

Zion National Park Visitor Center: Significant Energy Savings Achieved Through a Whole-Building Design Process

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ABSTRACT

The National Park Service (NPS) applied a whole-building design process developed at the National Renewable Energy Laboratory (NREL) to create a building that performs more than 70% better than a comparable code-compliant building at no additional construction cost. The NPS was committed to integrating aggressive energy efficiency and renewable energy features into the building design to reduce environmental impact and enhance visitor experience.

This whole-building design process involves a committed design team, including the energy consultant, in the earliest conceptual design phase and continues through building commissioning. The design team for this project included the architect, engineer, energy consultant, landscape architect, owner, operator, and others who could influence the building design and operation. *Extensive* whole-building energy and lighting computer simulations were conducted throughout the process, which included the integration of energy efficient and renewable energy technologies into the building.

The design team, inspired by natural cooling within the canyon, developed simple solutions to create an extremely energy efficient building. These strategies included natural ventilation cooling, cooltowers for evaporative cooling without distribution fans, daylighting, massive building materials, Trombe walls and direct solar gains for heating, engineered window overhangs for solar load control, a building automation system to maintain comfort and control the energy-efficient lighting system, and a roof-mounted photovoltaic system to offset building electrical loads and ensure a power supply during the frequent utility grid outages.

Performance data were taken over a 2-year period and show where and how energy savings were achieved. Construction and operation costs are also summarized.

Introduction

In a traditional design process, the architectural team determines the building form and articulation of the façade, including orientation, color, window area, and window placement. This architectural design is then handed off to the engineering team, who designs the heating, ventilating, and air-conditioning (HVAC) system, ensures compliance with applicable energy codes, and ensures acceptable levels of environmental comfort for building occupants. It is then the engineer's goal to create an efficient system within the context of the building envelope that already has been designed—the architectural decisions have been finalized and few changes can be made to the envelope design. In this traditional method, most of the energy savings are achieved by increasing the efficiency of the HVAC system.

The NREL whole-building design process differs from traditional design processes because it goes beyond engineering a building for energy efficiency or renewable energy

additions. The whole-building design process significantly minimizes energy consumption by creating a design team that includes building decision makers such as architects, engineers, and energy consultants from the onset of the conceptual design through the completion of the commissioning process (Torcellini, et al. 1999). The design team discusses all components of the building project as a single system, rather than as individual components, and must ensure that the building envelope and systems complement one another, including integration of energy efficiency and renewable energy technologies.

The potential of a high-performance building is best achieved by a team-oriented, multidisciplinary approach in which all members of the project team recognize and commit to the steps and actions necessary to achieve the agreed-upon project goals. This approach is challenging, but is made easier when the client has the vision to seek a high performance solution.

When establishing project goals, the most important criteria to consider are the owner's values. These values will ultimately set the decision-making criteria for the entire project. Traditional methods for evaluating energy efficiency goals often include first cost, simple payback, savings-to-investment ratio, life-cycle cost, or net-present value of savings. Although these criteria are useful, they quite often are not the sole criteria for decision making for buildings. It is important to define the goals by which decisions will be made early in the process. For example, high-performance buildings goals may include a disaster resistant building (e.g., able to function if no grid-power is available), have higher user satisfaction and productivity (from increases in comfort and indoor environmental quality), and have market benefits. If traditional methods are solely used to evaluate high-performance building design strategies, such as for a typical "value-engineering" process, then there is a risk the strategies will be singularly removed from the design without consideration of the effects on the total building performance. The result is a nonintegrated design.

The design should meet or exceed all the functional and comfort requirements of the building. Low-energy design does not imply that building occupants endure conditions that are considered unacceptable in traditional buildings. However, research has shown that some low-energy design strategies result in occupants being more tolerant of varying indoor conditions, increasing the opportunities for applications of these strategies (Brager 2000).

Although buy-in on design issues from members of the building decision makers is crucial to the whole-building design process as developed at NREL, its basis is a simulation-based, quantitative, and qualitative method to help architects and engineers create very low-energy buildings. *Extensive* simulation is used for every part of NREL's process because the energy use and energy cost of a building depends on the complex interaction of many parameters and variables. The problem is far too complex for "rules of thumb" or hand calculations. The interactions are best studied using computerized hourly energy simulation tools to thoroughly evaluate all the interactions of the building envelope and systems design features. Use of computer simulation should start in predesign as soon as the location, size, and type of the building are known.

This paper focuses on how low-energy goals were achieved at the Zion Visitor Center Complex by applying the whole-building design process. The building incorporates energy-efficient features including daylighting, shading, natural ventilation, evaporative cooling, passive solar heating, computerized building controls, and an uninterruptible power supply (UPS) integrated with a photovoltaic system. These "features" form the integrated energy

solution that met the project goals. The energy performance has been evaluated since the building was occupied in May 2000. The total energy reduction is approximately 70% versus a comparable code compliant building (USGVT 1995).

Through the Department of Energy's High-Performance Buildings Initiative, researchers from the Center for Buildings and Thermal Systems at the NREL worked closely with NPS on the project. NREL facilitated the holistic approach to the Zion Visitor Center design, developed some of the initial concepts for the "energy design," performed simulation-based optimization studies that determined how best to integrate energy efficient and renewable energy technologies, and evaluated the building performance after it was occupied. NREL also provided the metrics to measure the progress and success of the project. (Hayter, et al. 2001)

Zion Visitor Center Case Study

Zion National Park (ZNP) encompasses a canyon desert region located in southwest Utah. Summer daytime temperatures are hot (95°–100°F), but overnight lows are comfortable (65°–70°F). Afternoon thunderstorms with power outages are common from mid-July through mid-September. Storms may produce waterfalls as well as flash floods. High tourist season for the Park is springtime through late fall. In 2001, the NPS reported that recreational visits to Zion totaled 2,086,264, or 3,000 visitors/hour during high tourist season (NPS 2002).

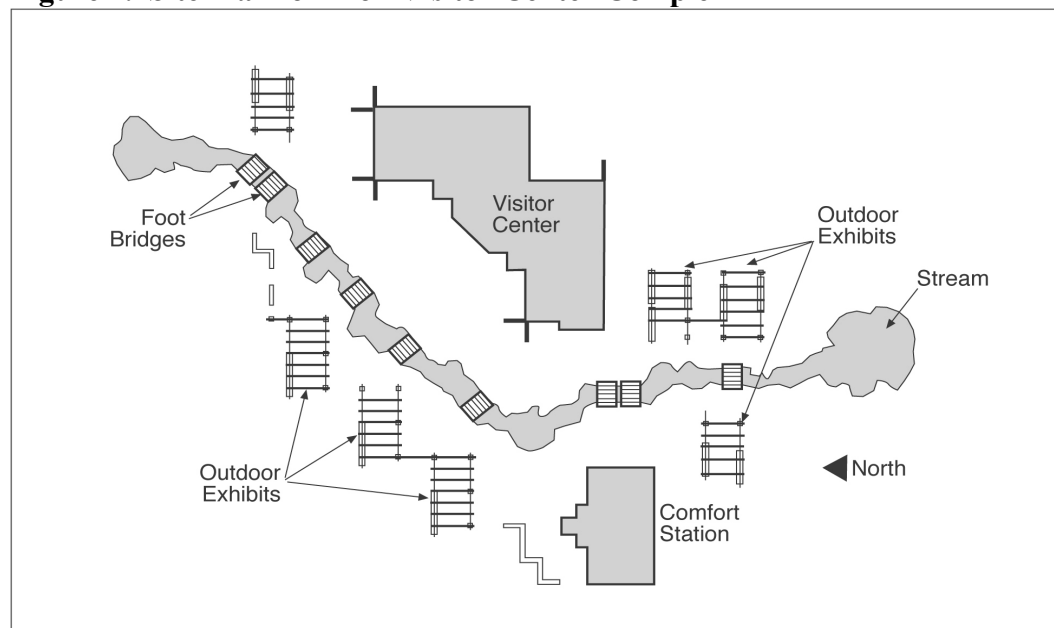
Before the new Visitor Center was built, most of these visitors drove private vehicles on a two-lane road up the narrow box canyon. On a typical summer day, 3000 cars visited the park, yet there were only 400 available parking spaces. The parking and traffic congestion hampered the visitor experience, adversely affecting the canyon's flora and fauna, and threatening visitor safety. As a result of increased traffic to the Park, it outgrew its existing 1960's visitor center. Interpretive space was limited and the restrooms were unable to handle the visitor load. The layout of this building was not conducive to effectively serving the large number of visitors.

The essence of the NPS mission is to conserve and protect the canyon and its natural resources for current and future generations. Project goals for the new visitor center were established in a comprehensive design workshop. Energy was an important part of these discussions. The design team wanted to minimize visitor impact on the Park as well as reduce air, noise, and light pollution to align the project with the NPS mission. Results for this goal included creating buildings that would use 70% less energy, eliminate private vehicle traffic, and provide only essential exterior lighting. The solution formed around the traffic flow, resulting in a propane powered shuttle-bus system for the park and gateway community of Springdale, Utah. The concept was that after visitors arrived in Springdale, they would not need their cars for the duration of their stay. The transportation system idea required a new infrastructure to support the buses. Although not emphasized in this paper, there were environmental benefits to using clean-burning buses, eliminating vehicle traffic from the park, and shared parking with the town to reduce the amount of parking required inside the park boundaries. NPS building procedures required a completed design before bids from contractors could be accepted.

The new transportation solution is relevant because it required a "transportation hub" to be built near the park entrance, which included a retail bookstore, visitor orientation, back-

country permitting functions, staff support areas, and restroom facilities. It was decided early in the design process that because of the warm, dry weather conditions during the peak visitor season, much of the exhibit space in the visitor's center could be permanently housed outside under shade structures and not inside a building. The restroom function (Comfort Station) was also separated from the main building to improve pedestrian traffic flows. Landscaping in the outdoor exhibit areas and between the buildings created shaded outdoor rooms, increasing the effective space available for visitor amenities. As a result, instead of one large building, two conditioned buildings were constructed: an 8475-ft² (787-m²) main visitor center building and a 2756-ft² (256-m²) Comfort Station (Figure 1). The Visitor Center houses 6642 ft² (617 m²) of public areas, 472 ft² (44 m²) of storage and utility areas, and 1361 ft² (126 m²) of staff support areas. The total area of the two buildings is approximately 7500 ft² less than the original plan because the majority of the exhibit and circulation space was moved outdoors. Landscaping helped define these outdoor spaces.

Figure 1. Site Plan for Zion Visitor Center Complex



Source: Adapted from NREL and NPS drawings.

Base-Case Analysis

NREL installed a weather station to record temperature, wind speed, wind direction, and solar radiation, and surveyed the complex geometry of the canyon walls to develop a set of sun-path diagrams near the proposed building site (Judkoff 1995). A theoretical base-case building was developed to provide a starting point for the analysis as well as a metric for evaluating the energy savings success of the project. It also set the groundwork for guiding the design process using hourly computer simulation tools (LBNL 1994, Palmiter 1985). Most of this analysis took place early in the design process in parallel with the programming and goal setting exercises. The base-case model has the same footprint area as the as-built building. It is solar neutral (equal glazing areas on all orientations) and meets the minimum requirements of the Federal Energy Code 10CFR435 (based on ASHRAE Standard 90.1-

1989 with additional lighting requirements) (ASHRAE 1989, USGVTM 1995). Outside ventilation air in the base-case model was set at a constant rate during occupied hours. Electric lights provided all lighting for the building set to retail and exhibit lighting levels. The maximum number of occupants was assumed to be 100 and the occupancy schedules were based on typical operation hours of the existing facility. The NPS provided expected visitor density data, which was used to establish mechanical air-exchange rates. Table 1 summarizes the building characteristics in the base-case model.

Table 1. Base-Case Model Characteristics

Item	Value
Wall R-Value (ft ² ·°F·hr/Btu)	13.9
Window U-Value(Btu/ ft ² ·°F·hr)	0.579
Window Solar Heat Gain Coefficient	0.61
Floor Perimeter Insulation (48 in vertical foundation insulation) R-Value (ft ² ·°F·hr/Btu)	4
Roof R-Value (ft ² ·°F·hr/Btu)	22.7
Infiltration (ACH)	1
Lighting levels (W/ft ²)	2.2
Equipment load (W/ft ²)	0.75

Conventional retail building construction characteristics vary so it is difficult to justify base-case model characteristics that do not conform to a universally accepted standard set of criteria. ASHRAE Standard 90.1-1989 is a consensus-based standard that outlines the minimum building energy design requirements. The Federal Energy Code 10CFR435 adopted this industry standard in its entirety and incorporated additional lighting requirements. Many states and municipalities do not require or do not strictly enforce Standard 90.1 or 10CFR435 requirements. Therefore, a building designed to meet 10CFR435 is often a better building than conventional construction. This method provides a standard metric for comparing percent savings from building to building.

The base-case building described in this paper is for energy comparisons only. It was unlikely NPS would have built the base-case building because it does not contain sufficient space to meet the ZNP anticipated visitor loads. A smaller building than was originally described in the program plan was constructed. This smaller building performs more than 70% better than the same size, code-compliant building for this specific location. The actual energy savings could be described as a larger number if the savings were compared to a larger base-case building designed to meet the original program plan.

The base-case model represents a typical NPS visitor center that meets consensus based energy codes; it does not take advantage of daylighting and it uses conventional heating and cooling systems. The climate in Springdale, Utah, is a cooling-dominated climate. Typical commercial buildings in this climate experience high cooling loads from internal gains (lights and plug loads), solar loading, and ventilation air for occupants. Buildings in this climate experience winter heating loads as well. Analysis of the base-case model showed that daylighting, shading, natural ventilation, evaporative cooling, and passive solar heating had the largest impacts. Additional hourly computer simulations to analyze the affect of each of these design solutions helped engineer all components to create a package

where the envelope design actually met most of the HVAC load, thus becoming itself an integral part of the HVAC system.

The Whole-Building Design Solution

An analysis of the impact on the building of different building variables (sometimes referred to as elimination parametric analysis) was completed using the base-case building simulations to evaluate the effects of specific elements of the building design. For example, the U-value of the wall, floor, roof, and windows were individually analyzed to simulate zero heat transfer across these components. The resulting building energy requirements from each of these parameters showed that daylighting, shading, natural ventilation, evaporative cooling, and passive solar heating reduced total building energy requirements the most.

Much of the building's architecture followed the Park's historic architecture as well as the canyon's own natural design that cools the area during the hot summers. Tall, wet canyon walls and hanging gardens cause a natural cooling effect in the canyon. The cooled air then drops out of the slot canyon into the wider canyon at its base. Architects incorporated similar tall elements in their design to give the building perspective within the canyon environment. These elements were integrated with the energy goals to create downdraft cooltowers as the primary cooling system (Figure 2). The "cooltower" effect is a passive solar technology that has been around for hundreds of years. It works like a chimney in reverse. Water is pumped onto a honeycomb media at the top of the tower. The evaporatively cooled air, which is denser than the ambient air, falls through the tower under its own weight where it then enters the building. No fans are required to cool the building. Windows strategically placed in the building relieve hot air, thereby moving the cool air through the space. The cooltowers enhance energy performance while giving the building a unique aesthetic style. The towers also mimic the natural "ventilation" and evaporative cooling effects of the Virgin River slot canyon that makes Zion famous. In addition to the cooltowers, thermal mass also contributes to some cooling of the building.

Figure 2. North Façade of Zion Visitor Center Showing Cooltowers

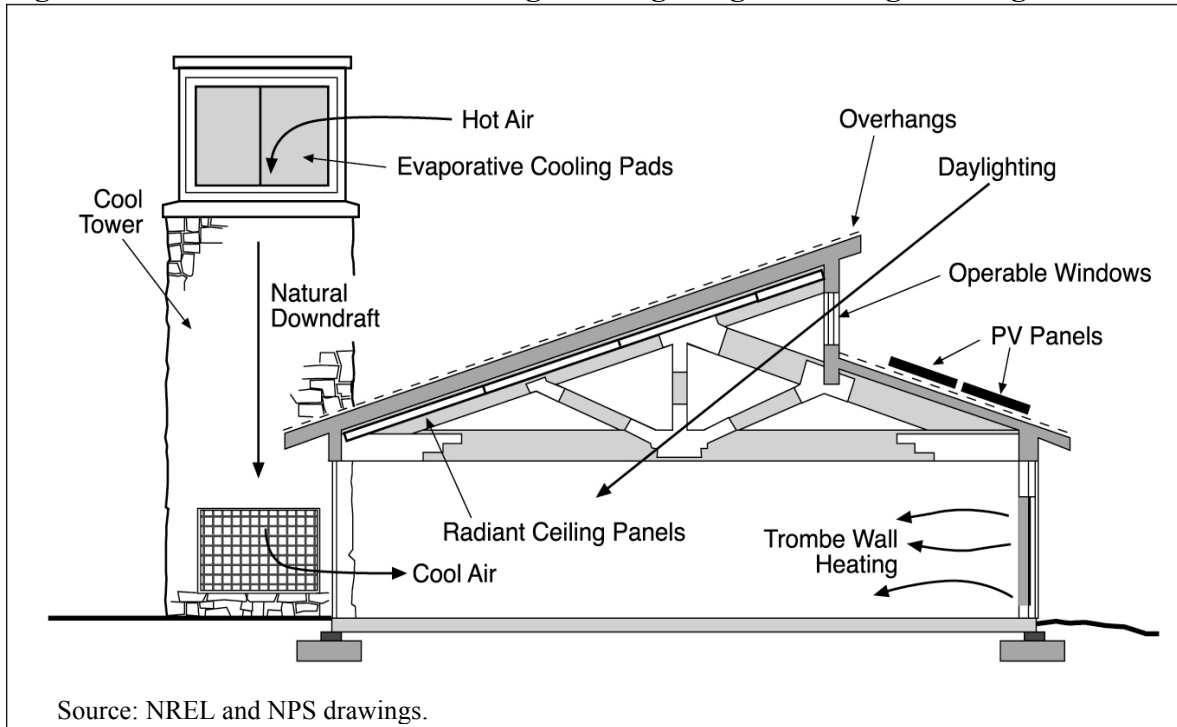


Source: NREL/Pix# 09252/Robb Williamson

Major internal gains to the space are the lighting and plug loads, each accounting for approximately 32% (total of 64%) of the total base-case energy load. The design intent was to use daylighting to meet 100% of the lighting load during the day. Clerestory windows and windows at 6 ft (2 m) above the floor were designed to provide most of this daylighting. The electric lighting system and related controls were designed to complement the daylighting design.

In addition, the building's overhangs, clerestories, roofline, and massive building materials all contribute to the building's energy performance. The design team relied on hourly computer simulations to engineer all components to create a package where the envelope became most of the HVAC system. Figure 3 shows many of the strategies integrated into this whole-building design. These strategies include a Trombe wall for passive solar heating, a solar-electric (photovoltaic) system to offset building electrical loads, operable clerestory windows for daylighting, natural ventilation, and direct gain winter heating, and engineered overhangs to eliminate summer solar gains.

Figure 3. Cross Section of the Building Showing Integrated Design Strategies



After the envelope was designed, the remaining heating, cooling, and lighting energy loads were studied. A small amount of heating remained. Because these heating loads were low, the most cost-effective solution for meeting this load was to install overhead, electrically powered radiant heating panels. Installing electric heat eliminated the need for a central heating system that would have required a hot-air furnace or boiler and associated ductwork or piping. Natural gas is not available on site, so a central heating system would have required transporting and storing propane or operation using electrical power. The cost of propane for this site is equivalent to the cost of electricity on an energy basis.

All cooling loads were met with natural ventilation using the computer controlled clerestory windows, evaporative cooling from the cooltowers, and careful design of shading devices and daylighting apertures to minimize solar gains. The only mechanical input to the cooling system is a pump to circulate water through the evaporative media. In addition, this system allowed for high ventilation rates in the summer when there are the most visitors in the building and low ventilation rates in the winter when there are fewer visitors. Natural infiltration through the building envelope as well as people entering and exiting the building

provides adequate ventilation during the winter. Tracer gas tests by NREL verified that adequate ventilation is available at all times of the year.

Next, the design team investigated the potential impact of incorporating a solar-electric system in the future. Mounts for a roof-mounted system were designed into the south-facing roof and were installed as it was constructed. A UPS system was included in the original plan for the building electrical system because of poor power reliability at the site. By specifying an inverter that could handle an input from a solar-electric system, the existing UPS became ready to be linked to a solar-electric system. Later in the design process, it was determined that a 7.2-kW solar-electric system would be installed (See ACEEE '02 paper "Photovoltaics for Buildings: New Applications and Lessons Learned").

After optimizing the architectural and engineering designs, the final set of bid documents and specifications were created. The design team carefully reviewed all drawings and documents to ensure that the design intent was clear and to minimize the chance for errors or misinterpretation of the design during construction. A final design computer simulation was completed to accurately reflect the requirements described in the drawings and specifications.

The design team carefully observed the building construction and was available to answer construction crew questions about the drawings and specifications. The design team reran the energy simulations before authorizing any suggested changes by the contractor. The good communication between the contractor and the design team was enhanced by frequent visits to the site during construction by the architectural and energy consultant members of the design team.

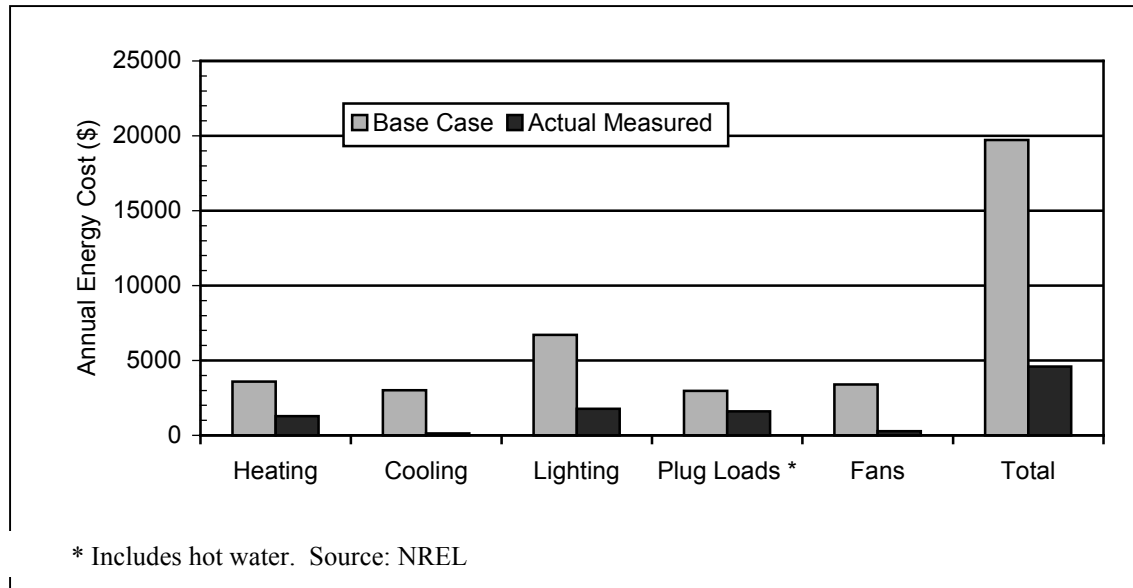
NREL has been monitoring the building since occupancy. Several issues have been corrected as part of the building commissioning process and subsequent monitoring. The close interaction between NREL and the NPS staff contributed towards ZNP staff acceptance of the unconventional technologies integrated into the building design.

Zion Visitor Center Measured Performance

Figure 4 summarizes annual energy costs based on NREL's monitoring measured performance for the performance period. Most of the power is purchased during off-peak periods to avoid demand charges. Heating the building during the off-peak, lower rate periods decreases utility costs. The result is a building that costs \$0.45/ft² (\$4.84/m²) to operate.

In terms of energy performance, the Zion Visitor Center Complex is using 70% less energy than would comparable facilities built to the applicable Federal codes. This translates into total annual savings of approximately 250,000 kWh (870 million Btu). The normalized energy usage is 26.9 kBTU/ft²/yr (8.5 kWh/m²/yr). These savings result in an annual reduction in CO₂ emissions of 310,000 lbs (155 tons), based on emission factors from electricity generation in Utah of 1.244 lbs CO₂ per kWh.

Figure 4. Annual Energy Costs in Dollars (Based on Data from April 2001-February 2002 and a Virtual Utility Rate of 5.7 cents/kWh.)



Construction Costs

The project construction cost was less than for a conventional visitor center having the same footprint: the bid for the project was well under the program document's original costs. Early in the design process, it was decided to move many of the exhibit spaces outdoors under permanent shade structures to decrease building size and separate the Visitor Center from the Comfort Station. Separating these functions moved the circulation space between the two buildings outdoors through the outdoor exhibits.

The building has a very small mechanical room because of the elimination of the need for ducts, large blowers, chillers, and boilers. Eliminating the need for fuel storage also resulted in lower infrastructure costs. This project demonstrates that it is possible to construct high-performance buildings for less cost than buildings not optimized for energy efficiency.

The base budget of the building included the infrastructure to provide for a future solar-electric system. Funds received late in the construction process was used to purchase the solar-electric system components and to cover the expenses to establish a net-metering agreement with the local utility. This is the first net-metered building in the State of Utah.

Lessons Learned

Several lessons were learned after construction and commissioning. These lessons are related to the performance of the cooltowers, daylighting system, solar-electric system, and the electric heating system.

Cooltowers. The cooltowers work well to provide cooling to the main area of the visitor center. Visitors find the towers fascinating and give them the type of attention often given to large fireplaces in public areas. The interaction of the visitors with the cooling system

provides an amenity that normally would not be achieved with a traditional cooling system. However, the enclosed offices in the building tend to overheat. Exhaust fans originally installed in the office area were not sufficient to move air through these spaces to counteract the effects of the Trombe wall that is providing heat to the spaces. The Trombe wall is shaded in the summer, but the diffuse component of the solar radiation still heats the wall. In the initial building design, the Trombe walls were sized to heat only open spaces, not enclosed offices. Late in the design process, the interior layout of the building was changed to place enclosed offices adjacent to a Trombe wall. Even in the winter, this Trombe wall provides more than enough heat to the office spaces. As a result, circulation fans were installed between the public and private spaces to help induce additional air flow. These fans improved the comfort of the office spaces; however, they also increased the overall building fan loads.

Functionally, the cooltowers have worked well, that is, they operate whenever a traditional single-stage evaporative cooler would operate. There are a few days each summer when the building temperature drifts to the high 70°F's (mid 20°C's) when the capacity of the cooltowers cannot meet the building cooling loads. To minimize the number of days these high temperatures occur, the interior mass of the building is cooled using nighttime natural ventilation.

There were several cooltower design detail issues that were problematic. These included poor flashing details in the cooltowers, poor material selection for the interior surfaces of the towers, and poor plumbing details for tower pumps, reservoirs, and connective piping. These issues have been or are being addressed and should be easy to avoid in future projects.

Daylighting. Designers intentionally chose to incorporate diffuse light in the space to reflect the lighting characteristics within the narrow slot canyon of the Park, keep solar heat gain to a minimum, and make the building interior psychologically “cooler.” A light-pine, tongue-and-groove ceiling was installed instead of NREL's recommendation for a white ceiling. The darker ceiling drastically decreases the daylighting effectiveness in the space. This decreased effectiveness is compounded by the use of 90% up-lighting fixtures that do not reflect off the ceiling. These fixtures were installed level to the horizontal beams in the space, some distance below the ceiling. This made the up-lighting fixtures not as efficient as intended.

The lighting controls are stepped controls. When the electric lights switch on or off, the occupants tend to be distracted. The absence of task lighting further decreased the effectiveness of the daylighting system because occupants required more use of overhead lighting to maintain sufficient lighting levels in work areas. Task lighting was installed in these areas after the building was occupied. Use of task lighting permitted building operators to decrease the ambient lighting threshold that controls the electric lighting. A similar problem existed in the Comfort Station where additional lighting was needed over the sinks. After occupancy, more lighting was provided over the sinks and the general lighting level could then be decreased.

Solar-electric system. The power quality at Zion is poor, especially during the summer thunderstorm season. Because of the frequent grid power disconnections, the UPS system has difficulties determining when to disconnect from and reconnect to the utility power. The

reliability of the solar-electric system has been excellent, but the transition between UPS and utility power has not been satisfactory. For example, in one case, the power turned on/off 40 times in less than 5 seconds before disconnecting. As a result, some small UPS back-ups have been installed for the critical loads.

Electric heating system. The electric heating system is controlled to operate only during periods that would not induce a peak demand on the utility bill. Utility data results are still being collected to evaluate the effectiveness of this control technique. Building heating costs are higher than expected because, in the process to optimize this control strategy, the electric heating system operation sometimes induces an electrical consumption spike resulting in a demand charge. One example occurrence of a heating system-induced spike is during the morning warm-up period. Adjusting the night setback to minimize or eliminate the morning spike has addressed this particular issue.

Summary

An integrated design approach including the design team and building users was followed from the onset of the conceptual design phase through building commissioning and occupation. Using the microclimatic phenomena of the canyon as a model, an integrated set of solutions for architectural design and energy efficiency was determined, including extensive daylighting, natural ventilation, evaporative cooling, and passive solar radiant heating using a Trombe wall. It is key to design a building that works with the environment in which it is located to minimize the use of fossil fuels. The building architecture was formed based on the programmatic and energy goals for the project. Tall vertical elements were preferred by the architect to harmonize the building with the surrounding natural environment. These towers were also used to passively cool the building. An HVAC system was designed to work with the building. A solar-electric system was installed to provide emergency power and supplemental power when utility power is available. Significant energy savings were achieved by fully integrating energy efficiency and renewable energy technologies into NREL's whole-building design process. The building construction cost was less and its energy consumption is more than 70% less than a conventional Visitor Center as verified by actual monitored data. To achieve this, it was essential that an energy consultant be involved with the integrated design team to keep the energy goals in mind for decision-making.

Acknowledgments

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consultants. In addition, William Talbert and Joshua Bruce contributed to simulating building performance and collecting and analyzing the energy data.

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