August 2000 • NREL/CP-550-28129

Conference Paper

A Case Study of the Energy Design Process Used for A Retail Application

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Presented at the American Solar Energy Society (ASES) Conference
Madison, Wisconsin
June 2000

National Renewable Energy Laboratory

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A CASE STUDY OF THE ENERGY DESIGN PROCESS USED FOR A RETAIL APPLICATION

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ABSTRACT

Designing and constructing low-energy buildings (buildings that consume 50% to 70% less energy than code-compliant buildings) require the design team to follow a process that considers how the building envelope and systems work together. The High-Performance Buildings Research Project at the National Renewable Energy Laboratory (NREL) developed a technique called the "energy design process." This process requires a design team to set energy-efficiency goals at the beginning of the pre-design phase. Detailed computer simulations used throughout the design and construction phases ensure that the building is optimized for energy efficiency and that changes to the design do not adversely affect energy performance. Properly commissioning the building and educating the building operators are the final steps to successfully constructing a low-energy building.

NREL's High-Performance Buildings Research project applies the energy design process in the context of real building projects. This paper defines the energy design process and describes how the process was used to optimize the design of the BigHorn Center, a retail building in Silverthorne, Colorado.

1. ENERGY DESIGN PROCESS

The National Renewable Energy Laboratory (NREL) developed the energy design process as a guideline for designing, constructing, and commissioning low-energy buildings. The design team must fully execute each step to ensure the successful design of a low-energy building (1). The process includes nine steps divided into three categories.

1.1 Pre-Design Steps

1. Simulate a base-case building model and establish energy use targets
2. Complete parametric analysis
3. Brainstorm solutions with all design team members
4. Perform simulations on base-case variants considering economic criteria

1.2 Design Steps

5. Prepare preliminary architectural drawings
6. Design the heating, ventilating, and air conditioning (HVAC) and lighting systems
7. Finalize plans and specifications

1.3 Construction/Occupation Steps

8. Rerun simulations before construction design changes
9. Commission all equipment and controls. Educate building operators to ensure that they operate the building as is intended.

2. THE BIGHORN CENTER

The BigHorn Center is located in Silverthorne, Colorado, at an elevation of 8865 ft (2700 m) and with 8246 base 65°F (4581 base 18°C) heating degree-days (2). It is a collection of retail spaces constructed in three phases. A catalogue retailer and two home improvement specialty stores make up Phases I and II. The Phase III building includes a 12,000-ft^2 (1115-m^2) hardware store, 5000 ft^2 (465 m^2) of offices and support areas, and a 22,000-ft^2 (2044-m^2) building materials warehouse. Both the retail space and warehouse are high-bay, open floor plans with small mezzanines. This paper focuses on the Phase III building design.

Step 1. Designers first created a base-case building that complied with 10CFR435 (based on ASHRAE 90.1-1989) (3,4). The base-case building has the same footprint area as the actual building and is solar neutral (equal glazing areas on all orientations). Infiltration in the base-case model was set at a constant rate of 0.5 air changes per hour (ACH) during occupied periods and 0.3 ACH during unoccupied periods. During occupied periods, the lighting was set at 2.32 W/ft^2, 1.34 W/ft^2, and 0.42 W/ft^2 (25.0 W/m^2, 14.4 W/m^2, and 4.5W/m^2) in the retail, office, and warehouse areas, respectively. Occupancy schedules were based on typical operation hours from an actual hardware store. The owner provided expected customer density data that were used to establish the air-exchange rates. Table 1 shows some of the base-case parameters.

TABLE 1: CHARACTERISTICS OF THE BASE-CASE BUILDING

Building Element	Value (USCS)	Value (SI)
Wall R-Value	16 ft^2·°F·hr/Btu	2.8 m^2·K/W
Window Area/Gross Wall Area	16%	16%
Window U-Value	0.32 Btu/ft^2·°F·hr	1.8 W/m^2·K
Window Shading Coefficient	0.69	0.69
Floor Perimeter Insulation R-Value	13 ft^2·°F·hr/Btu	2.3 m^2·K/W
Roof R-Value	23 ft^2·°F·hr/Btu	4.1 m^2·K/W

Designers simulated the base-case building and evaluated design strategies using the hourly building energy simulation tools DOE2.1e and SUNREL, a derivation of SERIRES (5,2,6). Designers established a goal to reduce energy costs by 60% as a result of the base-case analysis. The initial analysis showed lighting and fan loads to be the largest (Fig. 1). The design team also determined that daylighting and natural ventilation cooling strategies could substantially decrease these loads.

Step 2. Parametric analysis indicated that ventilation heating for the warehouse dominated the heating load. The high fan loads resulted from ventilation requirements and from moving heated air into the space. Internal gains from lighting and heat generated by fans created the only cooling loads in the base-case building.

Step 3. The design team, which included the owner, architect, engineers, and energy consultants, discussed options for reducing the energy loads based on the base-case and parametric analyses. Architectural guidelines established by the town included building height restrictions and a rustic exterior style. The Army Corps of Engineers placed restrictions on the site development due to the need to preserve wetlands. The owner was concerned about maintaining employee comfort and uniformly lighting the products.

Site-planning constraints forced a long, north-south building axis, contrary to typical passive solar building design. This constraint provided the opportunity for a north/south clerestory in the retail space and south-facing, sloped roof areas for building-integrated photovoltaics (PV) (Section 3).

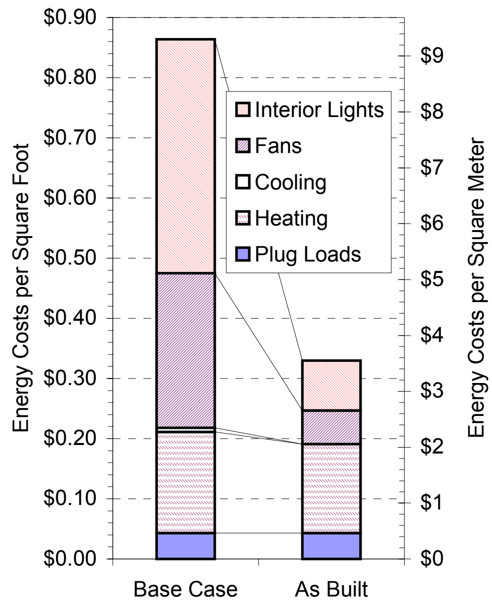

Fig. 1: Energy cost performance of the code-compliant base-case building compared with the as-built building.

Steps 4 and 5. Based on recommendations that resulted from the base-case and parametric analyses, project architects incorporated aesthetic strategies that would also maximize the building's daylighting potential. The total glazing area was engineered to minimize the sum of heating, cooling, lighting, and ventilation costs while maximizing daylighting availability and avoiding glare in the retail space. Daylighting enters the retail space through south- and north-facing clerestory windows, north-facing dormer windows, and windows on the east and west ends of the buildings. Overhangs over the south-facing windows block summer solar gains and help reduce building cooling loads.

Daylight enters the warehouse primarily through an east-facing dormer and translucent insulated ridgeline skylights (7). Providing daylight to the center of the warehouse was a more important design requirement than avoiding summer direct solar gain. In this particular case, the best design solution was to use skylights; however, it should be noted that this might not be the best solution in all climates and for all building types.

The daylighting distribution is improved by reflecting light off the bright white interior ceilings and walls. The hardware store floor tile is also white, to further brighten the space. Efficient compact fluorescent fixtures (controlled by a photo sensor centrally located in the retail space and a second sensor in the warehouse) provide auxiliary lighting when there is insufficient daylighting.

Step 6. After the envelope design had been optimized, engineers finalized the design of the building mechanical systems. Simulations indicated minimal summer cooling loads. Natural ventilation will offset these loads in the hardware store (Section 3).

The hardware store mechanical system features a hot-water radiant floor heating system. The system is divided into zones to provide flexibility in controlling the amount of heat supplied to various parts of the space. Priority comfort zones are identified where employees are working.

Two separate systems will meet heating loads in the warehouse. A transpired solar collector (TSC) will provide heated ventilation air, and an overhead gas-fired radiant heat system will offset the remaining heating loads. Customers will be allowed to drive vehicles into the warehouse to load product, which results in a high ventilation requirement in the warehouse. The large ventilation load combined with the long heating season in Silverthorne make the warehouse a good candidate for a TSC system (8, 9). Summer cooling loads will be handled simply by opening all the warehouse doors and operating the roof-mounted exhaust fans. The TSC system will operate only when heating is required.

Step 7. Architectural, mechanical, and electrical plans were finalized with input from the entire design team. By working together, all members of the team became more aware of the interactions between the building envelope and systems and better understood the importance of constructing the building as it was designed to meet the overall design goals.

Step 8. Many questions surfaced during construction, from insulation installation to the interaction of the energy management system (EMS) with the lights, windows, and HVAC systems. On-site inspections were made of these items. In addition, lighting zones for the stepped controls were determined in the field after the lights were installed to ensure uniform light distribution and proper interaction with the daylighting scheme. It was essential that the energy consultant stay in close contact with the electrical and controls contractors during construction.

Step 9. The building was nearing completion at the time this paper was written. Plans were in place for the energy consultant to provide workshops for the building employees on energy-efficient building construction and operation. These workshops will give the employees an opportunity to learn how to best use their new building as well give them information that they can use to better serve their customers.

3. SYSTEMS DESCRIPTION

Natural ventilation cooling. The summer average high temperatures in Silverthorne, Colorado, for June through September can reach the mid 70s (°F/25°C). The average summer wet-bulb temperature reaches the mid 40s (°F/7°C), which is equal to a relative humidity of about 53% (10). Because of these low temperatures, it is possible to use natural ventilation to maintain comfort.

The natural stack effect induces air movement through the building when the clerestory windows open. The EMS automatically opens these windows when cooing is needed. Ventilation air enters the building though open doors in both the front and the back of the building and through manually operated windows located at the west end of the building.

Ceiling fans. Ceiling fans in the hardware store improve comfort. To minimize stratification during the winter, the fans operate when there is more than a 5°F (2.8°C) temperature difference between the floor and the ceiling.

Radiant heating systems. A hydronic radiant slab is used to maintain comfort in the store. The radiant heat provides heat to the occupants without conditioning the large volume of air in the space. The retail area was divided into 10 zones so that more heat could be supplied to areas where heating requirements will be higher, such as the front perimeter area near the windows, the area where the cashiers will stand, and the paint mixing/stirring station. The objective of the heating system was to provide comfort to those working in the store.

Temperature sensors located in the slab relay information to the EMS that governs the hot water produced by four, staged boilers. The slab temperature is adjusted based on the occupancy schedule to ensure comfort during occupied hours.

Gas-fired, long-tube, overhead, reflective radiant heaters provide heat in the warehouse area. Heating is provided over the entry and exit vehicle doors and over the key work areas in the space. The remaining heaters provide additional heat when required for meeting design conditions. The set point for the heaters is in the 45°F to 50°F (7°C to 10°C) range, which is high enough to provide comfort in an area where people are dressed for the outdoor environment and are doing physical work.

Transpired solar collector. A TSC was installed on the entire available area of the warehouse south wall. The BigHorn Center TSC is 2250 ft^2 (209 m^2) and is constructed of dark brown, corrugated metal with flat slits cut into the material, through which ventilation air is drawn. When the fan is operating, solar energy absorbed by the dark façade is transferred into the warehouse (Fig. 2). The collector is virtually maintenance free with no moving parts other than a typical fan. The fan size and blade pitch were adjusted to take into account the high altitude. When the temperature of the indoor space drops below 60°F (15°C) and the temperature of the outlet of the TSC is 10°F (6°C) above the temperature of the warehouse, the TSC fans turn on.

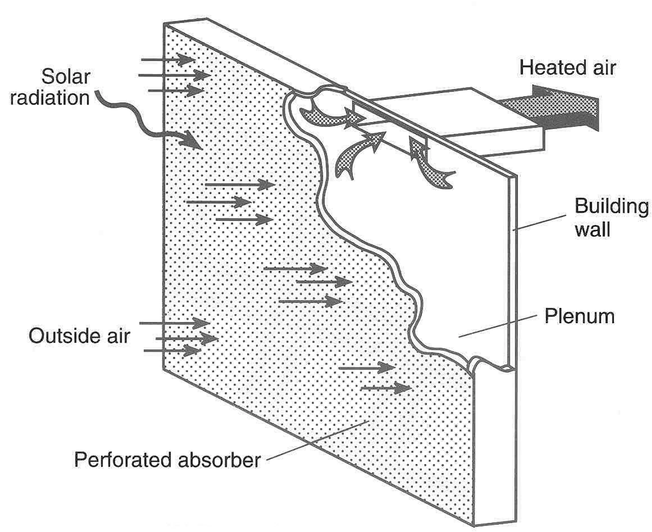

Fig.2: Schematic of the transpired solar collector (11).

Exhaust fans controlled by carbon monoxide sensors operate when the pollutant level in the warehouse exceeds an acceptable level.

Building-integrated PV system. Photovoltaic modules laminated onto the standing-seam metal roof panels were installed on the south-facing roof of the hardware store clerestory and the warehouse dormer (12). The amorphous-silicon PV modules were wired into three arrays, each serving one phase of the three-phase building power system (Fig. 3). The design capacity of the PV system is 8 kW. The BigHorn Center developer/owner has a net metering agreement with the local utility to receive full credit for power that the PV system exports back to the grid.

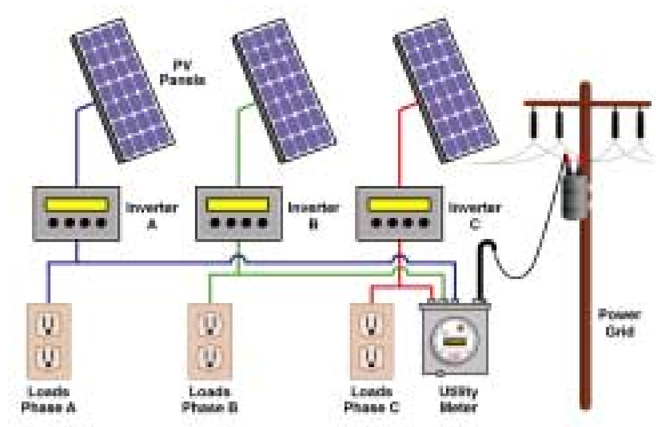

Fig. 3: Three-phase PV system.

Controls. The EMS optimizes operation of the mechanical and lighting systems in the retail store. The system controls set back and start up of the heating system, operates the automatic window actuators for the north-facing clerestory windows, operates the ceiling fans, and balances daylighting and electric lighting to maintain constant lighting levels in the space. The EMS also controls the lighting in the warehouse space. Thermostats control the warehouse mechanical systems.

4. BUILDING ENVELOPE

The building envelope was optimized to minimize heat loss/gain and infiltration. Extruded polystyrene insulation was installed on the outside of the steel stud walls to minimize thermal bridging. Batt insulation is located between the studs. Insulation was installed under the entire slab in the hardware store. All glazing was specified to be double-pane with a low-e coating.

5. EXPECTED BUILDING PERFORMANCE

The combined effect of the energy-efficient lighting fixtures and the daylighting system is expected to reduce building lighting loads 79% compared to the base-case building (Fig. 4). The greatest lighting energy saving occurs between April and September, when the days are longer. Decreasing lighting loads during these months has the added benefit of also reducing the internal gains on the building when the cooling loads are the highest. The elimination of the cooling system from this building was a direct result of eliminating the lighting loads and the direct summer solar gains.

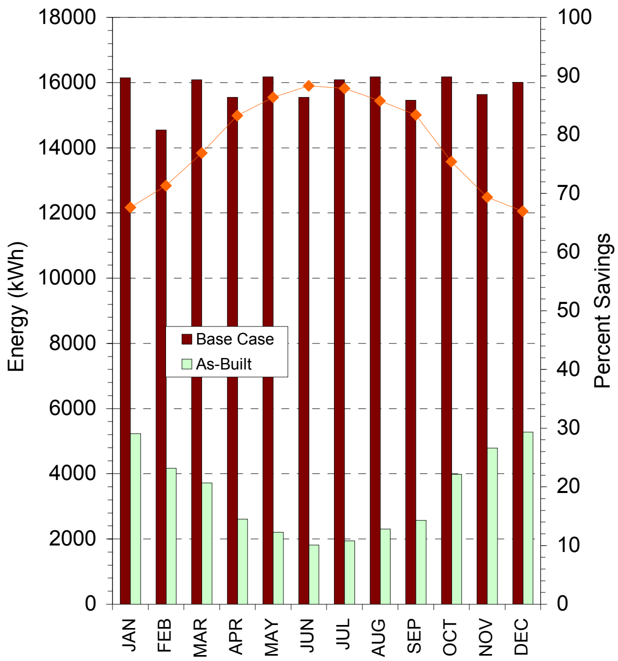

Fig. 4 Monthly lighting energy estimates for the base-case and as-built buildings showing percent savings.

Daylighting substantially reduced the electric lighting load and minimized the cooling loads, which can now be met completely with natural ventilation. Glazing selection and overhang lengths were engineered to work with the daylighting and thermal requirements of the building. The HVAC design includes radiant slab heating, natural ventilation cooling through automatic window control, and a TSC to preheat ventilation air for the warehouse. Finally, the building control system maximizes the ability of the roof-integrated PV system in reducing building electrical demand and energy loads.

Computer simulation results indicate that the BigHorn Center Phase III energy costs are expected to be 62% less than the code-compliant base-case building (Fig. 1).

6. <u>CONCLUSION</u>

The BigHorn Center is one of the first examples in the United States of truly integrated daylighting and natural ventilation cooling systems in a retail space. The BigHorn Center is the first commercial building in the State of Colorado to have a standing-seam metal roof-integrated PV system, and it is the largest building-integrated PV system in Colorado. The grid-tied PV system is also one of the first net-metered commercial buildings in Colorado.

The owners of this project made a strong commitment to sustainable design practices. Even with site constraints that restrict traditional passive solar design, a substantial energy savings can be achieved by optimizing solutions to the constraints.

The business plan for the project encompassed the ability to sell “green” products in the retail environment. To that end, the building became a statement to the sustainable mission and the energy features were an integral part in the design of the building. Photovoltaic modules integrated into the roofing was an additional cost; however, the marketing value of this investment, coupled with the other features, created a total cost-effective business plan.

The design team used a whole-building design approach to integrate improved daylighting opportunities, efficient mechanical systems, and improved building envelope features into an optimized building design. Building envelope features, such as the clerestory windows, minimized lighting and cooling loads.

The clerestory is an integral part of the design and provides the lighting, cooling, and ventilation to this retail building. The TSC integrated into the façade provides a substantial fraction of the warehouse heating needs, and the building-integrated PV system provides electricity – especially at peak times. The resulting building design saves approximately 21 kW in demand, making it possible for the 8 kW of PV power to meet a significant portion of the annual building electrical load. Designers anticipate that, during sunny summer days, it will be possible for the building to export power to the grid during business hours. If daylighting and other design features had not been incorporated, it would not have been feasible to purchase and install enough PV power to offset an equivalent portion of the base-case building load.

Improving the lighting system design and incorporating daylighting provided the greatest opportunities to reduce building energy costs. Optimizing the building envelope design and implementing efficient lighting fixtures and daylighting controls reduced the building lighting loads by an estimated 79%. The anticipated energy cost savings resulting from the combined effect of all the features discussed in this paper (not including the PV system contributions) is 62%, exceeding the original project goal of 60%.

7. <u>ACKNOWLEDGEMENTS</u>

NREL’s High-Performance Buildings Research Project and Photovoltaics in Buildings Task provided support for the energy design of the BigHorn Center Phase III. The U.S. Department of Energy provides project funding for these two activities from the Office of Building Technology, State and Community Programs, and the Office of Power Technologies, respectively.

Special thanks to Don and Betsy Sather, the owner/developer of the BigHorn Center, for following through with their vision for a sustainable building project. Also, thanks to the City of Silverthorne, Colorado, for working closely with the building owner/developer to make this building project a reality.

Marketplace Architects in Dillon, Colorado, completed the building architectural design. Tolin Mechanical of Silverthorne, Colorado, was the controls contractor. The building-integrated PV design was completed by Burdick Technologies Unlimited of Lakewood, Colorado, and Foltz Engineering in Estes Park, Colorado designed the TSC Solarwall system.

A final thank you is given to Mark Eastment who, as an NREL student intern, completed the building simulations during the design analysis stage of this project.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 2000	Conference Paper

4. TITLE AND SUBTITLE

A Case Study of the Energy Design Process Used for A Retail Application

5. FUNDING NUMBERS

BE00.4001

6. AUTHOR(S)

Sheila J. Hayter, P.E., Paul A. Torcellini, Ph.D., P.E.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER

NREL/TP-550-28129

8. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

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14. SUBJECT TERMS

High-performance buildings; retail; energy efficiency; BigHorn Center, Colorado

14. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclassified	unclassified	unclassified	UL