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PERFORMANCE OVERVIEW: PASSIVE SOLAR ENERGY FOR NON-RESIDENTIAL BUILDINGS

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PERFORMANCE OVERVIEW:
PASSIVE SOLAR ENERGY FOR NON-RESIDENTIAL BUILDINGS

by

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SOLAR BUILDINGS RESEARCH AND DEVELOPMENT PROGRAM
CONTEXT STATEMENT
November 21, 1985

In keeping with the national energy policy goal of fostering an adequate supply of energy at a reasonable cost, the United States Department of Energy (DOE) supports a variety of programs to promote a balanced and mixed energy resource system. The mission of the DOE Solar Buildings Research and Development Program is to support this goal, by providing for the development of solar technology alternatives for the buildings sector. It is the goal of the program to establish a proven technology base to allow industry to develop solar products and designs for buildings which are economically competitive and can contribute significantly to building energy supplies nationally. Toward this end, the program sponsors research activities related to increasing the efficiency, reducing the cost, and improving the long-term durability of passive and active solar systems for building water and space heating, cooling, and daylighting applications. These activities are conducted in four major areas: Advanced Passive Solar Materials Research, Collector Technology Research, Cooling Systems Research, and Systems Analysis and Applications Research.

Advanced Passive Solar Materials Research. This activity area includes work on new aperture materials for controlling solar heat gains, and for enhancing the use of daylight for building interior lighting purposes. It also encompasses work on low-cost thermal storage materials that have high thermal storage capacity and can be integrated with conventional building elements, and work on materials and methods to transport thermal energy efficiently between any building exterior surface and the building interior by nonmechanical means.

Collector Technology Research. This activity area encompasses work on advanced low-to-medium temperature (up to 180°F useful operating temperature) flat plate collectors for water and space heating applications, and medium-to-high temperature (up to 400°F useful operating temperature) evacuated tube/concentrating collectors for space heating and cooling applications. The focus is on design innovations using new materials and fabrication techniques.

Cooling Systems Research. This activity area involves research on high performance dehumidifiers and chillers that can operate efficiently with the variable thermal outputs and delivery temperatures associated with solar collectors. It also includes work on advanced passive cooling techniques.

Systems Analysis and Applications Research. This activity area encompasses experimental testing, analysis, and evaluation of solar heating, cooling, and daylighting systems for residential and nonresidential buildings. This involves system integration studies, the development of design and analysis tools, and the establishment of overall cost, performance, and durability targets for various technology or system options.

This report is an account of research conducted in the systems analysis and applications research area. It summarizes results of the performance evaluation phase of DOE's Non-Residential Experimental Buildings Program.

I. INTRODUCTION

In 1979, the U.S. Department of Energy (DOE) launched the Non-Residential Experimental Buildings Program to investigate the potential of passive solar technologies to meet the heating, cooling, and lighting requirements of non-residential buildings. After five years, 19 buildings have completed the design and construction phases and are finishing the final performance monitoring phase, compiling results relative to energy consumption, economic performance, and occupancy effects. The projects range from a 700 square foot classroom module in Alaska to a 66,700 square foot airport in Colorado, and comprise a variety of building types, including office buildings, community centers, an automobile maintenance shop, a bank, and several educational use buildings. Designs focus on passive heating, cooling, and daylighting strategies for reducing energy consumption.

During the design of these buildings, under Phase I, a team of technical experts helped each project architect maximize energy performance, enhance occupant comfort, and minimize cons [illegible] Each project team started by establishing a "base-case" building, a non-solar building which the owner probably would have ordinarily built. Team members then calculated heating, cooling, lighting, and other energy requirements, taking into consideration heat generated within the building by lights and people, occupant behavior, climate, and construction practice. These buildings were to reflect state-of-the-art practices for energy conservation. Designers then developed passive design schemes and estimated their costs and energy performance. Energy estimating techniques ranged from calculations of Los Alamos Scientific Laboratory solar load ratio or solar savings fraction, to computer simulation using mainframe programs developed by federal and private sector groups. The DOE required that the passive solar features address the building's major energy cost requirements, which in most cases were lighting and heating, with some significant cooling in the larger buildings or buildings located in more southerly locations. The designs also had to be aesthetically pleasing, integrate mechanical, lighting, and other support systems, and demonstrate "technical validity." The cost of the passive features had to be reasonable as measured by life cycle cost analysis. The resulting array of designs showed a bias towards south-facing roof apertures that provided both heat and light, Trombe walls, and circulation spaces that collected heat for distribution to the rest of the building. Glare and overheating were prevented by diffusing baffles, overhangs, and operable shades. Night flushing of building mass, evaporative sprays, and natural ventilation supplied the bulk of cooling. Both automatic and manual controls were represented. The solar designs are summarized in another document, *Design Overview: Passive Solar Energy for Non-Residential Buildings*, as well as in the individual design case studies published by the DOE in 1983.

After the buildings were constructed under Phase II, they entered the final Phase III: performance evaluation. This overview summarizes the results of their performance, answering the questions: How well do the buildings work? Specifically, do they save auxiliary energy? Do they function as well as conventional buildings in terms of maintenance, operation, and comfort? Finally, what do they cost compared with conventional buildings?

In the following pages, the reader will find that the answers to most of these questions are positive, thus countering past assumptions that non-residential buildings were unlikely candidates for passive solar technology by virtue of their high internal heat gains, large volume, and rigid environmental conditions. The program buildings saved signficant amounts of energy at little, if any, extra cost. Occupant satisfaction was above average. Moreover, their operation and use of the buildings had a significant impact on auxiliary energy consumption.

Building energy performance is a directly quantifiable issue that is of undeniable concern to the building owner since it translates to dollars and cents. As the owner expects energy efficiency more and more in his building, the designer must keep abreast of what is feasible, both technically as well as economically, for his climate and building type. Performance Overview: Passive Solar Energy for Non-Residential Buildings gives both the owner and designer actual numbers on how the best such buildings perform, thus establishing realistic limits and achievable goals for other passive solar non-residential buildings.

II. ENERGY

Two of the most frequently asked questions about passive solar building energy performance are: "Do the buildings save significant amounts of energy compared to conventional buildings?" and "Where do they save energy?" This last question is particularly applicable to non-residential buildings because they are often perceived as needing much less heat than do residential buildings. This section will address these issues.

A. DECREASE FROM NON-SOLAR BENCHMARKS

1. The Passive Solar Buildings Participating in the Program Used 47% Less Energy Than Their Conventional Counterparts.

On an area-weighted average, new buildings submitting a year or more of monitored consumption data used almost half the energy that the conventional base buildings would have used, and significantly less energy than research for Federal standards determined to be economically feasible. They also used about 60% less energy than average U.S. commercial buildings.[1]

. Comparison with Base Cases

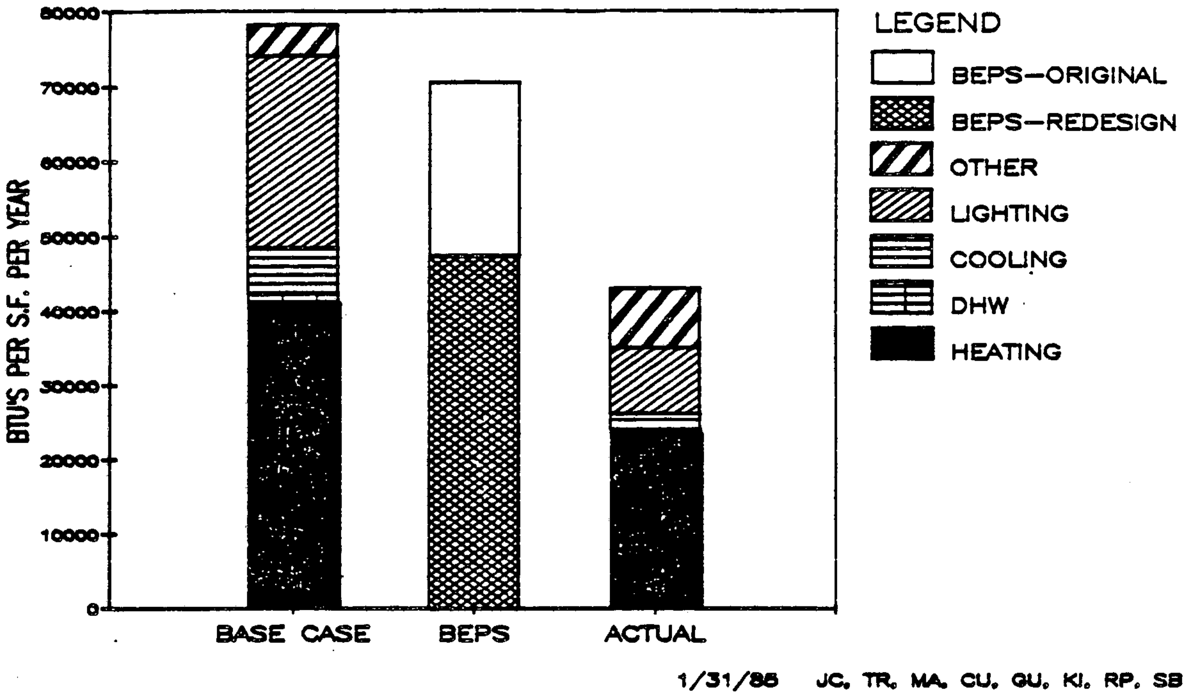
Figure II.1 shows the aggregated decrease in energy consumption from the base cases, and Figure II.2 shows the range of decreases over the buildings participating in the program. As one can see, the energy consumption of every building was either projected or actually measured to be substantially below that of its corresponding base case. Base case buildings are the non-solar equivalents which owners would have ordinarily built, and range from pre-engineered metal classrooms to standard corporate architecture. In the case of retrofits, base cases were the existing buildings. All base cases reflect the owners' budgets and the standard construction practices in their areas.

The distribution illustrated in Figure II.2 shows no particular pattern of climate, building type, or solar strategy that characterized the best and the worst performers, except that retrofits could not attain the same levels of reduction as could the new buildings. This was probably due to the retrofits' handicaps of deterioration from old age and a design for lower cost energy. Many of the cold climate participants such as Blake Avenue College Center in Colorado and the State Security Bank in Minnesota performed as well as those in sunnier, more moderate climates. Finally, buildings designed to reduce heating, cooling, and lighting are distributed fairly evenly across the range.

. Comparison with BEPS[2]

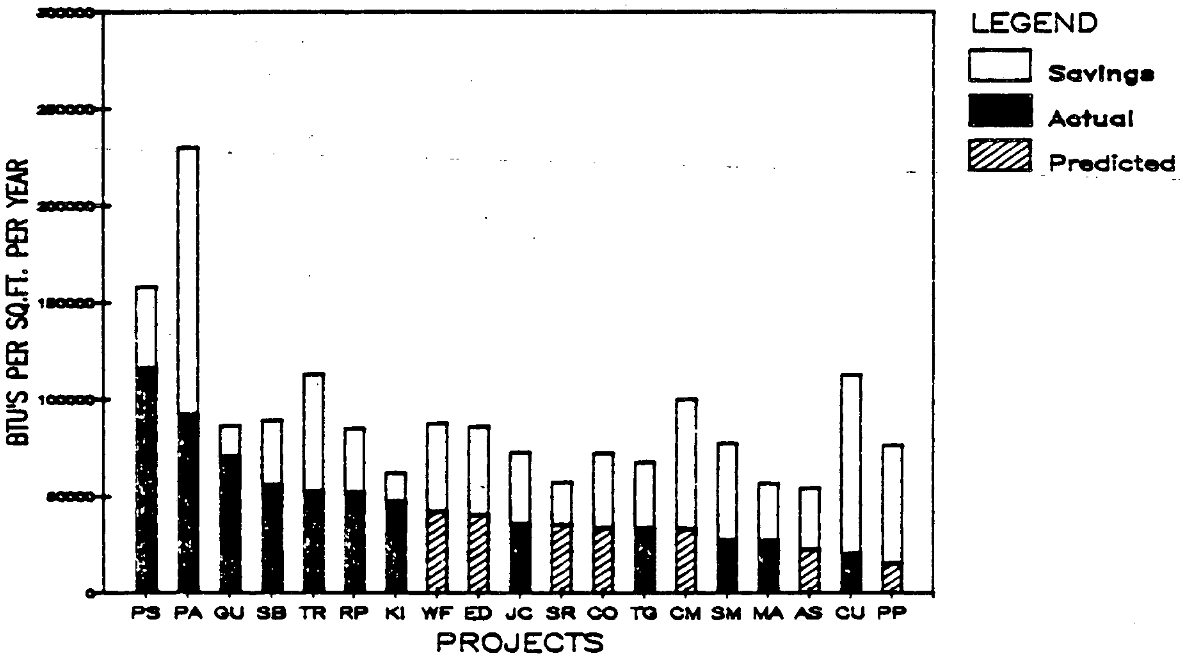
Like this program, the BEPS program also used base cases as benchmarks. Passive solar base cases approximated BEPS base cases within 10%, demonstrating good faith on the part of passive designers not to artificially raise these benchmarks to make savings appear greater. Furthermore, when the actual

Figure II.1
AUXILIARY ENERGY USE NEW BUILDINGS



1/31/86 JC, TR, MA, CU, GU, KI, RP, SB

Figure II.2
AUXILIARY ENERGY USE AS A FRACTION OF BASE CASE



1/31/86

energy consumption of new passive solar buildings is compared with the BEPS figures (Figure II.1), the average fell 14% lower. Only the retrofit projects exceeded BEPS budgets.

The primary difference between the design process in the BEPS program and in this one was that in the latter, technical assistance provided to the designers covered not only energy conservation, but passive solar heating, cooling, and daylighting. This indicates that passive solar technology, and not just conservation measures, contributed to the reduced energy consumption of these buildings.

2. Heating, Cooling, and Lighting Energy Was Reduced by Approximately Half, But "Other" Energy Increased.

. Primary Functions

- Annual Reductions. The most prominent observation is that all of the primary functions were reduced by large amounts (Figure II.1).In particular, daylighting strategies were not accompanied by increases in cooling or heating energy. Given that over half of the building designs focused on daylighting, the reductions in heating and cooling were particularly gratifying.

  Similarly, neither were solar heating strategies accompanied by increases in cooling energy. Solar heating was the focus of approximately 50% of the designs. This observation applies in particular to cooling energy in the fall months when one might expect solar apertures to collect unwanted heat gain from the low, southwest afternoon sun (Figure II.3).

  All of these observations help dispel the notion that non-residential buildings, due to their internal cooling loads, are poor candidates for passive solar design, especially passive solar heating and daylighting.

- Seasonal Variations in Lighting. A possible reason why daylighting designs incurred no cooling penalties is that auxiliary lighting energy (and therefore associated heat gains) was 22% lower in summer months than in non-summer months. This reduction in artificial lighting energy also reduces cooling, since daylighting efficacy (90-150 lumens/watts) is generally higher than that of artificial light (25-100 lumens/watt for fluorescent sources). Thus, less heat gains are generated.

  In June, July, and August, buildings submitting a full year of data reported, on the average, monthly lighting energy consumption of 567 Btus/s.f.; the other months required 729 Btus/s.f. This 22% decrease was due in large part to the greater availability of sunlight (34% to 60% increase depending on geographic location). The artificial lighting reduction did not match the increased availability of natural light because in most cases, as daylight hours extended past normal office hours in the summer, the daylight was no longer usable for offsetting artificial lighting energy.

. Other Functions. The doubled increase in the "other" category is noteworthy. "Other" energy users included

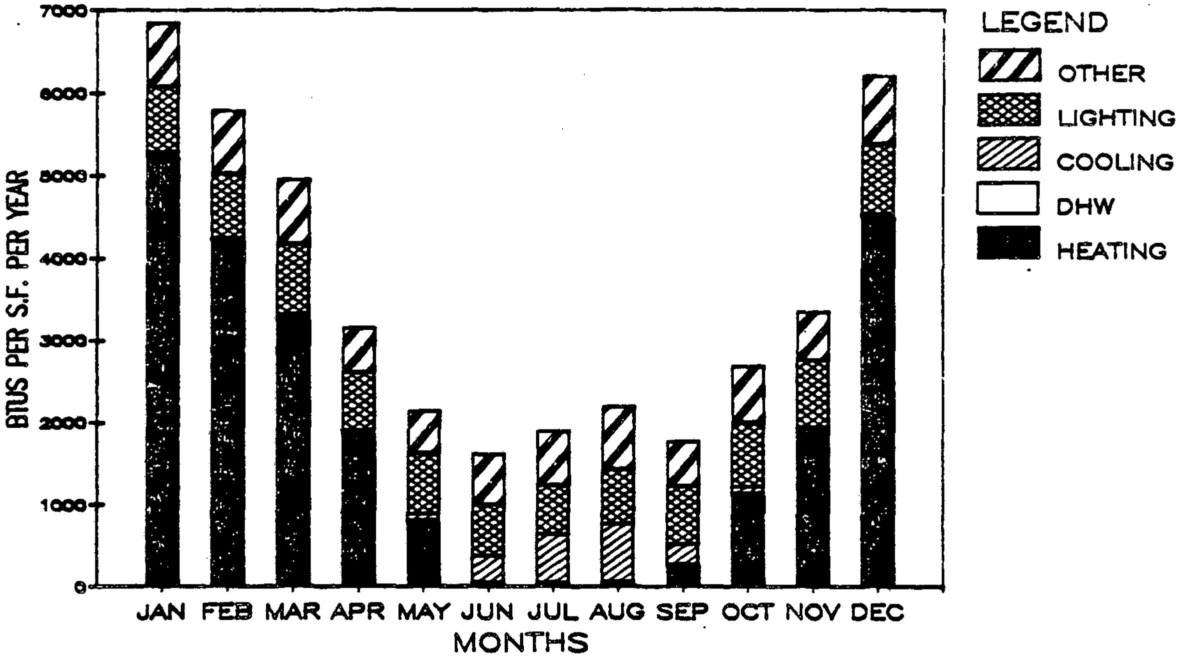


Figure II.3
AUXILIARY ENERGY USE
BY FUNCTION AND MONTH

1/31/88 JC, TR, MA, CU, GU, KI, RP, SB

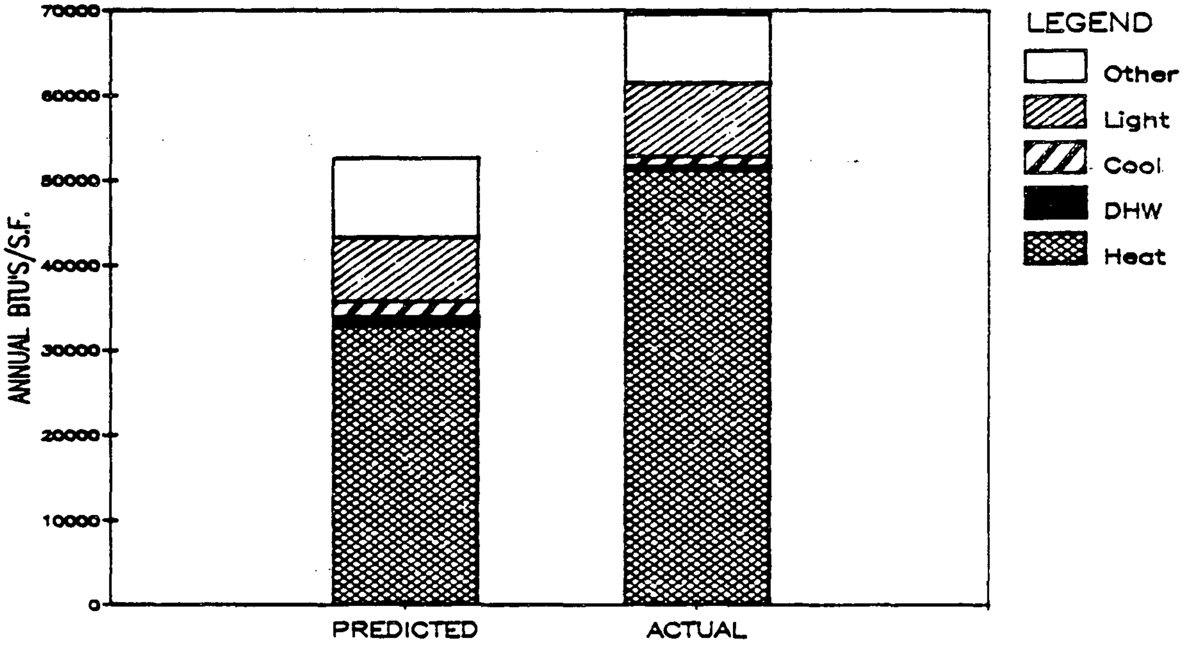


Figure II.4
AUXILIARY ENERGY USE BY FUNCTION
PREDICTED AND ACTUAL

1/31/88 for new and retrofit projects

fans, pumps, task lighting, wall appliances, and office equipment. In constructing the base-case building, designers tended to underestimate the contribution of these energy users as this increase reflects. The implication for energy design tools and the design process: is that more attention should be paid to this energy. Since much of it is consumed by equipment, which is controlled by unpredictable building occupants, then the designer should anticipate a range of "other" energy-related circumstances when estimating building energy consumption.

B. INCREASE FROM PREDICTIONS

1. Many Buildings Were Used More Than Their Owners Expected, Contributing to 20% Higher Than Expected Energy Use.

In the performance monitoring phase, actual building energy use fell beyond designers' projections, exceeding the projections by 20% on an area- weighted average. In only one case, the Johnson Controls Branch Office, was the actual energy consumption significantly lower than predicted. Others were as much as twice the predicted figure.

. Breakdown by Function

Figure II.4 shows the breakdown of predicted and actual energy use by function. Heating energy fell off mark by the greatest amount at 31% higher than the original estimate. This excess was compounded by the concurrent decrease in heating degree days in almost all cases. On the other hand, cooling performance beat initial estimates by 47%, conversely buoyed by the concurrent increase in cooling degree days.[3]

. Explanations for Discrepancies

Discrepancies betweeen the actual and the projected consumption resulted from at least two reasons: unanticipated building use patterns and design tool limitations.

- Unanticipated Building Use. Of the two reasons, this probably made the greater contribution to the discrepancy. Project monitors reported numerous instances where building operation was extended because of the popularity of the building, where more people used the building, or where storage spaces were turned into offices or classrooms, thus requiring space conditioning and lighting. The lesson learned is that because predicting building use patterns is so difficult, solar designers should anticipate post-occupancy changes by modelling their designs under a range of use patterns.

- Design Tool Limitations. Most of the design tools used were not intended to provide precise energy use estimates, but rather to give general design direction. Their precision, therefore, was limited. Specifically,:

  1. They were oriented primarily towards residential-scale buildings;

  2. They had primitive or no means for accounting for thermal mass effects, especially the interaction

of thermal mass with building setback; and

3. They were weak in handling the dynamic interactions between heating, cooling, and lighting.

III. ECONOMICS

The purpose of this chapter is to review two key questions underlying the economics of using passive solar energy in commercial buildings: (1) Do passive solar buildings cost more to build? and (2) Do passive solar buildings reduce annual operating costs? Based on the analysis presented here, passive solar commercial buildings cost significantly less to operate annually and can be built for about the same first cost as conventional designs.

A. CONSTRUCTION COST COMPARISON

1. Most Passive Solar Commercial Buildings Do Not Cost Any More To Build Than Conventional Buildings Of The Same Type.

Although a great deal of time has been spent in the past trying to isolate the incremental increase in first cost of solar buildings or components, it can easily be argued that, in the end, it is the total cost of a building that is of most concern to owners. Once a building budget is established, it is the goal of the design team to bring in a building that meets the owner's needs within the budget prescribed. The choice of specific building elements is left to the design team. It is their responsibility to trade off various building elements to arrive at a cost effective solution.

In this context then, it was decided that the most valuable analysis of passive solar construction costs would be a comparison of total passive solar building costs (per square foot) to typical conventional building costs. The cost per square foot of each passive solar building was computed from actual construction documents (see Figure III-1). This cost was then compared to a range of typical building costs (for similar building types) according to statistics compiled by either R.S. Means, F. W. Dodge, or both (see Figure III-2). The comparison was done for the actual year in which the building was built, to reduce any inflation effects, and was adjusted for building size and region where possible. In all, comparative data was available for 13 of the 15 new buildings completed in the Commercial Buildings Program.

Of the 13 buildings studied, 10 or 75% fell within or below the range of typical costs for conventional buildings of the same type. Specifically:

- 2 buildings fell below the range of typical costs
- 4 buildings fell within the range of typical cost but below the median for either Means or Dodge
- 4 buildings fell within the range of typical cost but above the median
- 3 buildings fell above the range of typical costs.

Of the three buildings which fell above the range of typical costs, one was a national award winning building, one was featured in a national architectural journal, and all fell within the owners' budget expectations. Although a comparison to national average figures cannot account for specific building characteristics or amenities, the fact that 3/4 of the passive solar buildings in the program fell within a reasonable range of first costs for comparable buildings clearly indicates that passive solar buildings need not cost any more than conventional construction. Supporting documentation for the analysis of construction costs is presented in detail in Appendix A-2.

B. OPERATING COST COMPARISON

2. Passive Solar Commercial Buildings Cost Significantly Less To Operate Annually Than Conventional Buildings Of The Same Type.

Unfortunately, there is no national data base of annual operating costs by building type equivalent to what Means and Dodge collect on construction costs. Therefore, a comparison of passive building operating costs to conventional building operating costs is much more difficult. Nevertheless, some data does exist, and it is often quite good for specific building types. Where data could be found, it is clear that utility costs for passive solar buildings are significantly less annually than for conventional buildings.

FIGURE III-1

PASSIVE SOLAR COMMERCIAL BUILDINGS
PROJECT DESCRIPTIONS AND COSTS

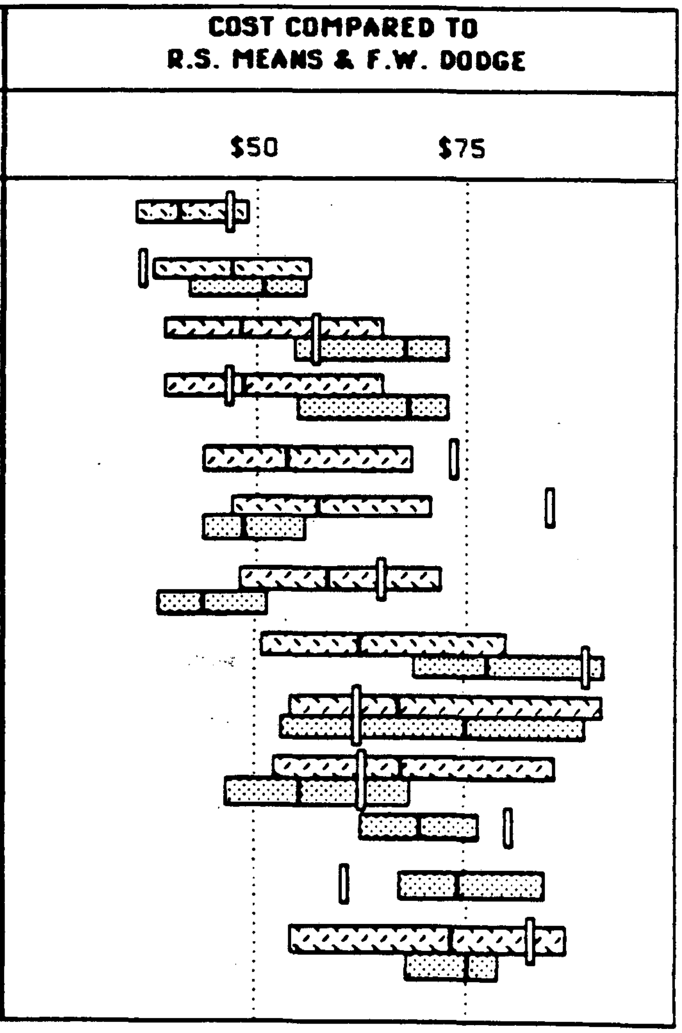
	CODE #	NAME	LOCATION	SIZE FT^2	TOTAL COST(1) $	COST/FT^2 $
NEW	TR	Two Rivers School	Fairbanks, AK	15,750	2,347,000	$149.00
	AS	Abrams School	Bessemer, Al	26,600	954,400	$ 36.00
	CU	C.U.M.C.	Columbia, MO	5,500	258,000	$ 47.00
	CM	Colorado Moutain College	Glenwood Sp., CO	31,900	1,874,000	$ 59.00
	MA	Mt. Airy	Mt. Airy, NC	13,500	1,188,000	$ 88.00
	SM	St. Mary's	Alexandria, VA	9,000	655,400	$ 74.00
	JC	Johnson Control	Salt Lake, UT	15,000	855,000	$ 57.00
	PP	Princeton Park	Princeton, NJ	64,000	3,000,000	$ 46.00
	SB	Security State Bank	Wells, MN	11,000	704,000	$ 64.00
	ED	Essex Dorsey	Baltimore, MD	13,000	850,000	$ 65.00
	SR	Shelly Ridge	Philly, PA	5,700	485,000	$ 85.00
	RP	RPI	Troy NY	5,200	423,900	$ 81.00
	GU	Gunnison Airport	Gunnison, CO	9,700	774,800	$ 80.00
	WF	Walker Field	Grand Jn., CO	66,700	4,000,000	$ 60.00
	TG	Toulistos Greenhouse	Memphis, TN	-----	--------	$ 12.00
RETROFIT	PA	Philadelphia Auto	Philly, PA	57,000	479,000	$ 9.00
	PS	Princeton School of Arch	Princeton, NJ	13,700	123,000	$ 9.00
	KI	Kieffer Store	Wausau	3,200	57,500	$ 18.00
	CO	Comal Co.	N. Braunfels, TX	4,800	14,000	$ 3.00

(1) Const. Cost + Contractor O.H. + Cont. Profit - Arch Fee - Land Cost - Site Work

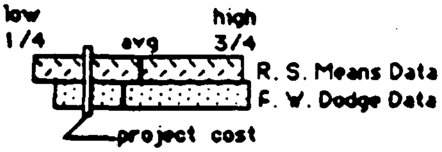
FIGURE III-2

COMPARISON OF NEW PASSIVE SOLAR BUILDING COSTS TO CONVENTIONAL BUILDING COSTS ($/FT^2)

PROJECT DESCRIPTION			
NAME CODE	SIZE & BUILDING TYPE	YEAR BUILT	$/FT^2
CU	Small Religious Ed.	1981	$47
AS	Small Elem. School	1981	$36
JC	Large Low Rise Office	1982	$57
PP	Large Low Rise Office	1982	$46
SM	Small Gymnasium	1982	$74
SR	Small Community Ctr.	1983	$85
ED	Small Senior Cit. Ctr.	1982	$65
MA	Average Library	1982	$88
SB	Small Bank	1981	$64
CM	Average Student Union	1981	$64
GU	Small Airport Term.	1981	$80
WF	Large Airport Term.	1982	$60
RP	Small Campus Police Ctr.	1981	$81



Legend:



A full year of utility cost information now exists for 10 passive solar commercial buildings in the program (see Figure III-3). These are actual energy cost data, taken in all cases from monthly gas, oil, and electric bills (excluding such extraneous costs as water or sewer charges often found on such bills). They have been computed on a per square foot basis to facilitate comparison but have not been normalized to reflect regional climate differences.

Comparative data was taken from principally four sources, depending on the building type in question:

- Nonresidential Buildings Energy Consumption Survey (NBECS) - This survey of over 5,000 nonresidential buildings conducted by the Energy Information Administration (D.O.E.) was based on a carefully selected statistical sample of the U.S. commercial building stock. It combined personal interviews with building operators and actual fuel bills collected from utility companies. From the data given, it is possible to compute an average total utility bill per square foot by building type either by region or by building size. Unfortunately, it is not possible to get both simultaneously. Although this data base is not equivalent to Means or Dodge (it exists for only a single year), it is clearly the best national data base across all building types.

- Building Owners and Manager Association (BOMA) - Each year, BOMA publishes the Exchange Report which includes a summary of office building operating costs for specific cities across the U.S. In many cases the data is further subdivided by location (urban vs. suburban) and sometimes by size. This is clearly one of the best data bases for office buildings but is limited to this single building type. Because data is specific, the number of buildings in any one category may be quite small. For this reason, any single datum can be badly skewed by one or two uncommon buildings.

- American Institute of Architects Foundation (AIAF) - Under contract to D.O.E. the AIAF recently prepared a summary of all available data on elementary and secondary schools. This report confirmed that few states report summary energy costs by square foot for schools. There are, however, a few states which offer this data. Maryland and New Jersey have particularly high quality data on energy cost per square foot. Their figures were used for comparison to school and school-like buildings in the program.

- Base Case Comparison (BASE) - Each design team participating in the Commercial Buildings Program was required to prepare a "Base Case Building Profile" as part of the design process. This base case was to represent a "good" or "average" building of the same type as the solar building being designed -- or a similar type. This building would represent common practice in the local area and would be the basis of comparison for the passive design. For owners of multiple buildings, the base case was often the last building built. In other cases the design team chose a building in the same locale and collected construction and operating cost data. In all cases, the base case was reviewed and approved as reasonable by the project monitoring team. Of the four comparisons used in this analysis, this is probably the "best" because of the effort made to find a reasonable comparison for the passive building actually built.

Of the 10 buildings studied to date, the total annual utility cost for all of them fell well below its base case alternative (see Figure III-4). The best performing building was 68% below its base case. The poorest performing building was 8% below its base case. The average across all 10 buildings was 51% less energy cost than the base case.

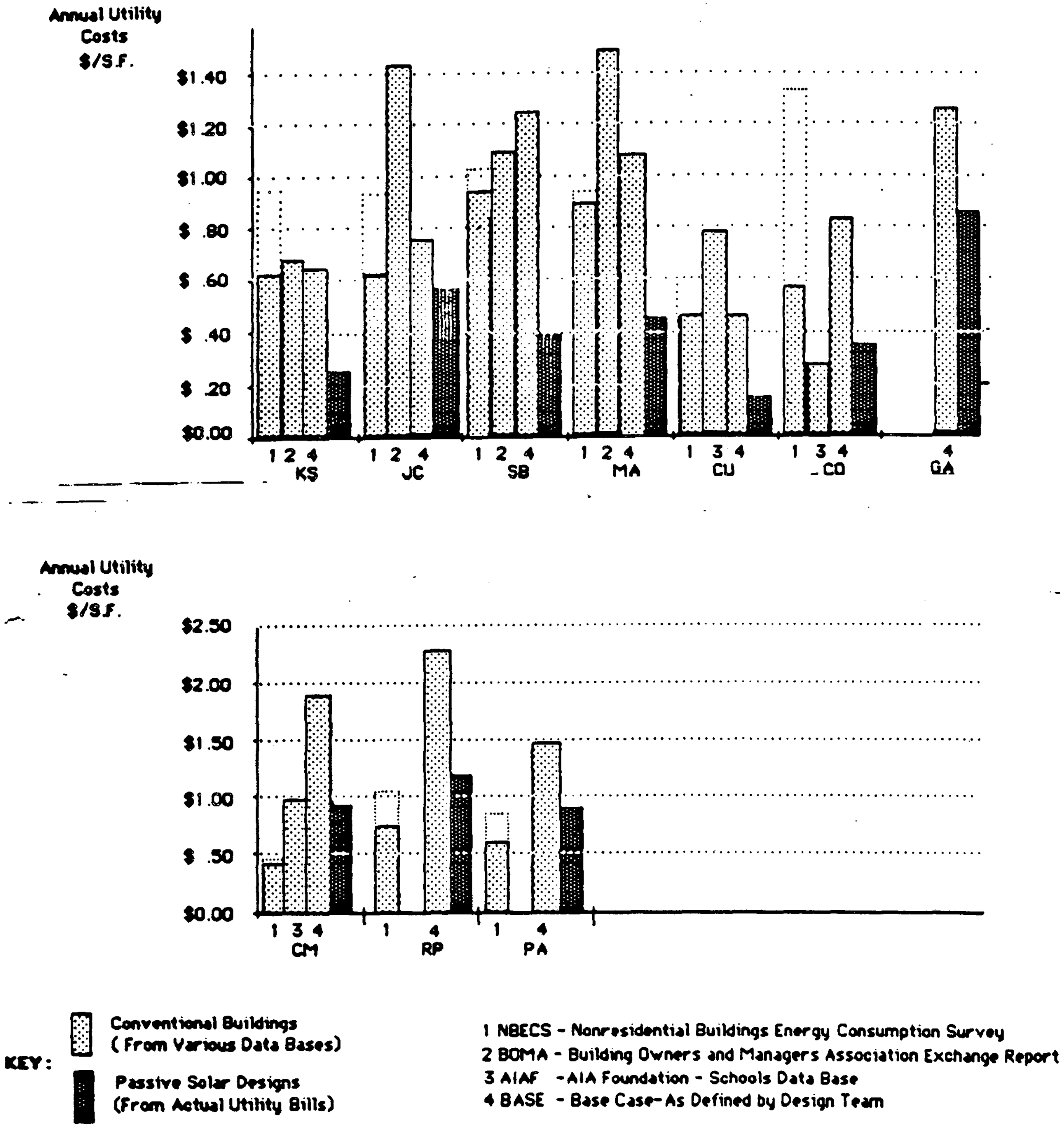
FIGURE III-3

PASSIVE SOLAR COMMERCIAL BUILDINGS
PROJECT DESCRIPTIONS
&
ANNUAL UTILITY COSTS

	CODE	NAME	LOCATION	SIZE FT.^{2}	STUDY PERIOD	ANNUAL UTILITY COST			ANNUAL UTILITY COST $/FT.^{2}
						ELEC. $	GAS $	TOTAL $	
NEW	CU	CUMC	Columbia, MD	5,500	11/82-10/83	236	569	805	.15
	CM	Colorado Mt. Col.	Glenwood Sp., CO	31,900	7/82- 6/83	27,388	2,340	29,728	.93
	MA	Mt. Airy	Mt. Airy, NC	13,500	1/83-12/83	6,119	No Gas	6,119	.45
	JC	Johnson Control	Salt Lake, UT	15,000	4/82- 3/83	7,249	1,219	8,468	.56
	SB	Sec. State Bank	Wells, MN	11,000	6/83- 7/84	3,938	430	4,368	.39
	RP	RPI	Troy, NY	5,200	6/83- 6/84	6,249	NA	6,249	1.20
	GU	Gunnison Airport	Gunnison, CO	9,700	9/81- 8/82	8,159	No Gas	8,159	.84
RETROFIT	KI	Kieffer Store	Wausau, WI	3,200	6/82- 5/83	386	399	785	.25
	CO	Comal Co.	N. Braunfels, TX	4,800	9/82- 8/83	1,161	515	1,676	.35
	PA	Philadelphia Auto	Philadelphia, PA	57,000	8/83- 7/84	19,279	31,176 Gas&Oil	50,455	.89

FIGURE III-4

COMPARISON OF ANNUAL UTILITY COSTS PER SQUARE FOOT AVERAGE CONVENTIONAL BUILDINGS VS. PASSIVE SOLAR DESIGNS



If one looks beyond the base cases alone to all of the data base comparisons done for this analysis, the conclusions are only modestly different. In this case, the best performer costs 80% less to operate than an average building of its type. The average reduction in cost (all buildings against all data bases) is 33%.

It is only fair to point out that, in some cases, the passive solar building spends more on energy per year than a comparative or average building. This is especially true when the passive building is compared to national average figures in the NBECS data base. In each of these cases, it could easily be argued that the base case more accurately represents local climate and utility cost characteristics.
On average, gas prices have increased 30% and electric costs as much as 150% since the NBECS data was collected. In all comparisons, the base case is significantly higher than the average figure. As one would expect given typical rate increases, it would be an interesting study in itself, though beyond what is possible here, to investigate these discrepancies and recompute the NBECS average costs. If NBECS were eliminated from the comparison, average savings across all remaining comparisons would be 48%.

A few numeric artifacts should not, however, distract from the key message of this analysis -- that passive solar buildings can spend significantly less on utilities than conventional buildings. Half of the buildings studied use less than 50¢ per square foot per year for utilities, and 9 of the 10 use less than $1.00. The average savings across all the buildings studied was from 30-50%. In fact, the lowest cost building in the program (a church school and community center in Missouri) spent only 15¢ per square foot per year for utilities. That is a total <u>annual</u> utility bill for both electricity and gas of $806.

C. OTHER COST-RELATED ISSUES

In a data base of 10 unique buildings, it is impossible to find enough similarities to be statistically accurate in commenting on any particular design feature. Nevertheless, several cost related issues have been identified which merit mention at least by anecdote. As more solar buildings are designed and built in the future, these issues should be studied further.

1. <u>Back-Up Systems or Multiple Systems Can Be Unnecessarily Costly</u>.

In the early days of passive solar design, there was reasonable cause for concern about whether or not systems would work as well as predicted. For this reason, designers were cautious and included either full scale back-up systems or designed multiple system options that could meet heating and cooling loads in case the passive solar system failed. In all cases these systems meant added first cost for equipment and will mean added operating and maintenance costs over the life of the building. As passive concepts continue to prove themselves, confidence in passive design will continue to grow. As this happens, such redundancy can be eliminated, thereby increasing cost effectiveness of the overall design.

2. <u>Commercial Quality Moveable Insulation Is Not Generally Available. Its Application And Use Can Be A Source Of Cost Problems.</u>

There is no question that moveable insulation is a key part of many passive solar designs. It was used widely in the Commercial Buildings Program. In most cases, however, high quality moveable insulation systems were not commercially available at the time of construction. Designers worked hard to develop special or site-built systems, but the end results were mixed. In at least five cases, there were either delays in the original installation, problems with operation once installed, or poor enough performance that the original systems had to be replaced. All of these situations had a more or less negative effect on cost.

This is not to say that moveable insulation should be removed from passive solar designs altogether--performance would clearly suffer from this approach. It is to say that designers should take special care in this area of passive solar design, should learn from past mistakes, and should identify products that can be expected to perform in a commercial environment.

3. <u>There Is A Growing Consensus That Passive Solar Designs Add Value By Increasing Building Amenity But This Can Be Verified Only by Anecdote.</u>

As can be seen from the occupant analysis in this report, there is no doubt that most occupants like passive solar buildings. In several cases there is a significant increase in building use. One owner claims that the productivity of employees is up because they like the space in which they work. In one school, children said they liked the passive solar area better, and in another school a principal reports that teachers are doing better.

If, and it is a big "if", any of these conjectures could be quantified, they would have a very significant impact on the economic analysis of a building. In most cases, a change of only a percentage point or two in the productivity of employees would overwhelm annual savings in utility costs. Payroll per year in most buildings outweighs utility costs by tens to hundreds of times. If a connection does exist and can be found between the quality of spaces that result from passive solar design and the productivity of occupants, the value of passive design as reported in this analysis would be small by comparison.

Such an analysis was clearly beyond the scope of this project. Nonetheless, findings here suggest that passive solar design, and the effects of daylighting in general, should become an important part of future research on productivity.

IV. OCCUPANCY

Two major questions underlie this Evaluation - Did the buildings save auxiliary energy and did they function as well as non solar buildings?. Occupancy evaluation focused on occupant impacts on building energy use and user satisfaction with the building environment (particularly as it related to the building energy system design). Both of these questions must be answered affirmatively for the buildings to be considered successful.

For each building, monthly measurements of building energy use, collected either by manual (submetered) or automatic data collection equipment, were compared to predicted energy use, and discrepancies between the two analyzed. Possible reasons for differences included poor predictions, design errors, construction mistakes, unusual weather patterns, and a variety of occupancy factors.

Occupancy issues were assessed in a number of ways. Full time and part time building users were asked to complete a questionnaire each month. Building operators and managers responded to a number of operations and occupancy related questions as part of their monthly reporting. Site visits and observations occurred at most buildings. Interviews were conducted with architects, building program personnel, building managers and selected staff on an as needed basis.

A. <u>SATISFACTION</u>

Overall satisfaction with the buildings was quite high, despite some concerns about several comfort issues.

1. <u>Overall Satisfaction With the Buildings was High.</u>

   Figure IV-1 illustrates the month by month overall satisfaction reported by building occupants on a 6 point scale.

   Although satisfaction did fluctuate some for each individual building, the pattern indicates a high degree of satisfaction with all buildings in all seasons of the year.

2. <u>The Popularity of Some Buildings Led to Longer Hours of Operations and Significantly Increased Occupancy Levels.</u>

   Figure IV-2 indicates the changes in both amount and pattern of occupancy from those predicted by the designer to those actually occurring in the occupied building. The only building which was occupied less than predicted was Johnson Controls, which hired fewer people than predicted to occupy the space.

3. <u>Most Users Liked the Appearance of the Buildings and Felt that the Solar Design had a Positive Effect.</u>

   The relationship between positive attitude toward building appearance and whether this attitude was affected by the fact that the building was solar was tested statistically. Solar had a significant influence on how well people liked building appearance.

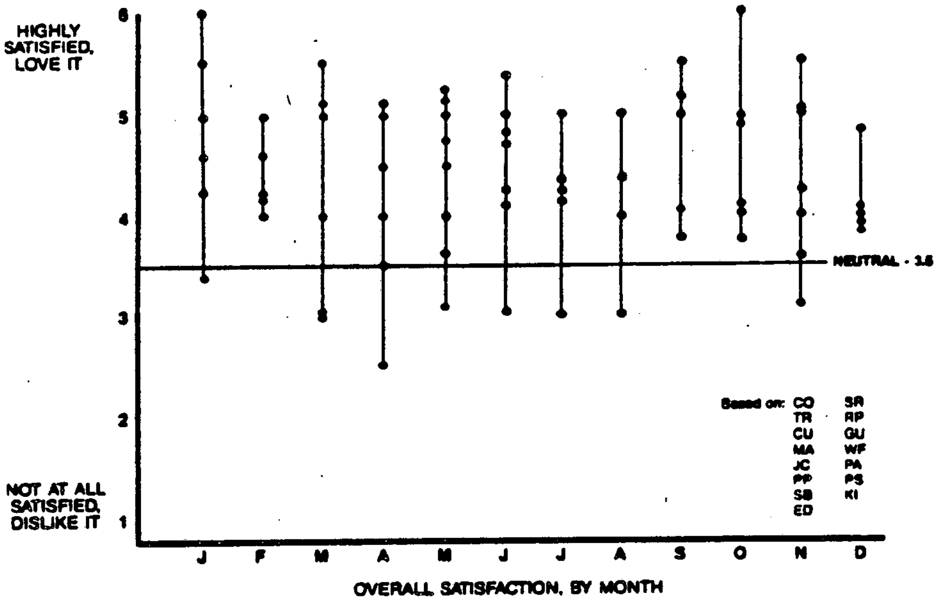


Figure IV-1

BUILDING	CODE	TIMING OF OCCUPANCY	NUMBER OF PEOPLE	DIFFERENT LOCATION	DIFFERENT ACTIVITY	USE OF SPACES DESIGNATED TO BE UNOCCUPIED	CHANGED OPERATIONS
Johnson	JC		−				●
Alaska School	TR	+	+				●
Essay Dorsey	ED	+	+	●	●		●
Mt. Airy	MA	+	+				
Phila Auto	PA			●	●		●
CMC	CM	+	+	●	●	●	
Comal	CO	+	+				●
CUMC	CU	+	+				
Shelly Ridge	SR	+	+				
Gunnison	GU		+		●	●	●
Kiefer	KI						
SAUP	PS				●		●
PPP	PP	+	+	●	●		●
RPI	RP		+	●	●	●	●
Wells	SB		+	●	●	●	●
Walker Field	WF				●		
St. Mary	SM	+	+				

Figure IV-2

4. Perceived Thermal Comfort was High, averaging 74%.

See Figure IV-3. Thermal comfort was reported highest during the Spring season, with most complaints during the winter season.

- Most complaints about thermal comfort were concentrated in the mornings of winter months.
- A repetitive pattern of 'too cool' mornings and 'too warm' afternoons occurred in many buildings. This finding is discussed further in Chapter V. INTEGRATION, Section C, Thermal Mass Issues.
- Ventilation strategies for cooling had numerous operational problems, interfering with their effectiveness in providing comfort. These are discussed further in Chapter V. INTEGRATION, Section D. Natural Ventilation.

5. Satisfaction with Lighting was Consistently High.

Daylighting was used in 100 percent of the designs and was usually very well received. Users spontaneously mentioned their delight in the daylighting in buildings with a wide variety of daylighting solutions.

Lighting controls varied from automated to manual. In most cases, lighting energy use was lower than predicted.

- Daylighting alone sometimes provided 100% of the illumination needs
- Artificial lighting and daylighting were well integrated in the buildings, providing acceptable lighting conditions almost all of the time. There were fewer than 5% of respondents who complained of too dim or too bright conditions, regardless of time of year, time of day, or building location.
- Glare problems reported in several buildings were usually associated with perimeter light sources rather than with overhead light sources.

6. There were Few Perceived Air Quality Problems.

The only consistent finding was complaints about stuffiness in areas that had not originally been designed for occupancy. Infiltration problems occurred in a number of the buildings shortly after move-in, but most of these were construction problems that could be remedied.

7. Some Complaints about Acoustics Occurred in the Majority of Buildings Studied.

Four types of perceived acoustical problems were examined: being disturbed by overhearing things, having difficulty on the telephone or with conservations, and having difficulty concentrating. Concentration and conversation problems were most frequent. Users responded by complaining, by adding acoustically absorptive materials and public address systems.

Acoustic problems were related to:

- Wall and floor surfaces, primarily designed to provide thermal storage mass, were constructed of nonabsorptive materials and thus bounce sound around the buildings.

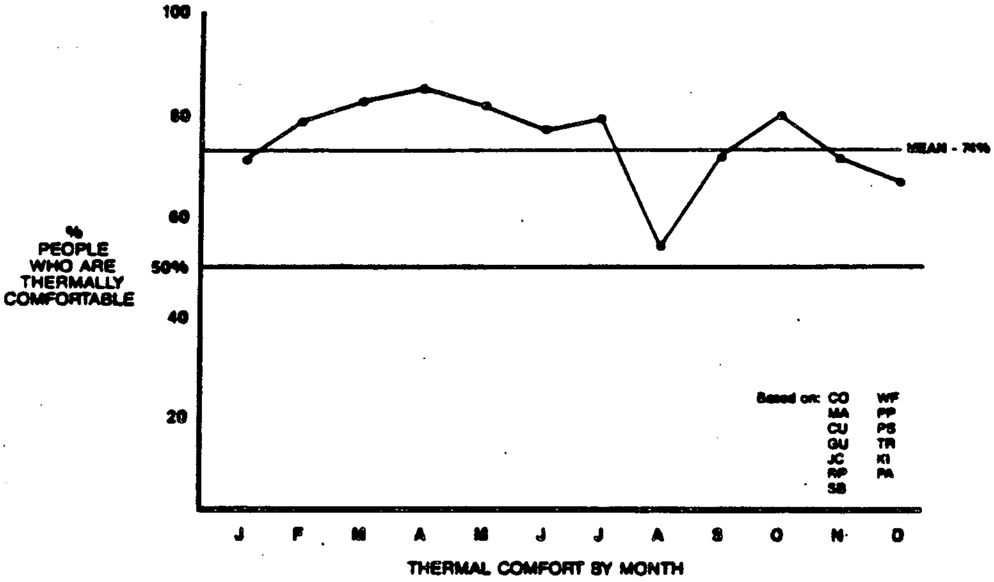


Figure IV-3

- Open plans designed to enhance convective currents and lighting distribution prevent sound isolation.
- Increased number of occupants using the buildings.

B. CHANGED BUILDING OCCUPANCY AND USE

Evaluation findings showed that many differences in occupancy patterns and in building operations occurred and that these changes probably strongly influenced actual building energy use, although the exact impact of these changes cannot be determined.

1. In Almost All Buildings in the Program, Actual Occupancy Patterns Differed Significantly from those Predicted.

As previously indicated on Figure IV-2, actual occupancy differed from that predicted in four ways:

- Timing of Occupancy. Because the buildings were very popular, people used them many more hours per day than had been predicted. Occupancy began earlier in the day, lasted longer into evening hours and included significant amounts of weekend use. This resulted in energy demands that had not been anticipated in design.
- Location of Occupancy. Spaces which had been designed to be unoccupied were frequently pressed into use, influencing energy use and comfort in those areas. These areas, such as storage areas and mezzanines, were not originally designed to provide comfortable conditions for occupants. In each case, users in those areas experienced some discomfort, and more energy was used trying to

achieve comfort than designers had predicted.

Number of Occupants. In all cases but one, buildings in this program were used by many more people than the designers had anticipated. In one case, almost twice as many users as had been anticipated were occupying the space. This popularity put unanticipated demands on the building energy systems.

Activity. Although this type of change in occupancy occurred less frequently than other types, spaces which had been designed to provide thermal comfort conditions appropriate for one set of activities became uncomfortable when other types of activities occurred in the space. For example, when a sunspace was temporarily filled with blackboards and used as a classroom , the area was uncomfortably warm. In addition, the adjoining offices which depended on borrowed light from the sunspace found that the blackboards blocked their light source.

C. CHANGED BUILDING OPERATIONS

Building energy use predictions were based on certain fairly specific operational assumptions. Each design team specified an operational protocol which was used as the basis for their energy use predictions. These assumptions ranged from straightforward instructions specifying when to switch a system from summer mode to winter mode, to fairly complex and subtle directions indicating what sequence of actions should be taken if the building became too warm during Spring and Fall seasons.

For some buildings, these operational protocols were explicitly transferred to the building users through written instructions, in others through a verbal briefing to the building users, and in still others the building operation was directly in the hands of an on-site building manager.

Building operations differed from those initially planned for a number of reasons.

1. <u>Changed Use Made Planned Operations Inappropriate</u>.

   In some cases the use patterns had so significantly altered from those predicted that operations had to change as well in order to provide comfortable conditions.

2. <u>Instructions were Inappropriate</u>.

   To be effective, operational instructions must respond to the needs, education, motivation, interests, or sophistrication of the building users. Sometimes only a few users received instructions; sometimes the user population changed and the new occupants were never instructed; and sometimes the language, format, and distribution of written information were too sophisticated for the building users.

3. <u>Instructions were Not Transferred</u>.

   The question of who has responsibility for effective transfer of operational instructions is often not made explicit. As a result, communication of useful information between the design team and the building users and managers sometimes does not occur.

4. Building Operations were Complex

   Some buildings had numerous operation and control options, each of which was only appropriate for limited situations. The complexity sometimes overwhelmed unsophisticated users.

5. Appropriate Actions were Unfamiliar

   When correct building operation depended on users doing actions that were unfamiliar, they often either did not perform the actions or performed them incorrectly.

6. Relationship Between Operational Actions and Comfort Was Too Indirect

   Users sometimes could not understand the relationship between the actions they were supposed to take and comfort conditions. This occurred either because the effects were indirect or because the actions seemed counter-intuitive to them (e.g. closing glass fireplace doors to keep the building warmer). Controls or operational components which were located close to users, were familiar

7. Following Instructions Did Not Result in Comfortable Conditions.

   In these situations, building occupants tried a variety of other means to achieve comfort. These ranged from adding portable electric heaters, fans and lights to blocking off light sources to reduce heat gain, darken a room or achieve privacy.

8. Operations Which Solved One Comfort Problem Contributed to a Different Comfort Problem

   In several cases, glare control devices, solar gain controls and ventilation systems were poorly combined. As a result, user attempts to control thermal problems interfered with the ventilation strategy, attempts to control ventilation caused problems with the lighting strategy etc.

V. RESULTS AND IMPLICATIONS OF SELECT DESIGN STRATEGIES

A. RETROFITS

Of the 19 building projects reporting performance data, 4 were retrofits of existing buildings: Comal County Mental Health Center (New Braunfels, Texas), Philadelphia Municipal Auto Garage, Princeton School of Architecture and Urban Planning, and Kieffer Store (Wausau, Wisconsin). Since their number is limited, it is difficult to make broad generalizations with confidence.

1. Design Options Were Limited, But Easier to Assess

Compared with new buildings, retrofits were handicapped by lack of control over siting, massing, form, glazing, thermal mass, and other issues usually addressed in early design phases. Thus, their performance level was also limited. However, the level was more easily quantified, since:

- The first costs were easy to isolate. In each case, they were the total project costs. First costs tended to be low, between $3 and $18 per sq. ft.
- The energy savings could be isolated directly. In each case, they were the difference from the original building. The level of savings was largely a function of the original building; the more inefficient buildings achieved more savings. In all cases, savings were significant, ranging from 14,700 to 137,700 Btu's/s.f. per year during the time periods buildings were monitored.
- Occupant satisfaction could be more accurately measured. This is because users could compare comfort and operation directly with that of their old building. Generally, occupants were more pleased with the retrofits compared with their old buildings.

2. It was Difficult to Significantly Improve Overall Building Amenities

Lacking design options, it was difficult to achieve amenities available to new construciton projects such as quantity and quality of light, or interest afforded by atriums. The best solutions focused on integrating conservation measures with solar with attention to reserving daylight. Conservation measures to reduce heating, cooling, and lighting loads such as in Comal County Mental Health Center, often precluded more expensive solar measures. Where existing windows created glare such as in the Philadelphia Municipal Auto Garage, solar components to mitigate glare, reduce heat loss, but retain light were custom-designed.

B. DAYLIGHTING

Daylighting solutions in these buildings saved energy while contributing to comfortable lighting conditions. Daylighting was used as a passive design strategy in all buildings in the program and relied on heavily in over half of them. Six types of daylighting solutions were used : Windows to reduce artificial lighting needs (78%) of buildings, Lightshelves (48% of buildings), Clerestories (39% of buildings), Roof monitors (35% of buildings)*, Sunspace and borrowed light (13% of buildings), and Skylights (13% of buildings). This section summarizes the experiences associated with these daylighting strategies.

The buildings illustrate good basic solutions to daylighting which could be used successfully in other buildings.

1. Daylighting Resulted in Significant Cost and Energy Savings While Contributing to User Comfort.

Approximately 55% savings over base case lighting energy use was achieved through the use of these daylighting strategies.

* <u>Clerestory:</u> An upper zone of a wall pierced with a window to admit light or air. <u>Roof monitor:</u> A raised section of roof with openings, louvers, or windows (not parallel to roof plane) used to admit light or air.

These energy savings, discussed in greater detail in an earlier section, were NOT achieved 'at the expense of' either energy use for heating or cooling or of user comfort.

2. Successful Daylighting Designs Shared a Number of Characteristics.

The most important aspect of the successful use of daylighting was distribution. If daylight was well distributed, a visually comfortable, and largely glare free environment was attained. The design solutions which were most successful had the following characteristics:

- Glare and contrast were controlled. Beam daylighting was not allowed to directly enter an occupied space. Baffles, diffusing reflecting surfaces, and/or diffusing glazing were used to break up beam lighting. Occupants were not able to directly see the light source from the spaces they usually occupied.
- Light was admitted into the space high on the wall plane or at the ceiling plane.
- The view was retained.
- A number of smaller roof apertures (clerestories and roof monitors) were used rather than a few large openings.
- All roof monitors and clerestories were designed with South facing glazing.
- Perimeter lighting through the combination of windows and light shelves was expensive and did not demonstrate greater energy savings than did overhead lighting systems.

3. Daylighting Provided Ambient Lighting in Most Buildings.

In most buildings, daylight provided ambient or background illumination, with artificial lighting used to provide task specific lighting. In three buildings, however, the Mt. Airy Library, Wells Security State Bank and St. Marys School Gymnasium, daylight provided the majority of the required task lighting.

4. Occupant Satisfaction with the Lighting Environment was Quite High.

Daylight is a principal contributer to the increased amenity of passive buildings. Fewer than 5% of occupants complained about 'too dim' or 'too bright' conditions, across all buildings and types of daylighting design. The many spontaneous comments about the delightful qualities of the daylighting attest to user satisfaction with this aspect of the buildings.

5. Manual Controls for Artificial Lighting can be Operated Successfully by Building Occupants.

Correct manual lighting control can result in both energy savings and acceptable lighting levels. Special studies carried out by Lawrence Berkeley Laboratory (LBL Report LBL-18069 "Effect of Daylighting Options on the Energy Performance of Two Existing Passive Commercial Buildings) concluded that in the two buildings which were studied in depth, users operated manual lighting controls in a more energy efficient manner than simple automated control systems would have. One reason for these results is that occupants were satisfied at illumination levels lower than those which industry standards recommend (and which automated control systems use), even when they had the option to increase those lighting levels. Although this is insufficient evidence on which to draw general conclusions, it does indicate that occupants can use lighting controls effectively under some conditions.

6. Integration of Daylighting and Artificial Lighting can be Successful.

The most successful integrations of daylighting and artificial lighting occurred when:

- Switching of any kind was unnecessary for extended periods (e.g. whole days)
- Variations in distribution of daylight could be supplemented according to need in the space by zoned switching
- Zones were laid out parallel to the daylight source rather than perpendicular to the daylight source
- Multilevel switching could supplement available daylight in a stepwise manner.

C. THERMAL MASS ISSUES

Despite the fact that passive solar buildings are often thought of as depending on high mass solutions, the buildings in this program could be divided into three groups, each using a different type of thermal mass solution. High mass buildings, such as Mt. Airy, CUMC, Alaska Two Rivers School and Comal County, used amount and distribution of large amounts of thermal mass to store, delay and diffuse heat energy throughout the building. Another group of buildings used localized thermal mass (such as trome walls), where the location of the mass was designed specifically to supply the heating/cooling energy needs of a particular area of the building. This group included Girl Scouts, St. Mary's Gym, Johnson Controls, RPI, CMC and Gunnison Airport. The third group of buildings used low mass design solutions, appropriate to their timing of occupancy, climate etc. Low mass buildings included Wells Bank, and Princeton Professional Park.

Analysis of energy, economic and occupancy issues has led to the following conclusions.

1. <u>High Mass Does Not Appear to Have Been a Contributing Factor in the Energy Efficient Functioning of These Buildings</u>

   - High mass construction is not necessary to achieve significant energy savings. The effective use of mass depends on understanding the interrelationships among several factors: occupancy schedule, type of building use, the type of energy problem and the way mass is distributed throughout the space.

2. <u>High Mass Does Not Necessarily Solve Thermal Comfort Problems, and in Some Cases Appears to Have Contributed to Problems.</u>

   High mass solutions are often associated w/ these problems:

   - Acoustic - Exposed hard surfaces of thermal storage material cannot easily absorb sound
   - Thermal - Regulation of timing and amount of 'heat delivery to space' is difficult
   - Mechanical system integration - the mechanisms by which thermal mass is charged by mechanical systems and natural passive systems is not well understood.

   Moderate amounts of well distributed thermal mass are apparently usually sufficient to solve thermal problems.

3. <u>Localized Mass can be an Effective Strategy to Provide Delayed Heat to Specific Building Locations.</u>

   Several buildings successfully used localized thermal mass to provide comfort conditions, while saving energy at little incremental construction cost.

4. <u>Several Low Mass Buildings Performed Well</u>

   The Wells Security State Bank and Alaska School used little energy while providing comfortable conditions for building users. As these buildings had daytime occupancy patterns, they required early morning warm up and had no need for delay of heat delivery to the space. The designs took advantage of direct gain strategies for heating.

D. NATURAL VENTILATION

Natural passive ventilation was used as an integral part of the cooling strategy in a number of buildings. While it is not possible to know exactly how well the natural ventilation systems performed, some problems with various approaches can be identified.

1. <u>Assumptions About Air Currents Were Sometimes Inaccurate.</u>

   A number of designer assumptions about the paths that interior ventilative currents would take in order to effectively cool and/or ventilate the space were found to be inaccurate. Particularly, when currents were assumed to turn corners or travel along indirect pathways to create comfortable conditions and save energy, these expectations were not substantiated.

2. Conflict Between Shading Devices and Apertures Impeded Ventilative Flows.

A variety of sources of natural ventilation were employed in the buildings, usually in the form of an operable window or door. In order to be effective, these sources had to remained unobstructed. However, in a number of buildings, shading devices were being used over these ventilation sources, impeding the inflow of air. These shading devices were being for:

- Glare control
- Darkening of space to show slides or films
- Solar gain control

3. Manually Operated Ventilation Control Strategies Can Work.

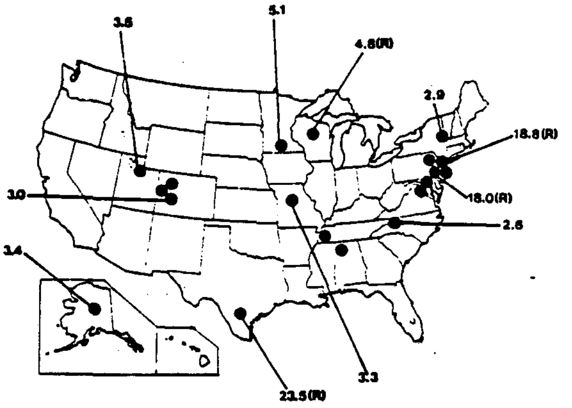
Controls are most effective when they are familiar, close to the affected user and simple to understand and operate. For example, clerestory windows which opened by pull chains were used effectively. On the other hand, users did not understand the proper operation of troumbe wall vents and thus used them either inappropriately or not at all.

E. CLIMATE DEPENDENCY

1. Solar Buildings Succeeded in a Wide Range of Climates, From Very Cold to Hot and Humid.

During the planning of this program, there was a particular effort to achieve a geographic and climate spread across the range of projects. The success of the buildings is distributed across the entire range (Figure V-E.1). Specifically, buildings reporting a full year of data are located in very cold areas with cloudy winters (Fairbanks, Alaska and Troy, New York), cold, sunny areas (Gunnison, Colorado and Salt Lake City, Utah), moderate areas (Columbia, Missouri), and hot, humid areas (Mt. Airy, North Carolina and New Braunfels, Texas). Urban areas (Philadelphia) are also represented. This distribution provides substantial evidence that solar architecture is not limited to sunny areas with large diurnal temperature swings such as the Southwest.

Figure V-E.1
HEATING BTU'S PER HEATING DEGREE DAY



NOTE: (R) indicates retrofit project

2. Energy Performance Was Not Dependent on Climatic Variables.

- By Heating Degree Day

There is essentially no pattern of heating energy performance by heating degree day.

Btu's/s.f. heating degree day is a good measure of the energy performance of solar buildings because it equalizes auxiliary energy without regard to size of building or heating climate. Data show this performance parameter to be relatively independent of heating degree days. The range is between 2.6 and 4.0 Btu's/s.f./yr./HDD, about half that of the base building values.

- By Horizontal Insolation

There is essentially no variation of heating energy performance by solar insolation. One would expect the buildings in sunnier locations such as Colorado and Utah to perform significantly better than those in the not-so-sunny locations such as Alaska and upstate New York. The data, however, show a fairly constant value near 3.5 Btu's/s.f./yr./HDD.

(Retrofits were not included in this analysis because the solar and conservation effects were not as easily controlled. In some cases, monitored space included areas not retrofitted because the heating system served the whole building. The main reason for their exclusion, though, is that most were so handicapped in their energy-conserving design features that even after extensive insulation, it is still inappropriate to compare them with new buildings which have the advantages of optimum orientation, massing, and form. Retrofit performance ranged from 4.8 to 23.5 Btu/s.f./heating degree day.)

F. RELIABILITY AND MAINTAINABILITY

1. Most of the Passive Solar Techniques Used Were Very Reliable and Did Not Increase Building Maintenance Requirements.

Most project teams spent a considerable amount of time during the design process to refine the passive techniques which would be used in the buildings and to make them as simple as possible. This proved to be time very well spent. Those projects which made use of simple solutions, and did not place unusual requirements on building occupants for successful operation were well accepted, performed satisfactorily and did not prove difficult to maintain. In fact, in many cases the building maintenance personnel responded very favorably to these buildings because they were easy to understand and operate.

By contrast, some techniques were used which required daily adjustment or used complex motorized controls; these proved frustrating to building personnel and were sometimes maintenance problems. For example, a few projects used operable insulating shades which did not prove durable enough for use in commercial applications. This required substantial maintenance on the part of building personnel, and usually resulted in the devices being used less regularly over time.

People proved willing to perform routine operations provided that they were easy to understand, the effects could be seen or felt, and the operations were not disruptive to other building operations. In some projects, for example, the designers' desire to have operable windows open during nighttime hours to promote natural ventilation and cooling of the building conflicted with security requirements and was quickly abandoned by building maintenance personnel. Adjustments which were necessary only on a seasonal basis were usually well accepted. For example, when Trombe wall vents needed to be adjusted only in the spring and fall to accommodate the change from the heating to the cooling season, they did not usually prove to be a problem. In a few projects multiple mechanical distribution devices, with sensitive construction tolerances were used; these almost always proved to be problems. If passive devices were difficult to install, or seemed counterintuitive to construction personnel, they would usually be built incorrectly, and in some cases were sabotaged by construction personnel. For example, in one project the auxiliary electric resistance space heaters were wired to operate continually, since the electrical contractor did not believe that the passive techniques would provide sufficient heating, and set about to assure that he would not be called back to the building to correct comfort problems. This was only discovered through performance monitoring of the building, and was then easily corrected.

2. Occupants Are Often the Most Complex Elements in Commercial Buildings.

In buildings where occupants and maintenance personnel could easily understand the reason for the inclusion of passive features, and the way in which they were intended to operate, few problems existed. When people either misunderstood or disregarded the passive elements in the building, problems inevitably arose. In some projects, for example, occupants placed plants and books on the light shelves, compromising their function as daylighting devices. In other projects, it was the routine response of building users to turn on artificial lights even when they were not needed. This was most easily overcome by orientation sessions in which the designers explained the intended use of the building and building occupants became comfortable with the way in which the passive systems were intended to operate. When a level of confidence and trust developed on the part of building occupants, daylighting and passive heating or cooling devices were well accepted.

G. SYSTEM INTEGRATION

1. Passive Heating, Cooling and Lighting Techniques Must be Carefully Coordinated With Conventional HVAC and Lighting Systems.

Since passive and conventional systems usually shared the requirements for maintaining space comfort and adequate lighting, the highest energy savings were realized where the integration of those systems was carefully thought through by the designers and carried out by building personnel. In particular, the best ones were designed to avoid competition between passive and conventional systems intended for the same purpose.

If artificial lighting systems are not controlled to be dimmed or shut off when adequate daylight is available, the energy saving potential will be lost, and worse, the spaces may overheat or experience high electrical demand charges. Similarly, mechanical heating systems which maintain comfort by providing short bursts of high temperature air may overpower the radiant heat provided by Trombe walls or other passive heating devices. This is particularly true since the conventional systems are usually controlled by thermostats which respond to dry bulb temperature, while the passive systems may rely on steady flow of a moderate quantity of radiant heat.

Mechanical cooling systems should also be considered when juxtaposed with natural ventilation systems or techniques making use of building mass and circulation of cooler night air.

In most projects, this interface did not prove to be problematic. In fact, in many projects the mechanical heating or cooling systems were shut off for large portions of the year because the passive techniques were capable of maintaining adequate space comfort.

However, in some projects, problems arose. For example, in one project which made use of a large atrium space with a significant amount of exposed concrete to provide thermal mass, the designer intended to allow a swing in space temperature to store adequate amount of heat in a space which was primarily used for circulation purposes. However, the mechanical controls subcontractor installed single setpoint thermostats, which automatically switched from heating to cooling based upon deviation from the setpoint. This conflicted with the intention for swing in temperature, and, until corrected, eliminated the potential energy savings. Similarly, in other projects where a significant degree of thermal mass was exposed on the interior of the building, night setback of the space temperature was employed. This proved problematic in some cases since the building proved hard to heat up in the early morning. People complained of feeling too cool because of the presence of radiant surfaces which had discharged their heat during the night and had to be recharged during the day. An easy solution was developed by minimizing the night temperature setback so that morning startup operations could be accommodated by the solar and mechanical heating systems.

2. <u>Manual controls were sometimes more energy conserving than automated devices.</u>

This was particularly true in those buildings where users perceived a greater level of control of the interior environment. Frequently, this resulted in the users voluntarily setting temperature or lighting conditions below those normally assumed by building designers.

For example, in the Mt. Airy Library and the Community United Methodist Church, which both used manual control of artificial lights to achieve savings in these daylit buildings, the manual controls actually proved to be more effective than automated dimming or switching devices could have been in producing energy savings. This was experimentally verified by Lawrence Berkeley Laboratory researchers who carefully monitored the use patterns in both buildings and compared the measured results of manual control of the artificial lights to predicted performance for automated controls. One of the reasons for this was the willingness on the part of occupants in both buildings to function at lower lighting levels than those recommended by industry standards. This voluntary action on the part of the building occupants is apparently connected to the high degree of personal control which users perceived in those buildings.

VI. CONCLUSIONS

The DOE Non-Residential Experimental Buildings Program has provided the largest data base of passive solar performance of non-residential buildings to date. The patterns that have emerged show that, in general, passive solar technology can provide substantial energy savings at little, if any, increased first cost. Performance parameters that contribute to the success or failure include occupant behavior, user control, fuel cost, and the skillful handling of design elements such as solar apertures, thermal mass, daylighting systems, and their integration with conventional design issues. Of minor concern are climatic limitations and predominant building load; passive solar buildings can perform well in a wide variety of climates to reduce heating, cooling and lighting needs. Passive solar does not place unnecessary constraints on comfort nor on building aesthetics and in fact can enhance both. The most potential for failure lies in poor or complicated controls, and designs that do not anticipate changing uses, but even in the worst cases, these buildings can still perform as well as conventional buildings.

Two questions emerge from these conclusions. The first is: "In light of these documented successes, what can be done to realize the potential of passive solar in other buildings being constructed today?" Market forces are strongest when the owner demands the product. Unfortunately, this overview is oriented primarily towards the solar designer and architect. Results from this program and other successful solar buildings need to be directed towards the building owner using techniques and channels normally used by this audience. Amenities such as user satisfaction and marketability need to be quantified and described in language understandable by these decisionmakers. Increased worker productivity should be documented and aesthetic benefits highlighted so that passive solar is not overwhelmed by the connotations of "alternative energy" but can also suggest a certain financial sophistication and technical advancement.

The second question is, "What technological shortcomings were uncovered that limit passive solar technology to the levels demonstrated in this program?" One area insufficiently investigated is the design and performance of large non-residential buildings. Only three out of 19 of the program participants had floor areas over 50,000 square feet, but almost half of commercial building floor area in 1984 occurs in buildings large than this. Also deserving of greater attention is the retrofit of exsiting buildings. About two thirds of commercial buildings existing in 1980 will still be in use in the year 2000 and therefore will require a large fraction of future building energy. Reducing this energy involves issues different from those surrounding new buildings. Existing buildings often are not oriented properly, have greater internal spaces inaccessible to solar heat and daylight, are built with heavy construction materials such as brick and concrete, are located on urban sites shaded by neighboring buildings, and have historic preservation covenants restricting design alternatives. Although these issues make their retrofit more difficult, potential savings are often greater than in new buildings since old buildings tend to be energy wasters.

More research is needed in the development of design tools. Design tools are procedures convenient to the designer for accurately measuring passive solar potentials during the design process. Tools that exist today are either cumbersome, requiring extensive computer input and taking long times to return results, or unsophisticated in their approach to integrating the many energy flows in a building. Many simple programs, for example, do not give credit to cooling energy when daylighting reduces heat gain from artificial lights. Energy design tools need to be integrated with those in non-energy areas of architecture, so that the architect can develop building designs on a computer screen and instantaneously know the implications for not only energy consumption, but construction cost, handicapped access, fire protection, and structure.

These topics point to another area where research is needed: whole building analysis. It is not enough to conduct research in separate architectural disciplines; as in design,t he disciplines must be integrated. Whole building systems research identifies the optimum integration of architectural, mechanical space conditioning, and electrical systems with passive solar technologies. This need was borne out in the Non-Residential Experimental Buildings Program when designers had little basis for answering questions such as: How well will open floor plans facilitate natural convection cooling? How consistently will occupants naturally keep lights off in daylighted spaces? How much is thermal mass necessary to store heat in buildings where lighting is the main energy load, or where heating is not needed at night?

Finally, more research is needed in the areas of advanced glazing products and daylighting techniques. Controls must also be further refined, especially automatic and manual controls that integrate solar and conventional heating, cooling, and lighting systems. These components are sufficiently far from market readiness that their research would benefit from public support.

APPENDIX A-1: NOTES, BACKGROUND AND SUPPORTING ANALYSIS FOR CHAPTER II - ENERGY PERFORMANCE

APPENDIX A-1.1

1. U.S. EIA Non-Residential Building Energy Consumption Survey, 1979 (average for existing buildings excluding health and food service facilities).

2. The Building Energy Performance Standards (BEPS) energy levels were determined by the U.S. DOE in 1979, based on a comprehensive survey of buildings designed between 1973 and 1976. These energy budgets represent the average building energy use by particular building type and location that was believed to be economically feasible to achieve.

3. Cooling degree days was determined to be the best estimate of cooling loads by G.B. Graves, Energy Systems Group, who conducted parallel research on the climatic sensitivity of building designs in this program.

APPENDIX A-1.2
ENERGY PERFORMANCE

		ANNUAL BTU'S PER SQ.FT.				ACTUAL
PROJ	PROJECT NAME	BASE	BEPS	PREDICTED	ACTUAL	DATES
JC	Johnson Controls	72,500	36,000	51,000	35,661	10/82-9/83
TR	Alaska DOT	113,000	#N/A	31,861	52,437	6/83-5/84
ED	Essex Dorsey	86,000	42,000	40,300	#N/A	
AS	Abrams Primary	54,000	35,000	22,180	#N/A	
MA	Mt. Airy	55,700	46,000	17,350	26,012	1/83-12/83
PA	Phil Municipal Auto	230,000	28,000	69,000	92,255	8/83-7/84
CO	Colorado Mt College	100,000	48,000	33,000	#N/A	
CM	Comal County	72,000	33,000	31,000	33,222	9/82-8/83
CU	CUMC	112,400	43,000	16,000	20,164	11/82-10/83
SR	Shelley Ridge GSC	57,000	42,000	35,000	#N/A	
GU	Gunnison Airport	86,400	63,000	66,700	70,589	9/81-8/82
KI	Kieffer Store	62,000	59,000	23,000	47,315	6/82-5/83
PS	Sch of Arch and Urba	158,000	42,000	75,000	115,947	6/79-5/80
PP	Princeton Prof Park	76,000	42,000	15,000	#N/A	
RP	RPI	85,000	48,000	28,500	51,953	9/83-8/84
SB	Wells Sec State Bank	89,177	48,000	25,577	55,867	1/84-12/84
TG	Toul Solganic Greenh	67,469	#N/A	33,320	#N/A	
WF	Walker Field	87,500	72,000	42,000	#N/A	
SM	St Mary's Gymnasium	78,000	51,000	27,100	27,329	5/83-4/84

APPENDIX A-1.3

ACTUAL ENERGY CONSUMPTION (BTU'S/SQ. FT.) AND DEGREE DAYS

PROJ	PROJ NAME	MONTH	ACTL HEAT	ACTL DHW	ACTL COOL	ACTL LIGHT	ACTL FANS	ACTL PASS	ACTL MISC	ACTL TOTAL	ACTL HDD	ACTL CDD	HEAT/ HDD	COOL/ CDD
CU	CUHC	1	4133	73	0	218	82	0	0	4506	1038	0	3.98	0.00
	11/82-10/8	2	2931	73	0	146	55	0	0	3205	783	0	3.74	0.00
		3	2567	73	0	156	51	0	0	2847	697	0	3.68	0.00
		4	2276	73	0	178	42	0	0	2569	510	0	4.46	0.00
		5	182	73	0	146	5	0	0	406	180	25	1.01	0.00
		6	0	73	0	109	15	0	9	206	15	225	0.00	0.00
		7	0	73	5	89	29	0	42	238	0	449	0.00	0.01
		8	0	73	71	80	29	0	27	280	0	511	0.00	0.14
		9	0	73	0	129	13	0	18	233	205	140	0.00	0.00
		10	0	73	0	167	7	0	2	249	366	3	0.00	0.00
		11	1802	73	0	146	36	0	0	2057	630	0	2.86	0.00
		12	2913	73	0	309	73	0	0	3368	775	0	3.76	0.00
		TOTAL	16804	876	76	1873	437	0	98	20164	5099	1353	3.30	0.06
GU	GUNNISON	1	9032	47	0	3457	0	0	0	12536	1674	0	5.40	0.00
	9/81-8/82	2	6848	49	0	3457	0	0	0	10354	1528	0	4.48	0.00
		3	3300	58	0	3833	0	0	0	7191	1103	0	2.99	0.00
		4	2249	53	0	3132	0	0	0	5434	780	0	2.88	0.00
		5	543	52	0	3370	0	0	0	3965	615	0	0.88	0.00
		6	0	49	0	3070	0	0	0	3119	428	38	0.00	0.00
		7	0	48	0	2781	0	0	0	2829	254	130	0.00	0.00
		8	0	50	0	3216	0	0	0	3266	191	229	0.00	0.00
		9	301	44	0	3417	0	0	0	3762	349	49	0.86	0.00
		10	239	48	0	3377	0	0	0	3664	713	0	0.34	0.00
		11	1003	53	0	3517	0	0	0	4573	945	0	1.06	0.00
		12	6321	46	0	3529	0	0	0	9896	1348	0	4.69	0.00
		TOTAL	29836	597	0	40156	0	0	0	70589	9928	446	3.01	0.00
KI	KIEFFER	1	8538	169	0	573	0	76	158	9514	1413	0	6.04	0.00
	6/82-5/83	2	5612	152	0	526	0	37	154	6481	1160	0	4.84	0.00
		3	4336	158	0	508	0	33	156	5191	1011	0	4.29	0.00
		4	2198	154	0	503	0	0	177	3032	730	0	3.01	0.00
		5	978	146	0	432	0	0	195	1751	459	0	2.13	0.00
		6	425	152	0	201	2	0	68	848	219	39	1.94	0.00
		7	364	175	0	259	0	0	82	880	24	210	15.17	0.00
		8	549	171	0	265	0	0	107	1092	83	115	6.61	0.00
		9	1158	173	0	302	0	0	82	1715	220	3	5.26	0.00
		10	1224	171	0	354	0	0	72	1821	527	0	2.32	0.00
		11	4887	142	0	395	0	8	164	5596	1000	0	4.89	0.00
		12	8352	150	0	561	0	107	224	9394	1224	0	6.82	0.00
		TOTAL	38621	1913	0	4879	2	261	1639	47315	8070	367	4.79	0.00
RP	RPI	1	4562	0	21	1141	426	1	1223	7374	1302	0	3.50	21.00
	9/83-8/84	2	2927	0	20	997	312	1	1160	5417	934	0	3.13	20.00
		3	3520	0	16	883	327	1	1157	5904	1069	0	3.29	16.00
		4	1610	0	7	775	264	4	1055	3715	393	0	4.10	7.00
		5	272	0	11	858	264	7	1159	2571	236	25	1.15	0.44
		6	42	0	654	627	554	59	998	2934	26	275	1.62	2.38
		7	16	0	966	659	649	69	1020	3379	5	343	3.20	2.82
		8	19	0	962	753	635	128	1064	3562	11	331	1.73	2.91
		9	21	0	472	968	480	45	937	2923	194	134	0.11	3.52
		10	658	0	55	1064	317	5	1003	3102	512	0	1.29	55.00
		11	1891	0	20	1052	290	1	1161	4415	823	0	2.29	20.00
		12	3995	0	20	1054	394	1	1173	6637	1194	0	3.35	20.00
		TOTAL	19533	0	3224	10851	4913	322	13110	51953	6701	1108	2.91	2.91

PROJ	PROJ NAME	MONTH	ACTL HEAT	ACTL DHW	ACTL COOL	ACTL LIGHT	ACTL FANS	ACTL PASS	ACTL MISC	ACTL TOTAL	ACTL HDD	ACTL CDD	HEAT/ HDD	COOL/ CDD
JC	JOHNSON	1	3249	49	0	134	774	0	531	4737	925	0	3.51	0.00
	CONTROLS	2	3619	39	0	121	719	0	616	5114	742	0	4.88	0.00
	10/82-9/83	3	2402	44	0	127	795	0	659	4027	632	0	3.80	0.00
		4	2352	41	0	102	755	0	120	3370	575	0	4.09	0.00
		5	2597	31	1	110	678	0	124	3541	293	7	8.86	0.14
		6	0	31	45	99	917	0	120	1212	61	160	0.00	0.28
		7	0	35	91	94	780	0	124	1124	7	364	0.00	0.25
		8	0	28	170	117	1053	0	124	1492	0	398	0.00	0.43
		9	0	31	93	94	817	0	121	1156	79	163	0.00	0.57
		10	1129	39	14	106	704	0	557	2549	502	0	2.25	14.00
		11	2020	40	1	117	661	0	115	2954	807	0	2.50	1.00
		12	3004	37	0	129	702	0	513	4385	1088	0	2.76	0.00
		TOTAL	20372	445	415	1350	9355	0	3724	35661	5731	1092	3.55	0.38
MA	MT AIRY	1	3257	21	77	292	865	2	32	4546	876	0	3.72	77.00
	1/83-12/83	2	2405	13	9	273	691	4	26	3421	750	0	3.21	9.00
		3	1521	10	227	370	563	4	31	2726	504	0	3.02	227.00
		4	1075	9	0	300	454	4	29	1871	355	0	3.03	0.00
		5	0	4	0	212	179	5	27	427	151	128	0.00	0.00
		6	0	1	539	131	343	6	30	1050	33	311	0.00	1.73
		7	0	0	1692	86	560	7	32	2377	0	481	0.00	3.52
		8	0	5	1807	157	578	6	31	2584	0	460	0.00	3.93
		9	0	1	401	26	132	1	7	568	0	405	0.00	0.99
		10	24	13	78	235	306	3	34	693	254	39	0.09	2.00
		11	700	17	104	307	394	2	32	1556	540	0	1.30	104.00
		12	3050	21	0	288	797	1	36	4193	1085	0	2.81	0.00
		TOTAL	12032	115	4934	2677	5862	45	347	26012	4548	1824	2.65	2.71
CM	COMAL CO	1	4021	259	0	544	143	0	280	5247	240	12	16.75	0.00
	9/82-8/83	2	2936	248	2	601	118	0	286	4191	158	42	18.58	0.05
		3	2315	225	0	777	95	0	306	3718	71	133	32.61	0.00
		4	729	175	10	683	28	0	298	1923	16	259	45.56	0.04
		5	64	109	90	565	0	0	284	1112	0	507	64.00	0.18
		6	0	88	666	543	0	0	340	1637	0	640	0.00	1.04
		7	0	60	815	579	0	0	352	1806	0	750	0.00	1.09
		8	0	55	902	533	0	0	331	1821	0	837	0.00	1.08
		9	0	124	935	595	0	0	279	1933	0	435	0.00	2.15
		10	581	215	254	712	17	0	245	2024	0	318	581.00	0.80
		11	1864	222	23	627	64	0	234	3034	42	118	44.38	0.19
		12	3530	241	1	604	130	0	270	4776	156	44	22.63	0.02
		TOTAL	16040	2021	3698	7363	595	0	3505	33222	683	4095	23.48	0.90
PA	PHIL MUN	1	21500	53	0	456	0	0	860	22869	790	0	27.22	0.00
	AUTO	2	18947	53	0	404	0	0	772	20176	580	0	32.67	0.00
	8/83-7/84	3	14316	70	0	386	0	0	965	15737	666	0	21.50	0.00
		4	4895	35	0	386	0	0	912	6228	435	0	11.25	0.00
		5	965	35	0	351	0	0	772	2123	173	18	5.58	0.00
		6	0	35	0	351	0	0	894	1280	0	255	0.00	0.00
		7	0	35	0	351	0	0	894	1280	0	279	0.00	0.00
		8	0	35	0	263	0	0	1158	1456	0	341	0.00	0.00
		9	70	35	0	316	0	0	947	1368	16	181	4.35	0.00
		10	2175	53	0	351	0	0	860	3439	236	3	9.22	0.00
		11	4509	35	0	351	0	0	782	5677	510	0	8.84	0.00
		12	9123	53	0	421	0	0	825	10422	837	0	10.90	0.00
		TOTAL	76500	527	0	4367	0	0	10641	92255	4243	1077	18.03	0.00

PROJ	PROJ NAME	MONTH	ACTL HEAT	ACTL DHW	ACTL COOL	ACTL LIGHT	ACTL FANS	ACTL PASS	ACTL MISC	ACTL TOTAL	ACTL HDD	ACTL CDD	HEAT/ HDD	COOL/ CDD
TR	ALASKA DOT*	1	218	0	0	1206	143	0	88	1655	1690	0	0.13	0.00
	6/83-5/84	2	245	0	0	1359	171	0	109	1864	1831	0	0.13	0.00
		3	116	0	0	1257	183	0	111	1667	1097	0	0.11	0.00
	6/83 HDD.	4	87	0	0	1315	177	0	107	1586	789	0	0.11	0.00
	CDD EST.	5	38	0	0	1131	183	0	60	1412	169	45	0.22	0.00
		6	0	0	0	408	157	0	0	565	211	31	0.00	0.00
		7	0	0	0	422	133	0	0	555	146	223	0.00	0.00
		8	20	0	0	1039	190	0	19	1268	103	213	0.19	0.00
		9	446	0	0	1821	177	0	0	2444	597	0	0.75	0.00
		10	198	0	0	1182	63	0	102	1545	1193	0	0.17	0.00
		11	240	0	0	1748	185	0	32	2205	1247	0	0.19	0.00
		12	236	0	0	1011	147	0	32	1426	1427	0	0.17	0.00
		TOTAL	1844	0	0	13799	1909	0	660	18212	10500	512	0.18	0.00
PE	EAUP	1	15940	0	0	2176	0	0	0	18116	995	0	16.02	0.00
	6/79-5/80	2	13670	0	0	2333	0	0	0	16003	1008	0	13.56	0.00
		3	7357	0	0	2201	0	0	0	9558	758	0	9.71	0.00
		4	5765	0	0	2252	0	0	0	8017	327	0	17.63	0.00
		5	2061	0	0	2404	0	0	0	4465	89	93	23.16	0.00
		6	6105	0	0	0	0	0	0	6105	35	139	174.43	0.00
		7	5139	0	0	3845	0	0	0	8984	0	293	5139.00	0.00
		8	6887	0	0	1340	0	0	0	8227	0	295	6887.00	0.00
		9	5635	0	0	1645	0	0	0	7280	42	114	134.17	0.00
		10	3131	0	0	3036	0	0	0	6167	316	0	9.91	0.00
		11	5948	0	0	2302	0	0	0	8250	426	0	13.96	0.00
		12	12574	0	0	2201	0	0	0	14775	794	0	15.84	0.00
		TOTAL	90212	0	0	25735	0	0	0	115947	4790	934	18.83	0.00
SB	WELLS	1	7227	48	80	131	217	0	456	8159	1668	0	4.33	80.00
	1/84-12/84	2	6018	66	9	196	284	0	646	7219	1018	0	5.91	9.00
		3	6527	75	9	190	296	0	744	7841	1175	0	5.55	9.00
	EXCEPT	4	1789	53	54	135	187	0	448	2666	486	0	3.68	54.00
	7/82	5	0	70	445	220	265	0	625	1625	109	220	0.00	2.02
	ENERGY	6	0	66	832	197	276	0	619	1990	28	169	0.00	4.92
	DATA	7	0	65	759	312	308	0	682	2126	16	239	0.00	3.18
		8	0	64	1156	158	337	0	789	2504	0	467	0.00	2.48
		9	782	65	570	203	253	0	715	2588	136	123	5.75	4.63
		10	3982	66	296	366	332	0	858	5900	296	0	13.45	296.00
		11	3200	66	33	308	306	0	727	4640	843	0	3.80	33.00
		12	6927	71	12	347	447	0	805	8609	1346	0	5.15	12.00
		TOTAL	36452	775	4255	2763	3508	0	8114	55867	7121	1218	5.12	3.49
SH	ST MARY'S	1	4810	0	0	202	317	0	273	5602	1079	0	4.46	0.00
	5/83-4/84	2	4208	0	0	239	249	0	256	4952	674	0	6.24	0.00
		3	3156	0	0	354	227	0	273	4010	781	0	4.04	0.00
		4	822	0	20	311	120	0	264	1537	365	0	2.25	20.00
		5	0	0	37	421	137	41	273	909	128	63	0.00	0.59
		6	0	0	0	15	119	144	256	534	0	240	0.00	0.00
		7	0	0	0	153	113	202	273	741	0	439	0.00	0.00
		8	0	0	60	197	128	237	273	895	0	432	0.00	0.14
		9	0	0	8	389	111	211	256	975	24	192	0.00	0.04
		10	2	0	0	541	110	176	273	1102	210	7	0.01	0.00
		11	931	0	0	534	140	0	264	1869	501	0	1.86	0.00
		12	3352	0	0	298	280	0	273	4203	961	0	3.49	0.00
		TOTAL	17281	0	125	3654	2051	1011	3207	27329	4723	1373	3.66	0.09

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* DOESN'T INCLUDE FORCED AIR HEATING ENERGY.

APPENDIX A-2

BACKGROUND AND SUPPORTING ANALYSIS FOR CHAPTER III - ECONOMICS

APPENDIX A.2.1

COMPARISON OF PASSIVE SOLAR COMMERCIAL BUILDING TO R. S. MEANS DATA BASE

PROJECT DESCRIPTION		MODIFIERS					DATA MODIFICATION					
Name	Cost/ Ft² $	Bldg. Type	City Cost Mod.		Size Mod.	Year	1/4		Median		3/4	
			City	•			Given	Mod.	Given	Mod.	Given	Mod.
Two Rivers Sch	$149	No comparable building type										
Abrams School	36	E. School	Birmingham	93.8	1.012	'81	39.85	37.83	49.05	46.56	59.30	56.29
C.U.M.C.	47	Rel. Ed.	Springfld.	99.7	1.012	'81	35.45	35.77	39.70	40.06	48.85	49.29
Colorado College	64	Stu. U.	Pueblo	98.0	1.000	'81	53.80	52.72	70.20	68.80	87.00	85.26
Mt. Airy	88	Library	Raleigh	94.9	1.000	'82	54.00	51.25	67.00	63.58	85.00	80.67
St. Mary's	74	Gym	Wash.,D.C.	100.4	1.015	'82	41.70	42.53	51.80	52.84	65.80	67.12
Johnson Control	57	L.R. Office	Salt Lake	99.8	.977	'82	38.90	38.12	49.60	48.61	66.00	64.68
Princeton Park	46	L.R. Office	Trenton	102.6	.955	'82	38.90	38.12	49.60	48.61	66.00	64.68
Sec. State Bank	59	Bank	Minneap.	98.6	.950	'81	58.00	54.33	72.80	68.19	96.50	90.39
Essex Dorsey	65	Com.Ctr.	Baltimore	100.8	.988	'82	48.30	48.30	57.50	57.50	71.50	71.50
Shelly Ridge	85	Com. Ctr.	Philadelphia	97.7	1.012	'83	48.30	47.82	57.50	56.93	71.50	70.79
Gunnison	80	No comparable building type										
Walker Field	60	No comparable building type										
RPI	81	Police Sta.	Albany	97.9	1.015	'81	53.80	53.46	74.40	73.93	87.10	86.55
Touliatos	12	No comparable building type										
Philly Auto	9	No comparable data on retrofit										
Princeton Arch	9	No comparable data on retrofit										
Kieffer Store	18	No comparable data on retrofit										
Comal Co.	3	No comparable data on retrofit										

'81 Data From Means Building Systems Cost Guide 1982 - 7th Edition (S.F./C.F. Cost Section)
'82 & '83 Data From Means Systems Cost 1983 - 8th Edition (S.F./C.F. Cost Section)

These were chosen instead of Means Square Foot Costs to gain range from 1/4 to 3/4 of data base.

APPENDIX A.2.1

COMPARISON OF PASSIVE SOLAR COMMERCIAL BUILDING TO R. S. MEANS DATA BASE

EXPLANATION

As can be seen on Table A.2.1, comparable data could be found in R. S. Means for 11 of the 19 buildings for which there is construction cost data. The R. S. Means Systems Cost Guide was chosen because this data base is built from real building information and because costs are reported in a range from the lowest 1/4 of the data base through 3/4 of the data base. The median is also given.

With the Means data base, it is also possible to modify a given value by various factors to more closely approximate a particular building. For this analysis, given values were modified by four factors to gain the best comparison possible between the data base and the passive solar buildings. The modifications were:

- Select the closest building type possible to the solar building
- Select a multiplier for the closest city to the solar building
- Select a multiplier to compensate for the size of the solar building
- Match the year of construction as closely as possible to the same year of Means data.

These modifiers are combined and applied to the data given. The result is shown in the "Modified" (MOD) column of the table.

APPENDIX A.2.2

COMPARISON OF PASSIVE SOLAR COMMERCIAL BUILDINGS TO F.W. DODGE DATA BASE

	PROJECT DESCRIPTION		COMPARATIVE DATA					
	NAME	COST/FT2 $	BLDG. TYPE	SIZE RANGE (000 FT^2)	YEAR	GROSS BUILDING COST $/$FT^2$		
						LOW AVG.	AVERAGE	HIGH AVG.
NEW	Two Rivers Sch.	149	No comparable building type					
	Abrams School	36	Elem. School	30-40	81	41.20	50.50	56.00
	C.U.M.C.	47	No comparable building type					
	Colorado Mt. Col.	59	VoTech School	20-80	81	47.00	55.00	69.00
	Mt. Airy	88	Pub. Library	15-60	82	69.54	78.76	90.42
	St. Mary's	74	No comparable building type					
	Johnson Control	57	Office Bldgs.	*	82	53.62	66.39	72.11
	Princeton Park	46	Office Bldgs.	*	82	53.62	66.39	72.11
	Sec. State Bank	64	Branch Bank	2.5-3.5	81	53.50	75.00	90.00
	Essex Dorsey	65	Sen. Cit. Ctr.	2-3	82	37.79	43.34	51.31
	Shelly Ridge	85	Comm. Halls	15-20	83	43.14	48.01	55.52
	Gunnison	80	Air Terminal	20-30	81	62.00	70.00	76.00
	Walker Field	60	Air Terminal	20-30	82	66.86	74.07	83.85
	RPI	81	Police Bldg.	18-24	81	69.00	75.00	79.00
	Touliatos	12	No comparable building type					
RETROFIT	Philly Auto	9	No comparable data on retrofits					
	Princeton Arch	9	No comparable data on retrofits					
	Kieffer Store	18	No comparable data on retrofits					
	Comal Co.	3	No comparable data on retrofits					

'81 Data from <u>1982 Dodge Construction Systems Costs</u>

'82 & '83 Data from <u>1983 Dodge Construction Systems Costs</u>

* Not Given

APPENDIX A.2.2

COMPARISON OF PASSIVE SOLAR COMMERCIAL BUILDINGS TO F. W. DODGE DATA BASE

EXPLANATION

The F. W. Dodge data base, Table A.2.2, works differently than Means. In the case of Dodge, one can select building type and the year, but there is no modification process. Instead, Dodge reports the size range of the buildings in the data base and gives three average figures for that building type (low average, average, and high average).

The Dodge data base is valuable for this comparison because it reports several building types not in the Means data base. In many cases both data bases report on the same building type but in no case are the ranges or medians similar. No effort was made in this analysis to resolve these apparent differences.

APPENDIX A.2.3

COMPARATIVE DATA FROM
NONRESIDENTIAL BUILDINGS ENERGY CONSUMPTION SURVEY
(NBECS)
1979 CONSUMPTION AND EXPENDITURES

CODE	COMPARISON BUILDING TYPE	NBECS DATA				RANGE FOR COMPARISON
		DATA BY TYPE & REGION ①		DATA BY TYPE & SIZE ②		
		Region	Avg Bill+Avg S F $	Size (000 ft^2)	Avg. Bill÷Avg.S.F $	
KI	Retail/Services	North Cen.	$ .61	< 5	$ .95	$ .61 - .95
JC	Office	West	.63	10 +	.92	.63 - .92
SB	Office	North Cen.	1.02	10 +	.92	.92 - 1.02
MA	Office	South	.89	10 +	.92	.89 - .92
CU	Education	North Cen.	.46	5-10	.60	.46 - .60
CO	Education	South	.57	< 5	1.33	.57 - 1.33
CM	Education	West	.43	10 +	.40	.40 - .43
PA	Auto Sales/Service	Northeast	.80	10 +	.60	.60 - .80
RP	Health ③	Northeast	N/A	<5 or 10 +	.73 or 1.02	.73 - 1.02

① Nonresidential Buildings Energy Consumption Survey - Part 2 - Dec., 1983 - Table 3

② Nonresidential Buildings Energy Consumption Survey - Part 1 - Mar., 1983 - Tables 11, 12, & 13

③ Most Closely Approximates 24-Hour Occupancy

APPENDIX A.2.3

COMPARATIVE DATA FROM NONRESIDENTIAL BUILDINGS ENERGY CONSUMPTION SURVEY (NBECS) 1979 CONSUMPTION AND EXPENDITURES

EXPLANATION

The Nonresidential Buildings Energy Consumption Survey (NBECS) is a careful accounting of both building characteristics and energy use. It was conducted once in 1979 on a carefully selected sample of about 6,000 buildings. It is significant because it is the largest single data base existing across all nonresidential building types that is based on real building experience and not on computer modeling.

From documents available to date, it is possible to get utility costs by building type and region or by building type and size not not by type, region, and size simultaneously. For this analysis, it was decided to report data both by region and by size as a range rather than to select either. The costs by region are based on all fuels. The costs by building size are limited to natural gas and electricity only. This difference is unfortunate but could not be resolved within the scope of this analysis.

It should also be noted that NBECS reports "Average square feet per building" and "Average expenditure per building (in dollars)". It is easy enough to divide the second by the first to arrive at average cost per square foot as was done for this analysis. It is not clear why NBECS did not choose to report this figure directly.

Finally, note that the NBECS data base reflects 1978-79 utility rates. Analysis of base case estimates (see Appendix A.2.6) suggest that between 1979 and 1983 electric rates increased to 148% and gas rates increased by roughly 30% overall. It would be much better for this comparison to increase NBECS data to match the year of operating data we have for each passive solar building. This is not possible, however, from the NBECS published data alone.

APPENDIX A.2.4

COMPARATIVE DATA FROM
BUILDING OWNERS & MANAGERS ASSOCIATION (BOMA)

PROJECT DESCRIPTION			BOMA OFFICE BLDG. DATA					MODIFIED DATA② $/S.F./YR.
CODE	NAME	LOCATION	COMPARISON CITY	SIZE FT^2	LOCATION	NO. BLDGS	AVG.UTILS① $/S.F./YR.	
MA	Mt. Airy	Mt. Airy, NC	Charlotte, NC	<50,000	D'Town	1	$1.35	$1.49
JC	Johnson Controls	Salt Lake, UT	Salt Lake, UT	<50,000	Suburb	3	$1.30	$1.43
SB	Sec. State Bank	Wells, MN	Minneapolis, MN	<50,000	Suburb	12	$1.00	$1.10
KI	Kieffer Store	Wausau, WI	Madison, WI	<50,000	Suburb	2	$ .62	$ .68

① Avg. Electricity + Avg. Gas, Excluding Water, Sewer & Other Charges

② All BOMA data is per rentable square foot. For this analysis, 10% is added to all BOMA figures. To approximate costs per gross square foot

APPEXDIX A.2.4

COMPARATIVE DATA FROM BUILDING OWNERS & MANAGERS ASSOCIATION (BOMA)

EXPLANATION

The BOMA Exchange Report publishes office building operating costs annually for selected cities in the U.S. This data base was used for comparison with the four projects in the program which were most like office buildings. The four nearest cities with data were selected for comparison. BOMA also disaggregates by both building size and location. The best comparison was selected in both these cases. It should be noted, however, that the smallest BOMA size category is "under 50,000 square feet" which is significantly larger than the passive buildings in the program.

It is also important to note that the BOMA data base can be quite small for a specific category. The number of buildings reporting data is shown on the table. With so few buildings reporting, it is possible for an operating cost figure to be skewed badly by one or two bad (high utility cost) buildings. This should be kept in mind when looking at the comparisons.

Finally, BOMA reports operating costs per "rentable" square foot which is a smaller number than the "gross" square footage of a building -- which is the basis for the passive buildings. For this analysis, 10% was added to the rentable square foot costs as reported in BOMA to approximate the gross square foot costs for comparison. Although reasonable, the 10% figure can be debated. It is an easy matter for a reader to alter the data he or she might wish to satisfy a different opinion.

COMPARATIVE DATA
FROM
AIA FOUNDATION -SCHOOLS DATA BASE (AIA/F)

- Typical New Jersey Elementary School (NJ DOE Audit Sample 10/80)
  - 39,000 S. F.
  - Utilities Cost $.78/S.F. Annually
  - Use is 124K Btu/S.F. (Point of Source)
  - Electricity is 7.4¢/kWh, Gas is $4.20/MCF
  - 5,000 HDD average
- Typical New Jersey Secondary School (NJ DOE Audit Sample 10/80)
  - 118,500 S. F.
  - Utilities Cost $.81/S.F.
  - Use is 125.83K Btu/S.F. (Point of Source)
  - Electricity is 7.4¢/kWh, Gas is $4.20/MCF
  - 5,000 HDD average
- Average Maryland Public School
  - 108,500 S. F.
  - Utilities Cost $.78/S.F.
  - Use is 76.5K Btu/S.F.
  - Electricity is 7.1¢/kWh, Gas is $6.40/MCF
  - 4,700 HDD average

The figures above were modified by the following percentages to more clearly reflect significant climate differences:

CU - Columbia, MO - Current electric rate of 8.16¢/kWh;
5,100 HDD Avg.: No Change

CO - N. Braunfels, TX - Current electric rate of 6.48¢/kWh;
1,600 HDD Avg.: -67% = .25 Elementary
.26 Secondary

CM - Denver, CO - Current electric rate of 6.45¢/kWh;
6,000 HDD Avg.: +20% = .97 Secondary

APPENDIX A.2.5

COMPARATIVE DATA FROM AIA FOUNDATION - SCHOOLS DATA BASE (AIA/F)

EXPLANATION

The AIA Foundation has recently completed a survey of available data on energy use and cost in elementary and secondary schools. They found that data on school operating costs per square foot is much more limited than one might expect. In fact, most energy use is reported in Btus per square foot, which facilitates comparisons across the U.S. independent of local utility rates. Unfortunately, in this case, it would be valuable to have that utility rate information.

Maryland and New Jersey do report utility cost data by square foot (as shown in Table A.2.5). That data was used for comparison with schools or school-like buildings in the Commercial Buildings Program. This data was modified in two cases to reflect significant differences in climate. Because heating is the principal energy use in schools, this modification was done based on heating degree days (HDD). Utility rates were judged to be close enough as not to require further modification.

APPENDIX A.2.6

COMPARATIVE DATA FROM PROGRAM BASE CASE DEFINITIONS (1980 DATA UPDATED TO 1983)

		BASE CASE						FUEL COST INFLATION					REVISED BASE CASE		
CODE	NAME	YEAR	ELEC.		GAS/OIL		TOTAL	YEAR	ELEC		GAS/OIL		ELEC	GAS	TOTAL
			$/S.F.	¢/kWh	$/S.F.	$/th			¢/kWh	%+	$/th	%+	$/SF	$/SF	$/SF
CU	C.U.M.C.	80	.06	4.4¢	27	$2.50	.33	83	8.16 (1)	+ 85%	NA	+30%(A)	.11	.35	.46
CM	Colorado Mt. College	80	1.17	4.0¢	---	-----	1.17	83	6.45 (5)	+ 61%	-------	--------	1.88	---	1.88
MA	Mt. Airy Library	80	.69	4.12¢	---	-----	.69	83	6.47 (2)	+ 57%	-------	-------	1.08	---	1.08
JC	Johnson Controls	80	.53	6.4¢	.12	2.86	.65	83	7.08 (3)	+ 11%	NA	+30%(A)	.59	.16	.75
SB	Sec. State Bank	80	1.01	7.3¢	.12	3.06	1.13	83	7.4 (4)	+ 1%	5.63(B)	+84%(B)	1.01	.22	1.23
GU	Gunnison Airport	80	.51	2.6¢	---	-----	.51	83	6.45 (5)	+148%	-------	-------	1.26	---	1.26
RP	RPI Police Station	80	1.07	5.0¢	---	-----	1.07	83	10.7 (6)	+114%	-------	-------	2.29	---	2.29
KI	Kieffer Store	80	.33	5.4¢	.17	5.60	.50	83	6.81 (7)	+ 26%	NA	+30%(A)	.42	.22	.64
CO	Comal Co.	80	.47	4.6¢	.13	3.35		83	6.48 (8)	+ 41%	NA	+30%(A)	.66	.17	.83
PA	Philly Auto	83	.42	10.0¢ Oils	.11 .93	6.04 6.57	-----	-- ACTUAL BUILDING PRE-RETROFIT----							- 1.46

(1) Missouri Public Service Co.
(2) Carolina Power & Light
(3) Utah Power & Light
(4) Wells Public Utilities
(5) Public Service of Colorado
(6) Central Hudson Gas & Electric
(7) Wisconsin Power & Light
(8) Texas Utilities Co.

- From Merrill Lynch Utilities Research Group
Report Dated August, 1984

(A) Average U.S. Natural Gas Price Increase 1980-1983=30% Computed from Annual Report of Energy Conservation Indicators - U.S.E.I.A. - Jan. '84
(B) Peoples Gas

NOTE: RPI Base Case Changed to Reflect 24-Hour Use - See Explanation.

APPENDIX A.2.6

COMPARATIVE DATA FROM PROGRAM BASE CASE DEFINITIONS (1980 DATA UPDATED TO 1983)

EXPLANATION

As explained in Chapter III, each design team in the project was required to propose or define a "base case" building to represent good but not necessarily energy efficient design within the area and of a similar type as the passive building being designed. This base case selection process was further judged by a jury of program monitors to pass on the fairness of the base case selected. In several cases, the base case was another building owned or operated by the passive building owner. In most other cases, comparable buildings were found or carefully specified.

In nearly all cases, base case utility costs were reported at 1980 utility rates. These rates and the resulting estimate of base case annual utility costs are shown on Table A.2.6. In order to make a more fair comparison, these base case costs were modified to reflect approximate utility rates for 1983 -- the year for which we have the majority of actual building operating data. Current local utility rates were taken from a national survey prepared by Merrill Lynch. Natural gas rates were increased by the national average increase for the period from an EIA report.

In one case, RPI, the base case was modified more substantially to reflect more closely current use of the building. The original base case had assumed occupancy 8 hours per day. In fact, the building is now used on a 24-hour basis. Lacking better information, lighting cost was doubled and both heating and cooling costs were increased 20% to reflect this change in use.

APPENDIX A-3

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APPENDIX A-4

OTHER PROGRAM DOCUMENTS AVAILABLE

Several other documents which report various aspects of the DOE Non-Residential Experimental Buildings Program are available. The following is a listing and a short description of each.

1. Design Overview: Passive Solar Energy for Non-Residential Buildings. This overview describes patterns that emerged from the design of the program buildings. It focuses on the design process and predominant design strategies. Will be available from the U.S. Department of Energy in 1985.

2. Passive Solar Commercial Building Program, Case Studies (May 1983). This is a collection of two to four page case studies describing the design of the 22 buildings that participated in the design phase. Available from the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161 in print and microfiche, DOE/CE-0042.

3. Performance Case Studies: Passive Solar Energy for Non-Residential Buildings. This is a collection of case studies reporting the performance of the 17 program buildings that were built and instrumented. Four of them yield extensive data, allowing conclusions to be drawn as to why they performed as they did. Will be available from the U.S. Department of Energy in 1985.

4. "Energy Effects of Electric Lighting Control Alternatives in Response to Daylighting" (1984). This report presents results from studying the south-facing apertures on two buildings, investigating the effectiveness of manual control of lighting systems on heating, cooling and lighting energy. Available from Lawrence Berkeley Laboratory, Passive Research and Development Group.

5. "Thermal Mass Total Building Analysis" (1985). This report analyzes the effects of the amount and exposure of thermal mass, including effects on acoustics and temperature setbcks. Will be available from Lawrence Berkeley Laboratory, Passive Research and Development Group.

6. Passive Solar Experimental Building Archive. This archive houses and disseminates project data in both hardcopy and computer form. Data include individual project data, monthly measured data, hourly monitored data, and system studies on occupant and energy issues. Archive Users Manuals are available from the American Institute of Architects Foundation, 1735 New York Avenue, N.W., Washington, D.C. 20006.

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