DESIGN OVERVIEW: PASSIVE SOLAR ENERGY FOR NON-RESIDENTIAL BUILDINGS

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October 1985

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DISCLAIMER

DESIGN OVERVIEW: PASSIVE SOLAR ENERGY FOR NON-RESIDENTIAL BUILDINGS

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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 systems analysis and applications concerning building design issues encountered in the design, construction and evaluation of twenty-two passive solar buildings in DOE's Nonresidential Experimental Buildings Program.

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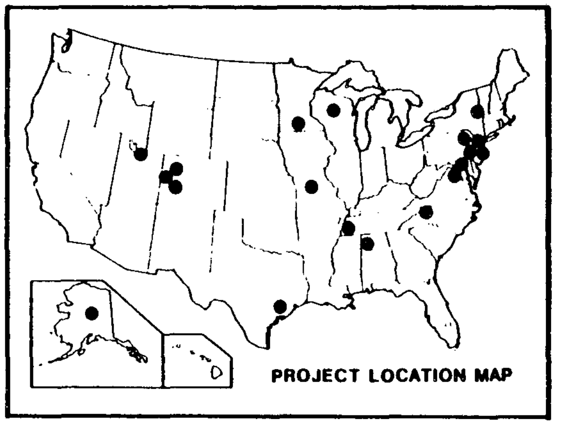
DESIGN OVERVIEW

Introduction

The Design Overview describes the most important building design issues encountered in the design, construction and evaluation of 22 passive solar buildings in the U.S. Department of Energy's (DOE's) Non-Residential Experimental Buildings Program. The buildings in the program encompass a broad spectrum of building types, climate locations, and design strategies as shown in the Project Location Map.



PROJECT LOCATION MAP

There were three phases in the program: design, construction, and performance evaluation. In the design phase, project designs were reviewed by a panel of technical experts in a series of meetings. The objective of the reviews was to ensure that designs effectively integrated strategies for passive cooling, lighting and heating with each other, with the building, and with the auxiliary mechanical and lighting systems. These reviews provided valuable feedback to designers from the earliest stage in design--when the greatest opportunities exist for saving energy--to the final preparation of bid documents.

The purpose of this overview is to distill the experiences of all participants in this phase of the program and to identify the common, predominant patterns emerging from their design processes. The observations and recommendations presented here are intended to aid design professionals who have limited experience in the application of passive technology in non-residential buildings. At the outset of this program in 1979, most design professionals, including the 22 program architects, had but limited experience. By the end of the program, though, the lessons they learned greatly increased their understanding of passive commercial building design, and

	PASSIVE SOLAR STRATEGY											
	HEATING			COOLING					DAYLIGHTING			
	Sunspace/Atrium	Mass Floor	Mass Wall/Water Storage	Earth Contact	Natural Ventilation	Forced Vent /Night Flushing	Shading Mechanisms	Evaporation/Radiation	Windows (More Nat. Light)	Lightshelves	Clerestories/Skylights	Sunspace/Atrium
Two Rivers School			●						●			
Abrams Primary School			●				●				●	
St Marys School Addn		●	●			●					●	
Blake Ave College Ctr	●	●	●			●	●		●	●		
Princeton School of Arch					●				●	●	●	
Mt Airy Public Library		●	●		●	●	●		●	●	●	
Johnson Controls Branch		●						●	●	●	●	
Kieffer Store Addition	●	●				●	●		●	●	●	●
Princeton Prof Park	●				●		●	●	●	●		●
Wells Security State Bank		●	●			●	●		●	●	●	
Community United Church		●	●		●	●	●	●	●	●	●	
Shelly Ridge Girl Scout Ctr	●	●	●	●	●	●	●		●		●	
RPI Visitor Info Ctr	●	●	●		●		●				●	●
Essex Dorsey Senior Ctr		●			●		●		●		●	
Comal County Health Ctr		●	●		●	●	●		●			
Gunnison County Airport			●			●	●		●	●	●	
Walker Field Terminal Bldg		●			●	●					●	
Phila Municipal Auto Shop					●		●			●	●	
Toukalos Greenhouse		●	●	●	●		●		●		●	

it is appropriate to document these for the benefit of others. The lessons are broad, applying not only to passive technologies in particular, but to energy-conscious design in general.

The contributors to this overview recognize that design methods and procedures are as varied as the individuals who make up the professions and the buildings they design. There is no single right or universal design formula to be followed. Thus, the guidance is broad and grouped according to the traditional phases of the design process rather than like a "How-To" book to be followed step-by-step. Building design lies in the dynamic integration of various architectural issues; the overview raises these issues and offers guidance on dealing with them, guidance supported by both the buildings and design team experiences of this program.

Three very broad lessons have come out of this program which pervade the entire overview. If the reader goes away with any impressions, they should be these:

- Consider energy-conscious design alternatives as early as possible in the design process.
- Support all design decisions with thorough analysis that addresses building efficiency in its broadest sense, including economics.
- Think of passive solar design as an architectural, mechanical, and electrical integration issue, not an "add-on" exercise.

Energy-conscious design must be viewed in a broad context. Building design is a problem-solving activity that integrates user needs, owner needs, and other requirements such as building codes. Energy is just one aspect of these and is rarely, if ever, the primary focus. It must be addressed, however, to achieve a fully successful building design.

SUMMARY OF PASSIVE SOLAR DESIGN GUIDELINES

The following is a list of the passive solar design guidelines that have emerged from this overview:

- I. General Observations:
    - A. For a designer's initial projects, good solar design will probably take extra time and effort.
    - B. Good energy-conscious design required more than intuition.
- II. Programming and Pre-Design:
    - A. Use the architectural and energy program for evaluating design decisions.
    - B. Identify the building energy problem early.
    - C. Use the "base case" building for evaluating design alternatives.
    - D. Set the energy ground rules for the design team.
    - E. Choose an appropriate design tool.
- III. Schematic Design:
    - A. Choose simple design solutions which address the major parts of the energy problem.
    - B. Pay close attention to system integration issues.
    - C. Choose architectural features that have multiple functions.
    - D. Develop the potential amenities associated with passive solar features.

IV. Design Development:

A. Select a design tool which permits a refinement of the schematic solution.

B. Integrate solar and conventional systems control strategies.

V. Construction Documents:

A. Bid documents should serve as a performance specification for evaluating product options.

B. Call out and specify components carefully.

VI. Construction and Building Acceptance:

A. Monitor construction to insure quality.

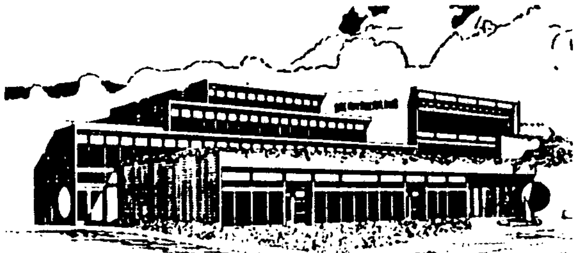
B. Consider post-occupancy performance monitoring.

GENERAL
OBSERVATIONS

Section I: General Observations About Solar Building Design

A. For a designer's initial projects, good solar design will probably take extra time and effort.

All of the buildings in the DOE program required more effort and resources than typical to settle on a final design solution. Program reporting accounts for a large proportion of the additional time, but, even so, design of these passive solar buildings took longer than usual. In most cases, the additional time was the result of having to "start over" or substantially revise an initial design concept.


COLORADO MOUNTAIN COLLEGE
GLENWOOD SPRINGS, COLORADO

Like many of the designers in the program, architect Peter Dobrovolny had just such an experience in designing the Blake Avenue Center for Colorado Mountain College in Glenwood Springs, Colorado. His initial schematic design relied on extensive use of direct gain and Trombe wall strategies to address a perceived dominant heating problem. Following review by a panel of experts and analysis by Lawrence Berkeley Laboratory (LBL) researchers, however, it was necessary to substantially alter the design to address lighting and cooling energy which were much more significant than the design team expected.

Residential vs. Non-residential

There are a number of important lessons to be taken from Dobrovolny's experience. First, and probably foremost, is that residential scale solar experience does not automatically translate to commercial scale buildings; it pays to do an energy analysis in pre-design to make sure that one focuses on the predominant energy problem.

Computer Analysis

Second is the value of computerized analysis for complex buildings. With the computer, iterative calculations to test new design strategies of the CMC building took minutes to complete. There is also another lesson related to reducing design time: while the design team tried to do their analysis to a great level of detail (including 14 different building zones), the LBL analysis was simplified to only five zones without a significant loss of analytical detail. Extreme precision was not necessary.

Learning Curve

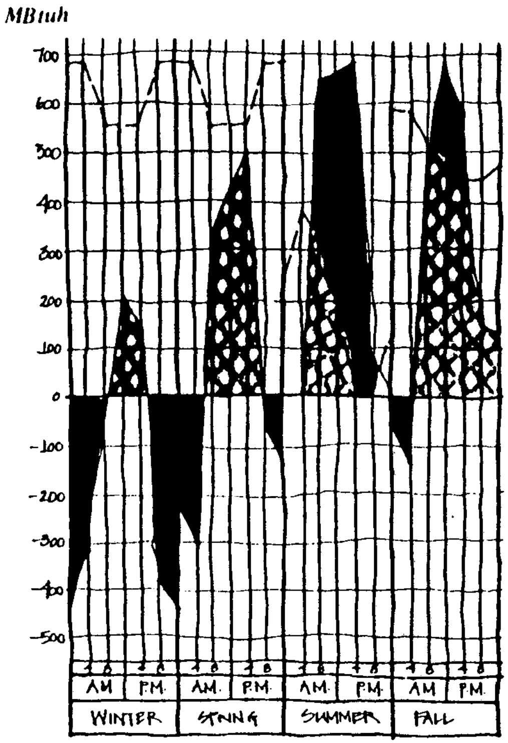
Finally, there is the painful but unavoidable problem that learning a new subject, like learning a new building type, takes time and costs money. According to Dobrovolny, "Much more of the design time was spent learning new information and developing new methodologies. This process will not need to be repeated. Also, information gathered by observing this building will promote development of rules-of-thumb to speed and improve design in the future. As a result, future passive efforts will be more refined and take much less time." In other words, the architect's time is likely to be much more profitable the second time around.

B. Good energy-conscious design requires more than designer intuition.

Simple Design Tools

All designers rely on intuition--it is the stuff that prevents design from becoming rote. During the design reviews Sarah Harkness, co-founder of The Architects Collaborative, characterized designer intuition as "informed experience". Initially, though, program architects found their experience not as "informed" as they would have thought. Repeatedly, highly skilled professionals found their intuitive grasp of energy problems in a building off-the-mark when tested by even rudimentary energy analysis techniques.

Upon realizing this, a few of the design teams began to modify their design process to start with simple energy analysis whose level of detail increased to match the increasing level of detail in their designs. One such team was Harrison Fraker's Princeton Energy Group which designed the Princeton Professional Park speculative office complex. Following site analysis, simple pre-design energy analysis tools were used to identify the energy problem and to set a



preliminary energy target by schematic design. These tools included both hand calculators and a microcomputer to apply several different analysis techniques: Solar Load Ratio, a thermal network analysis, and the simple bin method described in the ASHRAE Handbook of Fundamentals. None of these simple techniques could account for energy effects of complex issues such as building mass.

These early analyses showed that internal heat gain and solar loads would probably supply all the building's heating needs during occupied hours. Also, these preliminary estimates suggested that a "reasonably" designed solar building could use significantly less energy than the owners had come to expect in previous buildings.

Based on this analysis and a search of available literature, the team developed a number of guidelines for use during schematic design:

- Insulation could be used to reduce conductive losses for heating from 10-25% and for cooling from 10-20% over conventional design.

- Passive solar heating (in the Princeton area) could provide 60,000-90,000 Btus/sq. ft. of glass/year or reduce heating loads in the range of 40-50%.

- Natural ventilation could reduce cooling loads 10-20%, but only in the spring and fall "swing" seasons.

- A roof spray system could cut peak cooling demands 5-10%.

- Lighting loads could be cut 40-50% using efficient ballast and daylighting strategies.

Sophisticated Design Tools

As the team progressed into design development, they found that previously used tools often did not meet their needs for answering more specific questions. For example, the following design tools were either totally lacking or inadequate:

- Simple tools for calculating heating performance in buildings with high internal loads (as in many commercial-scale buildings).
- Tools for estimating annual daylight contributions.
- Design tools (and performance data) for assessing indirect cooling with evaporative roof sprays.
- Design tools (and performance data) for assessing cooling by natural ventilation.

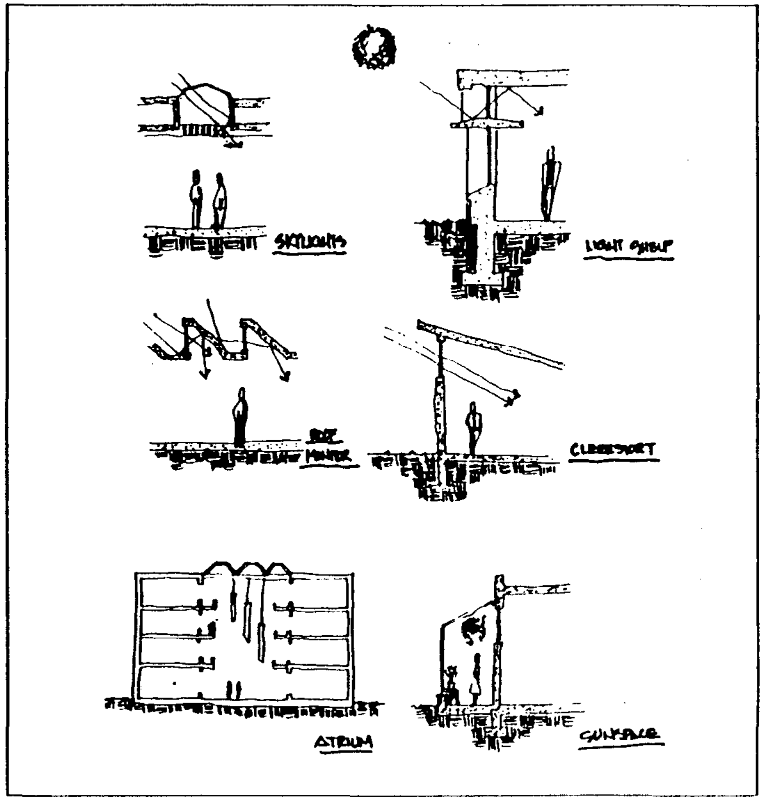
Lacking available design tools, the team developed their own: a 12-node thermal network model for heating analysis (including analysis of the underslab rockbed), and a 14-node model for cooling analysis of stratification, evaporative cooling, and radiative cooling. These dynamic models did take into account the effects of thermal mass. The team found it sufficiently accurate to calculate average monthly performance by extrapolating from average daily performance using modified degree days and an equivalent base temperature for the month.

Lighting Design Tools

Lighting analysis was based on measurements of actual light levels in a scale model of the building. From these measurements, the team calculated daylighting factors and translated them into seasonal performance. This yielded auxiliary energy and cost requirements for lighting.

Obviously, the levels of energy analysis employed by the Princeton Energy Group do not apply to all design projects. The point, though, is that analysis is needed to make informed choices among energy design options. Energy analysis is critical for a team embarking on their first energy-conscious design projects where intuition will not be sufficient for good decisionmaking.

A palette of aperture options



DAYLIGHTING

The prominence of daylighting as a design solution to energy-efficiency is a response to high electricity costs in non-residential buildings. Measured in Btu's, lighting energy may be secondary to heating and cooling, but the cost of delivering light is two to three times greater than the cost of delivering heated or cooled air. Furthermore, unlike in residential buildings, lighting is a major energy use.

Good daylighting demands that the designer have access to a palette of techniques, a vocabulary of daylighting strategies whose elements can be refined and combined confidently with other architectural elements. Daylighting apertures include: clerestories (vertical glazing at perimeter walls), roof monitors (vertical glazing at interior spaces), skylights (horizontal glazing), atriums, and conventional windows. Distribution devices include lightshelves, diffusing surfaces, and baffles. The designer must be aware of the differences between direct and indirect light, north and south light, clear and translucent glass, and how these differences affect light quantity, color, and glare over various times of the day and year.

Several design principles emerged from the daylight designs. Vertical glazing was found to be generally superior to sloped glazing and definitely superior to horizontal glazing in internal load-dominated buildings. Glazing sloped towards the sun admitted too much direct beam light and was difficult to shade with overhangs, thus causing glare and unwanted heat gain. Skylights admit even more heat gains from the high, summer sun while creating complications for ceiling plenums and their contents. Except for dramatic light at entrances and lobbies, diffused light is best, diffusion provided by either walls, ceilings, or special diffusing grids. The Johnson Controls Branch Office used diffusing walls and ceilings, whereas Mt. Airy Library and State Security Bank used diffusing grids. Providing light to core areas was best achieved using roof monitors. Distribution to core areas is necessary for good perimeter lighting since even light distribution across the room reduces bothersome brightness contrast caused by a single light aperture. Roof monitors faced south wherever there was even a modest heating load, and worked best using distribution of small openings rather than one large opening. Finally, light shelves were found to be expensive and did not demonstrate greater energy savings than did overhead daylighting systems.

PROGRAMMING & PRE-DESIGN

Section II: Programming and Pre-Design

A. Use the architectural and energy program for evaluating design decisions.

Just as an architectural space program is the basis for determining a building's spatial solution, the energy program is also the basis for determining a building's energy solution. The program should be a performance description--not the identification of a particular solution--which will be used to assess design alternatives as they are developed. Careful attention to this performance description and evaluation criteria before beginning design solutions will allow the designer to early identify those alternatives which have the highest potential for satisfying both architectural and energy requirements of the building.

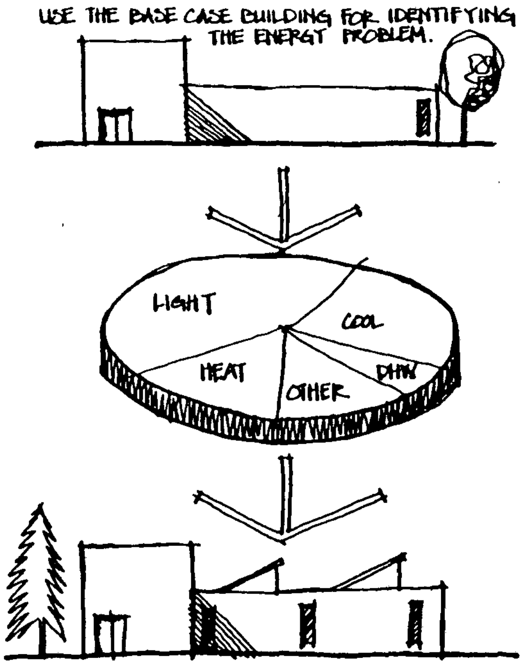
B. Identify the building energy problem early.

There can be no elegant solution to a mis-stated problem. Time spent in the programming phase to correctly identify the characteristics of energy use in the building is directly related to time saved during the design process because the range of alternatives which must be explored is narrowed.

For example, the architect/engineer team must establish the nature, timing and quantity of building energy requirements. How important are heating, cooling and lighting energy requirements? In what order? Do those requirements occur during occupied or unoccupied periods? Does the timing of those energy requirements coincide with the availability of solar or other environmental resources? Frequently, it is useful to establish the non-solar "base case" building for answering some of these questions.

C. Use the "base case" building for evaluating design alternatives.

Analysis of a conventional (non-solar) building helps determine the building energy problems identified



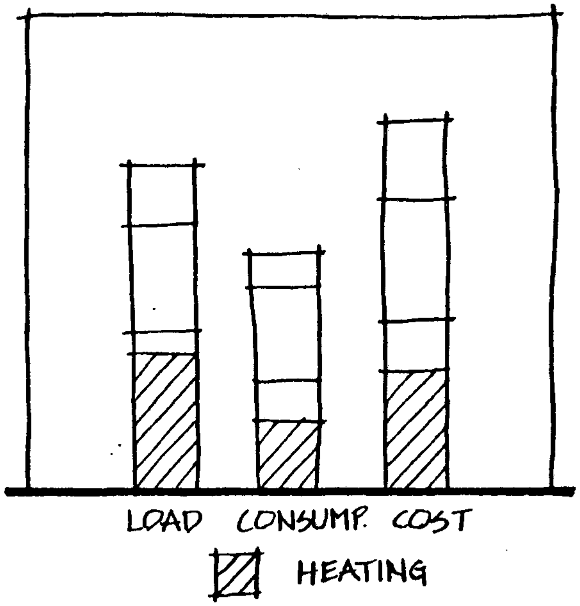
above. A wide variety of alternatives exists for establishing such a base case building. Among those used by designers in this program were computer modeling of a hypothetical building without solar features; comparison to a technical reference such as the Building Energy Performance Standards (BEPS) budget applicable to the building type and location; examination of the energy use records of similar buildings in the area; or assessment of the last building developed by the same owner. Whichever option is chosen, the objective is to identify the characteristics of the conventional building which the owner otherwise would have built.

The base case building can then be analyzed to establish the energy problem. It can be used to quantify the magnitude and timing of heating, cooling and lighting energy requirements. Internal heat generators such as computers or unusual ventilation requirements, such as those for a natatorium or gymnasium are an important part of this analysis. The anticipated use patterns of the building, including timing and number of people should be estimated, and the probability of changes in these patterns should be assessed.

In constructing the base case, assume common architectural, space conditioning and electrical systems. For example, an office building might make use of envelope requirements dictated by prevailing standards (such as ASHRAE 90), a variable air volume mechanical system, and lighting and equipment power levels of 2-1/2 to 3 watts per square foot.

It is important to distinguish among three commonly, but incorrectly interchanged terms in making this analysis:

Loads - These are the net heating, cooling and lighting quantities which must be met by the building mechanical and electric equipment. Traditionally, loads have been used for equipment sizing purposes. They are not very useful for energy decision making.



Energy Consumption - This is the non-renewable energy which must be purchased from utilities and supplied to the mechanical and electrical equipment to meet the loads. Since mechanical and electrical equipment operate with different efficiencies, their energy consumption may vary significantly from the loads.

Energy Cost - This is the price paid to utilities, including demand charges where applicable for supplying energy to the building. Since the costs of different fuels vary significantly, the proportions of the energy problem as seen from the perspective of "energy cost" may be quite different from that seen from the perspective of "energy consumption".

Distinction among "loads", "energy use" and "energy cost" is fundamental to correct decisionmaking in developing an energy-responsive building. Under most circumstances, the energy cost will be the most useful basis on which to make decisions. For example, what is the economic result of reducing the amount of electricity which must be purchased for building lighting? Similarly, what is the value of an equivalent reduction in building heating requirements? The designers in this program frequently found that the solution which was most appropriate for reducing loads or energy consumption was much different than that for reducing energy cost.

D. Set the energy ground rules for the design team.

Energy ground rules are the agreements among the client and design team members which describe their common objectives and identify assumptions that will underlie design decisions.

The Design Team

PASSIVE COOLING

Three strategies dominated in the designing of these buildings for low cooling energy. The first was the avoidance of heat gains using shading and landscaping. Use of exterior shades (Security State Bank, Colorado Mountain College) and overhangs (Mt. Airy) were the most direct approach. Interior shading using blinds and lightshelves is less effective. The second was natural ventilation/night flushing. Air flows must be direct; convoluted paths that wind through a building are a designer's fantasy. Also, it is difficult to combine natural ventilation with window shading if closing the shades reduces air flow. Third, well-controlled daylighting will reduce cooling since, lumen for lumen, daylight generates less heat than does artificial light. The designer's objective is to admit modest amounts of light distributed over large areas. Excessive light will generate excessive heat gains and poor distribution will require more artificial light in interior areas than necessary, also generating heat. This objective was best met in the Mt. Airy Public Library, St. Mary's Gymnasium, Princeton Professional Park, and the State Security Bank.

The architect, as programmer, will most easily gain the support and cooperation of design team members if he involves them at the earliest stage possible. Furthermore, the setting of energy ground rules demands involvement of the client and all the disciplines: architectural, mechanical, electrical, structural, and preferably the principals representing each discipline. Although this may apply to conventional buildings in general, a solar building requires a design team which is more diverse and more specialized than that of a conventional building. Hence, the involvement of top management at this early stage is important to avert assumptions which may lead to expensive re-designing.

An example of an energy ground rule could be "To achieve cooling comfort, passive means shall be considered before mechanical means." Suppose that A/E principals are ignorant of (or even disagree with) this requirement. Furthermore, suppose the architectural design relies on operable, southwest-facing windows to catch summer breezes. If the mechanical consultant simultaneously designs for minimal infiltration and the electrical consultant specifies circuitry to handle maximum KW chiller load and the owner requires windows closed for security purposes at night, the building will meet nobody's expections with regard to minimum energy consumption.

On the other hand, the most smoothly produced buildings in the program included those where maximum agreement was reached in the beginning, or where one organization performed many functions. At Johnson Controls, the owner was also the architect, the engineer, the control system designer, the control system installer, and the user of the building. Coordination and start-up problems were held to a minimum. In the case of the Solganic Greenhouse, the owner was also the energy consultant, general contractor, and user of the building. In the other projects, close involvement of disciplines approximated these ideal circumstances better than did disjointed communication and belated agreement.

Energy Objectives: Cost Reduction

The overwhelming objective among the program participants was to reduce energy costs. A corollary objective was to insulate the building owner from energy cost uncertainties since rising costs which fluctuate are unnerving and make cash flow projections difficult for the owner who operates on a narrow margin. It is not surprising that the designer of the Community United Methodist Church said, "Building owners want solar because they want low energy bills;" natural gas costs rose 70 percent during 1982 in his area and electricity costs even more. Of course, other objectives do exist which are discussed below.

Intangible Energy Objectives

The building owner may express a desire to work toward certain societal goals related to a sustainable energy resource or to an energy conservative planet. The architect of the Girl Scouts' Center said, "Using the natural energies was among the [Building Task Force's] earliest thoughts. Their motives are philosophical and educational, but also include the pragmatic concern for minimizing operating expenses." This philosophic commitment sought to create a special building at Shelly Ridge which would demonstrate a sensitivity towards nature and natural resources reflecting the Girl Scouts' longstanding commitment to such issues and to their role as an educator of the youth who are expected to experience a future of limited non-renewable energy supplies. (Ironically, the solar aspects fulfilled another more tangible objective by serving as a positive selling point in the fundraising campaign.)

Solar energy as a visible symbol was another common objective, presenting an interesting aesthetic problem to the designer. Faculty at the Princeton School of Architecture and Urban Planning said that the primary asset of their solar retrofit was that it serve as an educational tool showing the students a concern for our energy resources which would be increasingly important during their professional careers. The Community United Methodist Church pastor explained that, "The use of solar energy is a visible sign to the community concerning the stewardship of natural resources and the concern of the church for these resources." Princeton Professional Park's developer felt that the passive solar aspects might speed the necessary zoning approvals by making the project appear benign and, therefore, palatable to surrounding homeowners.

Solar energy in the form of sunlight for heat and and landscaping for cooling bring nature to the building occupants, an objective symbolizing health and wellbeing. Clear glass gives views of blue sky and operable windows admit fresh air, thereby improving the quality of the building environment. Gunnison Airport owners consciously wanted a natural atmosphere in their building which is a gateway for outdoors-oriented tourists. The owner of Kieffer Store even went so far as to suggest increased rent for solar amenities. Even if higher rent is not earned, these amenities bring with them other financial benefits. According to its designer, the clerestories at Princeton Professional Park "serve as an architectural amenity which gives the developer an intangible marketing edge over the competition for leasing space." Simply put, the energy savings pay for architectural features with environmental benefits which then become useful marketing tools.

Financial Energy Objectives

Solar energy can serve as a financial investment, an objective which requires the designer to weigh costs against benefits. In this program, this objective applied to both profit and non-profit owners who were explicit in their desire to maximize the return on their investment.

The owners of Comal County Mental Health Center and Princeton Professional Park earmarked particular building funds for energy improvements. In the first case, a non-profit organization, the fund comprised donations; in the second, a private development, the fund was raised from investors. In both cases, however, owners used the funds as a discrete investment whose return would have to match alternative investment instruments.

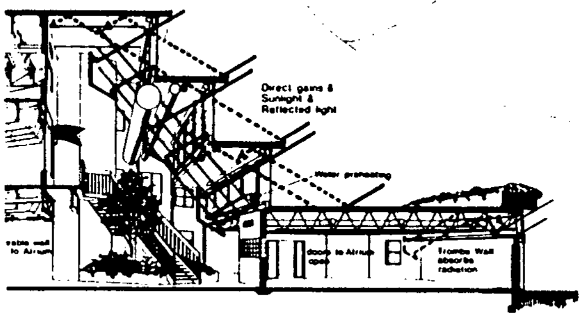
Flexibility

Besides setting energy objectives, the design team should resolve those objectives that compete. Two objectives whose conflict is peculiar to low-energy building are energy savings and flexibility: flexibility in space planning, thermal comfort, lighting quality, and building schedule.

The process of optimizing energy performance requires the designer to make assumptions about the expected building use and operation in order to project energy use. Some of these assumptions have room for change; others do not without compromising energy performance. When the actual building occupant behavior deviates from these assumptions, energy performance may not meet expectations; therefore, the architect who designs for such change usually must settle for increased energy consumption. Thus at the outset, the design team must settle issues such as whether atriums will be strictly used as such for circulation and therefore can tolerate more extreme temperatures, whether meeting rooms will never have to accommodate slide presentations and therefore can be daylighted, and whether schools will always be used during the daytime, thereby minimizing the need for thermal storage.

At times, balancing these goals becomes a key design issue. Princeton Professional Park was designed for the speculative office tenant. Consequently, the duration and magnitude of internal loads were unknown. A variety of tenant requirements had to be planned for, thereby complicating the design process, since most of the strategies examined met some requirements but not others.

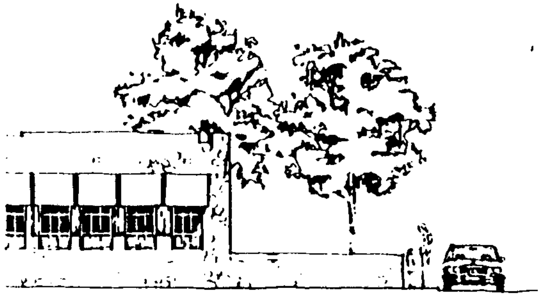
The Blake Avenue College Center expected primarily early evening use five days a week. The atrium was to be used as a transitional, circulation space only and therefore allowed to float in temperature. After the building was opened, however, faculty and students used it extensively and adopted the atrium space both day and night as their central gathering place. Consequently, the owner decided to condition the space to the same comfort levels as the rest of the building and extended the operating hours earlier in the morning as well as later into the evening.



BLAKE AVENUE BUILDING
GLENWOOD SPRINGS COLORADO
COLORADO MOUNTAIN COLLEGE

At the Gunnison Airport, a loft space which was designed as an overflow passenger lounge was converted into the home office of a small airline. The unplanned heat loads from the several CRTs and the host computer raised temperatures higher than were comfortable. Rather than increasing air conditioning capacity, though, the owner simply replaced fixed windows with operable ones.

The Comal County Mental Health Center was programmed for a five day work week. But soon after completion, the administration sublet space to a church group that uses the building on weekday evenings and weekends. The increased energy use was understandable, but the center may have missed the opportunity to justify even more solar measures than originally incorporated since higher use creates greater potential savings.



COMAL COUNTY MHMR CENTER
NEW BRAUNFELS, TEXAS

The program abounds with examples of changed use and instances where reasonable assumptions were not borne out. The local community booked Alaska's Two Rivers School so extensively in the evenings that the janitor had to change his work schedule to after midnight, thereby frustrating night setback. Mt. Airy Library staff decided to open earlier because of the building's increased popularity. However, the building's thermal mass was sized for later occupancy, thereby requiring more purchased energy to warm the building even during daylight hours. The Essex Dorsey Senior Center incorporated a Trombe wall that was to be shaded during the warm months of the year. However, the occupants demand such high temperatures that they prefer to leave the Trombe walls unshaded even during the summer to enjoy the radiant heat. The designer of the Princeton Professional Park assumed that tenants would select energy-conserving options rather than pay for higher energy use. The tenants, however, write off their energy costs as a business expense; equipment depreciation is available only to the building owner. Thus, a number of tenants selected the conventional option of dropped ceilings with recessed fluorescent troffers over the daylighting option.

The lesson to be learned from these occupancy issues is that it is difficult to predict the user's behavior patterns and therefore, the designer must consider a range of operating conditions when making assumptions leading to energy performance. If flexibility and energy performance are inversely related, the design team must decide upon an appropriate compromise. This will then dictate to the designer the performance required of the solar thermal and lighting systems.

User Control

The dependability of the user to operate the solar building correctly is another issue that must be agreed upon by the design team. At some point, the designer of every building must decide the degree to which its occupants and operator will have to flip switches, adjust settings, and replace expendable parts such as filters in order that the building function properly. The extremes are very close manual control on one hand and total automation on the other. The trade-offs are like that of a manual versus automatic transmission in an automobile: close control, low cost, but the requirement of an experienced, dependable driver versus higher cost, automatic operation, but potential breakdowns and maintenance problems. Thus, the design team must settle issues such as: Should the users have to open and close windows according to a daily and seasonal schedule? Should occupants be responsible for turning on and off electric lights in the presence of varying daylight? What about controlling air movement with ceiling fans? Resolutions of these issues are made even more elusive by the non-residential aspects of the occupancy; occupants are unpredictable when it comes to operating the building if they are not the owners paying the utility bills.

These issues require careful consideration since controversy surrounds the appropriate level of control. Many mechanical engineers recommend against operable windows, saying that users who open them will be conditioning the great outdoors. Even when maintenance personnel are available to operate the building, one cannot assume they will readily accept that responsibility. Gunnison County Airport employed a full-time maintenance man to manipulate systems for the transient users. Upon his realizing, however, that these tasks included closing doors, adjusting thermostats, and performing other functions he felt people should do for themselves, manual versus automatic control took on a different meaning.

Several problems can result from an inappropriate degree of user control. The occupants may misuse a system they do not understand. The Essex Dorsey Senior Center provided a winter/summer switch in each suite to control the Trombe wall night insulation. The users who were not trained properly assumed that the switch turned on the passive solar heat. The confusion was exacerbated since the twelve hour thermal lag did not clue the users that the system was responding to their action.

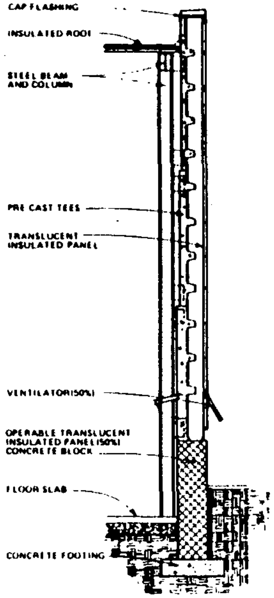
It is also a mistake to deny the occupant any control at all. St. Mary's Gymnasium employed a time clock controlled lighting system which had to be overridden frequently by community basketball team members playing after-hours. In another example, employees of the

Security State Bank felt the need for more outside air in their tightly constructed building. Their solution was to circumvent automatic control by normally opening the air handler's outside air dampers even during the winter months.

In spite of these complexities, the program did produce a guideline useful in overcoming them: with proper design and an understanding of building users' behavior, manual controls can be sufficient. Specifically, if users are a small, easily educated staff, centralized, manual controls are sufficient. But if users are transient, indifferent, or uneducated about how to control their environment, it is best to specify automatic controls.

Construction

The final ground rule to be established relates to construction quality. Specifically, the design team should anticipate how much the builder will know about solar construction. If the architect can depend on a contractor who is experienced in, say, earth-integrated construction, he will not hesitate to consider this option and will develop his construction documents to the appropriate level, assuming his contractor knows the implications of proper waterproofing and structural design. Generally, if the contractor is not expected to understand the system, then specifications must be tight and construction closely supervised to assure job quality. On the other hand if the contractor knows passive solar construction, he may provide an unanticipated quality of construction or even suggest effective, lower cost alternatives for critical subsystems. As an illustration, it was the contractor of the St. Mary's Gymnasium who encouraged the idea of a two-story Trombe wall of precast concrete tees bolted to a steel frame. The system was faster to erect, and provided a thermal capacitance which varied according to thicknesses available.



St. Mary's Parish School
Cross section through
Trombe wall

Identification of construction cost goals and the budgetary allowance for passive solar techniques should be established from the onset. If minimizing construction costs is a paramount concern, then the possibility that construction workers with lower skill levels will be employed should be recognized and the design developed accordingly. Under these conditions, complex passive solutions requiring considerable care during construction should be avoided in favor of simple solutions with a lower margin for construction error. The plans for Princeton Professional Park specified a contractor-built HVAC control system which had 11 different modes of operation. The system was designed, tested, rejected, redesigned over budget, and finally redesigned and installed by another subcontractor, incurring a 15 month delay in the installation of the system. In other projects, motorized insulating curtains caused similar difficulties.

E. Choose an appropriate design tool.

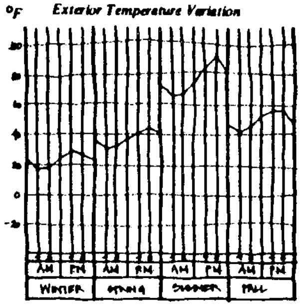
Even before schematic design, it is necessary to choose and use a design tool. At first this may seem peculiar, but if the performance of the base case discussed earlier is to be quantified, it must be established using the design tool chosen for subsequent iterations in the design process.

The Building Design Tool Council, a national consortium of building designers formed to provide guidance for energy design tool research, defines design tools as "any device which assists in the formulation and/or evaluation of energy efficient strategies for new or existing buildings." This broad definition comprises a number of procedures varying in accuracy, cost, and ease of use, including workbooks, nomographs, calculator routines, physical models, microcomputer software, and mainframe computer programs. The problem for the solar building designer is to choose the right tool for his needs.

Simple Input

Designers participating in the Non-Residential Experimental Buildings Program learned quickly which tools were appropriate. The best tools at early design stages were those that accepted simple input. A tool that requires mechanical equipment part-load curves is often too cumbersome for pre-design and schematic design. Consequently, the design tool should incorporate reasonable default values if it doesn't require detailed input. For example, if an hour-by-hour building operating schedule is not required for simulating an office building, the design tool should assume an 8 to 5 schedule five days per week, not the 24 hour occupancy that characterizes a residence.

Fast Output



The design tool should be able to return results quickly. Output that takes more than several hours to generate interrupts the designer's work rhythm and concentration. Thus, microcomputer software, nomographs, and simple formulas are more dynamic than physical models and mainframe programs (which can be used later during design development to make refinements). Many program designers used a program called Energy Graphics, a series of quick calculations whose output was in graphic form, to generate quick feedback. Others used hand-held calculator programs available at the time such as TEANET, PASOLE, and PEGFIX.

Organized and Clear

Output should also display results in a simple, organized fashion that makes subsequent design directions obvious. Reams of computer output or tables predicting the performance of each pump and fan require that the designer spend time reducing output to a usable form. Graphic output is most easily grapsed, and will readily indicate where and when peak loads exist.

Integrated

PHYSICAL MODELS

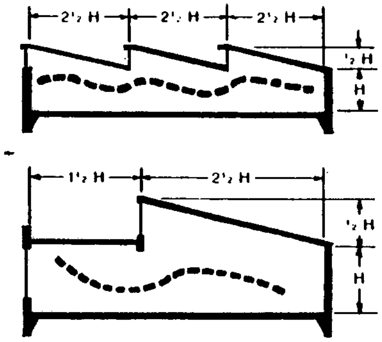
The best design tool for assessing the quantity and quality of light is a physical model. Light performs in models exactly as it does in full-sized environments, provided the architectural surfaces and details are accurately replicated. These details include the scale and geometry of spatial elements, window openings, texture, reflectivity, transparency, and opacity of key finishes. Color is important insofar as reflective properties are concerned. Transmission properties of glazing can be simulated, or described by numerical factors if the openings in the model are left uncovered.

The scale used for daylighting models can range from 3/4 inch = 1 foot, suitable for the study of single rooms, to 3/8 inch = 1 foot, generally suitable for larger configurations. Smaller models are difficult to detail and therefore are not recommended for room studies, although they may be appropriate for very large spaces.

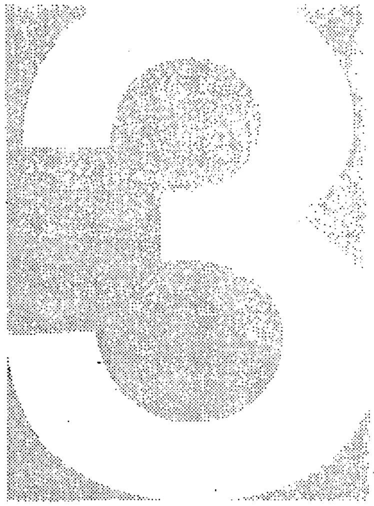
Use of models in the design of the State Security Bank resulted in dramatic design changes. It showed that in the early designs, uniformity of light needed to be increased (by adding sidelighting), that view was desirable, that the available daylight was overestimated. It told the designers that neither a fixed nor an operable shading/baffle system was best, but that a combination was optimum. Finally, the daylighting system could provide not only ambient light but the majority of task lighting as well.

Finally, the design tool should be comprehensive, integrating the various energy end uses. Output which tells the designer that his clerestory reduces artificial lighting needs by 30% but neglects the effects on heating and cooling leaves him more work since he still must calculate these effects. In 1981, most designers in the program used physical daylighting models to determine the quantity and quality of light. There were no quick programs to measure heating and cooling interaction, so mainframe programs (BLAST, TRACE, TRNSYS) were used to do this later.

The best design tools were described by one design team as those that "produced rapid energy snapshots of the project as it took shape on the designer's desk." Such tools led to design changes that, if postponed to design development, could not be easily incorporated. The designers of the Wells State Security Bank switched from a high mass to a low mass structure due to design tool feedback. The designers of Walker Field Terminal Building in Grand Junction, Colorado, dispensed with nighttime thermal storage once their output showed nighttime building loads lower than anticipated. If these developments had occurred later in the design process, the major structural changes would have been more difficult to make.



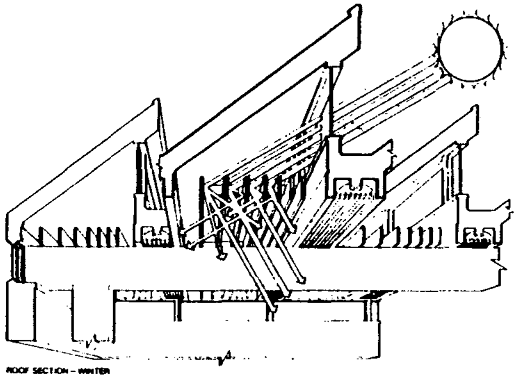
INTERIOR LIGHT LEVELS



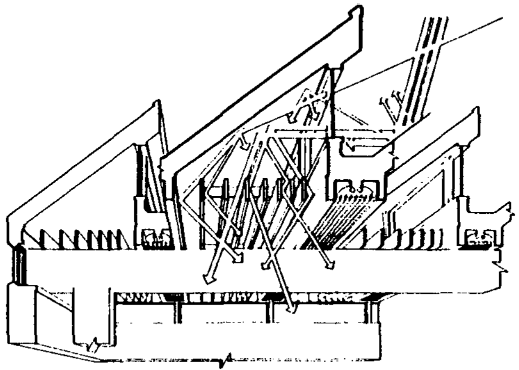
SCHEMATIC
DESIGN

SECTION III: SCHEMATIC DESIGN

A. Choose simple design solutions which address the major parts of the energy problem.



ROOF SECTION - WINTER



ROOF SECTION - SUMMER

DAYLIGHT ROOF MONITORS
MT AIRY PUBLIC LIBRARY

By examining the energy problem and available environmental resources identified during the programming phase, a basic palette of solutions can be identified. In this idea generation stage, focus on those solutions which appear to offer the best answer to the combined architectural and energy requirements of the project. When an element of the building can be used to satisfy multiple functions, economy, and overall building quality are improved. The solutions identified for development should be simple, realistic alternatives which avoid overly complex control requirements or which depend extensively on the actions of occupants for their success.

In this program, many different approaches were taken to arrive at schematic design solutions. In Princeton Professional Park, a medical office building, circulation requirements suggested a double-loaded corridor arrangement. This led to the development of a basic building cross-section which used the circulation space as a solar atrium. In the Security State Bank, simple physical models were used to explore alternate building forms that incorporated daylighting without aggravating heating and cooling loads. In the Mt. Airy Library, daylighting roof monitors which had been successfully used on a previous project were adapted to the requirements of this project.

The design alternatives should be carefully evaluated using either simple calculation techniques or quickly constructed physical models to gain an understanding of the relative success of the alternatives. Unless the project requirements are very unusual or complex, avoid the use of analytical techniques which require extensive, sophisticated inputs, or which are costly to use. At this stage in the design, the objective is to be sure that the potential design solutions meet the objectives established during the programming phase. Precise quantitative results are not as important at this stage as general indication of the energy results.

B. Pay close attention to system integration issues.

Perhaps the easiest and most likely way to get in trouble with energy-conscious design is to consider individual system performance in isolation. All design strategies have implications for other building systems and functions. This is especially true for passive, conventional HVAC, and lighting systems. Every building in the program was faced with the issue.

The St. Mary's School addition in Alexandria, Virginia provides just one example of the attention required to address the complexity of interacting building elements. The successful operation of the entire heating system involves the simultaneous interaction of the Trombe walls, the two linear roof apertures, the thermal storage mass contained in the floor slab and walls, and the mechanical system. Interior and exterior awning windows are provide for the various heating and cooling modes.

In the heating mode, solar apertures collect energy during the day which is stored in the building mass or allowed to stratify at the ceiling. Heating units turn on only when pre-heated air at the ceiling is unavailable. In the summer, ventilation air is pulled from the north side over the gym floor with the natural convection cycle induced by the rising hot air in the Trombe wall cavities. Roof fans assist the venting of warm air to the outside. When mechanical refrigeration is necessary (for assemblies of over 20 people only, according to the designers), interior and exterior awnings and windows are readjusted to check the natural convection cycle.

It is apparent from the above description that systems integration must receive close attention from the start, and that integration issues are not limited to mechanical systems. A given passive solar strategy can potentially affect virtually all building systems and functions from structure (massive vs. light frame) to finish (color, texture). A highly effective daylight aperture can become just another source of glare if surface contrasts are incompatible. The designer must think through all implications so that final decisions do not become future problems.

C. Choose architectural features that have multiple functions.

SOLAR SPACES AS FUNCTIONING ELEMENTS

Solar spaces such as atriums and "greenhouses" work best if they serve another important function. Not only do sunspaces add interest, but become more cost-effective if their benefits include more than energy reductions. For example, the RPI Visitors Information Center and Colorado Mountain College use sunspaces not only as solar collectors, but also as organizing circulation elements. Persons enter into dramatic spaces illuminated by direct beam sunlight creating light and shadow that change over the day. Princeton Professional Park is organized around a light and heat-collecting spine that transforms what might have been a banal corridor into a tree-lined walkway which is a major selling point for potential office tenants. Though amenities such as generous circulation or atmosphere cannot be easily assigned a dollar value, their practical and aesthetic benefits may be the difference that makes or breaks passive solar.

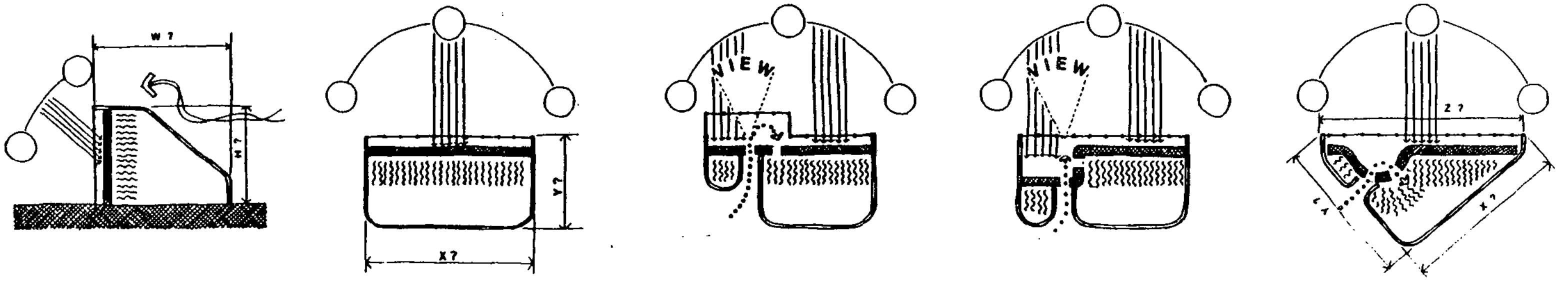
Often, the only way to economically justify passive solar features in a building design is to use them for several energy and/or physical functions. Fraker's Princeton Professional Park design provides a clear example of this strategy.

According to architect Fraker, the speculative office building developer's cost constraints meant that from the beginning only simple solutions would be investigated. "There just wasn't room in the budget for anything fancy like ice ponds and photovoltaics," Fraker observed. "We had to focus on simple things we could do to either the form or the envelope. Our other principal discovery," Fraker explained, "is that the more applications we could find for one basic concept, the more cost-effective the concept became. Take our idea for an atrium. If we used it only as expensive circulation space, it was certain to get rejected. However, if we included it as part of the lighting scheme and part of the heating and cooling systems as well, the cost was a lot more justifiable."

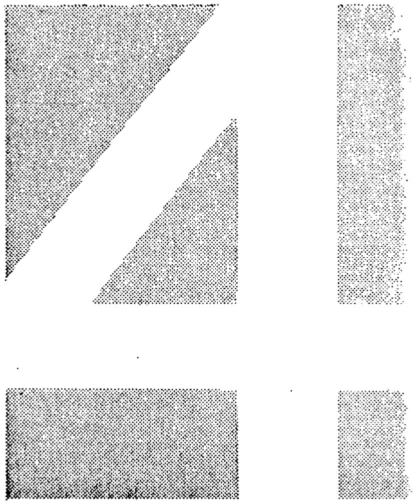
D. Develop the potential amenities associated with passive solar features.

Some aspects of certain passive solar strategies can be viewed as either liabilities or attributes. High ceilings and extra glazing can just be expensive or they can become valued features in a building, depending on how they are treated. The award-winning* Shelly Ridge Girl Scout Center in Philadelphia, Pennsylvania is an excellent example of the thorough refinement of passive features into obvious building amenities. The designer designer was able to transform a mundane Trombe wall into an undulating building element which created an interesting progression of spaces, heightening the senses of entry and arrival.

The solar wall, the dominant energy feature of the Center, received a great deal of analytical attention and underwent quite a few design revisions. The first variation of the basic sprung from a desire to integrate the building the entrance with the passive solar elements. The logical entrance to the building would be from the northeast or northwest, but a visitor entering from that direction would not be exposed to or involved with the solar wall. The design solution to that problem involved breaking the solar wall to permit an entrance sequence that brings the visitor through the solar space. The entrance sequence would help the visitor experience and understand the solar design as well as enjoy the scenic views to the south. A refinement of that concept produced a meandering solar wall that maintained the building's compact external surface area, and brought the heating element closer to the north walls for better heat distribution.



DESIGN REVISIONS
SHELLY RIDGE GIRL SCOUT CENTER



DESIGN DEVELOPMENT

SECTION IV: DESIGN DEVELOPMENT

A. Select a design tool which permits refinement of the schematic solution.

One of the objectives during the design development phase is to size components of both the conventional and solar systems for the building. This makes determination of the rate, quantity, and quality of energy flow important. For example, the Trombe wall may have stored a certain quantity of energy, but the rate at which that energy may be distributed and the temperature (or quality) of that heat are an important determinant in maintaining thermal comfort. More sophisticated analytical techniques which are capable of addressing these questions are now appropriate.

An examination of the potential for overheating, overcooling, or overlighting spaces should also be made at this stage. Such fine-tuning can often be achieved by properly sizing building components. For example, on the Mt. Airy Library, large quantities of concrete were exposed on the interior of the building to provide thermal mass which would store heat and moderate internal temperature swings. Thus, the building does not overheat during warm afternoons, but some comfort problems have been reported on cold winter mornings because the thermal mass cannot be heated quickly, after the mass has cooled off at night. Give consideration to the overall result of sizing a particular element so that the solution to one problem (such as overheating) does not create another (such as sluggish morning warmup).

THERMAL MASS

Both high mass and low mass buildings work well, but each must be examined carefully with respect to climate and building use. High mass buildings work well:

1. Where there is extended evening and weekend use, (Mt. Airy Library, Shelly Ridge Girl Scout Center). Such schedules can then take advantage of stored heat.
2. In sunny climates (Mt. Airy). Solar energy then can charge the mass.
3. With high cooling load (Mt. Airy, Community United Methodist Church, Comal County Mental Health Center). High mass absorbs heat gains.

Low mass buildings work well:

1. Where building hours follow typical 40 hour/week schedules (State Bank, Princeton Professional Park). In other buildings, night and weekend setback may contribute higher savings than does thermal mass, which dampens setback temperature savings. In general, setback is difficult in high mass buildings because the heating systems must recharge the mass before the buildings open. Occupants feel cold with cold walls and floors even though the air temperature is sufficiently high.

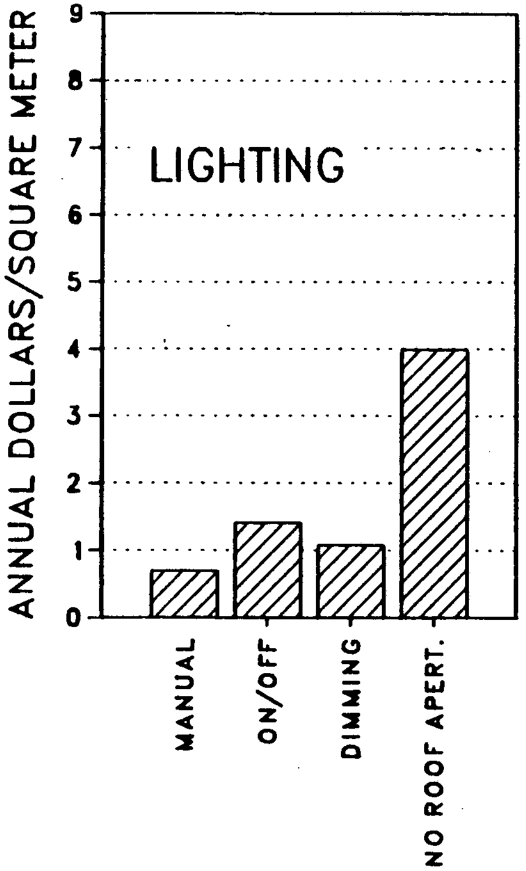
2. <u>In cloudy climates</u> (State Bank, Alaska Two Rivers School). Solar energy should meet the instantaneous heating load before being stored in thermal mass. Thus, with limited solar energy, storage becomes less important.

3. <u>High volume buildings</u> (St. Mary's Gymnasium, Philadelphia Municipal Auto Shop). High ceilings can be used to collect excess heat which can then be vented, thus minimizing cooling loads, or ducted to floor level, thus minimizing heating loads.

B. Integrate solar and conventional systems control strategies.

Whether the sequencing of building operations depends on manual or automated control approaches, the integration of the various elements must be carefully considered. For example, if large amounts of thermal mass are incorporated in the building, consider minimizing night setback temperature strategies which may make it difficult to achieve thermal comfort quickly during cold mornings.

If daylighting is an important element of the design solution, consider carefully the way in which artificial lights will be controlled. Manual control of the artifical lights can be effective if a small group of



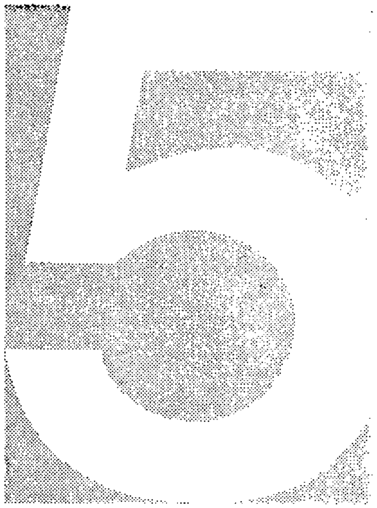
LIGHTING CONTROL ANALYSIS
MT AIRY PUBLIC LIBRARY

highly motivated users retains control. In fact, in some buildings in this program, manual control of lthe artificial lights proved to be more effective than automated dimming or switching devices would have been.

Try to avoid control operations which are counterintuitive to the occupants. For example, while closing fireplace doors may limit flue losses, it is not a natural response by people who wish to experience the fire's warmth.

The control sequences which are selected should be carefully documented for inclusion in the building operating manual. Be sure to specify the signals which are expected to lead to specifc actions on the part of building occupants, and explain those control sequences in clear, concise terms. Try to avoid control schemes which may conflict with each other. For example, Essex Dorsey made use of insulating panels to control heat loss which, unfortunately, restricted the amount of natural light. Similarly, blinds opened for solar gain cannot be expected to shield occupants from glare.

Finally, consider increasing temperature control tolerances in room and equipment thermostats. Since conventional heating systems address comfort requirements by short-term inputs of a large quantity of high temperature heat, excessive short-cycling to maintain tight temperature ranges can depreciate the slow steady heat available from passive elements.



CONSTRUCTION DOCUMENTS

Section V: Construction Documents

A. Bid documents should serve as a performance specification for evaluating product options.

Although plans and specifications may be tight, this does not mean that specific products should be called out in all instances. Such a prescriptive approach denies the contractor the leeway for maximum performance at minimum cost. Much more appropriate is a tight specification that spells out exactly how well the system is to function. An example would be, "Thermostats shall provide temperature control within a 2°F throttling range and accommodate both heating and cooling functions with an adjustable deadband of 8°F." When this performance criterion was initially omitted from the Gunnison Airport and Blake Avenue College Center specifications, single point thermostats were installed in swing spaces where energy savings depended on the diurnal temperature swings.

B. Call out and specify components carefully.

Conventional Versus Solar

Most building contractors will assume conventional building practice unless told otherwise, and then they still tend to do what they are accustomed to doing. At Gunnison Airport, the electrician wired the exhaust fan to the boiler circuit because it was the most convenient circuit available. As a result, the exhaust fan would not operate in the summer when the boiler had to be shut down at the main breaker. The designer of Princeton Professional Park failed to specify how foil-faced batts would be installed between roof joists. The contractor, accustomed primarily to above-ceiling installation, did not tape the joints. The water vapor which passed through condensed on the metal deck and dripped back into the conditioned space.

Altering Equipment

The designer should caution the contractor not to alter conventional mechanical equipment to fit solar control specifications. In Mt. Airy Library and Princeton Professional Park, the designers originally intended to optimize building performance by opening the heat pump and monitoring the position of certain valves. Upon learning that this would invalidate the equipment warranties, they changed to a strategy of monitoring interior air temperature as an indication of heating and cooling energy use.

Test and Balance

Although the testing and balancing of mechanical systems is usually specified for commercial-scale buildings, it is even more important when they rely on passive solar systems. For example, when mechanical cooling is introduced into a building to supplement natural ventilation, the fans either reinforce or fight natural air flows. The competent designer will design for the former, of course, but testing and balancing will ensure that his design intentions are indeed realized.

For example, at Mt. Airy Library, zones which are lower in elevation require more heat and less cooling since air stratifies according to temperature. The exact quantities are difficult to establish during design, and so adjustments must be made during test and balance.

Other systems besides the HVAC system may need fine-tuning; the designer should anticipate and provide for this. Automatic passive solar controls for night insulation, shading devices, and fans are cases in point. Before the testing and balancing, the photocell-controlled awnings in the State Security Bank opened and closed every few minutes due to short cycling. Although this is not easily quantified during design, a good test and balance would make the necessary refinements.

Troubleshooting

It is a fine line that separates testing and balancing from troubleshooting start-up problems; one activity often flows into the other. The latter usually extends into the break-in period for a new building, a duration of up to a year after the building is turned over to the owner. Difficulties during this time can be minimized if the designers specify sufficient ports for measuring fluids and thermometers for checking critical temperatures. Clear labels for switches, valves, and flow directions are also helpful, as are submeters for systems where problems leading to excessive energy consumption may lurk. For example, at Comal County Mental Health Center, all mechanical systems appeared to be operating properly immediately after installation. Each furnace put out its rated capacity when individually fired. But during the first heating season, the utility meter showed far less gas consumption than suggested by a run-time meter [illegible] technical monitor hypothesized that perhaps something was limiting natural gas flow to the burners. Indeed, when the owner checked the gas piping against the drawings, he found the diameter less than half that specified in the drawings. This, of course, results in a combustion that is too lean, and leads to a decrease in combustion efficiency. In at least five other projects, such submetering led to the resolution of initial start-up difficulties early after they were detected.

Training

Specifying training of building personnel is also standard practice in non-residential buildings, but must be specified more explicitly when energy performance is a measured criterion for the success of the building. Such specifications should include a designated time and duration of training, required attendees, topics to be covered (which include start-up, short-term and annual maintenance procedures, and elementary troubleshooting), and technical assistance during the first few months of building shakedown. At the training, comprehensive operating manuals should be distributed; they should have already been approved by the A/E team like any other shop submittal. The manual should include cut sheets on each mechanical components, as-built mechanical drawings, and schematic diagrams of all major control systems. If the design intent is for non-maintenance occupants to operate the building, they should be trained as well. At Princeton Professional Park, energy consumption was substantially lower in many of the rental suites following a user orientation session. At Shelly Ridge Girl Scout Center a similar session resulted in a decrease in energy consumption of one-half. These significant reductions underscore the need to specify such training sessions and hold the contractor to them before final payment.

6

CONSTRUCTION & BUILDING ACCEPTANCE

A. Monitor construction to insure quality.

On-site inspection throughout the construction process is traditionally part of the design team's responsibility. There are, however, a number of areas that merit special attention if the design team is attempting to achieve an energy efficient building. Specifically, the architect should check the integrity of the building envelope. Air leakage is a common reason that buildings fall short of their potential for energy efficiency. Areas that merit close inspection are the continuity of insulation and the integrity of air/vapor barriers, both of which tend to receive less than careful attention from contractors not specializing in solar construction. The mechanical engineer should check ductwork for air tightness and proper insulation. Excessive leakage will make it difficult to balance the HVAC system; furthermore, leakage occurring in the wrong areas could lead to excessive energy consumption.

Finally, lighting equipment should be checked, especially for the correct ballasts and fixtures. At times, high efficiency ballasts are specified but not delivered. Also check that fixtures are installed in the proper places. A lighting strategy that mixes high efficiency and regular fixtures can be confusing to or ignored by installers.

In the program, these lessons are best illustrated where contractors installed conventional materials and components that served solar purposes. At State Security Bank, specified glazing was replaced by another which did not have as high a transmissivity. The solar consultant for Gunnison Airport performed lengthy calculations to optimize a Trombe wall thickness at 12 inches. When the wall was formed, however, the contractor found some existing 14 inch forms on site, so he increased its thickness by the extra two inches for free without realizing the thermal consequences. In most cases, though, careful construction was encouraged throughout the program; for example, the Community United Methodist Church is even tighter and more comfortable than predicted due to the care and attention to detail provided by the builder.

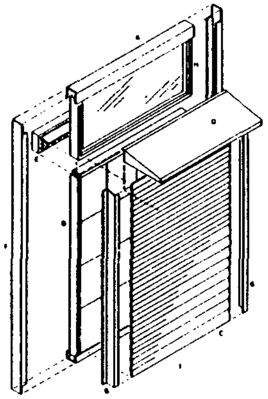
B. Consider post-occupancy performance monitoring.

Very few buildings achieve maximum energy performance within a year of their construction completion. Buildings are not like store-bought products which due to their mass production can be used immediately at rated capacity with full confidence. Clients do not fully realize this, and in fact may blame the designer for normal start-up problems.

The delicate integration of passive solar and conventional systems creates even a greater need for post-occupancy monitoring and fine-tuning than in non-solar buildings. Innovative systems such as the window insulating systems at Johnson Controls or the window shading at Princeton School of Architecture and Urban Planning can be subject to short cycling, damage by uninformed users, and maladjustment by contractors unfamiliar with the intended control strategy. Occupancy may have changed since the design of the system. For example at the State Security Bank, a storage room was turned into an automatic check-cancelling station with two operators. It is no surprise that they complained of air stuffiness until the ventilation system was readjusted.

RETROFITS

In retrofits, conservation measures should precede passive solar, and should be reflected in the base case building. Those passive solar measures that are still cost-effective will probably address a predominant heating problem since architectural lighting modifications are more difficult. Heat can be collected by components (Philadelphia Municipal Auto Shop, Princeton, SAUP) or by building additions, usually in the form of sunspaces (Kieffer Store). The latter strategy becomes more justifiable if the addition serves some other useful purpose that can accommodate high temperature swings. These include atriums, entryways, and greenhouses.



WINDOW RETROFIT
PHILADELPHIA MUNICIPAL AUTO SHOP

All of these examples of necessary fine-tuning are reasonable for any building owner to expect within the first year of building operation. In this year, all seasonal modes of operation will have occurred and problems identified. The architect who offers post-occupancy debugging services is not trying to cover for a bad design; he simply wishes to make building shakedown less trying and minimize disruptions to the functions the building houses.

RESULTS AND FUTURE DIRECTIONS

The Non-Residential Experimental Buildings Program has generated a rich and diverse collection of lessons and experiences in passive solar design. What has resulted from all of this effort, and what kinds of issues pertinent to future design research have emerged?

Of the 22 buildings designed, 19 were constructed and are yielding performance data which is documented in a series of case studies and in a companion performance overview, both to be published in 1985. Analysis of the energy savings, economics, and occupant satisfaction has shown the stakes to be high. Overall performance has been excellent, with program buildings using 47% less energy than their conventional counterparts on an area-weighted average. Most did not cost more to build than non-solar buildings of similar type and occupants satisfaction was, in all cases, higher than average. Certain buildings' performance was particularly outstanding, demonstrating utility costs as low as $.15/s.f./yr., while others encountered architectural and mechanical problems that kept performance not much higher than base building levels. In either case, results could be traced back to the design, expecially the design's flexibility for accommodating changing building uses.

Apparently, designers must ask more "what if" questions, but answering such questions is still not easy. Since 1980, little progress has been made on developing easily used design tools for non-residential buildings. Those that exist often require that the designer interrupt the creative process to generate performance feedback. One solution to this problem is an energy design tool that piggybacks with computer-assisted design and drafting (CADD) systems which are becoming more and more prominent as a professional offering.

From the schematic design on a CRT, an architect could be able to quickly retrieve heat gains, heat losses, natural lighting levels, shading factors, and the like, for various climatic conditions and operating schedules. Results can appear graphically as overlays on the working sketches. Such an "energy/graphics" option could offer various levels of complexity to correspond with progressive design phases, each one requiring and yielding more detailed information. It could also allow the architect to focus on specific building components such as overhangs and Trombe walls when the particulars of shading, sizing, and timing need attention.

With more sophisticated design tools, the architects can quickly answer questions that were identified in this overview as crucial. What happens to the success of a particular schematic design for a school: If the administration decides to offer night classes? If the building staff fails to operate the shading as instructed? If a new building goes up across the street? If a bid option of carpeting is accepted?

Design tools are but one issue of many that arose by the conclusion of this program. Its participants will agree that the program probably raised as many questions as it answered. Rather than providing the definitive answers to the question, "How should a passive solar building be designed?", the program has shown that there is still much room for making the process more efficient and for making the product more successful.

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