

**COMMERCIAL BUILDING DESIGN:
INTEGRATING CLIMATE, COMFORT, AND COST**

**BURT HILL KOSAR RITTELMANN ASSOCIATES
MIN KANTROWITZ ASSOCIATES**

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In 1979, the U.S. Department of Energy issued Program Opportunity Notice DE-PNO2-79C30142, (Passive Solar Commercial Buildings Design Assistance and Demonstration). This was in support of the Solar Heating and Cooling Demonstration Act (P.L. 93-409). The information in this book is largely based on the results of this program and on the individual building projects which were included.

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INTRODUCTION

Integrating climate, comfort, and cost concerns into a well-designed commercial building is a challenge for designers, consultants, and clients. While no solution is perfect, it is possible to reach an appropriate balance among these factors to solve each building problem. Climate-responsive buildings, designed with a careful understanding of the interrelationships among functional demands, cost constraints, and climate-related opportunities, often achieve this balance because of a unique and careful design process. This book describes that design process, presents a number of case-study buildings, and analyzes performance in terms of cost, occupant satisfaction, and energy use. By understanding the lessons learned through these buildings, this approach can be applied to new design problems.

How well do climate-responsive commercial buildings work? Concern about building operating cost has fluctuated dramatically within the past few years, along with changes in the price and supply of electricity and fuel. Yet organizations and institutions that use commercial buildings must plan for the long-term lives of buildings, lives in which operating costs will continue to affect profitability. Designing and constructing buildings that carefully use energy by being "climate responsive" makes sense over the long term of building life, whatever the current costs of auxiliary energy. But there are questions: How well do climate-responsive, nonresidential buildings actually work? Do they really save money? What design strategies work best? Do occupants' needs for comfort interfere with building function? This book answers those questions through in-depth examinations of a diverse group of buildings, from design and construction through evaluation of energy, cost, and occupancy performance. Analyses are based on field tests of actual buildings in use, and constitute the largest known data base for evaluating the design, cost, and performance of new and retrofit climate-responsive, nonresidential buildings.

While each building is unique, designs can be improved by analyzing experience. Every new building or retrofit is designed to resolve its own unique set of problems, opportunities, and constraints. No one building ever totally solves the problems presented by another, but lessons learned from approaches and concepts tried in one building can incrementally help improve the design of others. This is particularly true for climate-responsive, nonresidential buildings, where the interaction among climate, comfort, and cost increases the challenge of good design.

The purpose of this book is to help architects, engineers, and builders produce better climate-responsive, nonresidential buildings, by presenting new and useful information about a group of innovative energy-efficient buildings that have been thoroughly field-tested. This diverse group of passive solar nonresidential buildings, with their different climates, functional programs, organizational contexts, financing, designers and construction techniques, employs a wide range of experimental approaches. In analyzing building design and building performance, this book describes the most successful approaches as well as the less successful ones, in terms of design, construction costs, energy use, and occupant satisfaction.

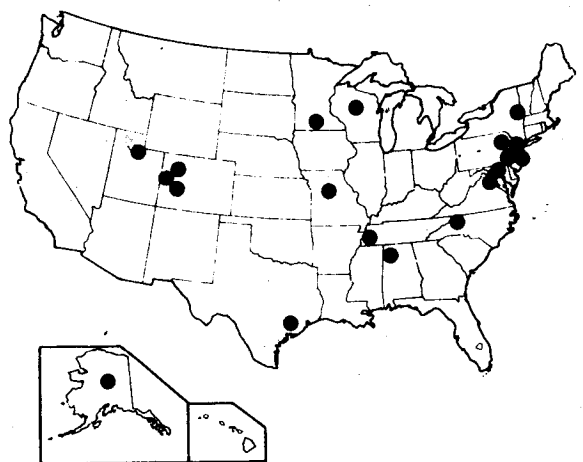
By systematically examining how buildings are designed and operated under a real world set of conditions, the authors hope to inform the next "generation" of climate-responsive design. What worked well and what is worth repeating? What is a good idea, and does it need to be refined? What experimental approaches experienced consistent problems? How

can these problems be solved in the future? The answers to these questions can guide designers, clients, and users toward energy-conserving buildings that are better in their energy performance and in their support of human activity.

The "Problem": Skepticism about nonresidential, climate-responsive design. Early attempts at climate-responsive design were almost entirely residential in scale, and directed at certain highly motivated pioneers, i.e., those who would tolerate large temperature swings and peculiar-looking buildings in return for direct financial savings and the satisfaction of publicly demonstrating their commitment to a resource-conservative philosophy and life style. Nonresidential buildings were assumed to be unlikely candidates for energy-efficient or passive solar technologies because of their high internal heat gains, large volume, and rigid environmental conditions. Furthermore, solar heating and daylighting were expected to increase cooling loads, which were already considerable. Thus, the design approaches for residential design were deemed inappropriate for larger, more complex buildings. One reason was the concern about technical building performance under the demanding and relatively inflexible programmatic requirements of the work environment (e.g., stringent requirements for a narrow comfort band, fixed working hours, and workstation locations). Another was uncertainty about how building users would respond to climate-responsive buildings in which they had no direct "stake" (e.g., no direct financial pay-off, no philosophical commitment, and no "pioneer" spirit). The questions became, "Can people who don't stand to benefit directly from financial or philosophical rewards be satisfied in energy-efficient, passive solar buildings and can these users successfully learn to operate these dynamic, flexible buildings to optimize energy savings?"

The "Solution": Examine the potential of energy-efficient nonresidential buildings through design and field testing. In 1979, the U.S. Department of Energy (DOE) instituted a large design development and field test program in response to these questions. The program, the Nonresidential Experimental Buildings Program, was intended to build a body of practical information on the design, construction, and performance of nonresidential, energy-efficient buildings and to investigate the potential of passive solar technologies to meet commercial building energy requirements. The program is the largest known attempt to guide design and simultaneously evaluate construction and operational costs, actual energy use, occupancy effects, and reactions in climate-responsive, nonresidential buildings. There were three phases in the DOE program: design, construction, and performance evaluation. Over 300 building owner/designer teams applied to participate in the program, but only the best 35 were selected. Of these, 22 buildings located across the country completed design; 19 completed construction.

PROJECT LOCATION MAP



Design Process: In the design phase, each project team established a "base case" building, a nonsolar building which the owner would ordinarily build. Team members calculated heating, cooling, lighting, and other energy requirements, taking into consideration internal loads, building occupancy, schedule, climate, and construction practices. Teams then developed an alternative design, using passive solar approaches to heat, cool, and light the building, and calculated the design's performance using a variety of energy- and cost-prediction tools. The tools ranged from complex mainframe, energy-simulation programs like BLAST (Building Loads Analysis and System Thermodynamics) to simpler, hand-calculated procedures. A panel of technical experts reviewed these project designs in a series of meetings. The review was aimed at ensuring that designs effectively integrated strategies for passive cooling, lighting, and heating with each other, the building, and the auxiliary mechanical and lighting systems. The review provided valuable feedback from the earliest stages in design through final preparation of bid documents. Twenty-two building teams completed the design phase.

Building Construction: In the construction phase, incremental costs associated with the energy systems were identified. While a portion of those costs were reimbursed through DOE cost-sharing funds, actual building construction costs were obtained by the organizations and institutions for whom the buildings were being designed. As a result, only 19 buildings were actually completed. Photos and logs of the construction process for these 19 buildings identify issues, problems, and processes that are unique to the energy-efficient designs and that might be applicable to other buildings in the future.

Performance Evaluation: The final phase, performance monitoring, included one complete year of monitoring actual cost and energy performance in each building. The evaluation was intended to provide information about these basic hypotheses:

- Actions of the building's occupants can help reduce building energy requirements.
- Inclusion of passive solar features enhances the ability of the building's occupants to perform their job responsibilities.
- Operating costs for these buildings will be significantly lower than for comparison buildings.
- Use of passive solar features reduces auxiliary fuel requirements for heating, cooling, and lighting.

To test these hypotheses, information was gathered each week from each building about actual energy use (disaggregated by fuel type and end use), occupancy patterns and conditions, weather, and energy costs. By comparing monthly patterns to those predicted for both the base case and the innovative building, the project team and technical monitors could analyze the basic patterns of building energy use.

Monthly logs completed by building managers, and questionnaires completed by both full-time and part-time building users also yielded qualitative information about how users responded to and interacted with the building's passive solar components. Twelve building teams completed a full year of performance evaluation.

THE BUILDINGS

The 19 completed buildings constitute varied responses to a wide range of design constraints and opportunities. Each design team faced a different climate, program, client, budget, and site. Yet each unique building design used passive solar and advanced energy conservation techniques to meet a significant portion of the heating, cooling, and lighting loads. Brief descriptions of the buildings follow.

The RPI Visitor Center, a 5,200-ft² office and police headquarters in Troy, New York. The building is designed to welcome visitors to the campus and serve as headquarters for campus police and other offices. It relies on a south-facing sunspace with mass walls and floor to supply warm air to the building through a system of plenums. Skylights with reflectors provide daylight and direct gain. Insulating shutters and curtains, and earth berming are also used.

Mt. Airy Public Library, a 13,500-ft² community library in Mt. Airy, North Carolina. The building is located on a hill next to City Hall, which is built of local white granite. While some direct gain through south-facing glazing is used, the strongest solar design feature of the building is the set of south-facing, sawtooth clerestories and light baffles that line up in rows along the central portion of the building. The feature provides diffused daylight to the central areas of the building.

St. Mary's School Gymnasium, an addition of a 9,000-ft² gymnasium to an existing school in Alexandria, Virginia. In response to varied times of occupancy, the delivery of radiant heat is phased to the interior of the building. This was accomplished by constructing the thermal mass in the concrete ceiling-to-floor Trombe wall in three different thicknesses.

Security State Bank, an 11,000-ft² bank in Wells, Minnesota. The building is used only during banking hours. It was designed to make direct use of solar gain through south-facing glazing, rather than having large amounts of thermal mass capture and store heat for later use. A large, south-facing clerestory with a baffle diffusion system provides abundant natural light.

The Essex-Dorsey Senior Center, a 13,000-ft² multipurpose senior center in Baltimore, Maryland. The center was housed in two Victorian schoolhouse buildings until this major renovation connected them and added needed lounge and multipurpose areas. A south-facing clerestory on the new wing provides daylighting and aids natural ventilation.

Shelly Ridge Girl Scout Center is a 5,700-ft² two-story, open-plan community education facility located near Philadelphia, Pennsylvania. Warmth is delivered throughout the day by selectively using direct gain and a Trombe wall in this compact, high-mass building.

Two Rivers School, a 15,750-ft² elementary school outside Fairbanks, Alaska. The building includes an experimental passive solar classroom originally designed to be a prototype of a small rural schoolhouse responsive to Alaska's harsh climate, high energy and construction costs, and need to provide even tiny villages their own schoolhouses. In addition to other features, the prototype classroom is equipped with a special thermal shutter system over much of the south-facing triple glazing.

Blake Avenue College Center, a 31,900-ft² community college building in Glenwood Springs, Colorado. The center was sited on the steepest portion of a south-facing site. As a combination community college, community center, day care center, and senior center, a wide variety of functions had to be integrated into one building. A three-story, central atrium unifies the functions and collects solar heat, acts as a plenum for the cooling system, and is a bright central lighting core from which adjacent offices and classrooms borrow light.

Princeton School of Architecture building, a retrofit project of a 13,700-ft² architecture school building in Princeton, New Jersey. The problem of integrating new conservation and solar features in an existing building was solved through utilizing existing skylight openings for specially designed direct-gain heating and lighting roof monitors.

Johnson Controls Branch Office Building, a 15,000-ft² office located in Salt Lake City, Utah. The building is one of several branch offices of Johnson Controls, a large environmental controls manufacturing and distribution company. The building combines a sophisticated computer control system with relatively straightforward passive solar design using a combination of features for direct solar gain and enhanced distribution of daylight.

Community United Methodist Church, a 5,500-ft² educational addition to a community church in Columbia, Missouri. The addition is located in a climate with high summer humidity and only modest solar availability. The addition features clerestories with overhangs and insulating shades and thermal mass in a relatively simple but effective configuration.

Princeton Professional Park, a 64,000-ft² speculative office building located in Princeton, New Jersey. The building illustrates how an energy-efficient building can be designed within the strict cost constraints typical for speculative office

development. A central atrium was designed to function as part of the heating, cooling, and lighting schemes, as well as part of the circulation between offices.

Kieffer Store, a 3,200-ft² addition to a retail store in Wausau, Wisconsin. A light and airy environment for retail shopping was created by using direct-gain sunspace for heating and lighting, and roof monitors.

Comal County Mental Health Center, a retrofit of a 4,800-ft² 1930s school building in New Braunfels, Texas. In order to preserve the historic appearance of the building, the energy-efficient features had to be integrated with the structure without significantly altering the building's exterior. In this hot, humid climate, a variety of defensive cooling strategies including an evaporative roof spray system became the major features of this cost-effective retrofit.

Gunnison County Airport, a 9,700-ft² airport terminal building in Gunnison, Colorado. The terminal is located in an area with a harsh, cold climate and expensive electricity. It uses a large thermal storage wall in tandem with an air distribution system and automatic night insulation to meet the large heating load.

Philadelphia Municipal Auto Shop project, a retrofit of a 57,000-ft² warehouse-like auto maintenance facility in downtown Philadelphia. An innovative solar window heater module was developed to replace the large expanse of existing south-facing windows, which had been a source of large infiltration losses.

Walker Field Terminal, a 66,700-ft² airport terminal building. It is the largest structure in the program and is located in Grand Junction, Colorado. Much of the energy needed for heating and lighting is provided by the prominent series of stepped, south-facing clerestories on the roof.

Touliatos Greenhouse, a 6,000-ft² commercial greenhouse building located in Memphis, Tennessee. Using direct gain through vaulted skylights and windows in a double-shed design, this greenhouse depends on biomass decomposition for auxiliary heat.

Abrams Primary School, a 27,400-ft² elementary school located in Bessemer, Alabama. The primary design feature is a set of water-filled PVC tubes mounted below the roof monitors and used to store heat as well as to diffuse sunlight and prevent overheating problems from direct solar gain.

ANALYZING THE PROCESS

This book is organized to help readers learn from the experience with and analysis of these buildings. The concept of carefully analyzing the process of design, construction, and operation of a building to learn how it actually functions when occupied is simply to do systematically what architects and/or designers have done informally in the past: observe the successes of the past and the exemplary work of peers and learn from them. This book consists of four chapters to support that learning process. A brief discussion of those chapters follows.

Chapter 1: The Design Process describes the most important building design issues encountered in design, construction, and evaluation of the 19 buildings. The chapter is an overview, designed to distill the experiences of all participants in the design phase of the program and to identify the common, predominant patterns emerging from the design processes. Recommendations about how and when to consider climate-responsive design alternatives are included.

Chapter 2: Building Performance discusses how well the group of buildings worked in terms of cost, energy use, and occupant satisfaction. The patterns show that, in general, climate-responsive approaches can provide substantial energy savings at little, if any, increased first cost. Performance parameters that contribute to 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 integration of those elements with conventional design issues. Other issues, such as climatic limitation and predominant building load are shown to be less important.

Chapter 3: Case Studies describes in detail eight of these climate-responsive buildings. Each case study introduces the particular design issues related to the building and presents the design process and construction details for the building. The case study characterizes the building's energy performance, construction and operational costs, and occupant response. Most importantly, it describes the interactions among these factors. Design and performance case studies are included for the following buildings:

- Mt. Airy Public Library
- Johnson Controls Branch Office Building
- Community United Methodist Church
- Security State Bank
- Shelly Ridge Girl Scout Center
- RPI Visitor Center
- Philadelphia Municipal Auto Shop
- Essex-Dorsey Senior Center

Chapter 4: Key Design Issues presents results of special, in-depth analyses performed to examine the sensitivity of building energy performance to a variety of design- and occupant-related issues. These include automatic-versus-manual control of lighting, effectiveness of different thermal mass configurations, interactions between thermal mass and thermostat setback strategies, energy versus impacts of different acoustic treatments, and the effects of occupant management of shading devices on building energy performance. The quantitative information presented in this chapter can be used to guide design decisions.

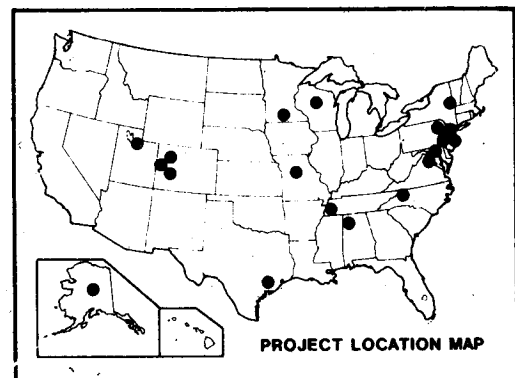
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The authors of this book come from a variety of educational and professional backgrounds, as do the readers. Thus the reader will notice differences in emphasis, style, and tone among chapters. It is hoped that this diversity in style will enhance the readability of the book.

THE DESIGN PROCESS

This chapter describes the most important building design issues encountered in designing, constructing, and evaluating the 19 passive solar buildings that are the subject of this book. The buildings encompass a broad spectrum of building types, climate locations, and design strategies.

The three phases in the Department of Energy (DOE) Nonresidential Experimental Buildings Program were design, construction, and performance evaluation. In the design phase, a panel of technical experts reviewed the project designs. The objective of the review was to ensure that designs effectively integrated strategies for passive cooling, lighting, and heating with each other, the building, and the auxiliary mechanical and lighting systems. These reviews provided the designers valuable feedback from the earliest design stage—when the greatest opportunities exist for saving energy—to the final preparation of bid documents.



	PASSIVE SOLAR STRATEGY										
	HEATING			COOLING					DAYLIGHTING		
	Sunspace/Atrium	Mass Floor	Mass Wall/Water Storage	Earth Contact	Natural Ventilation	Forced Vent/High Fueling	Shading Mechanisms	Evaporation/Radiation	Windows (More Nat. Light)	Lightshelves	Clerestories/Skylights
Two Rivers School											
Abrams Primary School											
St. Mary's 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											
Cornel County Health Ctr											
Gunnison County Airport											
Walker Field Terminal Bldg											
Phila. Municipal Auto Shop											
Touliatos Greenhouse											

SOLAR BUILDING DESIGN STRATEGIES

This overview distills the experiences of all design phase participants and identifies the common, predominant patterns emerging from the design processes. The observations and recommendations are intended to aid design professionals who have limited experience in the application of passive technology in nonresidential buildings. In 1979, at the outset of this program, most design professionals, including the 19 program architects, had limited experience. By the end of the program, the lessons they had learned greatly increased their understanding of passive commercial building design. The lessons are broad and apply both to passive technologies in particular and energy-conscious design in general. So that others may benefit, it is appropriate to document these lessons.

The contributors to this chapter recognize that design methods and procedures vary as widely as professional designers and the buildings they design. There is no single right or universal design formula to follow. Thus, the guidance presented in this chapter is broad and organized according to the traditional phases of the design process rather than the steps of a "how to" book. Building design occurs in the dynamic integration of various architectural issues; this chapter raises these issues and offers guidance on dealing with them—guidance rooted in both the buildings and design team experiences.

The three very broad and most important lessons to emerge from this program are:

- 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, which includes 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.