less than the kw demands of similar buildings with only small (16%) glass expanses.

One passive design, the overhanging shade, which is highly regarded by architects for its ability to reduce summer cooling loads, was found to have a large negative impact on building demands during Colorado Springs utility peaks. The effects of the overhanging shade on kilowatt demands is shown in Table III-6. For the two examples of south 16% glass, the shade has very little impact. The inclusion of an overhang requires about .1 kw of electricity to compensate for a slight reduction in direct solar gain. The real effect of the overhang shade is realized when 80% south glass is utilized. In this case the overhanging shade eliminated the equivalent of .9 kw of direct solar heat gain. The absence of the shade on the 80% glass Masonry Building with winter/summer shutters (Building #14) produced the lowest kilowatt demands of any building, 1.9 kw for the active system. The 2.6 kw demand for the all electric version of this Masonry Building No.14 was lower than any other building configuration except for Energy Conservation Building No. 2 with a 70 m² collector.

A final examination was performed to test the importance of fenestration to building demand at the time of utility peaks. Often overlooked is the importance of building orientation. Several buildings were re-oriented so that the major glass surface faced north rather than south. The results indicate that orientation particularly in buildings with large glass expanses contributes

heavily to building peak demand. This is evident by a range of about .3 kw additional demand for buildings with small areas of glass, and over 1.2 kw. for buildings with large areas of glass.

TABLE III-6
THE EFFECTS OF OVERHANGING SHADES ON BUILDING COINCIDENT
WINTER PEAK DEMAND
Colorado Springs

<u>2x4 Base Building, 16% glass</u>	A	<u>Building*</u>	
		B	C
Building 1 (with shade)	4.6	4.7	5.8
Building 2 (Without Shade)	4.6	5.7	5.8
 <u>Minimally Insulated Building, 16% glass</u>			
Building 16 (with shade)	9.2	10.1	10.2
Building 17 (without shade)	9.1	10.0	10.1
 <u>Masonry Building, 80% glass</u>			
Building 13 (with shade)	3.7	4.3	4.4
Building 14 (without shade)	1.9	2.5	2.6

*

- A. Building with active space conditioning and DHW solar system.
- B. Building with solar DHW system but conventional electric space conditioning.
- C. Building with conventional electric space conditioning and DWH.

C. THE ANNUAL CONSUMPTION (kwh) OF ELECTRICITY

The amount of kilowatts demanded by a building provides an indication of the amount of capacity potentially required by the utility. The value alone, however, does not produce a complete analysis of the impact of buildings on electric utility loads or finances. Neither does the peak coincident demand allow for calculation of cost-effectiveness to the consumer. For this information, a measure of the annual building performance (kwh of electricity consumed) is needed.

A thermal analysis for the base building is performed for configurations including solar or electric heating and hot water (Table III-7); similar analyses were performed for each building and are summarized in Table III-8. Configuration A is any given building with a solar heating and domestic hot water system with electric auxiliary. Configuration B has a solar hot water system with electric auxiliary and electric heating. Configuration C has electric heating and hot water, and is in this sense an "all electric house" although many buildings have passive solar systems operating in Configuration C.

Each configuration utilizes a compression air conditioner with a constant coefficient of performance (COP) of 2.4. Thus, 305 kwh of electricity consumed provides 734 kwh of cool energy delivered. For cooling purposes, the thermostat is set to 25°C. For heating, the solar storage delivers heat below 20°C, and the auxiliary system comes on below 18.4°C.

The Base Building

The annual performance of solar energy and energy conservation investments can best be evaluated by reference to some standard for comparison. In this case, the Base Building (Building No.1) is

taken to have a fully insulated 2x4 wood stud wall, light thermal mass 6" of attic insulation, 16% double glazed windows on the south wall and no overhang shade (see Table III-7). This building utilizes electricity for heating, cooling, and domestic hot water. The base building is a standard for all cost-effectiveness studies of energy-related factors in this report, thus, it is important that its thermal performance be understood in some detail.

Values for the Base Building appear in Table III-7; configuration C is taken as a conventional building and serves as a basis for comparison. The Table shows a total KWH consumption of 18,015, composed of 12,744 kwh for heating, 306 kwh for cooling* and 4,965 kwh for hot water. Comparisons similar to those performed for the peak demands, can be made to show the sensitivity of particular building design practices to annual electricity consumption. Again, for convenience, these alterations can be divided into active solar, building envelope and interior partitioning, and fenestration.

* The predicted cooling loads (kwh) in this report are lower than sometimes experienced by actual consumers. The modeling of cooling loads is more difficult than heating loads because of the existence of latent heat. ASHRAE Fundamentals (1977) suggests that results be multiplied by 1.3 to account for latent heat. Some problems have also been discovered in TRNSYS in the use of a constant ground water temperature and its effect on basement temperature. However, the most significant difference between cooling loads here and those sometimes experienced is the higher thermostat settings and air-conditioner COP's used in this study. Consumer acceptance of higher thermostat settings represents the most cost-effective alternative available.

TABLE III-7

THERMAL ANALYSIS

UTILITY: Colorado Springs Peak Period: Nov-March 4-9 PM, Weekdays

BUILDING: Base Building 2x4, 6" attic insulation, Light RM construction, no thermal shutters, W/O shade, 16% DBL Glaze

COLLECTOR: 35.0 meters sq., storage size 2.65 meters cu., 60 degree tilt

BUILDING DEMAND AT TIME OF UTILITY PEAK

BUILDING NO.1

A. Solar space heating, solar hot water	4.58 kw
B. Electric space conditioning, solar hot water	5.50 kw
C. Electric space conditioning, electric hot water	5.79 kw
Base Conventional Building (used as comparison)	5.79 kw

ANNUAL BUILDING ELECTRICITY CONSUMPTION BY DEMAND PERIOD (KWH)

	ON PEAK (540.HRS.)	OFF PEAK (8220.HRS.)	TOTAL (8760.HRS.)
Building No. 1			
A			
Electric for heat	164.	1801.	1965.
Electric for cool	0.	306.	306.
Electric for hot water	103.	601.	704.
Solar pump electric	0.	625.	625.
Total Electric Use	267.	3333.	3600.
B			
Electric for heat	942.	11802.	12744.
Electric for cool	0.	306.	306.
Electric for hot water	0.	2887.	2887.
Solar pump electric	0.	65.	65.
Total Electric Use	942.	15060.	16002.
C			
Electric for heat	942.	11802.	12744.
Electric for cool	0.	306.	306.
Electric for hot water	521.	4444.	4965.
Total Electric Use	1463.	16552.	18015.

TABLE III-8

BUILDING CONSUMPTION IN COLORADO SPRINGS

(Annual kwh)

<u>Building #</u>	<u>Solar Heating & Hot Water - (A)</u>	<u>Solar Hot Water Electric Heating-(B)</u>	<u>All Electric Heating & Hot Water - (C)</u>
1	3600.	16001.	18015.
2	3622.	15255.	18696.
3	2365.	12850.	16290.
4	2100.	12223.	15664.
5	3912.	5674.	9114.
6	1796.	7049.	10489.
7	1650.	12244.	15684.
8	3205.	11498.	14938.
9	5600.	11731.	15171.
10	987.	12249.	15689.
11	1879.	11924.	15364.
12	2124.	9730.	13170.
13	1289.	6258.	9698.
14	1432.	5564.	9004.
15	1276.	6453.	9893.
16	15518.	30417.	33857.

Active Systems

In the previous section, the evaluation of impact of active systems on utility capacity revealed a one third reduction in capacity requirements from the addition of a 35m^2 collector onto a 2 x 6 with total wall building. The same two buildings have significantly different annual electricity consumptions, however, as revealed in Table III-9. The all electric version utilizes 15,666 kwh annually while 35m^2 of collector reduces this annual consumption by only 2100 kwh.

Changes in the collector size do not radically change the performance of the active systems. Halving the collector size to 17.5m^2 increases the electric consumption to 5501 kwh and doubling the collector only decreases consumption to 987 kwh. Some of the effect of larger collector sizes is negated by the electricity used for the pump which increases as the size increases. More importantly, the larger systems only marginally reduce electricity consumption because larger collection capabilities are only marginally more effective during low radiation periods. It is also important to note that storage/collector ratios have little effect on performance just as was the case in peak demands.

Addition of a solar domestic hot water system to Building No.4 resulted in a 3505 kwh net savings in electricity used for hot water. The determination of cost-effectiveness of these systems is reserved for the financial analysis, the next section of this report.

The Building Envelope

Four insulating envelopes were modeled as shown in Table III-10. The most significant finding is the additional energy consumption of

TABLE III-9

THE EFFECTS OF ACTIVE SOLAR SYSTEMS ON ANNUAL KWH CONSUMPTION
FOR SPACE CONDITIONING AND HOT WATER
Colorado Springs

Energy Conservation Building 2 with 16% glass, shade

<u>Bldg.No.</u>	<u>Collector</u>	<u>Storage</u>	<u>Heating</u>	<u>Domestic Hot Water</u>	<u>Total*</u>
4A	35m ²	2.65m ³	945	488	2100
7A	35m ²	7.95m ³	392	527	1650
8A	35m ²	0.88m ³	2185	427	3205
9A	17.5m ²	1.32m ³	3815	1296	5501
10A	70.0m ²	5.30m ³	145	672	987
4B	5.6m ²	DHW only	10584	1460	12159
4C	None	None	10584	4965	15664

TABLE III-10

THE EFFECTS OF INSULATION ON ANNUAL KWH CONSUMPTION FOR
SPACE CONDITIONING AND HOT WATER
Colorado Springs

16% glass, shade

<u>Bldg.No.</u>		<u>Heating</u>	<u>Cooling</u>	<u>Total**</u>
2C	Base Building	13537	193	18696
16C	Minimally Insulated Building	28077	816	33857
3C	Energy Conservation Building 1	11190	134	16290
4C	Energy Conservation Building 2	10584	114	15664

* Does not include electricity for pumps.

** Includes domestic hot water.

the Minimally Insulated Building. The absence of any wall insulation (Building No. 16) almost doubles the annual electricity consumption to 33857 kwh from 18596 kwh for the Base Building with shades. Inclusion of an additional 2" wall and 6" roof insulation in Building No. 3 lowers consumption by 2347 kwh to 16290. An additional one inch of total wall insulation on the outside of the 2x6 insulated stud wall (Building No.4) reduces consumption by an additional 626 kwh.

The results vary slightly for the same set of buildings with 35m² collectors. The larger building load of the Minimally Insulated Building means a larger contribution for the active collection systems. Over 4000 more kwh of useful energy resulted from a 35m² collector on Building No. 16 than on Building No.2. Active systems will appear more cost-effective when placed on the Minimally Insulated Building. This is an example of the need to integrate all aspects of the building load. Cost-effectiveness of the entire building package (active system, energy conservation, and building design) is not guaranteed by the favorable performance of a single component.

Building Thermal Mass

Examinations of different levels of building thermal mass were made in Table III-11 to determine the impact of thermal mass on annual consumption. Three levels of building thermal mass (low-, medium-, and high-) were modeled. In otherwise essentially identical buildings which had only 16% of the south wall in window and a shade, the heavy thermal mass of Building No. 11 resulted in only very minor savings over the light thermal mass of Building No. 4, conserving 300 kwh (02%), and although cooling demand was cut by 69%, this represented an insignificant 67 kwh.

In two buildings with 80% south facing window area, and a shade but no thermal shutters, an increase from medium (Building No.5) to heavy (Building No.12) thermal mass produced somewhat improved results. Heating was cut by 1271 kwh (13.8%), cooling by 284 kwh (48.9%) and total demand dropped by 1555 kwh or 10.6%.

Two buildings with 80% glass, shade, and shutters showed small savings with the increase from medium (#6) to heavy (#13) mass. 791 kwh (7.5%) were conserved, again with the cooling load cut considerably (47%) and heating load cut relatively little (8%), and no change in hot water demand.

Thermal mass affects building loads by damping interior temperature through its ability to store heat for later convective/radiant fluctuations. In the Colorado Springs heating season ambient, temperature fluctuations are at a sufficiently low temperature that nearly all direct heat gain is immediately useful in meeting the heating load of the base building; therefore, the storage capabilities of the thermal mass are not used often enough to produce a significant impact on heating load. The capacity of the thermal mass is better used with 80% south-facing glass. This is because direct heat gain is much larger, resulting in more heat in the building than is necessary to meet immediate heating requirements. The presence of insulating thermal shutters appears to lower internal temperature fluctuations and, in part, duplicate the role of thermal mass.

Summer cooling loads, however, are significantly lowered by the introduction of additional thermal mass for all buildings studied. This is due to the ability of thermal mass to absorb excess heat for convection-reradiation during the cooler night time, thus, keeping the interior within the comfort zone more constantly.

TABLE III-11

THE EFFECTS OF THERMAL MASS ON ANNUAL BUILDING kwh CONSUMPTION FOR
SPACE CONDITIONING AND HOT WATER

Colorado Springs

<u>Bldg.No.</u>		<u>Heating</u>	<u>Cooling</u>	<u>Total</u>
	16% glass, shade			
4C	(R24 wall, R38 attic) light mass	10584	114	15664
11C	(R20 wall, R38 attic) heavy mass	10352	47	15364
	80% glass, shade			
5C	(R24 wall, R38 attic) medium mass	9179	581	14725
12C	(R20 wall, R38 attic) heavy mass	7908	297	13170
	80% glass, shade, winter shutters			
6C	(R24 wall, R38 attic) medium mass	4654	869	10489
13C	(R20 wall, R38 attic) heavy mass	4277	456	9698

TABLE III-12

THE EFFECTS OF FENESTRATION ON ANNUAL kwh CONSUMPTION
FOR SPACE CONDITIONING AND HOT WATER

Colorado Springs

<u>Bldg No.</u>		<u>Heating</u>	<u>Cooling</u>	<u>Total</u>
	Energy Conservation Building 2 w/80% glass, shade, medium thermal mass			
5C	no shutters	9179	581	14725
6C	winter shutters	4654	869	10489
	Masonry Building w/80% glass			
12C	shade, no shutters	7908	297	13170
13C	shade, winter shutters	4277	456	9698
14C	no shade, winter/summer shutters	3227	810	9004
15C	shade, no shutters, triple-glazed south windows	4570	358	9894
	Base Building w/16% glass			
1C	no shade	12744	306	18015
2C	shade	13537	193	18696

In addition, the benefits of thermal mass at time of utility peak demand where temperature fluctuations are greater, was demonstrated previously in this report.

Fenestration

The final area of examination is the use of windows and fenestration options to improve building loads. These applications were found to have a surprising impact on the capacity requirements of buildings; and, it is important to examine their effect on annual loads. (See Table III-12) The fenestration designs that have been examined are overhang shading, window size, and thermal shutters. Two buildings were modeled with and without an overhang shade: a conventional 2x4 building and a passive oriented masonry structure. In both cases, the shade functioned poorly.

The Base Building (No.1) with a shade was compared to a similar building (No.2) with no shade. The shade did reduce 113 kwh from the cooling load. It also, however, added 793 kwh to the heating load, for a total addition of 681 kwh due to the shade. While this is an increment of only 3.8% to the load, it does not support the installation of a shade.

The shade performed poorly in the Masonry Building as well. Cooling requirements were once again cut (354 kwh), but heating demand suffered badly rising 1049 kwh in Building No. 13 (with shade) over Building No. 13 (no shade). The total demand increased by 674 kwh (7.5%). The results stem simply from the fact that the shade is sun rather than season responsive. That is, if the shade blocks unneeded radiation in September, it will also block the radiation in the colder month of March when it is needed. This problem worsens in a passive solar building, particularly in Colorado

Springs, where direct solar heat gain comprises a greater proportion of the building load. An option that has not been examined but that may avoid some of these problems is a seasonally variant shade such as an awning or foliage-covered trellis.

Shutters were modeled on both well insulated buildings and passive Masonry Buildings. In other cases, the shutters had a largely positive effect. A building with a 2x6 stud walls with 1" total wall, medium mass, and 80% south-facing glass was modeled without shutters (#5) and with shutters which remained open at all times of little or no insolation (#6). The heating load was decreased by 4525 kwh (49.3%), while the cooling was increased by 288 kwh (49.6%).

Dramatic savings occurred when shutters were added to the Masonry Building. Building No. 12, with no shutters and 80% glass, consumed 7908 kwh for heating; the addition of a winter shutter (Building No. 13) decreased the heating demand by 3631 kwh (45.9%), and total demand by 26.4%. A winter/summer shutter (Building No. 14) with no shade decreased total demand by 4166 kwh. The inclusion of a summer shutter routine effectively eliminated all summer cooling loads. During the spring and fall, when temperatures fluctuate greatly, a significant amount of cooling was required in part because of a relative lack of sophistication in the controlling routine. A more sophisticated operation mode for the shutters could effectively eliminate this problem. It is unclear, however, whether this additional expense is a better system than human control. With a winter/summer shutter system such as that modeled here, and air conditioner would be used during spring and fall, but never in summer. In reality, a resident would most likely open the windows in lieu of running the air conditioner, such human intervention would effectively remove the need for better controllers.

The Masonry Building was also modeled using triple-glazed windows over 80% of the south wall (Building No. 15). This reduced heating demand by 3338 kwh (42.2%) from that of the double-glazed building, but this load was higher than that for shuttered buildings. It is important to realize that triple glazing is always in place and requires no human or mechanical control. This convenience inherent in triple glazing ensures its performance; unlike human or mechanical control where unreliability or malfunction may cause the shutters to perform at less than optimal efficiency.

Insulating devices to reduce heat loss/gain through windows are very effective. Winter/summer shutters offer real promise as they provide shading as well; triple glazing may offer a reasonable compromise between the need for control and the desire for enabling direct heat gain while keeping heat loss down.

Two window areas on the south-facing wall were modeled, 16% and 80% of the wall. The smaller window area reduced cooling loads (Building No. 11) from larger window areas (Building No. 12), but the cooling load is a small part of the total load. In addition, this problem for 80% glass can be alleviated through use of a summer shutter or seasonally variant shading such as a trellis or awning. These options unlike a fixed shade, also allow full winter use of the direct gain capabilities of the large window area. The shutters are also capable of reducing the problem of heat loss through windows. Triple glazing offers a reasonable alternative, reducing both initial cost and required control, while enhancing direct heat gain.

D. LOAD FACTORS

The thermal analysis so far calculated consists of two separate pieces of information: the kilowatt demand at the time of the

utility peak and the annual kilowatt hour consumption. Individually, neither of these values provides information concerning building thermal performance that is adequate for calculating building cost-effectiveness or building impact on the utility. Combining the two values together into one value called load factor does aid in comprehending building thermal performance, particularly on utility impact.

The individual building load factor (the average kilowatt demand divided by the kilowatt demand at the time of utility peak load demand) is an indication of the impact of a particular building on the utility load. This value is useful in providing a simplified indication of utility generation efficiency, but it should be noted that it does not provide an analysis of utility finances. Because load factor is merely a ratio and not an absolute value, it cannot predict the absolute level of impact--even a qualitative evaluation of financial impact.

The load factor for the Colorado Springs utility as a whole was 63% for 1975. The all electric Base Building only had a load factor for space conditioning and hot water of 36%. This indicates that these uses of electricity may worsen the overall load factor and operating efficiency of the utility.* Higher load factors would translate into more constant usage of generation facilities and, therefore, more efficient system operation.

A table listing the individual load factors for each of the buildings modeled is shown in Table III-13. Clearly the most

* Because other (non-coincident loads) aspects of the consumer's electricity usage are ignored, it is not clear from this analysis how individual's loads impact the overall utility load factor.

significant finding is the extremely low load factors for the buildings with active systems. All buildings with combined solar space and water heating systems had individual load factors of lower than 10%. This strikingly illustrates the cause for concern of utilities over the massive introduction of solar energy systems with electric back-up. It appears that in Colorado Springs, a large amount of the auxiliary energy required by the buildings with active systems is actually demanded at times of utility peaks. The larger the active system, the truer this is.

Several other significant trends are noticeable concerning load factors. All but one of those buildings that utilize large amounts of passive direct solar heat gain also have lower load factors. It is logical to assume that cloudy conditions that exist at times of utility peak will affect both active and passive solar collection. Counterbalancing the trend of low load factors for solar buildings are the improved load factors of energy conservation buildings. The use of attic and wall insulation beyond the Base Building improves the load factors of the all-electric buildings. One unique building is the Masonry Building with 80% south glass, a winter/summer operating shutter, and no shade. The load factor of this building is larger than the Base Building despite the dependence on passive heat gain for a large portion of building heating load. The inclusion of effective shutters (which operate on a seasonally differentiated basis) and heavy thermal mass provide an energy conserving device which counteracts any bad effect noticeable in other passive buildings.

The true extent of the impact of these buildings on the utility company cannot be assessed merely by the use of load factor. An example of this is the similar load factors obtained by Buildings

TABLE III-13

INDIVIDUAL LOAD FACTORS

Colorado Springs

<u>Bldg.#</u>	<u>Solar heating & hot water - (A)</u>	<u>Solar hot water electric heating-(B)</u>	<u>All-electric heating & hot water - (C)</u>
1	.09	.33	.36
2	.09	.31	.37
3	.08	.33	.40
4	.08	.33	.39
5	.11	.11	.18
6	.07	.21	.30
7	.06	.31	.37
8	.11	.31	.38
9	.16	.32	.39
10	.05	.30	.36
11	.08	.38	.45
12	.06	.19	.25
13	.05	.17	.25
14	.09	.29	.40
15	.05	.17	.24
16	.19	.35	.38

No.4 and No. 16. Building No. 4 has a yearly energy consumption of less than one half of Building No.16 and, therefore, has a completely different absolute effect on the utility loads and finances. This will be shown more clearly in the section on utility impact.

E. FINANCIAL IMPACT ON CONSUMER

The thermal analysis provided on account of the flow of energy through the solar energy system and electricity through the building-utility system. At the same time, there is a flow of money and resources made in solar and utility equipment investments and fuel to generate electricity. A financial analysis follows to determine the most appropriate combination of active solar, passive solar and energy conservation investment, such that total costs are minimized.

In the case of residential energy usage, several different perspectives can be identified because costs are not incurred directly by the end user. The cost of electricity for the user is not always recovered by utility tariffs which apply to broad ranges of users. There are costs, as well as some benefits which are not, however, reflected in electricity prices. These include dependence on foreign fuel supplies, the social cost of embargoes, and environmental degradation. The price a consumer pays as a determinant in his decision-making does not always lead to minimum total cost for society, as we examine below.

A procedure for accounting for the cost of each building from each of these perspectives has been developed herein. Table III-14 details the incremental costs of modifications to the Base Building, (a 2x4 insulated wood frame, with 6" attic insulation).

The Base Building serves as the basis of comparison with all other buildings. Three different supply function types have been examined using the Base Building. They include:

- A) a solar combined hot water and heating system, with solar collector sized for both heating and hot water;
- B) a solar hot water system with electric heat, with solar collector sized solely for hot water; and
- C) conventional electric hot water and heating system.

All of the above utilize a central compression air conditioner.

Base Building D listed in Table No. 16 is the Base Building with all other buildings. The incremental cost of each of the buildings is listed in the table. These costs are derived from Means (1976) and represent the base assumption. Below, sensitivity analysis will be performed on these costs.

The analysis presented in Table III-15 is for first year cost analysis. The same assumptions have been used to examine the financial situation of these buildings under lifecycle cost analysis. Both modes of analysis are relevant as there is no consensus as to which better reflects the investment decisions of homeowners. Lifecycle costs do allow the consumer to anticipate a rise in the cost of fuel and to plan accordingly. For a number of reasons, however, the individual probably does not base his investment decisions on a twenty year time horizon.*

The analysis begins with an assessment of the cost to the consumer in the first year. The sum of the amortized yearly investment in capital equipment, the electric bill and maintenance costs provides the total cost incurred by the consumer. Incremental

* One other method of accounting for consumer preference with time streams closer to the present is the use of very high discount rates.

TABLE III-14

BUILDING COSTS - COLORADO

	<u>Incremental Cost Over Base Building</u>	
Wall Models	<u>16%Glass</u>	<u>80% Glass</u>
2x4	-407.	
2x4, Insulated	0.	
2x6, Insulated	256.	932.
2x6, Insulated, 1" Total Wall	663.	1182.
8" Masonry, 4" Total Wall	3183.	2728.
Roof Models		
Standard Roof	0.	
Asymmetrical Roof Supporting 17.5m ² Collector	878.	
Asymmetrical Roof Supporting 35m ² Collector	797.	
6" Additional Ceiling Insulation	464.	
Solar System Models		
Collectors	160/m ²	
Fixed Collector Costs	1687.	
Storage, size DHW System	2500.	
Fenestration Models		
4" Overhang Shade	1108.	
Shuttering (with 80% South Wall Windows)	1015.	
Roller Blind Shades (80% Windows)	120.	
Medium Mass	700.	
Triple Glazing (w/80% South Wall windows)	1007.	
Load Management	2500.	

TABLE III-15
FINANCIAL ANALYSIS
FIRST YEAR COSTS

UTILITY: Colorado Springs peak period: November-March, 4-9 P.M., weekdays.

BUILDING: Base Building 2x4, 6" attic insulation, light room construction, no thermal shutters, without shade, 16% double glazing.

COLLECTOR: 35.0 meters square, storage size 2.65 meters cu., 60° tilt.

<u>TYPE</u>	<u>INCREMENTAL BUILDING COST (\$)</u>
A. Solar space heating, solar hot water	8254.
B. Electric space conditioning, solar hot water	2500.
C. Electric space conditioning, electric hot water	1.
D. Base conventional building (used for comparison)	0.

ANALYTICAL ASSUMPTIONS:

LIFE CYCLE: 20 years	MORTGAGE: 20 years
DISCOUNT RATE: 0.08	RATE: 0.085
ELEC. PRICE ESCALATOR: 0.070/YR.	DOWN PAYMENT: 0.00
FUEL COST ESCALATOR: 0.100/YR.	SALVAGE VALUE: 0.00
X-ELASTICITY: 0.0	

BUILDING	A		B		C	
RATE SCHEDULE	<u>AC</u>	<u>MC</u>	<u>AC</u>	<u>MC</u>	<u>AC</u>	<u>MC</u>
INCREMENTAL						
CAPITAL COST	872.	872.	264.	264.		
ELEC. BILL	90.	82.	400.	337.	450.	420.
MAINTENANCE	83.	83.	25.	25.	0.	0.
TOTAL COST						
(CONSUMER)	1045.	1037.	689.	626.	450.	420.

capital costs are calculated as those investments beyond the standard equipment in the all-electric Base Building. Should any of these buildings with additional investment for energy reduction have a lower first year cost than the Base Building than this would signal a very favorable investment. This would mean that even in the initial year of a long term investment, the entire yearly costs of the investment including the interest would be less than the savings in electricity cost.

The total incremental cost to the consumer for Base Building A under the existing rate schedule is \$1045. This figure represents the first year expenditure for the incremental amortized capital costs of a solar combined hot water and heating system (\$872) and electricity costs for electric air conditioning and auxiliary electricity for the solar systems (\$90), and maintenance (\$83).

The cost effectiveness of A, a combined solar hot water and heating system on the Base Building must be evaluated in comparison to C, the basis for comparison. In this case, the cost to the consumer for A (\$1046) is greater than the cost for C (\$450), and this signals that investment in a combined solar hot water and heating system is not desirable by the building owner under this particular set of assumptions. The first year cost to consumer for the hot water system on the Base Building (B) is also higher (\$689).

While the solar energy system on the Base Building is not cost-effective, there may be other buildings that may be cost-effective. A summary of the cost for each of the buildings is presented in Table III-16. This table examines these costs under existing average cost rates. The cost to the consumer in column one shows that the \$450 for Base Building C is the lowest value.

TABLE III-16
SUMMARY OF FINANCIAL ANALYSIS

- NO TAX CREDITS -

FIRST YEAR COSTS

<u>Bldg.No.</u>	<u>Solar heating & hot water - (A)</u>	<u>Solar hot water electric heating-(B)</u>	<u>All electric heating and hot water-(C)</u>
1	1045.	689.	450.
2	1106	729.	524.
3	1150.	745.	542.
4	1186.	772.	569.
5	1360.	717.	534.
6	1425.	889.	686.
7	1338.	773.	570.
8	1159.	754.	551.
9	918.	760.	557.
10	1929.	773.	570.
11	1447.	1031.	828.
12	1405.	928.	725.
13	1502.	959.	756.
14	1447.	834.	680.
15	1443.	856.	702.
16	1362.	1067.	864.

The next two closest buildings are also all electric versions.

A Base Building with an overhanging shade increases the first year cost by \$76 to \$526. The inclusion of the shade on the Base Building is not an effective investment. Another building, the Energy Conservation Building No. 1 (a 2x6 insulated wood frame with 12" attic insulation) also with a shade had a first year cost of \$542. To evaluate the cost-effectiveness of the additional insulation, the effect of an overhanging shade must be controlled; therefore, comparison must be between the two buildings with shades. The incremental investment in insulation beyond the Base Building (Building No. 3C vs. Building No. 2C) results in only a \$16 increase in total costs in the first year. With any increase at all in the price of fuel, this would become a feasible investment.

Additional investment in insulation (a 1" sheathing of styrofoam) in the Energy Conservation Building No. 2 (No. 4C) results in costs that are slightly higher than for Energy Conservation Building No. 1 (3C). Investments in the all-electric Masonry Buildings (No.'s 11C, 12C, 13C, 14C and 15C) are considerably higher. The first year costs for the active configurations are even higher still, generally twice the cost of an identical building with all-electric space heating and hot water.

The fact that the first year cost analysis yields higher costs for solar and or energy conservation investment does not bode badly for consumer investment in these alternatives. Annual increases in all fuel costs which are expected in the future will make some investments cost-effective over their life cycle. In life-cycle cost analysis, the report utilizes, as a base set of assumptions,

those assumptions adopted by DOE (Bezdek, 1978). These assumptions include:

- a) lifecycle = 20 years
- b) discount rate = 8%
- c) interest rate = 8.5%
- d) downpayment on incremental construction costs = 20%
- e) rate of annual increase in fuel cost = 10%
- f) rate of annual increase in electricity price = 7%

Maintenance costs are assumed to be one percent of capital cost of active systems and thermal shutters and increases at the level of inflation (6% per year). It is assumed that maintenance costs for insulation, windows and building structure remain constant for each building type. No salvage value for the solar energy system after the twenty year lifetime is assumed. An actual salvage value greater than \$0 would tend to make solar investment more cost-effective.

One of the problems with utilizing lifecycle cost is the need to provide information concerning future costs. Different perceptions exist with regard to future prices and the benefits accrued from future streams of income in comparison to present streams of income. It is, therefore, difficult to specify the appropriate price escalation rate and discount rate. Three future scenarios have been identified where the benefits of the future and energy conservation assume increasing importance. As a result, the name "Low", "Medium", and "High" have been used to label the scenarios.

- 1. Low - Discount Rate (DR) = 10%, Electricity Increase (EI)=6%.
- 2. Medium - DR=8%, EI=7%
- 3. High - DR = 6%, IE = 10%

LOW SCENARIO

(Discount Rate = 10%, Electricity Annual Price Increase = 6%)

As was the case in the first year cost analysis, the all-electric Base Building (1C) without the shade has the lowest lifecycle cost under the "Low" Scenario. The Energy Conservation Building No. (3C) is now the second lowest cost alternative. This implies that the additional insulation is a justifiable investment, while the investment in the shade is clearly not justifiable. Other Energy Conservation Buildings 4C and 6C are similarly cost-effective as are two Masonry Buildings 14C and 15C. Active solar investment does not appear cost-effective under this scenario.

MEDIUM SCENARIO

(Discount Rate=8%, Electricity Annual Price Increase=7%).

Although the all electric Base Building IC retains its position as the lowest cost alternative, the gap is less between that building and others. More importantly several buildings with shades are less expensive than the Base Building version with shade. This more equitable comparison illustrates that under this scenario, both 2x6 walls and 12" attic insulation, and 2x6 walls with total wall and 12" attic insulation are cost-effective over standard insulation.

This scenario is equivalent to the one used by Bezdek (1978) which found in Grand Junction solar hot water heaters to be cost-effective in comparison to hot water heaters. The low cost of electricity for Colorado Springs \$.025 as compared to \$.04 in the Bezdek study does not support this finding in Colorado Springs. In fact, the cost of solar systems were significantly higher than any of the all-electric Energy Conservation and Masonry Buildings.

HIGH SCENARIO

(Discount Rate =6%, Electricity Annual Price Increase =10%)..

This scenario gives the most value to the future of any of those examined, as a result, findings are significantly different under this scenario. The all-electric Masonry Building 14C with differentiating shutters on 80% south glass is the lowest alternative, Following closely is another Masonry Building with a permanent shade and 80% south triple glazing. Two other buildings which utilize passive design (80% glass and shutters) 13C and 6C, also, had lower costs than the Base Building 1C. A large number of buildings - 12- had lower costs than the all electric Base Building with shade including two with solar hot water systems (14B and 15B) and one with solar combined system a 17.5m² collector on Energy Conservation No.2 (9A). One finding is it is better to place a 17.5m² collector on an extremely well insulated building that it is to place a 35m² collector on Base Building. Unfortunately, it is not clear from the analysis what the cost-effectiveness of a 17.5m² collector is on the Base Building.

A finding worthy of note is the cost analysis for the Minimally Insulated Buildings. The lifecycle costs of \$24,000 and up are the highest value. The simple investment in wall insulation reduces the lifecycle cost almost in half. There appears to be no clearer savings derived from any other investment. Conversely, an extremely large investment, such as a 70m² collector system and additional insulation as in the Energy Conservation No. 2 (Building 10A), does not guarantee a savings as this building is among the highest costing buildings. In addition, as would be expected, investment in an active system on Masonry Buildings is not justified.

F. THE IMPACT OF TAX CREDITS

Conflict exists between the immediate needs of individuals and the long run optimum for society. The individual consumer is constrained in energy investment by the need to invest money up front for potential future savings. The government has found this first cost constraint to be so significant that tax policies are being developed which lessen the initial cost outlay. The most significant policies to date are tax credits which allow the investor to recoup a percentage of the initial investment in reduction in income taxes.

Four different tax policies have been examined here to assess the impact of tax policies on cost-effectiveness to the consumer. In addition, the economic efficiency of these tax credit policies will be addressed with regard to maximizing societal welfare, (see Appendix A for a more detailed discussion of tax credit policies). The policies include:

1. The proposed Federal Tax Policy for solar energy and energy conservation. For active solar, 30% of the first \$2,000 and 20% of the next \$8,000. For energy conservation, 20% of the first \$2,000.*
2. An alternative Federal Tax Policy where solar energy and energy conservation investment are treated equivalently. 30% of first \$2,000 and 20% of the next \$10,000.
3. The proposed California State Tax Credit Policy for solar energy. This state-of-the-art policy provides

*Author's Note: The actual tax credit policy adopted by Congress in October, 1978, provided only 15% of the first \$2,000 for energy conservation. The benefits of the tax credit in this analysis may exceed actual benefits by as much as \$100.

credits up to 55%, up to \$3,000 in credit for active systems, passive systems and energy conservation in conjunction with solar.

4. An alternative California Tax Policy, where energy conservation not in conjunction with solar, also is eligible for tax credit.

The results of the different (actual and hypothetical) tax policies on consumer first year costs is shown in Table III-17. The Federal tax credit (No.1) for solar has very little effect on the first year cost analysis. The all-electric Base Building without shade (1C) is still the least cost alternative, though the all electric Energy Conservation Building with shade (3C) is now less expensive than the all-electric Base Building with shade (2C). The reduction is enough to make the inclusion of additional insulation cost-effective between the two shaded buildings even in the first year. Otherwise, the desired impact of lowering the capital costs of larger active systems is not completely realized. The savings in active systems still leaves the cost of buildings with active systems higher than energy conservation and passive buildings. This is in spite of the fact that the latter two investments do not receive nearly the same benefits from the tax credit policy.

A Federal policy which treats each of these investments equally, places a definite advantage to additional insulation over any solar energy investment as Building 3C has a lower cost than 2C.

The California Tax Credit Policy represents an even broader commitment to the development of alternative investments over electricity. Tax credits are extended in larger quantities to both passive designs including overhanging shades, thermal shutters, window size and glazing and thermal mass. Only the investment in

TABLE III-17

THE IMPACT OF TAX CREDITS ON CONSUMER COST-EFFECTIVENESS

Colorado Springs

FIRST YEAR COST ANALYSIS

TAX POLICY	LOWEST COST ALTERNATIVE	OTHER BUILDINGS LOWER THAN BASE BUILDING WITH SHADE #2C
1. No Tax Policy	All-Electric Building with overhanging shade -#2C	None
2. Federal Solar Tax Policy (originally proposed) (Solar 30% first \$2000, 20% next \$8000); (Con- servation 20% first \$2000).	All-Electric Base Building #2C and All-Electric Energy Conservation Building #1 3-C	No others
3. Federal Solar= Energy Conservation Tax Policy (hypothetical) (Solar and Energy Conservation 30% first \$2000, 20% of next \$10,000).	All-Electric Energy Con- servation Building #1 3-C	No others
4. California Solar Tax Policy (existing) (55% of active and passive solar and Energy Con- servation in conjunction with solar up to \$3000.	All-Electric Masonry Building 14-C	13C, 15C
5. California Energy Conser- vation=Solar Tax Policy (hypothetical) - same as 4 but includes all energy conservation.	All-Electric Masonry Building 14-C	3C, 4C, 6C, 13C, and 15C

All Buildings with overhanging shade and/or thermal shutters.

energy conservation, not in conjunction with solar, is not eligible .

This excludes from credit any investment in the all-electric buildings that just improve insulation levels and excludes retrofitting with insulation alone for the Minimally Insulated Building.

The significant finding is that the all-electric Masonry Building with thermal shutters, 80% and no shade was the least cost alternative. The investment in energy conservation fell in ranking being replaced by several passive Masonry Buildings. In the original California solar tax credit, where energy conservation not in conjunction with solar, does not qualify, the cost-effectiveness of energy conservation alternatives was significantly altered. Savings accruing to the passive and active solar investments were not received by solely energy conservation alternatives. Energy conservation investment still remained favorable in comparison to active solar heating investment, however.

When benefits of the tax incentive were included for energy conservation, the position of these investments improved. Both investment in Masonry Buildings 14C and 15C and Energy Conservation Buildings 3C, 4C and 6C were lower than the all-electric Base Building with shade (2C). The best active system was a 17.5m^2 collector system. It should be pointed out again that the inclusion of both a collector and extensive insulation as is done here, is in part a duplication of effort. It is unclear whether separate investment in active systems or insulation would make the cost-effectiveness of the 17.5m^2 collection system on a Base Building greater than that of the all-electric Energy Conservation Building No.2.

The impact of tax credits on the life cycle cost analysis reveals an even clearer case of cost-effectiveness of the all-electric version of the Masonry Building with winter/summer shutter 14C. Under the medium lifecycle scenario, see Table III-18), it is illustrated that

Building 14C is the least cost alternative for three of the four tax credit alternatives. The existing Federal Tax Policy for solar does not provide enough benefits from energy conservation and passive solar to change the cost advantage of the Base Building without shade. With a tax policy that includes benefits of passive investment (cases 3, 5, and 5) the Building 14C becomes the least cost-effective.

An interesting change occurs when the high future oriented lifecycle scenario is examined, see Table III-19. The cost of fuel in the future becomes great enough to justify the inclusion of a solar hot water system onto the Masonry Building with winter/summer shutters. In addition, nearly every building with additional investment in either energy conservation, active or passive solar energy was less expensive than the Base Building 1C.

G. IMPACT ON UTILITY

The above cost-effectiveness evaluations provide an indication of benefits accrued to individual consumers as a result of investment in solar energy and/or energy conservation. Other impacts not accounted for in the consumer analysis also exist, including impacts on electric utilities that provide back-up power or that compete for energy sales. The true societal value of a new energy source must include these costs or benefits in the final cost analysis.

The introduction of new building designs or technologies will affect a utility by altering the utility load characteristics. It is important for the utility to be able to assess the extent of this impact in order to adjust long range capital expansion plans. In addition, a measure of the cost to service these new technologies must be obtained in order to evaluate the appropriateness of particular rate schedules.

TABLE III-18

THE IMPACT OF TAX CREDITS ON CONSUMER COST-EFFECTIVENESS

Colorado Springs

LIFECYCLE COST ANALYSIS

MEDIUM FUTURE SCENARIO*

TAX POLICY	LOWEST COST ALTERNATIVE	OTHER BUILDINGS LOWER THAN BASE C
1. No Tax Policy	All-Electric Base Building w/o shade 1C	None
2. Federal Solar Tax Policy (originally proposed) (Solar 30% first \$2000, 20% next \$8000, Energy Conservation 20% first \$2000).	All-Electric Base Building w/o shade 1C	None
3. U.S. Energy Conservation= Solar Tax Policy (<u>hypo-</u> <u>thetical</u>). (Solar and Energy Conservation 30% first \$2000, 20% of next \$10,000).	All-Electric Masonry Building, 80% Glass w/o shutters 14C	8C, 15C
4. California Solar Tax Policy (<u>existing</u>). (55% of active and passive Solar and Energy Conservation in con- junction with Solar up to \$3000).	14C	6BC, 9A, 12C, 13BC, 14B, 15BC
5. California Energy Conser- vation = Tax Policy (<u>hypothetical</u>). (Same as 4 but includes all energy conservation	14C	3BC, 4BC, 6BC, 7BC, 8BC, 9A,B,C, 12C, 13 BC, 14B 15 BC.

*Lifecycle 20 years., DP=8%, IR=8.5%, Downpayment =20%, Rate fuel cost increase= 10%, Rate electricity price increase = 7%.

TABLE III-19

THE IMPACT OF TAX CREDITS ON CONSUMER COST EFFECTIVENESS

Colorado Springs

LIFECYCLE COST ANALYSIS

HIGH FUTURE SCENARIO*

TAX POLICY	LOWEST COST ALTERNATIVE	OTHER BUILDINGS LOWER THAN 1C
1. No Tax Credit	All-Electric Masonry Building 14C	6C, 13C, 14B, 15BC
2. Federal Solar Tax Policy (originally proposed). (Solar 30% first \$2000, 20% next \$8000, Energy Conservation 20% first \$2000).	Solar hot water system on 80% glass, w/s shutters, 14B	3AC, 4AC, 6BC, 7ABC, 8ABC, 9ABC, 13BC, 14C, 15BC
3. U.S. Energy Conservation= Solar Tax Policy (<u>hypo-</u> <u>thetical</u>). (Solar and Energy Conservation 30% first \$2000, 20% of next \$10,000).	14B	3AC, 4AC, 6BC, 7ABC, 8ABC, 9ABC, 12BC, 13 BC, 14C, 15BC
4. California Solar Tax Policy (<u>existing</u>). (55% of active and passive Solar and Energy Conservation in conjunction with Solar up to \$3000).	14B	3ABC, 4ABC, 6BC, 7ABC, 8ABC, 9ABC, 12BC, 13BC, 14C 15BC
5. California Energy Conser- vation= Solar Tax Policy (<u>hypothetical</u>). (Same as 4 but includes all energy conservation).	14B	3ABC, 4ABC, 6BC, 7ABC, 8ABC, 9ABC, 12BC, 13BC, 14C, 15BC

*Lifecycle = 20 years, DR=6%, IR=8.5%, Downpayment =20%, RIFC=10%, RIEC=10%

Financially, the utility cost of service is affected by drops in demand and consumption. Determining the actual dollar impact of these changes is not often easily obtained or comprehended, due to the complexity of finances within the utility's position as a regulated industry. Financial impact upon the shareholders of a private utility is a separate issue from impacts upon the customers and the rates they are charged.

In general, the impact of individual loads on the overall revenue situation of utilities is not critical. Utility profits are determined through the regulatory mechanism where total system operation is concerned. Rate schedules are not created to produce equivalent profits from each kwh sold, but to combine broad ranges of user rate classes. Discrimination is inherent in any tariff and, in fact, is often justified by the regulatory commissions for other reasons of public good (for instance, energy conservation).

The impact of a particular part of an individuals load must be evaluated in reference to an issue of equity. If the cost to service that load is greater than the revenues received via the electric rate than those particular users are being subsidized by the rest of the utility customers. Examination of the building configurations will exhibit this more clearly.

The total cost of service to the Colorado Springs utility for the all-electric Base Building is \$396 for the first year (\$199 in variable costs, and \$197 in capacity costs). The revenue received by the utility under the average cost declining block tariff is \$450. This leaves a balance to the utility of -\$54 meaning that the cost of service for the space conditioning and hot water usage of the all-electric Base Building is exceeded by the electric bill by \$54. In Table III-20, the first year cost balance to utility is listed for each building from the existing average cost declining tariff block.

TABLE III-20

FIRST YEAR COST BALANCE TO UTILITY

<u>Bldg.No.</u>	<u>Solar heating & hot water</u>	<u>Solar hot water electric heating</u>	<u>All-electric heating & hot water</u>
1	106.	-37.	-54.
2	107.	-22.	-62.
3	85.	-30.	-68.
4	78.	-27.	-64.
5	87.	112.	74.
6	72.	29.	-9.
7	83.	-17.	-55.
8	73.	-16.	-54.
9	65.	-23.	-60.
10	67.	-11.	-48.
11	68.	-44.	-82.
12	110.	62.	24.
13	75.	53.	16.
14	44.	-4.	-38.
15	88.	60.	22.
16	94.	-87.	-124.

Two major trends in the first year cost balances can be identified. The most important is the large negative values for most of the all-electric buildings (C) and some of the buildings with solar hot water heaters (B). Building configurations with high electric consumption and high load factors have negative cost balances. A negative value implies that the electric rate recovers via the electric bill to the consumer more revenue than is estimated for the utility's cost of service.

In contrast, high positive cost balances for configuration A (the solar heating and hot water) buildings are observed. These results illustrate the revenue problem envisioned by utilities that must supply auxiliary power to solar systems. For example, the estimated cost of service for the active solar version of the Base Building in the first year is \$196 (\$40 for variable costs and \$156 for capacity costs, but the revenue is only \$90. In this example, the all-electric buildings are subsidizing the solar buildings. In comparing the impact on the utility of the all-electric and solar Base Buildings the difference in net revenue to the utility is \$160.

It has been suggested that a different tariff be designed for solar energy buildings because of the inability of the existing rates to recover sufficient costs.* Public Utility Commissions do have the power to create rates that differentiate users if there are significant differences in costs and revenues, particularly if harm can be shown to another set of customers. Whether, however, solar energy provides adequate benefits to all customers is a decision

* See, for example, the case of Colorado Public Service Corporation (Mills, 1977).

of the PUC's and government.

Rates are important because they provide a signal to the consumer as to cost of electricity. Disparity between rates and actual costs of service create inefficiencies in allocation of resources and deviations from maximum societal welfare.

The existence of buildings that have poor load factors is due, in part, to the existence of tariffs that ignore these differences of cost in the rate formulation. Residential buildings in general impact poorly on utility load factors. The existence of load management will not occur without incentives in the form of tariffs which differentiate the cost of on and off peak power. Other alternatives exist such as interruptable rates which also allow the utility to lower peak demands, without large disruptions in consumer comfort.

Time of use tariffs(TOU) are gaining popularity among utility professionals. A hypothetical TOU tariff has been simulated here to show the impact on the utility. In this case, the TOU tariffs generates less revenue than did the average cost tariff. The reason being that more of the building's energy consumption is off peak in comparison to the entire residential electric demand. This rate does not initially improve the discrepancy between revenues and costs. Given a price elasticity other than zero, changes in homeowners' behavior may improve the utility cost balance.

The existence of TOU rates provides incentives to consumers to invest in hardware that limits on-peak electricity consumption. Off-peak thermal energy storage (TES) may provide greater cost savings to the individual and benefits to the utility than solar energy charged storage. An exploration of this was performed in Colorado Springs, comparing a TES system to the previously modeled

systems. The control strategy for the TES system was simply to provide energy to storage via off-peak electricity until a critical tank temperature, sufficient to carry the building through the peak period, was surpassed.

The results indicate (in Table III-21) that the TES system utilized 2212 more kwh of electricity for heating (14956 kwh to 12744 kwh) than the conventional resistance heating unit for the same building (Base Building #1). The benefits of TES though are that the entire electricity consumption occurred off-peak. The operation of the TES system was sized to insure no on-peak electricity required. A smaller tank or lower tank temperature would lower tank losses and improve TES cost-effectiveness. Optimization of the TES system is beyond the scope of this project. The benefits to the utility in fuel savings, improved load factor and reduced capacity requirements are intuitive. Benefits to the consumer, however, can only be realized if some rate incentive is provided.

The results of the first year cost analysis reveal that this particular TES system is not cost effective to the customer. Although the TES system does lower costs of fuel, the reduction is insufficient to compensate for the added capital expense of a thermal storage device.

Despite complete avoidance of peak period electricity charges at \$.0996/kwh, the TES does not save money. The conventional electric resistance heating system in Colorado Springs utilizes a majority of its energy in the off-peak hours so that potential savings by TES is limited. Another important note is that unlike other investments explored in this study, the economics of TES system becomes worse in the lifecycle analysis. Because TES systems consume more electricity, future rises in price will make them less economic with time, at least in the case of this utility.

TABLE III-21

A COMPARISON OF THERMAL ENERGY STORAGE (TES)

VERSUS
ELECTRIC RESISTANCE HEATING (ERH)

Colorado Springs

(BASE BUILDING, NO SHADE 1C)

Thermal Analysis

	kwh s			kw demand at utility peak
	On Peak	Off Peak	Total	
TES	0	14956	14956	0.7
ERH	942	11802	12744	5.8

Financial Analysis - First Year Analysis

	<u>Incremental Capital Cost</u>	<u>Electric Bill- TOU Rate</u>	<u>Total Cost to Consumer</u>
TES	\$ 264	\$ 379	\$ 645
ERH	\$ 0	\$ 420	\$ 420

Medium Life Cycle Cost

TES	\$3070	\$11013	\$ 14083
ERH	\$ 0	\$12227	\$ 12227

The real benefits of TES systems are in the reduction in the kw capacity requirement of the utility. Other strategies might also enable the utility to reduce kw requirements without a commensurate increase in kwh consumption. Peaking problems can be alleviated utilizing interruptable service contracts with electric heating customers. The interruptable service lowers the kw capacity requirement of the utility. The infrequencies of peak electricity demand by solar buildings may make interruptable service contracts ideal. Experimentation has revealed that large amounts of building thermal mass dampen heat flows to such a degree that the exclusion of all on-peak electrical heating does not appreciably alter internal room temperature or comfort in the high mass Masonry Building.

H. SOCIETAL IMPACT

The need for utility capacity at system peak has been illustrated as a major problem to electric utilities. The opportunity for solar energy and/or energy conservation to benefit the utilities and society stems from the ability of these technologies to provide generation capabilities at a lower cost or curtail the need for the facility.

At present, the cost of an incremental kilowatt of capacity for Colorado Springs is \$34 per year. Compared to the typical U.S. utility, the cost of generation for Colorado Springs is low.

In Table III-22, the costs of several alternative technologies are compared to the \$34 per kw per year for conventional sources. The table illustrates the clear savings that insulation of Minimally Insulated Buildings have over new generation capacity. The \$41 per year for insulation saves the utility \$150 in generation costs

TABLE III-22

COMPARISON OF COSTS PER KW BETWEEN CONVENTIONAL GENERATION
TECHNOLOGY (COAL) AND DECENTRALIZED
ALTERNATIVES - Colorado Springs

<u>INVESTMENT</u>	<u>KW SAVED AT RESIDENCE OVER BASE BUILDING</u>	<u>SAVINGS IN \$ OF UTILITY GEN. CAP. (KW SAVED X \$34/KW/YR)</u>	<u>SAVINGS IN \$ OF VARIABLE COSTS TO UTILITY</u>	<u>TOTAL SAVINGS IN COST TO UTILITY</u>	<u>ANNUAL AMORTIZED COST TO CONSUMER OF DECENTRAL- IZED CAPACITY (New Con- struction)</u>
Insulation of uninsulated 2x4 wall (Bldg.16 - Bldg. 2)	4.4	\$150	\$162	\$312	\$41
Insulation to 2x6 6" addition- al attic insula- tion	1.1	\$ 37	\$ 27	\$ 64	\$76
Masonry, 80% glass and Thermal Shutters (Bldg.1- Bldg.14)	3.2	\$109	\$ 99	\$208	\$445
Solar Hot Water System vs. Con- ventional DHW	.3	\$ 10	\$ 39	\$ 49	\$264
35m ² Collector 2.65m ³ Storage on Base Building	1.2	\$ 41	\$175	\$216	\$873

alone. Savings in fuel costs are additional. The \$41 represents the cost of wall insulation in new construction. For retrofit purposes, this cost would be considerably higher, but in all probability, still represent a direct savings in capital generation costs.

Other investments in insulation and solar energy do not produce one to one cost savings in generation and, therefore, investments in these alternatives cannot be justified solely on the basis of forestalled generation capacity. This, however, does not preclude the feasibility of these alternatives based on a combined reduction in capacity and fuel. In addition, the differences between the cost of capacity are not so great that changes in cost of conventional electric generation capacity might not make these alternatives investments viable. For example, had the low \$34 per kw per year value for Colorado Springs been above \$69 (a value well below that of many utilities) then utility investment in insulation up to 2 x6 stud walls and 12" of attic insulation could be justified on societal capacity savings in capacity costs alone. It does not appear, however, in Colorado Springs that investment in active solar energy by the utility can be translated into significant reduction in conventional generation capacity.

The other aspect of utility costs is the short run energy costs. In Colorado Springs these costs have been calculated as \$.013 on-peak, and .009 off-peak periods. These values for short run costs are also very low in comparison to other utilities.

Including savings in variable costs to the utility along with savings in kw capacity costs provides a more complete indication of benefits of decentralized investment. In Table III-22, the fuel savings that accrue from investment in 3.5 inches of wall insulation

(\$162) is commensurate with cost savings in capacity (\$150).

Together, a savings in utility costs of \$312 per year is realized from an amortized investment of only \$41. For retrofit purposes, it appears as though costs of retrofited wall insulation can be eight times higher (\$320 per year or \$3000 total investment) and still produce a savings.

Other investments in Colorado Springs do not result in such significant benefits. Large amounts of insulation beyond the Base Building are not justified solely on utility savings in the first year. It is probable that given rise in fuel costs and inflation that this particular investment will produce greater dollar savings to the utility than investment in conventional generation facilities.

Solar energy investment in either a hot water system or a 35m² collector system does not produce an equivalent ratio of investment to benefits as results from those investments in energy conservation. A fuel savings of \$175 results from investment in the 35m² combined hot water and space heating system. However, a lack of corresponding reduction in kw capacity produced only a \$41 savings in generation capacity costs despite a yearly investment of \$873.

The above analysis provides only a partial picture of societal benefits. It is inappropriate to evaluate societal benefits over a one year lifetime, particularly when it is desired that the nation exist even longer than any particular investment lifetime.

*cf. Of the 10 utilities examined (see Feldman and Anderson, 1976), Colorado Springs had the lowest incremental fuel costs of any utility except Sacramento Municipal Utility District which is almost exclusively hydro.

Also, all costs, such as the impact on foreign dependence on energy supply, balance of trade and the environment have not been accounted for. These social costs are difficult to quantify and are often ignored completely, yet their cost is significant.* The real value of solar energy and energy conservation remains a political issue. This report will include a measure of each kw and kwh saved, but will refrain from including a dollar value. Table III-23 shows the societal benefits of different investments from a twenty year lifecycle perspective. Values exhibited here represent a very short term perspective as to societal benefits.

Clearly, the benefits to society of investment in wall insulation in poorly insulated home is shown. Societal savings of \$6600 and 4.4 kw's of capacity and 300,000 kwh in fuel are realized for an initial investment of \$390. The cost of retrofit of existing under-insulated housing stock, while considerably higher, would still appear to provide societal benefits far exceeding costs. Both the inclusion of additional insulation and passive solar also obtain benefit/cost ratios exceeding one.

The real key to societal benefits is the measurement of fuel saved. Investment in wall insulation saves the same amount of fuel as does an investment in a 35m^2 collector system despite a cost difference of over 20 to 1 (in new construction 1975 dollars). The reduction in capacity (kw) requirement as a result of the investment in insulation (4.4 kw) is almost four times greater than the reduction in kw from the active solar investment (12 kw).

Societal savings in fuel from additional energy insulation returns and equivalent amount of fuel savings as does investment in

*For an example, see Costello (1976, p.22) where a range of \$55 to \$330 in benefits to the nation per kw of capacity forestalled was estimated.

TABLE III-23

COMPARISON OF SOCIETAL BENEFITS AND COSTS BETWEEN
VARIOUS INVESTMENTS IN TECHNOLOGY

Colorado Springs

<u>INVESTMENT</u>	<u>KW SAVED BETWEEN ALTERNATIVES</u>	<u>KWH SAVED BETWEEN ALTERNATIVES IN (1000 kwh)</u>	<u>SAVINGS IN LIFECYCLE COST IN \$ OF UTILITY GENERATION CAPACITY COSTS</u>	<u>SAVINGS IN LIFECYCLE COST \$ OF UTILITY VARIABLE COSTS</u>	<u>TOTAL LIFECYCLE SAVINGS TO UTILITY IN \$</u>	<u>LIFECYCLE COST TO CON- SUMER OF INVESTMENT (ORIGINAL INVESTMENT COST)</u>	<u>RATIO OF SAVINGS TO COST</u>
Insulation of Un- insulated 2x4 Wall (Bldg. 16 vs. Bldg.2)	4.4	303	1720	4880	6600	479 (390)	13.8:1
Insulation to 2x6 and 6" Additional Attic Insulation (Bldg. 2 vs. Bldg.3)	1.1	48	570	776	1346	885 (720)	1.5:1
Masonry, 80% Glass and Thermal Shutters (Bldg.2 vs. Bldg.14)	3.2	194	1358	3118	4476	4485 (3652)	1.0:1
Solar Hot Water System vs. Conven- tional DHW	0.3	40	119	675	794	3070 (2500)	0.3:1
35m ² Collector 2.65 Storage on Base Building vs. Conventional Electric Building	1.2	288	500	4643	5143	10134 (8254)	0.5:1

a solar hot water system. In addition, the investment in energy conservation reduces kilowatt capacity requirements of the utility 1.1 kw for insulation to only 0.3 kw for the solar hot water system.

SECTION IV

OTHER CASE STUDIES

The case study of Colorado Springs illustrated the complexity in predicting the optimal cost-effective building configuration. The results for Colorado Springs depended on the utility area's climate, the utility characteristics, and many building design and cost parameters. The individual effect of each of the variables from a national perspective has not clearly been determined. It is unclear what sensitivity exists in the use of other locations, utilities or building costs. The following chapter will examine the sensitivity of these variables to illustrate the particularity of the Colorado Springs case study and to begin to develop national policy guidelines.

A. THE NEW ENGLAND ELECTRIC SYSTEM - Worcester

The first variation in utility location will be the use of another winter peaking utility, The New England Electric System, NEES, of Central Massachusetts and Rhode Island. The study point, Worcester, Massachusetts represents the largest city within the service area. Unlike the City of Colorado Springs, Department of Public Utilities, NEES is a privately owned utility. The other major difference between the two utility companies is the larger dependence upon oil as a fuel source in the NEES system. The January, 1975 breakdown of capacity consisted of 39% coal, 20% oil, 15% hydro, 9% nuclear, and 9% pumped storage. Partly because of this higher dependence on oil, fuel costs and subsequently electric rates are significantly higher at NEES. In this study, 0.045 \$/kwh is used as the cost of electricity as compared to only 0.025 \$/kwh in Colorado Springs. The long-run incremental cost of generation,

transmission and distribution utilized is \$81/kw.

The differences in degree days between Colorado Springs and Worcester is exhibited by a 10% higher consumption of energy in the Base Building in Worcester than in the Base Building in Colorado Springs. The higher insulation levels in Colorado Springs are also reflected in the thermal results; the same 35m² collector collects about 2000 kwh more useful energy in Colorado Springs than it does in Worcester.

The financial results for four buildings in New England were compiled as was done in Colorado Springs, and are shown in Table IV-1. The four buildings include:

1. The Base Building with shade - 2x4 insulated stud wall, 6' attic insulation, light room construction - 16% south double glazing.
2. The Energy Conservation Building #1, 2x6 insulated stud wall, 12" attic insulation, no total wall, light room construction, with overhanging shade, 16% south double glazing.
3. The Masonry Building, 8" concrete Block with 4" total wall, heavy room construction, 12" attic insulation, no overhanging shade, winter/summer variable thermal shutter and 80% double glazing.
4. The Minimally Insulated Building, 2x4 non-insulated stud-wall, 6" attic insulation, light room construction, with overhanging shade, 16% south double glazing.

The most significant difference between the results of Colorado Springs and Worcester is that even in the first year in Worcester, the investment in additional insulation beyond the Base Building is

TABLE IV-1

CONSUMER COST EFFECTIVENESS FOR NEW ENGLAND ELECTRIC SYSTEM

		Consumer Lifecycle Costs							
		1st year costs to Consumer		Low Future Scenario ²		Medium Future Scenario ³		High Future Scenario ⁴	
		w/o Tax Credit	w/55% Tax Credit ¹	w/o Tax Credit	w/55% Tax Credit ¹	w/o Tax Credit	w/55% Tax Credit ¹	w/o Tax Credit	w/55% Tax Credit ¹
Load Factor									
Base Building	.17	1357	1012	14700	11713	17193	13904	22222	18538
	.33	1122	925	14481	12766	17888	15992	26602	24479
	.37	966	928	13559	13207	17158	16770	26908	26489
Energy Conser- vation Building	.15	1349	1006	14265	11290	16424	13135	20513	16803
	.33	1086	847	13573	11456	16608	14267	24194	21573
	.38	929	849	12664	11890	15878	15045	24484	23551
Masonry Building w/Winter-Summer Shutters	.08	1531	1191	15299	12324	17227	13938	20192	16509
	.24	1116	783	12420	9445	14624	11335	19452	15769
	.31	959	700	11490	9108	13895	11261	19742	16792
Minimally Insulated Building	.26	1960	1613	23645	20670	28562	25273	40344	36660
	.36	1827	1653	24833	23326	23341	29475	47824	45958
	.38	1671	1655	23903	23760	30412	30253	48114	47936

1. Tax credit extended to both energy conservation and solar.
2. Low Future Scenario: Discount Rate = 10%, Electricity Escalation = 6%
3. Medium Future Scenario: Discount Rate = 8%, Electricity Escalation = 7%
4. High Future Scenario: Discount Rate = 6%, Electricity Escalation = 10%

justified as both the all-electric Energy Conservation Building and the all-electric Masonry Building have lower first year costs than the Base Building (Table IV-2). Any of the four tax credits previously examined further emphasized the value of insulation, with the California style tax policies creating a clear advantage to the Masonry Building. Although the lowest cost-alternative is the Masonry Building all-electric version, investment in a solar hot water system is also cost-effective in comparison to the Base Building all-electric version.

The real effect of higher electric rates for Worcester is seen in the lifecycle analysis (Table IV-3) where price of fuel becomes so great that nearly any investment which lowers energy consumption has a lower cost than the Base Building. The best investment, of the ones examined, remains, except for one case, the all-electric Masonry Building. In the "high" future scenario where cost of fuels are inflated so high that investment of a solar hot water system on the Masonry Building is justified.

Utility Impact

The performance of the different buildings at the time of utility system peak in Worcester is slightly improved over the Colorado Springs experience. The weather conditions at time of peak in Worcester are even more related to extreme cold than was the case in Colorado Springs. Performance of the solar systems at utility peak is not as poor as in Colorado Springs, yet, the load factors of the solar heated buildings is still less than half of the identical all-electric versions. As in Colorado, investments in energy conservation and solar hot water do not significantly lower load factors. As a consequence of low load factors for solar heated buildings, there is a commensurate imbalance in utility net revenues.

TABLE IV-2

THE IMPACT OF TAX CREDITS ON CONSUMER COST-EFFECTIVENESS

New England Electric System

FIRST YEAR COST ANALYSIS

TAX POLICY	LOWEST COST ALTERNATIVE
1. No Tax Policy	All-Electric Energy Conservation Building
2. Federal Solar Tax Policy (originally proposed) (Solar 30% first \$2000, 20\$ next \$8000, Conser- vation 20% first \$2000)	All-Electric Energy Conservation Building
3. Federal Solar= Energy Conservation Tax Policy (hypothetical) (Solar and Energy Conservation 30% first \$2000, 20% of next \$10,000)	All-Electric Energy Conservation Building
4. California Solar Tax Policy (existing) (55% of active and passive solar and Energy Conservation in conjunction with solar up to \$3000)	All-Electric Masonry Building
5. California Energy Conser- vation = Solar Tax Policy (hypothetical) - Same as 4 but includes all energy conservation.	All-Electric Masonry Building

All Buildings with overhanging shade and/or thermal shutters.

TABLE IV-3

THE IMPACT OF TAX CREDITS ON CONSUMER COST EFFECTIVENESS

New England Electric System

LIFE CYCLE COST ANALYSIS

LOWEST COST ALTERNATIVE

TAX POLICY	LOW FUTURE SCENARIO	MEDIUM FUTURE SCENARIO	HIGH FUTURE SCENARIO
No Tax Policy	All-Electric Masonry Building 14-C	All-Electric Masonry Building 14-C	Solar Hot Water Masonry Building 14-B
Californis Solar Tax Policy extended to include all energy conservation and solar. 55% up to \$3000.	All-Electric Masonry Building 14-C	All-Electric Masonry Building 14-C	Solar Hot Water Masonry Building 14-B

LOW FUTURE SCENARIO: Discount Rate=10%, Electricity Escalation =6%

MEDIUM FUTURE SCENARIO: Discount Rate =8%, Electricity Escalation=7%

HIGH FUTURE SCENARIO: Discount Rate=6%, Electricity Escalation=10%

Societal Impact

The societal benefits of investment in energy conservation are realized in the first year despite all ignorance of unincurred social costs and future fuel price rises. Masonry Buildings also have greater benefits to society.

The benefits to society are more clearly shown in the lifecycle cost assessment in Table IV-4. The clearest result is the poor economic performance of the Minimally Insulated Building. This building, which represents most present housing stock, had societal costs of twice that of any other building and utilized over 300,000 kwh and 4.6 kw of additional electricity and capacity in twenty years. The savings in benefits to society, from investment in wall insulation at a cost of \$344 (in new house) is \$8257 in present worth. There is a ratio of nearly 20:1 present worth benefits versus present worth costs (8257:422). In addition, savings also are realized by society in the large reduction of kwh consumption and kw capacity requirements. Large benefits also are realized by society for further investment in energy conservation to 2x6 insulated stud wall, 12' attic insulation, and in high mass construction and passive solar as in the Masonry Building. Benefits to society of investment in either a 5.6m² solar hot water heater or a 35m² solar heating and hot water system do not exceed the benefits from the energy conservation investment.

TABLE IV-4

COMPARISON OF SOCIETAL BENEFITS AND COSTS BETWEEN
VARIOUS INVESTMENTS IN TECHNOLOGY

New England Electric System

<u>INVESTMENT</u>	<u>KW SAVED BETWEEN ALTERNATIVES</u>	<u>KWH SAVED BETWEEN ALTERNATIVES IN (1000 kwh)</u>	<u>SAVINGS IN LIFECYCLE COST IN \$ OF UTILITY GENERATION CAPACITY COSTS</u>	<u>SAVINGS IN LIFECYCLE COST \$ OF UTILITY VARIABLE COSTS</u>	<u>TOTAL LIFECYCLE SAVINGS TO UTILITY IN \$</u>	<u>LIFECYCLE COST TO CON- SUMER OF INVESTMENT (ORIGINAL INVESTMENT COST)</u>	<u>RATIO OF SAVINGS TO COST</u>
Insulation of Uninsulated 2x4 Wall (Bldg. 4 vs. Bldg. 1)	4.66	324	1926	6331	8357	422 (344)	19.6:1
Insulation to 2x6 and 6" Additional Attic Insulation (Bldg. 1 vs. Bldg. 2)	.83	50	343	1609	1952	800 (651)	2.44:1
Masonry, 80% Glass and Thermal Shutters (Bldg. 1 vs. Bldg 3)	2.08	178	860	5639	6499	3750 (3054)	1.73:1
Solar Hot Water System vs. Conven- tional DHW	.28	35	115	1544	1569	3069 (2500)	.54:1
35m ² Collector 2.65 Storage on Base Building vs. Conventional Electric Building	1.22	248	504	8256	8760	10251 (8268)	.85:1

B. PUBLIC SERVICE COMPANY OF NEW MEXICO - ALBUQUERQUE

The case of Public Service Company of New Mexico (PNM) is an example of a summer peaking utility. Concerns in this utility are in reducing summer air conditioning and hot water loads. Active solar heating, therefore, does not reduce peak demands but does reduce annual sales. This lowers the utility system load factor and utility operating efficiency.

The PNM service area has a very high heating degree day and has experienced several system peaks during the winter months.

A similar trend as to building cost-effectiveness emerges in Albuquerque as it has elsewhere (Table IV-5). The all-electric Energy Conservation Building has the lowest first year cost. The all-electric Masonry Building has the lowest first year cost when California tax policies are applied. The significant change between Albuquerque and other locations is that under lifecycle analysis "high" future scenario, the solar heated Base Building is the lowest cost alternative. This building and the solar heated Energy Conservation building outstrip the all-electric Masonry Building in savings.

One reason for this outcome, is the large amounts of cooling required by the Masonry Building. Closer examination of this cooling load reveals that the heavy thermal mass combined with cool summer nights effectively eliminates almost all summer cooling requirements. The inclusion of 80% glass, however, causes significant winter overheating problems. As no provision is included in the model to ventilate rather than air condition, the Masonry cooling load remains. The example hampers evaluation of true cost-effectiveness of building but does illustrate a critical problem of passive buildings, that is overheating. It is possible that 40% south glazing will eliminate

TABLE IV-5

CONSUMER COST EFFECTIVENESS FOR ALBUQUERQUE

	Load Factor	1st year costs to Consumer		Consumer Lifecycle Costs			
				Low Future Scenario 2		High Future Scenario 3	
		w/o Tax Credit	w/55% Tax Credit 1	w/o Tax Credit	w/55% Tax Credit 1	w/o Tax Credit	w/55% Tax Credit 1
Base Building	.13	1098	753	12594	9305	14909	11226
	.68	882	690	13558	11717	19780	17717
	.70	690	658	12183	11849	19044	18670
Energy Conser- vation Building	.11	1142	799	12855	9566	14991	11429
	.65	870	641	12792	10558	18232	15730
	.68	678	608	11417	10690	17496	16681
Masonry Building W/Winter-Summer Shutters	.72	1481	1140	17023	13733	20305	16622
	.86	949	614	12204	8914	16001	12317
	.80	757	542	10828	8652	15265	12829
Minimally Insulated Building	.35	1334	987	17199	13914	22392	18708
	.91	1356	1185	22542	20908	34209	32379
	.88	1164	1152	21166	21040	33473	33331

1. Tax credit extended to both energy conservation and solar.
2. Low Future Scenario: Discount Rate=10%, Electricity Escalation =6%
3. High Future Scenario: Discount Rate=6%, Electricity Escalation=10%

much of this overheating without significantly increasing heating loads. This case was not examined, however.

The utility impact appears to exist for solar heating in Albuquerque particularly for the minimal contribution of the solar heating system to summer peak load reduction. The opposite appears to be true of solar hot water systems which improve the load factor in several cases.

Societal considerations appear again to favor initial investment in energy conservation by the consumer, (See Table IV-6). Societal benefits for active and passive solar, however, do exist. One particular benefit of solar hot water heaters is the benefit of solar hot water in reducing on peak electric loads. Although the savings in kwh for the passive energy investment (Row 3) is greater than the solar hot water heater (Row 4), the dollar savings to society per dollar investment is greater for the solar hot water heater because virtually all of the reduction is in on-peak electricity.

TABLE IV-6

COMPARISON OF SOCIETAL BENEFITS AND COSTS BETWEEN
VARIOUS INVESTMENTS IN TECHNOLOGY

Albuquerque

INVESTMENT	KW SAVED BETWEEN ALTERNATIVES	KWH SAVED BETWEEN ALTERNATIVES IN (1000 kwh)	SAVINGS IN LIFECYCLE COST IN \$ OF UTILITY GENERATION CAPACITY COSTS	SAVINGS IN LIFECYCLE COST \$ OF UTILITY VARIABLE COSTS	TOTAL LIFECYCLE SAVINGS TO UTILITY IN \$	LIFECYCLE COST TO CON- SUMER OF INVESTMENT (ORIGINAL INVESTMENT COST)	RATIO OF SAVINGS TO COST
Insulation of Uninsulated 2x4 Wall (Bldg.4 vs. Bldg. 1)	1.04	237	431	6196	6227	422 (344)	14.8:1
(SAVINGS PER \$10,000 INVESTMENT = \$192,645)							
Insulation to 2x6 and 6" Additional Attic Insulation(Bldg.1 vs. Bldg.2)	.27	37	110	950	1060	800 (651)	1.3:1
(SAVINGS PER \$10,000 INVESTMENT = \$ 16,283)							
Masonry,80% Glass and Thermal Shutters (Bldg.1 vs. Bldg.3)	1.20	123	495	1478	1973	3750 (3054)	.5:1
(SAVINGS PER \$10,000 INVESTMENT = \$ 6,450)							
Solar Hot Water System vs. Conven- tional DHW	.64	84	263	2665	2928	3070 (2500)	1.0:1
(SAVINGS PER \$10,000 INVESTMENT = \$ 11,712)							
35m ² Collector 2.65 Storage on Base Building vs. Conventional Electric Building	.73	255	302	7391	7693	10152 (8268)	.8:1
(SAVINGS PER \$10,000 INVESTMENT = \$ 9,305)							

C. THE CASE STUDY OF PACIFIC GAS AND ELECTRIC COMPANY

The Pacific Gas and Electric Utility represents a large summer peaking utility with significant winter heating loads. Capacity supply constraints, due to a large dependence on hydro-electric power, also contributes to the significance of winter electricity demands. Presently, most of this heating load is not supplied by electricity. Shifts to solar energy with electricity back-up will have an impact on PG&E different from utilities previously examined.

The impact of the various buildings on the summer peak load is similar to the impact in Albuquerque. The most significant reduction in kw capacity is realized by investment in wall insulation in an under insulated wall (a reduction of 1.7 kw--4.93 kw to 3.23 kw). Inclusion of additional insulation to the Energy Conservation Building #1 results in an additional .44 kw (3.23 to 2.78) kw reduction. The Masonry Building with shutters lowers kw capacity to 1.75 kw's.

The impact of these alternative investments on PG&E is most clearly demonstrated by investment in wall insulation in the minimally insulated building. The high opportunity cost of generation facilities for PG&E is reflected in the incremental generation costs of \$141/kw. The opportunities for energy conservation and solar hot water in load management are more significant. This is particularly true if supplies of oil and gas are reduced.

D. A CASE STUDY OF GEORGIA POWER COMPANY

The following analysis for Georgia Power was performed for a 5.6m² hot water system versus a conventional hot water system. The kilowatt demand of the conventional hot water system is .75 kw.

The solar hot water system reduced kw demand to only .29 kw. The electricity consumed by a conventional hot water system were 4965.7 kwh and only 1922.5 kwh for the solar system. This is a load factor of .76 for both the conventional system and for the solar hot water system.

The cost-effectiveness of the solar hot water system over the conventional system depends on the rate schedule applied. Georgia Power Company offers extremely low electric rates. \$.016/kwh for the last block in 1976. At this rate, solar energy cannot compete against electricity. In the life cycle analysis, solar hot water is still uncompetitive even if the initial electric rate starts at .026\$/kwh and is inflated annually at 10%.

SECTION V

SUMMARY AND CONCLUSIONS

In the preceding chapter, it was shown that the lowest cost building configuration varies depending on a number of important parameters. While it is impossible to isolate the specific impact of each parameter, the overall affect of the variables can be gleaned. This exercise is not only useful as a review of the preceding chapters, but serves as introduction to the following discussion in regard to public policy.

The major parameters that distinguish variation in the cost-effectiveness of particular building design fall into five categories.

1. The Weather: Insolation and Temperature
2. Building Configurations
3. Building Costs
4. Utility Costs and Rates
5. Financial Parameters

Each of these parameters will affect the determination of the least cost alternative. The importance of each parameter, particularly the sensitivity, will be highlighted.

A. WEATHER: INSOLATION AND TEMPERATURE

The importance that weather, insolation and temperature, and, to a lesser extent, wind speed and relative humidity play in determining the optimal building configuration is commonly understood. Weather and climate have traditionally played a significant role in building design. However, the impact of variations in solar radiation availability is not as well understood.

Colorado Springs experiences a high number of degree days and a high amount of solar radiation.* The importance of weather conditions as a variable in determining the cost feasibility of solar heating and hot water systems is not paramount. Worcester, Massachusetts, with less solar insolation and more degree days, paints a more favorable cost feasibility prospectus for solar heating and hot water equipment because of the much higher price of electricity in Worcester.

The weather at the time of utility peak also varies between regions and between utilities. Colorado Springs experiences its peaks during the winter. A recent trend, probably due to a higher saturation of electric resistive heating, has caused a shift in the utility peak demand from periods of cloudy low insolation and Christmas lighting around the winter solstice, to periods of extreme cold. The significance of this shift on solar performance is the necessary poor performance of the solar system during periods of low insolation and variable performance under conditions of cold. Worcester peak weather conditions appear to be similar to Colorado Springs, although the insolation available may be even higher.

Summer peaking utilities have different concerns as the solar heating capabilities do not significantly reduce electricity demand at the time of system peak. Hot water demand can be lowered in summer peaking utilities depending on the weather. In Atlanta, the hot water demands were lowered by .46 kw out of about .75 kw

*This data and all subsequent data on solar insolation and degree days is taken from the National Climate Center Tapes for each location. The specific years are referenced in Section II-A. The monthly radiation and heating and cooling degree days for these locations is presented in Figures V-1 through V-3.

FIGURE V-1 MONTHLY RADIATION FOR SELECTED LOCATIONS

DEGREE DAYS FOR HEATING

V-4

LEGEND

ALBUQUERQUE, N. M.	-----
ATLANTA, GA.	-----
BLUE HILLS, MA.	-----
BOULDER, CO.	-----
FRESNO, CALIF.	-----

FIGURE V-2 MONTHLY HEATING DEGREE DAYS FOR SELECTED LOCATIONS

DEGREE DAYS FOR COOLING

LEGEND

ALBUQUERQUE, N. M.	-----
ATLANTA, GA.	-.-.-.-.-
BLUE HILLS, MA.	
BOULDER, CO.	—————
FRESNO, CALIF.	—————

FIGURE V-3 MONTHLY COOLING DEGREE DAYS FOR SELECTED LOCATIONS

demand at the time of system peak. The weather in Albuquerque is more favorable at system peak as almost all of the hot water demand, .64 kw out of .73 kw, demand for hot water was provided by solar.

Investments in energy conservation will reduce heating or air-conditioning loads at time of utility peak. The more extreme the temperature, the greater the energy savings contribution.

B. BUILDING CONFIGURATIONS

Changes in the building configurations including the design, floor plan insulation, solar energy system, and passive solar energy system, impact on the kwh energy consumption, the kw demand at the time of utility peak and subsequently the economics. In every location of those buildings examined*, the most significant reductions in kwh, kw and costs were realized by the inclusion of wall insulation into a Minimally Insulated Building. No other single option including a 70m² collector system approached the energy reduction and, as a result, the cost saving that this investment produces.

The Base Building, consisting of an all-electric heating, cooling and hot water system, with "2x4" fully insulated stud wall, 16% south glazing, 6' attic insulation was the most economical building in several cost scenarios. Other investments that appeared to be cost effective under certain conditions (not listed in order of cost effectiveness) included:

1. additional energy conservation to "2x6" insulated stud walls and 12" (6" additional) attic insulation;

*The few buildings examined do not necessarily represent optimal configurations.

2. Masonry Building of 8" concrete block with 4" external Styrofoam^R insulation;
3. a solar hot water system with 5.6m² collector area;
4. a solar heating and hot water system with 17.5m² collector and 1.32m² storage;
5. a solar heating and hot water system with 35m² collector and 2.65m³ storage;
6. thermal shutters particularly ones that had different winter/summer operation modes;
7. 80% south facing glass - either double glazing and shutters, or triple glazing.
8. south orientation vs. north orientation.

Several practices were found to be particularly not cost-effective (not listed in order of cost-effectiveness) and include:

1. Minimally Insulated Buildings;
2. north orientation of major window expanse;
3. 80% south facing glass without either thermal shutters or triple glazing;
4. an overhanging shade, particularly on small glass expanses and areas with low cooling loads;
5. Active solar heating systems on the Masonry Buildings or the Minimally Insulated Building.

The actual economic trade-offs that exist between different building configurations are not as much dependent on differences in absolute savings of energy consumption as they are on the relationship of these energy savings to building costs, utility costs, and financial assumptions.

C. BUILDING COSTS

One of the largest variations among the previous studies of solar heating cost-effectiveness, is the construction/installation costs for the solar heating system. Variations in variable costs per square foot of collector range from \$2 to \$30/sq.ft. of collector.* The sensitivity of variations in the cost of solar has been indirectly examined in this study by the use of the tax credits. Tax credit policies both Federal and California favor solar energy investment over other alternatives. For instance, the California tax credit lowers the cost of a 35m² active solar collection system by \$3000 from \$8254 to \$5254 or a 35% reduction. A re-evaluation in Colorado Springs of the cost-effectiveness to the consumer utilizing this lower cost for the solar system, reveals an improved but still an un-economic assessment for the solar system. Only in the "high future" lifecycle scenario does the solar heating building utilizing these reduced costs values have a lower cost to consumer than the all-electric version of the same building (Base Building #1). While the situation in other locations, Albuquerque and Worcester, reveals a more favorable response of solar heating cost-effectiveness to a 35% reduction in the cost of the solar system, the response is due more to the presence of higher fuel costs than to cost reduction itself.

Other building practices that are not widely employed also initiate debate as to appropriate costs. The costs of utilizing masonry construction varies between regions and with familiarity of usage. The

*See methodology, Chapter II for detailed discussion of the derivation of solar and other building costs.

\$3600 incremental costs for the masonry structure over the Base Building may be excessive in many cases. The sensitivity of masonry structures appears to be more pronounced than it was to active solar heating. The price of shades and shutters, is also subject to variations in cost depending on which of a variety of systems is utilized.*

D. UTILITY COSTS AND RATES

The variation in utility costs is clearly the most responsible for variations in results between locations. The low cost of fuel and capacity for Colorado Springs, clearly favor the consumption of electricity as compared to either Worcester or Albuquerque. This phenomena is best illustrated by examining the impact of higher electric rates on building cost-effectiveness in Colorado Springs. The "appropriate block"**) electric rate for Colorado Springs was changed from the original 0.025 \$/kwh to 0.035 \$/kwh and 0.045 \$/kwh, the later which closely represents the value for Worcester and Albuquerque. The results are shown in Table V-1.

Recalling the results, utilizing the original electric rates (0.025 \$/kwh), the all-electric Base Building 1C is the lowest cost alternative in both the first year and "medium" lifecycle scenarios. When costs are raised by one cent to 0.035 \$/kwh, the least cost alternative shifts. In the first year analysis, the all-electric

*See Section II-C for the specific options examined in this report and other options available.

** There is much debate as to which electric rate best represents the cost of incremental heating loads to solar. We have used the lowest block rate because this is the electricity that solar investment actually replaces.

TABLE V-I
THE SENSITIVITY OF ELECTRIC RATES TO
CONSUMER COST-EFFECTIVENESS*
Colorado Springs

First Year Cost Analysis

RATE	LEAST COST ALTERNATIVE	OTHER BUILDINGS WITH COSTS LOWER THAN BASE BUILDING 1C
0.025 \$/kwh	All-electric Base Building, No Shade (1C)	-----
0.035 \$/kwh	All-electric Energy Conservation #2, with shade, 80% glass, thermal shutters, (6C)	None
0.045 \$/kwh	All-electric Energy Conservation #2, with shade, 80% glass, thermal shutters, (6C)	None

Medium Future Lifecycle Analysis**

RATE	LEAST COST ALTERNATIVE	OTHER BUILDINGS WITH COSTS LOWER THAN BASE BUILDING 1C
0.025 \$/kwh	All-electric Base Building, No Shade (1C)	-----
0.035 \$/kwh	All-electric Masonry Building, 80% glass w/s shutters (14C)	6C, 14B
0.045 \$/kwh	Solar hot water Masonry Building, 80% glass, w/s shutters (14B)	1A, 2A, 3AC, 4AC, 6BC, 9A, 13BC, 14C, 15BC

* No tax credits applicable.

** DR= .08, IR= .085, Electric Rate Increase= .07 per year, Fuel Cost Increase = .10 per year.

Energy Conservation Building #2 with 80% south glass, thermal shutter and shade has a lower cost than the Base Building (1C). For the "medium lifecycle analysis and a 0.035 \$/kwh, the all-electric Masonry Building with 80% glass and a winter/summer differentiating shutter, was the least cost alternative to the customer.

Utilizing the rate 0.045 \$/kwh, that was similar to the rate for Albuquerque and Worcester, produces significant changes. In the first year analysis, the same Energy Conservation Building (6C) was still the least cost alternative. In the "medium future" lifecycle scenario sixteen buildings had lower costs than the all-electric Base Building. The least cost alternative was 14B, the Masonry Building with 80% glass, thermal shutters and a solar hot water system. If costs in Colorado Springs were as high as they are in Worcester, it is not surprising to find that the cost effectiveness of solar heating systems would be more favorable in Colorado Springs, where weather is more favorable. This is illustrated by the large number of "A" type buildings that have costs lower than Base Building 1C in the lifecycle analysis with 0.045 \$/kwh as the electric rate.

E. FINANCIAL PARAMETERS

The sensitivity of final results to changes in financial parameters such as discount rate is acknowledged throughout the literature.* In this report, a variety of different values were utilized ranging from a first year analysis to "high future"

*See, for instance, Ruegg (1975), Brandenruchl and Beckman (1978), Shulze et al (1977), and Bennington et al (1976).

lifecycle analysis, see Chapter III-H. The results were indeed sensitive to changes in discount rate and rate of increase in electric rates.

The critical problem with this sensitivity is the lack of consensus as to the appropriate values. These financial parameters analyze the impact of unknown future prices. Concomitantly, there exist debate as to which scenario best reflects the interests of a particular individual, or society as a whole. The appropriate set of parameters for the consumer lie somewhere between the first year cost analysis which generally favors the Base Building in Colorado Springs and the Energy Conservation Buildings in Albuquerque, and Worcester, and the lifecycle analysis which favors more energy conservation, passive and active solar investment. On the other hand, national well-being may not be expressed sufficiently by even the most generous lifecycle cost analysis if the basis is a twenty year lifecycle. The application of public policy with such a short lifetime is probably inappropriate. This is particularly important when significant social costs are ignored as they have been here.

F. IMPACTS ON UTILITY

One factor virtually ignored in most assessments of solar energy is the impacts on the utility companies which supply auxiliary energy. The principal concern in this report is to examine the impacts of alternative technologies upon electric utilities both because electricity low capital costs make it a convenient back-up source and because electric utilities load management concerns portend significant interface problems.

Clearly, the most significant finding is the extremely low individual load factors* for the buildings with combined solar space and water systems. In Colorado Springs, the load factors for the buildings with combined space and hot water systems were less than 10% as compared to 36% for the all-electric Base Building. It appears that in Colorado Springs and Worcester, a large amount of auxiliary energy required by the buildings with active systems is actually demanded at times of utility peaks. The larger the active system, the truer this is. Counter balancing the trend of low load factors for solar buildings are the improved load factors of energy conserving buildings.

In summer peaking utilities such as Georgia Power Co. and Public Service Company of New Mexico, solar heating lowers annual consumption without any reduction in energy demand during summer peak loads. The load factors are necessarily poorer for solar heating systems. Solar hot water systems and some energy conserving techniques do improve load factors in these locations.

These variations in load factors produce variations in cost of service. In several cases, wide differences exist between the cost of service and the revenues received by utilities from solar buildings. This has prompted interest in higher rates for solar users.

The importance of the electric rate in the building/utility

* Individual load factor is the average kilowatt demand for space conditioning and hot water divided by the kilowatt demand for space conditioning and hot water at the time of utility peak load demand.

interface cannot be overestimated. The rate affects the cost-effectiveness to the consumer. The rate must also, however, reflect the cost of service to utility and the impact on society.

Electric utility rate schedules are developed to recover costs over a broad range of users. Variations in cost of service between a solar and non-solar home are less than the variations in cost of service between an underinsulated and insulated home. Refinement of rate design to better reflect costs of service will provide a better signal to all consumers with regard to utility impact. Rate designs which differentiate by time-of-use and/or weather sensitivity will better reflect the true cost of service and should yield greater economically efficient consumer response.

One potentially attractive rate schedule may be the use of an interruptable service contract. The electric utility can curtail the need for expansion by rolling out service to pre-arranged solar buildings, with the incentive to the customer being a lower charge. The infrequency of peak electricity demand by solar buildings may make interruptable service contracts ideal. An indirect benefit of these types of rates may be the increased use of building thermal mass. Results show that large amounts of building thermal mass dampen heat flows to such a degree that the exclusion of on-peak electrical heating in the Masonry Buildings does not appreciably alter internal room temperature or comfort even at design conditions. Under present rates that do not differentiate between time-of-day or weather sensitivity, no incentive to the consumer to invest in thermal mass exists despite great societal benefits.

G. THE APPROPRIATENESS OF SOLAR TAX CREDITS

A significant barrier to the development of alternative energy sources and energy conservation is the present cost of existing fuel sources. Subsidies to these existing fuel sources (Batelle, 1978) and the exclusion from the price the consumer pays of some social costs, including pollution costs and foreign trade deficit impacts, have kept the price of these existing fuel sources artificially low. Development of alternative investments which reduce the consumption of these scarce fuel sources is retarded. The high initial investment in solar and energy conservation has also hampered its development.

Congress, realizing the societal benefits that will result from investment in energy conservation and solar, has developed tax credits. California has also initiated tax credit policy which provides greater tax relief and extends benefits to passive solar energy. These tax credits are developed as a promotional incentive for solar energy investment. Energy Conservation investment is not afforded the same level of tax reduction as it is felt that these investments may not require as much assistance to be cost-effective.

From examination of the results of this survey, it appears that the U.S. tax credits do provide an improved economic picture for active solar investment. The benefits do not appear to be sufficient, however, to make active solar investment cost-effective against all alternatives. The tax credits for California do appear to promote the development of solar energy particularly passive solar energy. One finding of note is the trade-off that exists as a result of the tax credits. The investment in solar energy is often times enhanced at the expense of investment in

in energy conservation, which does not receive equivalent tax advantages.

The crucial issue revealed here is that while these tax credits may promote development of solar energy, rapid commercialization of solar energy in itself does not maximize societal benefits and may be an inefficient allocation of resources. The desire of energy legislation is principally to lower dependence on foreign sources of fuel, and to lower utility generation capacity, and not solely to promote development of solar energy. This is particularly true if investment in energy conservation may meet these requirements at less cost. It was found in this report to be particularly true of energy conservation at least up to 6" attic insulation and wall insulation of a 2x4 stud wall. For example, from Table IV-5, it is shown in Albuquerque that for \$10,000 investment in a 35m² solar energy collector, the returns to society excluding social costs are \$9305 in present value savings. For the same amount of investment in wall insulation in Minimally Insulated Buildings, the returns to society not including social costs are \$192,645 or 2100% greater. For a further investment in insulation to 12" attic and 2x6 fully insulated stud wall, the return to society is \$16,283. An inconsistency exists in the U.S. tax credits which provide \$400 (the actual tax legislation passed by Congress in October 1978 would only provide \$300 worth of benefits) of tax credit to the energy conservation investments, and \$2200 to the solar buildings, despite greater benefits from energy conservation. The inconsistency is harder to comprehend in the California Tax Policy where \$3000 worth of incentives are provided for the solar investment and no incentives are provided for the energy conservation investments alone.

Part of the reluctance to promote energy conservation results from a belief that energy conservation alone cannot solve this nation's future energy needs. The point is, however, that these energy conservation investments represent, at present, the least cost alternatives to society; and, society's inability to develop them is a gross misallocation of resources. The unequal tax credit policy which favors solar over energy conservation seems to provide an excess advantage to solar from the point of view of national well-being. Other barriers to energy conservation do exist such as tenant/landlord responsibility which may not fully be relieved by equal tax credit policy. The relevant point, however, is that if waste could be controlled easily, societal benefits justify the providing of nearly free energy conservation to any home similar to the Minimally Insulated Building.

Finally, the above analysis reveals the need to treat solar energy and energy conservation economics together. Trade-offs exist between the two investments and centralized electric energy. The cost effective to the consumer is not necessarily consistent with maximized national well-being. Public policy that addresses itself to the consumer and fails to consider societal impacts is not appropriate. To this degree, redirection of the tax policies is warranted.

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APPENDIX A

THE IMPACT OF STATE AND FEDERAL LEGISLATION

Federal energy policy had stalled in Congress due to protracted political conflict on issues such as natural gas pricing, utility rate reform and strategies for coal and nuclear development. Meanwhile, the initiative on less divisive issues, such as incentives for conservation and solar energy development, have been implemented by state legislatures. Due to their homogeneity, when compared with the federal scale, the initiative on the state level is all to the good. State legislatures can tailor policies to fit differing local background conditions and policy objectives. Important background conditions would include: climatic conditions, growth in local capital and mortgage markets, dynamism in the local building industry, and gas and electric utility generation mix and load characteristics. Differing policy objectives would include: equity of solar incentives, administrative ease in program set up, impact of existing solar industry, short and long term cost of incentives and trade-off between local and state level initiatives.

This Appendix asks a number of general questions with the objective of getting specific answers. First, different policies are defined. Second, we focus on the Federal National Energy Act and the states in which buildings have been modeled: Massachusetts, Colorado, Georgia, New Mexico and California, in an effort to determine to what extent state laws offer incentives or present barriers to the design options we have considered. The basis for this Appendix is the compilation of state energy conservation and solar energy laws available from the National Solar Heating and Cooling Information Center and the taxation guidelines for the states of New Mexico and California.

State and federal legislation can take a number of forms and can be evaluated along a number of dimensions. Legislation can permit:

1. tax credits--savings are permitted on the income tax payable,
2. tax deduction -- reduction in the amount of income on which tax is payable,
3. loan program -- certain groups are targeted to be eligible to borrow capital from the public sector usually are rates below the existing market,
4. weatherization -- increased insulation, storm windows, caulking and weather stripping to encourage building energy conservation,
5. public utility measures -- encourage or discourage solar market penetration through time of day rates, marginal cost pricing or discriminatory rates,
6. state-building conservation -- government buildings are equipped with solar energy systems or conservation measures,
7. state research demonstration and design (RD & D) -- attempt to encourage solar market penetration by subsidizing innovations which may prove to be commercialized at a lower risk in the future,
8. easements -- owners of solar systems may attempt to guarantee solar access by purchasing restricting rights for the air space on adjoining property,
9. other tax incentives -- include exemption from sales and use, property or estate transfer taxes.

Governments, particularly state governments are limited in the programs which they are able to sponsor by existing laws and the traditional relationships which exist between state and local authorities. States, such as New Hampshire, are not able to offer tax credits or tax deductions because there is no state income tax. States such as Georgia can only make property tax exemptions possible because regulations rest with the counties. Despite these limitations, exemptions from property and sales taxes are the options preferred by states.

Balancing equity, impact, and short and long term costs, the preferred program would include tax credits and loan program (with a double dipping provision) to be applied to active and passive solar systems and conservation-weatherization measures and utility restrictions. Tax credits, with the possibility of carry over to subsequent years would offset the high first cost of solar systems and conservation. A loan program would encourage all income groups to participate. Inclusion of conservation measures, as well as solar systems would encourage the widest possible energy savings. Utilities would be encouraged to adopt marginal cost pricing and time of day rates as an incentive for energy conserving and solar buildings.

National Energy Act (HR 5037 and HR 5263). The federal statutes which have been worked out by the Joint Senate-House Conference Committee (as of April, 1978) focus on grants, loans and tax credits as measures to increase residential energy conservation and solar market penetration. Grants, with a ceiling of \$800, would be available to low income families for energy conserving home improvements. Conservation loans would be

available for families making less than the median income for their area (in 1977 the national median was \$14,958). The interest rate on such loans would be between 7% and 12% and be determined by HUD. Home owners in all income groups could receive long term loans (mortgages) at interest rates between 7% and 12% up to 15 years. The Government National Mortgage Association would purchase these funds from private sources and resell them to home owners. This same agency is permitted to mortgage homes up to \$72,000 if the homes are equipped with solar heating or cooling systems (the present limit, without solar systems, is \$60,000).

Federal tax credits would also be available for conservation improvements with the maximum credit at \$400 or 20% of the first \$2,000.* Such a credit can be carried forward for one year. Tax credits are also available for solar systems at 30% of the first \$2,000 and 20% of the next \$8,000 with a maximum credit of \$2,200. "Double dipping", taking advantage of both loan/grants and tax credits is permitted. Eligibility requirements for solar systems has not yet been established. Conservation measures include: caulking and weather stripping, furnace efficiency modifications, ceiling, attic, wall or floor insulation, clock thermostats, storm windows and hot water heater insulation. The Senate has also included replacement fluorescent light systems, evaporative cooling devices, wood or peat burning stoves and meters which display the cost of energy, but these measures have not yet been approved in Conference Committee.

*Tax credits for energy conservation were reduced to 15% of first \$2000 in the final passage of the Bill.

Colorado. The state's legislature has chosen to use tax deductions as the major type of incentive. Colorado law (HB 1519) allows a personal itemized deduction attributable to installation, construction, reconditioning, remodeling or acquisition of alternative energy devices. Further, Chapter 344 provides that all solar systems shall be assessed at 5% of their actual value for the purposes of property taxation. Chapter 326 provides for creation of solar easements but does not mandate granting easements. Chapter 116 provides for computation of life cycle costing of competing energy systems prior to construction or substantial renovation of state buildings.

Massachusetts. According to Chapter 433, a corporation may take a tax deduction from net taxable income for expenditures on installation of solar systems. Such Residential and commercial solar systems are not subject to property taxation. Solar systems are exempt from the state sales tax. Chapter 28 permits banks and other lending institutions to make loans not to exceed \$7,000 if \$2,000 is for solar home improvements. Such loans may not exceed 10 years. Life cycle cost estimates must be made on all new state buildings which add more than 10% to existing floor space and cost more than \$25,000. To determine life cycle costs, initial building design must be placed on the selected site to maximize sun or wind exposure.

Georgia. Georgia has chosen to encourage solar development through exemption from local property taxation and the state sales tax. A ratified constitutional amendment (Legislative No.167) authorized localities to exempt solar systems from property taxation. Thus far, only Coweta and Haversham Counties have adopted such

exemptions. The state has authorized a refund of the sales tax on the purchase of machines and equipment used directly in solar systems. Machines and equipment includes controls, tanks, pumps, heat exchangers, and other devices but does not include walls, roofs or equipment ordinarily contained in usual buildings. The legislature has also authorized the Office of Energy Resources to establish an Energy Extension Service to provide information on conservation and alternative technologies, the Building Administrative Board to adopt state wide thermal efficiency standards for new and renovated buildings, created the Council for Energy Resources to evaluate state energy policies and disseminate information and has urged ERDA to locate SERI within the state.

New Mexico. This state has instituted a comprehensive tax credit (Chapter 12) for active and passive solar systems. Such a tax credit allows an individual to claim \$1000 credit not to exceed 25% of the system cost for a solar system installed on the individual's primary residence. All components of an active system, as long as they would not be contained in a usual structure, are eligible for credit.

The accompanying administrative code (Appendix II) is specific in the case of passive systems. Drum or trombe walls are eligible only to the extent they are part of the solar system and not structural. Masonry walls or floors are not eligible because solar collection is incidental to their primary use. Building insulation is not eligible for credit. Glass on a south facing wall is eligible in the proportion to glass on the entire structure. Skylights, if insulated against nocturnal heat loss are eligible for a 50% credit. Window insulation used to minimize heat loss is eligible for a credit if it can be demonstrated that insulation

(rather than decoration) is its primary function. Thus, insulating panels are eligible but draperies, blinds and curtains are not.

California. The state most closely identified with the sun and sun culture has one of the most definitive and liberalized incentive programs to encourage conservation and solar market penetration. The heart of the program is a 55% tax credit of \$3,000, which ever is less if the system costs are less than \$6,000 or a 25% tax credit with no ceiling if the system costs are greater than \$6,000. Active and passive systems and conservation measures qualify for the tax credit.

Forced air, forced circulating water, thermosiphon, integral collector storage and radiant energy systems are included as active systems. In order to qualify for the tax credit, active systems must also have appropriate R-value attic insulation, weatherstripping and caulked windows and doors, and for hot water systems water heater insulating jackets and flow restriction devices.

Passive systems include solar glazing with specific U values and south facing characteristics, solariums (air circulating devices qualify for the full credit while other parts of the solarium qualify for half credit) and thermal ponds. In association with passive systems, increasing the building mass also qualifies for a tax credit. Mass can be increased by water, masonry, rock, concrete walls or ceilings. Fireplaces or concrete on-grade slab floors do not qualify. Increases in heat mass qualify at different rates depending on climate and local insulation characteristics.

Glazing control is also eligible for the tax credit. Movable insulation such as shutters and drapes are eligible if they are weather stripped and gasketed to limit infiltration and airflow

between room and glazing. Roof overhang (shading) over 18 inches is eligible if it meets certain standards for summer shading and winter insulation.

Measures specifically designed to conserve energy are also eligible for the tax credit. Such measures include insulated walls, floors, ceiling and ductwork; multi-pane windows and weatherstripping. The California tax credit also includes swimming pool heaters and subterranean construction. Hearings for reversing the "passive" sections of the tax code are being held in 1979.

APPENDIX B

THE IMPACT OF BUILDING CODES

Scope:

This section discusses the limitations placed by model building codes on design modifications in some elements of a "typical" ranch house. Those modifications are for the purpose of (1) supplying solar energy as heating from both active and passive sources, (2) conserving energy in the building design, and (3) incorporating varying amounts of heat absorbing mass in the structure to act as heat storage. The intent of the study was to learn of any barriers placed by the codes on design features which might be considered reasonable options for reducing the need for fossil fuel energy use. The study was limited to (1) the building component options discussed below for single family detached residential structures only, (2) selected cities across the country chosen to represent various climates, and (3) the model codes studied. These were the following: the Building Officials and Code Administrators (BOCA) 1978 model code, the Uniform Building Code (UBC) 1976, and the One and Two Family Dwelling Code 1975. ASHRAE 90-75, a standard for energy conservation design in new buildings which has been incorporated into either the model code or separately enacted by the individual city was also studied. Finally, the Davis California energy conservation ordinance was studied as the most advanced energy-related code.

Codes Organization:

While historically building codes have been enacted by individual cities or towns in recent years, some of the states have adopted building codes to insure uniform regulations and to simplify procedures for both designers and builders operating

in the state. Even with a state code, the authority to enforce the code usually rests with the individual municipal building inspector (or building inspection department in larger cities) who is granted, under the code ordinance, limited police powers to enforce the code. Building codes are limited to addressing only health, safety, and welfare issues in building construction and major renovation. The model code organizations, such as BOCA and UBC, are private companies which prepare codes as models which may be enacted in whole or in part, or modified by the municipality or state which enacts them. Building codes are continually evolving; and, historically, building codes have developed as reactions to specific building disasters. Certain model codes appear to be more prevalent in different parts of the country. UBC is seen most in the western states, BOCA in the middle and northeastern states, and SBC (Standard Building Code) in the southern states.

Most of the existing codes are prescriptive codes; that is, specific materials, thickness or other dimensions or construction practices are written into the code language. This is natural when considering the way in which the codes came about, as reactions to particular situations which were, often tragically, found to be unsafe. The drawbacks to this type of code are that, in some cases, the intent behind the precept becomes lost and the regulation appears an arbitrary requirement. This discourages any alternative solutions which might be developed if the designer and the building official knew the intent of the regulation and were left the latitude to judge the efficiency of a new way of solving the problem.

Cities/Codes Selected

Eleven cities across the country were selected to represent varying conditions in climate and geographic region. Each city's Building Inspection Department was surveyed to learn which model code was used as the basis for the individual code. Additionally, the use of any model energy conservation standard was questioned. The results are listed below. In each case, the city's code was based on, but not exactly the same as, the model code or standard shown below.

City/State	Model Building Code	Model Energy Conservation Standard
Boston, MA	BOCA	ASHRAE 90-75
Worcester MA	BOCA	ASHRAE 90-75
Denver, CO	UBC	None
Boulder, CO	UBC	ASHRAE 90-75
Col. Springs, CO	UBC	None
Los Angeles, CA	UBC	State standards
San Francisco, CA	UBC	State standards
Sacramento, CA	UBC	State standards
Albuquerque, NM	UBC	ASHRAE 90-75 w/major modifications
Atlanta, GA	National	ASHRAE 90-75
Washington, DC	Special	None

Since the basic house being modified in the study was a one story detached residence which might be found outside of the jurisdiction of a city-enacted building code, and additional model code, the One and Two Family Dwelling Code, which deals only with residential construction and which has been used in the more rural

areas across the country, was studied. This code was developed under the auspices of four of the major model code organizations, UBC, BOCA, National and Standard Building Codes. As previously mentioned, ASHRAE 90-75 was studied as it appeared in a number of cases and is being considered by other cities and states which currently have no energy conservation provisions.

Code Review

With the list of building component options detailed above in mind, the codes were studied, searching for areas of conflict. No areas of absolute conflict were found, with one significant exception, the use of 80% glass.

The most significant concern was the large areas of glazing in some of the window options. The 80% south wall glazing options assume essentially that the entire south wall, floor to ceiling, is glazed, as it does not take much glazing support structure, when added to the foundation and floor framing to equal 20% of the total wall area. This raises two issues. First, the codes require protection from wind loads, which specify maximum sizes of individual glazing lights for various strengths and thicknesses of glass. Depending on the wind conditions in the area, this could mean using relatively expensive, strong or thick, glass in order to keep the individual glazing lights large in order to maintain the 80% glazing figure. In other words, one can hardly find such requirements. Another issue related to large glass areas is the potential danger through breakage caused by human impact, and the cost associated with using tempered or laminated glass or other safety glazing to protect against this. For instance, the UBC Code referring to glazing in locations

subject to human impact, set standards for glazing greater than 18 inches wide, with a bottom edge closer than 18 inches to a walking surface, and in doors and glazing adjacent to doors. However, as a result of the Consumer Products Safety Act (Federal Public Law 92-573), the Consumer Products Safety Commission has established a safety standard regarding Architectural Glazing materials which, as of July 6, 1977, pre-empts all state and local requirements unless they are identical to the new requirements. This standard (CPSC 16- CFR Part 1201) details locations in different types of buildings where glazing represents a hazard from human impact and describes an impact test which glazing must pass to be certified for use in these areas. The test involves a 400 foot-pound impact, and most glass manufacturers are now producing both tempered and laminated glass which can be certified⁽⁵⁾. As a performance standard, the CPSC requirements do not specify particular types of satisfactory materials--even annealed glass, if about one inch thick, will meet the requirements, and, of course, most plastics far exceed the requirements⁽⁶⁾. Clearly, this increases cost of glazing in certain areas; however, in many ways the CPSC standard is less stringent than the UBC requirements previously in force. For residential construction, the new standard requires certified glazing within 12 inches of either side of a door and if there is a 'chair rail' along a wall with glass adjacent to a walking surface, the glazing does not need to be certified. In this case, the rail is assumed to act more as a signal than a physical restraint to human impact⁽⁷⁾. In general, this is again a case in which the code's safety requirements may reasonably add some cost, but does not regulate against

a design element.

A serious barrier to the use of direct gain solar may result from ASHRAE 90-75. The use of large window areas may not permit the building UA to pass building standards via the simplified procedure. The inclusion of thermal shutters would maintain adequate UA values, but present ASHRAE 90-75 regulations require a more complicated calculation procedure when utilizing moveable insulation. The need for professional assistance in following the more involved calculation procedure may add prohibitive costs to the use of thermal shutters.

There were several areas which appear as though they might represent areas of conflict which were reviewed closely. One of these is the requirements concerning light and ventilation for various types of rooms. The codes prescribe minimum area of glazing (usually requiring half of it to be operable) to provide light and ventilation. 'Habitable rooms', such as living, dining or bedrooms, are given one percentage requirement, and other auxiliary spaces, such as bathrooms, laundry rooms, etc. are given other requirements. BOCA requires a minimum of 8% of the floor area served in a habitable room to be the area of glazing required, with a minimum of 3 square feet required in bathrooms. UBC and the One and Two Family Codes require 10% of the floor area served in habitable rooms to be the glazing area required. UBC requires 5% in other rooms; One and Two Family requires 3 square feet minimum in other than habitable rooms. The existing requirements were of potential concern when considering a reduction in the amount of glazing, particularly on the north side, for the purposes of reducing heat loss. The assumed cases calling for only

4% of the total north wall area in glazing could conceivably present problems for rooms with only one exterior wall on the north side (that is, away from the corners) if they were planned as habitable rooms. However, in house design utilizing direct solar heat gain through south glazing (as in the assumed cases which also called for only 4% north glazing), the main active living spaces considered desirable are located on the south side, to be in the sun, and the auxiliary and service spaces are located on the north because (1) they have to be somewhere, and (2) they provide buffer spaces between the main living spaces and the colder north wall. It is not uncommon to find bedrooms on the north side, but corner locations (so that part of the rooms glazing can be found on the east or west walls) would resolve the conflict. Finally, although undesirable from an energy viewpoint, the code does provide for an alternative method of meeting the requirements, that of mechanically-assisted ventilation. This solution, of course, may involve not only energy used to drive fans, but also increased heating load due to infiltration through the vent system (chimney effect).

Another potential problem was in the use of foam plastics as insulation in walls #2,4,5 and 6 due to the fire hazard presented by foam plastics of most kinds. Flame spread and smoke development standards are referenced by the codes and maximum levels established. Based on a UL study using the referenced test (ASTM E-84), the styrofoam insulation assumed in this study meets the code requirements. A BOCA Research Report (No. 76-27)

recommends to building officials that the material is acceptable as non-structural sheathing and insulation, if installed correctly provided that the wall is adequately braced and the interior spaces of the building are separated from the foam by a thermal barrier having a 15-minute finish rating (1/2 inch type 'X' gypsum wallboard, 1/2 inch regular gypsum wallboard with the stud spaces filled with fiberglass, or other) (3) .

APPENDIX C

TRNSYS UNIT DESCRIPTIONS

This Appendix presents the descriptions of the TRNSYS units used to simulate the building performances. Following the unit descriptions is a listing of the parameters used for the Base Building annual run.

Unit 1, Type 9 card reader. Reads from tape the month, day, hour wind speed, radiation on a horizontal surface and ambient temperature on an hourly basis.

Unit 2, Type 16 Radiation Processor. Converts total solar radiation for a horizontal surface to its beam and diffuse components for the following surfaces: south roof, north, east, south, and west walls and north roof. Outputs Solar Profile Angle for use in Solar Heat Gain routine. (See Table II-1 Building Configuration Constants).

Unit 3, Type 1 Collector. Uses mode 4 in order to accurately model collector performance by calculating U_L and τ . For Domestic Hot Water 5.6m^2 ; for combined DHW and space heating 17.5m^2 .

Unit 4, Type 13 Relief Valve. Models a tank temperature relief valve set at 100°C .

Unit 5, Type 5 Collector Loop Heat Exchanger. A counter flow heat exchanger with a UA of $23,740\text{ kJ/hr}^\circ\text{C}$.

Unit 6, Type 3 Collector Loop Pump. A pump between the collector and heat exchanger with a mass flow rate of 897 kg/hr .

Unit 7, Type 4 Tank. An unstratified liquid storage tank of 1.325 m^3 capacity.

Unit 8, Type 3 Tank to heat exchanger pump. A pump in the tank - heat exchanger loop with a mass flow rate of 879 kg/hr .

Unit 9, Type 2 Collector Loop Differential Thermostat. A differential thermostat between the collector and tank, controlling

collector loop pump and tank-heat exchanger loop pump. Dead band limits are: $t_{\text{COLLECTOR}} - t_{\text{STORAGE}} > 5.6^{\circ}$ - pumps turned on; $t_c - t_s < 1.7^{\circ}\text{C}$ - pumps turned off.

Unit 10, Type 23 DHW System. (See Table II-1 Building Configuration Constants). Models a domestic hot water system including pump, heat exchanger, preheat tank, and auxiliary heater. 300 liters daily use of hot water is delivered at 48.9°C , main water being mixed in if necessary to ensure that delivered temperature is 48.9°C . Solar energy is supplied to preheat tank, and auxiliary heat is added when necessary to bring water temperature up to 48.9°C . A typical diurnal hot water demand schedule is utilized (Mutch, 1974).

Unit 11, Type 11 Tee Piece. Combines the flow streams from the room heat exchanger and the DHW system before they reenter the tank.

Unit 12, Type 3 Tank to Room Pump. A pump between the room heat exchanger and tank with a mass flow rate of 2.029 kg/hr.

Unit 13, Type 17 Wall Model. (See Table II-3. Building Structure). Models the thermal performance of the south, east, north, and west walls and windows of the building using the transfer function methodology developed by Stephenson and Mitalis (1967). Five different wall types are modeled: uninsulated $3\frac{1}{2}$ " stud; insulated $3\frac{1}{2}$ " stud; insulated 6" stud; insulated 6" stud with 1" total wall (styrofoam insulation) on the outside; 8" masonry with 4" total wall on the outside. 16% or 40% windows are specified for the south wall. 100% window shading is specified so that direct heat gain may be treated more accurately in the solar heat gain routine.

Unit 14, Type 18 Roof Model. Models the thermal performance of a roof, with or without collectors, and ceiling using the heat transfer method. Two roof types are modeled: 6" insulation and 12" insulation.

Unit 15, Type 29 Solar Heat Gain Through Windows. Models the entry of solar energy through windows accounting for varying transmittance due to changing solar profile angles and for horizontal overhang shading. Both beam and diffuse radiation are taken into account.

Unit 16, Type 15 Wall and Roof Adder, Aux Heater, Aux Cool-Utility Energy, Aux Cool Delivered. Has 4 outputs:

Output 1 - combines the net energy flows from the walls and roof for input into the room model.

Output 2 - provides a constant heat input to the room, controlled by the room thermostat.

Output 3 - provides a measure of electrical energy used to run the room air conditioner.

Output 4 - the amount of cooling delivered to the room by the air conditioner, accounting for the coefficient of performance of the unit.

Unit 20, Type 19 Room. (See Table II-3. Building Structure). The room model simulates the building thermal performance, using the transfer function method where appropriate. All building energy flows are accounted for, including solar heat gains, conduction, internal generation from lights and people, room heaters, air conditioners and infiltration.

Unit 21, Type 8 Room Thermostat. (See Table II-1 Building Configuration Constants). A three-stage thermostat for the

separate control of the auxiliary heater, the solar heater and overall control of the cooling functions.

Unit 49, Type 15 Solar Heat Gain Eliminator. It is important to know what portion of solar heat gain is useful in heating the building to the desired temperature. This unit keeps an account of the solar heat gain which is beneficial for space heating, but does not effect actual simulation.

Unit 46, Type 15 Total Solar² and Total Auxiliary. Has 3 outputs:

1. Total solar heat and DHW supplied.
2. Total solar heat and DHW supplied and total useful solar heat gain through windows.
3. Total auxiliary heat supplied.

Unit 47, Type 15. Open/close Shutters. In summer, models automatic insulating window shutter control which opens shutters at night for radiative cooling and closes them during the day to reduce direct heat gain. In winter, closes shutters at night to reduce heat loss and opens them during the day to maximize direct heat gain.

APPENDIX D

UTILITY WEATHER, LOAD AND TARIFF DATA

Colorado Springs Weather Data

The small size of the City of Colorado Springs service area makes the selection of weather location easy. Local Climatological Data (L.C.D.) for Colorado Springs does exist and contains all of the required information, though cloud cover must be used instead of percent possible sunshine. The same is not true, however, for yearly weather sequences, where accurate solar radiation values are only available nationally for a few locations. The nearest available location for yearly weather including radiation is Boulder, Colorado. Although Boulder and Colorado Springs are both at approximately 105° W longitude, there is a deviation between the weather at Boulder and Colorado Springs. The former is in the foothills while the latter is in the front range area. While Colorado Springs receives more insolation than Boulder, it also has more winter heating degree days (12% more). (See ASHRAE Systems, 1976). Although these differences exist, Boulder weather data was selected as the only year weather sequence available to drive the model.

COLORADO SPRINGS LOAD AND FINANCIAL DATA*

I. Present Rate Schedule

a) Residential Service - General

Energy Base Charge:	\$/kwh
First	.0450
Next	.0370
Next	.0285
Additional kwh	.0220

Minimum charge \$1.35

*All data is based on 1975 prices.

Energy cost adjustment October 1975 .002287

Average cost of auxiliary electricity = .022 +
.002287 = .025 \$/kwh

II. Peak Load Data

<u>Year</u>	<u>Date on which Peak occurred</u>	<u>Peak Demand (mw)</u>
1971	December 7	225.2
1972	December 6	250.
1973	January 19	252.
1974	December 19	266.
1975	November 25	283.

III. Demand Periods

ON PEAK - Nov.-March; Mon-Fri., 1600-2000 inclusive.

OFF PEAK - All other times.

IV. Average Incremental Costs (Fuel & Variable O&M)*

ON PEAK = .0131 \$/kwh

OFF PEAK = .0109 \$/kwh

V.. Loss Data

Cummulative Loss Multipliers (Secondary distribution).

<u>Demand</u>	<u>Energy</u>	
	On Peak	Off Peak
1.0623	1.1296	1.0005

VI. Incremental Capacity Cost (Secondary distribution)*

Generating Capacity	\$25.0
T&D Capacity	\$8.5
Total	\$33.5

*Calculated via Cicchetti et.al. (1976) methodology.

DERIVED TIME OF USE RATE FOR COLORADO SPRINGS

Using the Cicchetti et.al. (1976) methodology, a set of marginal cost tariffs can be derived. These values were calculated as \$.065 on peak and \$.0109 off peak. For comparison purposes, it is better to establish a TOU tariff which produces the equivalent amount of revenue to the utility as the existing rate, but still preserving the cost ratio of on peak to off peak. The formula for deriving these rates is based on determining the percentage of consumption during each period. (For Colorado Springs these values are 10% on peak and 90% off peak). The formula, therefore, is:

$$P_{ave} = PRS_{on} \times P_{on} + PRS_{off} \times P_{off}$$

where

P_{ave} = Price of Electricity Average Cost (Based on 500 kwh, monthly consumption).

PRS_{on} = Percent of Residential Sales On Peak.

P_{on} = Price of Electricity On Peak.

PRS_{off} = Percent of Residential Sales Off Peak.

P_{off} = Price of Electricity Off Peak.

If the ratio of on peak to off peak price is preserved then

$$P_{on} = \text{Ratio} \frac{\text{marginal cost on peak}}{\text{marginal cost off peak}} \times P_{off}$$

Therefore:

$$.025 = .10 (5.963 P_{off}) + .90 (P_{off})$$

$$.025 = 1.4963 P_{off}$$

$$P_{off} = .0167 \text{ \$/kwh}$$

$$P_{on} = .0996 \text{ \$/kwh}$$

NOTE:

This rate is used here for comparative purposes and will probably not reflect implementable TOU rates, which must reflect elasticity, administration costs and other considerations.

These rates vary from the time of day rates used by the authors in a previous NSF study by Feldman et. al. (1976). In that case, the revenue constraint¹ assumption was not utilized and, as a result, the rates on peak and off peak² did not generate sufficient revenue.