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RENEWABLE ENERGY DEMONSTRATION PROJECT BY THE NATIONAL RENEWABLE ENERGY LABORATORY AND THE GENERAL SERVICES ADMINISTRATION

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INTRODUCTION

The Energy Policy Act of 1992 (EPACT) requires the General Services Administration (GSA) to implement a solar energy program to demonstrate and evaluate the performance of available technologies expected to have widespread commercial application. The GSA decided to carry out the project at the Denver Federal Center because of its proximity to the National Renewable Energy Laboratory (NREL). The location was thought to be of mutual benefit to NREL and the GSA: it provides NREL an opportunity to deploy technology and it provides the GSA an opportunity to gain a hands-on learning experience with renewables. The GSA plans to document their experience and use it as a case study in part of a larger training effort on renewable energy. This paper describes the technology selection process and provides an update on the status of the project.

APPROACH

The Denver Federal Center (DFC) is an 800-acre federal complex in Lakewood, Colorado, just west of Denver. The DFC was formerly the site of the Denver Ordinance Plant, and when the plant closed in the late 1940s, the buildings were converted to offices. Today, the DFC houses about 9000 federal employees, including the Department of Interior, Department of Agriculture, and General Services Administration.

On April 25, 1994, representatives from the GSA and NREL met to initiate this project. The GSA representatives at the meeting were familiar with the DFC site, including the buildings and power requirements, and NREL's representatives included experts in solar water heating, ventilation air preheating, daylighting, and photovoltaics. NREL provided an overview of each technology and identified key conditions that must be met to consider the technology (e.g., an unshaded south-facing area for solar collectors). Following the discussion of each technology, GSA representatives suggested buildings or sites to be considered for one or more of the technologies. At the end of the meeting, 14 potential sites were identified for evaluation. NREL and GSA staff next visited each site and discussed the potential project with the users. Some sites were rejected after the initial visit for a number of reasons. For example, the Archives Building (Building 48) was suggested for daylighting, but during the site visit, it became obvious that this was not a good candidate; the building is used primarily for storing records, and the lights are turned on only when people need access to the records.

A wide range of appropriate renewable energy technologies were evaluated for each site being considered. NREL provided a technology-neutral assessment to identify the most appropriate renewable energy systems to meet the DFC's needs. Technology-specific analysis methods yielded the initial investment cost for the installation and the maintenance costs expected over the lifetime of the installed technology. All costs were double-checked with industry suppliers. Based on these costs, a life-cycle cost analysis was performed using the ***Building Life-Cycle Cost*** software. This analysis program adjusts for the cost of money over time using the published federal discount rate of 3.1% for fiscal year 94. In addition, adjustments are made to energy costs over the lifetime of the investment, using the U.S. Department of Energy's (DOE's) Projected Price Escalation Rates for various regions around the United States. For this study, we used the escalation rates for the state of Colorado.

We presented our completed analysis to the GSA staff, who made the final decision as to the technologies selected for demonstration. NREL then initiated pre-retrofit monitoring, while GSA initiated the process to procure the hardware. At the time of this writing, initial findings from the pre-retrofit monitoring have been prepared by NREL, and GSA is still in the process of procuring the systems. The timeframe for GSA to complete the procurement process is unknown.

RENEWABLE MEASURES

Renewable energy can be used in many ways. From an economics viewpoint, incorporating renewable energy systems into existing buildings is generally more challenging than new construction or remote sites where power is not utility-generated. In the case of our project, cost-effectiveness is not the primary driver; rather, the project is driven by the GSA's interest in gaining first-hand experience in identifying renewable energy opportunities and in procuring systems. Because this is a demonstration project, NREL is interested in selecting renewable energy applications that are appropriately matched to the needs of the buildings. Based on the existing conditions at the Denver Federal Center, the following five renewable energy systems were considered as candidates for application.

Daylighting Skylights and Lighting Management Integration

Daylighting skylights are a commercially available product designed to use natural light from a clear or overcast sky to replace or supplement electric lighting in buildings. They were evaluated for use in two offices and the day care center. Daylighting skylights can be installed in both retrofit and new construction. They claim to deliver uniform illumination throughout a space, with lower heat gain than either electric lighting or standard skylights. Figure 1 is a diagram illustrating the major components of one of these products. They are applicable in single-story buildings and in the top story of multi-story commercial and industrial buildings. They are well suited to interior spaces such as atria, cafeterias, grocery stores, schools, and day care centers. Several variations on the product make it suitable for different applications. For example, one system that has a series of sunlight-tracking mirrors is most applicable for buildings needing lighting in the early morning and late afternoon/early evening hours. Another system without the tracking mirrors may be more applicable in a location where capturing light in the early morning/late afternoon is less important. The GSA decided to install two of the tracking systems. NREL will collect performance data on each system.

The east wing of the day care center has a strip of north and south windows that appear adequate to provide ambient lighting. The circuit for the existing fluorescent lamps is parallel to the windows. NREL evaluated lighting controls for the day care center, including dimmable electronic ballasts and light-level sensors, so that when natural lighting provided adequate illumination through windows, the artificial lights would be off. The lighting control system is capable of continuously dimming or brightening the lights as needed to supplement the available daylight.

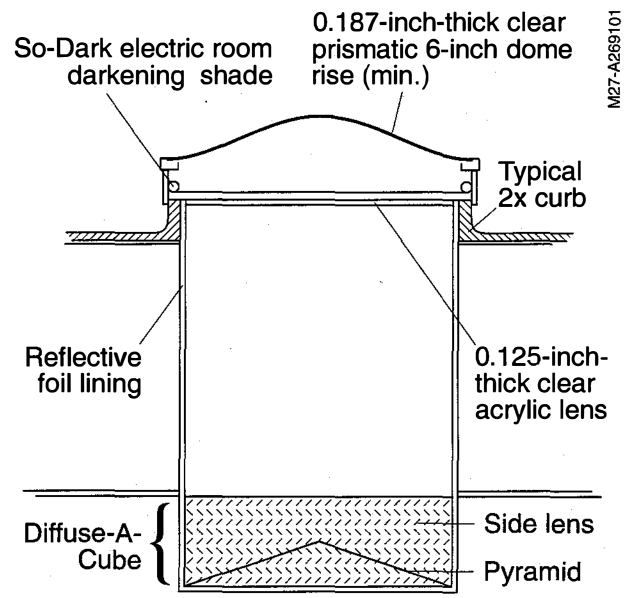

FIGURE 1. DAYLIGHTING SKYLIGHT IN A TYPICAL INSTALLATION

Photovoltaic Street Lamps

Photovoltaic (PV) street lamps were evaluated for one parking lot that appeared to be too dark. PV street lamps generally consist of six separate components: the lamp, ballast, PV array, controller, batteries, and lamppost. Figure 2 shows a schematic diagram of a complete PV street lamp, minus the lamppost. PV street lamps are shipped disassembled to the customer, with the amount of assembly required varying from manufacturer to manufacturer; in some cases, a significant amount of wiring and component assembly is required. The major advantage of these street lamps is that they eliminate the high costs associated with trenching and backfilling to provide buried power lines to them. A secondary advantage, because the devices are essentially standalone devices, is their ability to be relocated at minimal added cost.

There are several options available for each of the components. Hoo, Carlisle, and Hancock (1994) describe these options and discuss advantages and disadvantages. In our specific situation, the economics did not justify the costs, but the measure was considered because we identified the need for night lighting of a parking lot.

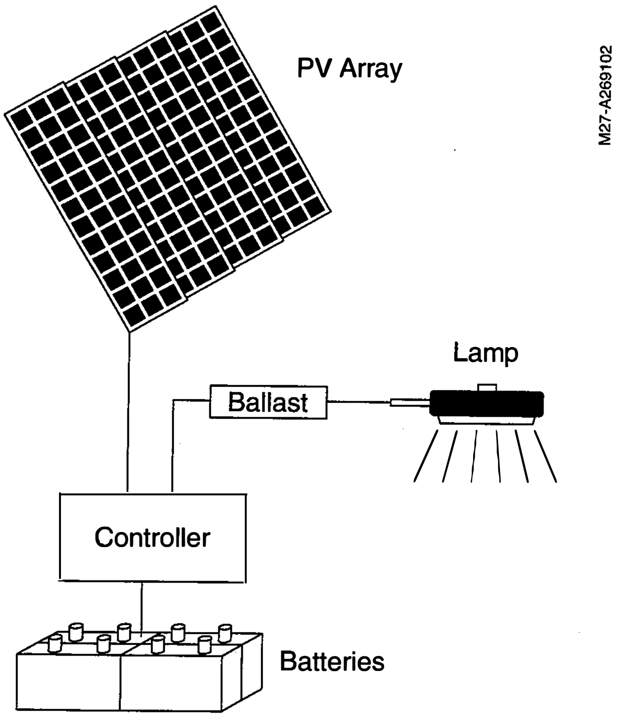

FIGURE 2. SCHEMATIC DIAGRAM OF A PHOTOVOLTAIC STREET LAMP

Photovoltaic-Powered Installations for Remote Instrumentation

Photovoltaics to power a remote sanitary sewer flow-metering facility was evaluated. The flow meter is needed to record the sanitary sewer flow history. Complete solar electric generators are available that provide 6, 12, 24, and 48 volts direct current (VDC) to remote instrumentation installations. Standard systems usually provide 12 VDC and typically comprise three major components: the PV array, system controller, and battery storage.

The batteries and system controller are usually housed in a single weather-tight enclosure. The PV panels can be mounted either on the ground or out of reach on a fixed-pole support. When possible, the fixed-pole support is recommended to minimize any possible tampering with the collector and to minimize the possibility of shading of the collector surface. These generators can have as few as one solar panel or as many as 18, and they provide a continuous output of 38 mA and 9 A, respectively. Batteries provide the system with additional power output during periods of high power consumption. In addition, they allow autonomous operation of the powered instrumentation during periods of low or no sun. Standard generators usually provide 8 days of autonomy at their rated power output. The system controller manages the charging operations of the batteries to prevent damage, which could occur because of overcharging. The controller also regulates the flow of power from the PV array and the battery storage to the powered instrumentation.

Solar Domestic Water Heating

Solar water heating was evaluated for the day care center. Figure 3 shows a typical solar domestic hot-water closed-loop antifreeze system. In this system, an antifreeze solution such as water/propylene glycol is circulated through the collector to provide freeze-protection in cold climates.

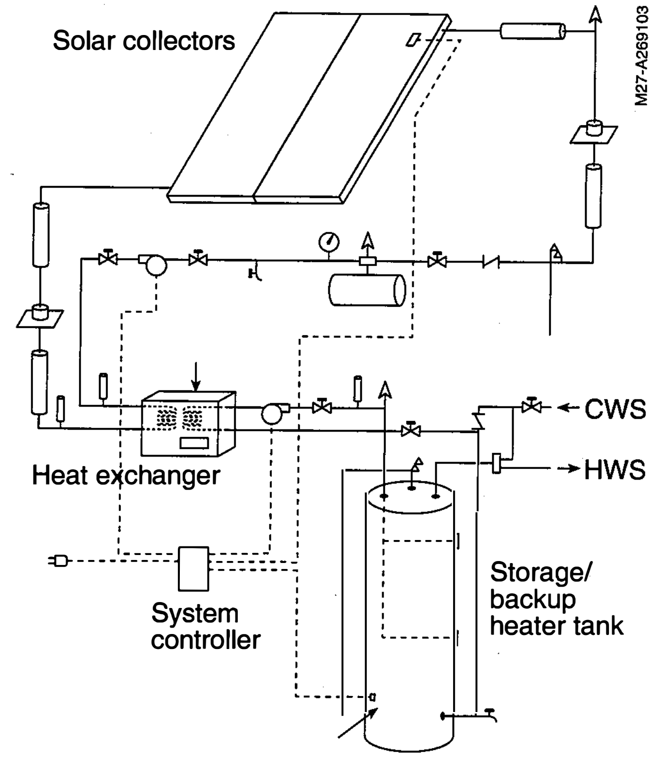

FIGURE 3. TYPICAL CLOSED-LOOP SOLAR HOT-WATER SYSTEM

A temperature sensor at the exit of the collector monitors the amount of solar radiation falling on the collector surface. When sufficient solar radiation is being collected, the system controller activates a circulation pump that circulates the antifreeze solution through the collector and heat exchanger. At the same time, a second circulation pump on the water supply side is activated. Water is drawn from the bottom of the storage tank and passed through the heat exchanger. The water is heated through a counterflow arrangement in the heat exchanger as the antifreeze solution is cooled. The cold antifreeze solution is returned to the bottom of the collector array to be reheated, and the hot water exiting the heat exchanger is returned to the top of the storage tank. This sets up a thermal stratification within the storage tank, which is advantageous because the water supplied to the various loads within the building is available at high temperatures very early in the day. As water is drawn from the storage tank, water from the central water main is introduced at the bottom of the tank as makeup. This arrangement maintains the thermal stratification within the storage tank until all the hot water has been consumed, or until the entire storage tank has been filled with heated water.

Unglazed Transpired Solar Collectors for Ventilation Air Preheat

Unglazed transpired solar collectors are relatively simple devices that can be used to preheat building makeup air. These devices have efficiencies on the order of 75%, making them among the most efficient solar heating systems available. Their design achieves these high efficiencies by eliminating optical transmission losses and minimizing convective heat losses at the expense of full radiative heat losses.

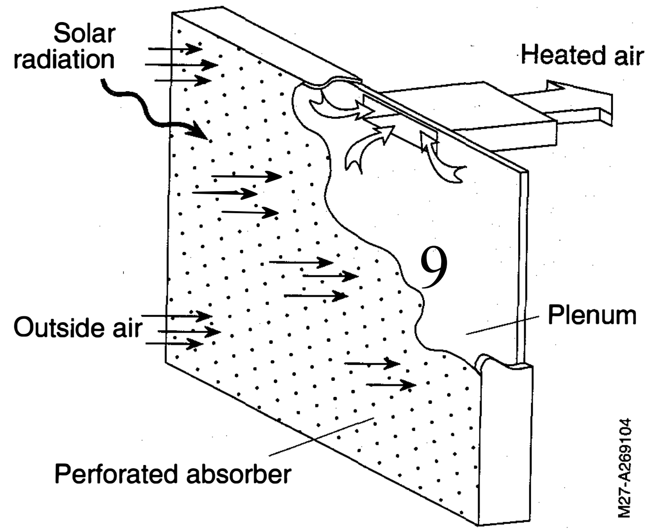

FIGURE 4. TYPICAL UNGLAZED TRANSPIRED SOLAR COLLECTOR FOR VENTILATION PREHEAT

Figure 4 shows a typical ventilation preheater. The main collector surface is composed of a perforated aluminum plate that can be either flat or ribbed and corrugated for structural support. The surface of the collector is covered with an array of equally spaced holes through which air is drawn. Plate porosity is 1% to 2%. The surface of the collector is also coated with a high-absorptance coating for absorbing the incident solar energy. The solar radiation falling on the collector surface heats the surface above the surrounding ambient temperature. As air is drawn through the holes in the collector surface, it is heated by 18°F to 27°F. The heated air then passes through the plenum and into the intake duct of the building's main ventilation system. Any additional heating required to bring the makeup air's temperature to the interior set point is supplied by the building's main heating system. During cooling months, the collector can be bypassed to prevent heating of the intake air.

The retrofit of an unglazed transpired solar collector for ventilation air preheat can often be done without adding any mechanical heating, ventilation, and air conditioning (HVAC) equipment. The pressure drop through the collector is usually quite small. As a result, it is generally possible to provide the necessary draw through the collector without adding any additional air-handling equipment. All the expenses involved in this type of retrofit are contained in the capital cost of the collector and any distribution header that may be necessary in connecting to the existing ventilation system intake.

Heating applications that benefit the most from solar ventilation preheat typically involve buildings with sufficiently large ventilation loads (makeup air rates) and suitably large blank south-facing walls. Several candidate buildings were proposed for evaluation for retrofits with transpired collectors for ventilation air preheat. None of the proposed buildings met the criteria listed below for evaluating a building's suitability for this technology. The criteria are ranked from most important to least important.

- The building must have a sufficiently large ventilation load (makeup air rate greater than 5000 cubic feet per minute).
- The building must have a south-facing wall that is large enough to accommodate the collector and on which it is architecturally acceptable to mount the collector. The wall should not be broken up by windows, or it should at least have a large section which is blank. The wall should also be relatively unshaded, not being shaded by other buildings or landscaping for significant portions of the day.
- Heat recovery in the building with heat exchangers is not a viable option. This is usually due to the nature of the ventilation system (i.e., no centralized return duct work). For this reason, office buildings are generally *not* ideal candidates for the technology. Promising candidates include, but are not limited to, industrial operations buildings and laboratory buildings.
- The building has a long heating season.
- The building is located in a good solar climate.
- The building operator is interested in using the technology.
- Ventilation air is electrically heated.
- The building has high ceilings.

RESULTS

The results of our economic analysis are categorized in Table 1

TABLE 1. RESULTS OF NREL'S RENEWABLE ENERGY SYSTEMS ANALYSIS AT THE DENVER FEDERAL CENTER

Renewable Technologies	**Site**	**Initial Investment, ($)**	**Payback Period**		**Recommendation**
			Simple, (years)	**Discounted, (years)**	
Daylighting and Lighting Management Integration	Room 290, Building 41	14,850	16	23	Implement as demonstration
	Room 288, Building 41	21,600	16	22	Long payback, not recommended
	Building 64 Day Care Center: Daylighting Retrofit	5,000	15	19	Partial implementation as demonstration
	Building 64 Day Care Center: Lighting Management	1,200	8	9	Implement
Photovoltaic Street Lamps	Parking Lot, Buildings 80 and 82	6,494	>25	>25	Implement
Photovoltaic-Powered Remote Instrumentation	Federal Center Main Sewer Discharge Line	5,137	Instant	Instant	Implement
Solar Hot-Water System	Building 64 Day Care Center	4,479	>20	>20	Implement as demonstration
Ventilation Preheat: Unglazed Transpired Solar Collectors	Building 14				Unsuitable for technology
	Building 810				Unsuitable for technology

Based on the analysis, GSA selected the following projects for implementation: the solar water-heating system, the photovoltaic-powered remote instrumentation, and both the daylighting and lighting management projects for the day care center. The daylighting project includes installing one daylighting skylight with a tracking device and one without; NREL is interested in collecting performance data from both types of systems.

CURRENT STATUS

NREL initiated pre-retrofit monitoring of the hot water and lighting loads in the day care center. Total hot water use by the day care center has been measured on an hourly averaged basis for several weeks, starting early in September. Hot water use includes sinks, a clothes washing machine, and a dishwasher. Figure 5 shows a typical profile, with an hourly averaged peak draw of about 45 gallons per hour. As seen from the figure, the usage is biased toward the morning, suggesting that the solar collectors should face slightly east of due south. Figure 6 is a bar graph showing cumulative total hot water use over a typical weekday and indicates that about 280 gallons of hot water are used daily.

The lights in the part of the day care center where the retrofits are proposed (the east and west rooms) are on a total of three separate electrical circuits. Figure 7 provides data for a typical weekday and shows that the lighting dips to zero at 1:00 p.m. (1300 hours) because all the lights are turned off during nap time after lunch.

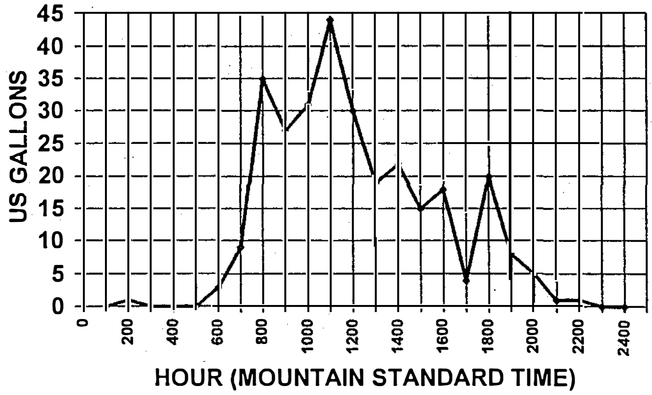

FIGURE 5. HOURLY USAGE OF HOT WATER DURING A TYPICAL WEEKDAY AT THE DAY CARE CENTER

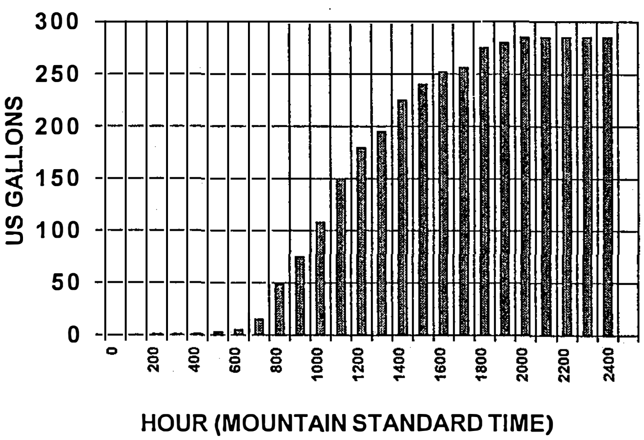

FIGURE 6. CUMULATIVE USAGE OF HOT WATER DURING A TYPICAL WEEKDAY AT THE DAY CARE CENTER

DISCUSSION AND LESSONS LEARNED

The technical issues were relatively easy to resolve. The major one, though, that we had not considered when we first looked at the technologies was the impact of glare from the daylighting skylights. Because of this characteristic, we decided not to pursue the daylighting retrofit in the offices. Instead, we agreed with the GSA to install two daylighting skylights in the day care center to collect field data for evaluating the issue further.

The procurement issues continue to be the most difficult problems to overcome, and we don't think that these issues are unique to the GSA. Problems that have plagued the project include the issue of sole sourcing versus competitive bidding, time delays, specification writing, and internal GSA coordination issues. As an example of this last issue, the vault for the sewer flow meter is being designed and specified by an organization within the GSA that is

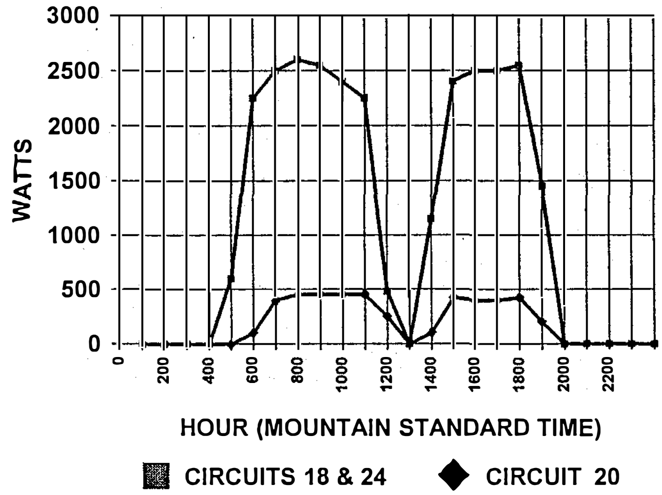

FIGURE 7. LIGHTING POWER USAGE DURING A TYPICAL WEEKDAY AT THE DAY CARE CENTER

responsible for water, not energy; therefore, the energy staff has no control over the project.

We observed that many construction projects are in progress at any one time in several of the buildings at the DFC. Consequently, it is important to coordinate and integrate the energy and renewable projects with these other projects.

In our analysis of hot water requirements for the day care center, we had underestimated water usage. We had assumed 164 gallons per day based on standards from the American Society of Heating, Refrigerating, and Air Conditioning Engineers; but as seen from the pre-retrofit monitoring of the hot water load, the usage is actually about 250 gallons per day.

We identified some good opportunities for energy savings in day care centers. We will prepare a short brochure, targeted for operators of day care centers, that discusses some of these opportunities.

CONCLUSIONS

A wide range of appropriate renewable energy technologies were evaluated for buildings at the DFC. NREL provided a technology-neutral assessment to identify the most appropriate renewable energy systems to meet the DFC's needs. The project provides a good opportunity in dealing with the challenges of implementing renewable retrofits in the federal government. It has allowed NREL and the GSA to screen projects and assess opportunities, as well as do pre-retrofit monitoring. The major barrier to date has been procuring the hardware. Once the GSA hurdles this barrier, the results of the pre- and post-retrofit should be useful to many people.

ACKNOWLEDGEMENTS
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