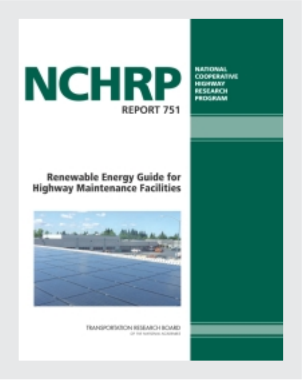

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 751

Renewable Energy Guide for Highway Maintenance Facilities

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TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2013
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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FOREWORD

By Edward T. Harrigan
Staff Officer
Transportation Research Board

This report presents a guide for the application of renewable energy technologies to the heating and cooling, lighting, and electrical power requirements of highway maintenance facilities. The guide will be of immediate interest to staff of state departments of transportation responsible for the planning, design, construction, and operation of these facilities.

NCHRP Project 20-85, "Renewable Energy Guide for Highway Maintenance Facilities," was conducted by Science Applications International Corporation, McLean, Virginia, with participation by New West Technologies, LLC, Landover, Maryland.

The objective of the project was to develop a guide for the planning, design, and operation of new and retrofitted highway maintenance facilities that are sustainable and energy efficient over their service lives through the effective use of energy capture technologies. In this project, the term "highway maintenance facility" was defined as a building used to garage, repair, and maintain vehicles and equipment, with associated storage, shop, office, and other occupied spaces. The term "energy capture technology" refers to the use of both active, renewable (such as wind, solar, and ground-source) energy sources and passive (such as solar-thermal) building and site modifications.

The development of the guide comprised several major tasks. The research team first conducted an extensive review of the worldwide literature on the use of renewable energy technologies to heat and cool, light, and provide electrical power for maintenance facilities operated by highway agencies as well as organizations such as transit agencies and the military. The literature review was supported by a survey of state, local, and municipal highway agencies, organizations with similar missions, and technology vendors to determine (1) energy capture technologies currently employed at highway maintenance facilities, (2) existing or planned highway maintenance facilities where energy capture technologies can be effectively employed, and (3) strategies for financing projects incorporating renewable energy sources. Finally, the survey results were used to identify case studies of the use of renewable energy technologies in highway and non-highway maintenance facilities.

The guide provides information specific to regional and facility-functional requirements and is suitable for possible adoption by AASHTO. It provides an extensive set of case studies illustrative of the use, benefits, and costs of renewable energy technologies in a variety of geographic and climatic regions in the United States.

The guide fully documents the results of the research and includes an appendix for estimating the costs and capabilities of several renewable energy sources and a glossary of terms.

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PART III Renewable Energy Technologies and Strategies

PART IV Case Studies

ABBREVIATIONS

AASHTO	American Association of State Highway Transportation Officials
AC	alternating current
ACH	air changes per hour
AGM	absorptive glass matt
ARRA	American Recovery and Reinvestment Act
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
AWEA	American Wind Energy Association
BAS	building automation system
BIM	building information model
BRAC	base realignment and closure
BBtu	billion Btu
Btu	British thermal unit
Btu/h	Btu per hour
Caltrans	California Department of Transportation
CBECS	Commercial Building Energy Consumption Survey
CDD	cooling degree day
CEC	California Energy Commission
CF	capacity factor
cf	cubic feet
cfm	cubic feet per minute
CHP	combined heat and power
CPI	Consumer Price Index
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COP	coefficient of performance
CREB	Clean renewable energy bond
CSP	concentrating solar power
DC	direct current
DOE	Department of Energy
DOT	Department of Transportation
DSIRE	Database of State Incentives for Renewables and Efficiency
DX	direct exchange
ECIP	Energy Conservation Investment Program
EER	energy efficiency ratio
EIA	Energy Information Administration
ERDC-CERL	Engineer Research and Development Center–Construction Engineering Research Laboratory
ERV	energy recovery ventilator
ESCO	energy services company
ESPC	energy savings performance contract

EUI	energy use intensity
fc	foot candle
FEMP	Federal Energy Management Program
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GHG	greenhouse gas
GHP	geothermal heat pump
HDD	heating degree day
HDPE	High-density polyethylene
HID	High-intensity discharge
HRV	heat recovery ventilator
HVAC	heating, ventilating, and air conditioning
IBC	International Building Code
ICC	International Code Council
IGCC	International Green Construction Code
IGSHPA	International Ground Source Heat Pump Association
IRR	internal rate of return
ITC	investment tax credit
kBtu	thousand Btu
kW	kilowatt
LCCA	life-cycle cost analysis
LCOE	levelized cost of energy
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
MACRS	Modified Accelerated Cost Recovery System
MMBtu	million Btu
MMBtu/h	million Btu per hour
m/s	meter per second
MW	megawatt
MTA	Metropolitan Transit Authority
NAS	National Academy of Sciences
NCHRP	National Cooperative Highway Research Program
NFPA	National Fire Protection Association
NIBS	National Institute of Building Sciences
NIST	National Institute of Science and Technology
NPV	net present value
NREL	National Renewable Energy Laboratory
NYPA	New York Power Authority
NYSERDA	New York State Energy Research and Development Authority
O&M	operation and maintenance
OSHA	Occupational Safety and Health Administration
PBF	public benefit fund
PV	photovoltaic
PTC	PVUSA test condition
PW	present worth
QECB	Qualifying energy conservation bond
RE	renewable energy
REC	renewable energy certificate
RFP	request for proposals
RLF	revolving loan fund

RPS	renewable portfolio standard
SDHW	solar domestic hot water
SEER	seasonal energy efficiency ratio
SIR	savings to investment ratio
SRCC	Solar Rating and Certification Corporation
SREC	solar renewable energy certificate
SSMR	standing seam metal roof
STC	standard test condition
SWCC	Small Wind Certification Council
TDS	total dissolved solids
TEMF	tactical equipment maintenance facility
TMY	typical meteorological year
TRB	Transportation Research Board
TSC	transpired solar collector
UL	Underwriters Laboratories
UPS	uninterruptible power supply
VFD	variable frequency drive
VRLA	valve-regulated lead acid

PART I

Introduction to the Guide

CHAPTER 1

Introduction

1.1 Background and Goals of the Guide

With few exceptions, state departments of transportation (DOTs) are facing unprecedented fiscal, energy, and environmental challenges. They are striving to reduce the energy requirements for lighting, heating, cooling, and operating highway maintenance facilities while recognizing the unique operational challenges associated with such facilities. At the same time, state governments are mandating energy conservation, energy efficiencies, and the implementation of renewable energy (RE) sources such as wind power, solar power, and ground-source heating and cooling. Toward meeting these goals, state DOTs are actively evaluating renewable energy sources for their applicability to highway maintenance facilities. Applicability metrics may include emissions reduction, emergency response, reliability, practicality, and cost-effectiveness. These alternatives to conventional energy sources may be effective alone or in combination and may even produce net energy above that required to operate the facility. In response to this situation, the National Cooperative Highway Research Program (NCHRP) launched NCHRP Project 20-85, "Renewable Energy Guide for Highway Maintenance Facilities." A principal objective of the project was to identify and develop best practices for the use of renewable energy sources and passive building and site modifications to both capture energy and reduce energy use in highway maintenance facilities. This document provides this information in the context of maintenance facility design, construction, and operation.

1.2 Scope

The *Renewable Energy Guide for Highway Maintenance Facilities* is intended for use by individuals involved in the development of vehicle maintenance facility projects and subsequent operations. These individuals include technical and management staff and those in a decision-making position. The term *highway maintenance facility* is defined as a building used to garage and repair and maintain vehicles and equipment, with associated storage, shop, office, and other occupied spaces. The term *renewable energy* refers to the use of solar, wind, and ground sources of energy for meeting building energy needs. This is accomplished through a variety of technologies that convert the renewable energy resources into electricity or thermal energy. This includes renewable electric technologies such as solar photovoltaics (PVs), wind, and concentrating solar power and active solar heating, geothermal heat pumps, and passive solar strategies that use building design elements to naturally heat, cool, and (day) light. The guide also addresses energy efficiency and whole building design (also referred to as *integrated design*) as a means to achieve facility energy and environmental objectives—particularly for new construction or major renovation situations. It addresses new construction as well as applications for existing buildings. Case studies of renewable energy technologies and strategies for vehicle maintenance facilities in various locations in the United States are also covered.

1.3 Approach

This guidebook was developed based on information from a variety of sources. A literature survey was conducted under the first phase of NCHRP Project 20-85, and a case studies document was developed under the second phase of the project. The case studies provided lessons-learned information from planning through operation and are included as Part IV of the guide. Information was also accessed from organizations such as the U.S. Department of Energy (U.S. DOE)/Office of Energy Efficiency and Renewable Energy (EERE), the National Renewable Energy Laboratory (NREL), and the National Institute of Building Sciences (NIBS).

1.4 Brief Overview of Each Section

The guidebook is organized as follows:

PART I: INTRODUCTION TO THE GUIDE

Chapter 1: Introduction. This chapter provides background information about the guide, its scope, and the approach used in assembling the information, as well as a brief overview of each section.

PART II: GENERAL CONSIDERATIONS

Chapter 2: Overview of Highway Maintenance Facilities. This chapter provides background and historical context for development of maintenance facilities, along with functional attributes of maintenance facilities, focusing on how these relate to energy use.

Chapter 3: General Project Considerations. This chapter examines the motivations for using renewable energy, the process of identifying renewable energy options, and ways to incorporate renewable energy into maintenance facilities, and includes a discussion of the project development processes.

Chapter 4: Project Financing. This chapter discusses the means by which renewable energy projects can be financed, what options are open to owners of maintenance facilities, and funding mechanisms, including direct funding, bonds, public benefit funds, revolving loan funds, third-party ownership, energy savings performance contracting, renewable energy certificates, and renewable energy incentives.

Chapter 5: Applicability Guide. The applicability guide provides some basic information about regional, site, and building considerations to help determine the renewable technologies of interest. It also provides a general screening approach and touches on economic evaluation methods.

PART III: RENEWABLE ENERGY TECHNOLOGIES AND STRATEGIES

Part III provides information about renewable energy technologies, including technology characteristics, cost and performance, applicability considerations, economics, design considerations, and screening methods. Selected technologies have best-practices information covering the planning, design, construction, and operation phases of project development. This is provided for each technology that is most likely to be implemented at maintenance-type facilities, not for all technologies. Energy efficiency and demand reduction is included in this section at a summary level due to the importance of this topic in making investments in renewable energy more effective. Energy storage is included since it is an enabling technology for enhancing the value of renewable energy. A chapter on general best practices applicable across renewable energy technologies is also included. The information provided is not engineering guidance but does include technical and programmatic elements. The chapters in Part III are:

Chapter 6: Energy Efficiency and Demand Reduction
Chapter 7: Daylighting

Chapter 8: Passive Solar Heating
Chapter 9: Natural or Passive Cooling
Chapter 10: Active Solar Heating
Chapter 11: Photovoltaics
Chapter 12: Concentrating Solar Power
Chapter 13: Wind Energy
Chapter 14: Geothermal Energy
Chapter 15: Biomass
Chapter 16: Hydroelectric (Small Scale)
Chapter 17: Energy Storage
Chapter 18: Emerging and Alternative Energy Technologies
Chapter 19: General Best Practices for Implementing Renewable Energy Technologies and Strategies

PART IV: CASE STUDIES

Chapters 20 through 22: This part includes the previously stand-alone document, “Case Studies of Renewable Energy Technologies on Transportation Maintenance Facilities.” It provides information on 11 renewable energy projects on vehicle maintenance or similar facilities, including lessons learned and best practices.

PART II

General Considerations

CHAPTER 2

Overview of Highway Maintenance Facilities

2.1 Overview

Many highway maintenance facilities were constructed during the rapid expansion of the U.S. highway system following World War II. Aging infrastructure is now an issue as some facilities will be closed and replaced with new facilities while others will be repurposed, updated, or renovated. This offers significant opportunity to incorporate renewable energy technologies and energy efficiency strategies in the next generation of highway maintenance facilities. While an increasing number of state transportation departments have expressed an interest in or have plans to build more efficient facilities and include renewable energy features, it is also clear that budget pressures make this a challenging proposition.[1] This is particularly true for facilities that will be built in regions that do not have relatively high utility prices or access to financial incentives to reduce the costs of the renewable energy systems. Nonetheless, consideration of renewable energy early in the process—from site planning to building design features—can make it possible to cost-effectively incorporate renewables at a later time.

The location of a site selected for a new facility as well as the size and characteristics of the site can affect the facility's energy use. In addition to the energy consumed by the building and its operations, consideration of the facility's service area and commuting distance for employees will also affect the overall energy consequences of the project. If renewable energy is being considered as part of a project, a thorough analysis of the opportunities for its deployment should be made of any site under consideration.

Additionally, environmental regulations (such as storm water management and treatment, site pollution containment) may have an impact on the selection of the site. Aspects of the site during the site selection process to consider, in addition to zoning restrictions, appropriate location, and adequate area, include:

- Availability of utilities,
- Access to adequate roadway infrastructure,
- Setback requirements,
- Floodplains and wetlands,
- Slope,
- Suitability of subsurface soils, and
- Existing vegetation and/or development on the site.

These items can all have an impact on the project budget and overall project feasibility, as well as the incorporation of renewable energy strategies.

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[1] Under phase I of NCHRP Project 20-85, 13 of 17 state DOTs responding to a survey indicated that they had plans to implement renewable energy systems at their facilities.

If pursuit of a building rating certification [such as Leadership in Energy and Environmental Design (LEED)] is being considered, site selection can have a significant impact on the rating score of the project and should be an integral part of the site selection process. Site selection should be based on the nature of the operations to take place at the facility as well as the quantity and types of vehicles actively using the site.

2.2 Building Functional Characteristics

Maintenance facilities serve a wide variety of needs, from simple maintenance and fluid changes for fleet cars and light trucks to major overhauls of large equipment such as bucket loaders, graders, and snowplows. They also frequently incorporate office and storage functions. A maintenance facility may house a number of personnel such as mechanics, drivers, road maintenance crews, supervisors, and administrative staff.

Any maintenance building will have an indoor space for mechanics to work on vehicles, ranging from a small bay to any number of large bays, the size dictated by the largest vehicle requiring servicing. Maintenance bays will have space for a mechanic to access the vehicle, tools, equipment, usually a vehicle lift, access to compressed air, and other aspects associated with vehicle repair and maintenance. Specialty bays or areas may also be required depending on the type of work; these can include welding and bodywork areas, tire repair, or other vehicle-related maintenance, each requiring specialty tools and design consideration. Wash bays require special consideration because of water capture, treatment, recycling, heating, and chemicals necessary for washing vehicles.

Other common elements in maintenance facilities are break rooms, restrooms, showers, parts storage, hazardous materials storage (batteries, solvents, fuel, and so forth), outdoor parking, and sometimes indoor vehicle storage and parking. Each of these spaces has its own functional requirements, energy use profile, and potential for energy reduction and utilization of renewable energy. Table 2-1 summarizes the typical primary end-use energy load drivers for a number of common spaces.

2.2.1 Office

Office spaces need to be kept at a comfortable temperature during working hours and meet general and task lighting requirements. For the heating and cooling requirements, it is common to find conditioned forced air ventilation. Plug loads include computers, copiers, and other typical office-type equipment.

2.2.2 Maintenance Bay

Heating and cooling maintenance bays can be a challenge. Two of the main features are high ceilings for lift clearance and large door openings. When bay doors are open, they allow uncontrolled infiltration, and the bays equalize with the ambient atmosphere. In addition, extra ventilation must be accounted for—1.5 cubic feet of air per minute removed per square foot of shop space,[2] with powered direct ventilation for any stationary running engines inside the building. Air cannot be recirculated from garage bays, but is directly exhausted. Such large ventilation loads require a large quantity of outdoor air to replace the heated exhaust air. In conjunction with heating the incoming air, many shop spaces use radiant heaters, either the infrared overhead gas-tube type or in-floor radiant heat.

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[2] ASHRAE, 2010a. Table 6.4, Minimum Exhaust Rates.

Table 2-1. End-use energy load drivers by space type or function type.

	Plug Loads	Heating and Cooling	Ventilation	Lighting	Water Heating
Office	Computers, office equip. up to 50% of electric load	Forced air	2–3 ACH	10 fc general, with additional task lighting ~30 fc	
Maintenance bay	Compressed air system, power tools, welders, installed equipment	Very little forced air – mostly radiant heating	20–30 ACH	10 fc general, portable task lighting	
Restrooms/ showers/lockers	N/A	Forced air	Exhaust fan always on. 5–6 ACH	10 fc general	Hot water
Break/kitchen	Microwave, refrigerator, water cooler, etc.	Forced air	5–6 ACH	10 fc general	Hot water
Training/meeting	TV, projector, computers, etc.	Forced air	2–3 ACH	10 fc general	
Storage	Inventory, computers	Minimal – forced air, if conditioned at all	2–3 ACH, unless specialized storage (batteries, tires, fuel, etc.)	5–10 fc	
Parking/security lighting	Block heaters, electric vehicle charging	N/A	N/A	Security lighting, ~5 fc	
Wash bays	N/A	Forced air or radiant heat	20–30 ACH	10 fc general	Hot water

Note: ACH = air changes per hour; fc = foot candles.

Many areas of the United States do without mechanical cooling in the bay areas. This necessitates natural ventilation schemes that allow hot air to escape from the top of the building while bringing in cooler air from ground level, or forced ventilation without cooling.

2.2.3 Restrooms/Showers/Lockers

Depending on the number of people at the site, restrooms may be shared with office areas or be separate and can include showers and locker room areas. In some cases, dedicated laundry facilities are provided. Energy loads include water heating for showers, laundry, and lavatory sinks. Electrical loads include lighting, hand dryers, and exhaust air ventilation systems. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standards for bathroom ventilation are 50 cubic feet per minute (cfm)/fixture continuous or 100 cfm/fixture.

2.2.4 Break/Kitchen/Training

Break rooms and kitchens may have a varying level of equipment, but often will include a water cooler, vending machines, coffee maker, microwave, refrigerator, dishwasher, and sink.

2.2.5 Storage

Storage can range in complexity from an outdoor area where equipment such as plows are kept, to more complex or separate areas for storage of batteries, tires, flammable liquids, and parts.

Certain types of storage may have special requirements or limitations. Refer to the requirements of the applicable building code and its referenced standards for specific requirements for storage of these types of items.

2.2.6 Parts Inventory

Most repairs involve some sort of powered tools. Many shops have a central compressed air system to run a variety of tools, including impact wrenches and grinders. Hydraulic pumps and hydraulic pressure systems are used for lifts, presses, and tire mounting machines, among others. Lighting, exhaust ventilation, parts washers, metalworking machines, welders, vacuums, and any variety of other tools used in the process of maintaining vehicles and the building itself contribute to energy use.

2.2.7 Parking/Security Lighting

Parking lot lighting can consume a significant amount of electrical energy. Typical lighting at highway maintenance facilities includes parking lot and exterior storage areas. Other loads external to the building can include vehicle crankcase heaters (in cold climates) and electric vehicle charging stations. Crankcase heaters represent a considerable power draw and should be considered in determining facility electrical demand.

2.2.8 Specialty

Many maintenance facilities will require spaces for specialized tasks outside of mechanical work. These specialty needs may require specific building designs and energy needs.

2.2.8.1 Wash Bays

Cleaning vehicles regularly can increase the longevity of the vehicles by making needed repairs, leaks, or corrosion easier to spot. Vehicle washing is therefore usually a part of a highway maintenance facility. Wash bays can be a dedicated space to wash vehicles within a garage or an automated system in a separate building for larger facilities. In some climates, the wash bay may be external to the building. Most codes require oil separators to treat wastewater from vehicle washing. Washing with heated water is a common practice in some areas and increases the effectiveness of soaps used. Heating and ventilation considerations can be similar to maintenance bays but must account for additional moisture/water vapor. This includes provisions to prevent freezing of water that drips off of the vehicles as they exit the facility.

2.2.8.2 Battery/Chemical Storage Rooms

Battery storage and chemical storage are separate tasks that require separate and dedicated spaces. Consult with the appropriate sections of Occupational Safety and Health Administration (OSHA), National Fire Protection Association (NFPA), and International Building Code (IBC) codes for the proper design and operation of these facilities.

2.2.8.3 Other

Depending on the complexity of the highway maintenance facility, there may be a variety of other activities with significant energy requirements, including:

- Welding. Highly energy intensive and produces large quantities of air contaminants. Use of modern inverter welding power sources can reduce the fume generation for pulsed-gas metal arc welding,[3] and local, demand-controlled ventilation can exhaust welding fumes, much the same as with vehicle exhaust systems.

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[3] Zhivov, 2006. http://www.pertan.com/FTLee/Zhivov_Welding.pdf.

- Paint booth. Highly energy intensive, the painting process uses pumps for paint sprayers or sophisticated electrodeposition. Lighting is provided on five sides of a square paint enclosure to provide uniform lighting while painting. OSHA standard 1910.94(c)(4) regulates the construction of spray booths and ventilation. Ventilation is required in paint spray booths to prevent paint or solvent vapors from reaching lower explosive limits, and this can also be energy intensive. Some paint booths are heated after application of paint, while maintaining the air quality, to aid in curing various types of paints and clear coats.

2.3 Energy Use in Maintenance Facilities

Energy use in maintenance facilities varies widely based on the specific construction characteristics of the buildings, their size, and their location. NREL estimates that energy use intensity (EUI) is between 27 and 101 thousand Btu per square foot per year (kBtu/ft^2/year), although some sources estimate it as high as 120 kBtu/ft^2/year. Maintenance facilities and vehicle service shops across the country have a number of unique attributes that contribute to an energy use profile that is quite unlike most other commercial buildings. One of these attributes is that a large portion of the buildings usually consist of vehicle repair bays, which are large, open spaces with high clearance, high ventilation demand, high heating demand in winter, and generally no cooling in summer. Even with attached office space, the vehicle bays are often a main driver of total energy consumption because of their design. The 2003 Commercial Building Energy Consumption Survey (CBECS) shows that by far the main drivers of energy use in the vehicle service category are heating and lighting, followed by process loads, which are categorized as "miscellaneous" (see Figure 2-1).[4] Process loads are generally the energy/load required to run equipment used in the servicing or repair of vehicles, including compressed air systems, welding, and any number of power tools used.

Recently, the U.S. Army Corps of Engineers Construction Energy Research Laboratory (CERL) and NREL worked together to examine energy use and possible energy reduction strategies for tactical equipment maintenance facilities (TEMFs). In order to do this, they developed an EnergyPlus energy model of a TEMF in each ASHRAE climate zone (see Figure 2-2) using minimum performance values from ASHRAE 90.1-2007.[5] These modeled values were taken as the baseline levels for TEMF locations and are much lower than the CBECS 2003 data for "other repair service" buildings (see Table 2-2).

The TEMF simulations have slightly different energy use categories than CBECS, so a direct comparison is not possible. However, in most climates heating dominates the energy use, followed by ventilation, lighting, and process energy (see Figure 2-3).[6]

When comparing the TEMF-modeled end use characteristics with the CBECS data for the different climate zones, it is apparent from both that lighting energy is relatively constant regardless of location. It follows that daylighting strategies may hold significant promise for the latitudes that have more consistent daylight during operating hours (Figure 2-4).

The CBECS survey shows a large proportion of heating energy even in warm climates (see Table 2-3), while the TEMF model shows an expected decrease. (Note that the TEMF model uses different climate zone notations than CBECS.) This may mean that measures to reduce heating energy should be examined for more moderate climate regions as well as for colder climates.

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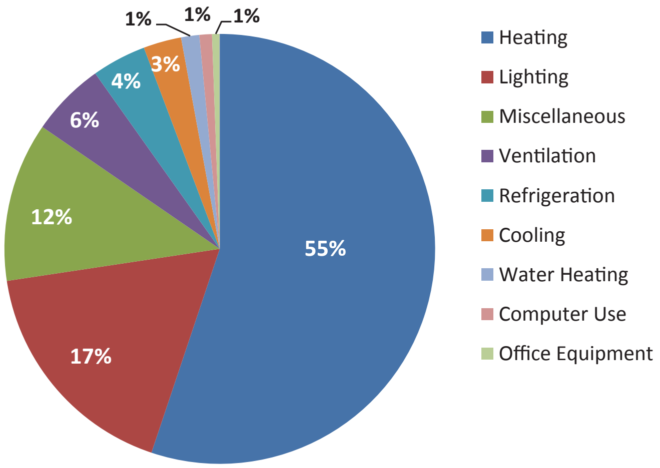
[4] U.S. Department of Energy. Buildings Energy Data Book. http://buildingsdatabook.eren.doe.gov/CBECS.aspx.

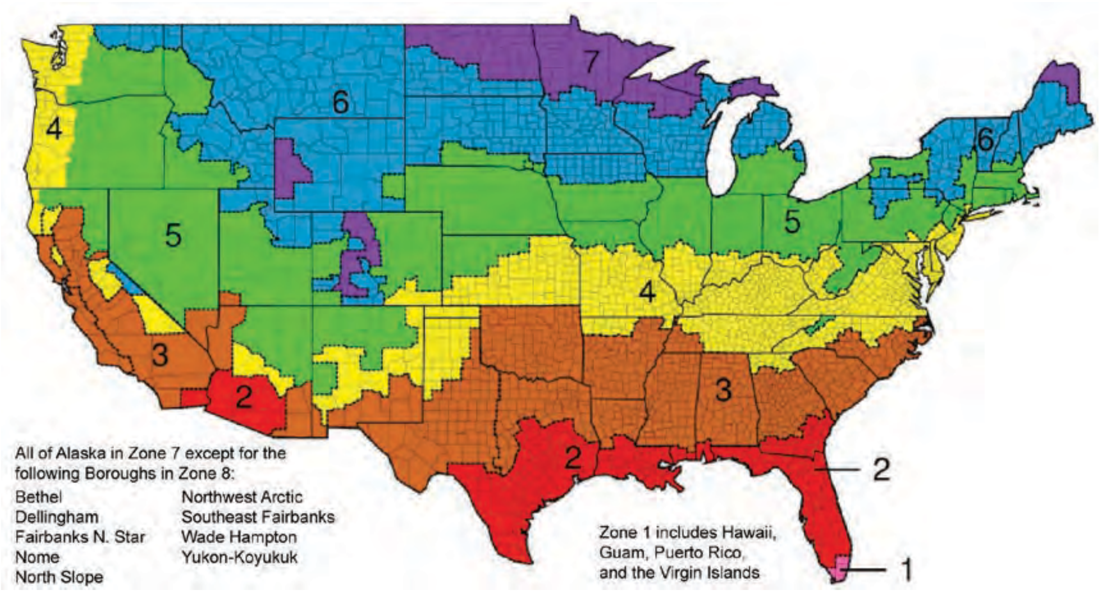
[5] EnergyPlus is hourly building energy analysis software and is available from U.S. DOE. http://apps1.eere.energy.gov/buildings/energyplus/.

[6] Langner, 2012.



Source: CBECS, 2003.

Figure 2-1. Energy consumption by end use, vehicle service commercial buildings.



All of Alaska in Zone 7 except for the following Boroughs in Zone 8:

Bethel	Northwest Arctic
Dellingham	Southeast Fairbanks
Fairbanks N. Star	Wade Hampton
Nome	Yukon-Koyukuk
North Slope	

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands

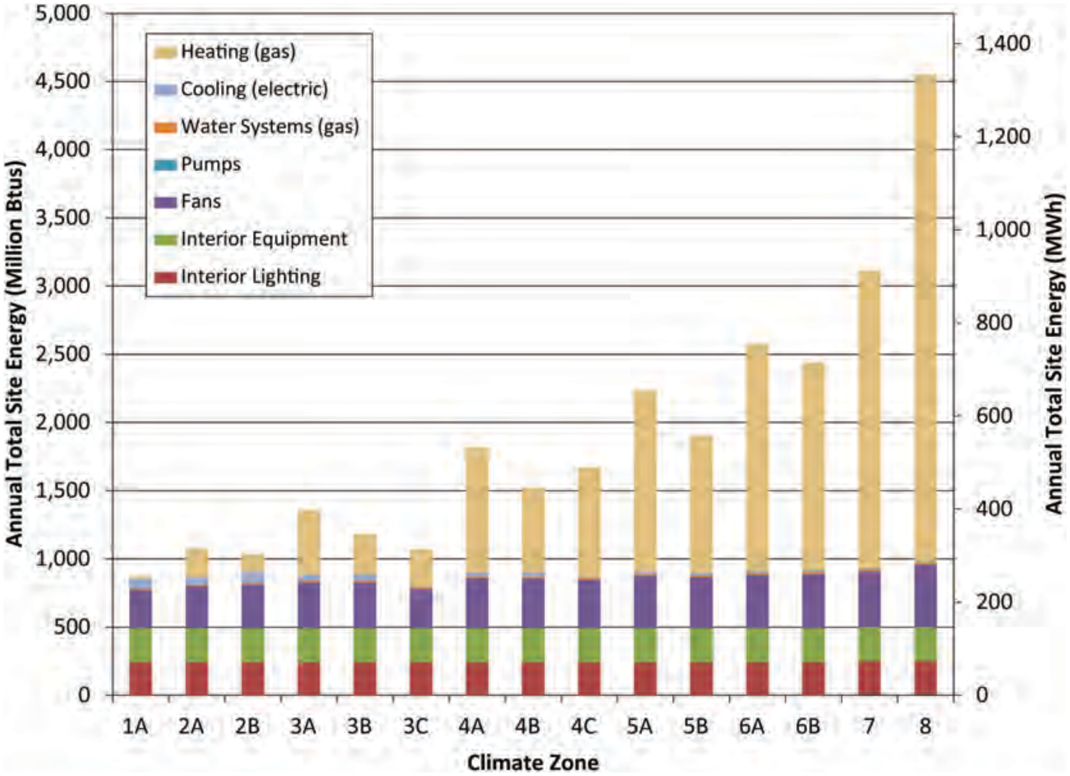
Source: http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/dbimages/full/973.jpg.

Figure 2-2. ASHRAE climate zone map.

Table 2-2. CBECS 2003 "other repair service" versus TEMF-modeled baseline EUI.

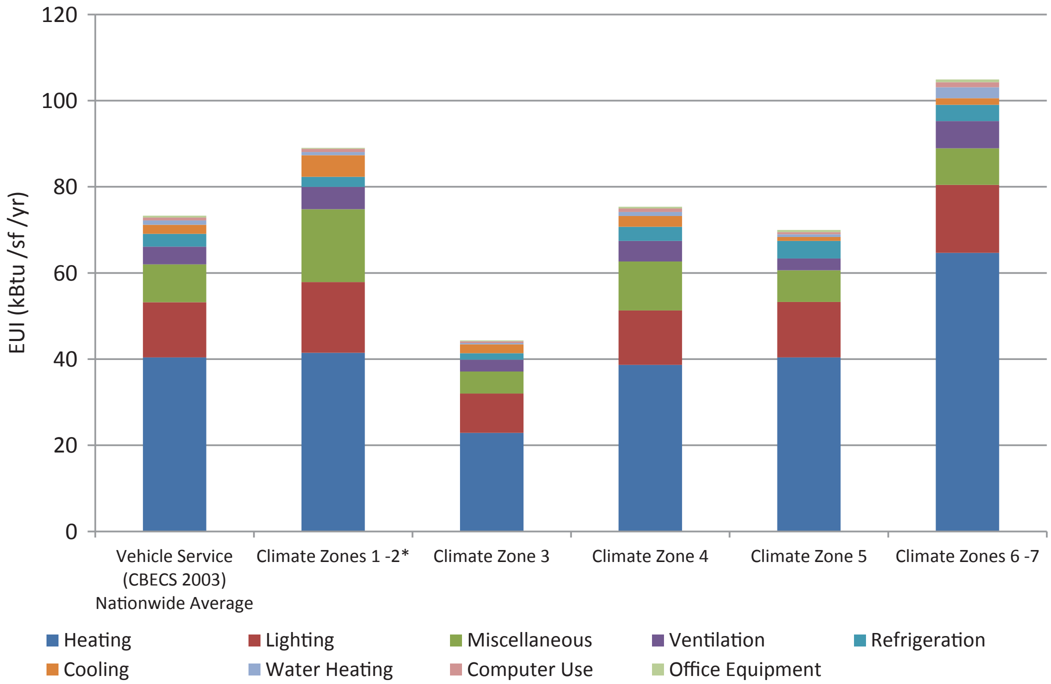
ASHRAE Climate Zone	City	CBECS 2003 Site Energy Budget kBtu/ft^2(kWh/m^2)	Baseline Site Energy Budget kBtu/ft^2 (kWh/m^2)
1A	Miami, FL	85 (268)	27 (85)
2A	Houston, TX	84 (265)	33 (104)
2B	Phoenix, AZ	82 (259)	31 (98)
3A	Memphis, TN	84 (265)	41 (129)
3B	El Paso, TX	79 (249)	36 (114)
3C	San Francisco, CA	76 (240)	32 (101)
4A	Baltimore, MD	93 (293)	55 (173)
4B	Albuquerque, NM	83 (262)	46 (145)
4C	Seattle, WA	86 (271)	51 (161)
5A	Chicago, IL	100 (315)	68 (214)
5B	Colorado Springs, CO	90 (284)	58 (183)
6A	Burlington, VT	111(350)	78 (246)
6B	Helena, MT	101(319)	74 (233)
7	Duluth, MN	119(375)	94 (296)
8	Fairbanks, AK	158(498)	138 (435)

Source: NREL/CP-5500-53810.



Source: NREL/CP-5500-53810.

Figure 2-3. TEMF baseline annual energy consumption by end use.



*Due to the few buildings (13) that were sampled in these regions, these data are not considered representative.

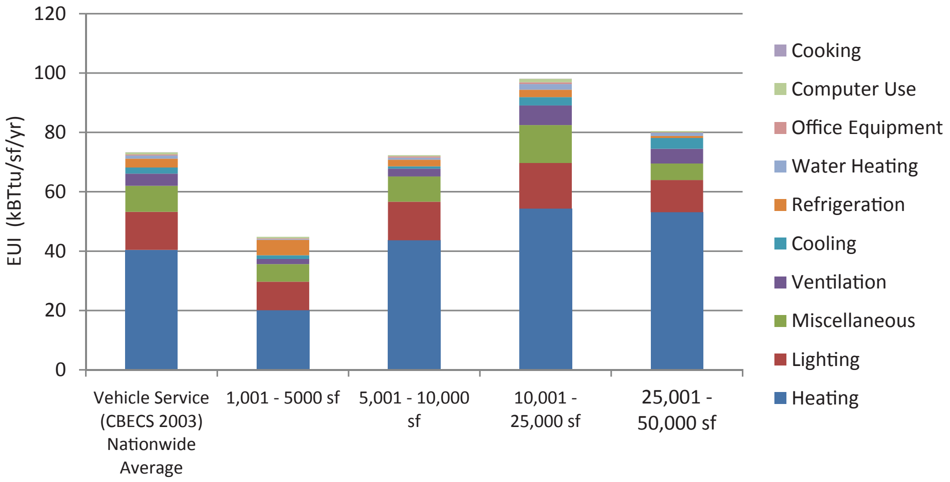
Source: CBECS, 2003.

Figure 2-4. Vehicle service building EUI by end use and climate zone.

Table 2-3. Annual energy consumption and EUI by fuel, end use, and climate zone.

	Vehicle Service (CBECS, 2003) Nationwide Total		Vehicle Service (CBECS, 2003) ASHRAE Climate Zones 7,6		Vehicle Service (CBECS, 2003) ASHRAE Climate Zone 5		Vehicle Service (CBECS, 2003) ASHRAE Climate Zone 4		Vehicle Service (CBECS, 2003) ASHRAE Climate Zone 3		Vehicle Service (CBECS, 2003) ASHRAE Climate Zones 2, 1	
Fuels	BBtu	kBtu/ft^2	BBtu	kBtu/ft^2	BBtu	kBtu/ft^2	BBtu	kBtu/ft^2	BBtu	kBtu/ft^2	BBtu	kBtu/ft^2
Electricity	37,820	31.27	9,479	39.28	8,936	28.82	7,724	34.98	7,067	22.03	5,153	38.15
Natural gas	46,770	38.67	15,544	64.41	10,063	34.54	7,507	34	6,781	21.13	6,845	50.89
Fuel oil	4,040	3.34	297	1.23	1,935	6.64	1,409	6.38	397	1.24	2	0.01
All major fuels	88,630	73.28	25,320	104.92	20,395	69.99	16,640	75.36	14,245	44.4	12,029	89.06
End Use	BBtu	kBtu/ft^2	BBtu	kBtu/ft^2	BBtu	kBtu/ft^2	BBtu	kBtu/ft^2	BBtu	kBtu/ft^2	BBtu	kBtu/ft^2
Heating	48,871	40.41	15,609	64.68	11,778	40.42	8,536	38.66	7,348	22.9	5,600	41.46
Cooling	2,524	2.09	376	1.56	259	0.89	552	2.5	660	2.06	677	5.01
Ventilation	4,960	4.1	1,525	6.32	800	2.74	1,057	4.79	875	2.73	702	5.2
Water heating	1,207	1	605	2.51	192	0.66	207	0.94	107	0.33	97	0.72
Lighting	15,488	12.81	3,809	15.78	3,742	12.84	2,788	12.63	2,930	9.13	2,218	16.42
Cooking	12	0.01	0	0	0	0	0	0	12	0.05	0	0
Refrigeration	3,620	2.99	910	3.77	1,888	4.08	721	3.27	485	1.51	315	2.33
Office Equipment	490	0.41	155	0.64	150	0.52	93	0.42	61	0.19	31	0.23
Computer use	835	0.69	287	1.19	139	0.48	177	0.8	128	0.4	104	0.77
Miscellaneous	10,620	8.78	2,045	8.47	2,146	7.36	2,508	11.36	1,637	5.1	2,285	16.91
	Vehicle service sample size: 125 represents 212,817 buildings w/ total area of 1,209,465,858		Sample size: 21 represents 28,523 buildings w/ total area of 241,336,600 ft^2		Sample size: 21 represents 28,523 buildings w/ total area of 241,336,600 ft^2		Sample size: 21 represents 36,817 buildings w/ total area of 220,805,100 ft^2		Sample size: 30 represents 55,579 buildings w/ total area of 320,869,808 ft^2		Sample size: 13 represents 21,713 buildings w/ total area of 135,076,850 ft^2	

Source: CBECS, 2003. Note: BBTu = billion Btu.



Source: CBECS, 2003.

Figure 2-5. Vehicle service EUI by end use and size.

Figure 2-5 shows the energy end-use distribution as a function of building size (floor area). Table 2-4 displays this same information in tabular form.

The wide variety of energy use exhibited by maintenance facilities results in a range of energy saving or renewable solutions being most effective depending on climate, building size, and use characteristics, among other factors. Both the TEMF and CBECS data show that lighting energy use is relatively constant.

Table 2-4. Annual energy consumption and EUI by end use and building floor areas.

	Vehicle Service (CBECS, 2003) Nationwide Total		**Vehicle Service (CBECS, 2003) 1,001–5,000 ft^2**		**Vehicle Service (CBECS, 2003) 5,001–10,000 ft^2**		**Vehicle Service (CBECS, 2003) 10,001–25,000 ft^2**		**Vehicle Service (CBECS, 2003) 25,001–50,000 ft^2**	
Fuels	Total BBtu	kBtu/ft^2	Total BBtu	kBtu/ft^2	Total BBtu	kBtu/ft^2	Total BBtu	kBtu/ft^2	Total BBtu	kBtu/ft^2
Electricity	37,820	31.27	9,324	25.52	7,082	26.33	15,765	39.74	4,271	27.49
Natural gas	46,770	38.67	5,368	14.69	10,622	39.49	22,555	56.85	8,225	52.93
Fuel oil	4,040	3.34	1,672	4.58	1,757	6.53	601	1.51	1.11	0.01
All major fuels	88,630	73.28	16,364	44.79	19,461	72.35	38,920	98.1	12,498	80.43
End Use	Total BBtu	kBtu/ft^2	Total BBtu	kBtu/ft^2	Total BBtu	kBtu/ft^2	Total BBtu	kBtu/ft^2	Total BBtu	kBtu/ft^2
Heating	48,871	40.41	7,336	20.08	11,740	43.65	21,543	54.3	8,251	53.1
Lighting	15,488	12.81	3,512	9.61	3,493	12.99	6103	15.38	1,683	10.83
Miscellaneous	10,620	8.78	2,163	5.92	2,293	8.52	5074	12.79	871	5.6
Ventilation	4,960	4.1	640	1.75	713	2.65	2618	6.6	771	4.96
Refrigeration	3,620	2.99	1,881	5.15	609	2.27	989	2.49	104	0.67
Cooling	2,524	2.09	455	1.25	203	0.75	1,122	2.83	564	3.63
Water heating	1,207	1	105	0.29	170	0.63	764	1.93	167	1.08
Computer use	835	0.69	178	0.49	107	0.4	467	1.18	61	0.39
Office equipment	490	0.41	94	0.26	132	0.49	227	0.57	26	0.17
Cooking	12	0.01	0	0	0	0	15	0.04	0	0
	Sample size: 125 represents 212,817 buildings with total area of 1,209,465,858 ft^2		Sample size: 59 represents 141,231 buildings with total area of 365,372,100 ft^2		Sample size: 24 represents 38,082 buildings with total area of 268,969,200 ft^2		Sample size: 29 represents 27,458 buildings with total area of 396,732,250 ft^2		Sample size: 11 represents 5,046 buildings with total area of 155,398,308 ft^2	

Source: CBECS, 2003.

CHAPTER 3

General Project Considerations

3.1 Why Use Renewable Energy?

The buildings in which we work serve a wide variety of purposes, protect us from nature's extremes, and yet also affect our health and environment. As the environmental impact of buildings has become more apparent, sustainable design and renewable energy have become ever more important. Sustainability and renewable energy go hand in hand, although it is possible to pursue either strategy independently. Sustainable buildings work to optimize energy efficiency and renewable energy, water efficiency and use, building materials selection, waste reduction, toxin reduction, indoor air quality, and smart growth and development. In general, the most effective approaches seek to minimize the building's energy requirements through energy efficiency and climate-sensitive design, use efficient equipment and design strategies, and incorporate renewable energy where feasible to meet a portion of the remaining energy needs (see Figure 3-1). Energy efficiency and energy conservation play key roles in reducing energy requirements and the size of the load that must be met by renewable energy. High-performance buildings employing aggressive energy efficiency and conservation measures can reduce loads by 50% or more compared to standard buildings. Since renewable energy systems have relatively high capital costs and low operating costs, smaller systems will result in lower project costs.

There are many different strategies on how to approach each issue in an organized, robust manner and to create a balance between them that results in better buildings with lower environmental impacts. These strategies have been codified into ratings systems, building and construction codes, and a number of guides:

- ASHRAE Standard 189.1.[7] ASHRAE Standard 189.1 addresses site sustainability, water use efficiency, energy efficiency, indoor environmental quality (IEQ), and the building's impact on the atmosphere, materials, and resources. These five key subject areas, as well as plans for construction and high-performance operation, are each addressed in a separate chapter. Standard 189.1 is used in conjunction with ASHRAE/Illuminating Engineering Society of North America (IESNA) Standard 90.1-2007, and ASHRAE Standards 62.1-2007 and 55-2004, but any requirements supersede those standards.
- International Green Construction Code (IGCC).[8] The IGCC creates a regulatory framework for new and existing buildings, establishing minimum green requirements for buildings and complementing voluntary rating systems that may extend beyond the customizable baseline of the IGCC. The code acts as an overlay to the existing set of international codes, including

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[7] ASHRAE, 2010b. Standard 189.1, The Green Standard. http://www.ashrae.org/resources--publications/bookstore/standard-189-1.

[8] The International Code Council (ICC), 2012 International Green Construction Code. Washington, D.C., March 2012.

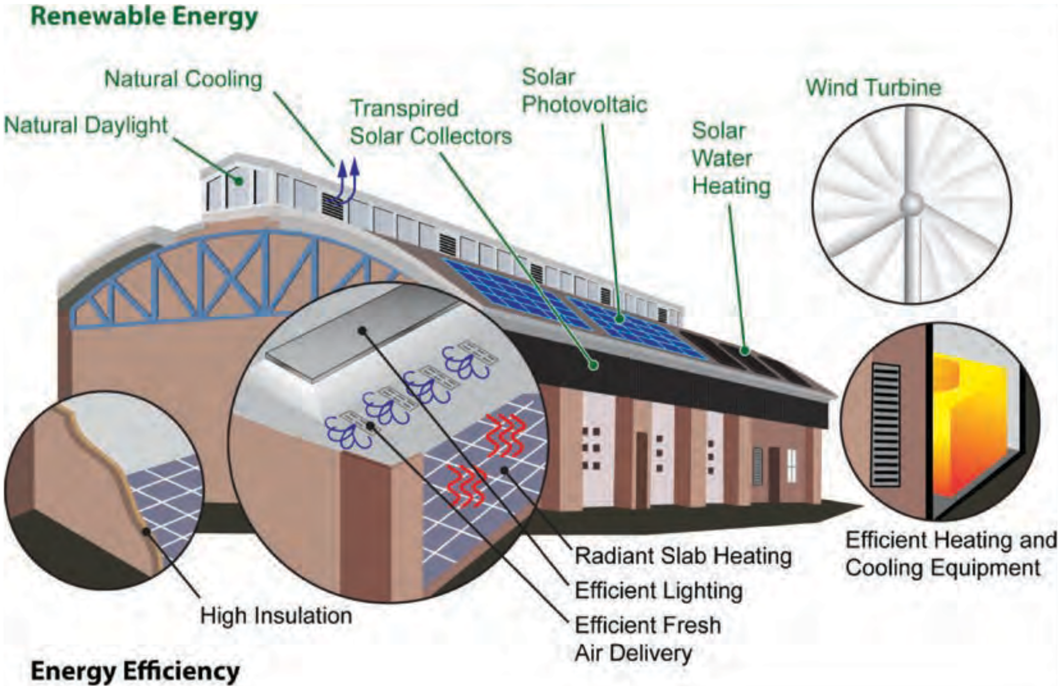

Figure 3-1. Renewable energy technologies and design strategies complement energy efficiency and conservation to meet building energy requirements.

provisions of the International Energy Conservation Code (IECC), International Code Council (ICC-700), and the National Green Building Standard, and incorporates ASHRAE Standard 189.1 as an alternate path to compliance.

- LEED certification.[9] LEED certification provides independent, third-party verification that a building, home, or community was designed and built using strategies aimed at achieving high performance in key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality.
- Green Globes.[10] Green Globes is a web-based program for green building guidance and certification that includes an on-site assessment by a third party. Green Globes offers a streamlined and affordable alternative to LEED as a way to advance the overall environmental performance and sustainability of commercial buildings. It is suitable for a wide range of buildings such as large and small offices, multifamily structures, hospitals, and institutional buildings such as courthouses, schools, and universities.
- Whole Building Design Guide.[11] Whole building design provides the strategies to achieve a true high-performance building: one that is cost-effective over its entire life cycle, safe, secure, accessible, flexible, aesthetic, productive, and sustainable. Through a systematic analysis of these interdependencies, and leveraging whole building design strategies to achieve multiple benefits, a much more efficient and cost-effective building can be produced.

In addition to the guides, there is increasing interest in developing *net zero energy* (also referred to as *zero net energy*) buildings or communities as a means to dramatically reduce the energy and environmental footprint of facilities. A net zero energy building is one that derives enough energy from on-site renewable resources to totally offset any purchased energy from the utility

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[9] U.S. Green Building Council. "What LEED Is." http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1988.

[10] Green Building Initiative, 2012. "Green Building Programs." http://www.thegbi.org/green-globes.

[11] Whole Building Design Guide. "Whole Building Design." http://www.wbdg.org/wbdg_approach.php.

or other off-site sources on an annual basis. The term *net* recognizes that there are periods during which purchased energy may be required (e.g., when there is insufficient solar resource), but that over the course of the year, this will be balanced by excess energy generated on-site, which can be put back into the utility grid. A zero energy building is one that derives all its energy from on-site renewable resources and does not require energy purchases from off-site sources. In the federal government, Executive Order 13514 establishes a requirement that new buildings constructed after fiscal year 2030 must be net zero energy buildings and also includes a solar water heating requirement (http://www.whitehouse.gov/administration/eop/ceq/sustainability). The Department of Defense is piloting net zero energy military installations (http://www1.eere.energy.gov/office_eere/pdfs/48876.pdf). Several states are involved in establishing net zero energy building policies, and certification programs for net zero energy buildings are being established (http://living-future.org/netzero/).

Energy for use in constructing and operating buildings has been calculated to be almost half of all the energy used in the United States (48.7%). The building sector consumes over three quarters of all electricity generated in the United States (75.7%).[12] Utility energy costs fluctuate with supply and demand. With increasing demand for most forms of energy and evermore questionable supplies, future operation costs are a major consideration for most building owners. Even when state-of-the-art sustainable practices are incorporated, additional energy is required for building operation in most cases. Incorporating renewable energy capture on new or existing buildings can significantly reduce, offset, or replace the amount of utility-produced energy required. This can have many positive effects on the economic and environmental impact of a building project.

3.1.1 Economic Benefits

Reduced Operating Costs

Renewable energy systems can reduce the cost of building operations. When properly integrated into the building design, renewable energy systems can replace a significant portion (or all) of the energy purchased from the grid.

Price Stability

Since renewable energy sources reduce the need for purchased energy, they can act as a hedge against volatile or increasing utility costs. Depending on the location of the project and the applicable utility regulations, incorporation of a renewable energy system may qualify for a fixed (or preferred) electric rate, resulting in predictable future utility costs and additional cost savings.

Income from Renewables

Where utilities are required to produce a portion of the energy from renewable sources, building or system owners may be able to sell renewable energy certificates (RECs) for the energy they produce to the utility. The sale of these RECs can further offset the building owner's energy operating costs.

Employment

Each project incorporating renewable energy will help stimulate the emerging renewable energy industry by creating a market for products and the specialized labor required for installation. The operation and maintenance (O&M) of these systems will create further economic activity downstream.

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[12] Architecture 2030, Santa Fe, NM, 2011, http://architecture2030.org/the_problem/problem_energy.

3.1.2 Environmental Benefits

Carbon and Other Emissions

By reducing the consumption of fossil fuels, renewable energy systems can reduce the emission of carbon dioxide and other greenhouse gases, as well as air pollutants associated with the burning of these fuels. When replacing consumption of fossil-fuel–generated electricity, renewable energy systems reduce the amount of power plant emissions released into the atmosphere.

Extraction/Disposal Impacts

In addition to the reduction of emissions associated with the burning of fossil fuels, renewable energy technologies can also reduce the need for extracting them from the earth. This results in a reduction of the environmental impact of resource extraction and the related disposal of any waste materials produced from their extraction (such as brine) or combustion (such as ash).

Thermal Pollution

Fossil fuel combustion and nuclear power generation also produce excess heat that can change the environment by raising the temperature of the air or water. Renewable energy systems have much less thermal impact on the environment.

3.1.3 Energy Security Benefits

By reducing our reliance on imported fuel sources and a vulnerable electricity grid, renewable energy capture and distributed generation can improve the security of our country and our buildings. In the future, clean, reliable sources of energy will be necessary for our national security, economic stability, and public health.

Imported Fuel

The transportation sector of our economy relies almost exclusively on oil for its fuel supply, and oil is still a heating source in some areas of the United States. Almost half of all oil consumed in the United States is imported. In our complex geopolitical world, the supply of oil is a major part of our energy security over which we have little control. Alternative and renewable sources of energy can help create a more secure energy supply.

Distributed Generation

On-site production of electricity can provide additional electric power reliability to the facility. Furthermore, on-site or distributed generation does not incur the losses associated with transporting power over long distances. The inefficiencies in transmission and distribution result in a grid-wide loss of about 7% of all electrical energy produced in the United States.[13] In addition, the complexity of the grid results in a degrading of the quality of the power delivered (variations in voltage, transients, and so forth). It is estimated that American businesses suffer over 75 billion dollars of losses due to power outages and quality disturbances each year.[14] Distributed generation also can help the grid by reducing peak demand and total loads.

3.1.4 Mandated Requirements

Policy

The incorporation of renewable energy may not be a choice on some future projects. Due to concerns related to the environment, energy security, and economics, the federal government and

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[13] U.S. Energy Information Administration. Frequently Asked Questions: How much electricity is lost in transmission and distribution in the United States? www.eia.gov/tools/faqs/faq.cfm?id=105&t=3.

[14] LaCommare et al., 2004, p. 26.

many states have mandated the use of renewable energy and/or sustainable design strategies for new projects and major renovations.

Examples are:

- Energy Policy Act of 2005. Requires purchase/use of renewable energy in federal projects with a credit bonus for RE generated on-site.
- Executive Order 13423. Requires that at least half of renewable energy in federal projects come from new RE sources.
- Executive Order 13514, High Performance Buildings/Sustainable Design. Requires that all federal buildings that enter the design phase after 2020 attain zero net energy usage by 2030.
- Arizona Executive Order 2008-29. Requires that 10% of energy be derived from renewable energy sources for state-funded new construction.
- California 2013 Building Energy Efficiency Standards (Title 24). Scheduled to take effect on January 1, 2014, require 30% more efficient nonresidential construction than the current standard. Solar-ready roofs to accommodate future installation of solar photovoltaics or solar thermal systems are also required. The rules also apply to major building additions and retrofits.
- Multiple states. Require LEED certification at silver or gold level, which in most cases will require on-site renewable energy generation or purchase of electricity that is produced from renewable sources.

Code

Building codes are evolving to reflect these governmental concerns. The IGCC,[15] released in the spring of 2012, and ASHRAE Standard 189.1[16] have renewable energy provisions. The American Institute of Architects is working to encourage adoption of the IGCC in all 50 states.

3.1.5 Lead by Example

At the federal, state, and local level, government has an opportunity to lead by example by designing sustainable and energy-efficient buildings, installing renewable energy systems, monitoring their performance, and sharing information.

3.2 The Process of Identifying Renewable Energy Options

To be most successful, renewable energy systems should be installed on buildings that have also incorporated features to minimize energy use. Unlike utility energy sources (e.g., natural gas, fuel oil, and electricity), the supply of renewable energy is intermittent and variable. The renewable energy system must be integrated into the design of the building and building systems to maximize its effectiveness and economic feasibility. This process is described as *whole building* or *integrated design*. Integrated design results in sustainable buildings that are cost-effective over their defined life cycle and meet other programmatic needs and requirements (such as being accessible, safe, secure, flexible, and aesthetically pleasing).

3.2.1 Energy Efficiency

In most cases, energy derived from renewable sources costs more per unit of energy delivered than energy from utility sources—though some renewable energy technologies are approaching

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[15] International Code Council, 2012. International Green Construction Code.

[16] ANSI/ASHRAE/USGBC/IES Standard 189.1-2009.

the costs of utility-delivered energy. Because of this, the impact of the energy efficiency of the building and any passive design strategies such as daylighting and natural ventilation is amplified when considering renewable energy technologies on a proposed project. As a general rule, energy efficiency and passive design strategies should precede the incorporation of renewable energy systems in order to maximize return on any investment in renewable energy systems. For renovation projects this may not be feasible, and where economic considerations can justify the addition of PV or wind strategies to offset electric utility costs, it may not be necessary.

3.2.2 Sustainable Design

With the advent of sustainable building rating systems (like the LEED rating system), it became apparent that the traditional process of building design was not capable of producing the desired outcomes due to the complex interrelations of buildings, sites, and systems on these types of projects. To avoid situations where decisions made early in the process worked against the stated project goals later, integrated design processes were identified as necessary for success. Integrated design is now required by many federal, state, and local jurisdictions and private entities and is rapidly replacing the traditional design process on projects of all types.

3.2.3 Integrated Design

As stated in *Integrated Project Delivery: A Guide,* by the American Institute of Architects, integrated project delivery is a “project delivery approach that integrates people, systems, business structures, and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction.”[17] Simply stated, it is a multidisciplinary collaboration of all stakeholders and consultants from project conception to completion. This differs from the traditional process, which is much more linear and segmented. Traditionally the owner employs an architectural consultant who brings in additional consultants as necessary, solicits bids, and obtains permits, and then the construction team is engaged. In integrated design, the owner, designer, consultants, code officials, contractors, and commissioning agents participate in the project from beginning to end. Recognizing that the ability to affect cost and functional capabilities decreases while the costs of design changes increase as the project progresses, integrated design endeavors to move design decisions to an earlier stage of the process where their impact on positive outcomes is maximized and the costs of changes are minimized. Practice has shown that this process produces the best results on projects incorporating high-performance sustainable design and renewable energy strategies and is essential to completing the requirements of building rating systems.

3.3 Pathways to Incorporate Renewable Energy into Highway Maintenance Facilities

This guidebook includes a review of renewable energy technologies and an analysis of the energy loads usually present in highway maintenance and transportation buildings of various configurations and construction types. The nature of the energy loads and the renewable energy sources are examined and compared to define a path for the incorporation of renewable energy sources that are appropriate for the proposed building project.

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[17] The American Institute of Architects, 2007.

3.3.1 Applications

Project types and renewable energy applications addressed by this guide include:

- Construction of new buildings,
- Additions to existing facilities,
- Renovations of existing facilities,
- Adaptive reuse of existing facilities, and
- Stand-alone supplemental renewable energy added to existing facilities without other work.

3.3.2 Building Use

The focus of the guide is on highway maintenance facilities. Depending on the size of the facility, a variety of ancillary and support areas may be part of the project. As indicated in Section 2.2 in more detail, these activities can include:

- Maintenance garage bays and the following support areas:
    - Restrooms/showers/lockers.
    - Break, training, and meeting rooms.
    - Parts inventory/parts counter.
- Specialty activities (included in some but not all highway maintenance facilities):
    - Wash bays.
    - Battery charging area.
    - Chemical storage rooms.
    - Compressor rooms.
    - Welding areas.
- Fueling area.
- Vehicle storage.
- Salt and other bulk maintenance material storage areas (usually outdoors but often under cover).
- Office area—the areas listed in the following may be shared with the maintenance area or be separate facilities, depending on scope of project:
    - Restrooms.
    - Break room.
    - Training and meeting room.

3.3.3 Building Form

The form or configuration of a building can enhance the performance of a renewable energy system or the energy efficiency of the building. It is important in the design process to consider potential applicable renewable energy technologies prior to committing to the building form and configuration. For example, in higher latitudes, solar photovoltaic collectors will perform better on a more steeply sloped roof than on a roof that is horizontal. When considering energy efficiency, knowing that a two-story building has less surface area, and therefore less heat loss, than a one-story building of equal square footage can affect the design process. The most efficient building solutions will be the ones where the form and configuration of the building work with the renewable energy technology to optimize performance.

3.3.4 Building Construction Types

Vehicle maintenance garages are constructed using a variety of construction materials and systems. Many of the renewable energy technologies presented in this guide are applicable to any of the types of construction encountered. However, some technologies may work best with a particular type of construction.

Building codes establish maximum allowable floor area and building height based on the type of construction used and the intended occupancy. The IBC has been adopted or is in use in all 50 states and many U.S. territories. In project planning, selection of construction type and the related code limitations can have an impact on selection of renewable energy systems (and the overall project budget). Again, as this can be a consideration in the incorporation of renewable energy in a project, awareness of these code limitations during the design process is important to a successful project.

3.3.5 Occupancy Use Group

As indicated previously, highway maintenance facilities can include a variety of ancillary activities. Of the 10 use groups defined by the IBC, three are found in most highway maintenance facilities:

- Use Group A: Assembly (e.g., meeting and training rooms).
- Use Group B: Business (e.g., management and business offices).
- Use Group S: Storage (e.g., vehicle repair areas, enclosed vehicle storage, and parts storage).

In most instances, the activities within the space will be the major determination of appropriate renewable energy technologies rather than the building code limitations. In planning for highway maintenance facilities, knowledge of the various use groups and the code-imposed limitations in height and area will affect the overall project planning more than renewable energy system selection.

3.4 The Project Development Process

When renewable energy has been identified as one of the goals of a project, it will affect the project planning process. To incorporate renewable energy into a highway maintenance facility project, an organized and prioritized approach is required. How the renewable energy system is incorporated will depend on many variables that will affect the feasibility and cost of the system and project. For a new construction project or an addition to an existing facility, renewable energy strategies and the project's programmatic requirements need to be fully integrated. When an existing facility is to be renovated or reused for another purpose, analysis of the existing conditions can provide direction to successful renewable energy strategies. When the addition of a renewable energy system is the sole purpose of a project, such as adding a solar PV array or wind turbine to an existing facility, matching of the energy loads and available renewable energy resources will provide the best results. Identification of project goals, budget, and resource availability are essential to achieving successful outcomes.

The basic process for building project development consists of four major phases, as illustrated in Figure 3-2: pre-design, design, construction, and operation and maintenance. When renewable energy is included, there are additional activities that are required within each phase. The process is summarized in Table 3-1, and the details are discussed in Sections 3.4.1 through 3.4.4.

In these sections, elements of the process described apply to both *traditional project delivery* and *integrated design project delivery* methodologies. Integrated design differs from traditional methods of project delivery by engaging as many of the participants in the building process as is practical and as early as possible and maintaining their involvement from project inception to post-occupancy. This participation by all involved parties allows their input and incorporates their expertise earlier in the project and generally results in better coordination due to their continued involvement. Integrated design strategies are well defined but can vary based on bidding requirements and other restrictions. In an integrated design project, the team members performing the various tasks described will have been brought in to the process earlier, and their contributions may be more fully integrated.

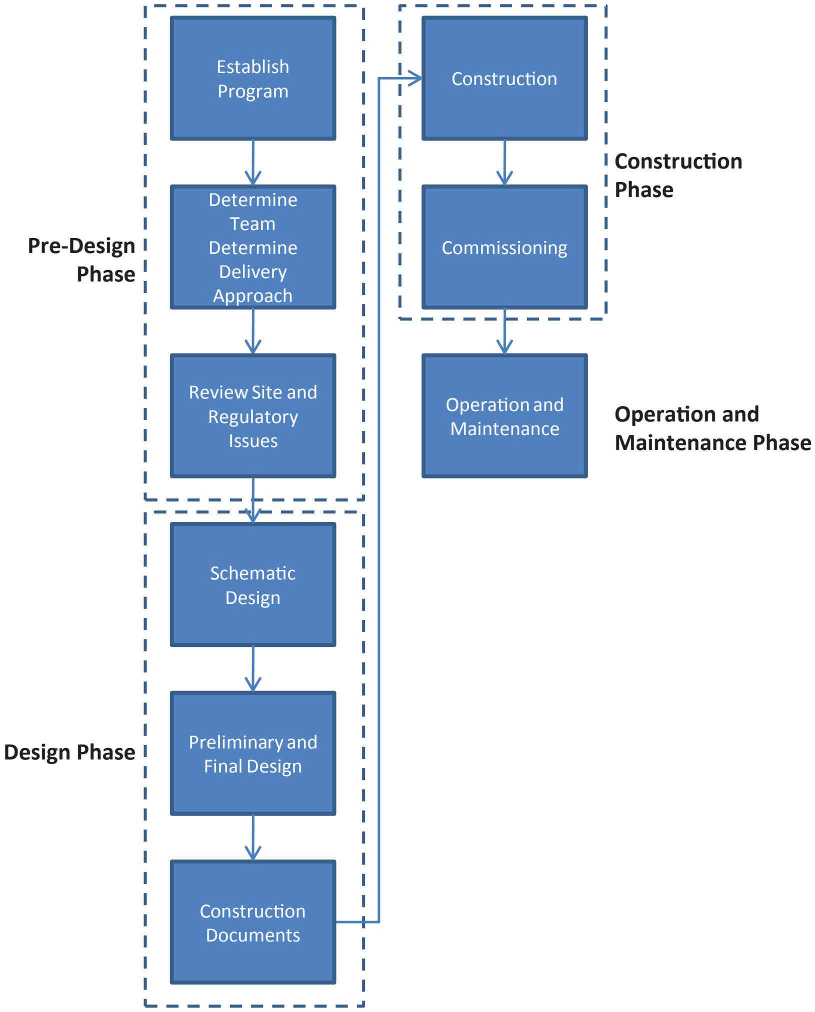

Figure 3-2. Project development process.

3.4.1 Pre-Design Phase

Establish Program

Any building project, whether it is new construction, a renovation, a reuse, or an addition, is essentially a problem-solving exercise. Incorporation of renewable energy is simply another part of the problem-solving process. In order to solve the problem, it is essential to have a thorough definition of what it is. In architecture, the building program is the problem definition phase of the project. It can be performed by the project owner prior to engagement of the architect or building team. It can be performed by consultants who specialize in space analysis and needs assessment, or it can be performed with the assistance of the architect. In a project using the integrated project delivery process, it may be defined during a design charette. A design charette is a workshop that includes the architect, mechanical and electrical engineering consultants, renewable energy consultants, commissioning agents, contractors, building occupants, and the owner. Depending on the complexity of the project, other stakeholders that may participate are utility companies, building officials, regulatory agencies, and loan institutions.

Regardless of how it is executed, the programming process defines the scope of the work to be performed. It documents the goals of the owner by engaging stakeholders in the project. Recognizing the limitations of budget, area, form, and arrangement, the defined goals need to be

Table 3-1. Renewable energy-related considerations in project development process.

Pre-Design	Pre-Design
• Program: project goals, budget, schedule, and priorities • Delivery approach • Team composition • Site and regulatory issues • Select design or design/bid firm	• Program: include energy and RE goals • Delivery approach: consider integrated project delivery and whole building design, as appropriate • Team composition: include energy and RE consultants, building-energy modeling consultants, and commissioning consultants • Pre-design workshop/design charette • Site analysis and initial screening of RE technologies and strategies • Select RE technologies and strategies including solar-ready approaches • Select design or design/build firm
Design	Design
• Schematic design • Design development: develop preliminary designs for all building systems • Construction documents • Request for proposals (RFP): develop bid package and select firm for construction	• Schematic design: develop schematic design incorporating RE technology and strategy • Design development: refine RE system model, determine impacts of RE system on the building [e.g., structural; heating, ventilating, and air conditioning (HVAC); or electrical interface], and cost • Construction documents: RE technology-related drawings and specs • RFP: develop bid package and select firm for construction
Construction	Construction
• Review and oversight • As-built drawings • Commissioning: testing and O&M training	• Review and oversight: RE experts to review RE-specific aspects throughout process; refine impacts of any changes from design • As-built drawings • Commissioning: RE-system–specific commissioning/acceptance testing and O&M training
Operation and Maintenance	Operation and Maintenance
• Ongoing O&M	• Ongoing O&M specific to RE systems • Monitoring of RE system performance

prioritized. Goals for a stand-alone renewable energy project will be quite different from those for a project where renewable energy is incorporated as one part of a much more complicated building program. A stand-alone project's goals will be driven by performance and cost relative to the available renewable resource and the facility's energy demand. A project where the renewable energy system is one element of many defined goals will require additional integration and prioritization to optimize the system within the total project.

Project goals may include design considerations addressing the aesthetics of the building, organizational goals of the building owner as part of an overall business plan, functional goals for efficient operations and organization of space, definition of current and projected space requirements, a conceptual budget with consideration of first costs versus life-cycle costs, and the schedule for the project. Detailed programming information includes a complete analysis of all activities to be housed within the project. When renewable energy is included in the project scope, the building goals and requirements need to mesh with the goals and requirements for the renewable energy system. Goals and objectives for the renewable energy system to be included in the building program may include, but are not limited to, the following:

- Energy performance, including:
  - Energy output levels.
  - Offsets to utility consumption, either peak load or overall reduction.
- Environmental performance, including:
  - Carbon offsets.
  - Aesthetic impacts.
  - Building rating such as LEED, Green Globes, Energy Star, and LBI (Living Building Institute).
- Economic performance, including:
  - Definition of budget for RE system.
  - Required return on investment or financial/economic figure of merit.
  - Reduction in operating costs.
  - Maintenance budget/major equipment replacement timetable and so forth.

Assess Renewable Energy Resources

Renewable energy resources vary by location and climate. When incorporating renewable energy into a project, a thorough analysis of available renewable energy resources is critical to its success. There are a variety of resources and tools available to provide initial and detailed information on site-specific renewable energy resources. These include averaged historical weather data such as typical meteorological year (TMY), which averages long-term collected weather data to produce the typically expected weather for a monitored location. Many energy performance modeling software programs use TMY data, and software has been developed that combines data from multiple reporting sites to generate weather data for almost all locations in the United States. The latest TMY data have been collected from 1,020 sites in the United States and its territories from 1991 through 2005 and are known as TMY3 data.[18] TMY3 includes 62 fields of data, including solar irradiance, luminance, sky cover, dry-bulb temperature, dew-point temperature, relative humidity, wind direction, and wind speed, as well as other information useful in predicting renewable energy system performance. Due to microclimate conditions, on-site monitoring may also be of value in some locations.

To identify renewable energy resources not related to weather and climate will require investigation into other areas. Examples of technologies using non-weather resources are biomass, hydroelectric, alternate fuels, and microgrids. Though still site-specific, resource availability will require investigation into feedstock, infrastructure, and other elements specific to the local area.

Identify Available Renewable Energy Technologies

Appropriate renewable energy technologies should be apparent for a proposed project after consideration of the available renewable energy resources and analysis of the project program and renewable energy system goals. Available renewable energy technologies are discussed in Chapter 5, which includes additional information on appropriate applications.

Identify Loads

Buildings require energy to meet a variety of loads. Some typical building loads that drive heating and cooling needs are:

- Heat loss, including:
  - Heat loss through the building envelope (floor, walls, windows, doors, and roofs).
  - Heat loss from ventilation and infiltration.

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[18] Wilcox and Marion, 2008. *User's Manual for TMY3 Data Sets,* Technical Report NREL/TP-581-43156, National Renewable Energy Laboratory, Golden, CO. http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/.

- Heat gains, including:
  - Solar gain through windows.
  - Heat generated by artificial lighting and office and other equipment.
  - Heat generated by building occupants.
  - Heat gain due to ventilation and infiltration.
- Other loads, such as water heating and process equipment requirements.

To size building heating, ventilating, and air conditioning (HVAC) equipment and provide adequate electrical capacity, it is necessary to quantify these loads. For initial analysis, information from CBECS is available for vehicle repair and service buildings. Using CBECS data for typical energy use per square foot and the electrical percentage of building energy can provide initial load estimates for building and electrical loads. CBECS information is an average of existing buildings. A new project should be able to attain energy consumption levels considerably below CBECS levels by incorporating current building technologies and energy efficiency strategies. It is very important when incorporating energy efficiency measures to emphasize that mechanical systems are "right-sized" by engineering consultants. Designs with excess capacity run at lower efficiencies and can neutralize energy efficiency efforts.

As building systems and envelope construction are developed in more detail, sophisticated energy modeling can be performed to refine the loads and design systems to meet the loads for the project. Modeling may be necessary to meet the requirements of building rating systems and the applicable building code. Most codes use the climate zones defined by ASHRAE (see Figure 2-2).

Identify Agency and Policy Requirements

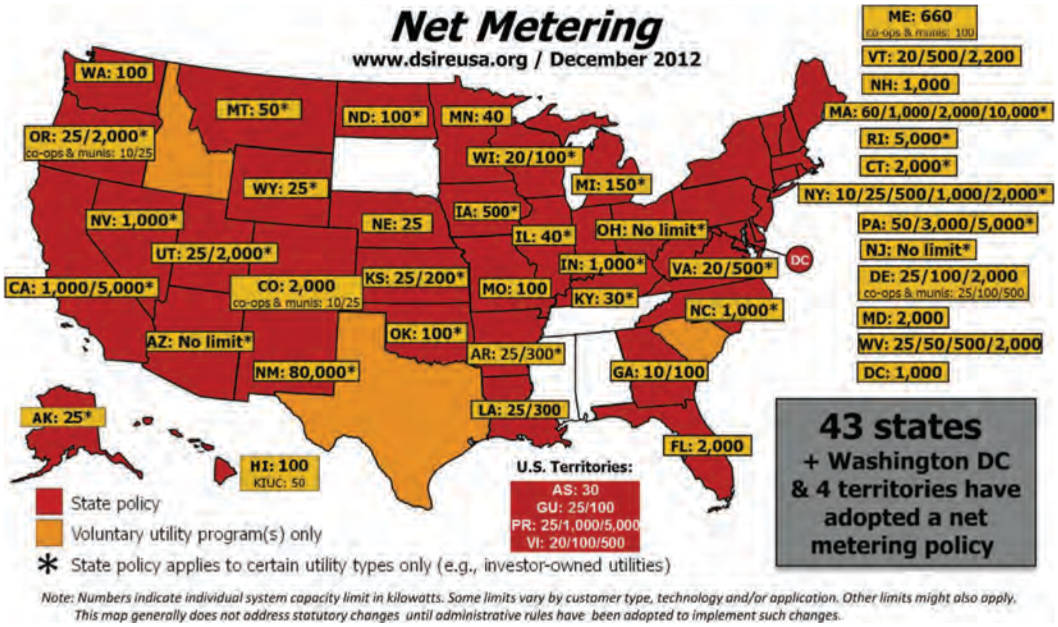
Various other requirements may have an impact on the incorporation of renewable energy on a highway maintenance facility. These can include requirements of various governmental agencies, local utilities, and building certification entities (if a building certification is sought for the project). Examples of governmental agency requirements and impacts are:

- Building codes, including energy codes that specify minimum building performance;
- Solar access legislation;
- Zoning restrictions, which may limit size, location, and visibility of renewable energy systems;
- Grid connection rules and regulations;
- Renewable portfolio standards (RPSs) and renewable energy set-asides that could affect financial performance; and
- Financial incentives such as grants, loans, and tax incentives.

Examples of requirements for renewable energy systems imposed by utilities are:

- Grid connection requirements,
- Maximum capacity of renewable energy systems, and
- Net metering requirements.

Net metering is a particularly important consideration because it results in electricity generated by the renewable energy system being valued at the retail electricity rate. The amount of electricity generated by the renewable energy system is credited against the electricity purchased from the utility, and the monthly electric bill is based on the net electricity purchased. If the net annual amount is in excess of the facility's needs (the amount generated on-site exceeds the facility use), the utility may provide payment for this surplus. Net metering programs often have restrictions based on renewable energy system capacity (e.g., maximum rated output in kW). Figure 3-3 shows a map of state net metering policies, and Figure 3-4 shows a map of interconnection capacity provisions. States that are not color coded have no state policies with regard to net metering or interconnection. The numbers are the renewable system capacity limits in kW.



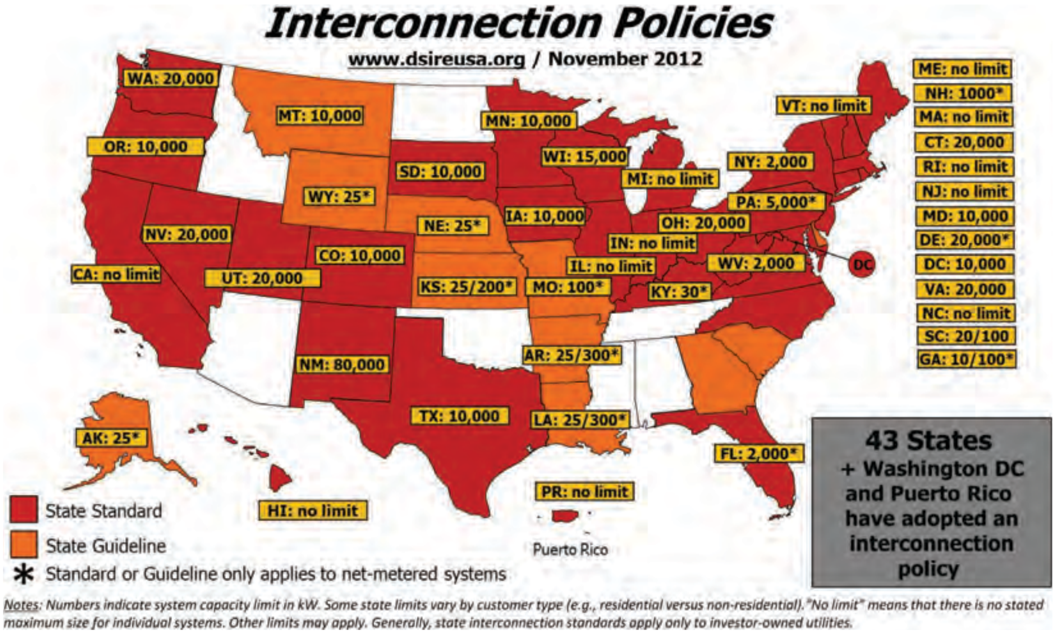
Note: Numbers indicate individual system capacity limit in kilowatts. Some limits vary by customer type, technology and/or application. Other limits might also apply. This map generally does not address statutory changes until administrative rules have been adopted to implement such changes.

Source: Database of State Incentives for Renewables & Efficiency, www.dsireusa.org.

Figure 3-3. Net metering policies.

Building rating systems (such as the LEED rating system) can also affect not only the renewable energy system but many other elements of the building design. Rating system requirements should be a part of the building program and may include:

- Modeling of energy performance of the building envelope and systems,
- Daylighting and associated modeling,
- Integrated commissioning for the project, and
- Adjustments to the size of renewable energy systems.



Notes: Numbers indicate system capacity limit in kW. Some state limits vary by customer type (e.g., residential versus non-residential). "No limit" means that there is no stated maximum size for individual systems. Other limits may apply. Generally, state interconnection standards apply only to investor-owned utilities.

Source: Database of State Incentives for Renewables & Efficiency, www.dsireusa.org.

Figure 3-4. Electric interconnection policies for renewable electric energy systems.

Because of the various jurisdictions where a project may be located, it is important to research, review, and incorporate the requirements of the governmental jurisdictions and utilities with authority over the project. With the rise in the number of renewable energy installations, there are an increasing number of qualified consultants available to assist in meeting agency and policy requirements.

Select Renewable Energy Technology

Based on the analysis of available renewable energy resources, the expected building energy loads, the available renewable energy technologies described in this guide, and code and policy impacts, select appropriate renewable energy technologies for the project. The selection process should integrate the program goals and design of the building with the renewable energy system goals to optimize performance. Additional modeling of the renewable energy system selected can be used to predict system performance, refine the sizing and performance of the building systems, and further integrate the building and the renewable energy system.

Consider Solar-Ready Design Features

Even if the initial analyses indicate that a solar energy system is not cost-effective, it may be beneficial to at least consider incorporating features that will facilitate the addition of solar systems at a later time. These include provisions for building or land areas that are unshaded to provide solar access, structural modifications to account for the installation of solar panels on the building, providing space in mechanical rooms for future equipment (e.g., solar storage tanks), chases to accommodate piping or wiring for future solar systems, and room for additional electrical equipment/panels. By making these investments in the original design, the facility will be able to more easily and cost-effectively install solar systems at a future date. Guidelines for solar-ready buildings have been developed by NREL (*Solar Ready Buildings Planning Guide*: http://www.nrel.gov/docs/fy10osti/46078.pdf) and states (e.g., Minnesota's Solar Ready Buildings Design Guidelines: http://mn.gov/commerce/energy/images/Solar-Ready-Building.pdf).

3.4.2 Design Phase

3.4.2.1 Preliminary Design

New Construction, Renovation, and Reuse. The work in this phase involves the preparation of preliminary design documents based on the building program and renewable energy goals. The preliminary design includes definition of the project scope, building form, schematic floor plans, exterior elevations, massing studies, and other documents necessary to illustrate the extent and organization of the project and to incorporate the renewable energy system into the design. Conceptual modeling of building and renewable energy system performance should be performed to verify the concept. In this phase, a preliminary budget based on unit costs per square foot will also be established. If the project includes addition of renewable energy to an existing building, the feasibility of adding to the structural, electrical, and other capacities of existing systems affected by the project should be verified.

For integrated design projects, in addition to these activities, initial budget, constructability, and schedule information would be provided by the contractors, initial life-cycle cost data produced, system concepts reviewed by the commissioning agents, and design verification completed by the designers. The use of a building information model (BIM) is typical in integrated design, with the model available to all parties. As the project develops, each entity uses the model and adds additional detail, resulting in less conflict between trades.

Stand-Alone Renewable Energy Projects. For projects not associated with an existing structure (such as a wind turbine or a ground-mounted solar PV array), the preliminary design process is relatively simple once renewable energy resources are identified, renewable energy goals defined, loads to be met determined, code and other limitations defined, and a renewable energy technology identified and selected. Preliminary design documents of the system are prepared to indicate the extent and configuration of the renewable energy system, along with initial economic modeling to identify the economic feasibility of the project. At this phase, interconnection requirements should also be confirmed.

3.4.2.2 Design Development

New Construction, Renovation, and Reuse. After review and approval by the owner, design development documents are prepared to finalize all design decisions and provide further detail of the architectural solution. The structural, mechanical, electrical, and renewable energy systems and materials are defined and integrated into the design solution, and quality levels are established through the development of details and outline specifications. Renewable energy systems are modeled with their impact incorporated into other building systems and their effectiveness and performance confirmed. An independent evaluation of the candidate systems can be undertaken. Project costs are refined from the preliminary budget to reflect additional information and detail.

For projects incorporating the integrated project delivery approach, this phase would be more detailed than a traditionally delivered project. The goal of this phase under integrated design is to have all building systems fully defined, coordinated, and validated in a complete BIM. The BIM can also be used to model envelope performance, daylighting, and system energy use, resulting in efficient and accurately designed systems. Costs are detailed and constructability and schedule established, and the project is ready to enter a somewhat shorter final documentation phase. Each stakeholder provides necessary input to coordinate all the work of the project.

Stand-Alone Renewable Energy Projects. For stand-alone projects, the details of structural, electrical, and other systems would be established in this phase. All design decisions would be made, energy and financial performance modeling completed, costs refined, and outline specifications completed with the project ready to enter the documentation phase.

3.4.2.3 Documentation

All Project Types. This phase includes the preparation of technical documents describing and detailing requirements for the construction of the project. Minor design decisions can occur during this phase as additional detailing is completed. Documents include drawings and specifications, a detailed budget, and bidding information. Technical documents produced during this phase will be used to obtain building permit approval and for obtaining bids from contractors.

Variations for Integrated Design. Because the integrated design process brings many of the contractors and agency review activities into the project early, building permits and bidding may be further along at this phase. In most projects, prices for major portions of the work have been committed to by the contractors at this phase. The goal of this phase under integrated design is to determine and document how the design intent will be implemented and not to change or develop it. Because of the participation of the construction trades and suppliers, the traditional shop drawing process is also part of this phase, using the BIM model to streamline the process.

3.4.2.4 Bidding/Negotiation

Traditional Project Delivery Methods. Activities of this phase are to solicit and obtain bids from contractors, review the bids submitted, and award contracts. There is some potential for value engineering at this phase that could change the scope of the work. When value engineering occurs, care must be taken to coordinate the work of different entities affected by any changes. Savings from one area of work can result in additional costs in another area if care isn't taken to manage value engineering. The traditional bidding process usually takes 4 to 5 weeks, review of bids may take 2 weeks, and award of contracts can take up to 60 days, depending on the entity.

Integrated Design Project Delivery. As the contractors and suppliers have been involved in the integrated design process by providing pricing during the design and documentation phase, this process is much shorter than a traditionally delivered project.

3.4.3 Construction Phase

3.4.3.1 Construction

Traditional Project Delivery Methods. The responsibilities of the design professionals in a traditionally delivered project include review of shop drawings and other submittals, observation of construction progress, and review and approval of payment applications by the contractors. In many instances where buildings incorporate complicated systems, a further activity of the design professional is to monitor changes to the work. The responsibilities of the contractors during this phase are to construct the project as documented and deliver the project to the owner as scheduled. Depending on the responsibilities assigned during the documentation phase, testing and inspections may be performed by the contractor with results reported to the design professionals and owner, or the owner may contract separately for these services.

Integrated Design Project Delivery. As the level of detail and integration of contractors and suppliers occurs early in integrated design, the construction phase is limited to quality control and cost monitoring.

3.4.3.2 Commissioning

Traditional Project Delivery Methods. One area of concern in traditional project delivery is commissioning. Commissioning is a process involving quality control steps at each phase of the project implementation process to ensure that the building performs as intended. This includes the development of a commissioning plan and designation of a commissioning agent, along with specific system operational tests and documentation requirements. Building rating certifications often require that commissioning be integrated into the project. If the rating system requirements are not defined early in the project, it may be difficult to incorporate acceptable commissioning activities later. Provided that commissioning has been incorporated into the project, testing and inspections are required during construction and at the completion of construction activities. Training of the owner's personnel in the operation of systems is also usually a requirement of the commissioning process.

Integrated Design Project Delivery. With commissioning agents involved since the inception of the project, commissioning activities continue throughout the construction phase and upon completion of the work.

3.4.3.3 Verification and Acceptance

Traditional Project Delivery Methods. Upon completion of construction, delivery of as-built drawings, delivery of operating and maintenance information, completion of punch list, acceptance of commissioning, and testing of all building systems, the project is determined to be complete. Final inspections are made by building code officials and other agencies, and a certificate of occupancy issued. Upon satisfactory verification of performance and approval by authorities having jurisdiction, the owner accepts the building or system.

Integrated Design Project Delivery. Similar to traditional methods, under integrated design the same activities will occur. In addition, the as-built BIM model can be made available to the owner and used in operation and maintenance of the project.

Renewable Energy System. For grid-tied systems, the utility must also accept the system. Coordination with the utility is essential to prevent the operation of the renewable energy system from being delayed beyond the occupancy date for the project. Where RECs are available, certification of system output is required before the RECs can be sold.

3.4.4 Operation and Maintenance Phase

Traditional Project Delivery Methods. Owner takes over operation and maintenance of the project. Contractors are responsible for warranty support and, depending on contract requirements, a 1-year inspection of the project.

Integrated Design Project Delivery. As with the previous item, owner takes over operation and maintenance. The as-built BIM model can be used by the owner in management of building maintenance and operation, including energy performance modeling and other operational systems.

3.4.5 Performance Monitoring

Traditional Project Delivery Methods. Depending on the building, there may be provisions for monitoring of building systems, but primarily from an operational status point of view. Monitoring of energy performance may be included for larger buildings.

Integrated Design Project Delivery. This is similar to traditional delivery methods. However, provisions for monitoring of renewable energy systems would be incorporated. These could include displays that allow building occupants or visitors to view the performance, which would serve as an educational feature.

CHAPTER 4

Project Financing

4.1 Introduction

State governments are increasingly aware of the environmental and economic benefits of developing renewable energy sources, including reducing carbon emissions, lowering state energy bills, and creating new high-quality jobs. But while the rewards of renewable energy projects can be great, the up-front capital costs can also be high. A wide variety of innovative financing options and incentives are available that help make the development of renewable energy projects feasible. This section discusses some of these available options and the advantages and disadvantages of each funding source.

4.2 Direct Funding

Conceptually, the simplest way for a transportation agency to pay for a renewable energy system is for the agency to pay for it directly using its appropriated funds. The agency purchases the system outright, and it owns both the system and its energy production. As the owner of the system, the agency will be responsible for ensuring the system's operations and maintenance after it is built. While using direct funding obviates the need for paying financing costs, it is often very difficult to secure, given budget pressures and competing priorities for agency funds. In addition, public entities are often not eligible to reap the benefits of certain tax incentives that are only available to private developers. (See Table 4-1 for advantages and disadvantages of direct funding.) For these reasons, transportation agencies may want to use some form of financing to pay for renewable energy systems.

4.3 Bonds

States have increasingly issued bonds to pay for renewable energy projects over the past decade.[19] States, municipalities, and other government agencies sell bonds to investors and then repay them (with interest) by a specific maturity date. Many state-issued bonds are tax exempt, meaning that interest payments from them are not counted as taxable income by the federal government. State bonds can therefore be appealing to investors despite relatively low interest rates. The most basic type of bond used is the *general obligation (GO)* bond. These bonds, which are used to finance large infrastructure projects, are backed by the full faith and credit of the state government. This means that the state pledges to use its taxation power to repay bondholders. Because investors treat GO bonds as very safe investments, interest rates can be relatively low, reducing the borrowing costs to the state.

State agencies or authorities can also issue *revenue bonds* to build infrastructure projects. These bonds are backed by the revenue created by the project they pay for rather than by the

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[19] Devashree, 2011, p. 7.

Table 4-1. Agency funding—advantages and disadvantages.

Agency Funding	
Advantages	**Disadvantages**
Conceptually easy to understand and monitor.	Difficulty obtaining appropriations for large up-front costs.
Zero financing costs.	Not eligible for certain tax incentives.
Agency owns system outright.	Agency responsible for long-term O&M.

Table 4-2. Bonds—advantages and disadvantages.

Bonds	
Advantages	**Disadvantages**
Allows agency to purchase system outright without need for appropriations.	Not eligible for certain tax incentives.
Low borrowing costs, yet still appealing to investors.	Agency responsible for long-term O&M.
Energy bonds do not add to general debt burden.	Energy bonds are less appealing to investors.
Federal tax subsidy bonds generally have 0% interest rates.	The availability of tax subsidy bonds is limited; CREBs are not currently available.

state's taxing power. It is now possible to issue *energy bonds,* a type of revenue bond in which the money for repayment comes from the revenue generated or saved by the energy project that it finances. These bonds do not add to a government's general debt or tax burden. However, since future energy savings are a relatively uncertain revenue stream compared to the certainty of taxes, it can be more difficult to bring energy bonds to market. There are not many examples of states using energy bonds to fund renewable energy projects.[20]

Federal tax subsidy bonds are another popular form of bond used to pay for renewable energy projects. Generally speaking, borrowers pay 0% interest on tax subsidy bonds, while bond holders receive federal tax credits in lieu of traditional interest payments. Two relevant tax subsidy bonds that have been used for renewable energy projects in recent years are known as *clean renewable energy bonds* (CREBs) and *qualified energy conservation bonds* (QECBs). The federal government is not currently accepting applications for new CREBs bond volume, but QECBs may be available if a proposed renewable energy project fits the official definition of a "qualified energy conservation project." The availability of federal bond programs can change year by year, so agencies should investigate whether they are a possible source of funding when embarking on a renewable energy project.[21] The California Department of Transportation (Caltrans) has successfully used CREBs to install photovoltaic systems at 70 of its facilities throughout the state, including 46 maintenance facilities (see Case Studies, 22.7). See Table 4-2 for advantages and disadvantages of bond funding.

4.4 Public Benefit Fund

States or public utility commissions are able to establish public benefit funds (PBFs) in order to raise money for renewable energy projects and incentives. Money for the PBF is collected through a small surcharge (*system benefits charge*) on customers' electric utility bills. The money is then disbursed by states, utilities, or third parties in the form of grants, loans, rebates, incentives, or even free assistance. Typically the beneficiary of a PBF must be a utility ratepayer. If a state agency is the customer of a utility that collects money for a PBF, it is eligible to use the fund to finance renewable energy projects. In many states, PBFs are the primary source of renewable energy incentives.[22] An estimated 18 states plus the District of Columbia and Puerto Rico have PBFs for renewable energy,

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[20] Cory et al., 2008, p. 12.

[21] Database of State Incentives for Renewables & Efficiency, http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US45F&re=1&ee=1; Saha, 2011, pp. 9–10.

[22] Cory, 2008, p. 9.

Table 4-3. Public benefit funds—advantages and disadvantages.

Public Benefit Funds	
Advantages	**Disadvantages**
Same as for other directly funded projects: agency owns system outright, easy to understand, and low or zero financing costs.	Same as for other directly funded projects: not eligible for certain tax incentives, and agency responsible for long-term O&M.
Funds raised consistently through use of a fee on all customers' utility bills.	No two programs are the same; the PBF may not fund the type of project the agency is interested in pursuing.
States can be creative in how they disburse funds.	Not available in all states.

Table 4-4. Revolving loan funds—advantages and disadvantages.

Revolving Loan Funds	
Advantages	**Disadvantages**
Relatively simple to set up and understand.	Same as for other directly funded projects: not eligible for certain tax incentives, and agency responsible for long-term O&M.
Often effective for projects costing up to $10,000.	Funds may not be sufficient for larger projects; does not leverage private-sector funding.
	Not available in all states.

mostly in the Northeast, the Midwest, and on the West Coast.[23] See Table 4-3 for advantages and disadvantages of public benefit funds.

4.5 Revolving Loan Fund

A revolving loan fund (RLF) is a form of financing in which a state (rather than private investors) loans money to public or private entities for clean energy projects, with the principal and interest payments being recycled back into the RLF to fund other projects. RLFs typically target small projects (costing up to $10,000), but they can also be used for much larger projects.[24] See Table 4-4 for advantages and disadvantages of revolving loan funds.

4.6 Other State Funding Options

A number of other options exist to fund renewable energy projects without seeking private-sector financing. Besides a variety of grant and loan programs, some of these financing options are:

- Pooled bond and pooled lease-purchase financing, in which the state aggregates multiple small clean energy projects to finance them more effectively;
- Greenhouse gas allowance auctions, which can raise revenue for direct funding of renewable energy projects; and
- State treasurer investments.[25]

4.7 Third-Party Ownership

4.7.1 Power Purchasing Agreements

Over the past decade, power purchasing agreements (PPAs) have become a very popular way to use third-party developers to finance a wide variety of renewable energy projects, especially solar photovoltaic systems on public buildings.[26] In a PPA, a renewable energy developer agrees to

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[23] Database of State Incentives for Renewables & Efficiency, http://www.dsireusa.org/solar/solarpolicyguide/?id=22.

[24] Saha, 2011, p. 20.

[25] Saha, 2011, pp. 13, 24.

[26] Cory, 2008, p. 23.

Table 4-5. Power purchasing agreements—advantages and disadvantages.

Power Purchasing Agreement	
Advantages	**Disadvantages**
Low/no up-front capital costs for the agency.	Significant transaction costs.
Typically include known, fixed energy costs over a long period of time.	Penalties for terminating the contract.
Agency not responsible for O&M.	Site access issues are complex.
Developer is eligible for tax incentives, potentially reducing cost of energy.	Management and ownership structures can be complex.
Increasingly common and well understood.	Not legally available in all states and jurisdictions.

build a generation system on a customer's site, while the customer signs a long-term (10 to 30 year) agreement to purchase the electricity produced.[27] The PPA is structured to provide energy at a rate that meets the requirements of the customer (e.g., it provides savings relative to utility-purchased electricity over the term of the agreement).

By signing a PPA, the customer is able to transfer all capital costs to the developer, thereby spreading out the costs of building a renewable energy system over many years. The customer is also able to avoid being responsible for logistics, including maintenance and operations, which are handled by the developer for the life of the contract. The developer, on the other hand, obtains a steady stream of income from the customer and is able to acquire financial incentives (such as tax credits and accelerated depreciation) that are only available to private entities. PPAs are therefore often mutually beneficial for customers and producers.

Depending on the terms of the contract, at the end of the PPA term the customer who hosts the equipment may be able to purchase the generating equipment outright, renew the agreement with similar or different terms, or remove the equipment. It is also possible for the agreement to allow the customer to purchase the system before the PPA agreement is over, though typically not until at least 6 years have passed, allowing the third-party developer to exhaust all available investment tax credits and accelerated depreciation benefits.[28] See Table 4-5 for advantages and disadvantages of PPAs.

Third-party PPAs are currently legal in over 20 states, the District of Columbia, and Puerto Rico for solar photovoltaic projects, but in some states their use is disallowed or restricted by law (see Figure 4-1).

The Denver, CO, Public Works Central Platte's 102-kW photovoltaic system is a good example of the use of a PPA to help finance a renewable energy project (see Case Studies, 22.5).

4.7.2 Partnership-Flip and Sale-Leaseback Models

It is now common for third-party developers of renewable energy systems to form partnerships with their institutional investors that affect ownership. These partnership agreements affect elements of the PPA between the state agency and the developer. It is therefore important for agencies to understand two of the most common of these advanced ownership models: the partnership-flip and sale-leaseback models.

4.7.3 Partnership-Flip Model

In the partnership-flip model, the developer and an institutional investor form a partnership (typically a limited liability corporation or special purpose entity) that owns the renewable energy project. It is this partnership that enters into a PPA with the public-sector agency/host of the renewable energy system.

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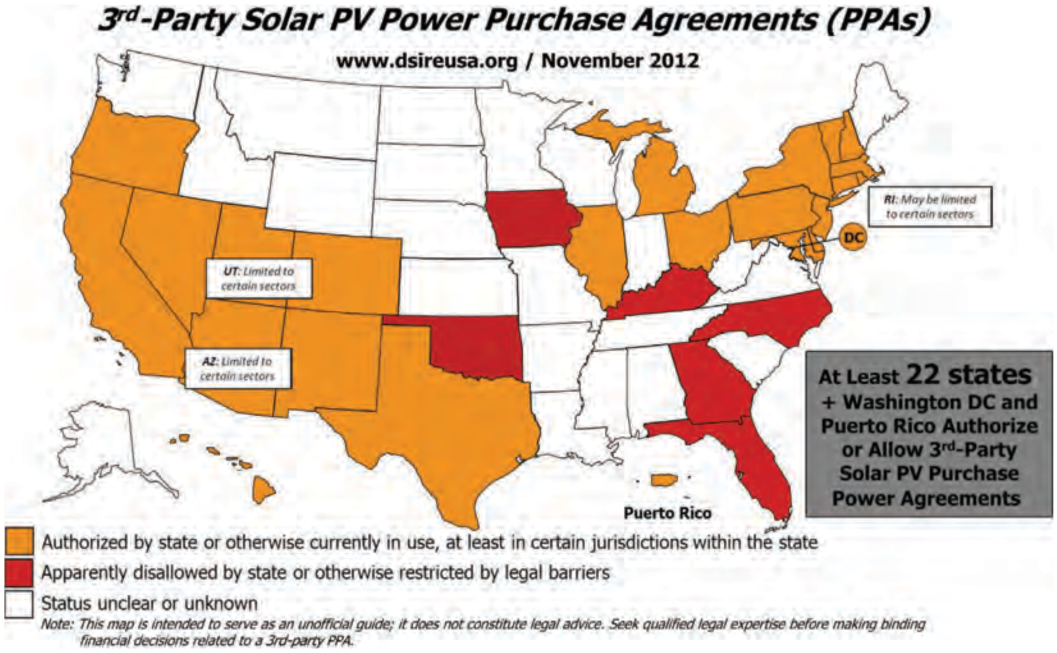
[27] McGervey and Stinton, 2011, p. 34.

[28] McGervey and Stinton, 2011, p. 47.



Source: Database of State Incentives for Renewables & Efficiency, www.dsireusa.org.

Figure 4-1. State solar photovoltaics power purchase agreement policies.

Initially, the investor has a disproportionate ownership stake in the partnership (nearly 100%) and receives most of the tax incentives and other income derived from the project. Once the investor has achieved a predetermined level of return on its investment (known as the *flip point*), the investor turns over (or flips) its majority stake in the partnership to the developer. After the flip point, the developer typically has the option to completely buy out the investor's stake in the partnership. Likewise, it is possible to arrange the PPA such that the state agency has the option to purchase the system and take full ownership either at the flip point or at predetermined times throughout the PPA later on.

4.7.4 Sale-Leaseback Model

In the sale-leaseback model, an institutional investor buys the renewable energy system after the developer has installed it. The investor then leases the system back to the third-party PPA developer for approximately the length of the PPA. This allows the investor to monetize various tax credits. These tax savings are shared with the developer in the form of reduced rents for leasing the system. The developer typically has the option to buy back the system at the end of the lease at fair market value. Likewise, it is possible to arrange the PPA such that the public entity has the option to purchase the system and take full ownership either at the sell-back point or at predetermined times throughout the PPA later on.[29]

4.8 Energy Savings Performance Contract

Under an energy savings performance contract (ESPC), the agency contracts with an energy services company (ESCO) to implement an energy efficiency or renewable energy project for one of its facilities. Implementing an ESPC requires no up-front costs for the governing agency.

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[29] Cory, 2008, pp. 28–30, and McGervey and Stinton, 2011, p. 35.

Table 4-6. Energy savings performance contracts—advantages and disadvantages.

Energy Savings Performance Contracts	
Advantages	**Disadvantages**
Low/no up-front capital costs for the agency, and payments do not exceed savings.	Primarily used for energy efficiency and conservation projects.
ESCOs provide technical resources that the agency otherwise would not be able to access.	Developing and implementing an ESPC can be a demanding task for an agency.
Agency may have discretion to allow ESCO to own energy assets eligible for certain tax incentives.	ESCOs traditionally do not own assets and are therefore not eligible for certain tax incentives.

Rather, the ESCO incurs all costs of implementing various energy projects and then receives payment based on the resulting energy savings; the two parties negotiate who maintains the energy projects over the term of the agreement.

ESPCs have a long history of being used in the federal sector, primarily for energy efficiency projects.[30] They have been used to fund renewable energy projects, although mainly in conjunction with energy efficiency projects. This is because the economics of a stand-alone renewable energy project may not be attractive enough under the ESPC structure. However, when bundled with energy efficiency measures, the portfolio may become economically attractive. See Table 4-6 for advantages and disadvantages of ESPCs.

4.9 Renewable Energy Certificates

In addition to electricity, renewable energy projects can also create a tradable commodity known as a *renewable energy certificate*. RECs represent the non-power benefits of a renewable power project to the environment and society; typically each REC represents 1 megawatt-hour (MWh) of renewable energy production. RECs are bought and sold, either bundled with or separate from the electricity that is generated, at the same time.

Utilities, businesses, and others buy RECs both to support renewable energy and to meet any obligations they may have under their state's renewable energy portfolio standard or other alternative energy obligation. An RPS is a requirement that utility power generators derive a specified amount or percentage of their total electricity sales (MWh) or capacity (MW) from renewable energy sources by a specified year. Currently, 29 states and the District of Columbia have an RPS in place, and another eight have voluntary goals (see Figure 4-2).[31] An RPS may have further requirements that specify the shares of the total requirement that must come from various types of renewable energy (e.g., a carve out for solar or wind). RECs that are associated with solar power tend to be worth more than other RECs, and so they are specifically labeled as solar renewable energy certificates (SRECs).

Agencies planning to build a renewable energy project should be sure to consider what will happen to the RECs/SRECs associated with the generation of clean energy. Selling RECs is a good way for an agency to finance the construction of a renewable energy project. SRECs can even account for as much as 40% to 80% of the total revenue stream of a solar project in some states.[32] However, once sold, the RECs are no longer available for the agency to use for compliance with its own renewable energy generation requirements.

Agencies should consider whether they want to keep or sell the RECs produced by their renewable energy projects and ensure that whatever contract they sign with third-party developers and investors clearly states which entity owns all RECs produced by the project.

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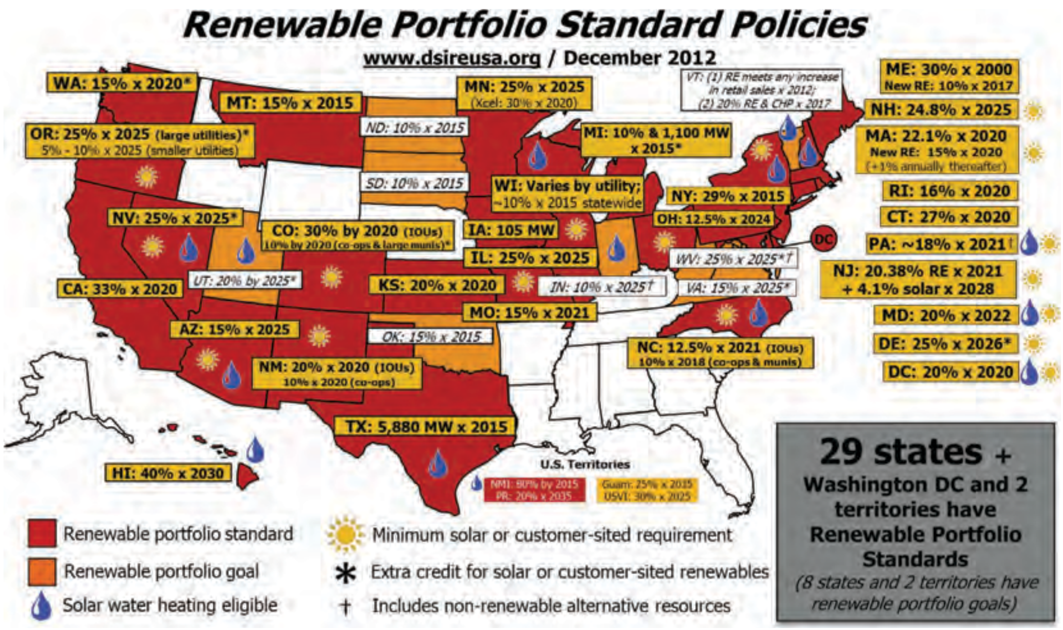
[30] McGervey and Stinton, 2011, p. 51.

[31] Database of State Incentives for Renewables & Efficiency, http://www.dsireusa.org/rpsdata/index.cfm.

[32] Cory, 2008, p. 7.



Source: Database of State Incentives for Renewables & Efficiency, www.dsireusa.org.

Figure 4-2. State renewable portfolio standards.

4.10 Renewable Energy Incentives

As mentioned previously, there are a variety of federal and state incentives that can be leveraged by third-party investors to lower the cost of renewable energy projects.

4.10.1 Business Energy Investment Tax Credit

The business energy investment tax credit (ITC) is a federal corporate tax credit available under 26 USC § 48. The credit is worth 30% of up-front expenditures for solar, fuel cell, and small wind projects; for some other technologies, such as geothermal, it is worth 10% of expenditures. The credit is available for eligible systems that are placed into service by December 31, 2016. In general, the recipient of the tax break must be either the original builder or user of the renewable energy system. Though the ITC can potentially save a lot of money, the rules associated with it are complex. Applicable sectors for the ITC are commercial, industrial, utility, and agricultural, so a state agency would require a PPA or other arrangement with a private third-party investor in order to take advantage of it.[33]

4.10.2 Modified Accelerated Cost Recovery System and Bonus Depreciation

Depreciation is the normal wear and tear that makes property less valuable over time. The federal government allows businesses to claim income tax deductions for depreciation. Under the Modified Accelerated Cost Recovery System (MACRS), the federal government establishes how long it takes for a type of asset to depreciate. The shorter the time it takes, the more quickly investors can recoup money through the use of depreciation tax deductions.

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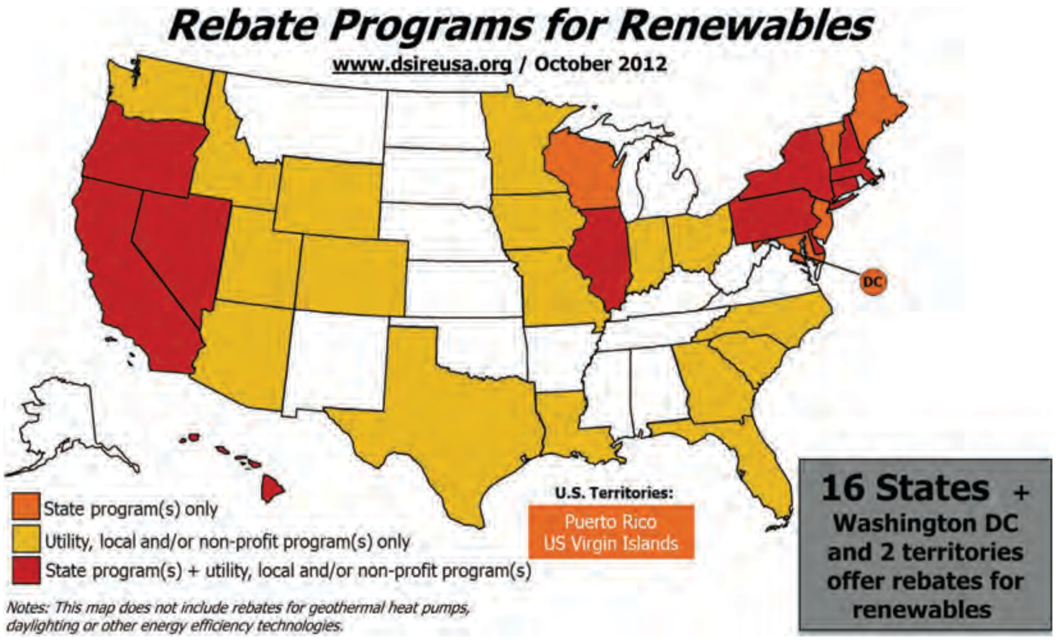
[33] Database of State Incentives for Renewables & Efficiency, http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F.



Source: Database of State Incentives for Renewables & Efficiency, http://www.dsireusa.org/.

Figure 4-3. Rebate programs for renewable energy technologies.

The federal government currently classifies a variety of renewable energy systems, including those using solar, geothermal, and small wind technologies, as 5-year property. This short time period allows investors to recoup the cost of the renewable energy project more quickly than would otherwise be possible. In addition, recent legislation allows *bonus depreciation,* meaning investors can claim an even larger tax deduction in the first year of the life of a renewable energy project. As with the ITC, MACRS and bonus depreciation are only available as tax credits for the private sector.[34]

4.10.3 Incentive Programs

The federal government, states, localities, utilities, and other third parties offer incentives to encourage renewable energy projects. These include grant programs, loans, net metering, tax incentives, and RPSs. Available programs and policies vary widely by state. Many state energy offices are good sources of information regarding which incentives are available for various types of renewable energy projects. North Carolina State University's Database of State Incentives for Renewables & Efficiency (DSIRE) also maintains a wealth of information about various incentives and contains maps and other charts showing where they are available (http://www.dsireusa.org/). Figure 4-3 is a map from DSIRE indicating which states have rebate programs for renewable energy technologies.

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[34] Database of State Incentives for Renewables & Efficiency, http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US06F.

CHAPTER 5

Applicability Guide

5.1 Renewable Energy Technology and Strategy Applicability Based on Region and Site Considerations

Table 5-1 provides summary information about the various renewable energy technologies covered in this guide in terms of applicability considerations. Also included in the table are the chapter numbers for the technology information in Part III and case studies (and section numbers) in Part IV that are associated with the technology. The table, along with additional information provided in this chapter, is intended to help the user navigate to their technologies of interest. The factors identified in the table are:

- Regional considerations. Applicability or effectiveness of the technology based on the geographical region.
- Site-specific considerations. Properties of the site, such as the presence of vegetation, structures that could provide unwanted shading, and other factors that could affect the ability to use the technology at the site.
- Building-specific considerations. Building-design–related factors.
- Energy contribution. Typical energy outputs or percent of building energy needs met.
- Installation costs. Typical technology/design strategy combined equipment and installation costs.
- Economics. Payback periods.
- Reliability. Reliability or operation and maintenance considerations.

It should be noted that the ability to generalize renewable energy technology applicability by geographic region, particularly in terms of renewable energy resources and key climate drivers, varies considerably by technology:

- Temperature and humidity. Temperature and humidity are major factors in building heating and cooling requirements. For skin-dominated buildings like most maintenance facilities, heat gains and losses through the building envelope (walls, roofs, windows) are substantially responsible for heating and cooling loads. In addition, the fresh air requirements for servicing vehicles contributes significantly to overall heating and cooling loads. As a consequence, the temperature and humidity are influential in decisions regarding building envelope selection, the degree to which fresh air must be conditioned, and opportunities for various energy efficiency and passive cooling technologies and strategies. In this case, the ASHRAE climate zones, which reflect a geographic segmentation that is based on temperature and humidity/moisture considerations, are useful for evaluating these technologies and strategies from a regional applicability perspective (see Figure 2-2).
- Solar resource. The amount of sunshine is another key factor in driving building heating and cooling requirements. This is of particular consequence for solar energy technologies—passive solar, active solar, photovoltaics, and concentrating solar power. However, regions based on gradations in solar resource do not necessarily correspond with the ASHRAE climate zones

Table 5-1. Overview of renewable technology options and applicability considerations.

Regional Considerations	Site-Specific Considerations	Building-Specific Considerations	Energy Contribution	Installation Costs	Economics	Reliability	Re Chapter # Case Study (Section #)
Daylighting: *The use of natural light (daylight) to illuminate a space to offset electric lighting requirements. This is accomplished through a variety of strategies that include side lighting and top lighting using windows, skylights, roof monitors, and clerestory windows to light the building perimeter or core areas. Integration with controls that dim or shut off electric lighting is an important element to ensure electricity savings.*							
Daylighting strategies can be used in all regions effectively. Furthermore, ample daylight is available to light spaces that are not in direct sunlight.	Shading.	Trade-off between glazed area (e.g., window-to-wall ratios) and window glazing type to balance visible light transmittance with solar heat gains and losses.	Reduces lighting requirements by 10%–30%.	Increases building costs by 2%–3%.	Payback periods are under 10 years.	Reliable, but the lighting controls must be maintained/sensor calibrated.	**Chapter 7** **Case Study:** Central Platte, CO (22.5) TRANSPO, IN (22.6)
Passive Solar Heating: *The use of the building elements to capture and store solar-derived heat to offset conventional heating energy requirements. Passive solar designs involve orienting the building to maximize winter solar heat gain through windows or roof apertures, increasing the amount of south-facing window area to increase solar gains, and using the mass of the building for heat storage.*							
Passive solar heating can be used in all climates but is more effective in regions that have greater winter sunshine.	Winter shading of the south-facing windows or glazed areas by vegetation or other structures must be avoided.	Depending on the type of design, there are trade-offs in terms of building aspect ratio (length to width), orientation, choice of window glazing, and the need for solar heat gain control during non-heating seasons. Most effective in perimeter spaces	Can provide 10%–30% of heating requirements.	Increases building costs by 0%–4%.	Payback periods are under 10 years.	Reliable and low maintenance.	**Chapter 8** **Case Study:** Central Platte, CO (22.5)
Natural or Passive Cooling: *The use of building elements to reduce unwanted solar heat gains and natural ventilation to reduce cooling requirements.*							
Solar heat gain avoidance strategies are effective in all regions, while natural ventilation is most effective in regions with moderate humidity.	Vegetation, wind patterns that can affect natural ventilation.	The use of shading devices to reduce heat gains, placement of windows to enable cross-ventilation.	Can reduce cooling requirements by 10%.	Increase building costs by 1%-3%.	Payback periods are under 10 years.	Reliable. The only issue is to ensure that occupant interaction does not reduce effectiveness.	**Chapter 9**
Active Solar Heating: *These systems use solar collectors to convert solar energy to thermal energy, which is transported by pumps or fans to storage tanks or directly to the space. Active solar water heating systems are used to preheat water for domestic or process uses, while active solar space heating or ventilation preheat systems are used to help meet space heating or ventilation air heating needs.*							
Active solar systems can be used in all climates but provide greater output in cold, sunny regions. For water and space heating systems that use liquid as the heat transfer fluid in	Requires area that is generally unshaded.	There needs to be adequate area for the collectors, and if roof mounted, structural loads imposed by the collectors must be considered.	Can meet 30% or more of water heating requirements and 20%–40% of space heating or ventilation air heating needs. Solar water heater output ranges from 125 kBtu/ft^2 to 250	Typical solar domestic hot water systems cost \$100–\$150/ft^2 of collector, while space heating systems are \$75–\$100/ft^2 of collector. Transpired solar collectors for	Without financial incentives, systems often have paybacks of 20 years or more, assuming natural gas is the fuel saved.	Reliable operation requires some additional maintenance. For transpired solar collector ventilation heating systems, there is little additional maintenance. Life is 20 years.	**Chapter 10** **Case Study:** St. Clair, MO (22.1) Coney Island, NY (22.4) Fort Drum, NY (22.2) Plattsburgh, NY (22.3**)**

Table 5-1. (Continued).

Regional Considerations	Site-Specific Considerations	Building-Specific Considerations	Energy Contribution	Installation Costs	Economics	Reliability	Re Chapter # Case Study (Section #)
the collectors, the degree of freeze protection needed can influence the type of system selected.			kBtu/ft^2, depending on collector and location.	ventilation preheat cost \$25–\$35/ft^2 of collector.			
Photovoltaics: *These systems use photovoltaic modules to convert sunlight into electricity. Since the output of the modules is direct current (DC) and buildings generally require alternating current (AC) power, DC-to-AC inverters are used. Photovoltaic systems only generate power when there is sunlight, and batteries are used if electric storage capability is desired.*							
Photovoltaic systems can be used in all climates but provide more electricity per module in sunny regions.	Requires area that is unshaded.	There needs to be adequate area for the PV modules, and if roof mounted, structural loads imposed by the collectors must be considered.	Can provide 10–20 kWh/ft^2 of module per year depending on the PV module efficiency and location.	Typical costs are \$6,000/kW to \$8,000/kW for systems that are 10 kW to 100 kW in capacity.	Without financial incentives, systems often have paybacks of 20 years or more, depending on the price of electricity saved.	Very reliable—20-year life.	**Chapter 11** **Case Study:** Central Platte, CO (22.5) TRANSPO, IN (22.6) Kilauea, HI (22.11) Caltrans, CA (22.7)
Concentrating Solar Power*: These systems make use of reflectors of various types to focus the sun's rays to achieve high temperatures in a receiver. The high temperatures are used to heat a heat transfer fluid, which is used to drive a power cycle to generate electricity.*							
Systems require direct-beam sunlight, which makes them most effective in sunny regions, such as the U.S. Southwest. These are regions where the direct normal solar radiation exceeds 200 kWh/ft^2/year (2150 kWh/m^2/year).	Requires area that is unshaded and very level.	The systems generally require significant land area (5–10 acres per MW). It is possible to mount parabolic trough-type systems on a flat roof. The structural loads imposed by the collectors must be considered.	Can provide 15–25 kWh/ft^2 of reflector area per year depending on the system type and location.	Typical costs are \$4,000 to \$7,000/kW.	Without financial incentives, systems have paybacks of 20 years or more.	Requires dedicated maintenance for systems with associated costs of \$0.02/kWh.	**Chapter 12**
Wind Energy: *Wind energy technologies convert wind energy into electricity through the use of wind turbine generators. The great majority of systems are of the horizontal-axis type, although there are some vertical-axis wind turbines on the market.*							
Wind turbine generators perform most effectively if average wind speeds are 15 mph (6.7 m/s) or more. Since wind varies considerably, even over small areas, wind turbine applications are very site-specific.	There must be sufficient land area for the wind turbine to provide adequate buffer between the turbine and structures.	In most applications, wind turbines will be mounted on the ground, so there are no special building-specific considerations.	Wind turbine output varies significantly with wind speed.	Typical costs are \$5,000/kW to \$6,000/kW for systems that are 10 kW to 100 kW in capacity.	Without financial incentives, systems have payback periods of 15–25 years.	Wind turbine generators are generally reliable. Maintenance costs are about \$0.01/kWh for smaller machines.	**Chapter 13** **Case Study:** Milford, UT (22.8) Northwood, OH (22.9)

(continued on next page)

Table 5-1. (Continued).

Regional Considerations	Site-Specific Considerations	Building-Specific Considerations	Energy Contribution	Installation Costs	Economics	Reliability	Re Chapter # Case Study (Section #)
Geothermal Heat Pumps: *Geothermal heat pumps use the heat in the ground, surface water, or groundwater as a heat source or sink for heat pump operation. Ground-source heat pumps use piping installed vertically in boreholes or horizontally in trenches. A heat transfer fluid (e.g., antifreeze mix) is pumped through the piping to transfer the heat between the ground and the heat pump indoor unit. The relatively constant and higher wintertime temperature of the ground, as opposed to the air, make geothermal heat pumps more efficient than air-source heat pumps for heating.*							
Geothermal heat pumps can be used in all regions, but are most effective in temperate climates and where there is a requirement for heating and cooling.	There must be adequate land for installing the ground loop. Furthermore, the heat transfer properties of the soil have a significant impact on the size of ground-loop field. If a pond is used, then the depth of the pond and total volume must provide sufficient capacity to act as a heat source.	There are no special building arrangements, although the number of heat pump units and the distribution system within the building (water to air, water to water, or radiant slab) must be considered. The heat pump will be more cost-effective if air conditioning is also required. This is because the air-conditioning function is inherent in the heat pump.	The system can meet all the building's heating requirements. Typical savings are 30%–50% compared to air-source heat pumps.	Typical costs are $4,000 to $6,000/ton of cooling capacity.	Without financial incentives, systems have paybacks of 15 years or more.	Generally reliable. Comparable to water-source heat pump. The main difference is the ground-loop or pond field and associated pumps.	**Chapter 14** **Case Study:** TRANSPO, IN (22.6) Elm Creek, MN (22.10)
Biomass: *Biomass systems use organic matter such as agricultural crops and agricultural wastes and residues, wood and wood wastes and residues, animal wastes, municipal wastes, and aquatic plants as fuel in boilers or gasifiers. The boilers are used to provide heat or to generate steam for use in electric power generation.*							
Biomass systems are most effective in localities that are in close proximity to a source of biomass. Otherwise, transport costs can make the biomass costs too high to compete with conventional fuels.	There are no site-specific issues except to have adequate space for storage of the biomass. Local environmental regulation (air quality rules) must be investigated.	There are no building-specific considerations other than providing space for the boilers.	Biomass-fueled heating systems operate at efficiencies comparable to gas or oil-fired heating equipment and are sized to meet total or average heating requirements.	Installed costs range from $150,000/million Btu/h to $300,000/ million Btu/h capacity wood chip/pellet system depending on type, size, and configuration.	Can be competitive against fuel oil and propane, but not generally natural gas.	Reliable. However, may require additional O&M staff for proper maintenance and operation.	**Chapter 15**
Hydroelectric: *Small hydroelectric power systems use hydro-turbine generators to extract power from the movement of water between two different elevations.*							
Small hydropower resources are very site-specific and can be found throughout the United States except in more arid areas.	There are site environmental and permitting issues that need to be considered.	There are no special building-specific considerations since the system is not part of the building.	Energy contribution is a function of local resource (flow and elevation head).	System costs are $3,000/kW to $7,000/kW for sizes in the 100 kW to 1 MW range.	Payback periods of 10–20 years.	Very reliable.	**Chapter 16**
Energy Storage: *Energy storage can be used in conjunction with renewable energy systems to increase the amount of energy that can be collected and to enable better matching of system output and loads. Lead acid batteries are the most widely used electric energy storage for PV and wind energy systems.*							
Battery storage can be used in any location.	Adequate area must be provided.	Adequate area must be available.	The storage capacity is a function of economics and space.	Lead acid battery costs are $140/kWh–$200/kWh. Other advanced batteries cost 3–7 times as much.	Varies depending on the application.	Very reliable with proper charge control and maintenance.	**Chapter 17**

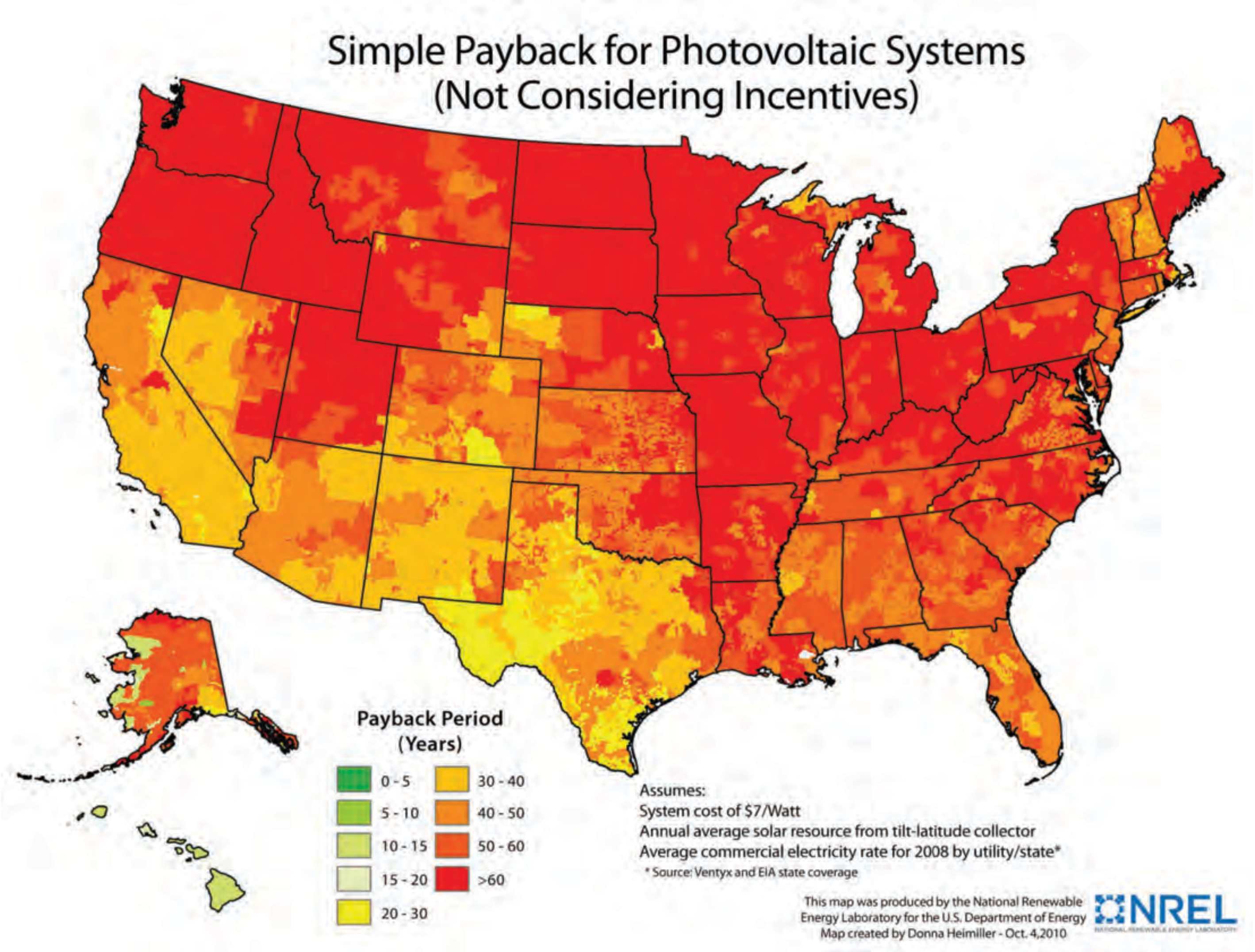
(see Figure 11-5 in comparison to the ASHRAE region map). For example, Hartford, CT, has a similar number of degree days as Denver, CO, but far less sunshine—particularly during the winter months. Therefore, the ASHRAE climate zones do not provide a good classification scheme for solar technology applicability. While the solar resource in any given location does vary somewhat from year to year, it is relatively stable over time. This makes solar maps (and the underlying data sets) useful for assessing the magnitude of the resource for a given location.

- Wind resource. Wind resources are very site-specific and vary widely. Their magnitude must be well known before investing in wind energy technologies. While wind maps indicating wind speed or wind power density are useful to generally indicate wind potential—for example showing that the middle of the country and the coasts hold the greatest potential, and the Southeast, the least—they are no substitute for local knowledge of wind speeds and patterns (see Figure 13-4). This requires the use of wind measuring equipment (e.g., anemometers) installed in the most suitable areas of the site and data collection of 1 year.
- Geothermal resource. In the context of this guide, the term *geothermal resource* refers to the use of the ground, groundwater, or surface waters as heat sources or sinks for geothermal heat pumps. Maps of ground or groundwater temperatures are useful indicators for geothermal potential in this context (see Figure 14-1). However, to ensure that the geothermal heat pump system makes economic sense, knowledge of the soil heat transfer properties should be known. This is accomplished by drilling a test well and undertaking certain measurements.
- Biomass resource. Understanding biomass resources on a regional basis is not related directly to the site's biomass resources but to the proximity of resources to the site. If local sources of biomass fuel are not available (e.g., within 50 miles of the facility), then the cost of the biomass fuel will likely be too high to make it economically viable. While wood-related biomass is the most widely used biomass fuel, there may be opportunities specific to the location, including proximity to a source of landfill gas, biodiesel, or other resources. For these reasons, local sources must be investigated to determine whether there is an adequate supply.
- Hydroelectric resource. Small-scale hydroelectric opportunities are limited to situations where there is a stream on the grounds of the maintenance facility. This is a site-specific opportunity that requires determination of the available power through flow and other measurements.

While the amount of renewable energy resources and site-specific considerations are highly important to the economics of the system, the availability of financial incentives can have equal or greater importance (refer to Section 4.10.3). NREL has examined the impact of incentives on the cost-effectiveness of solar technologies (photovoltaics, solar water heating, and space heating) for public entities. Figures 5-1 and 5-2 show the simple payback for photovoltaic systems assuming no incentives, and the use of available incentives, respectively. The results illustrate the large effect the incentives have on reducing payback periods and making PV system investments attractive. The main point is that incentives and utility rate structures should be investigated before eliminating a technology of interest from consideration.

Figure 5-3 identifies the general steps in determining which renewable energy technologies or strategies to consider. This involves an initial assessment of the site, the building, and cost-effectiveness. If this assessment indicates that the technology or strategy makes sense, more detailed information and analysis could be collected for confirmation and for the next step in the project development process.

Other factors that may enter into the decision include environmental benefits, importance to meeting sustainability objectives (such as obtaining LEED points), energy security, and how well the technology meets a specific need.



Source: NREL. http://www.nrel.gov/gis/images/femp/graphic_pv3_pbnoincen.jpg.

Figure 5-1. Payback for photovoltaic systems with no financial incentives.

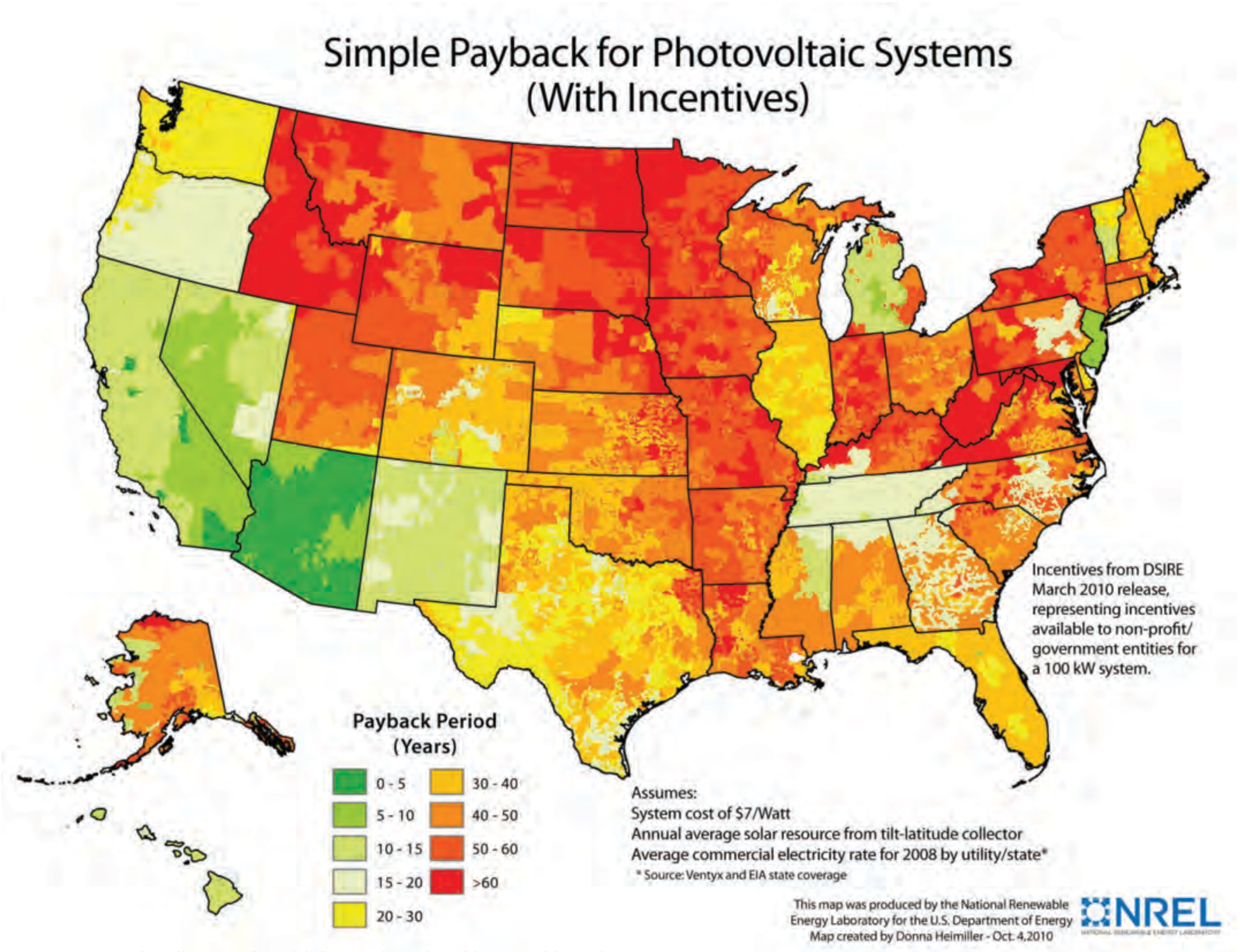
5.2 Economic Evaluation

Each organization will have its own requirements in terms of what constitutes a cost-effective or economic project and the associated evaluation method. These evaluation methods generally fall into two categories: simple payback analysis or life-cycle cost analysis.

5.2.1 Simple Payback Analysis

Payback analysis uses the metric on the time period it takes for the project savings to return the amount invested. Projects that result in simple payback (SPB) periods of less than an established value are considered cost-effective. Any costs or benefits beyond the payback period are not considered.

The SPB period is defined as the number of years it takes for the annual savings or income from a project to cover the investment costs in the project. The investment costs can be the installed capital costs or can include design costs, administrative costs, or other project costs. The savings can be defined as the energy operating cost savings or the net savings accounting for



Simple Payback for Photovoltaic Systems (With Incentives)

Incentives from DSIRE March 2010 release, representing incentives available to non-profit/ government entities for a 100 kW system.

Assumes:
System cost of $7/Watt
Annual average solar resource from tilt-latitude collector
Average commercial electricity rate for 2008 by utility/state*
* Source: Ventyx and EIA state coverage

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy
Map created by Donna Heimiller - Oct. 4,2010

Source: NREL. http://www.nrel.gov/gis/images/femp/graphic_pv4_pbincen.jpg.

Figure 5-2. Payback for photovoltaic systems with financial incentives.

differential annual operating and maintenance costs. In its simplest form, assuming uniform annual savings:

SPB = investment cost/annual savings.

5.2.2 Life-Cycle Cost Analysis

Life-cycle cost analysis (LCCA) accounts for the total costs of owning, operating, maintaining, repairing, and disposing of the system over a specified time frame or study period. The study period is often selected as the anticipated life of the system. The life-cycle cost accounts for price escalation as well as the time value of money via discounting. The analyses are typically done on a year-by-year basis to account for the timing of the expenditures and cash flows over the study period. Residual costs represent the net value of the system accounting for disposal costs or resale value (e.g., salvage value). Commonly used terms in LCCA are:

- Discount rate. This is a measure of the time value or cost of money (e.g., interest rate). It is based on considerations such as borrowing costs, required returns, and other factors such as the riskiness of the project investment.

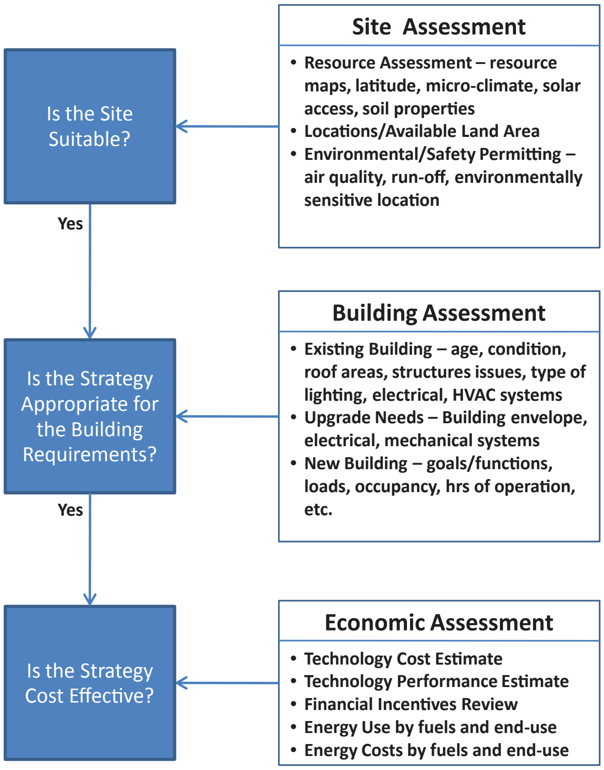


Figure 5-3. Screening process.

- Present value or present worth (PW) factors. These are discount factors that are used to convert amounts paid or received in a given year to equivalent base year amounts accounting for the time value of money (discount rate). Different factors are used to convert annually recurring amounts and amounts that are single payments or investments in a given year.

An important consideration when doing LCCA is whether general inflation is included in the discount rates or escalation rates. If the analysis includes general inflation in these rates, they are labeled as nominal rates, and the analysis is called a current dollar analysis. If the rates exclude general inflation, they are labeled as real rates, and the analysis is called constant dollar analysis. The Consumer Price Index (CPI), published by the U.S. Bureau of Labor Statistics, is an example of a general inflation rate. There are several LCCA figures of merit that can be used to gauge the cost-effectiveness of the project:

- Life-cycle cost (LCC) = present value of initial investment cost + annual and non-annually recurring operation, maintenance, and repair costs + replacement costs + residual costs.
- Net present value (NPV) = the difference between the discounted savings and costs over the specified evaluation period. If this is a positive value, then the project results in savings. A negative value means it loses money.
- Savings to investment ratio (SIR) = present value of savings in annual and non-annually recurring operation, maintenance, and repair costs/present value of differential investment costs, replacement costs, and residual values. If the SIR is greater than 1, then the project saves money. If it is less than 1, it loses money.
- Internal rate of return (IRR) = the value of the discount rate at which the NPV = 0 (discounted positive cash flows equal negative cash flows) over a specified time frame of interest. A project is considered cost-effective if the IRR exceeds a specified rate.
- Levelized cost of energy (LCOE) = annualized value of the LCC/energy output or savings. This is a way of expressing the amortization of the total costs of the system over the energy

output of the system. If the LCOE is less than the competing energy source over the study period, a project saves money. If it is higher, then it loses money.

LCC and NPV are useful for determining which projects are most cost-effective (e.g., lowest LCC or largest NPV). SIR and IRR are useful for screening for whether a project is cost-effective, but do not provide information on whether the project is the lowest life-cycle cost. LCOE is useful in comparing competing energy technologies on a unit energy output basis.

Good sources of information on life-cycle cost analysis are:

- Walter Short, Daniel J. Packey, and Thomas Holt, *A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies.* National Renewable Energy Laboratory, March 1995, NREL/TP-462-5173. http://large.stanford.edu/publications/coal/references/troughnet/market/docs/5173.pdf.
- Sieglinde K. Fuller and Stephen R. Petersen, *Life Cycle Costing Manual for the Federal Energy Management Program.* U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, NIST Handbook 135, 1995 Edition. http://fire.nist.gov/bfrlpubs/build96/PDF/b96121.pdf.

A good source for annually updated escalation and discount rates is:

- A.S. Rushing, J.D. Kneifel, and B.C. Lippiatt, U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis–2010,* Annual Supplement to NIST Handbook 135 and NBS Special Publication 709, NISTIR 85-3273-25. http://www1.eere.energy.gov/femp/pdfs/ashb10.pdf.

PART III

Renewable Energy Technologies and Strategies

CHAPTER 6

Energy Efficiency and Demand Reduction

6.1 Overview

Energy efficiency is a key piece of the puzzle when evaluating energy strategies and especially capital-intensive renewable energy projects. Having efficient and functional facilities can greatly reduce the power generation requirements, which will either reduce the quantity of renewable energy that needs to be generated or decrease the conventional energy that still needs to be purchased when renewables are installed. There are a few driving factors behind energy consumption in most commercial buildings, and this holds true for maintenance facilities of all types. According to the International Energy Agency, space heating is by far the most energy-intensive operation, accounting for 36% of total consumption, followed closely by lighting at 21%. Shop spaces will have higher heating, lighting, and ventilation loads compared to the industry average for commercial spaces, while buildings used for non-shop activities should follow much more closely.

Demand reduction refers to the strategy of reducing electric power requirements during utility-defined peak demand periods as a means of reducing utility bills. This strategy is most beneficial when the electric rate schedule includes high demand charges for power use during the peak periods. Many utility rates, especially those for commercial buildings, include energy usage charges plus charges based on demand. Typically, demand is measured over a short duration—a 15-minute time period—which represents the instantaneous power draw of the facility. Understanding the facility's electric use profile is the key to reducing peak demand. Note that reducing peak demand may not save much energy if the reduction is temporary or if it is done in a way that simply moves the energy use to another time period (referred to as load shifting). However, from the utility's perspective, reducing peak demand is very beneficial since it reduces its requirement for investment in "peaking plants," which are generators that are used for relatively short periods simply to meet spikes in demand resulting from extremes in weather (e.g., hot spells that increase air conditioning requirements and hence electric power generation requirements) or other situations. Facilities that are able to reduce their demand through strategic scheduling of equipment operation or other means—the use of on-site generation—are best able to benefit from reductions in demand charges. In much of the United States, utility peak demands are set in the summer, and high demand charges are established for summer peak periods. This is less beneficial for maintenance facilities since the maintenance areas are typically not air conditioned. Nonetheless, there are still some opportunities for demand reduction, depending on the mix of space types within the building or site. The use of building controls for implementing peak demand reduction is an effective strategy.

6.2 Types of Systems and Strategies

6.2.1 Energy Efficiency

Building Envelope. The building envelope has the greatest impact on energy efficiency since each function is specific to the characteristics of the building. Fenestration, insulation, and air infiltration all have a huge impact on energy use. Site selection and building orientation have a large impact on building efficiency, as do external factors such as energy spent transporting materials, commuting, security, accessibility, energy consumption, and the impact on local ecosystems and the use/reuse of existing structures and infrastructures. Therefore, it is important to address site selection early in the project development process to ensure that issues like solar access are considered.[35] An existing site with existing buildings represents a substantial amount of work and energy already invested in the site. By looking at the total energy expenditure to manufacture, transport, erect, and sustain buildings, the better options are usually reusing buildings or parts of buildings, followed by using local or recycled/recyclable materials. The number, size, and orientation of windows will let in light that can reduce the lighting and cooling load, as discussed in Chapter 7. The color of the roof will have a large effect on solar heat gain;[36] because many highway maintenance facilities have more roof area than wall area, cooling loads are driven by the roof heat gain, which is especially important for spaces cooled only by ventilation. There are a wide variety of high-albedo roofing products that minimize heat gain. Air movement in these facilities is very important, and when the ventilation supply is not enough to create air movement, high-capacity or high-velocity fans are an energy-efficient means to prevent air stratification and can increase both convective heating and cooling for workers at ground level. A well-sealed, well-insulated space will be more comfortable and require less energy. In some states, requirements for air sealing of buildings have been added to the building code. The idea behind a sealed building is to know where the air penetrates the building so it can be controlled. This allows the intake air to be reheated by the warm outlet air, especially with the use of a heat recovery ventilator (HRV) or energy recovery ventilator (ERV), instead of simply having arbitrary leaks in the building envelope.[37] A building with low air infiltration must be designed in such a way that humidity is well controlled inside and the dew point is outside the vapor barrier. Free modeling software for building envelope design is available from Oak Ridge National Laboratory.[38] Maintenance facilities can use this strategy for offices and non-vehicular spaces, but service bays prove a larger challenge, as discussed in Section 2.2.2, Building Functional Characteristics: Maintenance Bay.

Cooling. In many parts of the country, vehicle maintenance bays are ventilated but not cooled; in most locations, administrative and office spaces are air conditioned. Larger spaces that are cooled with a chiller and cooling tower have a number of energy-efficient options, including modular chillers that operate at peak efficiency over a very wide range of loads, and rotary scroll chillers, the most efficient traditional type, rated up to 80 tons. For smaller spaces, high-efficiency direct exchange (DX) equipment is now available, up to SEER 21, as well as some alternative cooling strategies, such as hybrid direct–indirect evaporative coolers[39] and air conditioners that use stored solar thermal energy to power an absorption cycle cooling system.[40] Cooling and

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[35] The Whole Building Design Guide provides a good discussion of the importance of site selection and the various considerations. http://www.wbdg.org/design/site_potential.php.

[36] U.S. EPA, Heat Island Effect. http://www.epa.gov/hiri/.

[37] BMT, Air Tightness of the Building Envelope in Practice. http://www.bmd.dk/uploads%5Cdocs%5Cair%20tighness%20of%20buildings%20final%20version1.pdf.

[38] http://www.ornl.gov/sci/btc/apps/moisture/index.html.

[39] Federal Energy Management Program, Technology Installation Review. http://www1.eere.energy.gov/femp/pdfs/tir_coolerado.pdf.

[40] U.S. Department of Energy, Heating & Cooling. http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12450.

heating equipment is generally sized to meet peak demand and so will generally not need to operate at full capacity to maintain a comfortable environment. Including a variable frequency drive (VFD) can match system capacity to the actual load throughout the entire year, resulting in major savings in system motor energy use: 25% to 50% compared with constant-speed systems.[41]

Heating. There are many strategies that can be taken to reduce heating loads beyond maximizing insulation and minimizing air infiltration. Heat loss from the duct system or piping can contribute up to 35% of the energy use of a heating system,[42] so ensuring that there are no air leaks and providing duct insulation are two low-cost strategies to improve overall system performance. In high-bay spaces, heat tends to rise to the top of the building, resulting in air stratification with the colder layer on the bottom. To combat this tendency, some spaces use high-efficiency fans to distribute heat evenly throughout the entire volume of the space. A more efficient heating strategy in tall, large-volume spaces is to put the heat closest to where it's needed: in the floor. This heats objects resting on the floor by conduction and other objects and surfaces by radiation. Radiant floor heating can be provided by a geothermal heat pump or a wide variety of boilers, some equipped to run on waste oil.

The use of energy-efficient heating equipment can reduce operating costs and energy consumed. Modern condensing boilers and furnaces achieve efficiencies of greater than 90% by using primary and secondary heat exchangers that remove both sensible and latent heat from the flue gases. Highly efficient heat pumps and geothermal heat pumps (see Chapter 14) are also options for highway maintenance facilities.

Lighting. A properly lit facility is necessary for safe, efficient operations. Often, past energy saving efforts resulted in de-lamping or simple removal of bulbs, which helps in over-lit areas, but when applied improperly can negatively affect facility operations or safety. Letting daylight into the building is the most effective way to save lighting energy but must be coupled with reducing the use of electric lighting and be planned carefully, as discussed in Chapter 7. Properly designed lighting systems can provide sufficient lighting for specific purposes, and using efficient fixtures and lamps with variable controls and occupancy sensors will reduce energy consumption. A number of energy-efficient lighting products have become more widely available in the last few years, including light-emitting diode (LED) lighting, induction lighting, high-intensity discharge (HID) lighting, and compact fluorescent and electronically ballasted fluorescent bulbs. The Department of Energy keeps updated information on lighting[43] and provides energy saving estimations for commercial lighting projects.[44]

6.2.2 Demand Reduction

6.2.2.1 Direct Digital Controls

Direct digital control (DDC) system is a term frequently found in building automation specifications. Over the last 60 years, control systems have evolved from pneumatic control to microprocessor-based controls, which have reduced costs and increased performance. Generally, DDC refers to the use of computers or microprocessors in concert with sensors and actuators to provide closed-loop control of building systems. DDC is not one controller but a combination of

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[41] The energy savings result from the VFD reducing speed to match loads. Since the motor power is a function of the motor speed cubed, any reduction in speed results in a far greater reduction in power and energy required. http://www.facilitiesnet.com/hvac/article/The-Benefits-of-VFDs-In-HVAC-Systems--11278.

[42] "Furnaces and Boilers," 2012. http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12530.

[43] http://www1.eere.energy.gov/buildings/lighting.html.

[44] https://www.lightingsolutions.energy.gov/comlighting/login.htm.

controllers and other devices within a building, also known as distributed control systems, which may not be HVAC-specific but control other aspects of the building operations.

6.2.2.2 Building Monitoring

Building monitoring systems provide real-time and historical data of building system operations. This involves retrieving data from meters, submeters, and sensors on individual systems as well as key equipment, which is organized and displayed in a way that makes it most useful to the building operator. The types of information that may be gathered are energy use; building, ambient, and equipment temperatures; water flow rates; and any other characteristic deemed worthwhile to monitor.

6.2.2.3 Building Automation

Building automation systems (BASs), also called energy management and control systems (EMCSs), control energy-consuming equipment in a building to reduce energy use while maintaining a comfortable environment. These systems may also include other features such as maintenance planning, fire- and physical-safety functions, and security services.[45] The line between building monitoring systems and building automation systems depends on the definition that the product vendor uses to describe its systems. Generally, monitoring is restricted to the collection and display of data, which are then used to make decisions on operating the systems. Building automation systems can implement these decisions via computer control of the systems.

Some of the most common strategies that building automation systems employ to cut energy use are:

- Scheduling. Scheduling turns equipment on or off depending on time of day, day of the week, day type, or other variables such as outdoor air conditions.
- Lockouts. Lockouts ensure that equipment does not turn on unless it is necessary. For example, a chiller and its associated pumps can be locked out according to calendar date, when the outdoor air falls below a certain temperature, or when building cooling requirements are below a minimum.
- Resets. When equipment operates at greater capacity than necessary to meet building loads, it wastes energy. A BAS can ensure that equipment operates at the minimum needed capacity by automatically resetting operating parameters to match current weather conditions. For example, as the outdoor air temperature decreases, the chilled water temperature can be reset to a higher value.
- Diagnostics. Building operators who use a BAS to monitor information such as temperatures, flows, pressures, and actuator positions may use these data to determine whether equipment is operating incorrectly or inefficiently and to troubleshoot problems. Some systems also use these data to automatically provide maintenance bulletins.

BAS systems can be used to help integrate lighting controls with daylighting to maintain a prescribed lighting level for occupied spaces. Window shade controls can be used to modulate daylighting as well as to help control passive solar heating and cooling loads. This level of tailored and detailed control is part of what makes modern building automation an effective energy efficiency tool.

6.2.2.4 Occupancy Sensors

Occupancy sensors detect human presence and prevent systems from running when they are not necessary. The most common type of occupancy sensors are lighting controls, which switch

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[45] Kamm, K., 2007. "Achieving Energy Savings with Building Automation Systems." http://www.automatedbuildings.com/news/apr07/articles/esource/070322105430kamm.htm.

off lights after a period of inactivity. These motion sensors use passive infrared, ultrasonic, or a combined multi-sensing technology, and some models can interface with building management or automation systems.[46] Many applications can use motion sensors instead of switches, but for larger areas or where the switch location does not cover the active area, an array of detectors must be installed to prevent the unintentional cutoff of lighting or other building functions in occupied areas.

6.3 Applications for Energy Efficiency and Demand Reduction

6.3.1 Economics

Energy efficiency strategies are often the most effective investments, with generally quicker payback and higher return on investment than renewable energy projects. The less efficient the building is, the greater the advantage of energy efficiency improvements. As energy efficiency improves, additional efficiency projects have less of an impact, and renewable energy systems become the more appealing investment.

6.3.2 Commissioning

Total building commissioning is defined by the National Conference on Building Commissioning as the "systematic process of assuring by verification and documentation, from the design phase to a minimum of one year after construction, that all facility systems perform interactively in accordance with the design documentation and intent, and in accordance with the owner's operational needs, including preparation of operation personnel."[47]

Energy, water, productivity, and operational savings resulting from commissioning offset the cost of implementing a building commissioning process. Recent studies indicate that on average, the operating costs of a commissioned building range from 8% to 20% below that of a non-commissioned building.[48] The one-time investment in commissioning at the beginning of a project results in reduced operating costs that will last the life of the building. In general, the cost of commissioning is less than the cost of not commissioning. Continuous commissioning or periodic recommissioning of buildings is an enhancement to O&M that typically makes facility operations and management more efficient. The cost of commissioning is dependent on many factors, including a building's size and complexity and whether the project consists of new construction or building renovation. In general, the costs of commissioning a new building range from 0.5% to 1.5% of the total construction cost. For an existing building, never before commissioned, the cost of retro-commissioning can range from 3% to 5% of total operating cost. [49]

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[46] Examples of the various types of sensors can be found at the Leviton product website: http://www.leviton.com/OA_HTML/SectionDisplay.jsp?section=37707&minisite=10251.

[47] http://www.wbdg.org/ccb/GSAMAN/buildingcommissioningguide.pdf.

[48] U.S. Department of Energy, 1998. Building Commissioning Guide.

[49] U.S. Department of Energy, 1998. Building Commissioning Guide.

CHAPTER 7

Daylighting

7.1 Overview

Daylighting is the use of natural light, admitted into a building in a controlled manner, to illuminate the interior space. The intent of this strategy is to provide adequate lighting levels for the intended occupancy use while reducing electricity consumption for interior lighting. To do this, daylighting systems incorporate wall or roof apertures (windows, skylights, and so forth) to allow daylight into the building, shading and reflecting elements to control solar heat gain and decrease glare, and control systems to modulate the interior electrical lighting as necessary to maintain required lighting levels while reducing the energy consumed by electric lighting.

Daylighting design requires balancing the reduction of energy loads for lighting provided by the daylighting system with the potential impacts on heating and cooling loads. For example, lights give off heat to the space, which can be detrimental during the cooling season but beneficial during the heating season. By reducing electric lighting, daylighting systems reduce these lighting-related heat gains. However, if the daylighting design introduces more direct sunlight to the space, this could increase solar heat gains, which could offset cooling load reductions. Daylighting also offers the opportunity for more building occupants to have views to the building exterior.

7.2 Types of Systems and Strategies

Daylighting systems can include daylight admitted to the building interior by apertures on the building perimeter (wall or roof apertures) or by apertures to the building core areas (core daylighting). Solar heat gain can negate the energy savings of daylighting systems if not properly controlled. In general, east and west apertures will be energy liabilities while south- and north-facing apertures can be designed to allow daylighting of a space while not contributing an unacceptable amount of overheating. For this reason, most daylighting designs do not incorporate large east- or west-facing apertures.

Perimeter Systems (Wall Apertures or Side Lighting). Windows are the most common daylight collectors. High windows allow light to penetrate deeper into the space, while low windows provide better views from the interior. Daylight penetration from low windows is limited to the building perimeter. A system incorporating both high and low windows combined with glare control strategies such as overhangs and light shelves can provide daylight up to 30 ft into a space.[50]

Perimeter Systems (Roof Apertures for Top Lighting). Skylights are common daylight collectors on roofs. Roof monitors, which incorporate either vertical or sloped windows, are also considered roof apertures, as are clerestory windows (see Figures 7-1 through 7-4). Roof apertures are

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[50] Ander and FAIA, 2011. http://www.wbdg.org/resources/daylighting.php.

Source: http://wiki.naturalfrequency.com/wiki/Daylight_Strategies.

Figure 7-1. Roof monitor providing top lighting, EcoTect model.

Source: http://wiki.naturalfrequency.com/wiki/Daylight_Strategies.

Figure 7-2. Sawtooth roof monitor providing top lighting, EcoTect model.

Figure 7-3. Roof monitor on West Ox Road Fairfax, VA, maintenance facility, Virginia Department of Transportation.

Source: NREL.

Figure 7-4. Daylighting with clerestory windows at Bighorn Home Improvement Center, Silverthorne, CO.

an effective method of providing daylight to low-rise buildings that have interior spaces that are open to the ceiling. They do not work well in multistory applications without affecting the design of the floor plan significantly, except for top floor applications. Traditionally, skylights have been viewed by many facilities managers as opportunities for potential roof leaks. To counter this perception and respond to the increasing demand for viable daylighting components, many manufacturers of roofing materials have recently added roof aperture systems (various forms of skylights) to their offerings and have included these elements as a part of their roof system water-tightness warranties.

Core Daylighting Systems (Light Wells, Atriums, and Courtyards). A courtyard or atrium uses a daylighting strategy that employs a large roof aperture combined with wall apertures located at one or more stories (see Figure 7-5). Many large, complex projects use this approach to provide daylighting to spaces remote from the building perimeter. Depending on location and building configuration, the strategies can employ either horizontal or sloped apertures or vertical apertures installed in light monitors.

Core Daylighting Systems (Concentrators and Light Guides, Fiber Optics). Systems that use a concentrating collector to focus sunlight, combined with light pipes or fiber optic cables, have the potential to transport daylight over considerable distances within the building. These systems are still largely experimental, but do hold promise for increasing daylight use to interior areas of taller and multistory buildings, including in retrofit situations.

7.3 Applications

Daylighting works with most nonresidential building spaces, including those usually encountered in a vehicle maintenance facility, such as office, storage, and shop areas. Daylighting of these spaces can reduce the energy required to operate electric lighting.

Source: http://wiki.naturalfrequency.com/wiki/Daylight_Strategies.

Figure 7-5. Atrium core daylighting in multistory application, EcoTect model.

An office area at a vehicle maintenance facility may be of limited size and able to be adequately daylighted with wall apertures. A warehouse space or vehicle maintenance or storage area will normally be one or two stories in height and quite a bit larger in area than the supporting office space. Consequently, it may be best to provide daylighting using roof apertures or a combination of roof and wall apertures.

Climate and Resource Availability. Properly designed daylighting systems will work in all climates in the United States, including regions that experience diffuse, overcast skies over prolonged periods of time. Because of the variations in climate, the amount of aperture, shading, and anti-glare strategies as well as the impact of the daylighting system on overall building energy consumption will vary with location.

Building Occupancy and Use. Daylight alone can provide adequate lighting for many tasks. Most maintenance areas can benefit substantially from a properly designed daylighting system. The illumination needs of circulation areas and general office areas can also be reasonably met with daylight and task lighting. For specific activities, supplemental task lighting may be required.

Building Type and Construction. Daylighting is applicable to most construction methods and building types. Wall apertures will easily work with any wall system. Roof apertures will work best with flat roofs. (Sloping roofs require daylight to penetrate through any space between the ceiling plane and the roof plane.)

The best daylighting strategies are those that respond to the local climate conditions and specific building use and building design. Understanding the interrelationship of these elements is essential to a successful design solution.

7.3.1 Economics

Illumination of interior spaces represents 20% of all the site energy consumed and an average of 38% of the site electricity consumed in commercial buildings.[51] This is a significant amount

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[51] Consumption & Efficiency, 2009.

of both total building energy and electricity consumed. Daylighting is a strategy that can significantly reduce this energy consumption and the related carbon emissions resulting from reduced electrical consumption.

Additionally, heat generated by lighting increases a building's cooling loads and decreases heating loads. Well-designed daylighting systems have been shown to save the energy required to illuminate the building and provide additional savings (10% to 20%) in cooling loads, resulting in a total load reduction of up to 33%.[52] The actual economic impact of a daylighting strategy will vary depending on time of occupancy of the building, size and shape of floor plate, type of system employed, and many other potential variables. However, the majority of the savings are due to the reduction of electric use for lighting.

Control systems and controllable fixtures can add $0.50 to $0.75 per square foot to the overall building cost. Using these controls in concert with well-designed wall and roof apertures can result in potential savings of $0.05 to $0.20 per square foot annually.[53]

Daylighting of work areas can provide economic benefits to employers in addition to many benefits to building occupants, including better health, reduced absenteeism, increased productivity, and an increase in general well-being.[54] These benefits have proven significant enough that some building codes (mostly in Europe) require workers to be no more than a specified distance (usually about 25 ft) from a window. In addition to benefiting occupants, there are resulting economic benefits to employers from reduced absenteeism and increased productivity.[55]

7.3.2 Design Options

Due to the complex nature of daylighting system design, it has become a specialty service offered by many consulting firms. Daylighting system design requires control of the quality of the daylight as much as the quantity. This requires strategies to control glare and respond to changes in ambient daylight. Additionally, the system needs to balance heat gain and heat loss with the lighting energy saved.

Control of electric lighting in a daylighting system can either be manual or automatic. Automatic controls will respond more quickly to changes in ambient light. Dimming of lighting fixtures for daylighting purposes can be controlled by photosensors, timers, switching fixtures in groups, separately switching lamps within fixtures, or using continuous dimming fixtures. Controls need to be integrated with sensors to maintain necessary illumination levels, and the daylighting system should be integrated with the building energy management system to optimize performance.

Daylighting design can have an impact on the building design and orientation, such as:

- The shape of the building footprint may need to be modified to optimize daylighting.
- The shading strategy may become an important part of the building's exterior design.
- The building may need to be reoriented on the site to optimize daylight exposure.
- A light well or courtyard may be necessary to provide daylight access in larger buildings.
- Perimeter offices may need to be relocated to permit daylight to reach open office areas.
- Interior design may need to be modified to reflect daylight.

Rules of Thumb. The following rules of thumb apply to daylighting design and can be used during the conceptual design phase of a project.[56]

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[52] Ander and FAIA, 2011. http://www.wbdg.org/resources/daylighting.php.

[53] Ander and FAIA, 2011. http://www.wbdg.org/resources/daylighting.php.

[54] Ander and FAIA, 2011. http://www.wbdg.org/resources/daylighting.php.

[55] Davis et al., 2009.

[56] Torcellini et al., 2006. http://www.nrel.gov/docs/fy06osti/37542.pdf, p. 37.

- Vertical wall aperture: Penetration of useful daylight into the building is equal to approximately 2.5 times the window head height minus the windowsill height.
  Example: For a window head height of 10 ft with a sill height of 3 ft:
  10 ft – 3 ft = 7 ft × 2.5 = useful daylight penetration of 17.5 ft.
- An economical practical limit for high-quality daylight is from 25 ft to 30 ft into a space.
  Thus, for daylight admitted from north- and south-facing apertures, the maximum practical floor-plate dimension in the north–south direction is between 50 ft and 60 ft.
- Interior surfaces should be highly reflective:

Ceiling reflectance	>80% of light striking the surface is reflected.
Wall reflectance	>50%.
Floor reflectance	>20%; design should try to achieve twice the luminance of the electric lighting system.

Predicting Performance. The interrelation of building design elements (facade and interior layout, proportions of rooms, and so forth) indicates that a thorough analysis is required for any daylighting design solution. Since light levels are not affected by scale, physical models (small-scale three-dimensional mock-ups of the space) incorporating actual reflectance levels can be used. In addition, there are over a dozen daylight simulation software programs available to predict system performance, with several available for download at no cost.[57]

Design Recommendations. Daylighting design should respond to the building program established prior to commencing the design process. The following recommendations are general in nature and may assist decision making at the conceptual level.

- If incorporating daylighting into a design, it is recommended that a competent consultant who has successful experience with daylight technology and modeling software be engaged.
- High-performance glazing allows more glazing area with less heat loss and allows more light and less heat into the space than standard glazing. Depending on the climate zone, glazing should be selected for proper visual light transmittance and solar heat gain factor to maximize daylighting performance.
- When large glazed areas are anticipated, window assemblies with a low-emittance (low-E) coating and a gas-filled void can provide a higher level of comfort and better performance.
- A successful design needs to balance heat gain in summer and heat loss in winter to provide the best overall annual performance.

Codes, Standards, and Rating Systems. The International Green Construction Code was released in March of 2012 and has requirements for daylighting. Some local jurisdictions have similar requirements. ASHRAE Standard 90.1-2007 also limits the total area of fenestration and has a window-to-wall ratio. These limits apply to buildings that use the Prescriptive Building Envelope path to compliance with the standard.

Daylighting of interior spaces is a requirement of many of the U.S. Green Building Council's LEED rating systems. It is recommended that a thorough code and standards review be performed prior to commencing any project to identify applicable building code and rating system requirements relative to daylighting, wall aperture limits, and other requirements.

Occupancy issues:

- Control of daylighting systems can be complicated; thus, commissioning of system performance to design requirements is critical, as is education and training of occupants and maintenance personnel.
- Occupant interaction with daylighting systems can be an issue.

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[57] U.S. Department of Energy, 2011. *Building Energy Software Tools Directory*.

State of the Technology. Daylighting for buildings is a readily available and efficient strategy for incorporating renewable energy into vehicle maintenance facilities. Daylighting design has progressed rapidly with the development of high-performance glazing systems and the advent of sustainable building rating systems and BIM software. Improvements in glazing technology have allowed more glass to be incorporated into buildings with less thermal impact. Rating systems generally require daylighting and views for regularly occupied spaces, driving the demand for daylighting. BIM, when combined with other available software, provides accurate three-dimensional modeling of daylighting performance integrated with building energy requirements. Initial costs to include daylight strategies are minimal, and it may only require rearrangement of already planned glazing, revisions to glazing materials, or adding of shading elements to include daylight strategies.

Trends in daylighting will see the continual development of new glazing materials that will improve system efficiencies. Highly insulating glazing materials such as nanogels (used as translucent insulation in available glazing systems with *R*-values as high as 20) should continue to drop in price and will increase in use as production is scaled to meet demand. The availability of improved modeling tools will improve system design and reduce costs. As more climate-responsive buildings are constructed, the aesthetics of daylighting will become more visible and accepted. Automated shading systems that respond to daylight availability and demand will be integrated into lighting controls and building automation systems. One current trend in design is to use a pattern guide to predict daylighting performance. The pattern guide developed by the New Buildings Institute[58] is available for free and includes analysis of 19 commonly occurring patterns in daylighting systems and recommendations for implementation.

7.4 Best Practices

Rules of Thumb for Sizing and Performance

- Daylighting systems with automatic controls and dimmable fixtures can reduce energy consumption for lighting between 35% and 60% [per the New Buildings Institute (www.newbuildings.org)].
- The effective depth of side-lighting strategies is limited to 2.5 times the window height. Minimum surface reflectance values of interior finishes: ceilings = 80%, walls = 60%, floors = 20%.

Site Considerations

- Site selection and planning should take daylighting basics into account. Daylight admitted through the south- and north-facing windows is easiest to control. Daylighting admitted by east and west windows is difficult to control and can overheat interior spaces. Therefore, orient the long dimension of building in an east/west direction for side-lighting strategies. Minimize east and west windows since it is difficult to control direct sunlight through the windows, particularly during the early morning or late afternoon when sun angles are low.
- Avoid future shading of daylit facades from new building construction, growth of landscape elements, and so forth.

System Selection

- An integrated process is necessary in the design of daylighting systems. The inputs of the owner, occupants, architect, lighting designer, mechanical engineer, and energy modeler all need to be integrated into the final design.
- Set a realistic daylighting goal for the project for the design team to achieve.

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[58] New Buildings Institute, 2012. *Daylighting Pattern Guide.* http://patternguide.advancedbuildings.net/home/.

- One-story buildings with dimensions greater than 60 ft in total depth (from face to face) are candidates for top-lighting strategies. Side-lighting strategies require overall dimensions of less than 50 ft to 60 ft.
- Daylighting requires supplemental electrical lighting. Lamp and luminaire selection should work with the daylighting, sensor, and control strategies and systems.

Design Best Practices

- Integrated daylighting strategy requires consideration of site, climate, and patterns of use, with integrated electric lighting designed to respond to daylight and provide the highest-quality and most visually appropriate and energy-efficient interior environment.
- A qualified daylighting consultant should be engaged.
- Early consideration and modeling of the impact of light levels, heat gain, and daylighting inputs are necessary.
- Use software to model the impact of daylighting on whole building performance. This will be required when a building rating certification is pursued.
- Strategies to control glare and excess heat from daylighting are critical to the success of the system.
- Segregate view windows from daylighting apertures. Low windows may cause local glare at the building perimeter and require a different shading strategy than high windows that deliver light deeper into the space.
- Locate open office areas at the building perimeter to allow daylight to penetrate into work spaces. Provide enclosed private offices with glazed walls to allow access to daylight.
- Sunlight is not the same as daylight. Direct sun penetration should be avoided. Diffuse daylight should be the primary source of daylight in a space.
- Since daylighting can be supplemented with task lighting for specific activities, acceptable task lighting strategies need to be a part of the overall lighting plan.
- As standards are revised and adopted, lighting power densities, maximum fenestration area, light sensing and controls, and other elements of a daylighting system will be affected. Similarly, building rating systems are also being continually revised and updated. Review applicable standards prior to design to determine specific criteria.

Construction

- Confirm that glass products delivered for installation have the visible light transmittance specified.
- Commissioning is applicable to daylighting, including lighting controls, occupancy sensors, movable shading, and other elements.
- Controls and monitoring:
  - Use passive controls to tune the daylighting system to the project's latitude and climate zone. Passive controls include light shelves, reflectors, shades, and sunscreens.
  - Dimming of lighting is most accepted by occupants when it is done slowly.
  - Match range of response of light-level sensors with anticipated light levels from daylighting strategies. Top lighting may require different sensors than side lighting or an atrium.

Operations and Maintenance

- As occupancy of spaces changes, changes to the spaces can affect performance of daylighting. Changes to colors can affect light reflectance, relocation of partitions can reduce access to daylight, and activities with differing light levels may replace the activities for which the space was designed.
- Maintenance personnel should be familiar with the system concept and controls. Routine maintenance as simple as dusting may be required for reflective surfaces; more complicated recalibration of controls may be necessary for differing seasons.

- Routine maintenance of components is required for optimum performance. This includes cleaning of glazing areas and any highly reflective surfaces as well as checking controls/sensors.
- Include maintenance personnel in the commissioning process.

Rules of Thumb for Cost/Performance

- Since a properly designed daylighting system reduces daytime energy demand, cost calculations should include demand pricing if applicable to the utility servicing the project.
- Daylighting systems should provide a minimum savings of 10% on the building's cooling load and electrical lighting load compared to baseline for the building type.
- Do not dim lighting below 10% of rated output since energy savings do not increase below this level.
- Refer to ASHRAE Standard 90.1 for lighting power densities for various occupancies and IESNA standards for lighting level for various tasks. Each of these should be integrated into the daylighting design.

CHAPTER 8

Passive Solar Heating

8.1 Overview

Passive solar heating is defined as using the various elements of a building to collect, store, and distribute heat collected from the sun. In these systems, thermal energy is moved by the naturally occurring forces of conduction, convection, and radiation rather than by fans, pumps, and other mechanical devices. In most latitudes in the United States, the low angle of the sun in winter means more solar energy is directed horizontally, toward the south-facing wall. In passive solar design, solar energy enters the building through south-facing windows, is absorbed by surfaces and mass within the building, and the heat is radiated into the space. During the summer, the high angle of the sun directs more energy vertically, onto the roof of the building, and the amount of sun striking the southern windows can be easily controlled with simple overhangs. The advantages of passive solar include relatively low initial cost and low operating cost. Depending on climate and passive solar strategy, elements of passive solar heating systems can also be a part of a passive or natural cooling system or the building's daylighting strategy.

8.2 Types of Systems and Strategies

Passive solar designs can include various strategies for collecting, storing, and distributing solar energy, but in all cases a properly sited and efficient floor plan coupled with a high-performance building envelope and energy-efficient building systems and appliances will yield the best overall performance. Passive systems are generally categorized as follows:[59]

Direct Gain and Sun Tempered. In this strategy, the sun is admitted to the space via south-facing windows. In a *sun-tempered space,* windows are generally clustered on the south facade, and the size of the solar aperture and the room area are balanced to maintain comfort levels during occupied periods. South window apertures are maximized, while windows on other orientations are minimized to reduce heat loss and control overheating. Sun-tempered spaces generally do not incorporate significant amounts of thermal mass. A *direct-gain* passive design incorporates mass in the space to store the solar energy. The mass is most effective when in the direct sun path and is usually sized to balance with the amount of energy admitted to the space by the solar aperture. As in all passive systems, performance is most effective when the solar aperture incorporates a movable insulation system to reduce heat loss through the aperture at night.

Indirect Gain. Indirect gain incorporates placing a high-mass material between the occupied space and the solar aperture, with the mass usually in the form of a wall. This strategy is also known as a *mass wall* and is characterized by the close proximity of the mass to the aperture

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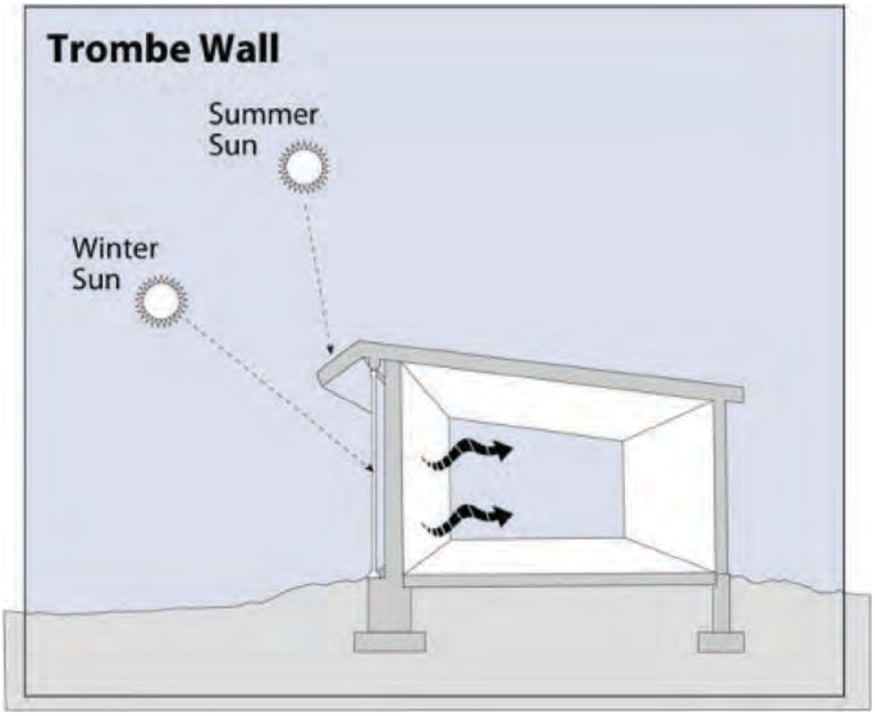
[59] Mazria, 1979.

(usually 3 in. to 6 in.). The side of the thermal mass behind the aperture is directly heated by the sun, and the stored solar heat is slowly released via radiation into the occupied space from the opposite side of the wall. The mass in an indirect gain system is typically made of concrete, masonry, or containers of water. The amount of mass is determined by the available solar radiation at the site, local climatic conditions, and the heating load of the building. The most well-known indirect gain system is the Trombe wall, which has been successfully incorporated into many residential and small commercial projects (see Figures 8-1 and 8-2). Performance of indirect gain systems can be tuned using a variety of strategies, including various wall coatings to control solar absorption and re-radiation, venting of the space between the glazing and the wall, and various exterior movable insulation systems.

Isolated Gain. To accommodate the inherent overheating and large nighttime heat loss of direct-gain systems, *isolated-gain* designs arrange occupied spaces around a unoccupied (or minimally occupied) space that contains the solar aperture. The common form of this strategy is called a *sun space.* Heat from the sun space is admitted to adjacent spaces when needed, and when not needed the sun space is allowed to overheat or cool below acceptable indoor design temperatures. Because the sun space is normally not an occupied space, wider temperature ranges are more acceptable. Mass can be incorporated into the sun space to moderate temperature swings, or a mass wall can separate the sun space from the occupied portion of the building. Venting of the sun space can be via manually operated windows or doors. Performance of isolated-gain systems can be enhanced by night insulation of the aperture, shading strategies, venting of the space during overheating, and incorporation of thermal mass.

Thermal Mass. A critical component of a passive solar design is the incorporation of thermal mass. Masonry and concrete are typical construction materials and are the most common materials used for thermal mass. Water is a good material for thermal mass and stores more energy per volume than concrete or masonry. However, water needs to be protected from freezing. A more



Source: http://energy.gov/energysaver/articles/passive-solar-home-design.

Figure 8-1. Trombe wall basics.

Source: NREL.

Figure 8-2. Trombe wall at Zion National Park Visitor's Center.

recent and more efficient technology uses materials that change phase, absorbing and releasing thermal energy as they melt or solidify. Phase change materials are available in some construction products, including concrete masonry units, gypsum wallboard, and floor and ceiling tiles. Though phase change materials offer enhanced performance, they are not widely available and are inherently expensive.

Hybrid Systems. Many passive solar heating systems include a combination of direct gain, indirect gain, and isolated gain and may incorporate daylighting strategies as well. The choice of passive strategy should take into consideration the need for daylighting and time of occupancy. A building may have different passive strategies for different spaces, or one space may combine more than one passive strategy.

8.3 Applications

Climate/Resource. In areas of the United States where heating is required, passive solar strategies will work well on residential and small commercial buildings. Successful systems have been built all over the country, from cloudy climates such as in Oregon to sunny climates such as in Arizona, New Mexico, and much of the Southwest.

Building Occupancy and Use. In most commercial buildings, large internal heat-generating loads such as high numbers of people, office equipment, solar gains, and lighting result in total heating loads that are usually less of an annual energy impact than the building's cooling loads. These buildings are load-dominated and require cooling in some portion of the building during most months. Small commercial and residential buildings are skin-dominated, losing most of their heat through their wall, window, and roof surfaces without the intensity of internal loads of larger commercial buildings. In most climates, they require heating during the day for the majority of the heating season. Thus, a skin-dominated building is a better match for passive solar heating.

Building Type and Construction. Because of the need for building mass to store passive solar energy, buildings with inherent mass, such as masonry buildings and buildings built using concrete slab-on-grade or precast concrete plank floor systems, are economical to incorporate passive strategies into. However, framed buildings with very little mass can incorporate a separate mass wall to store and distribute solar energy with a well-insulated, easy-to-construct, and economical building envelope.

8.3.1 Economics

Passive solar can be a very economical solar strategy since the elements of the system are usually part of the building structure or skin and function as part of the building and part of the solar energy system. Incremental cost increases may include additional mass for thermal storage, solar shading systems, high-performance glass, and night insulation. Due to the wide variations in passive strategies, potential materials, and design possibilities, it is difficult to make a general statement relative to the costs of passive solar systems. There are accurate tools for predicting performance to allow analysis of proposed design solutions.

8.3.2 Rules of Thumb

Site Considerations. To collect energy efficiently, the passive solar aperture should be oriented toward the south and be a maximum of 15 degrees to the east or west of solar south. Sun from the east and west is the most difficult to control with elements of the building and should be minimized. North-facing windows will not receive solar gain.

Building Footprint. In general, the long axis of the building should be oriented east/west to provide the largest southern solar wall exposure. South-facing sun is the easiest to control with shading. Interior layout: Spaces that are occupied during the day should be located to the south, with buffer spaces, such as circulation areas, storage areas, and spaces with high internal gains, located to the north.

Windows. East and west apertures are difficult to control with shading and should be kept to a minimum to prevent overheating. North apertures allow light but not solar heat since they do not receive significant amounts of direct solar radiation. Use high-performance windows for east, west, and north exposures. South-facing apertures should be shaded to allow solar gain in the winter but exclude it during the summer. Consider how glare will be controlled at large window areas.

Window-to-Floor Ratio. For a passive heating system to function, there needs to be a balance between the window aperture, the floor area of the room/space, and the amount of mass available for thermal storage. It is critical to consider latitude, climate conditions, and the area of the space when sizing windows and thermal mass.

Sun-Tempered Spaces. Solar apertures for spaces with no or minimal thermal mass should be limited or daytime overheating of the space is likely to occur. Seasonal shading and night insulation will enhance overall performance.

Direct-Gain Spaces. With appropriately sized thermal mass located in the floor and/or walls, larger solar apertures than in sun-tempered spaces are possible without overheating the space and with corresponding higher levels of performance.

Indirect Gain – Mass Walls. In this strategy, the entire area of the mass has adjacent glazing. Interior temperature is controlled by the mass of the wall, and the amount of mass should be calculated for the climate conditions. For masonry, the energy absorbed by the exterior surface of the wall takes approximately 1 hour to reach the interior surface of the wall. Thus, for an 8-in. masonry wall, energy absorbed at noon will be radiated into the adjacent occupied space at 8:00 p.m. The thickness of the mass needs to correlate to the occupancy times of the space and the amount of available solar energy to make sure the mass can be heated to comfortable temperatures by the sun.

Isolated Gain – Sun Spaces. Properly designed sun spaces will collect enough heat to maintain reasonable temperatures in the space plus add a significant amount of heat to the adjacent occupied spaces. Modeling of performance, taking into consideration the latitude, climate, thermal mass, and spaces to be heated, is critical to a successful design.

Predicting Performance. Many different currently available building energy modeling software programs can accurately predict passive solar performance. They take into account local weather data for heating and cooling loads, solar resource availability, building orientation, window size and location, glass characteristics, shading, building mass, and other variables to calculate performance.

8.3.3 Issues and Considerations

Overheating. Overheating can be an issue in passively heated buildings. Care must be taken during the design to consider window shading and solar gains during the non-heating seasons.

Glare. Because of the large glass areas associated with passive design, glare can make spaces uncomfortable. Care must be taken in the design to minimize the negative impacts of glare.

8.3.4 Codes and Standards

Various codes and standards limit maximum window area to a percentage of wall area under their prescriptive compliance path. This can be an issue with passive solar buildings and may require thermal modeling, which can be quite expensive, to verify that the building's energy performance falls within the intent of the code or standard.

8.4 Best Practices

Rules of Thumb for Sizing

Depending on climate zone and latitude, glass area will vary. In general, the south wall should have the highest window-to-wall area ratio, with other exposures having a low window-to-wall area ratio. General rules of thumb for sizing glazing are:

- Sun-tempered. South-facing glass area equal to 5% to 7% of total floor area.
- Direct-gain passive solar. South-facing glass area between 9% and 12% of total floor area.
- Providing south-facing glass areas in excess of 12% can cause overheating and should only be done when additional thermal mass is incorporated into the design.
- Adequate thermal mass is considered to be six times the area of the accompanying glazing (per the Whole Building Design Guide).
- Shading. South-facing windows can be easily shaded to allow winter solar gain while preventing summer solar access. Various design and analysis tools are available, including this free overhang annual analysis tool from Sustainable by Design: www.susdesign.com/overhang_annual/index.php.
- Comfort. In passive solar design, an understanding of thermal comfort of occupants is critical. Since many passive strategies incorporate thermal mass, the mean radiant temperature of the space can have more impact on comfort than relative humidity and air temperature and needs to be taken into account.

Site Considerations

- Site selection should take into consideration solar access when passive solar strategies are contemplated.
- Use site-specific climatic and solar data in selection and design of passive systems.

- Orientation of solar collection elevations of building should be within 15 degrees of south for maximum performance. If orientation cannot be directly to the south, rotation of building axis to the east is preferable to the west.
- Use site and landscape strategies to allow solar heat gain during the winter and protect the building from unwanted winter wind exposure.
- Distribution system:
    - Thermal mass that is directly exposed is preferred. If direct solar exposure during heating season is not possible, thermal mass should be exposed to the conditioned space.
    - The amount of thermal mass must be appropriate for solar resource, or mass may reduce mean radiant temperature and affect comfort.

System Selection

- Define acceptable thermal comfort ranges for the intended occupancy and select appropriate passive strategies.
- Consider occupancy use when selecting a passive strategy:
    - Sun-tempered and direct-gain systems can contribute to glare in occupied areas and may not be acceptable. If these strategies are considered, incorporate them into the building's daylighting strategy.
    - Indirect gain can be designed to delay the delivery of solar energy and may be appropriate for buildings that are occupied in the evening and at night.
    - Sun spaces, atria, and other isolated-gain spaces may have wide temperature swings and are not appropriate for all occupancies.
    - Building shape, massing, and layout can have significant impacts on passive solar strategies. Selection of passive strategies should be integrated into the development of the floor plan and building organization.

Design Best Practices

- A compact design incorporating a well-insulated, airtight envelope and high-performance windows is an essential element of a passive solar building.
- During the schematic design phase, locate buffer spaces at the building perimeter, where appropriate to the program, to reduce loads and optimize comfort.
- Locate spaces tolerant of temperature swings in sun spaces and other isolated-gain locations.
- Locate spaces that do not require conditioning to design temperatures to the north, east, or west.
- Whole building energy modeling is recommended to optimize performance and predict impacts of the passive design on both heating and cooling loads.
- Coordinate passive heating strategies with daylighting and natural cooling strategies.
- Each facade should address the solar exposure characteristics of its orientation to maximize performance.
- Incorporate ERV strategies to minimize energy requirements and maintain indoor air quality. Although ERVs are not passive strategies, they are an essential requirement for a building with an airtight building envelope.
- Avoid significant glass areas oriented to the west or east. Where east and west glass is included, consider the impact on heating loads and include either active or passive shading strategies.
- Supplemental heating systems should be correctly sized to avoid overcapacity and inefficient operation.

Construction

- Many opportunities for proper insulation and air sealing can only be seized during the construction process. Close monitoring of critical installations is essential.
- Provide commissioning of air-barrier performance to verify that designed infiltration levels are achieved.

- Controls and monitoring:
  - Provide ongoing monitoring of building energy use to verify performance and ensure that building occupancy activities are not in conflict with passive system design and operation.
  - Use automated or passive shading to optimize blocking direct solar radiation in the cooling season with allowing solar gains during the heating season.

Operations and Maintenance

- Use of movable insulation requires active participation of building occupants. Depending on occupancy use, this may not be reliable.
- During continued occupancy, ensure that landscape elements do not alter solar access.
- Provide training on the design and operation of the system to building maintenance staff, and document system functions in a building user guide.
- Rules of thumb for cost/performance:
  - Limit window-to-wall ratio to a maximum of 50% unless utilizing a buffer space.
  - Sun tempering can reduce heating requirements from 5% to 25% at little or no additional cost.
  - Other passive solar strategies can reduce heating requirements from 25% to as much as 75%, depending on climate, latitude, and building occupancy, and can be cost-effective on a life-cycle basis.
  - Concrete slab floors are the least expensive method of incorporating thermal mass into a project. Do not cover with carpet.

CHAPTER 9

Natural or Passive Cooling

9.1 Overview

Like passive solar heating, most natural cooling (or passive) cooling strategies have a long history. Before air conditioning and motor-driven ventilation, all cooling of buildings was done by using the forces of nature. If passive solar heating is defined as using the design of the building to collect, store, and distribute solar energy, then the definition of natural or passive cooling is for the building's design to control the heat gain of a building. Heat that does not get into the building during the cooling season does not require energy or equipment to remove. Passive heating and natural cooling are interrelated and require thorough coordination to arrive at a successful design solution where both approaches are to be applied.

The control of heat gain is critical to natural cooling strategies. When considerations for summer cooling are neglected in a passive solar design, the glazing and thermal mass can work to increase heat gain and storage at a time when it is not wanted, causing extremely uncomfortable interior conditions.

Natural cooling strategies are most effective for buildings in dryer climates that experience relatively cool nighttime temperatures. A well-designed system can function in more temperate zones with higher humidity levels but must be carefully designed. Many of the same strategies to take advantage of passive solar heating are appropriate for natural or passive cooling. Proper building orientation, floor plan layout, internal mass, window location, window shading, site shading, and building envelope design can minimize the cooling load to maximize the impacts of natural ventilation and building mass strategies. In some situations, passive cooling strategies can be enhanced by the addition of mechanical ventilation and evaporative cooling, which can maintain comfort levels without the energy required to operate vapor-compression air-conditioning systems.

9.2 Types of Systems and Strategies

Comfort during the cooling season is dependent on the humidity and temperature of the air. Climates with high temperature and high humidity may not be appropriate for natural cooling. However, many of the strategies may reduce the required mechanical cooling loads.

Natural Ventilation. The building design, site location, and window arrangement all contribute to internal air movement. Because naturally ventilated spaces require operable windows to be open during occupied times, this strategy may not be acceptable for all types of buildings. There are three basic approaches to natural ventilation: single sided, cross-ventilated, and stack effect.

Single-sided ventilation uses high and low operable windows located on the same side of the occupied space to provide ventilation. This strategy requires relatively tall ceilings and is effective for a limited depth of space.

Cross-ventilation uses operable windows on a minimum of two walls of an occupied space. This approach can be very effective, provided that the occupied spaces are open, unobstructed, and of limited dimension.

Stack effect can be created by a tower specifically designed to induce ventilation or an atrium or other architectural space. By providing low intake openings and high exhaust openings, natural ventilation can be enhanced as the buoyancy of the warm air creates a chimney effect within the space.

High Mass. Buildings with high ratios of mass to floor area are able to absorb heat energy during the day and release it at night. A typical example of this type of strategy would be an adobe building in the southwestern United States. The high mass of the building is essentially a thermal flywheel that dampens wide temperature swings in the occupied portions of the building.

High Mass with Nighttime Ventilation. The performance of a high-mass building can be enhanced by closing the building to the warm air of the day and opening the building to flush out the heat during the night. In some instances, naturally cooled buildings use mechanical ventilation to improve the heat removal during the night, but because vapor-compression air-conditioning equipment is not used, this type of system uses considerably less energy.

Evaporative Cooling. There are a variety of passive evaporative cooling strategies that have long been employed on buildings. Fine water spray evaporative cooling can reduce the temperature of shaded outdoor spaces in dry climates. In more humid regions, roof ponds are an example of a passive evaporative cooling strategy. Even when supplemented with mechanical fans, these systems are still highly energy efficient.

Shading. Temperatures in the shade can be significantly lower than in areas with full solar exposure. Natural cooling strategies incorporate shading of windows to reduce heat gain as well as shading of the site and building. Solar panels (e.g., photovoltaic modules) can serve as awnings to provide shading and solar power.

9.3 Applications

Climate/Site. Climates with relatively low humidity and low nighttime temperatures during the cooling season will accommodate natural cooling systems best. Orientation of buildings should be to maximize impact of summer breezes. Shade trees or shade structures can help reduce the temperature of entering ventilation air.

Building Occupancy and Use. Natural cooling strategies are applicable to buildings with occupancies that can tolerate some temperature swings and variable air movement. High-mass buildings would also be good candidates for passive solar heating.

Building Type and Construction. As in passive solar-heated buildings, natural cooling strategies also incorporate thermal mass. Buildings with inherent mass are economical to incorporate natural cooling strategies. In ventilated buildings, cross-ventilation or stacked ventilation can be provided to enhance airflow. Limiting the sources of heat by shading windows and minimizing heat transfer and infiltration through the building envelope will enhance the performance of natural cooling systems. Careful integration of daylighting strategies will balance electric lighting energy savings with heat gains in a way that optimizes annual energy performance. Internal thermal building loads should also be minimized. Light-colored pavement adjacent to the building and light-colored siding and roofing can reduce cooling loads. Ventilation through a space works best when spaces are narrow (35 ft to 45 ft) with open interiors, which can affect the floor plan of larger buildings. Due to potential solar gain, windows at the east and west exposures should be avoided.

9.3.1 Economics

Natural cooling strategies can be a part of the building and may have minimal impact on the overall cost of a project. Added costs include those from operable windows, increased quantity of windows, shading of windows with architectural elements, and landscape shading. Performance modeling of natural ventilation systems can be quite complex and can also add to the project cost. Color selection can have an impact on performance and usually does not represent a significant additional cost. The percentage of natural cooling will vary with building design and location and can vary widely. The San Francisco Federal Building is totally naturally ventilated. At 18 stories tall with over 600,000 ft^2 of floor area, it is an extreme example. However, many employees find that the variations in temperature produce less-than-ideal working conditions.

9.3.2 Predicting Performance

Rules of thumb do not apply except in the simplest cases. Due to variations in building design, climate, and latitude, natural cooling systems should be modeled on a case-by-case basis. Many projects now employ computational fluid dynamic simulations to fine-tune natural ventilation. Building energy modeling software programs should also be used to accurately predict natural cooling contribution to the building's thermal performance.

9.4 Best Practices

Rules of Thumb for Sizing

- Natural cooling strategies can be very effective, but due to the variations in climate, building layout, building use, occupant preference, and many other factors, rules of thumb do not generally apply.

Site Considerations

- Climate will determine appropriate natural cooling strategies. Consideration of daily temperature variations and extremes, relative humidity, prevailing winds, and other site-related factors are critical in selecting natural cooling strategies.
- Use of the prevailing wind during the cooling season can affect selection of building site and orientation of major activity areas.
- Use site and landscape strategies to reduce cooling loads and protect the building from unwanted solar exposure and heat island impacts.

System Selection

- Include thermal mass within the insulated envelope of the building.
- Integrate thermal mass for cooling with thermal mass that is part of a solar heating strategy to optimize annual energy performance.
- Use high-performance windows.
- If incorporating only natural cooling strategies, windows should have a low shading coefficient to minimize solar gains.
- If natural cooling is combined with passive heating, clear windows in combination with low-E coatings and operable external shading designed to allow solar gains in the winter and block solar gains in the summer should be used.
- Where west and east windows are included for natural cooling, include external shading to limit heat gain.
- Coordinate natural cooling strategies with daylighting and passive heating strategies.
- Coordinate passive evaporative cooling strategies (roof ponds and water spray) with building design and detailing.

- Thermal mass must be sized for daily temperature swings, or the temperature of the mass may become uncomfortably high and affect occupant comfort.
- Supplemental ventilating and cooling systems should be correctly sized to avoid overcapacity and inefficient operation.
- Controls and monitoring:
  - Automated controls to open and close windows are available to provide natural ventilation. More sophisticated systems are required for night-flushing strategies.
  - Integrate natural ventilation controls with building HVAC and lighting system controls to optimize building energy performance.

Operation and Maintenance

- During continued occupancy, ensure that changes to building layout and landscape elements do not alter breeze and ventilation access.
- Maintain operable shading devices to perform as designed.
- Provide training on the design and operation of the system to building maintenance staff, and document system functions in a building user guide.
- Rules of thumb for cost/performance:
  - Because the primary methods of natural cooling are preventing heat gain and providing ventilation to remove unwanted heat, rules of thumb are not applicable.

CHAPTER 10

Active Solar Heating

10.1 Overview

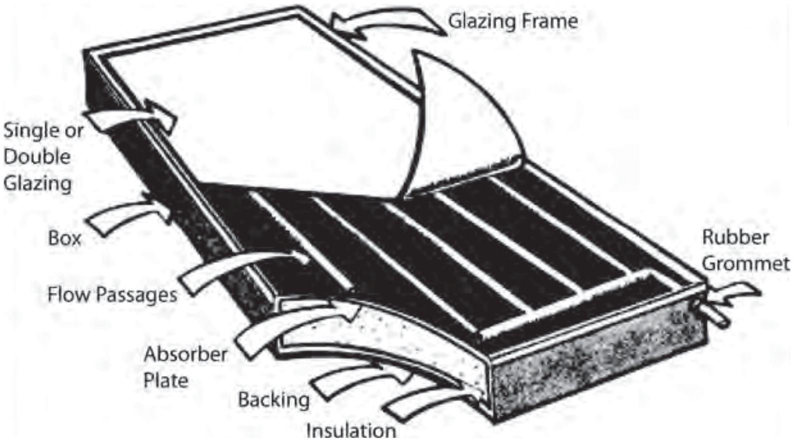
Active solar heating systems use solar collectors to convert sunlight into thermal energy that can be used for water heating, space heating, or heating ventilation air. The solar collectors are essentially heat exchangers that are designed to trap the solar heat and transfer it to either liquid or air. Depending on the application and the climate, certain types of solar collectors may be advantageous. Solar collectors are categorized as liquid or air, depending on the medium they are designed to heat (e.g., water, water/glycol mix, other heat transfer fluid, or air). Standardized testing and rating methods have been developed to enable comparison of products and ensure basic levels of equipment integrity [e.g., ability to withstand wind loads, stagnation temperatures (high temperatures associated with periods of sunshine and no flow through the collectors), and heavy rains].

10.1.1 Flat Plate Liquid Collectors

Flat plate solar collectors are the most widely used and consist of a metal absorber plate (the heat exchanger) through which liquid can flow—either directly through integral flow passages or through piping or channels in direct contact with the absorber plate. The absorber is housed in a box-like enclosure that has a transparent cover plate on one side to admit sunlight, with the other surfaces (sides and back) designed to protect the absorber and provide structural rigidity. Insulation is provided behind the absorber and on the edges of the collector box to reduce heat losses. When sunlight strikes the absorber plate, it heats the plate and the fluid that is in contact with it. The absorber plate typically has a dark coating that helps it to maximize the absorption of solar energy. Variations on the basic design include the use of different materials for the transparent cover plate, the number of cover plates, and the type of absorber coating. These variations represent trade-offs between improved solar transmission, heat retention, and overall efficiency. Flat plate liquid collectors (see Figure 10-1) provide temperatures that range from 120°F to 160°F and are well suited for applications such as water heating and space heating.

10.1.2 Evacuated-Tube Collectors

Evacuated-tube solar collectors enclose a tubular absorber or combination fin and tubular absorber within a clear glass tube. The space between the absorber and the outer tube is under a vacuum. What the vacuum does is reduce the heat losses due to convection from the absorber. Multiple tubes are connected in closely spaced rows to form a collector or array. The reduced heat losses enable the collectors to achieve temperatures from 160°F to 300°F, depending on the design. In some cases, a reflector is used in conjunction with the tubes to increase the amount of solar energy reaching the absorber. An advantage of the evacuated-tube collector is its perfor-



Source: Florida Solar Energy Center.

Figure 10-1. Flat plate liquid solar collector.

mance under very cold conditions. This type of collector is well suited for medium- to higher-temperature water heating, such as process water heating, or as a source for thermally activated cooling systems. The downside is that they cost more than flat plate collectors. Figure 10-2 shows an image of an evacuated-tube collector. The Coney Island, NY, train maintenance facility is an example of a facility using evacuated-tube collectors to provide solar-heated water for washing vehicles (see Case Studies, 22.4).

10.1.3 Flat Plate Air Collectors

Flat plate air collectors heat room air or ventilation (outside) air that is in contact with the absorber. A fan is used to draw air through the collectors and into ductwork for distribution to storage or to the space. While they do not achieve temperatures quite as high as flat plate liquid collectors, they are well matched for ventilation air heating and for systems that use air-side

Photo by Alan Ford, NREL/PIX 09501.

Figure 10-2. Evacuated-tube collector.

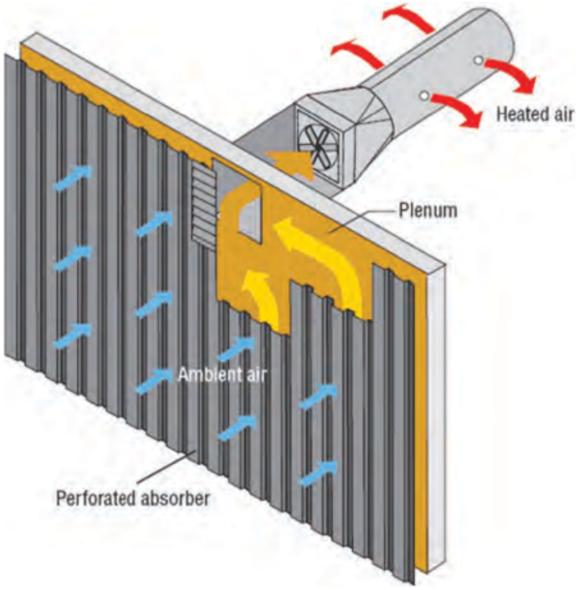
distribution. Unlike liquid solar collectors that heat air, no heat exchangers are needed between the collectors and the heating load, thereby reducing thermal losses. They also do not need freeze protection and are therefore well suited for colder climates. The St. Clair, MO, DOT facility case study is an example of a facility using solar air collectors for providing space heating (see Case Studies, 22.1).

10.1.4 Transpired Solar Collectors

Transpired solar collectors (TSCs) use a perforated metal panel as the absorber plate, which is attached to the exterior of a building and acts as external cladding. They are typically installed on a wall that has a proper orientation for capturing solar energy (e.g., south-facing walls). The collectors are attached to the walls by framing materials, which are spaced to provide optimized channels for airflow between the collectors and the wall. Outside air is drawn across the collectors from the bottom to the top and into the building by ventilation fans. Since the collectors do not have a transparent cover plate to reduce heat loss, they provide lower temperatures than glazed collectors. However, they do provide sufficiently high temperatures for preheating ventilation air—typically 20°F to 60°F above the outside temperature—and achieve fairly high efficiencies. A variation on the design uses a combination of glazed and unglazed TSCs to increase the temperatures. A transpired solar collector is depicted in Figure 10-3, and transpired solar collectors on an NREL facility are depicted in Figure 10-4.

10.1.5 Solar Collector Mounting

Solar collectors are typically mounted on the roof of a structure but can be mounted on the ground or on the building walls. Optimal year-round performance is achieved for collector arrays that are south oriented and tilted from the horizontal at angles nearly equal to the latitude. Depending on the slope of the roof, this will require variations in support structures and mounting strategies. Architectural integration with the structure—for example, mounting the solar collectors parallel to the roof slope—may be desirable for aesthetics and result in less-than-optimal tilt/orientation. Key considerations include the ability of the roof to take the additional loads



Source: U.S. Department of Energy.

Figure 10-3. Transpired solar collector.

Source: NREL (http://www.nrel.gov/news/features/feature_detail.cfm/feature_id=1522).

Figure 10-4. Transpired solar collectors on NREL facility.

imposed by the weight of the collectors and support structures, as well as the associated wind loads. Minimizing roof penetrations and making allowances for access and maintenance of collectors and the roof are also important design considerations.

10.2 Types of Active Solar Systems and Strategies

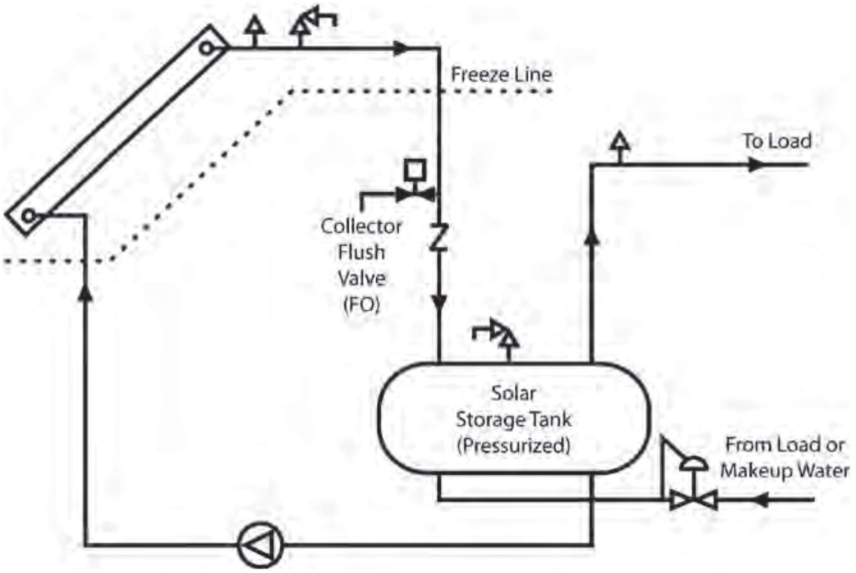
10.2.1 Solar Water Heating Systems

Solar water heating systems are categorized as direct if the service or domestic water is heated directly in the collectors, or indirect if there is a heat exchanger between the solar collector loop and the service or domestic hot water. Further distinctions are whether the system uses pumps or natural convection to circulate water through the solar collectors (thermosiphon systems). Tanks for storing solar-heated water are another major component of solar water heating systems, and distinctions are made between single-tank and two-tank systems. In a single-tank system, one tank is used for storing solar-heated water. Any heat required in addition to that supplied by the solar energy is added by an auxiliary heater (e.g., electric heating element) that is also in the tank. In a two-tank configuration, the heat from the solar collectors is stored in a preheat tank, and a second tank provides supplemental heat to boost temperatures, if needed. The designs typically have provisions for bypassing auxiliary heaters and tempering the water to maximize use of the solar energy while ensuring that supply temperatures do not exceed safe levels.

The suitability of the systems depends on the climate and application. For climates where the possibility of freezing is prevalent, indirect systems that use antifreeze fluid in the solar collector loop or that allow the water to drain from the collector loop are generally used. For mild climates, with little possibility of freezing and with supply water that has low total dissolved solids (TDS), direct systems can be safely used.

10.2.1.1 Direct Solar Water Heating Systems

In a direct solar water heating system, potable water is circulated through the collectors and then to the load (see Figure 10-5). Since these systems do not require heat exchangers, they can have lower cost and higher efficiency than indirect systems. If occasional freezing temperatures are encountered, the systems need to be drained. An alternative is to circulate warm water from



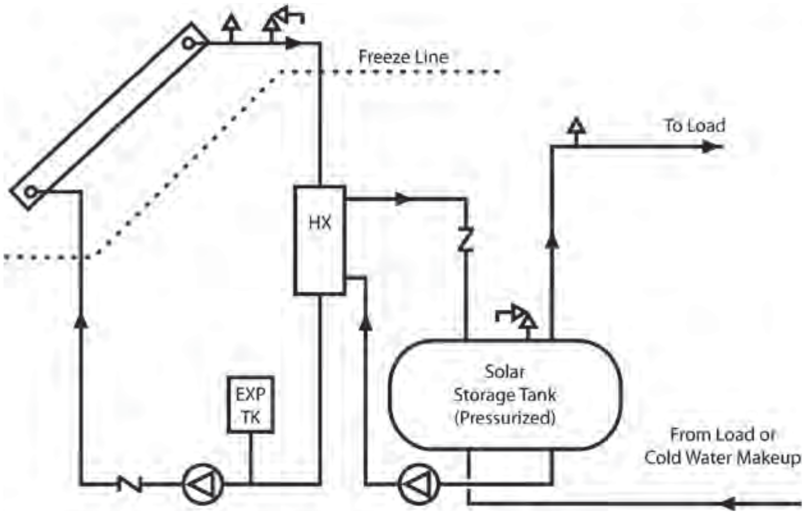
Source: *Design Manual for Commercial/Large Active Solar Systems* (http://www.solar-rating.org/commercial/designmanual/ASHRAEDesignManualIntro.pdf).

Figure 10-5. Direct system with recirculation freeze protection schematic.

the storage tank through the collector loop for short periods of time. In areas that have local potable water with high TDS, excessive scaling can occur in direct systems.

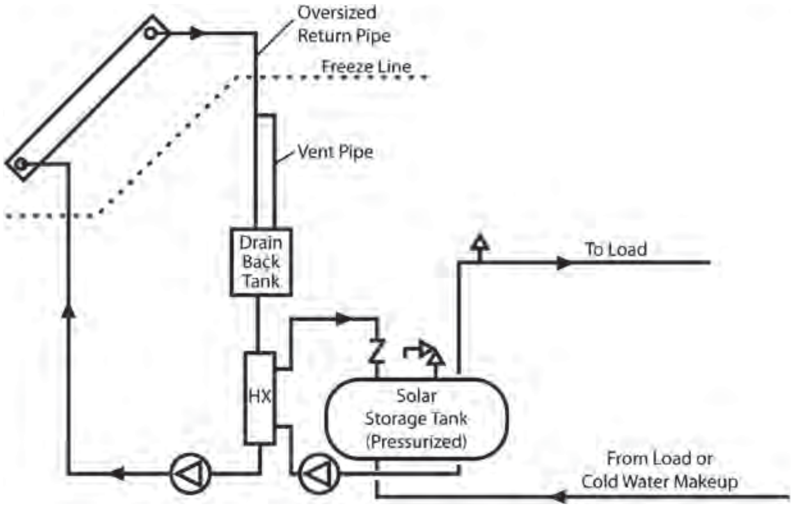
10.2.1.2 Indirect Solar Water Heating Systems

Indirect systems circulate fluid through the collectors and transfer the heat to water in the storage tank through a heat exchanger. The fluid in the collector loop is typically an antifreeze–water mix or other fluid that has a low freezing point (see Figure 10-6). However, it can also be water. When an antifreeze solution is used, the heat exchangers used typically must be of a double-wall construction. This design helps ensure that leaks in the heat exchanger do not result



Source: *Design Manual for Commercial/Large Active Solar Systems* (http://www.solar-rating.org/commercial/designmanual/ASHRAEDesignManualIntro.pdf).

Figure 10-6. Antifreeze system schematic.



Source: *Design Manual for Commercial/Large Active Solar Systems* (http://www.solar-rating.org/commercial/designmanual/ASHRAEDesignManualIntro.pdf).

Figure 10-7. Drain-back system schematic.

in the antifreeze solution mixing with potable water. When water is used, the designs incorporate a means of draining the water when needed. Drain-back systems drain the water into a tank or separate reservoir whenever the solar collector loop pump is off (see Figure 10-7). The case study of the St. Clair, MO, DOT facility includes drain-back solar water heating systems that provide domestic hot water and heated water for washing vehicles (see Case Studies, 22.1). Drain-down (also referred to as drain-out) systems drain the collector loop water whenever the temperature is low enough to make freezing a possibility. Special valves are used that can open or close in response to the temperature sensor/control to automate draining. The collector loop must be refilled with water after each drain-out event. For systems that rely on draining the water, the collector and associated piping must be installed with sufficient pitch to enable complete draining to occur. Recirculation of warm water from the storage tank through the collectors can also be used to prevent freezing. However, if this is more than an infrequent requirement, it can result in a significant penalty in terms of conventional energy use.

10.2.1.3 Other Types of Solar Water Heating Systems

Integral collector storage (ICS) combines a small water-storage tank within a box-like collector enclosure so that the solar energy heats the storage water directly. These are best suited for regions that do not experience freezing temperatures. They are primarily for residential applications with small water heating requirements.

Thermosiphon systems use a tank that is elevated above the top of the collectors. When the water in the collector loop is heated, it becomes less dense and rises naturally to the water in the tank. The colder water in the tank moves down to the collectors, and circulation is established. The benefit is that no pumps or controls are needed for circulation of the water. When the temperature of the water in the collectors is no longer higher than that in the tank, circulation stops. However, freezing is an issue, so these systems are best suited to climates where freezing does not occur. Provisions for automated drain-out can be added but add complexity. Indirect thermosiphon systems are also possible.

Air-collector–based water heating systems use flat plate air collectors rather than liquid collectors and an air-to-water heat exchanger in the solar collector loop for heat transfer. This introduces some inefficiencies to the system. The storage tank side of this configuration is the same as in the liquid collector systems. An advantage of the system is that freezing of the collectors is not an issue. However, provisions must be made to prevent circulation of air across the heat exchanger during periods when the system is not operating (e.g., unwanted thermosiphoning) and freezing temperatures are encountered. This is to prevent freezing of liquid in the water side of the heat exchanger.[60]

10.2.2 Space Heating and Combined Water and Space Heating Systems

Space heating systems using liquid collectors are typically indirect systems. Water or an antifreeze solution is circulated through the solar collectors and then through a heat exchanger. The heat exchanger transfers the heat to one or more tanks for thermal energy storage. The water from the tanks is circulated through a water-to-air or water-to-water heat exchanger depending on the distribution system (e.g., air handling units, fan coil units, convectors, radiators, or radiant heat systems). For smaller heating requirements, the use of multiple water heater tanks can be advantageous. For larger systems, single large tanks are more cost-effective. A key consideration is the temperature requirement of the building distribution system. Since the output of flat plate solar collectors is typically less than 140°F during heating season operation, this may not be high enough for certain distribution system configurations (e.g., baseboard convectors) but is adequate for others (e.g., radiant heating).

In a combined system, water heating is accomplished by using a separate heat exchanger and pump to circulate water between the main storage tank and a separate solar water heater tank. The circulation occurs as long as the temperature of the main tank exceeds that of the solar water heater tank, subject to a high temperature limit. When there is a demand for water, the water from the solar water heater tank is used and (if needed) is boosted to the required temperature by auxiliary heat.

10.2.2.1 Solar Heat Pump Systems

The thermal energy from a solar system can also be used as a heat source for the evaporator of a heat pump (series heat pump arrangement). Since the solar heat will be at a higher temperature than the outside air, this will require less work (energy) by the heat pump's compressor, thereby improving its performance. In this arrangement, the heat source is the solar-heated water in the storage tank. A parallel solar heat pump system makes use of the solar energy directly by use of a heat exchanger upstream of the heat pump indoor coil. If the heat from the solar-heated air is adequate, the heat pump will not be needed to boost the temperatures. If it is not warm enough, then the heat pump and/or auxiliary heater will provide the additional heat.

10.2.2.2 Seasonal Storage Systems

During the non-heating seasons, solar space heating systems are underutilized. This is true even for combined systems, where the water heating load is small relative to heating requirements. During the summer, operation of the system may only be required for a few hours per day, with the solar collectors being idle the rest of the time. One possibility to make use of the available heat in the summer is to store it for use during the heating season. This requires a considerable storage volume and significant insulation. While this is possible for an individual building, it is more cost-effective to do this on a larger or community scale. One such strategy uses boreholes in the ground through which solar-heated antifreeze solution circulates. Over time the boreholes and surrounding soil are heated to useful temperatures. During the heating season, the antifreeze solution is circulated through the boreholes and the heat is supplied to the buildings. Figure 10-8 shows an example in the form of a schematic of the Drakes Landing community-scale seasonal storage system at Okotoks, Alberta, Canada. These systems can benefit from higher temperature

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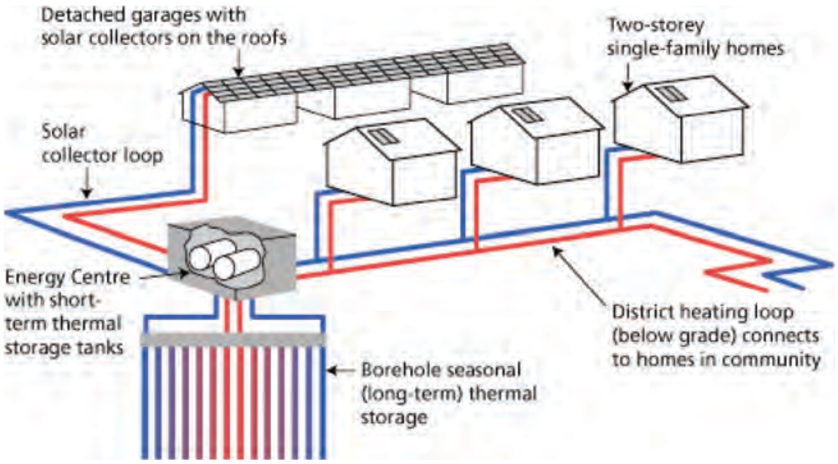
[60] Hunn et al., 1987, p. 64.



Source: http://www.dlsc.ca/.

Figure 10-8. Seasonal storage.

collectors since the higher temperatures reduce the size of the storage volume required to store the same amount of heat. At Drakes Landing, the earth reaches a temperature of nearly 180°F when fully charged.

10.2.3 Solar Ventilation Air Heating Systems

Preheating of ventilation air is accomplished by the use of transpired solar collectors (also referred to as unglazed transpired collectors) or flat plate air collectors. The solar collectors heat the ventilation air, which is mixed with the room air. The ventilation air temperature is boosted by conventional heaters if needed, depending on the design requirements. In this system, there are no storage tanks or heat exchangers involved, which reduces complexity and costs. However, this also means that solar heat cannot be stored for use during periods when there is no sunshine. Figure 10-9 shows an application of the transpired solar collector (trade name "SolarWall") on a fire station. The case studies of the vehicle maintenance facilities at Fort Drum, NY (Case Studies, 22.2) and the Plattsburgh, NY, hangar (Case Studies, 22.3) illustrate two different versions of the transpired solar collector ventilation air heating systems.

Source: Conserval: http://solarwall.com/en/products/solarwall-photo-gallery.php?img_count=36.

Figure 10-9. Willow Springs, NC, fire hall SolarWall system.

10.3 Applications

10.3.1 Active Solar Water Heating Screening Methods

The following provides methods to help determine the performance and economic suitability of active solar technologies at a screening level.

10.3.1.1 Manual Methods

Solar resource maps of available solar energy can be used in conjunction with assumptions about solar water heating system efficiency to estimate system output. The basic steps are:

Step 1: Determine Solar Resource

Obtain the solar radiation values per unit area for the location from the resource map (see http://www.nrel.gov/gis/solar.html). (Units are typically in kWh/m^2/day or Btu/ft^2/day.) Two other sources for solar radiation data that can be used for resource estimation are the *Solar Radiation Data Manual for Flat Plate and Concentrating Collectors* (http://rredc.nrel.gov/solar/pubs/redbook/) and the PVWatts software (http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/). The data manual provides monthly and annual solar resource data for flat plate and concentrating solar collectors at several different tilt angles. The units are in kWh/m^2/day, which can be converted to Btu/ft^2/day by multiplying the values by 317.1. Use the tilt angle equal to the latitude for the first pass. The PVWatts software can be run for the specific location, and the solar resource appears on the results page [Solar Radiation (kWh/m^2/day)] after "calculate" is selected.

Step 2: Determine Solar Array Area

This should be based on an initial estimate of available area and amount required to meet between 40% and 70% of the annual water heating load. As a starting point, assume that about 1 ft^2 of solar collector is needed for each 2 gal of hot water used on a daily basis. For example, if the daily usage is 1000 gal of hot water, consider a 500 ft^2 area as the initial estimate. Appendix A provides information for estimating hot water energy requirements.

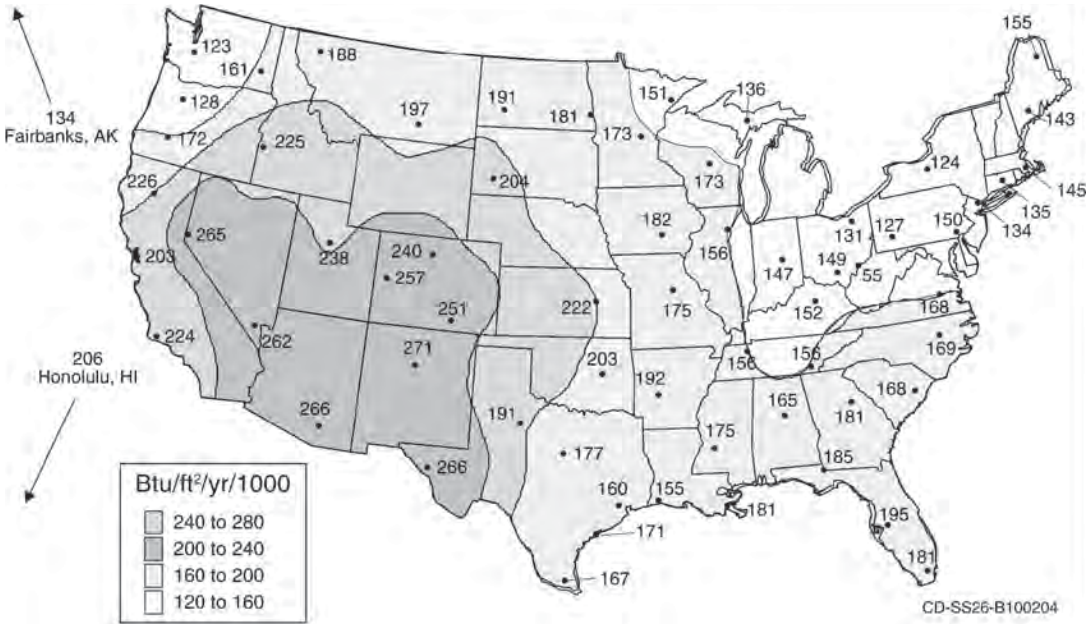
Step 3: Determine System Output

Multiply the solar array area × solar energy available/unit area × efficiency of the solar system × number of days per year. Typical efficiencies are between 35% and 45%. Efficiencies from manufacturer's equipment can be obtained from the Solar Rating and Certification Corporation (SRCC).

Step 4: Refine Solar Array Area

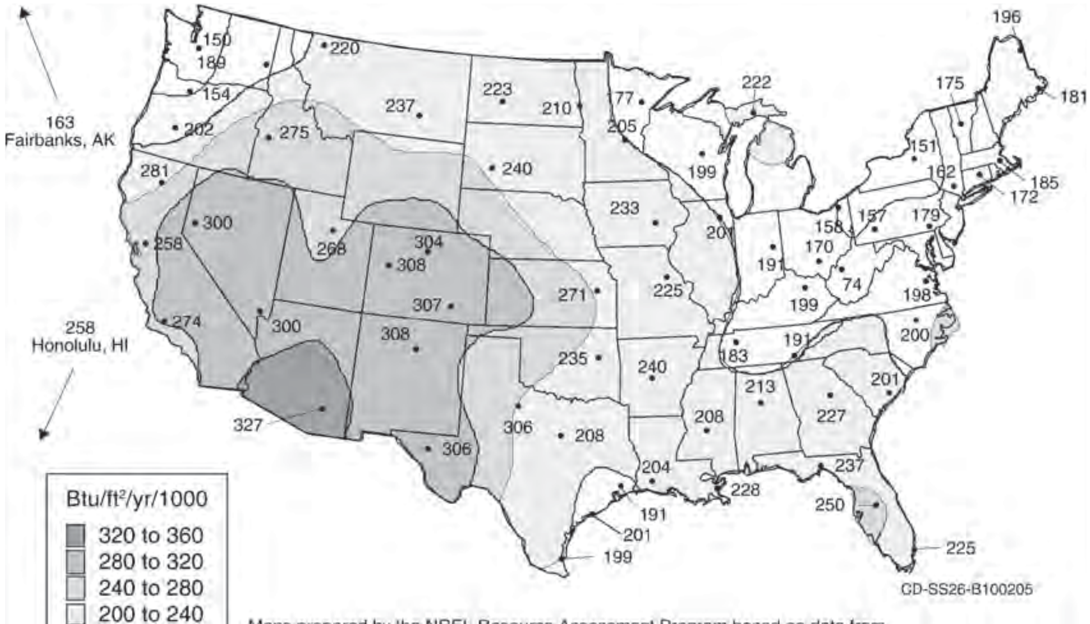
Compare the annual output to the annual solar water heating load. If this is between 40% and 70%, this is a good starting point. If not, change the assumed area and redo the calculation so that it falls in this range. Note that a system should generally be sized to provide no more than 100% of the water heating energy required on the sunniest days of the year. This minimizes any excess energy (oversizing) of the system, strictly from an energy capture perspective. If the *Solar Radiation Data Manual* or PVWatts is used, then the average daily solar array output for the sunniest month can readily be calculated. In this situation, the average daily water heating load would need to be estimated for the sunniest month and compared to this solar resource data.

The ASHRAE *Active Solar Heating System Design Manual* (http://www.solar-rating.org/commercial/index.html) has tables of pre-calculated outputs for solar water heating systems assuming two different levels of solar collector efficiency (average and good). These were based on the use of solar water heating system performance estimation software. The maps in Figure 10-10 and Figure 10-11 have been generated from these tables by the Department of Energy. They can be used in a manner similar to the method outlined previously. In this case, simply use the values from the map and multiply by the solar array area to determine the annual output.



Source: U.S. DOE Federal Energy Management Program (FEMP): Federal Technology Alert: Solar Water Heating.

Figure 10-10. Annual output of solar water heating system for average efficiency flat plate solar collector.



Maps prepared by the NREL Resource Assessment Program based on data from ASHRAE's *Design Manual*. Copyright 1995 by the American Society of Refrigeration and Air Conditioning Engineers, Inc., Atlanta, GA. Reprinted by permission from *Active Solar Heating Systems Design Manual.*

Source: U.S. DOE FEMP: Federal Technology Alert: Solar Water Heating.

Figure 10-11. Annual output of solar water heating system for high-efficiency flat plate solar collector.

Another manual performance estimating method is to use the SRCC collector rating to estimate output for solar water heating systems. The SRCC rates solar collectors (OG-100) and residential-size solar water heating systems (OG-300) and provides a method for comparing systems (http://www.solar-rating.org/facts/collector_ratings.html#EfficiencyVsCost). A benefit of this method is that actual manufacturer's data are used.

10.3.1.2 Rules of Thumb for Sizing

- Size systems to provide between 30% and 70% of water or space heating loads on an annual basis.
- For solar water heating, size so that the system provides 90% to 100% of the load on the sunniest days of the summer. This maximizes the solar utilization.
- Assume 1 gal to 2 gal of water per square foot of collector for tank sizing. Use the low end of the range for colder, cloudier climates, and the high end for warmer, sunnier climates.
- The solar collector array should be south facing (true south) and tilted to an angle equal to the latitude plus or minus 10 degrees:
  - Solar water heating. A tilt angle equal to the latitude will provide the most output for systems with relatively uniform year-round loads, such as for water heating for domestic or process applications.
  - Solar space heating or combined water and space heating. A tilt of latitude plus 10 to 15 degrees will increase wintertime output.
  - Solar cooling/maximize summer output. Use a tilt of latitude minus 10 degrees.
- Note that orientations within 30 degrees of true south and tilt within 10 degrees of latitude will still provide adequate solar energy capture. Architectural integration considerations and local solar conditions (e.g., presence of early morning fog) may dictate different orientation and tilt selection.
- Assume collector loop pump flow rates of between 0.02 gal/min and 0.05 gal/min per square foot of collector area.

10.3.1.3 Software Tools

Solar water heating system software includes:

- RETScreen. This software is sponsored by Natural Resources of Canada (NRCAN). It is free and can be downloaded as a stand-alone package. It also includes an economic analysis module. http://www.retscreen.net/.
- Federal Renewable Energy Screening Assessment (FRESA). This software is sponsored by the U.S. DOE Federal Energy Management Program (FEMP). It is an online screening tool that provides energy and economic analysis information, including life-cycle cost analysis. https://www3.eere.energy.gov/femp/fresa/.
- FChart. This software provides a simple method for determining the performance and economics of selected solar system configurations. http://sel.me.wisc.edu/fchart/new_fchart.html.
- TRNSYS. This software provides detailed analysis that is more appropriate for larger and more complex systems. http://sel.me.wisc.edu/trnsys/.

10.3.1.4 Economic Screening

The economic screening requires knowledge of how much purchased fuel the solar water heating system has saved, the cost of the fuel, and the capital and any nonfuel operating and maintenance costs of the system: Typical assumptions and information sources are:

- Solar domestic hot water system costs: \$100/ft^2 to \$150/ft^2, assuming systems between 40 ft^2 and 80 ft^2.

- Solar domestic hot water system efficiency: 40% (output is 175,000 Btu/ft^2/year to 300,000 Btu/ft^2/year, depending on location).
- Commercial-size solar water heater costs: \$100/ft^2.
- Solar space heating efficiency: 30% (output is 125,000 Btu/ft^2/year to 200,000 Btu/ft^2/year).
- Solar space heating system costs: \$75/ft^2 to \$100/ft^2.
- Annual O&M costs: 2% of system costs.
- Energy prices (per unit): depends on location [see Energy Information Administration (EIA) for statewide costs as a default: http://205.254.135.7/electricity/state/ and http://205.254.135.7/dnav/ng/ng_pri_sum_dcu_nus_a.htm].
- Fuel savings: fuel savings = solar energy used/efficiency of conventional water heater.
- Efficiency of water heater/boiler/furnace: electric resistance 100%, natural gas: 80%.
- Energy operating cost savings: energy operating cost savings = fuel savings × unit energy price.

10.3.2 Transpired Solar Collector Ventilation Air Heating System Screening Methods

10.3.2.1 Manual Methods

Solar resource information can be used in conjunction with assumptions about the transpired solar collector system efficiency and ventilation air operating hours to estimate system output. The basic steps are:

Step 1: Determine Solar Resource

Two sources for solar radiation data that can be used for resource estimation are the *Solar Radiation Data Manual for Flat Plate and Concentrating Collectors* (http://rredc.nrel.gov/solar/pubs/redbook/) and the PVWatts software (http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/). The data manual provides monthly and annual solar resource data for flat plate and concentrating solar collectors at several different tilt angles, including vertical south-facing surfaces. The units are in kWh/m^2/day, which can be converted to Btu/ft^2/day by multiplying the values by 317.1. Use the tilt angle equal to vertical, assuming that the transpired solar collectors are to be wall mounted. The PVWatts software can be run for the specific location, and the solar resource appears on the results page [Solar Radiation (kWh/m^2/day)] after "calculate" is selected. Input the tilt angle 90 degrees to model a vertical south-facing wall. Non-south-facing orientations can also be modeled if using PVWatts.

Step 2: Determine Transpired Solar Collector Area

This should be based on the building ventilation air requirements, available collector mounting area, and the flow rates that are suggested for transpired solar collectors. An airflow rate of 3 cfm/ft^2 to 10 cfm/ft^2 of collector is typical. As a starting point, assume 6 cfm/ft^2 and divide this number into the building ventilation air requirements. For example, if the ventilation air requirements are 3,000 cfm, then the collector wall area would be 500 ft^2 (3,000 cfm/6 cfm/ft^2). The resulting area should be compared to the available mounting area. If the wall area is less than this value, then assume the wall area as the mounting area. If the wall area is greater than this value, then use the calculated value as the transpired solar collector area.

Step 3: Determine Ventilation Usage Fraction

Estimate the number of days per week the ventilation system will be on. Calculate a ventilation usage fraction by dividing the number of days the ventilation is on by the total number of days per week. For example, if the facility's ventilation system is on 5 days per week, then the ventilation usage fraction is 5/7 or 0.714.

Step 4: Determine Transpired Solar Collector System Output

Determine which months of the year constitute the heating season for the facility. From the *Solar Radiation Data Manual* or the PVWatts output, for each of these months, multiply the daily solar radiation values by the number of days in that month (or if heating is only required for less than a full month, the number of days heating might be needed). Then sum these values to get the useful annual solar radiation. The units are in kWh/m^2, which should be converted to Btu/ft^2 by multiplying the values by 317.1. The annual output is calculated by multiplying the useful annual solar radiation by the efficiency of the transpired solar collector system by the transpired solar collector area (in ft^2) by the ventilation usage fraction. A value of 50% should be used for the transpired solar collector efficiency. For example, a 500 ft^2 array with a useful solar radiation of 250,000 Btu/ft^2/year would provide 62.5 MMBtu/year (250,000 Btu/ft^2/year × 50% × 500 ft^2). Note that additional benefits from the use of transpired solar collectors, such as heat loss reduction and possibly destratification, are not included in this value.

10.3.2.2 Rules of Thumb for Sizing

- Size systems based on ventilation air requirements assuming transpired solar collector flow rate of 3 cfm/ft^2 to 10 cfm/ft^2 of transpired solar collector.
- The TSC should be south facing (true south), although orientations within 30 degrees of true south will still provide adequate solar energy capture. Architectural integration considerations and local solar conditions (e.g., presence of early morning fog) may dictate different orientations.
- The color for the TSC should be dark, although it does not have to be black. The selection of colors other than black will reduce the amount of solar radiation that can be absorbed. The selection of the color will be a trade-off between architectural integration and performance. The manufacturer should specify the absorptivity of the paint.

10.3.2.3 Software Tools

Transpired solar collector performance software includes:

- RETScreen. This software is sponsored by NRCAN. It is free and can be downloaded as a stand-alone package. It also includes an economic analysis module. http://www.retscreen.net/.
- FRESA. This software is sponsored by the U.S. DOE FEMP. It is an online screening tool that provides energy and economic analysis information, including life-cycle cost analysis. https://www3.eere.energy.gov/femp/fresa/.

10.3.2.4 Economic Screening

The economic screening requires knowledge of how much purchased fuel the transpired solar collector ventilation air heating system has saved, the cost of the fuel, and the capital and any nonfuel operating and maintenance costs of the system. Typical assumptions and information sources are:

- TSC costs: \$25/ft^2 to \$35/ft^2.
- TSC efficiency: 50% (100,000 Btu/ft^2/year to 150,000 Btu/ft^2/year), not including any heat loss recapture or destratification savings.
- Annual O&M costs: 1% of system costs.
- Energy prices (per unit): depends on location (see EIA for statewide costs as a default: http://205.254.135.7/electricity/state/ and http://205.254.135.7/dnav/ng/ng_pri_sum_dcu_nus_a.htm).
- Fuel savings: fuel savings = system output/efficiency of conventional heating system.
- Efficiency of conventional heating system: electric resistance: 100%, natural gas: 80%, air-source electric heat pump: coefficient of performance (COP) = 2.
- Energy operating cost savings: energy operating cost savings = fuel savings × unit energy price.

10.4 Active Solar Best Practices

10.4.1 Solar Water and Space Heating Systems Best Practices

Site Access/Array Mounting Best Practices

- Ensure adequate roof or ground area is available, such that the solar collector array is not shaded between 9 a.m. and 4 p.m. Use sun charts (see http://solardat.uoregon.edu/SunChartProgram.html to create sun charts for specific locations) or other tools to check for obstructions that could shade the solar collectors during the course of the year. Sun charts for June 21, December 21, and March 21 provide information for the sun at its highest position, lowest position, and average position.
- Minimize roof penetrations. Consider ballasted mounting for flat roofs for rack mounting; clip-type connections for standing seam metal roofs. High wind areas need special consideration.
- Allow clearance between roof and collectors of 1½ in. to 2 in. for stand-off or rack-mounted arrays unless using integrated or flush-mounted design.
- Account for snow shedding/damming and potential for additional snow loads.
- Leave room for accessing the collectors. This could be up to 20% of the collector array area.

Piping/Distribution Systems

- Solar-ready design. Install plumbing chases that can easily be accessed for solar thermal distribution.
- Antifreeze systems. Use nontoxic (e.g., propylene glycol) heat transfer fluid in the solar collector loop. Always consult the local plumbing code.
- Water treatment. For indirect water systems, ensure that measures are taken to prevent scaling, such as water treatment or the use of deionized water.
- Make sure there is a process/system for overheat protection. Design for times when there is high solar radiation and low or minimal usage. Avoid overheating.
- Backup freeze protection must allow complete draining of collector loop/piping exposed to freezing unless an antifreeze system is used.
- Make sure adequate allowance has been made for thermal expansion of piping; use proper fittings/connectors to avoid leaks.
- Drain-back systems require proper pitch to ensure that all the water can drain out of the collector loop and piping.
- Generally use a double-wall heat exchanger between collector loop and potable water. Always consult the local plumbing code.

System Selection

- Match system type to climate. Use direct systems in non-freezing areas, glycol or drain-back systems elsewhere. The supply's water hardness (TDS) needs to be taken into account when using direct systems.
- For colder climates, use flat plate collectors with selective absorbers or collectors. Consult SRCC OG-100 list to review efficiencies/output of tested solar collectors (http://www.solar-rating.org/facts/collector_ratings.html#EfficiencyVsCost).
- Evacuated-tube collectors can be beneficial in colder climates or when higher hot water temperatures are required. A cost trade-off analysis should be used when considering more expensive evacuated-tube collectors.

Construction

- Acceptance testing/commissioning. Make sure start-up is with solar collectors still covered or occurs during early morning.
- Consider using in-house staff to assist with construction only if they are trained or there is proper supervision.

- Equipment and installer certifications:
  - Certifications. SRCC OG-100 (collectors). OG-300 for solar domestic hot water systems (smaller/residential-size systems).
  - Make sure that vendor products are readily available.
  - Make sure that firm has demonstrated experience installing this type of system.
- Use ASHRAE *Active Solar Heating Systems Design Manual* for larger systems (http://www.solar-rating.org/commercial/designmanual/ASHRAEDesignManualIntro.pdf).
- Consultant should document load estimation, solar contribution, and savings. Software tools such as RETScreen, FCHART, or another recognized tool should be used for the solar contribution estimates. Load estimates should be based on measurements or calculations according to ASHRAE or similar.
- Consider contractors who have received training through organizations such as North American Board Certified Energy Practitioners: http://www.nabcep.org/.

Controls and Monitoring

- Include monitoring instrumentation. Temperatures and flows.
- Be careful about integrating control with BAS or EMCS—likely better to leave controller independent.

Operation and Maintenance

- If in-house staff are to maintain, then make sure they are adequately trained, have O&M experience, and so forth.

10.4.2 Transpired Solar Collector Best Practices

Site Access/Array Mounting Best Practices

- Ensure that the selected area for mounting (e.g., wall) is not shaded between 9 a.m. and 4 p.m. Use sun charts or other tools to check for obstructions that could shade the solar modules during the months of the heating season. Sun charts for June 21, December 21, and March 21 provide information for the sun at its highest position, lowest position, and average position.
- Make sure that the area selected for intake air does not have the possibility of drawing from contaminated air sources (e.g., vehicle exhaust).

Construction

- Select firms that have experience in the installation of TSC systems.
- Consultant should document load estimation, TSC contribution, and savings. Software tools such as RETScreen or another recognized tool should be used for the TSC contribution estimates. Load estimates should be based on measurements or calculations according to ASHRAE or similar.

Controls and Monitoring

- Integrate the TSC operation with the building management system or energy management system, if available. Make sure that the fan operation is linked to the fire protection system such that it will shut off if a fire alarm is activated.
- Use variable-speed drive fans to modulate airflow through the TSC system in order to optimize solar energy capture. This would control the temperature rise based on variations in ambient temperature and wind conditions and indoor space temperature requirements.
- Install performance monitoring equipment to determine the amount of energy being supplied by the standard test condition (STC) system.

Operation and Maintenance

- Provide training in system operation for in-house maintenance personnel.

CHAPTER 11

Photovoltaics

11.1 Overview

PV systems consist of modules of solar cells that convert sunlight to electricity. The electricity generated is direct current (DC), which can be used to run DC-powered equipment or to charge batteries. In many cases, the DC power is converted to alternating current (AC) by use of an inverter so that it is compatible with AC-powered devices and the electric grid. PV systems can be tied to the electric grid (grid connected) or used in off-grid situations. The major benefit of being grid connected is that the utility is able to provide power during periods when the PV system output is not sufficient to meet the facility's loads (e.g., periods when there is no sunshine). In an increasing number of jurisdictions, the utility allows electricity that is in excess of the facility's requirements to be exported to the grid, and pays for this electricity via a *net metering* arrangement. Off-grid PV systems generally use batteries if there is a desire to use PV-generated electricity during periods when there is no sunshine. For PV water pumping, it may be possible to store the water during periods of sunshine for use during periods when there is no sunshine.

11.2 Types of Systems and Strategies

11.2.1 Photovoltaic Modules

Photovoltaic modules consist of solar cells—semiconductor materials—that generate electricity when exposed to light energy. The dominant type of PV module is based on crystalline silicon (c-Si) materials—either monocrystalline or polycrystalline. The solar cells are encapsulated and housed in assemblies that provide structural rigidity and protection from the elements. Typical modules for use in building applications range from 125 W to 300 W in capacity, although some higher output modules are available (see Figure 11-1). Amorphous silicon (a-Si)-based PV modules are also available that can be applied to flexible substrates (e.g., metal roofing materials). These tend to have lower efficiencies and somewhat lower costs per unit area. Other materials that are used include cadmium telluride (CdTe), cadmium sulfide (CdS), copper indium diselenide (CIS), and copper indium gallium (di)selenide (CIGS). These are classified as *thin-film PV modules* because they require less semiconductor material than crystalline silicon PV modules. The principal advantages of thin-film PV modules are (potentially) lower cost than crystalline silicon modules and the ability to be applied to various substrates. In general, the efficiencies of thin-film PV modules (11%) are higher than those of amorphous crystalline PV modules (7%), but lower than for crystalline PV modules (14%).[61] Module efficiencies and power ratings

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[61] U.S. Department of Energy, 2011. *2010 Solar Technologies Market Report,* p. 58. http://www.nrel.gov/docs/fy12osti/51847.pdf. Note that efficiencies of 20% are now available in commercial monocrystalline silicon PV modules.

Source: Dennis Schroeder/NREL.

Figure 11-1. Crystalline silicon PV Modules on parking garage at NREL's South Table Mountain facility.

provided by manufacturers are generally at STCs. These conditions are an incident solar radiation of 1,000 W/m^2, module temperature of 25°C, and air mass of 1.5. Another rating condition is based on the PVUSA program and is called the PVUSA test condition (PTC) rating. The rating conditions in this case are an incident solar radiation of 1,000 W/m^2, ambient temperature of 20°C, and wind speed of 1 m/s. The PTC provides a more real-world rating condition (ambient temperature) and results in lower efficiencies and rated outputs than the STC. It is used by the California solar incentive programs for estimating PV module performance (see http://www.gosolarcalifornia.org/equipment/pv_modules.php). Typical PV system costs have been $6/watt to $8/watt installed for grid-connected systems (no batteries) for systems under about 250 kW. PV system costs have been decreasing over the past few years as PV module costs have declined, and costs below $6/watt are becoming more prevalent. Typical system output is 8 W/ft^2 to 12 W/ft^2 (86 W/m^2 to 129 W/m^2), accounting for inverter losses as well as other system losses.

11.2.1.1 Photovoltaic Module Mounting

Photovoltaic modules are typically mounted on the roof of a structure (e.g., maintenance building or parking area shade structure) but can be mounted on the ground or on the building walls. Optimal performance is achieved for PV arrays that are south oriented and tilted at an angle, with respect to the horizontal, about equal to the latitude. Depending on the slope of the roof, this will require variations in support structures and mounting strategies. Architectural integration with the structure—for example, mounting the modules parallel to the roof slope—may be desirable for aesthetics and result in less-than-optimal tilt/orientation. Key considerations include the ability of the roof to take the additional loads imposed by the weight of the modules and support structures as well as the associated wind loads. Minimizing roof penetrations and making allowances for access and maintenance of the PV modules and the roof are also important design considerations. Ballasted mounting, where weights are used to keep the PV modules and support structures in place, is a method for minimizing roof penetrations (see Figure 11-2).

Shading of crystalline silicon PV modules from roof-mounted equipment, building parapets, and landscape elements should be analyzed and avoided because intermittent shading of one cell in a module causes the entire module to shut down. Intermittent shading of amorphous silicon PV reduces output only from the area of the module that is shaded.

Source: Genmounts:
http://www.genmounts.com/index.php/project-list/.

Figure 11-2. Ballasted mounting support structure.

Building-integrated photovoltaics (BIPV) where the PV modules replace building envelope materials or components are also a possibility. For example, flexible thin-film amorphous silicon PV panels have been attached to metal roofing substrates to form an integral exterior roofing membrane (see Figure 11-3). The case study of the Kilauea Military Camp, HI, vehicle storage structure is an example of such an application (see Case Studies, 22.11). Translucent PV panels have been used for glazing in windows and skylights. PV tiles and shingles have also been used for roofing materials.

11.2.1.2 Tracking Systems

Tracking systems can be used with flat plate modules to increase the output of the system. By tracking the movement of the sun through the sky, more direct-beam sunlight can be captured. This additional solar energy—as much as 40% more—translates into increased output (see Figure 11-4). Trackers can be single axis or dual axis. Single-axis trackers typically have their axis in a north–south direction and track east–west. Dual-axis trackers track the sun's position in the

Source: NREL.

Figure 11-3. Amorphous silicon PV material and metal roofing application—Big Horn Home Improvement Center, Silverthorne, CO.

Source: NREL.

Figure 11-4. Sun-tracking PV systems on the roof of the Arizona National Guard's Eco-Building at Papago Park Military Reservation.

sky hourly, daily, and seasonally. They are more typically used with concentrating PV systems.[62] Trackers add cost and complexity to the systems and are most effective in regions where there is substantial direct-beam sunlight, such as the southwestern United States. They also provide more power in the morning and afternoon than non-tracking systems. Tracking systems tend to be used for larger installations serving a utility or community rather than for individual facilities.

11.2.2 Power Conditioning Equipment

Power conditioning equipment includes components designed to help the DC power from the PV system conform to the requirements of the intended loads and applications. For grid-connected systems, inverters sized to meet the maximum output of the PV array are required. These are generally stand-alone devices, although some PV modules have been developed that include micro-inverters as part of the module. For off-grid systems or those that use batteries, charge controllers are the principal means of regulating the power from the PV modules. The charge controllers control the rate of charge and discharge to ensure that the batteries operate within their specified charging and discharging regimes. This helps to prevent damage to the batteries and premature failure. The batteries most commonly used with PV systems are deep-cycle lead acid batteries (either flooded or sealed/maintenance-free types).

11.3 Applications

11.3.1 Manual Screening Methods

Solar resource maps of available solar energy on surfaces tilted at various latitudes can be used in conjunction with assumptions about photovoltaic system efficiency to estimate system output. The basic steps are:

1) Determine solar resource. Obtain the solar radiation values per unit area for the location from the resource map (see http://www.nrel.gov/gis/solar.html and Figure 11-5; units are typically in kWh/m^2/day or Btu/ft^2/day). Another source for solar radiation data that can be used for

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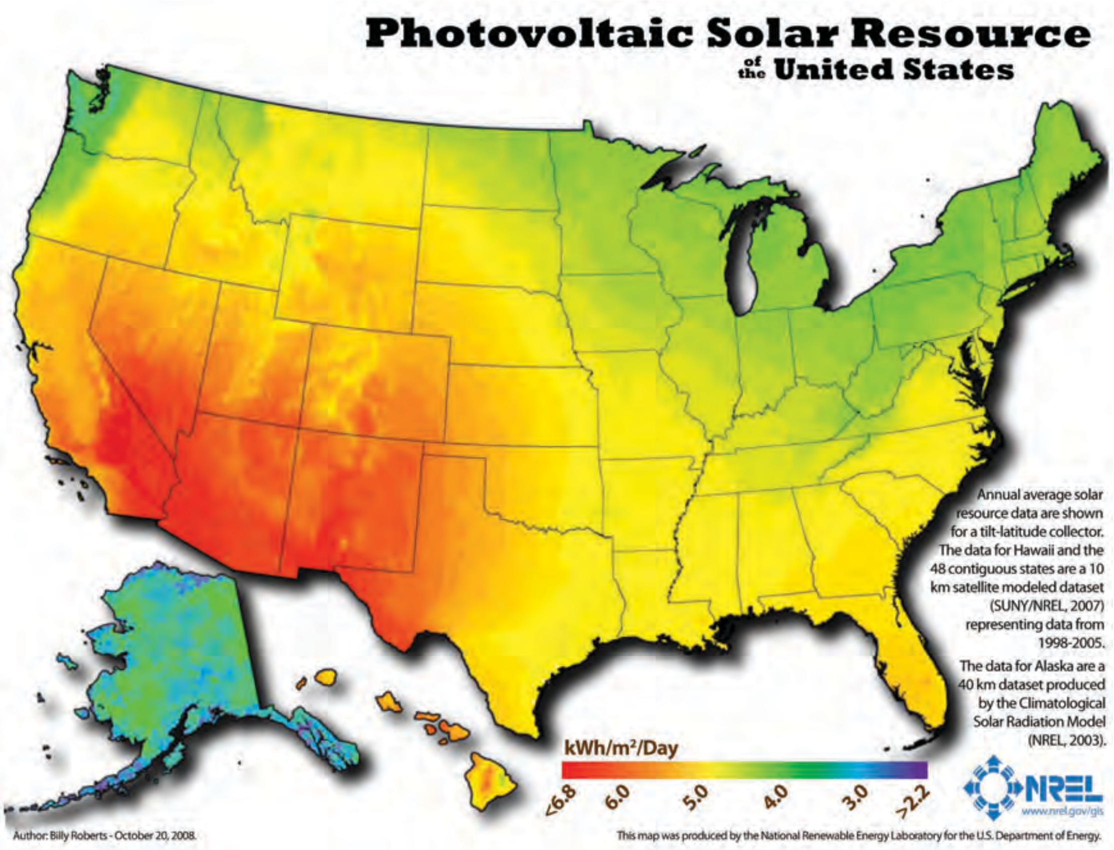
[62] The DOE article "Flat-Plate Photovoltaic Balance of System" describes the basics of different tracking options for PV systems: http://www.eere.energy.gov/basics/renewable_energy/flat_plate_pv_balance.html.



Source: NREL http://www.nrel.gov/gis/images/map_pv_national_lo-res.jpg.

Figure 11-5. Solar resource map for photovoltaic systems.

resource estimation is the *Solar Radiation Data Manual for Flat Plate and Concentrating Collectors* (http://rredc.nrel.gov/solar/pubs/redbook/). The data manual provides monthly and annual solar resource data for flat plate and concentrating solar collectors at several different tilt angles. Use the tilt angle equal to the latitude for the first pass.

2) Determine photovoltaic array area. This should be based on an initial estimate of available area and amount required to meet a portion of the facility's electrical requirements.
3) Determine annual photovoltaic system output. Multiply the solar array area × solar energy available/unit area × efficiency of the solar system × number of days per year × loss factor. Typical efficiencies at standard test conditions (PV module DC rating) are:[63]
   - Crystalline technologies:
     - Mono-Si: monocrystalline silicon, 14%–19%.
     - Poly-Si: polycrystalline silicon, 13%–15%.
   - Thin-film technologies:
     - **a-Si:** amorphous silicon, 6%–8.5%.
     - **CdTe:** cadmium telluride, 8%–11%.
     - **CIGS:** copper indium gallium diselenide, 8%–11%.

   Alternatively, the manufacturer's efficiency value for the specific module of interest can be used. The loss factor accounts for reductions in system output due to losses in the inverter, wires, dirt, and other mechanisms. A value of 0.77 (23% loss) is a good value to use. If the system does not use an inverter, then the factor should be 0.84.

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[63] *Green Energy Life Cycle Assessment Tool User Manual*, 2012, pp. 4–6.

4) Refine solar array area and other parameters. The array area can be varied along with assumptions on efficiency. If the *Solar Radiation Data Manual for Flat Plate and Concentrating Collectors* is used (http://www.nrel.gov/docs/legosti/old/5607.pdf), then the influence of tilt angles as well as tracking can also be investigated. Note that in general, tilt angles of ± 10 degrees from latitude and orientations of ± 30 degrees from true south do not appreciably change performance.

Another method that is sometimes used is based on *sun hours.* A sun hour is defined as 1000 watts (1 kW) per square meter of sunshine falling on a surface that is perpendicular to the sun's rays. This also corresponds to the amount of solar radiation (peak sun) that is used to define standard test conditions. A table or map of sun hours gives the equivalent number of hours per day that an area receives the peak amount of sunshine. For example, if during the 10 hours of sunshine the total solar energy that is received on a 1-m^2 area is 6 kWh, this is equivalent to 6 sun hours per day (daily solar energy divided by 1,000 W). In order to calculate the annual electricity production using sun hours, the following relationship is used:

$$\text{Annual output (kWh/year)} = \text{sun hours (kWh/m}^2\text{/day)} \times 365 \text{ (days/year)} \times \text{PV array area (m}^2\text{)} \times \text{efficiency} \times \text{loss factor.}$$

11.3.2 Software Tools

Photovoltaic system performance software includes:

- PVWatts. This software is available through NREL. It is an online screening tool. http://www.nrel.gov/rredc/pvwatts/.
- In My Back Yard (IMBY). This software is available through NREL. It is an online screening tool that provides a geographic information system (GIS)-user interface that enables the PV system to be sketched on a photo of the location. http://www.nrel.gov/eis/imby/.
- RETScreen. This software is sponsored by NRCAN. It is free and can be downloaded as a stand-alone package. It also includes an economic analysis module. http://www.retscreen.net/.
- FRESA. This software is sponsored by the U.S. DOE FEMP. It is an online screening tool that provides energy and economic analysis information, including life-cycle cost analysis. https://www3.eere.energy.gov/femp/fresa/.

11.3.3 Economic Screening

The economic screening requires a knowledge of how much purchased electricity the photovoltaic system has saved, the cost of the electricity, and the capital and any nonfuel operating and maintenance costs of the system. Typical assumptions and information sources are:

- Photovoltaic system costs:[64]
  - $8/watt ($8,000/kW) for systems under 10 kW.
  - $6.50/watt ($6,500/kW) for systems between 10 kW and 100 kW.
  - $6.00/watt ($6,000/kW) for systems between 100 to 250 kW.
  - $5.50/watt ($5,500/kW) for systems larger than 250 kW.

  Note that these are based on 2010 (see Appendix A, Figures A-2 through A-4) prices, and prices have been declining. However, the prices are strongly dependent on market factors such as silicon prices, as well as on technology improvements.
- Annual O&M costs: $0.005–0.01/kWh.
- Electricity prices (per unit): depends on location (see EIA for statewide costs as a default). http://205.254.135.7/electricity/state/.

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[64] U.S. Department of Energy, 2011. *2010 Solar Technologies Market Report*, p. 56. http://www.nrel.gov/docs/fy12osti/51847.pdf.

- Electricity savings: electricity savings = electricity generated by the photovoltaic system.
- Electricity cost savings: electricity cost savings = electricity savings × unit electricity price. Note that if there is net metering, and the amount generated by the PV system exceeds the facility requirements, the energy cost savings would depend in part on what, if any, the utility paid for this excess. In this case the cost savings would be the sum of the savings associated with the electricity used on-site and the amount received for the excess.

11.4 Best Practices

Rules of Thumb for Sizing

- When sizing, make sure to calculate the amount of electricity that is in excess of the facility's requirements (if any) over the annual billing period. Where net metering is allowed, determine if there are any system size restrictions. If net metering is allowed, then determine if the utility will pay for the excess electricity, and how much. Use this information in the economic analysis to help determine the appropriately sized system. If net metering is not allowed, the system needs to be designed based on the hourly daytime load, or battery backup can be considered. Consider the trade-offs of the added cost and maintenance of battery storage. The PV array area needed will vary from about 80 to 120 ft^2 per kW of capacity, depending on module efficiency.
- Make sure to account for system losses when estimating the output of the system. A typical loss factor of 0.77 (23% losses) should be used for systems with inverters and applied to the rated output of the module or array.
- Make sure to account for the likely temperatures to be experienced by the PV modules when estimating the system output. Most photovoltaic modules will have reduced outputs at temperatures above the standard rating condition (25°C). This is due to the reduction in voltage with increases in temperature. A typical reduction will be around 10%. Under these conditions, a module that has an STC rating of 200 W will only produce 180 W. Furthermore, most modules have a tolerance of about ±5%, so the actual output could be lower. An exception is amorphous silicon modules, which actually show some increase in output with increasing temperature.
- When sizing inverters, account for temperature and solar radiation variations under extreme conditions, and include an oversize factor (e.g., 5%). When possible, install inverters in shaded or cooler areas.
- The solar array should be south facing (true south) and tilted to an angle equal to the latitude. However, orientations within 30 degrees of true south and tilt within 10 degrees of latitude will still provide adequate solar energy capture. Consider mounting collectors at a small pitch, even if horizontal mounting is desired. This can help make rain more effective at keeping the collectors clean. Architectural integration considerations and local solar conditions (e.g., presence of early morning fog) may dictate different orientation and tilt selection.

Site Access/Array Mounting Best Practices

- Ensure that adequate roof or ground area is available, such that the solar array is not shaded between 9 a.m. and 4 p.m. Use sun charts or other tools to check for obstructions that could shade the solar modules during the course of the year. Sun charts for June 21, December 21, and March 21 provide information for the sun at its highest position, lowest position, and average position (see http://solardat.uoregon.edu/SunChartProgram.html to create sun charts for specific locations). Shading can be a significant problem for PV systems since the output of whole strings of panels can be nullified by partial shading.
- Minimize roof penetrations. Consider ballasted mounting for flat roofs for rack mounting, and clip-type connections for standing seam metal roofs. Take into account high wind loads.

- Allow clearance between roof and modules of 1½ in. to 2 in. for stand-off or rack-mounted arrays unless integrated or flush-mounted design. PV panels need cooling to perform well, so mounting arrangements that can increase heat transfer away from the modules are preferred.
- Account for snow shedding/damming and potential for additional snow loads.
- Leave room for accessing modules and for fire code compliance. For roof-mounted systems, this could require a buffer zone of 4 ft to 6 ft in from the perimeter.[65] This could reduce the available area by up to 20%.

Electric Distribution Systems

- Solar-ready design. Install conduit that can easily be accessed for connecting the PV array to the inverter and electric service panel.
- Make sure the service panel is adequately sized for the PV system plus the other electrical loads.

System Selection

- Make selection based on cost-effectiveness and architectural integration requirements.
- Make sure to specify the rating assumptions clearly—STC, PTC, or other—and the tools or methods used for energy output estimation. The Caltrans case study (see Case Studies, 22.7) provides a useful example of the importance of proper specification.
- Make sure inverter requirements are specified clearly.

Construction

- Consider in-house staff to assist with construction only if they are trained or there is proper supervision.
- Equipment and installation certifications:
  - Make sure to work with utility to understand interconnection requirements, net metering rules, and so forth.
  - Certifications: UL-approved PV modules (UL 1703) and inverters (UL 1741). Adherence to NEC (e.g., National Electric Code (NEC) Article 690: Solar Photovoltaic Systems).
  - Warranties: 5 years on the system, 20 years on the PV modules, and at least 5 years on the inverters.
- Make sure that vendor products are readily available—ask for experience/history of meeting delivery times.
- Make sure that firm has demonstrated experience installing this type of system.
- Consultant should document the estimated PV system output and savings. Software tools such as RETScreen, PVWatts, or another recognized tool should be used for the estimates.

Controls and Monitoring

- Include monitoring instrumentation and metering in all projects.
- Consider online data access and visual display.

Operation and Maintenance

- If in-house staff are to maintain, then make sure they are adequately trained, have O&M experience, and so forth.

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[65] This is based on the photovoltaic system provisions of the International Fire Code. See http://irecusa.org/wp-content/uploads/2010/10/Brooks-Fire-Guidelines-Webinar-Nov2010.pdf.

CHAPTER 12

Concentrating Solar Power

12.1 Overview

Concentrating solar power (CSP) systems use concentrated solar energy as a source for higher-temperature process needs and for generating electricity. The CSP systems use mirrors or lenses to focus the sun's rays on a receiver or absorber, through which a fluid circulates. This fluid is then used to heat process water or another fluid in a power generation cycle (e.g., steam turbine/generator/Rankine cycle) or a refrigeration cycle (e.g., absorption chiller). All these systems have mechanisms for tracking the sun. These are required in order to effectively focus the direct-beam component of solar radiation. There are several system types that are distinguished by the type of concentrator. These include parabolic trough systems, parabolic dish systems, and central receiver (heliostat/power tower) systems. Fresnel-lens–based concentrators have also been used. Since CSP systems can only use direct sunshine and not diffuse sunshine (e.g., sunlight that is scattered by clouds and the atmosphere), they are best suited to geographical regions that experience many clear sunny days, such as the southwestern United States. Current CSP applications are targeted at utility bulk power generation markets. Utility-scale CSP systems (e.g., 50 MW or more) have installed costs of from $4,100/kW to $8,500/kW.[66]

12.2 Types of Systems and Strategies

12.2.1 Parabolic Trough Systems

These systems use a parabolic-trough–shaped concentrator to focus the sun's rays on a tube that is located at the focal line of the reflector (see Figure 12-1). The tube has a dark coating that maximizes absorption but also minimizes heat losses. Some designs surround the receiver tube with an evacuated glass tube (similar to an evacuated-tube solar collector) to further reduce heat losses and achieve higher temperatures. Typical concentration ratios are 30 to 100 suns, and temperatures generated are from 300°F to 800°F. The heat transfer fluid can be water or a fluid that does not boil over the normal operating temperature range. Thermal storage tanks can be used for storing heat to extend the system's operating periods and to help modulate the system output. The systems have multiple rows of trough collectors connected to achieve the desired output. They are typically oriented on a north–south axis, with sun tracking from east to west throughout the day. An advantage of these systems is relatively lower costs. Parabolic trough systems have been installed for industrial process heat applications and for electric power applications.

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[66] U.S. Department of Energy, 2012. SunShot Vision Study, p. 105. http://www1.eere.energy.gov/solar/pdfs/47927_chapter5.pdf.

Source: Kramer Junction Company.

Figure 12-1. Parabolic trough concentrating solar power system at Kramer Junction, CO.

12.2.2 Parabolic Dish Systems

Parabolic dish systems use parabolic-dish–shaped concentrators with the receiver at the dish's focal point (see Figure 12-2). The heated fluid in the receiver is used to drive a heat engine power cycle. Typical concentration ratios are 250 to 500 suns, and temperatures generated are from 700°F to 900°F. Parabolic dish Stirling engine systems have the engine generator integrated with the dish to make a compact power source. Systems have been developed that provide up to 30 kW of output, with an efficiency exceeding 30% (net power out divided by solar energy heat input). Dish Brayton engine systems are currently being developed. A major benefit of these systems is their modularity.

12.2.3 Central Receiver (Heliostats/Power Tower) Systems

These systems use a field of many large mirrors to focus sunlight on a receiver that is located at the top of a tower (see Figure 12-3). Typical concentration ratios exceed 1000 suns, and temperatures generated exceed 1000°F. A molten salt is generally used as the heat transfer medium in the receiver due to the high temperatures. Thermal storage systems can be used to extend the system's availability. Central receiver systems are utility-scale systems and are not suitable for smaller applications.

12.2.4 Fresnel Concentrator Systems

A Fresnel lens focuses sunlight passing through it either at a point or on a line, depending on the lens design. The receiver is situated beneath the lens at the focal point or focal line of the lens assembly. An alternative approach uses a Fresnel design as a concentrator, with the receiver situated above the concentrator at the focal point or focal line of the concentrator. A linear Fresnel concentrator with a tubular receiver has generated temperatures above 700°F.

Source: Science Applications International Corporation.

Figure 12-2. 25-kW solar dish Stirling engine system.

Source: Sandia National Laboratories.

Figure 12-3. Solar One central receiver system at Dagget, CA.

12.3 Applications

Most CSP systems are targeted at large, multi-megawatt, utility-scale applications and require substantial flat land area (e.g., about 5 to 10 acres per MW). As a result, they are generally not suitable for typical maintenance facility applications. A possible exception is solar dish engine systems, which are currently under development. For general screening purposes, CSP systems have been able to achieve the following solar thermal to electricity conversion efficiencies:[67]

- Parabolic trough: 13% to 15%.
- Fresnel lens: 15% to 25%.
- Parabolic dish: 20% to 30%.
- Central receiver (heliostat/power tower): 15% to 18%.

In order to determine the annual output, the annual direct solar energy on a concentrating tracking collector should first be obtained either from the *Solar Radiation Data Manual for Flat Plate and Concentrating Collectors* (http://www.nrel.gov/docs/legosti/old/5607.pdf) or from the PVWatts software. This is available for parabolic trough collectors. This value should be multiplied by the efficiency for the type of CSP system and the collector concentrator's aperture area (projected area in the plane normal to the sun, not the surface area of the concentrator).

12.3.1 Economic Screening

The economic screening requires a knowledge of how much purchased electricity the CSP system has saved, the cost of the electricity, and the capital and any nonfuel operating and maintenance costs of the system: Typical assumptions and information sources are:

- Capital costs: $4,000/kW to $7,000/kW.
- Annual O&M costs: $0.02/kWh.
- Electricity Prices (per unit): depends on location (see EIA for statewide costs as a default). http://205.254.135.7/electricity/state/.
- Electricity savings: electricity generated by the CSP system.
- Energy operating cost savings: Electricity savings × unit electricity price. Note that if there is net metering and the amount generated by the CSP system exceeds the facility requirements, the energy cost savings would depend in part on what, if any, the utility paid for this excess. In this case, the cost savings would be the sum of the savings associated with the electricity used on-site and the amount received for the excess.

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[67] U.S. Department of Energy, 2011. *2010 Solar Technologies Market Report,* pp. 75-76. http://www.nrel.gov/docs/fy12osti/51847.pdf.

CHAPTER 13

Wind Energy

13.1 Overview

Wind turbines convert the kinetic energy in wind into mechanical power as the wind turns the rotor blades of the turbine, which in turn spins a shaft connected to either a transmission or directly to a generator that produces electricity. Power output from wind turbines increases exponentially with wind speed. (Power is proportional to average wind velocity cubed.) When analyzing wind resources, it is important to assess both the magnitude of the wind speeds and the frequency with which they typically occur during the day and year. Occurrence of sufficiently large combinations of both values is a primary factor for identifying economically feasible projects, and sites should be chosen to optimize that combination.

Wind turbines may be connected to the grid at transmission levels (typical for large, multi-turbine wind plants) or distribution levels. At the distribution level, they may be connected on the customer side or the utility side of the meter. This guidebook focuses on the customer-side application.

13.2 Types of Systems and Strategies

Wind machines are characterized by the axis around which the rotor blades rotate, whether the blades are attached upwind or downwind of the tower, and the number rotor blades. The wind energy market has adopted the three-bladed, upwind, horizontal-axis turbine for the vast majority of installations, although alternative designs may be beneficial under certain circumstances and for specific purposes.[68]

Figure 13-1 shows a small horizontal-axis wind turbine with a two-blade rotor and coupled generator mounted atop a stand-alone tower. As a general rule of thumb, towers should be constructed at least 30 ft above and 300 ft away from any obstruction to avoid turbulent airflows.[69] In addition, power output generally increases proportionally with increasing tower height. Small upwind machines place the rotor blades in front of the tower and use a tail feature to keep the turbine facing into the wind. The force of the wind on the tail moves (yaws) the turbine passively—that is, without the help of a motor. Larger systems usually employ an electric motor directed by wind sensors to yaw the turbine. Downwind machines, much less prevalent in the market, are noisier than upwind machines and suffer from blade flexing and fatigue issues and reduced power output as a result of the wind-shadowing effect from the tower on the rotor blades.[70]

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[68] Randolph and Masters, 2008, pp. 475, 464, 468.
[69] O'Dell, 2007, p. 7.
[70] Randolph and Masters, 2008, pp. 475, 464, 468.

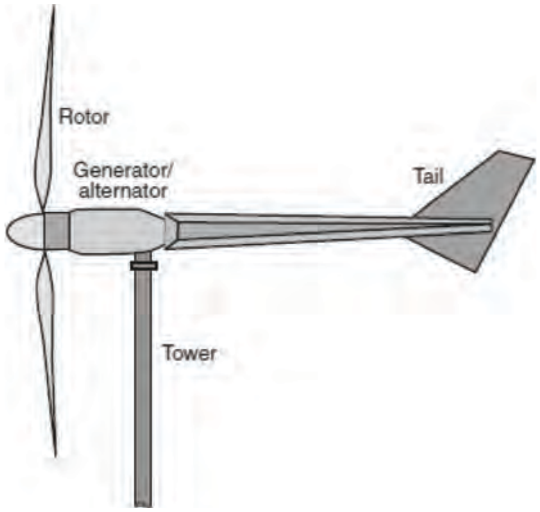

Figure 13-1. Upwind, horizontal-axis wind turbine.

Vertical-axis machines are much less common than horizontal-axis turbines but have certain advantages that make them useful for low- to medium-power applications where cost and reliability outweigh efficiency (e.g., remote and unmanned locations such a ocean buoys). Vertical-axis machines are less efficient than horizontal-axis machines but accept wind forces equally from all directions, require no yaw control, and have no issues with tower shadow. Another advantage of vertical-axis machines is that the electric generator can be mounted at the ground for easier access and maintenance.[71]

Two common vertical-axis designs are the Savonius rotor and the Darrieus rotor, shown in Figure 13-2. These designs may be employed independently or combined, as also shown in Figure 13-2. The Savonius rotor is composed of two hollow, half cylinders mounted in the shape of an "S" allowing wind to blow through the cavity. Savonius rotors can operate in wind speeds as low as about 5 mph but have a peak efficiency of only about 30%.[72] The Darrieus rotor design employs two or three blades bowed out from the center vertical axis with an aerofoil cross-section (similar to an airplane wing). The Darrieus rotor has a peak efficiency of 35% but is not self-starting like the Savonius rotor. This means that the rotor blades must be spinning before the wind will exert a driving force.[73] A Darrieus rotor can overcome this issue by integrating a Savonius rotor into the design or using its generator as a starter motor with power from batteries or the grid. Figure 13-3 shows a Darrieus type wind turbine on a state transportation facility.

Although there are no standard definitions for turbine size categories, turbines generally referred to as small and suitable for commercial use range in size from about 1 kW to 100 kW. Turbines rated between 100 kW and 800 kW to 900 kW are generally identified as medium sized. Many municipalities have completed projects with medium-sized turbines at schools or other government facilities or have located one or several turbines away from the load at a site with better winds. Some projects have involved the sharing of the energy among several facilities.

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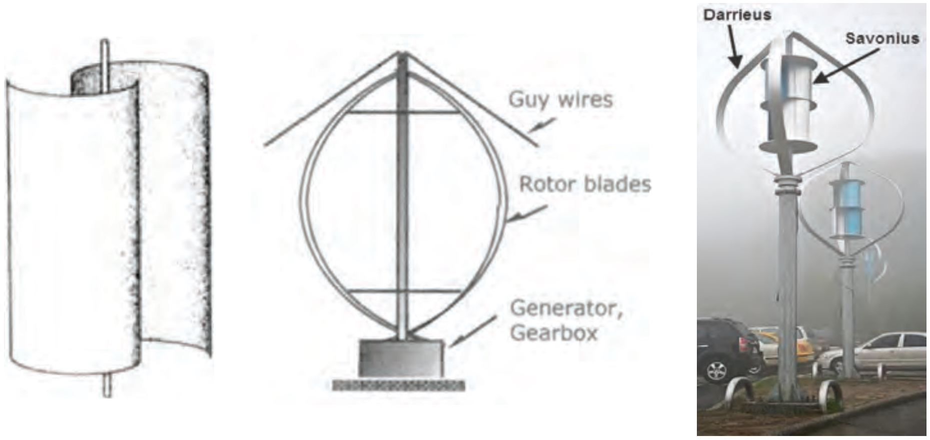
[71] Shepherd and Shepherd, 2003, p. 332.
[72] Shepherd and Shepherd, 2003, p. 332.
[73] Shepherd and Shepherd, 2003, p. 332.



Savonius rotor

Darrieus rotor

Combined Darrieus-Savonius wind turbines at Jinguashi Historic Gold Mine in Taiwan

Sources: Shepherd and Shepherd, 2003, pp. 475, 464, 468; http://upload.wikimedia.org/wikipediia/commons/f/f7/Taiwan_2009_JinGuaShi_Historic__Gold_Mine_Combined_Darrieus_Savonius_Wind_Turbines_FRD_86638.jpg.

Figure 13-2. Vertical-axis wind turbines.

Source: Conway Welcome Center in Southwest Missouri, http://www.windspireenergy.com/case-studies/missouri-department-of-transportation/.

Figure 13-3. Windspire Darrieus type wind turbine at Missouri Department of Transportation Conway Welcome Center.

The amount of energy a turbine produces annually is often expressed using a term called the *capacity factor* (CF). The CF represents the actual annual energy output of a turbine as a fraction (or percentage) of the energy that the turbine would produce if it could run at full-rated capacity every hour of the year. The CF is calculated using a distribution of wind speeds and the turbine's power curve (a curve that represents the turbine's power output at each increment of wind speed), which is a function of its design. A typical CF for a modern large wind turbine installation in a site with good resource is about 30% to 40%.[74] Small turbine projects typically, but not always, have a lower CF (in the 20% to 30% range) for two reasons. First, since the electricity is used on-site by the customer, it is valued at the retail rate rather than the wholesale rate that larger installations (wind farms) obtain. This means that customer-sited projects using smaller turbines connected to the distribution system can be cost-effective in lower wind resource sites typical of most customer locations, compared to the remote sites selected for large wind farms connected to the transmission system. Second, smaller turbines tend to be less efficient than the larger ones. As an example, a wind turbine with a rated power output of 10 kW and a CF of 30% will generate about 26,280 kWh per year.[75]

13.3 Applications

13.3.1 Applicability

Climate/Resource

Although attractive wind sites are most abundant in the middle of the country in states from Texas through North Dakota,[76] and to a somewhat lesser degree in northern border and West Coast states, there are many other states that have potential sites. In general, less potential for wind energy exists east of the Mississippi River, with the Southeast part of the country having the lowest wind resources. However, local terrain features can heavily influence the resource level at any given location, either negatively or positively, making individual site evaluation a critical early step when considering wind energy.

Table 13-1 shows the standard system used to classify wind resource levels. It lists the amount of available power in the wind for corresponding ranges of average annual wind speed.[77] This system is used for portraying wind resource levels both on maps of any size area and at specific sites. As a general rule of thumb, the threshold for economic viability of large wind energy plants supplying the bulk power market is class 4 or higher.[78] However, customer-sited projects can be cost-effective more often in class 3 sites, depending on the retail rates of electricity and other factors listed in the economics section that follows.

Figure 13-4, produced by NREL, uses the power classification system in Table 3-1 to map U.S. wind resources on a very low level of special resolution. The figure shows that, on a regional level, the largest amount of opportunities for developing wind energy in the United States are found through Midwestern states such as Texas, Oklahoma, Kansas, Nebraska, Wyoming, Montana, Minnesota, Iowa, and the Dakotas. These and several neighboring states consistently experience class 3 wind conditions or higher in many locations.

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[74] Randolph and Masters, 2008. pp. 475, 464, 468.

[75] Annual energy output (kWh/year) = 10 kW × 8,760 h/year × 30% = 26,280 kWh/year.

[76] Elliott and Schwartz, 1993. pp. 5–6.

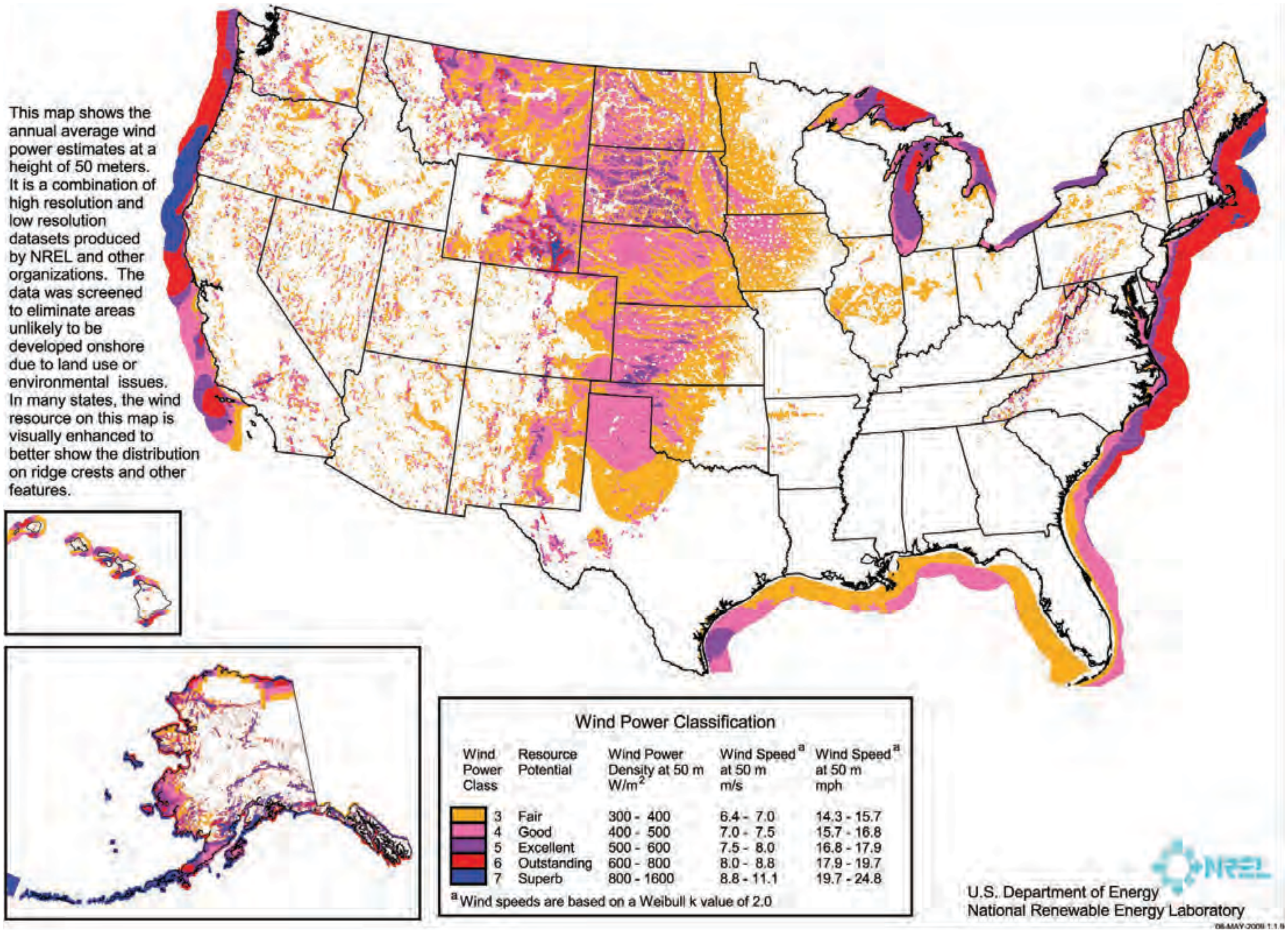
[77] Randolph and Masters, 2008. pp. 475, 464, 468.

[78] Randolph and Masters, 2008. pp. 475, 464, 468.

Table 13-1. Standard wind power classifications.

Wind Power Class	Resource Potential	Wind Power Density at 50 m (W/m^2)	Average Wind Speed at 50 m (mph)
2	Marginal	200–300	12.5–14.3
3	Fair	300–400	14.3–15.7
4	Good	400–500	15.7–16.8
5	Excellent	500–600	16.8–17.9
6	Outstanding	600–800	17.9–19.7
7	Superb	>800	>19.7

Source: Randolph and Masters, 2008. *Energy for Sustainability: Technology, Planning, Policy*, Island Press, Washington, D.C., pp. 475, 464, 468.



Source: http://www.nrel.gov/gis/pdfs/windsmodel4pub1-1-9base200904enh.pdf.

Figure 13-4. United States wind resource map ≥ class 3 at 50 meters.

13.3.2 Economics

In general, grid-connected systems can be practical if favorable combinations of the following conditions exist:

- Average annual wind speed exceeds 10 mph at the hub height of the turbine.
- Purchased electricity exceeds 12 cents per kilowatt-hour.
- Utility requirements for grid connection are not prohibitively expensive.
- Good incentives exist for purchasing wind turbines and/or for the selling of electricity back to the grid.
- Occurrence of wind is significantly correlated with the facility's electric load.

According to the American Wind Energy Association, small wind energy systems cost between \$3,000 and \$5,000 per kilowatt of generating capacity. Wind energy becomes more cost-effective for larger turbine rotor sizes.[79] This is because the cost of a turbine rotor is approximately proportional to its diameter, while the power output is approximately proportional to the diameter squared. As a result, larger systems typically require a larger initial investment but have shorter payback periods.

The intermittent nature of wind, and an often limited degree of coincidence between wind and peak electricity demand, present challenges to wind energy economics. Peak wind conditions often occur at night and during the winter months when electricity demand is relatively low in many locations.[80] Batteries can help mitigate this issue but are currently very expensive. An alternative solution that is gaining popularity for customer-sited applications is to develop hybrid systems consisting of both solar PV panels and wind turbines. Solar PV systems produce peak power in the afternoon and during the summer months.[81] When used in concert, hybrid systems can provide more consistent power throughout the year.

13.3.3 Rules of Thumb

Site Selection

- Many states have high-resolution wind resource maps available for them from the U.S. Department of Energy's Wind Powering America Program.[82] These are a good starting place for assessing the potential for viable projects at specific locations.
- On a site-specific level, locations should be evaluated for potential benefits from terrain features such as hilltops and ridges that can accelerate wind speeds.
- Sites should be as clear as possible of obstacles such as buildings or trees, which can decrease wind speeds and increase turbulence that leads to greater fatigue failure of turbines.

Siting Issues

- Turbine height. Some jurisdictions restrict the height of structures with towers in certain areas, in which case a variance would be required. However, this restriction is less likely at sites zoned for maintenance facilities.
- Visual. Turbine owners should be conscious of neighbors that might object to a turbine that obstructs their view.
- Noise. Unless the maintenance facility is very near other buildings, turbine noise should not be an issue. The noise level of most modern wind turbines is around 52 to 55 decibels, similar to a standard refrigerator.[83]

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[79] O'Dell, 2007. p. 7.

[80] O'Dell, 2007. p. 7.

[81] O'Dell, 2007. p. 7.

[82] http://www.windpoweringamerica.gov/windmaps/resource_potential.asp.

[83] O'Dell, 2007. p. 7

- Flicker. Placement of turbines should avoid the creation of shadows on buildings that can result from rotating turbine blades when the sun is at certain angles during the year.
- Environmental. Care should be taken to make sure that the turbine is not located in the path of migratory birds. Placing turbines in areas with bat populations may require consultation with appropriate agencies or experts to determine level of risk and the potential for successful mitigation approaches.

13.3.4 Manual Screening Methods

Unlike solar energy resource estimation, wind resource estimation is highly site-specific and usually requires a good local source of wind data to make an accurate prediction of energy production. Major advances in computational techniques for wind resource assessment over the past two decades have resulted in the development of a new generation of higher-resolution data for much of the country over the past several years. Under the sponsorship of the U.S. DOE, a set of state summary maps and associated GIS data files has been created and can be downloaded from DOE's Wind Powering America website (http://www.windpoweringamerica.gov/windmaps/). In addition to the state maps on the DOE website, some states have sponsored additional analysis to produce larger-scale maps.

In some instances, these state maps can produce a useful quick estimate of potential energy production. The calculation approach for such use is described in the following. However, this approach is not a substitute for sources of measured data from nearby locations or, finally, an actual site assessment. In some cases, local terrain features or obstructions have the potential to significantly change even these high-resolution data that have been estimated by analytic (modeling) techniques.

The steps for a manual quick calculation of projected wind energy production are:

Step 1

Determine the wind power density range (in units of watts per square meter, or W/m^2) for your site using the largest-scale state map that you can find from the DOE Wind Powering America site or a state agency. Note that maps are shown for various heights above the ground, including 30 m, 50 m, and 80 m. You should select the map that most closely matches the hub height of the turbine you are using for your calculation. Also note that all maps show resource levels classified by average annual wind speed (meters per second, or m/s), but some do not show power density. If you cannot find a map with power density, this calculation approach will not work.

Step 2

Select the swept area from the turbines listed by rated capacity in Table 13-2 for which you want to estimate energy production. You may use your own figure for swept area if you have

Table 13-2. Representative rotor diameter and swept area for selected turbine capacity.

Turbine Rating (kW)	Rotor Diameter (m)	Swept Area (m^2)
2.4	3.7	10.9
10	7	38.5
20	9.5	71
50	19.2	289
100	21	346
850	52	2122
1,600	82	5278
2,500	100	7850

data for a specific turbine that varies from the data in the table. The swept area of the turbine is calculated with the following formula:

Swept A/area (m^2) = 3.14 × [rotor diameter (m)/2]^2.

Step 3

Determine annual energy output using the following formula:

Annual output = swept area (m^2) × wind power density (W/m^2) × 1,000 W/kW × 8760 hours/year.

13.3.5 Software Tools

Whereas the maps referred to in the previous section showed wind resource data at a grid resolution of 2 km^2, a tool newly developed under a U.S. DOE grant achieves a higher degree of accuracy by using data at a grid resolution of several hundred square meters. Therefore, this is the recommended tool to use for obtaining an estimate of the site wind resource. A free version of the tool requires establishing a login password, and the user is prompted to download and install a Microsoft browser add-in called Silverlight to enable web-based interactions. The tool is called the Distributed Wind Site Analysis Tool and is available at https://dsat.cadmusgroup.com/Default.aspx.

All calculation tools combine distributions of wind speed with wind turbine power curves (plots of generated power versus wind speed) and assumptions about system losses to estimate system output. Several other tools with useful energy and financial calculation capabilities and turbine power curves and specification data sets are:

- Windustry Wind Project Calculator: http://windustry.com/your-wind-project/community-wind/community-wind-toolbox/chapter-3-project-planning-and-management/wi.
- Excel Wind Analysis Tool: http://www.inl.gov/wind/software/.
- NREL Wind Energy Finance Calculator: http://analysis.nrel.gov/windfinance/login.asp.
- FRESA: https://www3.eere.energy.gov/femp/fresa/.

13.3.6 Economic Screening

The economic screening requires knowledge of how much purchased electricity the wind energy system has saved, the cost of the electricity, and the capital and any nonfuel operating and maintenance costs of the system.

Rules of Thumb for Cost/Performance

- Wind costs: \$3,000 to \$6,000/kW wind system output: Capacity factors can vary widely from much less than 0.20 to well over 0.30, depending on the wind resource and the design of the turbine. This is why accurate resource assessment and optimized siting are so critical. Table 13-3 provides typical wind energy system costs.
- O&M costs: \$0.01/kWh small turbine; \$0.02/kWh for large turbine.
- Electricity Prices (per unit): depends on location (see EIA for statewide costs as a default, http://205.254.135.7/electricity/state/).
- Electricity savings = electricity generated by the wind energy system.
- Electricity cost savings: electricity cost savings + electricity savings × unit electricity price. Note that if there is net metering, and the amount generated by the wind energy system exceeds the facility requirements, the energy cost savings would depend in part on what, if any, the utility paid for this excess. In this case the cost savings would be the sum of the savings associated with the electricity used on-site and the amount received for the excess.

Table 13-3. Wind energy system costs.

Turbine Rating (kW)	Installed Cost Range ($/kW)	Installed Cost to Use with Default Power Curve ($/kW)
10	5,000–8,000	6,000
20	3,200–6,000	5,000
30	3,200–6,000	5,000
50	3,600–6,000	5,000
100	4,000–5,000	5,000
850	2,500–3,000	2,800
1,600	2,300–3,000	2,700
2,500	2,300–3,000	2,700

Source: Lorand et al., 2012.*Green Energy Life Cycle Assessment Tool User Manual*, Water Environment Research Foundation, 2012, pp. 5–6.

13.4 Best Practices

Rules of Thumb for Sizing

- When sizing, as with solar electric systems, make sure to calculate the amount of electricity that is in excess of the facility's requirements (if any) over the annual billing period. Where net metering is allowed, determine if there are any system size restrictions. If net metering is allowed, then determine if the utility will pay for the excess electricity and how much. Use this information in the economic analysis to help determine the appropriately sized system. If net metering is not allowed, the system needs to be designed based on the hourly daytime load, or battery backup can be considered. Consider the trade-offs of the added cost and maintenance of battery storage.
- The presence of a better wind resource or fewer impediments to a project (e.g., environmental concerns) at an off-site location could provide the impetus to explore a cooperative project within the department or with other departments or agencies. Installing a larger turbine could improve project economics.

Siting/Regulatory

- Research zoning and regulatory issues and discuss with zoning officials to ensure that turbine generator meets requirements for height, set back/distances from roads and buildings, noise, visibility, and, if near airports, FAA requirements (e.g., lighting). For large-scale installations (e.g., 5 MW or more, wind parks), additional regulations involving the state public utilities must be accounted for.
- Confirm lack of potential for interference with radar at military installations and other airports.
- Contact state/local environmental agencies such as wildlife agencies to discuss environmental review process and requirements to ensure compliance. This could include reviews of possible impacts on birds, bats, and other wildlife in proximity to the wind turbine generator.
- For small wind turbines (e.g., under 100 kW), make sure that the tower height is such that the bottom tip of the rotor is at least 30 ft above the ground and the turbine is sited at least 300 ft from any structures, trees, or geologic formations.[84] This is to minimize the possibility of wind turbulence that could affect the wind turbine performance and lifetime.
- Make sure to check the permit requirements for temporary meteorological towers for obtaining wind data.

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[84] U.S. Department of Energy, 2005. *Small Wind Electric Systems: A Consumer's Guide*. http://www.windpoweringamerica.gov/small_wind.asp.

- Wind data should be collected for 1 year at the site if local data is not available. An anemometer can be used for this purpose. Sometimes this time period can be reduced if the data can be correlated with other data from nearby sites. Ideally, it should be mounted at a height equal to the approximate hub height of the rotor. Companies who specialize in this area should be considered for larger projects.

System Selection

- Wind energy systems should be selected on the basis of cost-effectiveness and track record of reliability and durability.
- Make sure that the turbine is designed and, if possible, certified to withstand the turbulence levels and severe event loads for the site.
- If utility or state incentive programs are available for wind energy systems, make sure that the wind turbines qualify for the incentives. Qualifying equipment may be listed on the program's website. Qualified installers may also be listed. Examples are:
  - http://www.nyserda.ny.gov/en/Page-Sections/Renewables/Small-Wind/Eligible-Wind-Turbines.aspx, and
  - American Wind Energy Association (AWEA), which has a good list of sources (http://www.awea.org).

Construction

- Acceptance testing/commissioning. Make sure that the acceptance testing is done over a sufficient period of time to confirm proper operation.
- Consider in-house staff to assist with construction only for small projects. For example, at the Milford, Utah, DOT facility (Case Studies, 22.8), the foundation work for the tower was done by maintenance facilities staff.
- Make sure to work with the utility to understand interconnection requirements, net metering rules, and so forth.
- Certifications. AWEA promulgated standards in 2009. They are intended to be in compliance with the American National Standards Institute (ANSI) Essential Requirements and be eligible for adoption as American National Standards. The International Electrotechnical Commission (IEC) started standardizing international certification of wind turbines in 1995, and the first standard appeared in 2001, with a number of additional standards appearing since then. The United States participates in this process, and its standards are developed such that they are compatible with the IEC standards. There are several UL and Canadian standards that apply to a number of small wind turbine components such as motors, generators, gear boxes, and controls. While most small wind turbines have not been certified by an independent testing organization, there has been some movement in this direction. The Small Wind Certification Council (SWCC; http://www.smallwindcertification.org/) has begun certifying some equipment. In addition, NREL has been performing independent testing of a number of small wind turbines. The sites should be checked to see if wind turbine generators under consideration have been independently tested or certified by these organizations.
- Warranties. Warranties of 5 years on the system, wind turbines and tower, and inverters is typical. Explore options beyond the standard warranty period.
- Make sure that vendor products are readily available: ask for experience/history of meeting delivery times. This was an important lesson learned from the Ohio DOT Northwood Wind Turbine project (Case Studies, 22.9).
- Make sure that the firm has demonstrated experience installing this type of system.
- Consultant should document the estimated wind system output and savings. This should be based on the manufacturer's power curves and local wind speed data, if available.

Controls and Monitoring

- Include monitoring instrumentation for measuring and recording wind speed and output, as well as any other metering needed per the interconnection requirements of the utility.

Operation and Maintenance

- O&M services should be contracted with firms experienced with the wind turbine equipment. While much of the maintenance is fairly routine—lubrication, checking and tightening bolts, and so forth—there are safety risks associated with performing these functions at the tower heights.
- Proximity to repair personnel and parts can be a distinguishing factor to consider between turbine brands.

CHAPTER 14

Geothermal Energy

14.1 Overview

The geothermal heat pump (GHP), also known as the ground-source heat pump, is a highly efficient renewable energy technology that is gaining wide acceptance for both residential and commercial buildings. GHPs are used for space heating and cooling as well as for water heating. They operate similarly to air-source heat pumps but use the heat in the ground, groundwater, or surface bodies of water (ponds, streams), rather than heat in the air, as the source for the heat pump. They overcome a key problem with air-source heat pumps—low performance in winter when air temperatures fall below about 40°F. Since the ground is at a relatively constant temperature throughout the year below a certain depth—higher than air temperatures in the winter and lower in the summer—it enables the GHP to operate more efficiently than an air-source heat pump. According to the EPA, geothermal heat pumps can reduce energy consumption up to 44% compared to air-source heat pumps and up to 72% compared to electric resistance heating with standard air-conditioning equipment. GHPs also improve humidity control by maintaining about 50% relative indoor humidity, making GHPs very effective in humid areas.

Geothermal heat pump systems allow for design flexibility and can be installed in both new and retrofit situations.

Additional benefits include:

- Hardware requires less space than that needed by conventional HVAC systems;
- Systems provide excellent zone space conditioning;
- They have relatively few moving parts, and all moving parts are indoors (compared to air-source heat pumps); and
- Underground piping often carries warranties of 25 to 50 years, and the heat pumps often last 20 years or more.

14.1.1 Heating and Cooling Efficiency of Geothermal Heat Pumps

The heating efficiency of GHPs is indicated by the COP, which is the ratio of heat provided to energy input. The cooling efficiency is indicated by the energy efficiency ratio (EER), which is the ratio of the heat removed (in Btu per hour) to the electricity required (in watts) to run the unit. Beginning in January of 2012, an Energy Star-qualified geothermal heat pump is required to have a COP of at least 3.0 and an EER of at least 14.1.[85]

A geothermal heat pump removes heat from the geothermal ground loop and transfers the heat to the space either through a water-to-air heat exchanger, if air-side distribution systems

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[85] http://www.energystar.gov/index.cfm?c=geo_heat.pr_crit_geo_heat_pumps.

are used, or water-to-water heat exchangers, if water-side distribution systems are used. Water-to-water GHPs coupled to radiant distribution systems can be an effective means of heating maintenance facility areas. Radiant heating is most commonly done by running pipes in a concrete floor slab, but can also include radiators or radiant panels mounted on the walls or overhead. When used for heating, this strategy de-couples the heating load from the ventilation load, which is particularly helpful in spaces with a large volume, high ceilings, or that have a high ventilation demand. Using the GHP for radiant cooling is possible but requires careful control of the humidity of the conditioned space to avoid condensation problems. A closed-loop, Energy Star-rated, Tier 3 water-to-water geothermal heat pump has a COP of at least 3.1 and an EER of at least 16.1.

For GHPs that use air-side distribution (water-to-air GHP), cooling mode operation is the same as for standard cooling systems and does not introduce any special humidity control requirements, A closed-loop, Energy Star-rated, Tier 3 water-to-air geothermal heat pump has a COP of at least 3.6 and an EER of at least 17.1.

14.2 Types of Systems and Strategies

There are four basic types of ground-loop systems. Three of these—horizontal, vertical, and pond/lake—are closed-loop systems. The fourth type of system is the open-loop option. Which one of these is best depends on the climate, soil conditions, available land, and local installation costs at the site.

14.2.1 Horizontal

This type of installation is generally most cost-effective for new construction where sufficient land is available. It requires trenches at least 4 ft deep. The most common layouts either use two pipes, one buried at 6 ft and the other at 4 ft, or two pipes placed side-by-side at 5 ft in the ground in a 2-ft-wide trench. The "Slinky" method of looping pipe allows more pipes in a shorter trench, which cuts down on installation costs and makes horizontal installation possible in areas it would not be with conventional horizontal applications.

14.2.2 Vertical

Nonresidential buildings often use vertical systems because the land area required for horizontal loops would be prohibitive. Vertical loops are also used where the soil is too shallow for trenching, and they minimize the disturbance to existing landscaping. For a vertical system, boreholes (also referred to as wells) are drilled about 20 ft apart and 100 ft to 400 ft deep. Into these boreholes go two pipes that are connected at the bottom with a U-bend to form a loop. The vertical loops are connected with horizontal pipe (i.e., manifold), placed in trenches, and connected to the heat pump in the building. Of the four methods, vertical well fields extract the most amount of energy from the smallest area of land. A rough rule of thumb is that there should be a minimum of 225 ft^2 of land area available per ton (12,000 Btu/hr) of design load capacity. See Fundamentals of Commercial Geothermal Wellfield Design for a discussion of the design considerations for various configurations.[86]

14.2.3 Pond/Lake

If the site has an adequate body of water, this may be the lowest-cost option. A supply line pipe is run underground from the building to the water and coiled into circles at least 8 ft under the

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[86] Jeppesen, K. C., Fundamentals of Commercial Geothermal Wellfield Design. http://www.ghpsystems.com/wp-content/uploads/Fundamentals_of_Commercial_Geothermal_Wellfield_Design.pdf.

surface to prevent freezing. The coils should only be placed in a water source that meets minimum volume, depth, and quality criteria. This will ensure adequate heat source availability and prevent the possibility of icing of the coils.

14.2.4 Open-Loop System

This type of system uses well water/groundwater or surface body water as the heat exchange fluid that circulates directly through the GHP system. Once it has circulated through the system, the water returns to the ground through the well, a recharge well, or surface discharge. This option is practical only where there is an adequate supply of relatively clean water, and all local codes and regulations regarding groundwater discharge are met.

14.3 Applications

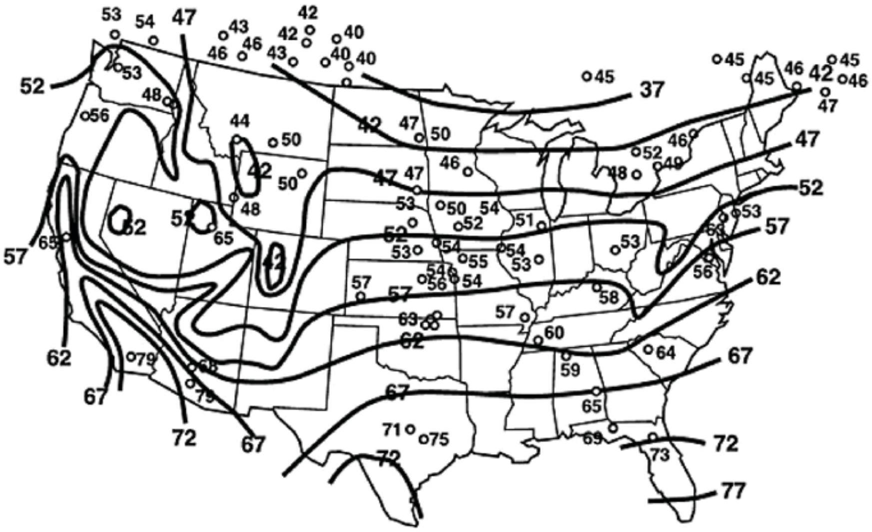
14.3.1 Site Evaluation for a Geothermal Heat Pump

Because ground temperatures below about 5 ft are relatively constant throughout the United States, GHPs can be effectively used almost anywhere. However, the specific geological, hydrological, and spatial characteristics of the site will dictate the best type of ground loop for a particular site. The depth of the soil and heat transfer properties can determine how much piping is needed or whether to use a vertical or horizontal installation method. Surface water can be used as a source of water for an open-loop system or as a repository for coils of piping in a closed-loop system, depending on factors such as depth, volume, and water quality. The amount of land and layout of the installation site, landscaping, and the location of underground utilities or sprinkler systems also contribute to the system design. Horizontal ground loops (generally the most economical) are typically used for newly constructed buildings with sufficient land. Vertical installations or more compact horizontal Slinky installations are often used for existing buildings because they minimize the disturbance to the landscape.

The screening of commercial-scale geothermal heat pump systems is best accomplished by the use of software tools using inputs specific to the site or local region. In general, the heat pump will be able to perform more efficiently in the heating mode when the source temperatures (heat from the ground or water) are higher. The reverse is true during the cooling season, when the ground or water serves as the sink for heat removed from the building. Even though ground temperatures are relatively constant as compared to air temperatures in a given location, there are seasonal variations and significant geographical differences. Figure 14-1 shows the variation in mean annual ground temperature in the continental United States. These are representative temperatures at depths of 30 ft or below and remain fairly constant at greater depths. In general, the colder regions can expect to have a seasonal COP of about 3 during the heating season, while moderate climates can expect to see a COP of 4 to 5 (excluding auxiliary pumps). For the cooling season, the reverse holds true, and geothermal heat pumps in colder regions will have better performance. Note that the comparison of geothermal heat pump energy use to alternative heating and cooling systems should also take into account the pump energy to move the fluid between the geothermal source (e.g., ground loop) and the heat pumps and any system differences if a different distribution system is used (e.g., radiant heating versus air).

14.3.2 Software Tools for Screening Geothermal Heat Pumps

RETScreen (http://www.retscreen.net/) is a screening level tool that can be used for geothermal heat pumps. It is free and can be downloaded as a stand-alone package. It also includes an economic analysis module. Note that assumptions about sizing the geothermal field (heat exchangers) are needed.



Source: U.S. DOE FEMP, Ground Source Heat Pumps Applied to Federal Facilities.
http://www1.eere.energy.gov/femp/pdfs/FTA_gshp.pdf.

Figure 14-1. Mean earth temperature.

14.3.3 Economic Screening

The economic screening requires knowledge of how much purchased fuel the GHP system has saved relative to a base technology (e.g., space heating system and cooling system), the cost of the fuel, and the capital and any nonfuel operating and maintenance costs of the system. Typical assumptions and information sources are:

- System costs: $4,000/ton to $6,000/ton of rated cooling capacity.
- Annual O&M costs: 2% of system costs.
- Energy prices (per unit): depends on location (see EIA for statewide costs as a default: http://205.254.135.7/electricity/state/ and http://205.254.135.7/dnav/ng/ng_pri_sum_dcu_nus_a.htm).
- Energy savings: energy savings = electricity used by the GHP – energy in fuel used by base system (in same energy units).
- Energy cost savings: energy cost savings = electricity used × unit price of electricity – fuel used by base system × unit price of fuel.

14.4 Best Practices

Rules of Thumb for Sizing

- Commercial systems should be sized using appropriate software tools and not be sized using rules of thumb. The size of the ground loop will vary depending on loads, properties of the geothermal heat source, and the type of configuration:
  - Horizontal loop fields. 100 ft to 400 ft per refrigeration ton.
  - Vertical loop fields. 200 ft to 600 ft per refrigeration ton.
  - Lake or pond. 300 ft per refrigeration ton.

Siting Best Practices

- Check environmental permitting requirements before determining the type of geothermal system. This is especially important when considering groundwater systems. Many states and localities have specific regulations governing the installation of geothermal heat pumps.

Selecting a Designer

- Make sure designer has experience with GHP projects of similar scale. Retain a GHP consultant that will have authority in approving the design.

Design Best Practices[87]

- Make sure block loads on the peak heating and cooling loads are used as inputs for system sizing. This is important to properly account for load diversity.
- Make sure that the thermal properties of the ground/heat source are well known. This may require drilling test wells and taking soil samples.
- Individual zones in the building are best served by separate heat pumps.
- The ground loop should be configured based on the layout/zones within the space. For compact floor plans, a common circulating loop connecting a common set of wells can be effective. For areas that are spaced out, separate fields for each heat pump unit could be more appropriate.
- Consider radiant heating distribution, particularly in the maintenance shop areas.
- Use thermally enhanced grout in boreholes to improve heat transfer with the soil and improve performance.
- Pumping energy should be minimized through proper design and the use of high-efficiency pumps and variable-speed drives.

Installation Best Practices

- Make sure installation contractor has experience with GHP projects of similar type and scale. The lessons learned from the Elm Creek Park Administrative and Maintenance Center are instructive with regard to the problems that can arise without careful attention to ground-loop piping installation (see Case Studies, 22.10).
- Installers should be certified by the International Ground Source Heat Pump Association (IGSHPA) and have the tools and knowledge necessary.
- Consider certification by the National Ground Water Association.

Commissioning

- Make sure that vendor products are readily available.

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[87] Phetteplace, G. *A Guide for Best Practices for Ground-Source (Geothermal) Heat Pumps.*

CHAPTER 15

Biomass

15.1 Overview

Biomass refers to woody materials, grasses, agricultural crops, and other plant-based materials that can be used directly as fuels or processed into gaseous or liquid fuels for generating heat and/or power. Wood and wood waste are the most commonly used solid biomass fuels. They can be burned directly in wood combustors/boilers, or they can be converted to a gas through gasification (biogas). Other biomass fuels are derived from waste products and include landfill gas and gas from wastewater treatment plant operations. Biogas can be burned in gas boilers, engine generators, or gas turbine generators (e.g., microturbines, combustion turbines) to generate power and heat [combined heat and power (CHP)]. Solid fuel combustors/boilers can also generate steam for steam turbine generator-based CHP. The types and uses of biomass will vary with what is available as a supply (local resources and waste products) and what the demands are (electric generation, heat, or both). With all biomass fuels, a major consideration is proximity to a reliable supplier for this renewable resource. A series of biomass resource maps are available from NREL that provide a general idea of the amount of biomass available in the United States by type (http://www.nrel.gov/gis/biomass.html).

15.2 Types of Systems and Strategies

15.2.1 Biomass Heat

Biomass heating systems that use wood consist of wood combustors/boilers along with the ancillary equipment for fuel storage and handling, systems for dealing with the by-products of the combustion process (exhaust systems, ash handling systems), control systems, and systems to distribute the heat to the building. Space for wood storage is required to ensure an adequate supply and is sized based on facility requirements (e.g., number of days supply security and space constraints). Wood handling/conveyance systems move the wood to the combustion box. These can be fully automated or semi-automated systems. The heat from the wood combustion can be transferred to either air or water (e.g., via the boiler) for ultimate use in facility heating. Since these are direct combustion systems, they are subject to environmental rules regarding emissions, waste disposal, and so forth. Environmental rules are an important consideration, and regulations must be researched before proceeding. For buildings smaller than 10,000 ft^2, wood pellet systems are appropriate. For larger buildings or central systems serving a number of buildings totaling more than 100,000 ft^2, wood chip systems are likely to be the most economical[88] (see Figure 15-1). Backup boilers are often used with these systems and enable the wood-fired boilers to be sized more economically (e.g., smaller than that required to meet peak heating

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[88] Whole Building Design Guide. "Biomass for Heat." http://www.wbdg.org/resources/biomassheat.php.

Source: http:///www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr168.pdf.

Figure 15-1. Woodchip boiler in Mount Wachusett Community College (MA) biomass plant.

demand). Systems that use cordwood are also available but are best suited for smaller building applications. A key drawback is the need to manually fuel the systems. The main benefit is the relatively wide availability of cordwood.

15.2.2 Biomass Power

Wood-fired biomass boilers can be used to generate power by coupling the steam output to steam turbine generators. Units are available in sizes from 50 kW to utility-scale units in the multi-megawatt range. These are most commonly used in larger industrial or utility applications. A back-pressure turbine can be used for driving the generator as well as providing steam for space heating or water heating. The other biomass power technologies—gas turbines, microturbines, or internal combustion engine generators—use biogas as the fuel. Waste heat from the engines/turbines can be used as a heat source for space heating or water heating, increasing the overall efficiency of biomass fuel utilization. Gasifiers can be used to convert the solid biomass to gaseous form. Alternatively, if landfill gas is available, this can be a cost-effective fuel source. Gasified fuels generally require some degree of cleanup to enable their use in the power systems. This rids the fuel of constituents that can be damaging to the power systems.[89]

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[89] U.S. Environmental Protection Agency, 2007. *Biomass Combined Heat and Power Catalog of Technologies*, Chapter 6, Power Generation Technologies. http://www.epa.gov/chp/documents/biomass_chp_catalog_part6.pdf.

15.3 Applications

15.3.1 Biomass Heat

Biomass furnaces/boilers that use either pellets or wood chips are the most common biomass heat equipment. Equipment efficiencies range from 70% to 85%. Pellets cost about $200/ton and have a heat content of about 16 million Btu/ton. Wood chips cost about $50/ton and have a heat content of 10 to 12 million Btu/ton. Equipment costs are about $165,000 for 0.5 million Btu/h, $195,000 for 1 million Btu/h, and $265,000 for 1.7 million Btu/h output. The economic sizing of the system will require looking at several scenarios, from meeting all the loads with the boiler(s), or only a portion with the boiler and the balance with conventionally fueled equipment. This price can be compared to the price of conventionally fueled equipment to determine whether it makes sense to evaluate biomass heat further.

Biofuels such as landfill methane can be used with conventional heating equipment, without the need for solid fuel storage and conveyance systems. However, the gas would require pretreatment or cleanup prior to use and would need to be piped to the site. Furthermore, the energy content per unit volume would need to be accounted for in evaluating its performance and overall economics.

15.3.2 Biomass Power

Biomass power systems have considerations similar to biomass heating systems insofar as the price of the biomass fuel is a main driver for competitiveness. In general, CHP systems require spark spreads of 4 to 5 [ratio of purchased electricity price to CHP fuel source price on an equivalent fuel basis (e.g. $/million Btu)] to be competitive with electric power. For example, if the biomass fuel price is $11/million Btu, then the competing electricity rate should be $44/million Btu, or $0.15/kWh or higher.

15.4 Best Practices

Rules of Thumb for Sizing

- Sizing of biomass systems for heating should take into consideration options that include backup conventional fuel sources to meet peak demand. This could result in a system that is less costly than one where the biomass system is sized to meet peak heating demands.
- Consider multiple, smaller boilers to meet demand, which improves overall performance due to boilers operating closer to their design rating.
- Consider thermal storage to reduce boiler cycling.

Siting Best Practices

- Check environmental permitting requirements and impacts on equipment costs. There may be a need for additional pollution control equipment, especially for particulate control. In addition, the amount of time for permitting should not be underestimated.

Selecting a Designer

- Make sure designer has experience with biomass projects of similar scale.

CHAPTER 16

Hydroelectric (Small Scale)

16.1 Overview

Water moving downhill represents significant energy potential, and even small quantities can make a good renewable energy source. Small hydroelectric power projects rarely require dams or water diversion techniques. This type of installation is called a *run-of-the river* system.

- Small, run-of-the-river hydroelectric power systems consist of these basic components:
  - Water conveyance. Channel, pipeline, or pressurized pipeline (penstock) that delivers the water.
  - Turbine or waterwheel. Transforms the energy of flowing water into rotational energy.
  - Alternator or generator. Transforms the rotational energy into electricity.
  - Regulator. Controls the generator.
  - Wiring. Delivers the electricity.

Two variables, volume and pressure, determine the amount of energy and thus the power extractable from the water source. Pressure is produced by the vertical distance the water flows between the collection point and the turbine generator (also called *elevation head* or *head*). The greater the vertical distance, the higher the pressure and the greater the power generated.

- Power = density of water × volumetric flow rate × acceleration due to gravity × net head × system efficiency.
- Energy = power × time.

Net head is the difference between the elevation head and any hydraulic losses (e.g., friction losses in piping). The system efficiency accounts for inefficiencies in the hydro turbine, the generator, the transformer, and so forth. Hydroelectric systems are classified by the amount of electrical power they generate (large: >30 MW, small: 100 kW to 30 MW, micro: <100 kW) and the head:

- High head: >50 m (164 ft).
- Medium head: 10 m to 50 m (33 ft to 164 ft).
- Low head: <10 m (33 ft).

16.2 Types of Systems and Strategies

Different turbine designs have been developed based on the head and flow rate, which represent a trade-off in cost and performance (e.g., efficiency). In general, the turbines are classified as reaction- or impulse-type turbines. Impulse-type turbines such as Pelton and Turgo require a medium or high head and use nozzles to spray a jet of high-velocity water onto the turbine blades, which can spin the wheel at an efficiency of 70% to 90%. Low-head systems require a reaction-type turbine in which all blades are in contact with the water at all times. This type of turbine is commonly used in large-scale hydro projects but is generally too complicated for small installations. A variation of the reaction turbine, the propeller-type turbine, is ideally suited for micro-hydro sites with sufficient volume but very low head. The most effective of the propeller types for this situation is the Kaplan turbine, which allows adaptable propeller angles. Kaplan turbine efficiencies are typically over 90% but may be lower in very low head applications.

16.3 Applications

Hydropower screening is site-specific and requires flow data and elevation data. Ideally, the flow data would be on an hourly basis and enable the development of a flow duration curve. The curve is a plot of flow as a function of percent time (or annual hours) that that flow is met or exceeded. Given the flow range and head, the general type of turbine can be selected. This enables estimation of the efficiency as a function of flow. The potential power available from the water can be determined from the following relationship:

- Power = density of water × volumetric flow rate × acceleration due to gravity × net head × system efficiency.

A rule of thumb for this calculation is that power = 7 × Q × H, where power is watts, Q is in cubic meters per second, and H is the gross head or elevation head in meters.[90] The hydro-turbine generator output power duration curve can then be plotted with this information. The facility's power electric load duration curve can be superimposed on the hydro-turbine generator output power duration curve to help size the system. The size should be between the minimum firm flow rate and the maximum flow rate, and should take into account whether net metering is allowed and net metering capacity rules (e.g., capacity limits, whether the basis for net generation is monthly or annual). The useful energy can then be calculated as the area under the curve bounded by the output of the hydro-turbine generator and the load requirement curve.

16.3.1 Software Tools for Screening Hydropower Systems

Hydropower system performance software includes:

- RETScreen. This software is sponsored by NRCAN. It is free and can be downloaded as a stand-alone package. It also includes an economic analysis module. http://www.retscreen.net/.

16.3.2 Economic Screening

There is a wide variation in costs for hydro turbines, ranging from about \$2,000/kW to \$4,000/kW for systems between 1 MW and 10 MW, to \$3,000/kW to \$7,000/kW for systems between 100 kW and 1 MW. In general, the smaller the system, the higher the normalized cost.

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[90] RETScreen, *Small Hydro Project Analysis*, www.retscreen.net/download.php/ang/109/0/textbook_hydro.pdf.

CHAPTER 17

Energy Storage

17.1 Overview

Energy storage technologies can be used in combination with renewable energy systems to improve the availability of the systems to deliver heat or electricity. Batteries are the most commonly used electric energy storage technologies with renewable energy electric systems, although other technologies are entering the market. While grid-connected systems frequently do not incorporate storage, higher penetration of wind and solar electric technologies will increase the value of electric energy storage. This is because the storage devices can help smooth out power fluctuations due to the variability of the power supplied by renewable energy sources.

17.2 Types of Systems and Strategies

17.2.1 Batteries

Batteries are the most widely used electric energy storage devices with renewable energy systems. These are generally used in off-grid applications, where access to utility power is not available. The key factors in selecting batteries are the application duty cycle (charge-discharge cycle duration and depth of discharge) and operating environment (e.g., ambient temperatures). The depth of discharge—the percent of the battery's capacity that is accessible—is a particularly important consideration. Batteries that are able to discharge 50% or more of their capacity without impairing their service lives are categorized as *deep cycle.* Batteries that are designed to regularly discharge less than this fraction are categorized as *shallow cycle.* The depth of discharge can be provided as an overall limit or as a daily limit. Applications that require high output over short periods of time—automobile or engine start-up or uninterruptible power supplies (UPSs)—and where the batteries otherwise remain fully charged can be well served by shallow-cycle batteries. In contrast, batteries for renewable electric systems are required to provide steady power for extended periods of time and are not fully charged for long periods. These applications are best served by deep-cycle batteries. If shallow-cycle batteries are used for this latter application, then more batteries will be required. Terminology that is useful to know for batteries is:

- Battery state of charge. The percent of the battery's rated capacity at a particular point in time.
- Battery capacity. The amount of electrical charge (current over a specified period of time) stored in a battery measured in amp-hours. The energy capacity is derived by multiplying the capacity by the voltage under the specified condition.
- Cut-off voltage. The specified minimum voltage below which further discharge will cause damage to the battery.
- Charging and discharging regimes. The specified charging and discharging strategies to ensure reliable charging or discharging of the battery. This is accomplished by the use of

charge controllers. Typical charge rates for PV batteries are 0.02 to 0.10 times the rated capacity of the battery, depending on the type of battery.

- Battery life. Number of years or number of charge/discharge cycles before battery is no longer able to be charged.

While there is a wide variety of batteries on the market—lead acid, lithium ion, nickel cadmium, and newer/developmental batteries such as sodium sulfur batteries and flow batteries (iron chromium, zinc bromine, and vanadium redox)—the most commonly used batteries for renewable energy systems are deep-cycle lead acid batteries. While they are not the most efficient batteries, they represent a good compromise in price and performance.

- Flooded lead acid battery. These are called *flooded* because the electrodes are totally covered by the sulfuric acid electrolyte. These require regular maintenance—adding water that has been lost due to the chemical reactions in the battery is the most frequently required maintenance item. Other maintenance includes keeping the terminals clean and, depending on the battery, may involve adding electrolyte.
- Sealed absorptive glass matt (AGM) battery. AGM batteries incorporate an AGM to absorb the sulfuric acid, thereby reducing the formation of gases and reducing water loss. These are labeled as *maintenance-free* batteries. A trade-off to the lower maintenance is the requirement for more controlled, lower voltage charging to prevent overcharging. This type of battery costs more than flooded lead acid batteries.
- Sealed gel-cell battery. In this battery, silica gel is mixed with the sulfuric acid, which reduces gas formation and water loss. This also results in a maintenance-free battery. The trade-off to the lower maintenance is the requirement for more controlled, lower voltage charging to prevent overcharging. This type of battery costs more than flooded lead acid batteries. Sealed gel-cell batteries do not usually have as long a life, nor are they able to be discharged as deeply as flooded lead acid or sealed AGM batteries.

Note that valve-regulated lead acid and sealed lead acid batteries limit or eliminate the release of hydrogen gas to the atmosphere through the use of pressure vents or valves. Lead acid batteries cost from $140/kWh to $200/kWh, with the higher end of the range representing the maintenance-free types. The other commercially available and advanced batteries cost three to seven times as much as lead acid batteries.

17.2.2 Other Electric Energy Storage Technologies

17.2.2.1 Flywheels

Flywheels use the kinetic energy of a rotating disk to store energy. For electric energy storage the flywheel is turned by an electric motor, which in turn is powered by electricity provided by the renewable energy system or conventional electricity generator. When electric power is needed, the flywheel turns the generator, which converts the kinetic energy (mechanical energy) back into electricity. Flywheels spin at very high speeds, and friction losses must be minimized to achieve the highest efficiencies (85% or more). Flywheels are best suited to applications that require electric power quickly (within seconds) and over short time periods. This makes them well suited for use in uninterruptible power supplies. Since flywheels can respond quickly to power requirements, they can be effective in frequency regulation of electric power systems. There are limited commercial products at this time, and current costs are higher than battery systems.

17.2.2.2 Pumped Hydro

Pumped hydro systems use electricity to pump water from a storage unit or reservoir to a higher elevation. When needed, the water is allowed to flow through turbines that turn a generator that produces electricity. These are essentially hydro power systems. Pumped hydro systems are typically used by utilities to provide additional electric generating capacity during peak demand periods. They are charged during off-peak/low-demand periods.

17.2.2.3 Compressed Air

Compressed air can be used as a means of storing energy for later use. An electrically or mechanically powered air compressor is used for the compression process, and the air is stored in caverns or pressure vessels (storage tanks). The compressed air can be used to generate electricity by allowing it to expand through a turbine generator. There are several technology approaches that differ based on how they treat the heat generated by the compression process. If this heat is not used (e.g., for the expansion process), it represents wasted energy. Much of current activity has been on large-scale systems (multi-megawatt) that can be used by utilities, in the same manner as pumped hydro systems. They are charged during off-peak/low-demand periods (air is compressed and stored) and discharged (air is expanded through the turbine generator) to generate electricity during on-peak/high-demand periods.

17.2.2.4 Thermal Storage

Electric energy can be used to heat water or ceramic material for discharge at a later time. For example, an oversized water storage heater can be used to provide additional capacity. However, the energy must be used to offset thermal loads and is not converted back to electricity. Assuming that the thermal loads are met by electric systems to begin with, the system shifts the electric loads.

17.3 Applications

Energy storage screening can be done based on the value of the electricity stored versus the value of avoided purchased electricity. In general for grid-connected applications, battery storage is not economic on the basis of avoided purchased electricity alone. The batteries would also need to provide energy reliability and security—either to the user or the utility. For off-grid applications, the sizing of the battery bank is typically based on the number of days storage desired. The economics would need to be weighed against electricity provided by distributed power sources (e.g., propane or diesel engine generator sets) also used at the site.

17.3.1 Software Tools for Screening Energy Storage

Electric energy storage systems can be evaluated as part of a renewable energy system using the following software:

- RETScreen. This software is sponsored by NRCAN. It is free and can be downloaded as a stand-alone package. It also includes an economic analysis module. http://www.retscreen.net/.
- HOMER. This software can evaluate hybrid power systems that are grid-connected or off-grid. http://www.homerenergy.com/.

17.3.2 Economic Screening

Energy storage systems are sized based on the duration of storage needed. Lead acid batteries cost from $140/kWh to $200/kWh, with the higher end of the range representing the maintenance-free types.

CHAPTER 18

Emerging and Alternative Energy Technologies

18.1 Combined Heat and Power

Combined heat and power, also known as cogeneration, is an efficient approach to generating power and thermal energy from a single fuel source. While it is not a new technology, various smaller-scale CHP systems are under development. These include microturbines and fuel cells. By installing a CHP system designed to meet the thermal and electrical base loads of a facility, CHP can greatly increase the facility's operational efficiency and potentially decrease energy costs.[91] Cogeneration is a very useful energy efficiency tool but is only renewable when the fuel source itself is renewable. This largely limits truly renewable CHP systems to those that use biomass-derived fuels (although photovoltaic/thermal hybrid systems would technically qualify). CHP systems achieve total system efficiencies of 60% to 80% for producing electricity and thermal energy.[92] The success of any biomass-fueled CHP project is heavily dependent on the availability of a suitable biomass feedstock.

Biomass feedstocks include:

- Forest residues and wood wastes,
- Crop residues,
- Energy crops,
- Manure biogas,
- Urban wood waste,
- Food processing residue,
- Wastewater treatment biogas, and
- Municipal solid waste (MSW) and landfill gas.

18.2 DC Distribution Systems

The use of DC rather than AC power distribution is being explored as a means to improve the overall efficiency of the distribution system within buildings or microgrids. Many devices use DC power, such as office equipment, fluorescent and LED lighting, security and fire alarm systems, occupancy and daylighting sensors, and a wide variety of building systems. Many renewable energy options produce DC power, and that power usually is connected directly to the grid through an AC inverter and a direct metering or net metering arrangement. By

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[91] See the U.S. EPA website on combined heat and power for a good overview of the subject: http://www.epa.gov/chp/.

[92] The catalog of CHP technologies provides technical information on the various CHP options, including biomass-fueled systems: http://www.epa.gov/chp/documents/biomass_chp_catalog.pdf.

connecting DC loads directly to the DC power generated by the renewable systems, two energy conversions are avoided. For example, for photovoltaic systems, the elimination of the inverter could result in savings of 5% to 10%. In addition to these efficiency gains, having a separate distribution system within the building would allow the DC system to operate either in conjunction with the AC grid distribution, or alone using renewable energy generation and either battery storage or an alternate energy source (generator). This can allow critical systems to operate through power outages without interruption, which may be useful if the maintenance facility is a critical function for incident or disaster response efforts. One standard, the EMerge Alliance standard,[93] has set an early start for a 24-volt system and includes a list of companies that make compatible DC equipment. Another competing standard, the REbus DC Microgrid specification, has established a slightly different method of technical specifications.[94] Buildings on DC systems could be interconnected to form a microgrid as a means of optimizing the use of distributed generators, such as renewable-power generators to enhance reliability, and optimizing their operation.

18.3 Microgrids

Microgrid systems are small-scale electric power distribution networks that can be operated independently of the larger electric utility power network or be connected to it, depending on requirements. The independent operation is made possible by the use of distributed generators—conventionally fueled engine generators, gas turbines, renewable energy technologies—together with electric storage (e.g., batteries), power conditioning equipment, switchgear, and controls. The ability of microgrids to optimally use the various technologies as a stand-alone or in conjunction with utility power enables increased reliability/energy security and reduced energy operating costs. While standby generators, UPSs, and distributed generators/combined heat and power equipment have been serving facilities for many years, the microgrid provides a means of optimizing their operation. Microgrids are well suited for college campuses, military installations, or other multi-building situations [e.g., industrial parks, corporate campuses, and (potentially) transportation maintenance facility stations]. The service reliability of buildings on the microgrid is enhanced by providing access to multiple power sources. Microgrids can also support the larger electric power grid by going off-line (islanding) in the event of a power disturbance. Microgrids can improve the economics of intermittent renewable resources such as wind or photovoltaics by enabling each to be operated in an optimal fashion. Microgrids are largely in the development stage, with most activity underway in public institutions. The three leading applications that are under current deployment are listed in the following; each tends to have a different topology, especially remote systems:[95]

- Institutional/campus microgrids. The typical focus of these microgrids is to aggregate existing on-site generation with multiple loads that are co-located in a campus setting. These microgrids tend to be among the largest and therefore may require master controller systems.
- Military-base microgrids. The focus of these microgrids is on security, both cyber and physical. Since the U.S. Department of Defense has a mandate to shift over to renewable energy supplies as a matter of national security, distributed renewables will have to play a vital role.
- Remote off-grid microgrids**.** Since these microgrids never connect to a larger grid, and therefore operate in an island mode on a 24/7 basis, there is a greater need for storage than with other topologies.

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[93] EMerge Alliance home page: www.emergealliance.org, accessed 8/14/2012.

[94] REbus home page: http://rebuspower.com, accessed 8/14/2012.

[95] Lorand et al., 2012. NCHRP Project 20-85, Task 1: Literature Review, p. 40 (internal project document).

The unique aspects of a microgrid that are the focus of current research and development efforts include:[96]

- Switch technologies for connecting to/disconnecting from the main power grid;
- Inverters, converters, and power conditioning equipment that are lower cost and capable of working with a variety of distributed generators, and methods to optimize the control of multiple inverters;
- Uniform standards and communications protocols; and
- Common integration framework for various systems.

According to Pike Research, it is anticipated that by 2018 nearly 4,000 MW of microgrid power will be in operation globally.[97]

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[96] U.S. Department of Energy, 2011. *Microgrid Workshop Report*, pp. iii and iv. http://energy.gov/sites/prod/files/Microgrid%20Workshop%20Report%20August%202011.pdf.

[97] Microgrid Enabling Technologies, http://www.navigantresearch.com/research/microgrid-enabling-technologies.

CHAPTER 19

General Best Practices for Implementing Renewable Energy Technologies and Strategies

19.1 Overview

The following provides best practices that apply in general when considering renewable energy technologies. These should be used in conjunction with the technology-specific best practices included in the previous chapters in Part III.

19.2 Pre-Design

- For new buildings or major renovations, consider an integrated delivery process and whole building design strategies. These should result in the best opportunity to achieve substantial energy reductions and enhance the value of renewable energy strategies.
- Establish energy objectives for the project, including for renewable energy. These could be quantitative, such as a target percentage contribution of renewable energy technologies relative to a specific baseline, achieving a certain number of points from LEED through renewables, or a certification level. Make sure that criteria based on the objectives and priorities are also established as part of the process.
- Include renewable energy consultants and commissioning agents on the team early in the process.
- Make sure provisions are identified for performance monitoring of the renewable energy systems. Use visual displays of performance information as a means of verifying operation and raising energy awareness.
- Use building energy models early in the process to establish a baseline. However, if the renewable energy project is not physically connected to the building, this may not be necessary. Instead, a technology-specific model such as those described in the technology screening sections of the guide can be used.
- Incorporate solar-ready principles during the planning phase even if the current project will not incorporate solar. Guidelines for solar-ready buildings have been developed by NREL (*Solar Ready Buildings Planning Guide:* http://www.nrel.gov/docs/fy10osti/46078.pdf) and states (e.g., Minnesota's Solar Ready Buildings Design Guidelines: http://mn.gov/commerce/energy/images/Solar-Ready-Building.pdf).
- Research environmental, permitting, and other regulatory issues related to the site and meet with the appropriate regulatory agency officials. Since these issues can be significant factors in project cost and schedule, they should be researched early. The Caltrans CREBs case study provides a good example of how a proactive process expedited the review of many photovoltaic systems across California (see Case Studies, 22.7). This would not have been possible with a piecemeal approach.
- Understand the energy rate structures and utility requirements for on-site renewable power generation. Meet with the utility account representatives and review the implications of the various system options.

- Make sure the plan takes into consideration potential changes to loads (future load increases/decreases) so that these can be accommodated. This includes provisions for system expansion.
- Develop initial estimates of energy requirements of the building and various end uses.

19.3 Design

- Incorporate solar-ready design principles so that the building can add solar energy equipment (solar thermal or photovoltaic), even if it's at a later date.[98] This means:
  - Roof area should be free from shading by current or future structures or vegetation.
  - Roof area should be largely unobstructed to enable possible future installation of solar arrays.
  - Roof should be designed to be capable of supporting the weight of solar arrays, including support structures and other equipment.
  - Access areas for piping or conduits should be established.
  - Space should be allocated for solar storage tanks and heat exchange equipment (solar thermal).
  - Space should be allocated for inverters, breakers/disconnects, and electric meters (photovoltaic).
- Develop good estimates of energy requirements for the building and various end uses. These can be based on modeling or a combination of modeling and energy data for existing buildings. Ideally, load profiles showing energy use for typical, peak, and minimum days during the principal seasons should be generated. These can help with matching system capacities and operating strategies to the building.
- Make sure designers have requisite experience with the technologies. Request references for projects of similar type and scope. If in-house staff are to be used, they should be given training first.
- Make sure measurement and verification and system performance monitoring equipment is incorporated in the plans. This includes visual displays and remote access capability, as appropriate.
- Bid documents:
  - Ensure that equipment specifications incorporate applicable safety and performance certifications.
  - Ensure that the specifications clearly assign warranty responsibilities for equipment and installation, including repairs. For example, if solar equipment is mounted on the roof and the roof needs to be repaired, it should be clear who is responsible for removal and re-installation, if required.
  - Incorporate requirements to ensure that the supplier can provide repair and replacement in a timely fashion, and request evidence supporting the claims.
  - Ensure that the commissioning of related items is incorporated, including O&M manuals and training.

19.4 Construction

- Make sure contractor has experience with the renewable technologies in similar applications and on a comparable scale. Require installer training certifications, if available for the technology in question. Consider asking for a minimum number of references. Contact references or visit the project.
- Follow commissioning plan and quality control processes.
- Make sure there is close coordination among all the subcontractors. This was an important lesson learned drawn from several of the case studies included in Part IV. (For example, see Case Studies, 22.5 for Central Platte, CO, experience).

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[98] Lissell and Watson, 2009. http://www.nrel.gov/docs/fy10osti/46078.pdf.

19.5 Operation and Maintenance

- Educate staff and building occupants on any renewable energy system-specific considerations. This is particularly important for certain technologies where occupant interaction can have performance impacts (e.g., overriding controls). Daylight sensor placement and calibration, for example, can have a significant impact on the effectiveness of the systems. The systems should first meet the safety, health, and comfort (thermal, visual, acoustic) requirements.
- Perform periodic recommissioning.

PART IV

Case Studies

CHAPTER 20

Introduction

20.1 Background

Part IV of the *Renewable Energy Guide for Highway Maintenance Facilities* integrates a case studies document that was originally a stand-alone document developed under NCHRP Project 20-85. The 11 case studies provide examples of the application of various renewable energy technologies and design strategies to maintenance facilities. The lessons learned and best practices from the case studies should prove valuable to transportation facility planners, designers, and decision makers.

20.2 Approach

Candidate projects for case studies were based primarily on two sources that were developed during the preparatory phase of NCHRP Project 20-85:

- Literature review summary. This summary provided information on renewable energy technology developments, including projects demonstrating the application of the technologies on various buildings.
- Survey of renewable energy technologies at highway maintenance facilities. Under this task, information was obtained on the status of and plans for the use of renewable energy technologies and strategies on highway maintenance facilities. Included was information on specific projects and/or contacts for potential case studies.

A total of 35 projects were identified, of which 15 were considered as the most promising for case studies. Key factors in determining the mix of projects to include as case studies were:

- Renewable energy technology type and end use,
- Building type and application,
- Climate region,
- Lessons learned, and
- Data availability.

Ultimately, 11 projects were selected as case studies, which included various types of vehicle-related maintenance facilities—road maintenance, transit, and public works:

1. St. Clair, MO, Maintenance Facility Solar Thermal Systems.
2. Fort Drum, NY, Solar Ventilation Air Heating System on Maintenance Facilities.
3. Plattsburgh, NY, Solar Ventilation Air Heating System on Airport Facilities.
4. Coney Island, NY, Train Maintenance Facility Solar Water Heating System.
5. Denver, CO, Public Works Central Platte Campus.
6. South Bend, IN, Public Transportation Organization Maintenance Facility.

7. Caltrans Clean Renewable Energy Bonds Program, Sunrise Maintenance Station Photovoltaic System.
8. Milford, UT, Highway Maintenance Station Wind Turbine.
9. Ohio Department of Transportation Northwood Outpost Garage Wind Turbine.
10. Elm Creek Park Maintenance Facility (MN), Geothermal Heat Pump System.
11. Kilauea Military Camp, HI, Corrosion-Resistant Roof with Integrated Photovoltaic System.

For each case study, information was gathered via interviews with the project principals and a review of the various documents obtained from the contacts interviewed or online sources, including plans/specifications and project reports. We used a data-collection form that mirrored the outline for the case studies. This allowed us to organize the information by the major steps in project development process and outcomes:

- Pre-design (project planning) phase.
- Design phase.
- Construction phase.
- Results (post-commissioning project operation phase).
- Lessons learned.
- Future plans.

CHAPTER 21

Summary of Case Studies

21.1 Overview of the Case Studies

The 11 case studies cover a variety of technologies, building applications, geographic locations, project delivery, and funding mechanisms (see Table 21-1):

- Renewable energy technologies. The technologies include solar photovoltaics (four projects), solar thermal for space heating (one project), ventilation air heating (two projects), water heating (two projects), wind energy (two projects), and geothermal (ground source) heat pumps (two projects), as well as design strategies to make better use of site resources to meet the building's energy requirements (e.g., daylighting—two projects).
- New versus existing buildings. Four of the projects are new buildings, while the others are existing facilities that have had renewable energy technologies added.
- Locations. The geographical coverage includes nine states—California, Colorado, Indiana, Minnesota, Missouri, New York, Ohio, Utah, and Hawaii—representing seven ASHRAE climate zones (1A, 3B, 4A, 5A, 5B, 6, and 7).
- Project delivery mechanisms. Four of the projects are design–build, while the rest are design–bid–build. The designs were developed in-house for three of the projects, while the designs of the other projects were contracted out.
- Project funding mechanisms. Four projects required no direct capital funds from the agency or organization. Alternative financing mechanisms included PPAs, utility financing, and bonds. Six of the projects used financial incentives from utilities or federal or state agencies to reduce project capital costs.

Table 21-2 briefly characterizes each of the 11 case studies in terms of the renewable energy technologies, performance and economics, and lessons learned/best practices.

Some of the key findings regarding renewable energy technology are highlighted in the following:

Solar Space Heating. The roof-mounted solar air heating system at the St. Clair, MO, maintenance facility appears to be operating well; however, there is uncertainty about savings due to lack of performance monitoring equipment. The sense is that energy is being saved, but due to the relatively high location of the solar-heated air distribution point (near the ceiling), it is not clear whether building occupants are aware of the heat from the solar air collectors. Due to the relatively high costs of the system, it has a long payback period.

Solar Ventilation Air Heating. The solar ventilation air heating systems manufactured by SolarWall appear to be performing well, based on projections of short-term monitoring results. The Fort Drum, NY, system is an earlier design that has no glazing over the perforated corrugated metal collector wall. The system at Plattsburgh International Airport, NY, has the upper portion glazed to provide higher outlet temperatures. This newer system is providing higher temperatures, but as implemented, is not able to make the best use of the available heat. Nonetheless,

Table 21-1. Renewable technologies, funding, and delivery mechanisms.

Project Name and Location	ASHRAE Zone	Renewable Technology	Funding Mechanism	Delivery Mechanism
• St. Clair, MO, Maintenance Facility Solar Thermal Systems	4A	SH, SWH	Direct	DBB (agency design)
• Fort Drum, NY, Solar Ventilation Air Heating	6A	SVH	Direct	DB
• Plattsburgh, NY, Solar Ventilation Air Heating	6A	SVH	ARRA grant	DB
• Coney Island, NY, Train Maintenance Facility	4A	SWH	Utility financing and incentives	DBB (NYPA design)
• Denver, CO, Public Works Central Platte Campus	5B	PV, DL	PPA, various incentives	DB
• South Bend, IN, Public Transportation Organization (TRANSPO) Maintenance Facility	5A	PV, GHP, DL	Direct and ARRA grants FTA grants	DBB
• Caltrans CREBs Program, Sunrise Maintenance Station	3B	PV	CREBs (bonds) and utility incentives	DBB (agency design)
• Milford, UT, Highway Maintenance Station Wind Turbine	5B	W	Direct and state/fed grant	DB (agency design)
• Ohio Department of Transportation Northwood Outpost Garage Wind Turbine	5A	W	Direct	DBB
• Elm Creek Park Maintenance Facility (MN), Geothermal Heat Pump System	6	GHP	Direct	DBB
• Kilauea Military Camp, HI, Maintenance	1A	PV	Direct	DBB

Key: SWH (solar water heating), SH (solar heating), SVH (solar ventilation heating), PV (solar photovoltaics), W (wind turbine generator), GHP (geothermal heat pump), DL (Daylighting), ARRA (American Recovery and Reinvestment Act), FTA (Federal Transit Administration), CREBs (Clean Renewable Energy Bonds), DBB (design–bid–build), DB (design–build), NYPA (New York Power Authority).

the monitoring indicates significant energy savings, even without the benefits of destratification (reduction of temperature gradients from floor to ceiling due to better mixing of air in the space). The relatively low capital cost of the system as compared to other solar thermal systems makes this a potentially attractive option where there are substantial ventilation air requirements. In the case of Plattsburgh, the capital costs were fully covered by incentives.

Solar Water Heating. The solar water heating systems at the St. Clair facility, while not monitored, appear to be providing substantial amounts of solar-heated water. During the summer months, the electric heating element is not required, indicating that the system is able to meet the entire requirements. The two separate systems serve domestic water purposes and vehicle washing, respectively. The flat plate liquid collectors/drain-back design is well suited for smaller

Table 21-2. Summary of case studies.

Project Name and Location	Renewable Technology	Performance and Economics	Lessons Learned and Best Practices
• St. Clair, MO, Maintenance Facility Solar Thermal Systems • 2273 North Service Rd. East St. Clair, MO 63077 • ASHRAE Zone 4A	• Solar air collectors for heating vehicle maintenance area. • Two solar water heating systems to serve domestic hot water and vehicle washing. • Rooftop installation on *new* 9,000 ft^2 maintenance building.	• Performance is estimated since systems are not monitored. Solar Space Heating: • Cost: $138,000 for 1,040-ft^2 solar air collector system ($133/ft^2). • Annual savings: 215 MMBtu gas/$1,505. • Payback: 92 years. Solar Water Heating: • Cost: $16,000 for 256-ft^2 liquid collector systems (two) ($63/ft^2). • Annual Savings: 16,676 kWh (56.9 MMBtu) elec./$1,156. • Payback: 13 years. • Solar water heating works well.	• Maintain design flexibility. • Ensure good communication among all members of the project team. • Be aware of special code requirements for solar equipment (e.g., wind loads for solar collectors). • Install solar system performance monitoring equipment. • Placement of solar-heated air output important for occupant comfort.
• Fort Drum, NY, Solar Ventilation Air Heating Systems • Fort Drum, NY 13602 • ASHRAE Zone 6A	• Unglazed transpired solar air collector systems (SolarWall) for ventilation air heating. • Solar collectors installed on the facades of 27 *existing* vehicle maintenance buildings.	• Performance is estimated. • Cost: $3,400,000 for 110,000-ft^2 solar air collector systems ($31/ft^2). • Annual savings: 44,317 MMBtu gas/$398,853. • Payback: 8.5 years. • Systems appear to be performing well.	• Fan noise may be an issue in some cases. Solutions: variable-speed drives to reduce speed, adding silencers, and adding duct insulation for ducted systems. • Gravity dampers for outside air intake should be avoided to eliminate the downward flow of cold air. • Connect the system to existing direct digital control systems if available.
• Plattsburgh, NY, Solar Ventilation Air Heating Systems • Plattsburgh International Airport • 137 Margaret St. Plattsburgh, NY 13642 • ASHRAE Zone 6A	• Two-stage unglazed transpired solar air collector systems (SolarWall) for ventilation air heating. • Solar collectors installed on the facades of three *existing* 28,000-ft^2 hangars and one 26,50-ft^2 industrial building.	• Cost: $614,219 for 17,800-ft^2 solar air collector systems ($34.42/ft^2) for four buildings. • Annual savings: 521 MMBtu gas (hangar 3)/$6,252 (hangar). • Payback: 19 years. • Output temperatures exceed expectations. • No savings from destratification.	• Incorporate wall fans and destratification fans to help mix/distribute solar-heated ventilation air. • Incorporate control strategy based on solar supply temperature and desired space air temperature.
• Coney Island, NY, Train Maintenance Facility Solar Water Heating System • Brooklyn, NY 11224 • ASHRAE Zone 4A	• Evacuated-tube collector solar water heating system to serve vehicle (train) wash. • Rooftop installation on *existing* 300,00-ft^2 maintenance building.	• Cost: $564,905 for 1,762-ft^2 solar evacuated-tube collector systems ($320.62/ft^2). • Annual savings: 104,000 kWh (355 MMBtu) elec./$100,000. • Payback: 5.6 years.	• Water can be used as a good heat transfer fluid with evacuated-tube solar collector systems in colder climates. • Ensure that solar collectors are certified to meet wind load specifications.

(continued on next page)

Table 21-2. (Continued).

Project Name and Location	Renewable Technology	Performance and Economics	Lessons Learned and Best Practices
		• System is performing well and close to predicted performance.	• Ensure good communications of the specifications among the system designer, specifier, solar collector manufacturer, and installer.
• Denver, CO, Public Works Central Platte Campus • 1271 West Bayaud Avenue, Denver, CO 80223 • ASHRAE Zone 5B	• Photovoltaic system for electricity. • Daylighting strategies to reduce electric lighting requirements. • Rooftop PV installation on *new* LEED Gold 39,546-ft^2 fleet maintenance building.	• Cost: N/A. 20-year PPA for the 102-kW PV system. • Annual savings: 153,506 kWh (524 MMBtu) elec./$5,986. • Payback: N/A. Savings is discount of $0.039/kWh for electricity provided by the PV system. • System appears to be performing well and exceeded projected output over first 10 months of operation.	• Get all the key players involved early to ensure that everyone knows the objectives and vision of the project. • Plan examiners will bump wind loads/snow loads for untested technology like PV. • Roofer must do all the penetrations of roof membrane in order to maintain the warranty. • PPA covers all system operations, which benefits an entity like the City of Denver, which has no expertise in the operation and maintenance of a solar PV system.
• South Bend, IN, Public Transportation Organization (TRANSPO) Maintenance Facility • 1401 South Lafayette Boulevard, South Bend, IN 46612 • ASHRAE Zone 5A	• Photovoltaics, geothermal (ground source) heat pump and radiant slab heat distribution, daylighting, and super insulated building shell. • Roof-integrated thin-film PV on a *new* 167,000-ft^2 combination maintenance/office facility – LEED Platinum rating.	Photovoltaic System: • Cost: $600,000 for 93.5-kW system ($6,417/kW). • Annual savings: 97,259 kWh (332 MMBtu) elec./$5,474. • Payback: 110 years. Ground-Source Heat Pump: • Cost: N/A. • Annual savings: 38,429 kWh (131 MMBtu) elec./$2,152. • Payback: N/A.	• Having a general contractor or construction manager hired as a team member early in the process would have been extremely valuable. • Close coordination and scheduling between the subcontractors is needed to avoid problems. • Provide real-time performance monitoring for measurement and verification and education purposes.
• Caltrans CREBs Program, Sunrise Maintenance Station Photovoltaic System • 11325 Sanders Drive Rancho Cordova, CA 95742 • ASHRAE Zone 3B	• Rooftop PV installation on *existing* 4,000-ft^2 storage building.	• Cost: $193,402 for 35.6-kW system ($5,433/kW). • Annual savings: 46,546 kWh (159 MMBtu) elec./$6,703. • Payback: 23 years. System at Sunrise facility is performing as expected, except for some down time due to inverter problems.	• Make sure to work with the utility before undertaking PV projects. • Plan for regulatory reviews early in the design process. • Roof-mounted PV panels should be tilted at least 10 degrees to enable dirt to wash off. • Specify slightly oversized inverters (about 5% larger) to ensure efficient, reliable operation. • All costs of performance monitoring, including ongoing analysis, should be accounted for.

Table 21-2. (Continued).

Project Name and Location	Renewable Technology	Performance and Economics	Lessons Learned and Best Practices
• Milford, UT, Highway Maintenance Station Wind Turbine • Milford, UT 84751 • ASHRAE Zone 5B	• Wind turbine generator to serve *existing* 3,434-ft^2 maintenance station.	• Performance is derived from utility meter data, not from separate monitoring system. • Cost: $13,500 for 1.8-kW system ($7,500/kW). • Annual savings: 3,250 kWh (11 MMBtu) elec./$260. • Payback: 52 years	• Using maintenance crews to assist with installation is a cost-effective method to match project grants. • Keep the key players involved throughout the process. • Emphasize energy efficiency as part of the project. • Include energy monitoring to encourage occupants to practice conservation.
• Ohio Department of Transportation, Northwood Outpost Garage Wind Turbine • 200 Lemoyne Road, Northwood, OH 43619 • ASHRAE Zone 5A	• Wind turbine generator to serve *existing* 57,182-ft^2 maintenance complex.	• Cost: $200,000 for 32-kW system ($6,250/kW). • Annual savings: N/A. • Payback: 12 to 16 years. • No performance data yet.	• Identify and verify any environmental restrictions at the proposed site prior to selecting a particular technology. • Researching the companies/contractors involved in the manufacture of equipment and construction of renewable energy projects is critical. • Make sure procurement process accounts for risks with new technology—timely repair and parts availability requirements.
• Elm Creek Park Maintenance Facility (MN), Geothermal Heat Pump System • 12400 James Deane Parkway Maple Grove, MN 55369 • ASHRAE Zone 6	• Geothermal (ground source) heat pump systems that serve *new* 11,676-ft^2 maintenance garage.	• Cost: N/A. • Annual Savings: N/A. • Payback: N/A.	• Do thorough research on equipment manufacturers. • Perform soil conductivity tests before considering geothermal heating and cooling. • Extreme care needs to be taken in installation of well field loops to prevent contamination. • Require VFDs on pumps. • Water-to-air units had fewer problems than water-to-water units.
• Kilauea Military Camp, HI, Corrosion-Resistant Roof with Integrated Photovoltaic System • Kilauea Military Camp • Volcanoes National Park, HI 96718 • ASHRAE Zone 1A	• Roof-integrated thin-film photovoltaic system on *existing* 9,000-ft^2 vehicle storage structure.	• Cost: $195,674 for 15-kW system ($5,433/kW). • Annual savings: 19,128 kWh (65.3 MMBtu) elec./$6,729. • Payback: 29 years. • System electricity output is as expected.	• The permitting process is a critical-path item and more likely to be a cause of delay than technical or construction issues. • If breaks occur in the material's surface, the cells are extremely vulnerable to intra-cell corrosion. This vulnerability within the cells dictates that any breaks should be sealed at once.

applications. Freeze protection is provided by draining of the water from the collectors when the collector loop pump shuts off. The evacuated-tube liquid collector-based water heating system at the Coney Island, NY, train washing facility has demonstrated performance close to projected during its first year of operation. While the system is considerably more expensive than the flat plate collector system on an installed cost basis, it is capable of providing better performance on cold sunny days, and delivering higher temperatures (if needed). Thus far, there have been no problems with this pressurized all-water system, in terms of any freezing or over-temperature issues. Freeze protection of the collectors is provided by recirculation of heated water when the outside air temperature falls below a specified set point. The economics look attractive in this particular application due to the avoidance of very high electric demand charges ($30 kW). Furthermore, the system is paid for over a 10-year period, structured in a way to ensure positive cash flow. In regions where electricity costs are more typically like the national average, the economics would not be nearly as attractive.

Solar Photovoltaic Systems. The photovoltaic systems appear to be working well. The new Central Platte, CO, public works facility PV system exceeded its expected output for the first 10 months of operation. The crystalline silicon PV modules are architecturally integrated in the sawtooth design of this LEED Gold fleet maintenance/office facility and are generating electricity under a PPA. The agreement enables the system to be paid off through power purchases, structured in a way to eliminate up-front costs. The savings are assured since the agreed-upon rates are discounted relative to standard electricity rates over the term of the agreement. Performance data from the Sunrise Maintenance Facility's crystalline silicon PV system in Rancho Cordova, CA, indicate that the system output is in line with expectations. There were some issues with the inverters that have been remedied. The CREBs program used to finance the system eliminated initial capital costs, making this an attractive proposition. The roof-integrated thin-film system at the new South Bend, IN, Transportation Organization (TRANSPO) maintenance facility represents a different technology (lower efficiency), but is amenable to a variety of roof integration situations. Performance data from the system are not yet available. The PV system at Kilauea Military Camp (KMC) uses a similar technology.

Wind Turbine Generators. The small wind turbine generator at the Milford, UT, maintenance facility appears to be performing well based on analysis of electricity bill data. System costs were able to be reduced from $13,500 to $6,500 due to grant funds that made the project economical. The Northwood, OH, wind turbine is not yet operational, so there is no performance data to report. The main problem was a damaged blade, which has taken many months to replace. The projected payback is 12 to 16 years.

Geothermal Heat Pumps. The geothermal heat pumps at the South Bend, IN, TRANSPO facility appear to be working well in terms of meeting heating needs. They are not separately metered, and the savings are based on projections. The Elm Creek Park geothermal system in Maple Grove, MN, is currently working properly, but had a variety of problems due to a combination of design and installation issues. Most of the problems were not unique to the geothermal heat pump system, but were general shortcomings in design and installation (e.g., in-ground piping loops inadequately protected from plugging with debris).

21.2 Lessons Learned

Some of key lessons learned across the projects are highlighted in the following (see the individual case studies in Chapter 22 for details):

21.2.1 Pre-Design (Project Planning) Phase

During the planning phase, it is important that the objectives of the project are clearly defined and that provisions are made for determining the project delivery approach, key organizations involved and roles, procurement process to be used, and monitoring and evaluation method. Maintaining flexibility was cited as an important attribute at this stage in the process. In several cases, the selection of the renewable technologies or other features was not predetermined but was an outcome of site evaluations. Evaluations can include resource assessments, such as wind monitoring, soil samples to determine conductivity for geothermal heat pump applications, the impacts of shading due to tree canopies or other structures, and environmental or other site-specific restrictions. Other factors, such as the local utility's view toward renewable energy projects and the impacts of rates or other regulatory factors, were cited. The availability of financial incentives to help defray system costs is another important factor in the selection of the technology. Ensuring good communication throughout the process was cited by a number of projects as a key element in successful projects. In particular, there were several instances where a miscommunication resulted in improperly sized equipment being installed, or where there was reworking of systems due to the failure to communicate plans properly.

21.2.2 Design Phase

A major lesson learned was to coordinate design efforts and to make sure to properly account for the impacts of the renewable energy components on standard building design. It was found in one project that plan examiners will bump wind loads/snow loads for untested technology. Getting the key players involved early was cited as very important to smooth project development. For example, in implementing roof-mounted solar thermal or photovoltaic systems, coordination among the roofer, solar equipment installer, and electrical contractors is essential. Where there are third-party arrangements, such as power purchase agreements, the developer buys equipment, the general contractor installs, and the power purchase provider owns, operates, and maintains; thus, there is an issue of coordination between the developer and installer. The determination of who completes the design depends on the capabilities of the sponsoring organizations and internal processes. For example, the Caltrans CREBs program found it advantageous to centralize their PV project designs and came up with strategies to expedite plan reviews with regulatory bodies (e.g., permitting authorities, fire marshal). Other organizations contracted out the design and construction of their projects. In some instances, renewable energy specialists were hired as advisers for developing the design specifications.

21.2.3 Construction Phase

A major lesson learned from the construction process was that close coordination and scheduling between the subcontractors is needed to avoid sequencing issues. In some instances, completed work had to be removed and then redone. In addition, more attention to testing and balancing requirements of the HVAC system would have been helpful. A major lesson learned in this phase for the Milford wind project was that while in-house staff may be able to accomplish significant portions of a small project, the use of experienced contractors in key areas is critical.

21.2.4 System Commissioning and Operation

In a number of instances the desirability of planning for and implementing monitoring and evaluation was cited. This performance monitoring can be used to ensure that systems are operating as intended. It can also be used for educational purposes—to raise awareness on the part of building staff or visitors—in the effectiveness of energy strategies in reducing energy operating costs or meeting environmental goals. The added costs of performance monitoring—including ongoing costs for analysis—were cited as one of the concerns with incorporating performance monitoring equipment.

CHAPTER 22

Individual Case Studies

22.1 Case Study: St. Clair, MO, Maintenance Facility Solar Thermal Systems

22.1.1 Overview

The St. Clair Maintenance Facility is operated by the Missouri Department of Transportation and consists of six buildings totaling 29,800 ft^2. It is located on the service road along I-44 in St. Clair, MO, west of Route 47, which has average daily traffic of 33,100 vehicles. The buildings are primarily of pre-engineered, insulated metal construction. A roof-mounted solar air heating system is used to provide supplementary heat to Building A, a 9,000-ft^2 maintenance building. The principal use of Building A is vehicle maintenance (equipment storage and routine repair), with some office space, and an adjacent wash bay for vehicle washing. The facility is occupied 10 hours per day in the summer and 8 hours per day during the rest of the year. The exception is during snow emergencies, where it may operate all hours, and the portion of the facility that houses offices of the Missouri State Highway Patrol, which operates all hours. About 20 to 25 individuals work in the building. The solar air heating system consists of 40 flat plate solar air collectors (1,040 ft^2 total array area) that warm air drawn from the building, which is subsequently discharged back into the space. In addition to the solar air heating system, there are two solar water heating systems. Each has four flat plate solar liquid collectors (128 ft^2) that are mounted on each end of Building A's roof. (See Figure 22-1.) These serve to displace electricity used by electric water heaters that serve the wash bay and domestic water needs. The solar air heating system cost was $138,000, and the solar water heaters cost $16,000, bringing the total solar project cost to $154,000. The systems are not being monitored, but based on solar panel and system rating information, it is estimated that the solar air heating system saves 215 MMBtu and $1,505 in annual operating costs, assuming natural gas unit costs of $7/MMBtu and a gas heater efficiency of 80%. From an economic perspective this equates to a payback period of 91.7 years. The water heating systems save 56.9 MMBtu and $1,167 in annual operating costs, assuming electricity unit costs of $0.07/kWh. From an economic perspective this equates to a payback period of 13.7 years. Based on fuel bills, during the summer months, the solar water heating systems supply most of the energy for water heating. Overall there is great satisfaction with the system. A similar solar air heating system has been installed at a nearby Park Service facility based on the experience with this system.

Site and Building Information: Location: St. Clair, MO

- Address: 2273 North Service Rd. East
  St. Clair, MO 63077

Source: J. E. Foster Building Company.

Figure 22-1. Solar air collector array (foreground) and one of the solar water heating system collector arrays (rear row).

- Tel.: 636-629-2697
- ASHRAE climate zone: 4A
- Annual heating degree days (65°F base): 4,758
- Average high temperature/low temperature (summer): 87.3°F/68.0°F
- Average high temperature/low temperature (winter): 40.6°F/24.0°F
- Average Annual precipitation: 37.5 in.
- Building A floor area: 9,000 ft^2 (7,950 ft^2 conditioned)
- Occupancy: 20 to 25
- Schedule: 10 h/day summer; 8 h/day rest of year

Renewable Energy Features:

- *Solar air heating system:* Serves Building A maintenance bay area and office.
- *Solar water heating systems:* One system provides domestic water, and the second system is used for vehicle washing.
- *Solar heating for Building E:* Supplies all heat for the 1,500-ft^2 fabrication shop.
- *Daylighting for cold storage buildings:* Two pole barns have glazed panels in the upper portion of the exterior walls to allow daylight into the building.

22.1.2 Project Development Process

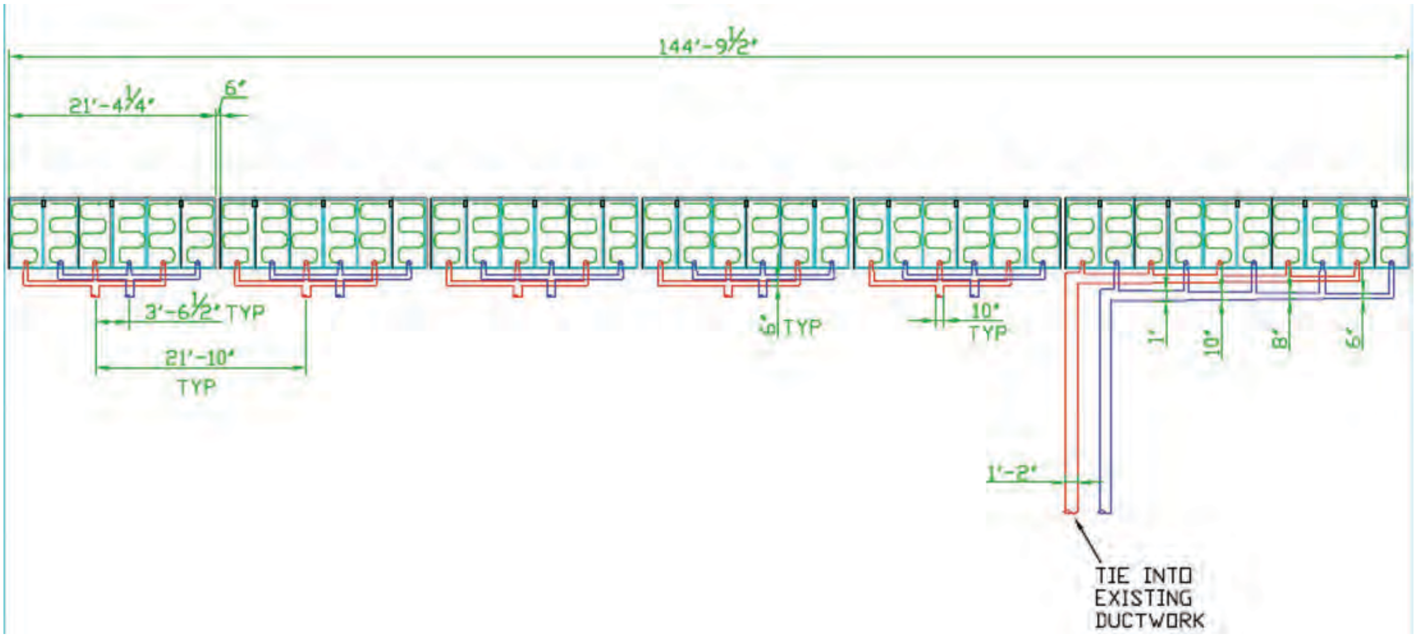
22.1.2.1 Pre-Design (Project Planning) Phase

In planning for the construction of the new Building A, it was decided to incorporate green or sustainability features that were considered practical (e.g., economical). Operating cost savings were a major factor in considering various options. The use of renewable energy resources, including wind and solar, were suggested, as were water-retention strategies. Wind was eliminated due to inadequate wind resource, and water retention was eliminated due to the potentially high costs and long paybacks due to difficulties in excavating in a rock shelf. Solar systems for space heating and water heating were evaluated and determined to be economical based on the energy savings of the systems. At the time, natural gas prices had been particularly volatile and were coming down from new highs. Building A was designed to meet the needs of the current fleet and Missouri DOT operations, and was most suitable for placement of the roof-mounted solar collectors. The construction of the new building and the solar system was part of an overall site development plan that had been in the works for 11 years. It included the renovation of Building D (including significant energy upgrades) and its conversion from a vehicle maintenance facility to a bridge maintenance facility. A fabrication shop, Building E, was also constructed, which was to be heated by its own solar array. Given the highly visible location of the site (near a major roadway), the addition of the solar systems provided a good opportunity to showcase Missouri DOT's efforts in incorporating green/renewable energy features.

The project team consisted primarily of the Missouri DOT regional staff, which developed the basic functional requirements for the buildings. In general, Missouri DOT uses its in-house designers for all their projects. A design–bid–build approach was used, with in-house Missouri DOT staff being the lead designers with assistance from G2 Power Technologies, LLC, a solar firm, on the design specifications for the solar thermal systems. The solar systems were bid competitively based on performance specifications, although there were no specific energy-monitoring equipment requirements. The funding for the project was from Missouri DOT capital improvement budgets, and there was no special financing and no incentives involved. According to Ed Warhol, one of the main designers for the project, "This was a very successful process. The area team, design, and facilities work hard to make this process work. Communication was a very important part of this process." An important lesson from the planning state is to be flexible and look at various options, recognizing that one size does not fit all.

22.1.2.2 Design Phase

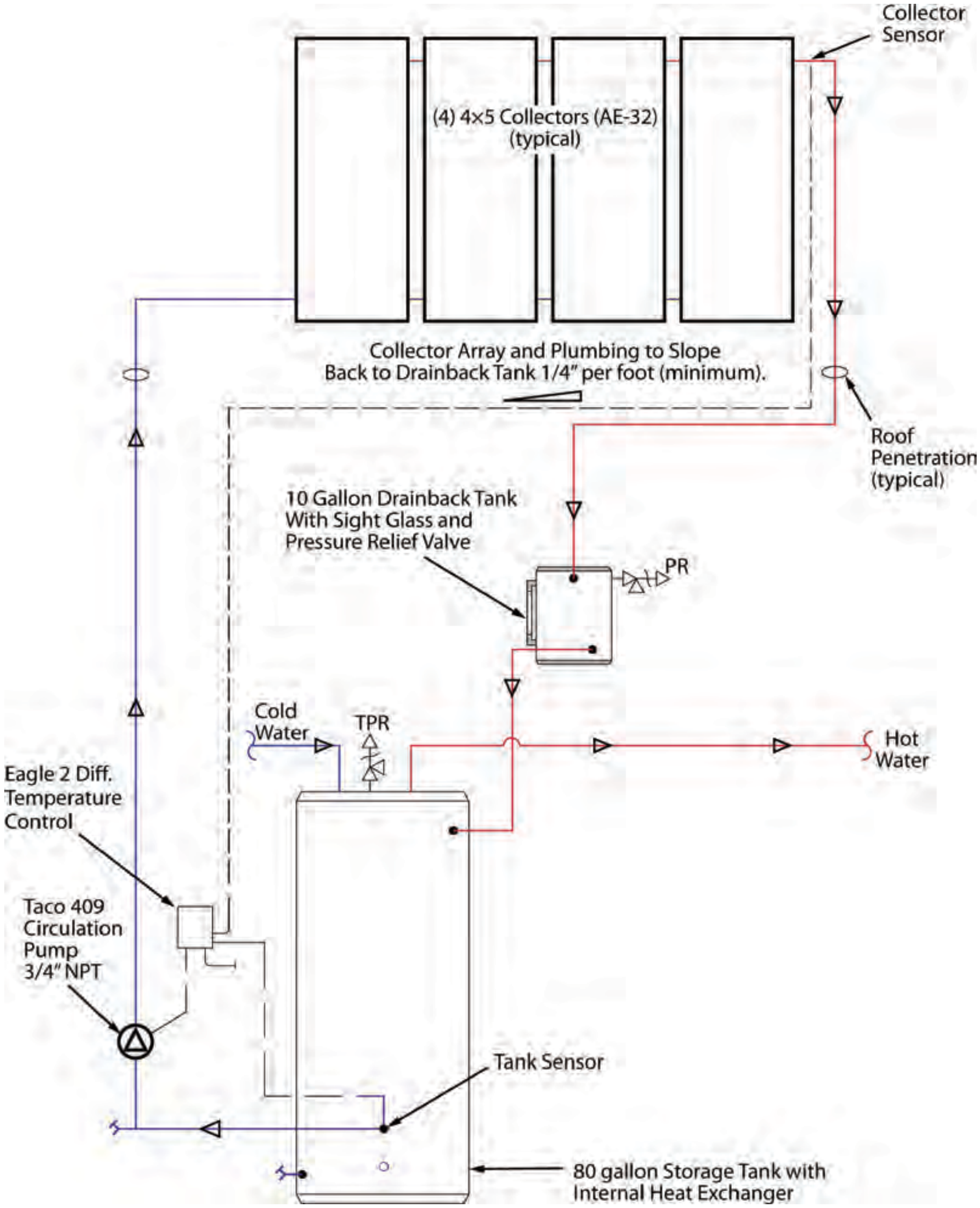
The design team consisted of Missouri DOT staff with support from G2 Power Technologies, LLC, for the design and specification of the solar air heating and hot water systems. The solar air heating system capacity (number of panels) was based on the estimated requirements for the floor area being served and the collector output (per manufacturer). The result was a system of consisting of six panels (in pairs) per zone serving five zones within the main maintenance area, and 10 panels (in pairs) serving the office area (see Figure 22-2).



Source: Dan Poett, G2 Power Technologies, LLC.

Figure 22-2. Layout of solar air collectors on roof of Building A.

The solar water system capacities (number of panels and size of storage tanks) were estimated based on the number of people and vehicle washes (see Figure 22-3). There was no information on the amount of hot water used, either for domestic purposes or for vehicle washing. The final system design—solar air heating and water heating systems—was consistent with the design concept. There were no significant changes during the design process. It was not until the construction period—but prior to installation of the solar systems—that some design changes needed to be made. The major lessons learned were to coordinate design efforts and to make sure to properly account for the impacts of the renewable energy components on standard building design. This includes structural considerations such as dead loads and wind loads associated with the collectors, solar collector array attachments, and roof and wall penetrations.



Source: Dan Poett, G2 Power Technologies, LLC.

Figure 22-3. Schematic of solar water heating system.

Project Team

Building Owner's Representative

Representative from Missouri DOT

Design
Senior Facilities Designer
Missouri DOT

Senior Facility Operations Specialist
Missouri DOT

General Services Facilities Manager
Missouri DOT

Design

Solar Design Adviser
Representative from G2 Power Technologies, LLC

Construction

General Contractor
J. E. Foster Building Company

Solar System Supplier/Installer
G2 Power Technologies, LLC

Equipment Manufacturer
Solar air system: Your Solar Home
Solar water heaters: AET Technologies, Inc.

Mechanical Contractor
J. E. Foster Building Company
Scott-Lee Heating and Cooling

Construction Oversight
Missouri DOT

Commissioning: N/A

22.1.2.3 Construction Phase

The construction contract was awarded to J. E. Foster for the overall building project. A subcontract was awarded to G2 Power for both the solar air heating system (SolarSheats equipment—by Your Solar Home) and the two solar water heating systems (Eagle Sun Systems by AET Technologies). This covered both the equipment and the installation. Some changes to the design (as-built) were required due to differences in the roofing system and mounting requirements of the solar collectors. These included the following:

- Supporting of the panels to the roofing system. Placement of the structural support members for attachment of the solar panels.
- Roofing system panel sizes. Due to the penetration of the ducts, the panel sizes were larger than normal to prevent cutting of the ribs.
- Attachment of the solar panels to the roofing systems was an issue. The metal building was ordered from one manufacturer and the solar panels from another, and the actual attachment detail was unknown. This was reviewed prior to any installation and worked out before any issues developed.

The systems were straightforward in terms of design and operating requirements. There were no complicated control systems and interfaces to deal with. Formal commissioning was not performed. The J. E. Foster Building Company performed a complete walk-through with Missouri DOT staff and provided a 1-year warranty. The lessons learned include:

- Make sure proper planning is done and any issues are ironed out before design begins. This occurred on this project and helped flag potential problems and helped with timely implementation of solutions.

Source: Ed Warhol, Missouri DOT.

Figure 22-4. Solar collectors for water heating on each end of Building A.

- Make sure there is good communication among all the team members. For example, communication between the solar panel manufacturer and the roofing manufacturer for penetration and attachment information helped ensure that the installation was successful.

Figure 22-4 through Figure 22-8 show various aspects of the systems during and after installation.

22.1.3 Results

The systems appear to be operating well, although they have not been instrumented to provide energy performance data. It may be worthwhile to compare the overall building energy use (e.g., natural gas) to similar facilities in the area. However, comparing electric energy use (e.g., savings from the solar water heaters) would be difficult since the complex is master-metered, as are other similar operations. The solar water heaters have been able to provide enough hot water without the need to operate the electric heating elements for much of the time. The solar air heating system provides warm air that is reducing the need for unit heater operation. Quantifying the economics of the systems is not possible due to the lack of system performance data. The systems

Source: Ed Warhol, Missouri DOT.

Figure 22-5. Solar collectors for water heating.

Source: Ed Warhol, Missouri DOT.

Figure 22-6. Solar collectors for water heating and mounting structure for solar air collectors (foreground).

Source: J. E. Foster Building Company.

Figure 22-7. Solar air collector array.

Source: J. E. Foster Building Company.

Figure 22-8. Ductwork/interior of Building A.

are not being monitored, but based on solar panel and system rating information it is estimated that the solar air heating system saves 215 MMBtu and $1,505 in annual operating costs, assuming natural gas unit costs of $7/MMBtu and a gas heater efficiency of 80%. From an economic perspective, this equates to a payback period of 91.7 years. The water heating systems save 56.9 MMBtu and $1,167 in annual operating costs, assuming electricity unit costs of $0.07/kWh. From an economic perspective this equates to a payback period of 13.7 years. Based on fuel bills, during the summer months, the solar water heating systems supply most of the energy for water heating. Overall there is great satisfaction with the system. A similar solar air heating system has been installed at a nearby Park Service facility based on the experience with this system.

The system maintenance requirements are fairly routine, involving checks of filters and pump and blower operation. A minor maintenance issue that was encountered was the need for more frequent filter changes on the air distribution system, due to the presence of welding, fabrication, and truck exhaust. The solar hot water system circulation pumps also needed to be replaced, either due to debris in the lines or air in the system. These were replaced (in part) under system warranty. The maintenance is provided by Missouri DOT staff with assistance from an on-call service company. No specialized maintenance services have been required.

Solar Air Heating System for Building A

- Solar collector type: flat plate air, SolarSheat 1500 GS, manufactured by Your Solar Home, Inc.
- Solar collector array area: 1,040 ft^2 (40 collectors)
- Heat transfer medium: air
- Freeze protection: none required
- Over-temperature protection: none
- Thermal storage: none
- Primary heating: natural gas-fired unit heaters for garage area
- System cost: $138,000
- Annual energy savings: 215 MMBtu
- Annual energy operating cost savings: $1,505
- Economics: 91.7 years (payback period)
- Applicability: buildings that have space heating requirements with warm air distribution systems

Solar Water Heating Systems for Building A

- Solar collector type: flat plate liquid, EagleSun System
- Solar collector array area: 256 ft^2 (two systems, four collectors each)
- Heat transfer medium: water
- Freeze protection: closed-loop drain-back system
- Over-temperature protection: closed-loop drain-back system
- Thermal storage: 80 gallon tank (domestic water)/120 gallon tank (vehicle wash)
- Supplemental heating: 4,500 kW electric element in tanks
- System cost: $16,000 (two systems)
- Annual energy savings: 56.9 MMBtu
- Annual energy operating cost savings: $1,167
- Economics: 13.7 years (payback period)
- Applicability: all buildings with water heating loads

22.1.4 Lessons Learned

- Communication between the solar panel manufacturer and the roofing manufacturer for penetration information and attachment is very important. Make sure that the shop drawing information is reviewed as soon as possible, as was done on this project.
- The hot air circulation system does provide some heated air, reducing the need for supplemental heating. Unfortunately, the end users do not really experience this due to the location of the air distribution outlets at the ceiling line.
- Solar hot water systems work well and are recommended applications.
- Add provisions for monitoring the performance of the system, depending on costs.

22.1.5 Future Plans

There are no specific plans to build similar systems at other Missouri DOT locations at this time.

22.2 Case Study: Fort Drum, NY, Solar Ventilation Air Heating System on Maintenance Facilities

22.2.1 Overview

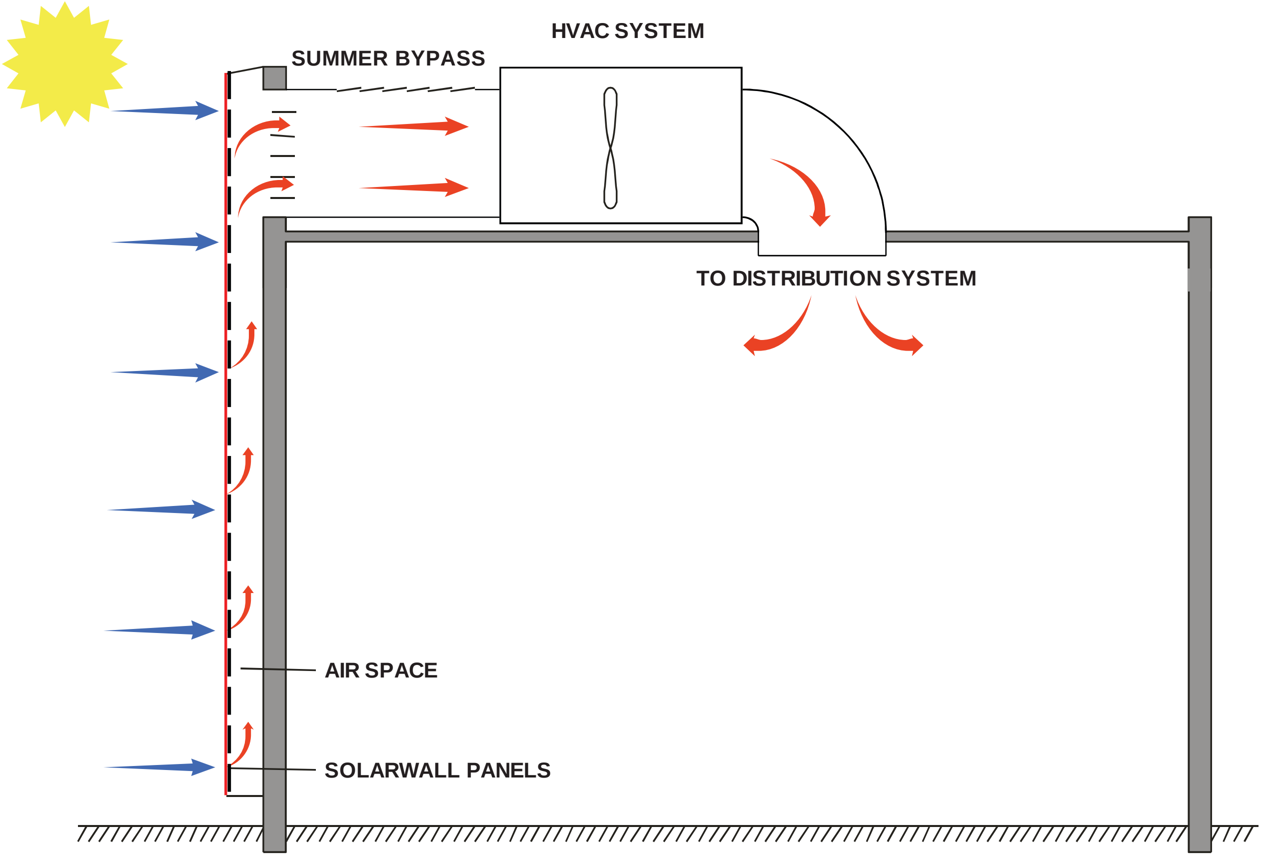
The U.S. Army's Fort Drum near Watertown, NY, has applied solar ventilation air heating systems to 27 existing vehicle maintenance buildings to help reduce energy operating costs and meet Army energy and environmental objectives. Since 2006, more than 110,000 ft^2 of solar collectors have been installed. The buildings selected for the solar applications generally have large south-facing (or southeast/southwest) wall areas that are best suited for mounting the solar collectors and maximizing exposure to the sun, and they have large requirements for fresh air. The solar ventilation air heating technology uses a perforated corrugated metal cladding (e.g., painted galvanized steel) as the solar collector. This unglazed transpired solar collector (trade name SolarWall, supplied by Conserval) is typically installed on the south-facing vertical surfaces of the building. It is attached to the walls by framing materials, which are spaced to provide optimized channels for airflow between the collectors and the wall. Outside air is drawn across the collectors from the bottom to the top and into the building by ventilation fans. This air is then ducted into the building's existing air distribution network or directly into the space. The system provides solar-heated air whenever the collectors are sufficiently warmed by the sun and there is a need to heat the ventilation air. The systems generally heat the air to a temperature of 20°F to 60°F above the outside temperature. This temperature rise is based on the amount of sunshine available and the ventilation airflow rate. In addition to providing solar-heated air, the system can help destratify air in high bay areas and recapture heat that would ordinarily be lost through the walls. In the summer, the collectors can help shield the wall from the sun, reducing cooling needs.

While actual performance data on the systems are not available, it is estimated that the annual output of all of the systems is on the order of 31,022 MMBtu. This figure includes the solar contributions and the heat loss captured by the system and destratification. This results in a natural gas savings of 44,317 MMBtu, assuming a gas heater efficiency of 70%. The avoided greenhouse gas (GHG) reductions are about 2,000 tons of carbon dioxide equivalent (CO_2e) annually. The cost of all the systems was \$3.4 million, or an average of about \$31/ft^2 of collector installed. There were no financial incentives used to reduce the cost of the system. Based on a natural gas cost of \$9/MMBtu, the annual operating cost savings are \$398,853, and the estimated payback period is 8.5 years. The systems have generally been working well, with some valuable lessons learned regarding fan selection, fan noise, placement and type of air intake and distribution, and controls.

Figure 22-9 shows a representative building facade with the unglazed transpired solar collectors, while Figure 22-10 provides a schematic that illustrates the general operation of these types of systems.

Source: Conserval: http://solarwall.com/media/download_gallery/FortDrum-SolarWall.pdf.

Figure 22-9. Fort Drum Vehicle Maintenance Garage (P-10670) with unglazed transpired collectors (SolarWall) installed above garage doors.



Source: Conserval.

Figure 22-10. Unglazed transpired collector (SolarWall) operation.

Site and Building Information: Location: Fort Drum, New York

- Address: Fort Drum, NY 13602
- ASHRAE climate zone: 6A
- Annual heating degree days (65°F base): 7,289 (Watertown AP)
- Average high temperature/low temperature (summer): 76.1°F/54.2°F
- Average high temperature/low temperature (winter): 33.2°F/13.9°F
- Average annual precipitation: 37.3 in.
- Occupancy: varies by building
- Schedule: varies by building
- Ventilation air requirements: 300,000 cfm (27 buildings)
- Renewable energy features: solar ventilation air preheating using unglazed transpired collectors (SolarWall)
- Other energy/sustainability features: Various energy projects have been instituted including geothermal heat pumps in some buildings.

22.2.2 Project Development Process

22.2.2.1 Pre-Design (Project Planning) Phase

The project was motivated in large measure by the need for a cost-effective means to reduce Fort Drum's energy operating costs and to reduce greenhouse gas emissions. In addition, it was viewed as an opportunity to improve and upgrade ventilation systems. Given the large number of buildings that had substantial requirements for ventilation air, means to reduce the energy for heating this air were explored. The SolarWall system, which uses unglazed transpired collectors, was identified as a promising candidate for heating ventilation air. The Fort Drum energy manager had knowledge of the technology through other installations, and based on initial estimates, thought it would be a good application. He worked closely with the Army Corps of Engineers to develop the project. The Energy Conservation Investment Program (ECIP) was tapped as the funding source. ECIP is an internal U.S. Department of Defense program that was established to promote projects that reduce energy use. However, since it has a limited budget, projects are awarded through internal competition. The SolarWall system, manufactured by Conserval Systems, Inc., was identified as the supplier due to its established position with the technology. The contracting for the project was based on a specification developed by the energy manager, the Army Corps of Engineers, and Conserval as a design–build project.

22.2.2.2 Design Phase

The systems were designed through close cooperation between the Fort Drum energy manager, the Army Corps of Engineers, and Conserval staff. Since there were a large number of buildings with different facades and ventilation systems, a number of different designs were developed. Some buildings required improvements to the ventilation systems to provide for more controlled ventilation. Integration with existing ventilation systems and the current requirements of the buildings were key focuses, as were ensuring occupant comfort. This required some customization of the design solutions and specifications of different equipment (e.g., types of fans/drives, types of dampers used, and controls). For example, designs that would help reduce space temperature gradients by mixing higher temperature air near the roof with solar-heated ventilation air were developed. The objective was to lower the temperatures near the roof, thereby reducing heat loss, while improving overall comfort through more even heating and distribution of air. The possible intake of vehicle exhaust fumes entering through the collectors was also considered, particularly when parking areas were adjacent to the proposed collector mounting area. The SolarWall colors were selected to best match the facade of the particular building. While a black collector is the most beneficial from a heat collection standpoint, other dark colors can still provide good performance.

Project Team

Fort Drum
Energy Manager
Fort Drum

Design
Conserval Systems, Inc.
Conserval Engineering, Inc.

Construction

Installation Contractor
Conserval Engineering, Inc.

Solar Collector Manufacturer
Conserval Engineering, Inc.

Construction Oversight
Army Corps of Engineers

Commissioning
Army Corps of Engineers
Conserval Engineering, Inc.

22.2.2.3 Construction Phase

Project construction was performed by Conserval, with oversight provided by the Army Corps of Engineers. The project proceeded in phases over the approximately 18-month construction period. The installation was accomplished primarily by two sheet metal workers and two electricians. There were some issues uncovered during the construction period, including noise associated with certain installations (depending on type of fan and location), comfort issues related to the type of intake (gravity-type intake dampers), which caused the relatively cold air from the system to be directed too close to building occupants, and control operation/sequencing.

Figure 22-11 shows the construction of the solar wall support structure, while Figure 22-12 shows the completed system. Figure 22-13 is an interior view of the building, showing a ducted distribution system. Figure 22-14 shows a building with a ductless air distribution approach.

22.2.3 Results

One of the systems was monitored (Shop Building 91, with 4,100 ft^2 of collectors); however, only limited data collection was performed. Additional data monitoring activities have been launched, and it is expected that performance information on the building will be available over the next year. In the meantime, estimates from performance models and the limited monitoring indicate that the SolarWall systems provide about 31,022 MMBtu of heat. This figure includes the solar contributions and the heat captured that would ordinarily be lost through the walls, as well as destratification savings. This results in a natural gas savings of 44,317 MMBtu, assuming a gas

Source: Conserval, John Hollick. Transpired Air Heaters in a Cold Weather Application, presentation at Energy Smart Expo, March 28, 2008.

Figure 22-11. Framing structure for SolarWall on Shop Building 91 at Fort Drum.

Source: Conserval, John Hollick. Transpired Air Heaters in a Cold Weather Application, presentation at Energy Smart Expo, March 28, 2008.

Figure 22-12. SolarWall installed on Shop Building 91 at Fort Drum.

Source: Conserval, John Hollick. Transpired Air Heaters in a Cold Weather Application, presentation at Energy Smart Expo, March 28, 2008.

Figure 22-13. Distribution system using flexible ducts with existing system.

Source: Conserval, John Hollick. Transpired Air Heaters in a Cold Weather Application, presentation at Energy Smart Expo, March 28, 2008.

Figure 22-14. Installation using ductless fan.

heater efficiency of 70%. The avoided greenhouse gas reductions are about 2,000 tons of CO_2e annually. The associated annual energy operating cost savings are estimated to be $398,853. The estimated payback period is 8.5 years. The systems have generally been working well, with some valuable lessons learned regarding fan selection, fan noise, placement and type of air intake and distribution, and controls.

Solar Ventilation Air Heating System Information

- Solar collector type: unglazed solar transpired collector (SolarWall)
- Solar collector array area: 110,000 ft^2 (27 buildings, 50 systems)
- Backup ventilation heater: varies—gas-fired heaters
- System cost: $3,400,000
- System cost per unit collector area: $31/$ft^2$ collector
- Annual system output: 31,022 MMBtu (solar heat and captured heat from buildings and destratification benefits)
- Annual system output per unit collector area: 0.282 MMBtu/ft^2 collector
- Annual energy savings: 44,317 MMBtu (assumes 70% efficient gas-fired heaters)
- Annual energy operating cost savings: $398,853 (@$9/MMBtu natural gas)
- Economics: 8.5 years (payback period)
- Applicability: buildings that have high ventilation air requirements, ample south (or near south) oriented wall area, and are in moderate-colder regions

22.2.4 Lessons Learned

- Fan noise may be an issue in some cases, so measures to dampen the noise should be taken. Solutions include use of variable-speed drives to reduce speed, adding silencers, and adding duct insulation for ducted systems.
- Gravity dampers for outside air intake should be avoided to eliminate the downward flow of cold air.
- Distribution ductwork should be added, if not already in place, to ensure better distribution of air, to reduce noise, and for overall comfort.
- Consider connecting to existing direct digital control systems, if available. This can provide better year-round operational control.

22.2.5 Future Plans

- Additional buildings with SolarWall are being considered.
- Performance monitoring of one system has just begun.

22.3 Case Study: Plattsburgh, NY, Solar Ventilation Air Heating System on Airport Facilities

22.3.1 Overview

The Plattsburgh International Airport in Plattsburgh, NY, installed a total of 17,840 ft^2 of SolarWall two-stage ventilation air systems on four existing buildings in 2011. The buildings include three 28,000-ft^2 hangars, designated as Hangars 3, 4, and 5, and a 26,500-ft^2 industrial facility, designated as the Trans-Ed building. The airport is a former military installation (Plattsburgh Airport Base) that was converted to private-sector use in 2008, as a result of the federal government's divestments under the Base Realignment and Closure Act (BRAC). The primary objective of the project was to reduce heating bills in order to keep rental costs competitive.

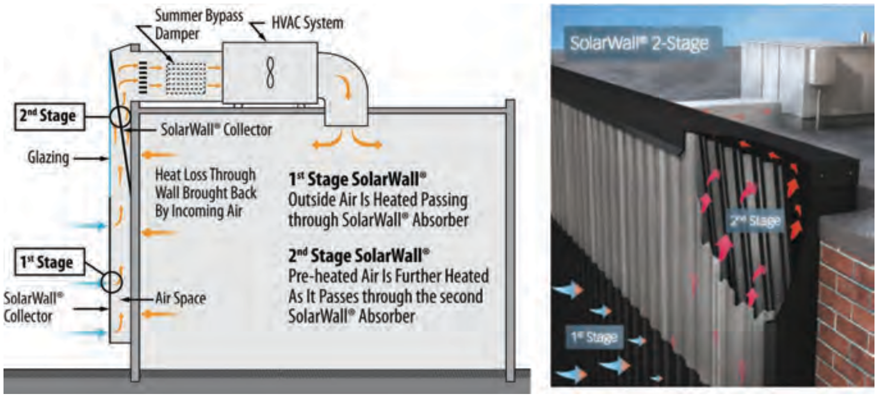
The traditional solar ventilation air heating technology, which has been in use for over 20 years, uses a perforated corrugated metal cladding (e.g., painted galvanized steel) as the solar collector. Conserval had recently developed a new, two-stage transpired solar collector system, and Plattsburgh International Airport was willing to demonstrate the new technology with the New York State Energy Research and Development Authority's (NYSERDA's) support. The two-stage system operates with the lower half of the wall constructed as a traditional transpired collector, which acts as the first stage. The solar preheated air then enters the top portion of the unit (second stage), which has the transpired collector covered by a clear plastic (polycarbonate) glazing. This transpired collector (SolarWall, supplied by Conserval) is typically installed on the south-facing vertical surfaces of the building. It is attached to the walls by framing materials, which are spaced to provide optimized channels for airflow between the collectors and the wall. Outside air is drawn across the collectors from the bottom to the top and into the building by ventilation fans. The air is heated as it passes across the unglazed portion of the collectors and heated even more as it passes through the glazed portion. This air is then ducted into the building's existing air distribution network or directly into the space. The system provides solar-heated air whenever the collectors are sufficiently warmed by the sun and there is a need to heat the ventilation air. The single-stage system was designed to heat air up to 50°F above ambient. The two-stage system is now heating the air to a temperature of 36°F to 85°F above the outside temperature; recent monitored data show gains of over 100°F above ambient. This temperature rise is based on the amount of sunshine available and the ventilation airflow rate. In addition to providing solar-heated air, the single system could help to destratify air in high bay areas and recapture heat that would ordinarily be lost through the walls. With higher delivered air temperatures from the two-stage system, the method of achieving the destratification savings may require modifications for future designs. In the summer, the collectors can help shield the wall from the sun, reducing cooling needs.

Hangar 3 is currently being monitored for performance. Based on preliminary data from January 9, 2012, through February 24, 2012, it is estimated that the annual output of the 3,500-ft^2 collectors will be on the order of 365 MMBtu, or 0.104 MMBtu/ft^2. This figure includes the contributions of the solar and building heat loss recapture, but not the savings from destratification. This results in a natural gas savings of 521 MMBtu, assuming a gas heater efficiency of 70%. Based on the delivered natural gas cost of $12/MMBtu, at the time of the proposal, the annual operating cost savings from the hangar was projected to be $6,252. The avoided greenhouse gas reductions are 42,607 pounds of CO_2e annually. The cost for the Hangar 3 system was $121,606. The lack of destratification savings means that the solar portion of savings results in an estimated payback period of 19 years. It is estimated that had the destratification changes been implemented in Hangar 3 from the outset, they would have increased the annual natural gas savings to 840 MMBtu. With destratification, the payback period would be expected to drop to the 11-year range. However, the entire $614,219 cost of the project (all four buildings) was covered by a $621,000 grant from NYSERDA. The funding to NYSERDA originated with the U.S. DOE and the American Recovery and Reinvestment Act (ARRA) of 2009. One of the most valuable lessons learned with this project was how best to configure and operate the two-stage system for future installations. This strategy is now being tested at another installation.

Figure 22-15 shows the two-stage transpired solar collectors, with the unglazed portion on the lower section of the wall. Figure 22-16 illustrates how the two-stage design operates.

Source: Conserval.

Figure 22-15. Hangar with unglazed transpired collectors (two-stage SolarWall).



Source: Conserval

Figure 22-16. Two-stage unglazed transpired collector (SolarWall) operation.

Site and Building Information: Location: Plattsburgh, New York

- Address: 137 Margaret St., Plattsburgh, NY 13642
- ASHRAE climate zone: 6A
- Annual heating degree days (65°F base): 7,817 (Plattsburgh Airport)
- Average summer max/min temperature: 79.8°F/54.6°F
- Average winter max/min temperature: 25.6°F/6.7°F
- Average annual precipitation: 34.43 in.
- Floor area: 110,500 ft^2 (3 to 28,000 ft^2 hangars and 1 to 26,500 ft^2 industrial/maintenance building)
- Occupancy: varies by building
- Schedule: varies by building
- Renewable energy features: solar ventilation air preheating using two-stage unglazed transpired collectors (SolarWall)
- Other energy/sustainability features: none

22.3.2 Project Development Process

22.3.2.1 Pre-Design (Project Planning) Phase

The airport manager was exploring ways to reduce energy operating costs in order to make hangar rental fees attractive. Due to the severe winter climate, heating costs were a major contributor to facility operating expenses. He met with a representative of Conserval Systems to determine if the SolarWall unglazed transpired collector systems would provide a good solution for reducing his heating costs. Conserval provided the analysis, which indicated that four of the buildings were good candidates and would be economical for installation. The RETScreen software tool from NRCAN was used to estimate the energy provided by the systems. Based on this information, the airport manager applied for a competitively sourced grant from NYSERDA. This funding originated with the U.S. DOE based on ARRA funds. The NYSERDA program was targeted at municipalities and focused on energy savings projects. The city of Plattsburgh applied for and received two grants totaling $621,000. A design–build approach was used to implement the project, with the airport issuing a competitive solicitation to perform the work. Dynamic Construction was selected with a bid of $614,219.

22.3.2.2 Design Phase

The design for the project was based on the information initially developed by Conserval, with small modifications made by Dynamic Construction to fit the specific building requirements. The changes were due to the presence of a crane in one of the hangars, which interfered with the air distribution duct work. The result was a change to one of the fans and a reduction in the solar collector area of a few hundred square feet. Table 22-1 summarizes some of the design features and costs. The design phase was completed within 3 weeks of project award.

Overall project management was performed by the airport manager, with design–build responsibility with Dynamic Construction. Conserval performed as advisers on the design.

Table 22-1. Project design features and costs.

Building Description	Size of SolarWall	Number of Fans and Design Flow Rate	Total Installed Cost	Cost per ft^2 Installed	Estimated Payback (Years)
Hangar 3	3,500 ft^2	2 fans @ 2,000 cfm ea	$121,606	$34.75	11
Hangar 4	3,500 ft^2	2 fans @ 2,000 cfm ea	$121,606	$34.75	11
Hangar 5	6,000 ft^2	3 fans @ 3,000 cfm ea	$200,631	$33.33	10
Trans-Ed	4,840 ft^2	3 fans @ 3,000 cfm ea	$170,376	$35.20	10

Project Team

Owners Representative
Airport Manager (former)
Plattsburgh International Airport

Design
Conserval Systems, Inc.

Construction

Installation Contractor
Dynamic Construction

Solar Collector Manufacturer
Conserval Systems, Inc.

22.3.2.3 Construction Phase

Project construction was performed by Dynamic Construction, including installation of the SolarWall, fan duct work, controls, and electrical work. The project was completed using Davis-Bacon Act wages. In order to install SolarWall on the hangars, Dynamic needed two vertical lifts, an electric scissor lift, and a forklift (see Figures 22-17 and 22-18). The systems for Hangars 4 and 5, as well as the Trans-Ed building, took 4 weeks to install, while Building 3 took 6 weeks. This was followed by a 2-week monitoring and installation period. The entire project took 5 months from the time the NYSERDA grant was awarded until the systems became operational.

22.3.3 Results

The Cadmus Group, Inc., as part of an evaluation of NYSERDA's ARRA-funded renewable energy projects, began performance monitoring of the Plattsburgh Airport SolarWall project in 2011. The monitoring includes:

- Fan electricity consumption;
- SolarWall delivery temperature, humidity, and airflow;

Source: Conserval.

Figure 22-17. Construction of unglazed two-stage SolarWall showing support framing and installation of polycarbonate glazing.

Source: Conserval.

Figure 22-18. Completed two-stage SolarWall installation.

- Outdoor air temperature and humidity;
- Incident solar radiation; and
- Indoor air temperature at 5-ft, 19-ft, and 33-ft heights.

Based on these measurements, Conserval was able to calculate energy savings due to preheated air delivery, destratification, and reduced heat loss through the building envelope. Shortly after monitoring began, it was discovered that the controls schedule for summer/winter operation had been reversed. This appears to have happened during the replacement of some broken sensors during installation. This was fixed before the winter season. Using data collected between January 9, 2012, and February 24, 2012, Conserval estimated that the annual output of the 3,500-ft^2 collectors on hangar 3 will be on the order of 365 MMBtu. This figure includes the contributions of the solar and building heat loss recapture, but not the savings from destratification. This results in a natural gas savings of 521 MMBtu, assuming a gas heater efficiency of 70%. Based on the delivered natural gas cost of $12/MMBtu, at the time of the proposal, the annual operating cost savings from the hangar was projected to be $6,252. The avoided greenhouse gas reductions are about 21 tons of CO_2e annually. The cost for the Hangar 3 system was $121,606, which results in an estimated payback period of 19 years. However, the entire $614,219 cost of the project (all four buildings) was covered by the NYSERDA grant. The systems have been working well and have actually provided a temperature rise in excess of 100°F, exceeding expectations (see Table 22-2 and Figure 22-19). It has been observed that the buildings now take only 45 min to reheat versus 3 hours before the system was installed.

Solar Ventilation Air Heating System Information
- Solar collector type: unglazed transpired solar collector (two-stage SolarWall)
- Solar collector array area: 17,840 ft^2 (four buildings)
- Monitored Building 3 solar collector array area: 3,500 ft^2
- Backup ventilation heater: gas-fired heaters
- Total system cost: $614,219 (without grant, $0 including grant)
- Monitored Building 3 system cost: $121,606

Table 22-2. Representative performance data—February 4, 2012.

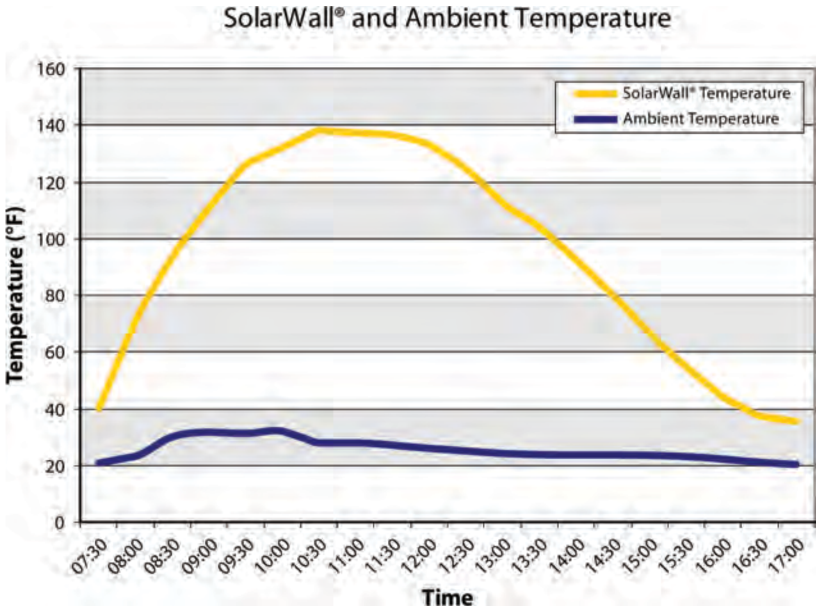
Time (Eastern Daylight Time)	SolarWall Temp (°F)	Ambient Temp (°F)	Solar Rad (W/m^2)	Temp Rise (°F)	Airflow (cfm)
07:30	40.04	20.80	28.6	19.2	1,008
08:00	71.5	23.3	64.7	48.3	1,841
08:30	93.8	30.2	190.3	63.6	1,961
09:00	111.4	31.7	256.5	79.6	1,943
09:30	126.5	31.2	318.9	95.3	1,870
10:00	132.2	32.4	371.5	99.8	1,962
10:30	138.2	27.8	414.4	110.3	1,951
11:00	137.1	28.0	417.8	109.1	1,941
11:30	136.7	27.0	449.1	109.6	1,864
12:00	133.6	26.2	461.9	107.4	1,747
12:30	124.6	25.3	453.8	99.3	1,714
13:00	112.9	24.0	434.1	88.9	1,769
13:30	104.0	23.8	400.8	80.2	1,776
14:00	92.6	23.7	357.0	68.9	1,803
14:30	79.8	23.7	304.0	56.1	1,768
15:00	66.7	23.5	246.1	43.2	1,776
15:30	55.0	23.1	182.5	31.9	1,642
16:00	44.2	22.1	116.8	22.1	1,466
16:30	37.5	21.1	44.3	16.4	1,045
17:00	35.5	20.1	8.4	15.4	502
Average	**93.7**	**25.4**	**276.1**	**68.2**	**1,667**

Source: Conserval.

- Total system cost per unit collector area: $34.43/ft^2 collector
- Annual system output: 365 MMBtu (solar heat and captured heat from monitored Building 3)
- Annual system output per unit collector area: 0.104 MMBtu/ft^2 collector
- Annual energy savings: 521 MMBtu (monitored Building 3 only—assumes 70%-efficient gas-fired heaters)
- Annual energy operating cost savings: $6,252 (monitored Building 3 only—assumes $12/MMBtu natural gas
- Economics: 19 years (payback period without grant)
- Applicability: buildings that have high ventilation air requirements, ample south (or near south) oriented wall area, and are in moderate-colder regions

22.3.4 Lessons Learned

The two-stage SolarWall provided higher temperatures than expected at the flow rates and levels of solar radiation measured. However, the current system is not configured to take advantage of the relatively high-temperature solar-heated air. As designed, the solar-heated air is distributed by the blowers to the space through ductwork and dampers at the ceiling level. At this high distribution point, the solar-heated air cannot effectively fall to the occupant level because it has a higher temperature (lower density) than the room air. This negates its value in destratification. An alternative would be to use less expensive wall fans with variable-speed drive motors to modulate airflow to provide 65°F to 80°F air. The fans would introduce this solar-heated fresh air into the area below the ceiling without the expense of ductwork. Instead, large high-velocity, low-speed destratification fans would be used. These fans typically can destratify air over a 1,500-ft^2



Source: Conserval.

Figure 22-19. Representative performance data—February 4, 2012.

to 3,000-ft^2 floor area, depending on the height. They would be controlled (on/off) based on the temperature of the air below the ceiling. It is estimated that had these changes been implemented in Hangar 3 from the outset, they would have increased the annual natural gas savings to 840 MMBtu. Other lessons learned are:

- If available, connect the system to existing direct digital control systems/building automation systems. This can provide better year-round operational control. If this is not available, then use the simple time clock control provided. Make sure to install some sort of lockbox to prevent tampering with the settings.
- Introduce performance monitoring earlier in the process as a means of confirming performance and identifying any issues.

22.4 Case Study: Coney Island, NY, Train Maintenance Facility Solar Water Heating System

22.4.1 Overview

The Coney Island Train Maintenance Facility, located in Brooklyn, NY, sits on approximately 75 acres of land that serves as a major maintenance hub for the New York Metropolitan Transportation Authority (MTA)–New York City Transit (NYCT) trains. The main buildings include the 360,000-ft^2 maintenance barn, a 37,500-ft^2 electric motor repair shop, a 30,000-ft^2 pneumatic repair shop, and storage areas and other specialty buildings. The facility operates year round and has 1,200 employees. Over the past few years, a number of energy efficiency and renewable energy projects have been undertaken, under the auspices of MTA–NYCT, through arrangements with the New York Power Authority (NYPA). NYPA is the electric power provider. In 2010, a solar water heating system was installed on the maintenance barn and was designed to meet the majority of the hot water needs of the facility. The hot water is used for washing the trains—about 50,000 vehicle washes per year—and for domestic hot water uses. The solar system consists of 1,762 ft^2 of evacuated-tube collectors that heat the water up to temperatures as high as 190°F.

Source: New York Power Authority, 2011. *MTA Coney Island Train Yard, Vacuum-Tube Solar Hot Water System Final Report,* NYSERDA, Agreement No. 9915, Appendix – April 2010 Progress Report, p. 2.

Figure 22-20. Solar collector array on the roof of the MTA Coney Island maintenance barn.

The evacuated-tube solar collectors provide higher temperature water and more efficient operation in colder ambient conditions than flat plate solar collectors. The collectors, which were specially designed to meet the wind load standards of the New York State code (120-mph equivalent wind load), are installed on the roof of the building. Solar-heated water is stored in the 2,500-gal tank that was formerly the 240-kW electric resistance storage water heater.

The solar system displaces approximately 104,000 kWh of electricity annually (67% of the estimated hot water load of 156,000 kWh) and reduces electric demand by about 217 kW. When solar-heated water is either not available or insufficiently warm to meet the requirements, a new natural gas-fueled instantaneous steam water heater is used. The system cost $564,905, not including the $150,000 grant from NYSERDA. In addition, NYPA provided the financing for the system. The MTA pays off the system over time through bill payments. The estimated payback period is 5.6 years (no incentives) or 4.1 years (with incentives) based on an estimated savings of approximately $100,000 per year. The system has been performing up to expectations. Lessons learned include ensuring that the installation contractor understands any special equipment requirements (e.g., connections to special collector fittings) and specifications (e.g., nomenclature for pressure vessel specifications to ensure proper sizing), and collector stagnation-related issues (e.g., ensuring that the system is properly filled and purged of air upon start-up). Based on the positive experience with this system, the MTA is planning to implement similar solar thermal projects at other sites.

Figure 22-20 shows the solar collectors installed on the facility.

Site and Building Information: Location: Brooklyn, New York

- Address: Brooklyn, NY 11224
- ASHRAE climate zone: 4A
- Annual heating degree days (65°F base): 4,910 (La Guardia AP)
- Average high temperature/low temperature (summer): 80.3°F/65.5°F

- Average high temperature/low temperature (winter): 43.3°F/30.8°F
- Average annual precipitation: 46 in.
- Maintenance barn floor area: 360,000 ft^2
- Occupancy: 1,200
- Schedule: 24/7
- Water heating requirements: 13,000 gal/week of hot water
- Renewable energy features: Solar water heating system using evacuated-tube collectors
- Other energy/sustainability features: efficient lighting systems (T-5 lamps, motion sensors)

22.4.2 Project Development Process

22.4.2.1 Pre-Design (Project Planning) Phase

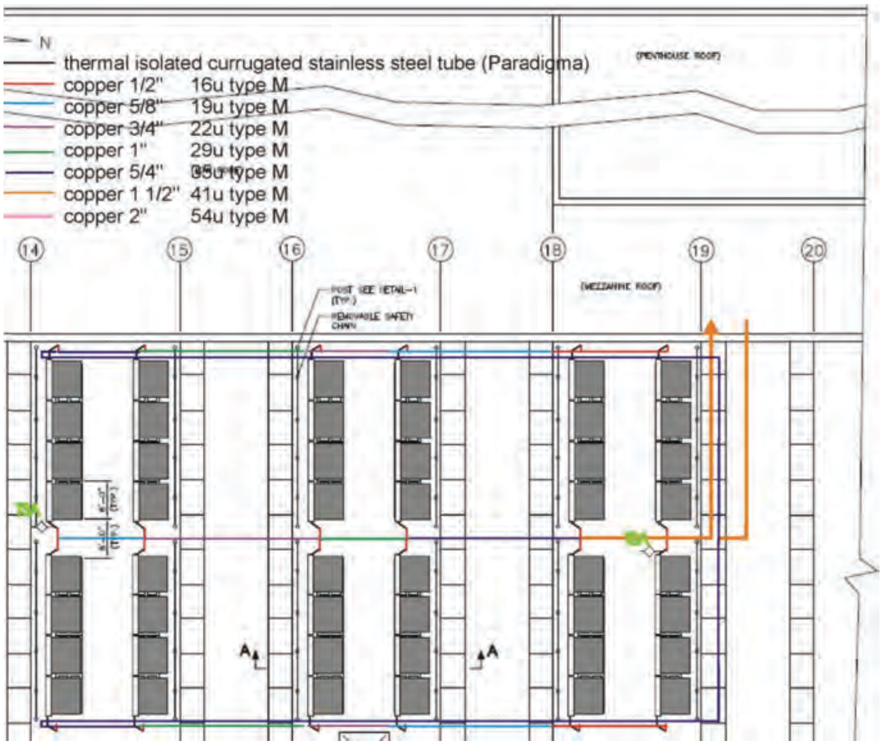
The project was conceived as a result of an energy audit/assessment performed by NYPA, the organization that provides MTA with electric power. Electric water heating was identified as a good target for operating cost savings. Monitoring of the hot water heater electricity consumption/loads was performed to provide a baseline for energy use. Solar water heating was screened and determined to be potentially economical for the application. The principal objectives of the solar water heating project were to reduce energy operating costs and provide environmental benefits (e.g., greenhouse gas reductions). This also helped meet the MTA's broader policy goals regarding sustainability. MTA signed an agreement with NYPA in 2009 to proceed with the project. MTA had already engaged NYPA on several other projects (e.g., efficient lighting upgrades), so there was already a good working relationship. The planning team consisted of NYPA and the MTA Energy Management Organization and facilities staff. The team decided on a design–bid–build process. The financing for the project was to come from NYPA's energy efficiency program. The program allows the customer to pay for the system through utility bill payments over terms of up to 20 years. The payments are structured so that they are offset by the projected reductions in energy operating costs due to the system. For the Coney Island project, the term was set at 10 years. MTA participated in the program to eliminate the need for MTA capital funds. In addition, NYSERDA was identified as a potential source for incentives (ultimately a $150,000 grant). General requirements for system performance evaluation based on NYSERDA and MTA were formulated.

22.4.2.2 Design Phase

The design was led by NYPA, in close coordination with the MTA Energy Management Organization, and facilities staff. A major area of focus was the structural requirements that a roof-mounted system would pose, as were concerns about roof maintenance and minimizing roof leaks. For this reason, a ballasted support structure was decided on. The roof was carefully analyzed to identify the areas where the ballasts/supports could be safely located. In addition, the collectors had to be able to withstand wind loading equivalent to 120 mph, so this was included in the specification.

The design documents and specifications were packaged into a request for proposals (RFP) that was issued by the NYPA Procurement Division. There were three bidders that responded, and the successful bidder (low-bidder) was Leonard Powers, Inc., of New York City. The solar collector specified was manufactured by the German firm Paradigma Energie.

Figure 22-21 shows the layout of the solar collectors and piping on the roof.



Source: Ke He, NYPA.

Figure 22-21. Solar collector array and piping layout.

Project Team

Building Owner's Representative
Director, Agency-Wide
Environmental and Energy Policy
New York Metropolitan
Transportation Agency

Design
New York Power Authority

Construction

Installation Contractor
Leonard Powers, Inc.

Solar Collector Manufacturer
Paradigma Energie (Germany)
Linuo Ritter USA, Inc. (Regasol USA)

Construction Oversight
NYPA

Commissioning
NYPA, Paradigma Energie, Leonard Powers, Inc.

22.4.2.3 Construction Phase

The most significant issue that arose prior to construction was the ability of the solar collectors specified to meet the New York State code for wind loading requirements. NYPA and MTA worked with the manufacturer to ensure that the collector would meet the requirements. Paradigma Energie undertook wind tunnel testing and made design changes to certify compliance. The

Source: New York Power Authority, 2011. *MTA Coney Island Train Yard, Vacuum-Tube Solar Hot Water System Final Report,* NYSERDA, Agreement No. 9915, page 11, Figure 11.

Figure 22-22. Solar collector array and piping layout.

resulting collector designs became an additional offering by the manufacturer. The other issues that arose included the following:

- Expansion tank volume. A misunderstanding about the distinction between "acceptance volume" and "vessel volume" resulted in the installation of undersized expansion tanks (initially). This caused a loss of collector loop fluid due to over-pressurization, and caused stagnation to occur.
- Swagelok connection. The overtightening of Swagelok-type connectors on the solar collector inlet and outlet caused several to crack, requiring replacement.
- Stagnation during commissioning. Due to inadequate purging of air, there was insufficient fluid in the collector loop upon initial start-up. The collectors went into stagnation when their protective vinyl covers were removed during the commissioning process. This prevented completion of the commissioning until after the stagnation period ended.

Discussions among the parties—NYPA, the collector manufacturer, and the installation contractor—resolved these issues quickly. All were involved in the commissioning process, with the collector manufacturer's commissioning engineer leading the acceptance testing. Training of MTA facility staff was provided by the solar collector manufacturer. This phase of the project took approximately 6 months—from November 2009 to April 2010. A major lesson learned was to ensure good written and oral communications of the specifications among the system designer/specifier, solar collector manufacturer, and installer.

Figure 22-22 shows a closer view of the solar collectors and piping.

22.4.3 Results

The solar water heating system was monitored using an ISTEC Btu meter capable of storing up to 13 months of data. The performance of the system was compared to estimates produced by two solar screening/evaluation tools: RETScreen (NRCAN) and TSOL (Valentin Software), and they were found to be in good agreement. From June 2010 through May 2011, the solar system displaced approximately 104,000 kWh (67% of the hot water load of 156,000 kWh) of electricity and reduced electric power demand by 217 kW. The avoided greenhouse gas reductions are 80 tons of CO_2e. The associated annual energy operating cost savings are estimated to be about $100,000. The savings were due in large measure to the high electric power demand charges ($30/kW) avoided (about $6,500/month). The estimated payback period is 5.6 years (no incentives), or 4.1 years with incentives. The system is working well and the maintenance requirements have been as expected. There have been no undue burdens on facility staff.

Solar Water Heating System Information

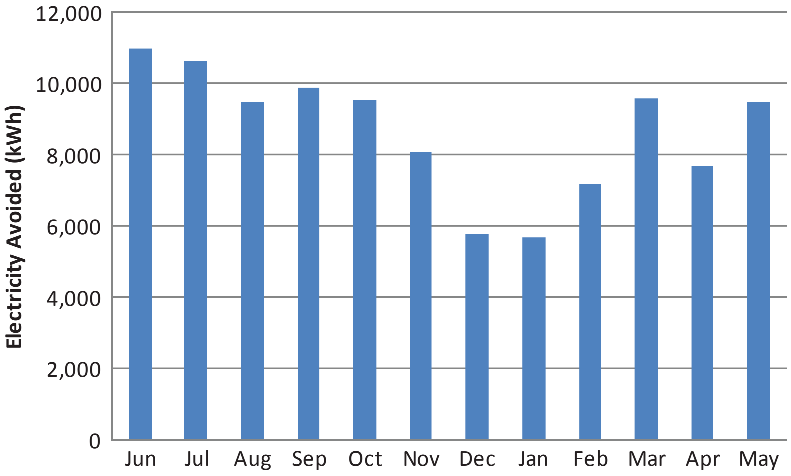
- Solar collector type: evacuated tube
- Solar collector array area: 1,762 ft^2 (48 collectors)
- Closed-loop system (pressurized)
- Heat transfer fluid: water
- Freeze protection: recirculation of heated water
- Over-temperature (collector stagnation) protection: expansion tank sized to accept boiling water
- Storage tank volume: 2,500 gal
- Backup heater: steam-fired instantaneous water heater
- System cost: $564,905 ($414,905 after NYSERDA incentive)
- Annual energy savings: 104,000 kWh (355 MMBtu)
- Percent of annual water heating energy met: 67%
- Electric power demand reduction: 217 kW
- Annual energy operating cost savings: $100,000

Economics:
- 5.6-year payback period (no incentives)
- 4.1-year payback period (with incentives)
- Applicability: all buildings that have hot water requirements, especially if higher temperature water is needed

Figure 22-23 shows the monthly contributions of the system in terms of avoided electricity purchases.

22.4.4 Lessons Learned

- Ensure that solar collectors are certified to meet wind load specifications.
- Water can be used as a good heat transfer fluid with evacuated-tube solar collector systems in colder climates.



Source: Ke He, NYPA.

Figure 22-23. Avoided electricity purchases from solar water heating system contribution June 2010 through May 2011.

- Make sure there is a common understanding of "acceptance volume" versus "vessel volume" to ensure that the properly sized expansion tank is installed.
- Make sure that the installation contractor follows the recommendations for installing the quick-connect–type fittings versus more traditional fittings to avoid damage to the connectors.
- Make sure that the primary collector loop is fully charged with fluid and purged of air prior to exposing collectors to sunlight during initial start-up.

22.4.5 Future Plans

MTA is implementing similar projects on some of its other transit/transportation facilities:

- A 661-ft^2 solar collector array (18 panels) system at the Pelham train yard. This was commissioned in March 2012. This is a drain-back system, where the water is automatically drained during periods of freezing or stagnation.
- A system at the Jamaica train yard is being evaluated.

22.5 Case Study: Denver, CO, Public Works Central Platte Campus

22.5.1 Overview

To accommodate the right-of-way for a new light rail line, the City and County of Denver, CO, needed to relocate an existing public works facility to a new site. The new Central Platte Campus is located on a property adjacent to the Platte River with visibility from a major interstate highway. The activities to be accommodated included routine vehicle maintenance for the city's vehicle fleet, sand and salt storage, automatic vehicle wash and chassis wash, engine repair, and supporting office space for street maintenance, fleet maintenance, solid waste, traffic, and right-of-way enforcement. The campus has six structures totaling 105,000 ft^2, including a fleet maintenance facility of 39,546 ft^2, enclosed heated storage of 13,493 ft^2, office and warehouse of 29,056 ft^2, a 6,640-ft^2 wash bay, 15,676 ft^2 of salt storage, and 7,200 ft^2 of covered storage. The completed campus was turned over to the city for occupancy on October 1, 2010. Total construction cost was $25,000,000. The campus supports a fleet of 500 vehicles. Construction of the various structures included tilt-up concrete panels for the fleet maintenance, office/warehouse, and vehicle wash; pre-engineered steel structures for covered vehicle storage and heated vehicle storage; and a pre-engineered wood dome structure for salt storage.

The 33-acre site is a remediated brownfield. The site was used for a variety of industrial processes from the 1880s until 2008. These activities included mineral processing and chemical manufacturing. Located approximately 4 miles from downtown Denver, the site is adjacent to the Platte River and the city's Art Deco-style wastewater treatment plant and is visible from Interstate 25. The buildings are oriented with the long dimension running north–south to allow the vehicle bay doors to face east and west. This orientation was selected to allow solar access to the east and west sides of the buildings to prevent the build-up of ice and snow that would likely occur if half the bays faced the north. Both the fleet maintenance building and the office warehouse building achieved the LEED Version 2.2 Gold certification requirements. A variety of LEED-compliant sustainability strategies, including the 101.66-kW solar photovoltaic system, were incorporated to achieve the LEED rating.

Renewable Energy: The project includes a 102-kW photovoltaic solar energy array that was funded through a PPA. The array is integrated into the sawtooth roof design. The PV system is producing in excess of the pre-construction projections—153,506 kWh annually. In addition to the solar array, the building includes an extensive daylighting system interconnected to artificial lighting systems.

Other Sustainable and Energy Efficiency Strategies: To meet LEED requirements, the design of the building envelope and systems reduces energy consumption significantly as compared to a standard building. The maintenance garage is heated by a radiant floor heating system in combination with a tempered air ventilation system. Evaporative cooling, high-efficiency water heating and energy recovery systems are also incorporated. Energy-efficient lighting and task lighting are integrated into the daylighting system. Storm water detention and pretreating is provided, as are low-flow plumbing fixtures and materials and finishes with recycled content.

Figures 22-24 through 22-26 show various aspects of the buildings, including the photovoltaic systems.

Source: RNL Design, architect.

Figure 22-24. Central Platte Public Works Facility—initial rendering of entire campus (with PV at all buildings), operations building in foreground and vehicle maintenance building in far background.

Figure 22-25. Vehicle maintenance building showing PV and shading strategies at doors.

Source: RNL Design, architect.

Figure 22-26. Central Platte Public Works Facility — operations center entry facade.

Site and Building Information: Location: Denver, Colorado

- Address: 1271 West Bayaud Avenue, Denver, CO 80223
- ASHRAE climate zone: 5B
- Annual heating degree days (65°F base): 6,020
- Average high temperature (summer): 90°F
- Average low temperature (winter): 15°F
- Average annual precipitation: 15.81 in.
- Facility floor area: 105,000 ft^2
- Occupancy: 192
- Schedule: 6 a.m. to 6 p.m. office warehouse; 5 a.m. to 9 p.m. fleet maintenance

Renewable Energy Features:
- Solar photovoltaic system, net metered (100 kW)
- Daylighting
- Integrated design for PV and daylighting oriented for optimum solar efficiency

Other Energy Efficiency Features:
- Efficient lighting systems (T-5 and T-8 lamps, motion + occupancy sensors integrated into daylighting design, task lighting, portable shop task lighting)
- Building automation system
- Building envelope and systems designed to reduce energy consumption
- Hydronic radiant floor heating in combination with variable air volume tempered ventilation system
- Non-mechanical (indirect/direct evaporative) cooling system with variable air volume
- High-efficiency condensing boiler plant
- Ventilation system complies with ASHRAE Standard 62.1.
- Ducted general exhaust with energy recovery on major exhaust air systems
- Occupancy sensor controlled HVAC terminals
- CO_2 sensors interconnected with ERVs at high-density occupied spaces
- Dedicated vehicle exhaust system at maintenance bays

Sustainability Features:

- LEED Gold rating (V 2.2) at fleet maintenance building and office/warehouse building
- Facility fully commissioned
- On-site pretreatment of storm water using a detention pond
- Low-flow and water-efficient plumbing fixtures used throughout the buildings
- Materials and finishes with recycled content

22.5.2 Project Development Process

22.5.2.1 Pre-Design (Project Planning) Phase

The project was necessitated by the right-of-way location of the regional light rail system. The need to relocate the city's vehicle maintenance and other operations resulted in the development of the Central Platte Campus. Construction completion and occupancy occurred in October of 2010. Denver was planning a citywide solar energy project on the heels of successful installations at the Denver International Airport, Colorado Convention Center, and Denver Museum of Nature and Science. The timing of the PPA coincided with the design and construction of the Central Platte Campus and supported the project's sustainability goals. The Central Platte solar installation is intended to reduce utility costs, reduce environmental impact, support LEED certification, and serve as a visible reminder of Denver's commitment to renewable energy due to the prominent location of the campus.

The project was financed through a PPA as part of a public–private partnership. A third-party solar developer designed, built, operates, and maintains the system, and the city purchases each kilowatt-hour generated by the system over 20 years. The project took advantage of an up-front rebate ($2.00 per watt, capped at $200,000), a per kilowatt-hour performance-based payment from the local utility to account for the renewable energy credits ($0.10/kWh constant price for solar renewable energy credits or SRECs set for 20-year period), and federal incentives, including the investment tax credit and accelerated depreciation schedule. In addition, because the project was located within a qualified distressed census tract, it qualified for new markets tax credits. These incentives were accepted by the solar developer and passed through to the city in the form of a price per kilowatt-hour below that of electricity off the grid.

The project was only cost-effective due to these incentives. Colorado's RPS was the one policy that helped the project the most, and it was also helped by the extension of the investment tax credit through 2016. The city worked closely with the utility, Xcel Energy, to secure incentives through the Solar*Rewards program, to allow those incentives to be provided directly to the developer, and on system interconnection. All systems in Colorado need to be interconnected and net metered to allow electricity produced to be fed to the grid if the system is producing more energy than the building is using, and to offset consumption at other times. The city hopes the 102-kW system will also serve to reduce peak demand charges over time.

In addition to the architects and engineers, the design team included a LEED consultant who also provided energy modeling and daylighting design, a civil engineer and landscape architect to design site-related elements for the LEED certification, a programming and equipment consultant to ensure the efficient organization of the facility, and a commissioning agent to verify the operation of the building systems.

The project delivery method was a design–build competition with a fixed budget. The process was intended to provide a best-value design solution. The competition was based on an RFP that included the city's design criteria. Three teams were shortlisted for the main competition phase, and selection was by a panel consisting of city officials and end users from each department that was to reside at the site. During the competition phase, progress meetings were held with the city and user groups to provide feedback on the design solution. The project team consisted of the architectural design team in conjunction with mechanical, electrical, plumbing, structural and civil engineers, and equipment and sustainability consultants. The team worked closely with the general contractor and mechanical, electrical, and plumbing contractors to maintain a fixed budget. During the competition, the design team was allowed approximately 3 months to complete the design and establish the construction cost. The structure of the delivery approach allowed for flexibility in design and provided an opportunity for a unique design solution.

22.5.2.2 Design Phase: Renewable Energy System

The project was originally designed to include three 100-kW photovoltaic solar energy arrays on three separate buildings. Three of the main buildings were designed to accommodate a roof-mounted PV array. The arrays were to be integrated into the sawtooth roof designs, with the solar array oriented to the south and the daylighting system oriented to the north. This configuration placed the PV array at the optimum solar orientation. However, during the course of the project, Xcel Energy revised their incentive program to limit installations to one PV system per contiguous site. Thus, two of the 100-kW arrays were dropped from the project.

The building envelope, mechanical systems, and lighting systems were optimized to perform significantly better than ASHRAE 90.1-2004. Energy design was modeled as required by the LEED rating system and, along with other LEED requirements, resulted in the fleet maintenance building and the office/warehouse building achieving a LEED Gold certification. A lesson learned during the design phase was that plan examiners will bump wind loads/snow loads for untested technology. Solar installations are held to a higher standard. This project was asked to meet higher than required wind loading.

Figures 22-27 and 22-28 provide comparative views of the impact of daylighting on the maintenance area looking away from the light monitors versus looking toward the light monitors. The lighting system includes automated controls. Figures 22-29 through 22-31 show the photovoltaic array and close-ups of the mounting structure.

Figure 22-27. Daylighting looking away from light monitors.

Figure 22-28. Daylighting looking toward light monitors.

Source: Main Street Power.

Figure 22-29. Central Platte Public Works Facility—solar PV array.

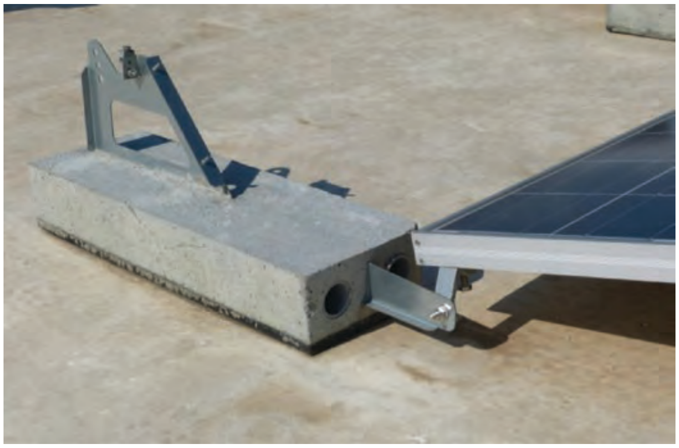


Figure 22-30. Ballast mounting—single-ply roofing installation.

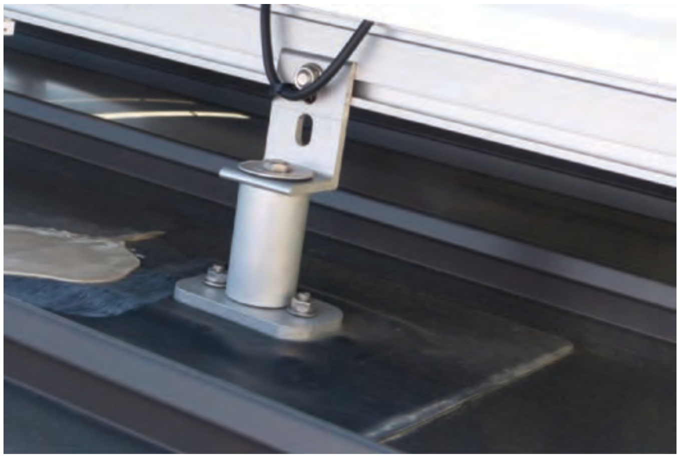


Figure 22-31. Penetrating mounting—standing seam metal roof installation.

22.5.3 Results

Project Team

Building Owner's Representative
City and County of Denver Public Works Division
Engineering Specialist—Major Projects Office
Public Works, Capital Projects Management

Architect
RNL Design

Consultants
Maintenance Design Group: equipment
Ambient Energy: LEED, energy and daylight modeling
MKK Consulting Engineers: mechanical, electrical, and plumbing engineering (MEP) engineering

Construction
Pinkard Construction, general contractor
Duro Electric, electrical contractor
AMI Mechanical, mechanical and plumbing contractor
Millander-White, PV system installer
Encore Energy Services, electrical subcontractor for PV

PV System
101.66-kW DC system installed at multiple tilt angles
442 module 230-watt panels, Canadian Solar CS6P230
39.6 kW installed at 10.5-degree tilt
62.1 kW, installed at 18.43-degree tilt
0.82 DC-to-AC derate factor
System became operational on March 7, 2011.

PPA Provider
Main Street Power

Commissioning Agent
Architectural Energy Corporation

22.5.3.1 Construction Phase—Renewable Energy System

Since this was a design–build project, the design team worked directly with the construction team for the entire project. However, the installation of the PV array, which was provided through the PPA between the city and Main Street Power, commenced after the building was substantially complete. Even though the installer coordinated roof connections with the design–build team, there were still issues with roofing warranty and roof connections. Additionally, after bidding, the roof underwent value engineering. This resulted in a change to the PV mounting system, which introduced some coordination issues. Some lessons learned during the design phase are:

- Roofer must do all the penetrations of roof membrane in order to maintain the warranty.
- Confirm required wind loads/snow loads for solar installations.
- Roof-mounted PV systems require thorough coordination between roofer, PV installer, and electrical contractors.
- PPA process: Developer buys equipment; general contractor installs; power purchase provider owns, operates, and maintains—thus, there is an issue of coordination between the developer and installer. It was recommended that the construction team be in charge of this coordination.

22.5.4 Results

The PV system includes panels deployed on the facility roof at two different angles: 10.5 degrees and 18.43 degrees. The production for each installation angle was modeled, and expected production as well as design electric consumption was predicted as indicated in the Table 22-3.

Table 22-3. Design specifications for PV system.

10.5-Degree Tilt		18.43-Degree Tilt	
Installed power (DC) kW	39.6	Installed power (DC) kW	62.1
DC-to-AC derate factor	0.82	DC-to-AC derate factor	0.82
Array type	Fixed tilt	Array type	Fixed tilt
Array tilt	10.5	Array tilt	18.43
Estimated generation kWh	55,850	Estimated generation kWh	92,151
Total Generation kWh:		148,001 kWh	
Total design electric consumption kWh:		213,322 kWh	
(Does not include 756 MMBtu of natural gas.)			

The system became operational in March of 2011. During the initial 10 months of operation, the PV system produced in excess of the pre-construction projections: 153,506 kWh annually. Overall, the results of the renewable energy installation are meeting the expectations of the owner. The system has been economically beneficial since it was commissioned. The price paid per kilowatt-hour of electricity from the PPA, $0.0293/kWh, is $0.039/kWh below the cost of electricity from the utility. This represents an annual savings of $5,986.00. If the price of electricity continues to escalate faster than the contract price of the solar-produced power, the system will continue to save the city additional money. It is estimated that the savings over the 20-year life of the PPA will be approximately $200,000 when utility rate increases are factored in.

The system is operated and maintained by the solar developer (power purchase provider), per the terms of the contract. The city's General Services Department and Sustainability Office monitor the system's costs and benefits, but all maintenance costs are borne by the power purchase provider. The system is monitored by a production meter (that tracks production and quantifies production of the system's renewable energy credits) and a monitoring software package. Performance can be viewed via a website that shows real-time generation of the system. This information is available to the owner and the public. Tracking the performance allows the developer to learn as soon as possible if the system is not producing up to its specified capacity. The system uses NREL's virtual weather station and monitors production of the array only. Performance can be viewed at http://www.alsoenergy.com/powertrack/lobbyview.aspx?sid=84. Figure 22-32 shows the system output from March 2011 through December 2012.

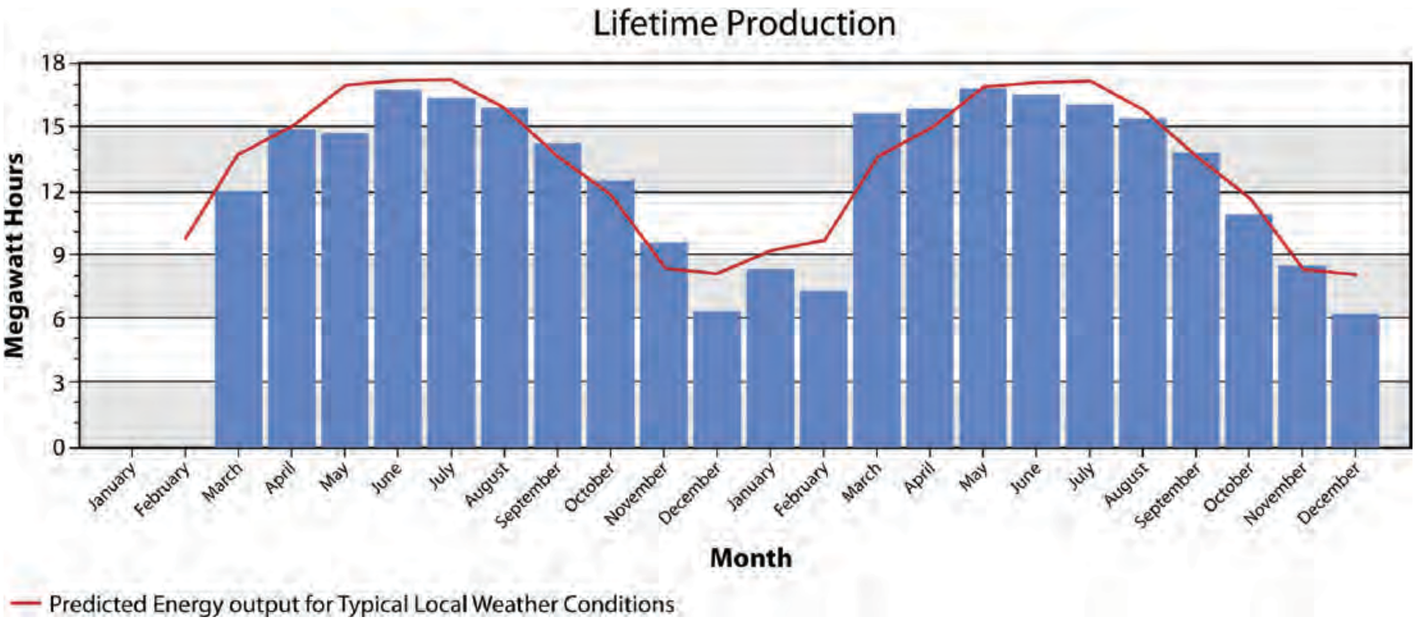


Figure 22-32. Solar energy production.

Table 22-4. Predicted building energy performance.

	Proposed Design		Baseline Design		Savings	
Energy Type	Energy Use (kBtu/year)	Cost	Energy Use	Cost	Energy Use	Cost
Electricity	728,068	$21,890	1,049,598	$32,558	30.6%	32.8%
Natural Gas	755,934	$6,829	1,166,693	$10,395	35.2%	34.3%
Total		$28,719		$42,953		33.1%
Total (Model Outputs)	1,483,895		2,216,290		33.0%	

Bills for service are monitored and reconciled monthly by the city's General Services Department. To date there have been no operational issues with the renewable energy system.

22.5.4.1 Building Energy Performance

As part of the certification process for LEED, the building energy performance was also modeled by the design team. Table 22-4 shows the modeled performance of the building to be 33% below the baseline design. The reduced building loads allow the energy produced by the PV system to be a larger percentage of the overall building demand.

22.5.5 Lessons Learned

- The PPA covers all system operations. This benefits an entity like the City of Denver that has no expertise in the operation and maintenance of a solar PV system.
- Additionally, the PPA is being paid based on system production, so they have an incentive to keep the system operating at peak performance.
- The PPA allows public entities to obtain some of the benefits and incentives available to the private sector.

22.6 Case Study: South Bend, IN, Public Transportation Organization Maintenance Facility

22.6.1 Overview

South Bend Public Transportation Organization (TRANSPO) is municipally owned by the City of South Bend, IN. It is the nucleus of transit services for the South Bend and Mishiwaka communities. All administration, operations, vehicle maintenance, and storage are housed under one roof in their newly constructed facility of 167,000 ft^2, which was completed in November of 2010. The facility is sized to house and maintain 76 vehicles and is constructed primarily of steel-framed and load-bearing steel stud construction with masonry and prefinished metal panel exterior finishes and polycarbonate glazing. The facility currently operates 20 hours per day (4:00 am–midnight) year round with 115 employees. Thirty-five of the employees are housed in the building, while 80 are drivers who are in the building at various times during their shifts. The project was partially funded by the federal government (20%), with the remaining (80%) being local funds. Additionally, two grants were obtained from the FTA and ARRA to help fund the facility.

The 20-acre site is a remediated brownfield and formerly housed the Studebaker automobile factory. The facility is the first development in the master plan for Ignition Park, which will be a future home for light industry in South Bend. The building is oriented along the east–west axis to maximize solar gain, create great daylighting opportunities within the building, and create south-facing traffic flow and access into the building. The architecture team pushed renewable energy and achieving a

LEED Platinum rating from the project's beginning. The client was interested in obtaining a LEED certification but when told a LEED Platinum rating was attainable, they embraced pursuing the highest LEED rating. The project incorporated efficient function and best practices to develop an energy-efficient and economical building that uses a variety of strategies to reduce energy consumption and meet sustainable building goals.

Renewable Energy: The project includes a 93.5-kW thin-film PV solar energy system installed on the south-facing portion of the bus storage roof. With an initial cost of $600,000, the system is estimated to generate 7% of the facility's electricity—about 97,259 kWh annually. This equates to a savings of $5,474 in electricity bills. A ground-source (geothermal) heat pump system incorporating 48 wells, each 300-ft deep, provides space conditioning for office areas, housing maintenance, administration, and operations. The ground-source heat pump is estimated to save 38,429 kWh, or $2,152. Extensive daylighting is provided throughout the facility. Artificial lighting systems are connected to motion and occupancy sensor systems. The fixtures are automatically shut down or dimmed depending on the presence of workers and the total amount of daylight detected in each zone. In addition, TRANSPO has purchased RECs equal to about 35% of the total electricity use of the facility.

Other Sustainable and Energy Efficiency Strategies: The project was designed to meet the 2030 Challenge, a nationally adopted initiative by the American Institute of Architects to reduce and eventually eliminate CO_2 emissions by buildings by the year 2030. All areas of the building are conditioned. However, the largest area, bus storage, is only heated to approximately 50°F during the heating season, or to a level to ensure that ice and snow buildup is melted off the vehicles while stored. The design of the building envelope and systems reduces energy cost by 39.8% and consumption by 54.1% as compared to ASHRAE Standard 90.1-2004 and has an EUI of 46.4 kBtu/ft^2/year. The maintenance garage is heated by a radiant heat system connected to both gas and electric boilers. The electric boiler is used during off-peak hours at a negotiated rate. Exhaust systems in bus storage and the maintenance garage are ducted. The facility is controlled by a Honeywell WEB-AX Building Automation System. All storm water is retained on-site and is filtered through bioswales, which use plants to naturally filter out all particulates and toxins that are typical from parking lot runoff. The storm water conveyance design re-establishes wetlands and native habitat.

Figures 22-33 and 22-34 show an elevation view of the facility and a view of the roof-integrated thin-film photovoltaic system, respectively.

Source: Merlin Maley, RNL Design.

Figure 22-33. TRANSPO maintenance facility.

Source: Merlin Maley, RNL Design.

Figure 22-34. TRANSPO roof-integrated thin-film photovoltaic system.

Site and Building Information: Location: South Bend, Indiana

- Address: 1401 South Lafayette Boulevard, South Bend, IN 46612
- ASHRAE climate zone: 5A
- Annual heating degree days (65°F base): 6,294 (South Bend Regional Airport)
- Average high temperature (summer): 72.9°F
- Average high temperature/low temperature (winter): 30.4°F/23.3°F
- Average Annual Precipitation: 39.7 in.
- Facility floor area: 167,000 ft^2
- Occupancy: 115
- Schedule: 20/6

Renewable Energy Features:

- Solar photovoltaic system, net metered (93.5 kW)
- Daylighting
- Ground-source (geothermal) heat pumps (48 wells, each 300-ft deep)

Other Energy Efficiency Features:

- Efficient lighting systems (T-5 and T-8 lamps, motion and occupancy sensors integrated into daylighting design, task lighting, portable shop task lighting)
- Building automation system (Honeywell WEB-AX)
- Building envelope and systems designed to reduce energy consumption by 54.1% compared to ASHRAE Standard 90.1-2004 (energy use intensity of 46.4 kBtu/ft^2/year)
- Gas/electric boilers allow off-peak electric use to heat radiant slab at maintenance.
- Ducted exhaust systems

Sustainability Features:

- LEED Platinum rating (first LEED Platinum-certified maintenance/admin/operations facility in the United States)
- Meets 2030 Challenge criteria (CO_2 reduction)
- Facility fully commissioned
- Building flush-out prior to occupancy
- On-site treatment and discharge of storm water using bioswales.

22.6.2 Project Development Process

22.6.2.1 Pre-Design (Project Planning) Phase

The project consolidates all administration, operations, maintenance, and storage for TRANSPO on one site and under one roof. The conceptual design for the project began in June of 2007, with construction completion and occupancy in November of 2010. TRANSPO was interested in a LEED-rated building. The architect pushed for the highest LEED rating attainable (Platinum) and assembled a team that found the project and site could meet the requirements for LEED Platinum. The requirements of the 2030 Challenge were also identified as possible for the project. In addition to the architects and engineers, the design team included a LEED consultant who also provided energy modeling and daylighting design, a civil engineer/landscape architect to design site-related elements for the LEED certification, a programming and equipment consultant to ensure the efficient organization of the facility, and a commissioning agent to verify the operation of the building systems.

TRANSPO recognized that transit service providers' duty is to spend money on improving and increasing transit service in their communities. Every dollar saved in operational expense for their facility can then be used to provide better services. To meet this objective required the proposed building to be extremely energy efficient and economical to operate. The design team identified various strategies to meet TRANSPO's need for low operating costs and meet the requirements of the LEED rating system and the 2030 Challenge.

Grant funds from ARRA, the FTA (FTA-Section 5307-Urbanized Areas and FTA-Section 5309-Capital Investment), and an FTA Transit Investment for Greenhouse Gas and Energy Reduction (TIGGER) grant were used for the building and the renewable energy system. Support from these programs was instrumental in achieving the facility that was eventually constructed. Fundraising for the building began in 2002.

The project delivery method was the traditional design–bid–build approach. Increased reporting and documentation was required due to the FTA and ARRA grant processes and LEED-certification process guidelines. The key lesson learned during the pre-design phase was that having a general contractor or construction manager hired as a team member early in the process would have been extremely valuable. This team member could have provided insight and knowledge in best construction practices and scheduling to help reduce the overall cost of the project.

22.6.2.2 Design Phase

The architectural design team was selected through a competitive request for qualifications process. Many of the design decisions were based on the stated pre-design objectives of having a sustainable, energy-efficient building with low operating and maintenance costs. Strategies that were incorporated include:

- The building envelope, mechanical systems, and lighting systems were optimized to perform significantly better than ASHRAE 90.1-2004. Energy design modeling indicated an energy use reduction of 54.1% from the standard and an EUI of 46.4 kBtu/ft^2/year. These design activities were essential to achieving the LEED Platinum rating and meeting the requirements of the 2030 Challenge.
- Incorporation of a grid-tied, thin-film, roof-mounted photovoltaic solar array reduces the building's annual utility cost by approximately 4.9%. The photovoltaic array was not included in the initial design due to budget restrictions, but was added to the project after obtaining the TIGGER grant.
- Areas of the facility that are both heated and cooled have ground-source heat pumps that more efficiently use electricity for space conditioning than other electric-based types of systems. The system includes 48 wells that are 300-ft deep, providing heating and cooling for the administration and operation portions of the facility.

- Coordination with the local utilities led to inclusion of both electric and gas-fired boilers to allow the system to take advantage of reduced off-peak electric rates while using lower cost (per Btu) gas to fire the boilers during the day.
- Radiant slab heating provides a flywheel effect to carry the off-peak purchased electrical heat into the on-peak portion of the day. The radiant slab heating system is in the vehicle maintenance portion of the facility.
- Exhaust systems are ducted.
- Building automation provides efficient operation of the systems. Honeywell WEB-AX equipment was installed.
- Use of dimmable, energy-efficient lighting, motion sensors, occupancy sensors, a building-integrated daylighting system, daylight sensors/controls, and task lighting reduce electrical consumption for lighting.
- Use of building commissioning at the completion of construction to verify systems are performing to design specification.

Project Team

Building Owner's Representative
TRANSPO Maintenance Manager

Architect of Record
Forum Architects

Design Architects
RNL Design

Consultants
Maintenance Design Group: programming
Ambient Energy: LEED, energy and daylight modeling
M/E Design Services: MEP engineering
Keller Engineering: structural engineering

Construction
General Contractor
Robert Henry Corporation

Commissioning Agent
Primera

22.6.2.3 Construction Phase

Project delivery was by the traditional design–bid–build process. The renewable energy system was bid as part of the general construction contract, and the selected bidder entered into an agreement with the PV installer. Daylighting, as part of the architecture of the building, was included under the general contract, with controls provided by the electrical contractor. Commissioning was done by a third party contracted by the owner and selected based on their experience and relatively close location to the project site. A major lesson learned from the construction process was that close coordination and scheduling between the subcontractors is needed to avoid sequencing issues. In some instances, completed work had to be removed and then redone. In addition, more attention to testing and balancing requirements of the HVAC system would have been helpful.

Figure 22-35 shows the photovoltaic system electrical connections. Figures 22-36 and 22-37 illustrate the ground-source heat pump system. Figure 22-38 highlights daylighting applications in the building.

22.6.3 Results

TRANSPO's new building is twice the size of their previous facility, and to date the utility costs are the same. The solar PV system is operational and has been producing power since

Source: Merlin Maley, RNL Design.

Figure 22-35. Close-up of roof-integrated thin-film photovoltaic system showing electrical connections.

commissioning. It is estimated to provide 7% of the electricity of the facility, or 97,259 kWh annually. This equates to a savings of $5,474 in electricity bills. The ground-source heat pump is estimated to save 38,429 kWh or $2,152 annually. Extensive daylighting is provided throughout the facility. In addition to lowered utility costs, the new facility is designed to increase operational and maintenance-related efficiencies. The design team concentrated on the organization and layout to create a safe and efficient vehicle circulation pattern and to meet or exceed TRANSPO's functional requirements. Improved indoor air quality has resulted in happier and healthier

Source: Merlin Maley, RNL Design.

Figure 22-36. Construction of ground-source (geothermal) heat pump wells.

Source: Merlin Maley, RNL Design.

Figure 22-37. Ground-source heat pump distribution header.

employees and reduced absenteeism. Occupants are very happy with the bright ambient daylight throughout the building.

22.6.4 Lessons Learned

TRANSPO is using measurement and verification (part of the LEED-certification process) as a tool to track energy performance. They are also using the facility to educate about sustainability and their mission. The two goals of education and performance are related. However, the ability

Source: Merlin Maley, RNL Design.

Figure 22-38. Daylighting of representative spaces—part of integrated lighting solution.

to tell the energy story in real-time was not identified as a goal until after construction had begun. Identifying this up-front would have allowed the relatively small investment in infrastructure required to provide real-time performance to be included in the budget.

22.7 Case Study: Caltrans Clean Renewable Energy Bonds Program, Sunrise Maintenance Facility Photovoltaic System

22.7.1 Overview

Caltrans has undertaken the installation of PV systems at 70 of its facilities throughout the state. This was made possible through the use of the U.S. Internal Revenue Service (IRS) CREBs program to help finance the projects. A major driver for Caltrans was to help meet energy objectives for state buildings that called for a 20% reduction in grid-purchased electricity by 2015.[99] Of the 70 facilities, 46 are designated as maintenance-related. The photovoltaic systems range in capacity from 3 kW to 165 kW (CEC-AC rating) and total about 2.4 MW (CEC-AC rating). The Sunrise Maintenance Station photovoltaic system located in Rancho Cordova in Sacramento County is a representative Caltrans CREBs PV project that was installed in 2010. The station, which was constructed in 2001, consists of four buildings totaling 24,000 ft^2 and supports road maintenance operations and electrical crews that repair signals and signs. The buildings are of metal construction and meet California energy code (Title 24) requirements. The maintenance bay areas of the maintenance and repair bay building are heated with gas-fired unit heaters or radiant heaters, while the office areas are both heated and cooled. The electrical loads are for lighting and HVAC, with some intermittent loads for the fuel island and air compressors. The station is occupied 10 hours per day and has a staff of 30 people, most of which are in the field during the day.

A 30-kW (CEC-AC rating/35.6 kW DC STC rating) PV system was installed on an existing 4,130-ft^2 material storage building roof canopy to serve the station. The PV system consists of 192 Canadian Solar brand panels (180 watts DC-rated output each) of crystalline silicon cells that are mounted at a slight tilt on the standing seam metal roof. The 2,638-ft^2 PV array is tied into the distribution network and has net metering. The performance is monitored by a separate meter that can be remotely accessed via the Internet. The system generated about 46,546 kWh of electricity during its first full year of operation (June 2010–May 2011) and saved an estimated $6,703 in utility bills. The system cost $193,402, or $6,447/kW (CEC-AC rating) or $5,590/kW (DC rating). This was partially offset by a $40,000 incentive from the Sacramento Municipal Utility District (SMUD), the utility provider. This incentive was given directly to the state to help accelerate the payments on the bond. The economics and savings equate to a 23-year payback period with incentives (27 years without), not including CREBs design and administrative costs. The system has worked well, although there was a problem with the inverters that reduced the output during the summer of 2011. Overall, there has been satisfaction with the system at Sunrise, as well as at the other sites, and Caltrans plans to continue to look for opportunities to incorporate PV systems into its facilities (e.g., as part of LEED for new construction).

Figures 22-39 and 22-40 show the photovoltaic system on the storage canopy.

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[99] Caltrans, 2011. *Clean Renewable Energy Bond Program 2011 Annual Report,* p. 2.

Source: Alan Torres, Caltrans.

Figure 22-39. A 30-kW photovoltaic system at Sunrise Maintenance Station installed on material storage canopy.

Source: Alan Torres, Caltrans.

Figure 22-40. Close-up of PV array.

Site and Building Information: Rancho Cordova, California

- Address: 11325 Sanders Drive, Rancho Cordova, CA 95742
- ASHRAE climate zone: 3B
- Annual heating degree days (65°F base): 2,229
- Average high temperature/low temperature (summer): 91°F/58.5°F
- Average high temperature/low temperature (winter): 59.5°F/43.4°F
- Average annual precipitation: 19.9 in.
- Building floor area: 4,000 ft^2
- Occupancy: 30 (typically 5 to 6 on-site during the day, the remainder in the field)
- Schedule: 10 h/day
- Renewable energy features: 30-kW (CEC-AC)/35.6-kW (DC) photovoltaic system

22.7.2 Project Development Process

22.7.2.1 Pre-Design (Project Planning) Phase

The CREBs program was established by the federal government under the Energy Policy Act of 2005. It was designed to help promote green power projects by state and local public entities by allowing them to issue *tax credit bonds.* These bonds bear no interest; however, they allow the bondholder to take credits against their federal taxes. The credits are based on rates that are set daily by the Treasury Department and are a function of the term of the bond. Public entities that issue the bonds benefit because they only have to pay the principal and not the interest portion of the bond note. The CREBs program is no longer taking applications.

In 2006, Caltrans applied for CREBs program support for 94 Caltrans photovoltaic projects. Ninety-three of these projects were approved, at an estimated cost of $45.6 million.[100] Subsequent to the CREBs award, the number of projects was reduced to 70, with a budget of $19.9 million, based on better information and screening of the initial sites. The projects were selected based on a general site screening that included considerations of building roof area, shading, condition, expected life (roof and building), electricity use, utility rates, utility incentives, and regulations. The performance of the photovoltaic systems (efficiency) and roof area and electricity requirements was used to size the systems. Based on this information and the cost of typical systems, the economics (benefit/cost) of the PV installations were determined. The initial calculations indicated that the systems could pay for themselves within the 15-year term of the CREBs.

To implement the Caltrans CREBs program, a project team was established from the Caltrans Division of Business Facilities and security and district staff. A design–bid–build approach was used with Caltrans headquarters staff responsible for the design requirements, performance specifications, generating the design, developing the procurement documents, and providing overall project management and oversight. Key members of the design team took a specialized course in PV to prepare for the work. The construction management and oversight at the individual project level were assigned to regional staff from a group within the construction division. The design team staff was responsible for the final inspections, including performance verification. It was decided that the systems for each site should be bid individually, rather than bundled into fewer larger procurements. This was done to encourage participation by more firms and to help generate more work for local economies. The Sunrise Maintenance Station photovoltaic project was developed using this process. Key factors in selecting the Sunrise facility were easy access to the clear roof, no major changes required to the structure or electrical connection requirements (e.g., new electric service panels), the availability of rebates from SMUD, and the relatively high price of electricity ($0.144/kWh).

A major lesson learned during the planning process was to make sure to work with the utility before undertaking PV projects. It is important to understand the implications of installing a photovoltaic system on the choice of electric service tariffs. The utility may require that customers with PV systems switch to a special PV or on-site generator type tariff. Such tariffs often include additional charges for such things as standby power, which are not in standard tariffs. In any case, a careful determination of what the utility costs will be under the existing tariff or special tariff should be made. The facility should work with the utility account representative to understand the tariff options and their cost impacts.

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[100] Caltrans, 2011. *Clean Renewable Energy Bond Program 2011 Annual Report,* p. 2.

22.7.2.2 Design Phase

The design was based on meeting the system capacity as defined during the planning phase. A performance specification was used as the basis for the competitive procurements. This required all bidders to meet the system capacity, based on the California Solar Initiative (CSI) requirements (CEC-AC module rating). The CSI is a state incentive program to spur the installation of solar technologies. The CEC-AC rating is intended to provide a more realistic assessment of the useful output of the PV panels than either the nameplate DC rating (STC rating) or the PTC rating. It is used under the CSI program as the basis for determining performance-based rebates. It is supposed to provide an estimate of the AC output of PV panels, accounting for losses in converting PV-generated DC power to AC. A key specification developed for this project was inverter performance requirements (voltage output) under extreme conditions (e.g., very hot days and cold, sunny days). This was done to ensure that the inverter would be able to continue to operate under a broad range of conditions. The specification also included requirements for performance monitoring of the system. Any special requirements pertaining to site conditions were identified when possible. The winners were selected on the basis of the lowest bid that could meet the requirements.

In order to expedite design reviews by the fire marshal, a streamlined process was established. Plans for three representative projects were reviewed, with changes made to comply with photovoltaic system guidelines developed by the fire marshal's office. Each of the 70 projects, including Sunrise, was still reviewed, but the review time was reduced from 4 to 6 weeks per project to as little as a day. In the case of Sunrise, the specification requiring that no more than 100 ft^2 of roof area be disturbed by the installation of the system was waived. This is because the roofing was metal and the structure and its contents did not pose a fire hazard. A major lesson learned was to plan for regulatory reviews early in the design process. Another lesson learned was that the CEC-AC rating was limited in its effectiveness. While the rating does take into account inverter losses, it does not include other factors such as dirt and wire losses. A better way would be to specify the DC nameplate data and use a site-specific performance adjustment (derate) factor to estimate the system output.

Project Team

Building Owner's Representative
CREBs Project Manager
California Department of Transportation

Design
Division of Engineering Services
California Department of Transportation

Chief, Office of Electrical and Mechanical Water and Wastewater
California Department of Transportation

CREBs Program Manager/Lead Engineer
California Department of Transportation

Senior Electrical Engineer
California Department of Transportation

Transportation Engineer
California Department of Transportation

Construction
General Contractor
Wenham Construction

Solar PV Panel Manufacturer

Canadian Solar
- Model CF5a-180M (180W DC)

Construction Oversight

California Department of Transportation
Division of Construction

Commissioning
California Department of Transportation
Division of Engineering Services

Source: Alan Torres, Caltrans.

Figure 22-41. Sunrise Maintenance Station—maintenance and repair bay building.

22.7.2.3 Construction Phase

The PV construction contract was awarded to the firm that could meet the specification for the lowest price. For Sunrise, the installation of the PV system was performed by Wenham Construction. There were no construction issues encountered, and the installation followed the design specifications. Figures 22-41 through 22-44 show the maintenance station and repair building, as well as the materials storage building before and after installation of the roof-mounted photovoltaic array.

22.7.3 Results

All the Caltrans systems are being monitored to determine the annual electricity generated and the avoided cost of utility-generated power. The photovoltaic system at Sunrise has a separate meter that records the electricity generated at 15-min. intervals, which can be remotely accessed via the Internet. The system generated 46,546 kWh of electricity during its first full year of

Source: Alan Torres, Caltrans.

Figure 22-42. Sunrise Maintenance Station materials storage building prior to photovoltaic system installation.

Source: Alan Torres, Caltrans.

Figure 22-43. Photovoltaic module mounting detail.

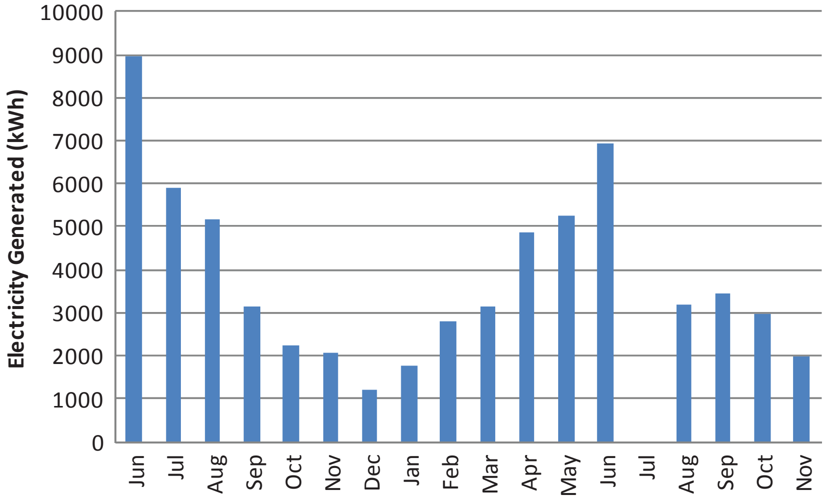
operation (June 2010–May 2011) and saved an estimated $6,703 in utility bills. The system cost $193,402, or $6,447/kW (CEC-AC rating) or $5,590/kW (DC rating). This was partially offset by a $40,000 incentive from SMUD, the utility provider. This incentive was given directly to the state to help accelerate the payments on the bond. The economics and savings equate to a 23-year payback period with incentives (27 years without), not including CREBs design and administrative costs. The system has worked well, although there was a problem with the inverters that reduced the output for several months during the summer of 2011. Overall, there has been satisfaction with the system at Sunrise as well as at the other sites, and Caltrans plans to continue to look for opportunities to incorporate PV systems into its facilities.

Photovoltaic System:

- PV system type: polycrystalline silicon, Canadian Solar module model CF5a-180M (180 W DC)
- PV system rated capacity: 30 kW (CEC-AC rating)/35.6 kW (DC)

Source: Alan Torres, Caltrans.

Figure 22-44. Electric interface for the photovoltaic system.



Source: Alan Torres, Caltrans.

Figure 22-45. Electricity generated by PV system: June 2010 through November 2011.

- PV system area: 2,638 ft^2 (192 modules @ 13.4 ft^2/module)
- System cost: $193,402 (without $40,000 SMUD incentive)
- Annual energy displaced: 46,546 kWh
- Annual energy operating cost savings: $6,703
- Economics: 23 years (payback period with incentives) and 27 years without incentives
- Applicability: All buildings that have adequate roof space, full exposure to sunlight, and no structural issues

The performance of the PV system is shown in Figure 22-45. Note that due to problems with the inverter, the there was reduced output in June and August 2011 and no output in July 2011.

22.7.4 Lessons Learned

Some general lessons learned across all the CREBs projects include:[101]

- Larger systems cost less than smaller systems, although the administration costs are the same. The construction costs for systems less than 50 kW are averaging $7 to $8 per watt (CEC-AC rating), while systems between 50 kW and 150 kW are averaging $5 to $6 per watt (CEC-AC rating).
- Project support costs for design, project management, oversight, monitoring, and reporting are about 25% of the capital cost.
- Buildings that are in environmentally sensitive areas or are historical add significantly more time and cost to photovoltaic system project development. The issues should be identified early in the process and mitigated.
- Roof-mounted photovoltaic panels should be tilted at least 10 degrees to enable dirt to wash off. Depending on the location, dirt can significantly reduce the system output.
- Specify slightly oversized inverters (about 5% larger) to ensure efficient, reliable operation under a broad range of conditions.

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[101] Caltrans, 2011. *Clean Renewable Energy Bond Program 2011 Annual Report,* adapted from Exhibit 4.

- The costs of performance monitoring, including labor costs associated with data review and evaluation, should be accounted for.
- Understand utility rules regarding interconnection and net metering and how they affect utility bills. For example, in net metering situations, PV-generated electricity in excess of the facility's annual requirements will generally not be compensated by the utility. Installing a PV system may result in a different tariff and rate structure, which could affect savings. When sizing systems, it is important to understand both current and projected usage (load growth or reduction).
- Ensure that design teams benefit from the learning curve when doing multiple systems. Communication and information transfer via the Internet can be very helpful.

22.7.5 Future Plans

- Caltrans planned to complete the remaining PV installations by the end of 2012.
- Caltrans plans to continue to look for opportunities to incorporate PV systems into its facilities. Several new buildings are being planned that will use PV systems as a way of meeting LEED requirements.
- There are no plans to expand the system at Sunrise at the present time.

22.8 Case Study: Milford, UT, Highway Maintenance Station Wind Turbine

22.8.1 Overview

The Milford Maintenance Station, located in Milford, UT, serves as a highway maintenance station for the Utah Department of Transportation (Utah DOT). The main building is a 3,434-ft^2, five-bay storage and office facility. The facility operates year round and has a varying number of employees depending on the season; as few as two employees can be present during the construction seasons. In April 2006, then-governor John Huntsman Jr. unveiled the "Utah Policy to Advance State Energy Efficiency." One plank of this policy was increasing renewable energy within the state government. Utah DOT explored locations to site a small wind turbine to become more familiar with the technology, and the Milford Maintenance Station was identified as a site with good wind resources, available land, low power use, and the permitting environment necessary to actually implement the project.

A U.S. DOE grant was applied for and awarded to cover 50% of the $13,500 installed cost of the 1.8-kW-rated turbine (see Figure 22-46). Utah DOT provided the remaining funding, which was partially offset by the involvement of the Milford maintenance personnel in the construction process. The project was designed in-house and installed in less than a month. The turbine has functioned as expected and without significant maintenance requirements. Not accounting for rate increases, the estimated savings is 3,000 kWh annually, and the turbine has a payback period of 16 years (based on the installed cost after the grant and offset labor). This process was an important first step for the Utah DOT to understand what exactly goes into wind projects and given its success has allowed the Utah DOT to begin exploring larger-scale wind projects. This project highlighted several important lessons learned, including that using on-site maintenance crews to perform the labor can be an effective way to minimize costs, using specialized contractors for portions of the process is vital, and involving key players throughout the process is important. The facility is scheduled to be replaced in the coming years, and the current wind system as well as solar photovoltaic systems and energy efficiency measures will hopefully be integrated into the design of the new facility.

Source: Tim Ularich, Utah DOT.

Figure 22-46. The 1.8-kW wind turbine at the Milford Maintenance Station.

Site and Building Information: Location: Milford, Utah

- ASHRAE climate zone: 5B
- Annual heating degree days (65°F base): 5,765
- Average high temperature/low temperature 77.0°F/15.1°F
- Average annual precipitation: 10.16 in.
- Maintenance station floor area: 3,434 ft^2
- Occupancy: two to five people
- Schedule: 6:00 a.m.–4:30 p.m.
- Electric energy requirements: 192 kWh/week
- Renewable energy feature: 1.8-kW wind turbine

22.8.2 Project Development Process

22.8.2.1 Pre-Design (Project Planning) Phase

The project was conceived to meet Utah's goal of increasing the use of renewable energy within government facilities and as an opportunity to become more familiar with the installation and utilization of wind turbines. The feasibility of the project was determined through an analysis of the Milford Municipal Airport's anemometer data as well as the station's energy consumption.

The airport is approximately 1.5 miles north of the station and has similar topography. It was concluded from data obtained via the local airport that wind levels were sufficiently high to support a turbine: an average of 10.7 mph. Given the levels of wind recorded, it was expected that a small turbine would produce roughly 25% to 35% of the station's electric energy use, or 3,000 kWh annually. Additionally, the site in Milford offered no major obstacles to permitting, and the city itself was viewed as being very amiable to wind towers. The local utility, Rocky Mountain Power, was not as familiar with renewable energy projects; however, they were open to education about the process. All of these reasons made this facility a good test bed for a wind energy project. In order to fund the project, a U.S. DOE grant was applied for and awarded to cover 50% of the costs of the project. The remaining funding was provided by Utah DOT, with the maintenance personnel at the location playing a central role in the actual construction process to offset a portion of the cost. This project was implemented as a design–build project, with in-house personnel selecting the turbine, and used a state-contracted renewable energy distributor, AEE Solar, to procure the parts. The planning team consisted of central maintenance staff, the local maintenance station supervisor, and senior management. The whole process—from design and parts order to construction and final inspection—took less than a month. An important lesson learned was that using maintenance crews to assist with the installation is a very cost-effective method to match project grants.

22.8.2.2 Design Phase

The design was led by Utah DOT and was closely coordinated with the local maintenance staff at the Milford Maintenance Station and Green Power Solutions, Inc., the electrical contractor. The local maintenance staff was tasked with the heavy labor activities, and the electrical contractor helped erect the turbine and wire the main disconnect and main service panel. The turbine selection process—type and capacity—was driven by the relatively small electrical load and a desire to simplify the installation. The turbine selected was the Skystream 3.7 manufactured by Southwest Windpower, Inc. This small turbine—installed rating of 1.8 kW at the rating condition of 20-mph wind speed—is designed for homes and small business applications. The unit's controls and inverter are housed inside the turbine, allowing for easier installation. There were no special local codes that applied to the project. The design team decided to use the 2008 NEC as the electrical standard and followed the manufacturer's recommendations with respect to turbine placement. The turbine was designed on a mono pole such that guy wires would not be an issue with respect to yard space and function. A lesson learned in the design phase was to get all the key players involved early to ensure that everyone knows the objectives and vision of the project.

Project Team

Building Owner's Representative
Deputy Maintenance Engineer
Utah DOT

Design
Deputy Maintenance Engineer
Utah DOT

Construction
Electrical Contractor
Green Power Solutions, Inc.

Wind Turbine Supplier
AEE Solar

Wind Turbine Manufacturer
Southwest Windpower, Inc.

Construction Oversight
Utah DOT

Commissioning
Utah DOT

22.8.2.3 Construction Phase

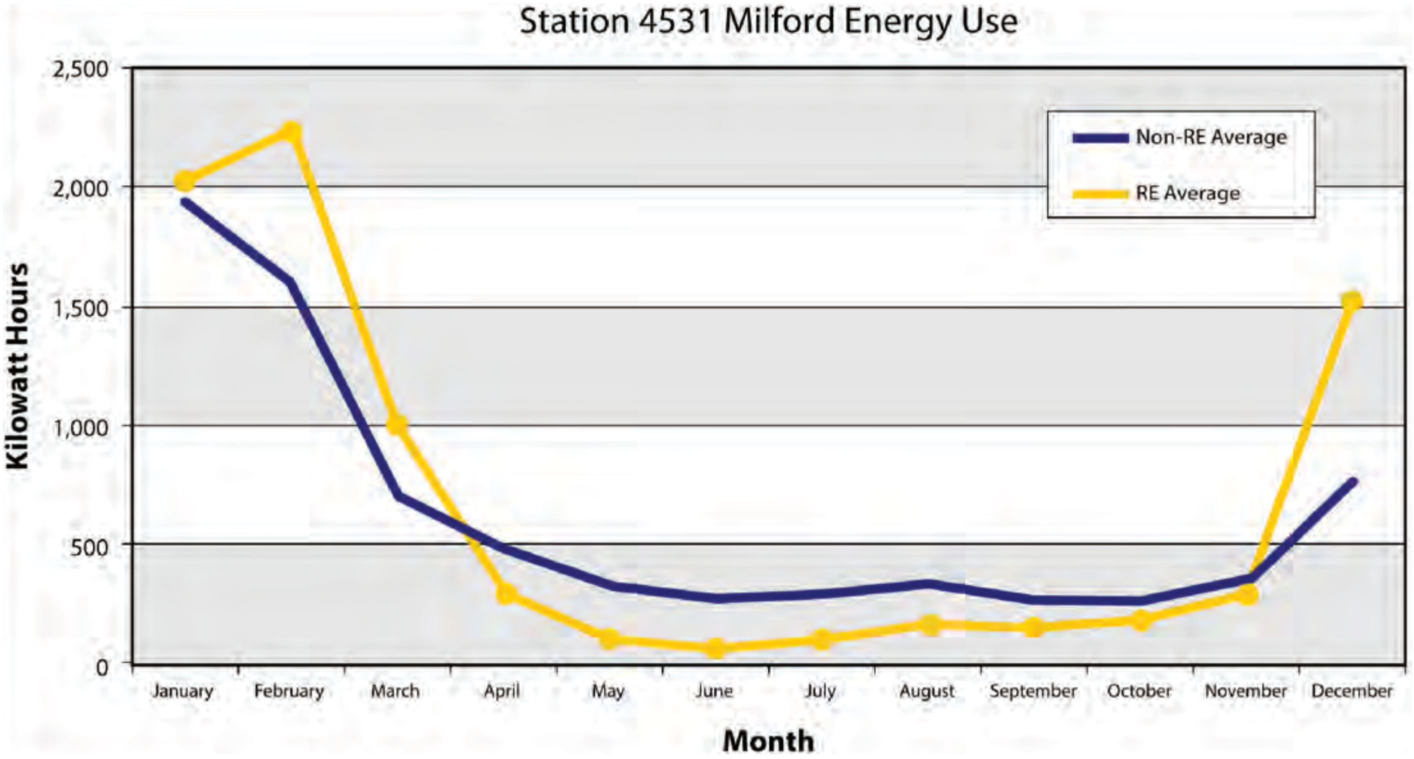
The construction phase of this project was very straightforward. The Utah DOT project lead designed the foundation and selected the turbine location after walking the site with the site foreman. The site foreman supervised the local maintenance staff as they performed the excavation, trenching, and concrete pouring, including the wiring and placement of the reinforcement cage for the turbine (see Figure 22-47). The electrical contractor was brought in to assemble the turbine and wire the system. The turbine was inspected by the local utility, which focused on the point of interconnect to the local distribution system. Both the primary designer and the electrical contractor had significant experience with renewable energy systems and reviewed the project extensively. A major lesson learned in this phase was that while in-house staff can accomplish significant portions of a project like this, the use of experienced contractors in key areas is critical.

22.8.3 Results

The wind turbine generator is monitored and accessed using net metering readings since the monitoring interface that was ordered with the turbine has been unable to consistently connect with it. Soon after the turbine was operational, the station installed multiple electrical block heaters on their plow trucks for use during the winter months. This ultimately increased the load at the facility. Had this new load been anticipated, a larger turbine might have been procured. The system has performed as expected, based on the review of the net metering readings and the monthly bills at the station, accounting for the impact of the block heaters (see Figure 22-48). It is saving an estimated

Source: Terry Wiseman, Utah DOT.

Figure 22-47. Construction of the wind turbine at the Milford Maintenance Station.



1800 Watt Skystream 3.7 Wind Turbine Installed: March 21, 2008
Note: Some plow trucks outside have been plugged in during winter months.
Source: Tim Ularich, Utah DOT.

Figure 22-48. Comparison of Milford Station 4531 electricity use with wind turbine generator installed.

3,000 kWh to 3,500 kWh of utility-purchased electricity annually, which equates to a utility bill savings of $240 to $280 annually. While the system is running as expected, it is only economical using the U.S. DOE grant. This grant cut the installed cost from $13,500 to $6,500, and resulted in a payback period of 16 years (based on the installed cost after the grant and offset labor). One of the drivers of the economics of this turbine is that Utah has relatively low power rates (about $0.08/kWh average commercial rate), making the electricity generated by the wind turbine generator less valuable than it would be at locations with higher electricity prices. The turbine has not required maintenance. There are upgrades available for the inverter, which would increase the turbine power output. There have also been improvements to the communications equipment that could enable on-site staff to better monitor the wind turbine performance. One lesson learned is that it is very important to properly study the wind resource and site the turbine appropriately. Given the significant installed cost, this pre-installation analysis is vital.

Wind generator system information:

- Wind turbine type: Skystream 3.7
- Tower height: 45 m
- Design rating: 1.8 kW @20 mph
- System cost: $13,500 ($6,500 after DOE grant)
- Annual energy savings: 3,000 to 3,500 kWh
- Percent of annual electricity met: 25% to 35%
- Electric power demand reduction: 1.8 kW
- Annual energy operating cost savings: $240 to $280
- Economics: 30+ years (payback period with no grant); 16 years (payback period with grant)
- Applicability: sites with suitable wind and land area

22.8.4 Lessons Learned

- Perform a site-specific study to determine the wind resource.
- Make sure to accurately forecast facility load requirements, accounting for load growth, to ensure the best match of wind turbine output to facility needs.
- Check local ordinances early in the process to assess viability.
- Keep the key players involved throughout the process.
- Start with a small project to understand what is truly involved with an evolving technology. This can be an important step to building toward larger-scale implementation.
- It is important to emphasize energy efficiency as part of the project.
- Try to include better energy monitoring to encourage the occupants to practice conservation.
- Try to find a way to incentivize employees to conserve energy and other resources.

22.8.5 Future Plans

The facility is scheduled to be replaced; the on-site wind resource will hopefully be integrated into the plan for the new facility.

22.9 Case Study: Ohio Department of Transportation, Northwood Outpost Garage Wind Turbine

22.9.1 Overview

The Ohio Department of Transportation (Ohio DOT) District 2 manager wanted to implement some form of alternative energy system to offset energy usage at an existing rest area site in the district. Wind, solar, and geothermal sources were considered. After investigation of the site and the available and applicable technologies, a 1.3-kW wind turbine was selected due to the above-average wind resource in northwest Ohio. Upon completion of research on the loads at the site, turbine capacity was increased to 30 kW in order for the turbine to make a significant load reduction. However, during the site review process, the U.S. Fish and Wildlife Service asked that the turbine not be installed at the rest area site due to the proximity to several bird migration paths. Ohio DOT District 2 agreed not to install the turbine at the originally selected site. After researching energy use and costs for several of the existing District 2 facilities, the Northwood Maintenance Facility was identified as having high use and high unit cost for electricity with adequate site area for the turbine. The decision was made to install the turbine at Northwood with unit installation beginning in early 2011.

The Ohio DOT Northwood Outpost includes a main building of approximately 31,150 ft^2 for housing vehicle maintenance, vehicle washing, and offices. Additionally, there are two equipment storage buildings totaling 8,200 ft^2, an open-faced equipment storage building of 6,320 ft^2, and 11,520 ft^2 of salt storage. All buildings are approximately 20 years old, except one of the equipment storage buildings, which is just over 10 years old. The facility is normally occupied during normal working hours (7:00 a.m.–4:00 p.m.) except during snow and ice conditions, when the facility operates up to 24 hours per day. There are approximately 15 on-site staff and an additional 15 staff who work out of the facility, operating 18 trucks, five mowers, and one loader performing roadway maintenance for 372 lane miles.

The facilities are not specifically designed to be of above-average energy efficiency, nor have any sustainable design strategies been incorporated. The repair area has ducted exhaust and typical HVAC controls. The intent of the project was to offset the electrical usage as much as possible, with the target being 65% on an annual basis.

Renewable Energy: The project consists of a tower-mounted 32-kW horizontal-axis wind turbine with a hub height of 85 ft. The system includes an inverter, switching, and a separate meter to tie to the local electrical grid operated by Toledo Edison (which is part of First Energy in Akron,

Source: Alex Weinandy, Ohio DOT.

Figure 22-49. Overview—Ohio DOT Northwood Outpost garage.

Ohio). The system is sized to meet 65% of the annual electric load of the building. In addition to reduced electrical costs, the system offsets utility-produced electrical energy consumption, generated primarily from coal, resulting in a positive environmental impact. No grant monies or incentives were used to install the approximately $200,000 wind turbine generator. All funding for the project came from state funds allocated to Ohio DOT District 2.

Figures 22-49 through 22-52 show photos of the wind turbine generator.

Source: Alex Weinandy, Ohio DOT.

Figure 22-50. View of turbine hub and blades—Ohio DOT Northwood Outpost garage.

Source: Alex Weinandy, Ohio DOT.

Figure 22-51. View toward I-280—Ohio DOT Northwood.

Source: Alex Weinandy, Ohio DOT.

Figure 22-52. View from I-280—Ohio DOT Northwood.

Site and Building Information: Location: Northwood, Ohio

- Address: 200 Lemoyne Road, Northwood, OH 43619
- ASHRAE climate zone: 5A
- Annual heating degree days (65°F base): 6,482 (Bowling Green waste water treatment plant)
- Wind power class 2—200–300 w/m^2
- Facility floor area: 57,182 ft^2
- Occupancy: 30
- Schedule: 9 h/day—5 days/week

Renewable Energy Features
- Wind turbine, net metered (32 kW)

Other Energy Efficiency Features
- Ducted exhaust systems

Sustainability Features
- None

22.9.2 Project Development Process

22.9.2.1 Pre-Design (Project Planning) Phase

The intent of the original project was to demonstrate a renewable energy source at a high-visibility rest area on State Route 2. After consideration of renewable energy resources at the site and alternative technologies, including solar PV, solar thermal, geothermal, and wind, a wind turbine was identified as the best solution. Analysis of electrical loads at the site revealed that the initially selected turbine capacity was inadequate, so a larger turbine was specified. However, during the site analysis, a wind turbine on the site was vetoed by the U.S. Fish and Wildlife Service due to its proximity to migratory bird flyways.

Committed to the wind turbine concept, Ohio DOT proceeded to identify an alternative location for the turbine. The Northwood Outpost Garage site, adjacent to Interstate 280, was identified and selected in lieu of the initial Route 2 site. The specified turbine capacity was intended to provide approximately 65% of the annual electrical load at the Northwood site. Coordination between the utility, Ohio Edison, and Ohio DOT resulted in the net-metered connection of the turbine.

Planning involved representatives of Ohio DOT District 2 and the Statewide Facilities Division of the Ohio Department of Transportation. The project delivery method was a design–bid–build process using a contractor selected from Ohio DOT's pre-approved contractor list. Pre-approved contractors bid to a performance specification prepared by Ohio DOT. The selected contractor subsequent to award engaged all design and subcontract work for the installation and was responsible for obtaining permit approvals. The performance specification indicated a 30-kW minimum capacity. The provided turbine is rated at 32 kW, illustrating the potential for a performance specification to result in an installation that exceeds the minimum established requirements while adhering to the project budget.

The key lesson learned during the pre-design phase was to identify and verify any environmental restrictions at the proposed site prior to selecting a particular technology. Additionally, once a technology has been selected, an energy audit to establish the base load will allow accurate sizing of the renewable energy system.

22.9.2.2 Design Phase

The project was bid as a performance spec to a pre-approved bidders list. The pre-design work determined the size of the turbine and location on the site. The site was able to allow the turbine and tower to meet the 100-ft fall-zone requirement should the tower fail. The successful bidder selected and paid for the design professionals (architect and engineer) to prepare documents for permitting and installation. Since this project was limited to the addition of a wind turbine system to an existing facility, the design only required location of the turbine on the site and documentation necessary to indicate compliance with the applicable codes. Compliance with the Ohio Building Code required indication of the structural adequacy of the tower and footings per the International Building Code and compliance of all electrical elements with the National Electrical Code. Due to the proximity of the installation to a regional airport, installation was coordinated with the FAA. However, compliance with FAA requirements did not affect the tower height or other design parameters. Local zoning approval was sought even though Ohio DOT, by virtue of being a state agency, is exempt from local zoning regulations.

Based on the wind resource, the wind turbine generator is predicted to yield a payback of 12 to 16 years. The predicted service life of the turbine is 20 years. The turbine has a 1-year warranty from the date of commissioning. The state of Ohio is in the process of putting a maintenance contract out to bid. Although installation was completed in the summer of 2011, the turbine was not able to be commissioned due to a defective part in the turbine.

Project Team

Building Owner's Representative
Ohio DOT Transport Administrator
Ohio DOT Program Manager
Ohio DOT Energy Specialist

Architect of Record
Shremshock Architects, Inc.

Consultants
Prater Engineering Associates

Construction
General Contractor
Zenith Systems, LLC

Wind Turbine Installer
LTI Power Systems

Wind Turbine
TecWind LLC, 32-kW, horizontal-axis, 3-blade machine, manufactured in China
Inverter: Aurora model number PVI-6000-OUT-US-W, supplied by TecWind

22.9.2.3 Construction Phase

As mentioned previously, project delivery was by the traditional design–bid–build process but limited to contractors on Ohio DOT's pre-approved contractor list. Since the project was for the renewable energy system only, coordination was limited. To minimize disruption of District 2 activities, there were periodic project schedule and delivery schedule meetings between the contractor and Ohio DOT.

Due to the change in location of the system, additional engineering was required as well as rescheduling of the installation. The installation was completed in April of 2011, followed by testing and commissioning of the turbine. There have been control issues with the tie-in to the power grid, resulting in the turbine shutting itself down. The turbine became non-operational due to a mechanical failure. The turbine was not operational as of the end of 2012.

22.9.3 Results

Ohio DOT is disappointed in the delays in getting the turbine into service. Based on experience thus far, implementation of a service contract for the unit is a high priority. The unit's performance will be monitored in-house by Ohio DOT. Since no on-site wind monitoring equipment was specified, system performance will be evaluated based on the net-meter output and locally available wind data (from the local weather station).

Ohio DOT is still in the developmental stages of its renewable energy applications. Researching the companies/contractors involved in the manufacture of equipment and construction of renewable energy projects is critical. On this project, the procurement process did not provide the desired or necessary level of quality control over the project. However, when the project is finally operational, Ohio DOT is anticipating the use of renewable energy will be viewed positively by the public.

22.9.4 Lessons Learned

- Buy American if possible, or at a minimum specify that repair parts be stocked and available locally. Ohio DOT has experienced long delays in receiving replacement parts from overseas.
- The lowest bid is not always the best bid.
- Research the bidder/contractor before it is hired. Specifically, investigate the number of previous successful installations and the relationship with the turbine manufacturer, and contact the references provided.
- Specify that the tower be painted the same color as the turbine housing.

22.10 Case Study: Elm Creek Park Maintenance Facility (MN), Geothermal Heat Pump System

22.10.1 Overview

The Elm Creek maintenance facility is located in Elm Creek Park Reserve in the Three Rivers Park District in Maple Grove, MN. The maintenance facility serves all of the service vehicles and equipment for the 4,900-acre park and serves as heated storage for three park police vehicles. The maintenance complex includes two other buildings: the old maintenance building and a cold storage building. The old maintenance building is currently used for storage for the park's snowplowing equipment and cold weather equipment. The cold storage building is an uninsulated, four-sided concrete structure with no heat or plumbing that stores snow grooming equipment, snow cats, and snowmobiles. Included in the main maintenance shop are offices for the administrative staff, maintenance supervisor, facilities supervisor, and crew chiefs (see Figure 22-53). Vehicle and service bays include two mechanic's bays, a vehicle storage bay, a wash bay, and three bays for park police vehicles. A geothermal well field supplies heat and cooling to the building. The offices are supplied with hot and cold air from two water-to-air heat pumps and a fan unit to distribute the conditioned air. The bays are supplied with heat from three water-to-water heat pumps and a hydronic radiant floor heating system. The system has been redesigned since it was first installed and has had a number of issues going back to the original system and the redesign. Lessons learned were that proper planning and meticulous installation can prevent many problems from occurring, which may prevent sub-optimal system performance. The Three Rivers Park District is currently underway on a new geothermal system for a visitor's center in the park, which has already benefited from the operations of the other geothermal systems.

22.10.2 Project Development Process

22.10.2.1 Pre-Design (Project Planning) Phase

The Three Rivers Park District's ethos in building park infrastructure is to be as environmentally conscious as possible while making accessible the great outdoors and related

Source: Elm Creek Administrative and Maintenance Center, Elm Creek Park Reserve, Three Rivers Park District.

Figure 22-53. Southwest elevation, Elm Creek maintenance facility.

activities. The highlighted project included two buildings, a ski chalet and a maintenance and storage garage. An RFP was sent to a group of eight pre-qualified contractors that Three Rivers Park District uses for projects. Short, Elliott, and Hendrickson, Inc. (SEH), a local design and engineering firm, won the design–bid–build contract. The project requirements included space requirements and office arrangements, and consideration was given to solutions that help the Three Rivers Park District reach district-wide sustainability targets by 2050. Although not in place at the time, Three Rivers currently prescribes energy use intensity profiles for new buildings, varying by type, which has led to new geothermal systems being designed and installed.

Site and Building Information: Location: Maple Grove, Minnesota

- Address: 12400 James Deane Parkway, Maple Grove, MN 55369
- ASHRAE climate zone: 6
- Annual heating degree days (65°F base): 7,876
- Annual cooling degree days: 699
- Winter (Oct.–March) high: 36°F/avg.: 28°F/low: 19°F
- Summer (April–Sept.) high: 74°F/avg.: 63°F/low: 53°F
- Average annual precipitation: 29.41 in.
- Facility floor area: 11,767 ft^2
- Schedule: 24/7

Renewable Energy Features
- Geothermal heat pumps

Other Energy Efficiency Features
- VFD drives on compressor motors and system pumps
- Building automation system
- Building envelope and systems designed to reduce energy consumption
- Hydronic radiant floor heating in combination with variable air volume tempered ventilation system

Sustainability Features
- Designed for low CO_2 emissions

22.10.2.2 Design Phase

During the design of the facility, SEH proposed a pond-loop geothermal system for the maintenance shop and a horizontal coil geothermal field for the chalet. This system would cost slightly more up front than the alternative gas boiler system but was projected to save money over the lifetime of the building. The Three Rivers Park District had enough latitude in the building budget that they opted to spend the money on the geothermal system instead of proceeding with a conventional build. Another benefit, especially in regard to the maintenance garage, was that the radiant slab would be heated in the winter, which would allow for a more comfortable working environment for the mechanics during the long heating season.

The geo-source system, in its preliminary design presented by SEH during design development, was expected to save an estimated $2,200 in annual operating costs (heating and cooling) compared to a conventional HVAC system with natural gas (assumed current energy costs, no inflation). The geothermal equipment was estimated at $60,000 to $70,000 initial cost, which included heat pumps, loop piping, pumps, glycol, and so forth. The contractor's schedule of values indicated a total mechanical (HVAC) cost of $200,000. This cost normally would include all the geo-source equipment as well as the ductwork, fans, controls, in-floor radiant piping, and so forth. It is impossible to delineate the true portion of cost of the geo-source equipment from this overall number.

Project Team

Building Owner's Representative
Senior Manager, Architecture
Three Rivers Park District

Architect
Short, Elliott, & Hendrickson, Inc.

General Contractor
Lund-Martin Construction, Inc.

Geothermal Installer—Pond
UMR Geothermal

Geothermal Installer—Ground Loop
Dedicated Geothermal, LLC

The design team was led by SEH project manager and a project representative. The project manager was instrumental in producing a design for the maintenance facility that used geothermal heat pumps to heat a radiant slab in the storage, maintenance, and wash bays of the facility. With interest from Three Rivers Park District in geothermal, a reasonable projected payback, and the stated goals of the park, a geothermal pond loop was selected.

The original ground side of the geothermal heating and cooling system was designed to be submerged in a 1.4-million-gallon, lined, manmade pond adjacent to the new maintenance building and near the ski chalet. The water-side loop was to feed three Econa water-to-water heat pump units and two water-to-air heat pumps. The water-to-air heat pumps produce hot and cold air for the offices and preheat a makeup air unit in the garage spaces. The makeup air unit also has a natural gas–fired heating element that comes on when the heating rate outpaces the capacity of the geothermal preheat coil.

This pond is used in the winter for snowmaking and is replenished when necessary from the municipal water supply. In the winter, the pond is kept at or near 34°F, which helps the efficiency of the snowmaking equipment. Theoretically, extracting heat from the bottom of the pond

Source: Elm Creek Administrative and Maintenance Center, Elm Creek Park Reserve, Three Rivers Park District.

Figure 22-54. Plate exchanger.

during winter would assist with thermal management of the water while simultaneously providing heat for the maintenance facility. The depth and volume of a pond are important factors in heat capacity. A pond with a large surface area will be colder in the winter and warmer in the summer than one of the same volume that is deeper. The snowmaking pond has a depth of about 12 ft. The original water-source heat exchanger design called for two sleds of plastic loops to collect warmth during the winter months and dissipate heat during the summer. The original designer of the system had departed the firm when the plans were finalized, however, and the two sleds were replaced with a single, 35-ton capacity, pre-manufactured stainless steel heat exchanger unit. The manufacturer of the unit, the manufacturer of the heat pumps, and the engineering firm calculated that this unit would provide the equivalent heating and cooling capacity of the plastic coil units.

Figures 22-54 through 22-59 show various aspects of the geothermal heat pump systems from construction through completion of the installation.

22.10.2.3 Construction Phase

The maintenance garage was constructed in 2006 and the spring of 2007 with a combination of concrete masonry unit blocks and poured concrete construction and incorporated hydronic

Source: Elm Creek Administrative and Maintenance Center, Elm Creek Park Reserve, Three Rivers Park District.

Figure 22-55. Pond with heat exchange piping.

Source: Elm Creek Administrative and Maintenance Center, Elm Creek Park Reserve, Three Rivers Park District.

Figure 22-56. Drilling rigs during installation of vertical well field.

radiant pipes in the poured concrete slabs of the vehicle bays. Five heat pumps were installed—three water-to-water units to heat the vehicle bays and two water-to-air units to heat and cool the air for the offices. Because of the relatively short cooling season, no cooling was designed for the garage bays.

The heat exchanger was installed in the pond. Because the 1.4-million-gallon pond is a lined, manmade pond wholly owned by the Three Rivers Parks District, no permit was necessary. However, had the pond been a natural lake or otherwise owned by the Minnesota Department of Natural Resources, a permit from the Department of Natural Resources and an environmental impact analysis would have been required.

Source: Elm Creek Administrative and Maintenance Center, Elm Creek Park Reserve, Three Rivers Park District.

Figure 22-57. Two water-to-air heat pumps supply the office spaces.

Source: Elm Creek Administrative and Maintenance Center, Elm Creek Park Reserve, Three Rivers Park District.

Figure 22-58. Three water-to-water heat pumps supply heat to the radiant heating system in the vehicle bays.

Source: Elm Creek Administrative and Maintenance Center, Elm Creek Park Reserve, Three Rivers Park District.

Figure 22-59. Installation of geothermal wells and piping.

The system initially appeared to be working quite well, but filters quickly filled up with a sludge that was supposedly caused by impurities or additives to the city water supply precipitating out of the ethylene glycol mixture. This sludge continued to accumulate in the filters, which had to be cleaned periodically, for a few months before the phenomenon stopped. The water temperature in the pond was highly elevated (estimated in the mid-80°F range by the end of the first summer of operation, which decreased the efficiency of the heat pump units). During the heating season, as the pond temperature dropped and was maintained for snowmaking purposes, the water-side heat exchanger began having issues with freezing the surrounding water, which greatly decreased the efficiency of heat transfer and led to the maintenance facility being under-heated. An engineer programmed the system to reverse the flow for 2 hours overnight, heating the pond and preventing the heat exchanger from freezing over.

The periodic nighttime cooling of the building to keep the heat exchanger free from pond ice was not a viable long-term option since it led to the building being under-heated and was relatively energy intensive. After two heating seasons, the decision was made in 2008 to abandon the pond loop and install a vertical well system instead. The new ground-side loop consisted of 36 175-ft vertical wells that housed high-density polyethylene (HDPE) pipe loops, which were then plumbed to the existing water-source heat pump units. This array of 175-ft wells was permitted by the Minnesota Department of Health, with a specific permit for use as a heat exchanger. The wells were filled with bentonite/silica sand grout, a common practice where ground wells are required to be sealed from the water table. When the ground loops were installed, a proper flushing was not performed by the installation contractor, which would have consisted of a high volume of fluid moving through the pipes to dislodge any debris that may have been knocked in during construction. As a result, a fair amount of debris from the well field that had fallen into pipes during construction remained in the system, and eventually made its way into the heat pump filters. Each time one of the filters became impacted enough to constrict flow, the corresponding heat pump had to be taken out of service to clean the filter. Shortly after commissioning, this happened frequently, but over time became an infrequent occurrence. In addition to the flushing problem, another side effect of changing from a pond to a ground-loop system was that a portion of the first system's ethylene glycol remained, which had an adverse effect on the new propylene glycol heat transfer fluid.

Despite these setbacks, the geothermal system did provide adequate heat to the building, and backup heating was not required. The system is currently running as it should and is satisfactorily heating the vehicle bays and heating and cooling the office spaces.

22.10.3 Results

The Elm Creek maintenance facility, despite the flaws in execution of the geothermal system, still touts energy consumption that is better than similar building types within Three Rivers Park District.

A direct comparison to the Hyland and Baker facilities—the other two operations and maintenance facilities owned and operated by Three Rivers Park District—is not possible because each case varies greatly in either layout's operating schedule. These have conventional non-geo-source heating and cooling systems. Elm Creek is the only one of the three maintenance centers that also houses a public safety function and a winter recreation (ski hill) maintenance function. Both of these functions at Elm Creek require 24-hour operations, with especially intense use during the winter season for the maintenance function.

Elm Creek Administrative and Maintenance Center Schedule
7 days per week

Maintenance: Snowmaking (Approximately 3 Months)
24 h continuous occupancy for 10 people day shift, three to five people on evening and overnight shift

Maintenance: Normal Operations
(approximately 9 months)
20 h/day—15 people day shift, three to five people on evening shift

Public Safety
(year round)
Three to four people day/evening shift
(approximately 3 months)
One person 24/7 (night shift)

Total Staff Operating out of Building
21 to 22 maintenance, four to six public, two to three other administrative (day shift only)

Hyland includes approximately 6,500 ft^2 of unheated storage with very low energy use intensity. Therefore, the average $kBtu/ft^2$/year at Hyland is significantly decreased compared to Elm Creek (total kBtu/year at Hyland = 1,010,265/15,000 ft^2 = 67 $kBtu/ft^2$/year). A true comparison cannot be made between the two buildings unless the energy used by the unheated storage space (ventilation and lighting) can be separated from the rest of the Hyland facility energy.

Baker is a more apt comparison in size than Hyland, but does not support 24/7 activities nor does it have as intense winter use. At Baker, all staff are present for day shifts plus single custodian evening shifts 8 months of year. For 4 months of the year, a couple of staff are added to the evening shift on weekends.

Baker has had a number of energy-saving retrofits, including a lighting retrofit for high-bay spaces completed in 2010. Elm Creek will receive the same retrofit by 2013. Baker has a programmable thermostat to control nighttime setback temperatures. Baker's energy use, while very comparable to Elm Creek's, is less efficient per occupant-hour:

- Elm Creek Administrative and Maintenance Center (2007): 11,767 ft^2; consumes 63 $kBtu/ft^2$/year.
- Hyland Maintenance Center (1998): 21,495 ft^2; consumes 47 $kBtu/ft^2$/year.
- Baker Administrative and Maintenance Center (2000): 12,754 ft^2; consumes 64 $kBtu/ft^2$/year.

22.10.4 Lessons Learned

As a result of some of the early failures and inconsistencies from this system, a number of lessons have been applied to the park district's policies toward future geothermal projects. Some of these are:

- Perform soil conductivity tests before considering geothermal heating and cooling.
- Use premixed, pre-diluted geothermal heat exchange fluid (glycol mix). Additives to the municipal water supply can act as contaminants in a sensitive system.

- To ensure that the entire system will work as planned, extreme caution must be used when changing a design for a geothermal heat exchanger. (There is speculation on the part of SEH that the original heat exchanger loops may have been a better solution than the plate heat exchanger.)
- Require VFDs on pumps.
- Extreme care needs to be taken in installation of well field loops to prevent contamination.
- Proper flushing of well field loops is critical for system performance.
- Strainers and expansion tanks are now a required part of system design.
- Water-to-air units had fewer problems than water-to-water units, but radiant floor heat is a more efficient and comfortable way of heating large open spaces.
- Thorough research on equipment manufacturers is encouraged to ensure the quality of installed equipment. Manufacturer and installation contractor support are both key elements in any unplanned circumstances.
- Install accessible valves for different heating zones. The police bays tend to be overheated and could have been cut off during shoulder months if zone valves had been installed with the in-floor radiant piping.

22.11 Case Study: Kilauea Military Camp, HI, Corrosion-Resistant Roof with Integrated Photovoltaic System

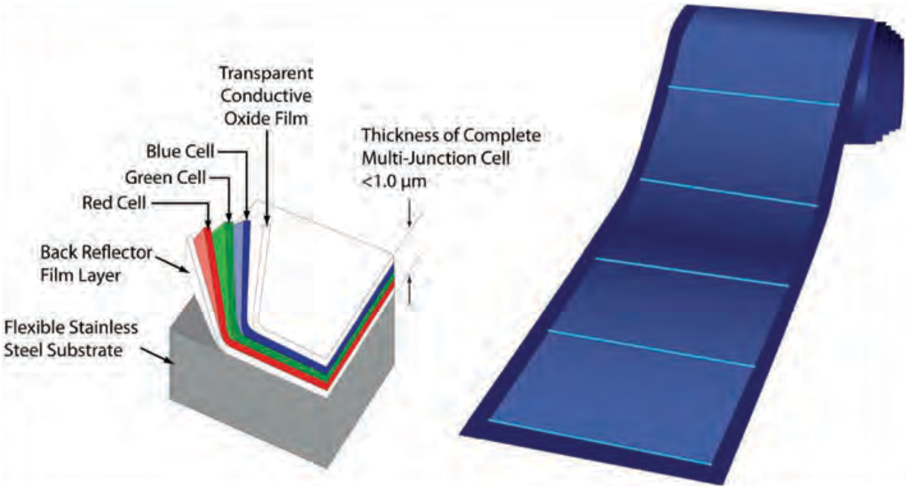
22.11.1 Overview

KMC is located within Volcanoes National Park, HI. Many of the buildings at KMC have metal roofs that have experienced significant corrosion. Building 84 was selected as a test bed to determine the impacts of a roof-integrated thin-film solar photovoltaic system on the roof corrosion resistance of today's metal roofing and high-performance coatings. In addition, the electrical performance of the PV roofing system would be assessed. Building 84, which was constructed in 1946, is a 5,500-ft^2 vehicle storage structure with some office and storage space on the east and west ends of the facility. The facility is not heated or cooled, except for the office area, though it does have electricity for general-purpose lighting and electrically operated equipment. The building is occupied 9 h/day, 5 days/week by five to 10 people. The roof-integrated photovoltaic system consists of 200 panels (eight strings of 20 panels and four strings of 10 panels) of thin-film amorphous silicon photovoltaic modules laminated to an aluminum-zinc coated standing seam metal roof (SSMR) with a polyvinylidene fluoride (PVDF) fluorocarbon anticorrosion coating. The photovoltaic system is rated at 15 kW, and the solar-generated electricity is converted from DC to AC power by use of an inverter. To evaluate corrosion resistance performance over time, several material coupons and a functional PV roofing panel were installed on a ground-mounted rack. The electrical performance of the system is being monitored, and the results indicate that the system is performing as designed. Over the first year of operation, 19,128 kWh were generated by the system, with a daily average of 52.4 kWh. The associated energy operating cost savings is $6,729 with local electricity rates at $0.3518/kWh. Thus far, the roofing system has not exhibited any signs of corrosion. The PV system cost was $195,674 (excluding all roofing costs). The cost and savings equate to a simple payback period of 29 years. The system construction was relatively straightforward, with attachment of some of the PV panels to the SSMR taking place on the ground, and attachment of others taking place after the roofing was installed. Overall, the system appears to be operating well, with little maintenance requirements. It appears to be a potentially good solution for a versatile roofing power-generation system. Lessons learned include the need to prioritize the permitting process to allow for connection to the power grid, which has potential to delay project completion, and the awareness that PV panels are susceptible to breaks, which can necessitate sealing them, at the cost of reducing efficiency.

Figures 22-60 and 22-61 show the roof-integrated photovoltaic system and the material layers used in the thin-film photovoltaic collectors, respectively.

Source: Materials and Structures Branch of the Construction Engineering Research Laboratory – Engineer Research and Development Center.

Figure 22-60. Close-up of roof-integrated thin-film photovoltaic system.



Source: Materials and Structures Branch of the Construction Engineering Research Laboratory – Engineer Research and Development Center.

Figure 22-61. Thin-film photovoltaic collectors by Uni-Solar.

Site and Building Information: Location: Volcanoes National Park, Hawaii

- Address: Kilauea Military Camp, Volcanoes National Park, HI 96718
- ASHRAE climate zone: 1A
- Annual heating degree days (65°F base): 10
- Average high temperature/low temperature (summer): 83.2°F/68.3°F
- Average high temperature/low temperature (winter): 71.9°F/63.8°F
- Average annual precipitation: 126.3 in.
- Building floor area: 5,500 ft^2
- Occupancy: 5 to 10
- Schedule: 9 h/day

Renewable Energy Features

- Roof-integrated thin-film photovoltaic system

22.11.2 Project Development Process

22.11.2.1 Pre-Design (Project Planning) Phase

The project was conceived by the Engineer Research and Development Center–Construction Engineering Research Laboratory (ERDC-CERL) as a means of demonstrating a potentially promising solution for meeting the power needs of military facilities located in marine environments. Metal roofs are widely used on a variety of military facilities, including vehicle storage and maintenance facilities. An ongoing problem in marine environments is the degradation of metal roofs due to corrosion. While there are many anticorrosion roof coating materials in use today, the impact of roof-integrated thin-film photovoltaic systems on metal roof corrosion had not been researched. Given the attractive properties of thin-film photovoltaic materials, particularly their relatively light weight and their ability to be mounted on metal substrates without requiring roof penetrations and attachment structures, the Army decided to perform corrosion and performance tests on a typical application. The KMC was identified as a good location for the test, given the climate and the need for alternative energy power sources, which are primarily driven by the very high electricity prices (in excess of $0.25/kWh). The project team consisted of ERDC-CERL, Mandaree Enterprise Corporation, and subcontractors. A fixed-price design–build approach was used. The photovoltaic system and metal reroofing project was bid competitively based on performance specifications, although there were no specific energy-monitoring equipment requirements. The sponsors of the project, which was performed under the Department of Defense Corrosion Prevention and Control Program, included the Office of Under Secretary of Defense, Office of Corrosion Policy and Oversight; Deputy Assistant Secretary of the Army Acquisition Policy and Logistics; Assistant Chief of Staff for Installation Management and Headquarters; and U.S. Army Installation Management Command.

22.11.2.2 Design Phase

The design was created by Mandaree Enterprise Corporation and their subcontractors. A major area of focus was how to integrate the panels into the roof design without sacrificing the corrosion resistance of the structure. The first step was to commission an engineering study of the new roofing system. It was determined that the design wind load was a 3-second, 105-mph gust at a 50-year mean recurrence interval. The existing roof framing system was inadequate to support this load so it was replaced.

A PV system configuration was specified to optimally fit the building. In order to accommodate the larger area of the shed roof section, the design team chose a larger PV cell bank configuration, made up of four strings of 10 panels. These panels were the Uni-Solar PVL-144 solar cells, which have a total output rating of 7.2 kW. These cells were too long to fit on the gabled roof section, so a bank configuration of eight strings of 20 Uni-Solar PVL-68 solar cells was used. These cells have a total output rating of 10.9 kW. The system was designed to be connected through the grid by an inverter, capable of supplying power to the building or back to the grid. Additionally, a wireless monitoring capability was integrated into the design to track the power characteristics of the system.

22.11.2.3 Construction Phase

The existing roof on Building 84 at KMC was replaced with an aluminum-zinc–coated SSMR with a Durapon 70 PVDF fluorocarbon coating on the external-facing surface. For the gable roof section, the solar panels were assembled on the ground and then installed on the roofing panels and finally wired to an inverter and connected to the grid. For the shed roof section, the solar panels were adhered after the roof panels were installed. When the power produced exceeds the building's needs, the excess is sent to the grid for use by other buildings

Source: Materials and Structures Branch of the Construction Engineering Research Laboratory – Engineer Research and Development Center.

Figure 22-62. Building 84 prior to installation of the roof-integrated thin-film photovoltaic system.

at KMC. There is no means for energy storage within the system. Due to permitting and technical issues, the activation of the inverter was delayed until December 2010, and monitoring did not begin until January 2011.

The corrosion performance of the roof is evaluated by periodic visual examination of the completed roof, by examination of exposure coupons mounted on-site, and by laboratory testing of coupons of the roofing material. Performance monitoring of the PV system was accomplished through the use of a remote module manufactured by Fat Spaniel, Inc. In addition, sensors are mounted on a functional PV roofing panel installed on an exposure rack on-site at KMC. These sensors allow the recording of corrosion conditions between the thin-film PV cells and the roof surface.

Figures 22-62 through 22-66 illustrate the construction of the roof-integrated photovoltaic system.

Source: Materials and Structures Branch of the Construction Engineering Research Laboratory–Engineer Research and Development Center.

Figure 22-63. Building 84 roof construction.

Source: Materials and Structures Branch of the Construction Engineering Research Laboratory–Engineer Research and Development Center.

Figure 22-64. Individual SSMR panels with photovoltaic panel attached prior to mounting.

Source: Materials and Structures Branch of the Construction Engineering Research Laboratory – Engineer Research and Development Center.

Figure 22-65. Installation of the SSMR panels on roof.

Source: Materials and Structures Branch of the Construction Engineering Research Laboratory – Engineer Research and Development Center.

Figure 22-66. Inverter and associated hardware.

Project Team

Building Owner's Representative
Kilauea Military Camp
Maintenance Mechanic Supervisor
DPW-KMC Engineering/Maintenance Shop

Design
Construction Engineering Research Laboratory
U.S. Army Engineer Research and Development Center
Mandaree Enterprise Corporation
Penta Engineering Group, Inc.

Construction
General Contractor
Ultimate Roofing

PV System Supplier/Installer
Hawaii Solar Roofing, LLC

PV System Manufacturer
Uni-Solar

22.11.3 Results

Remote monitoring was used to monitor electrical generation performance. From this monitoring, it has been observed that the system is performing as expected. It has been producing on average 52.4 kWh daily for the first 2 months of operation. This will put it roughly in line with the expected annual output of 19,128 kWh. Additionally, the PV material has proven to be an effective barrier to moisture intrusion and corrosion initiation. While some additional maintenance is required to ensure that the cells remain sealed, the system has shown promising early results.

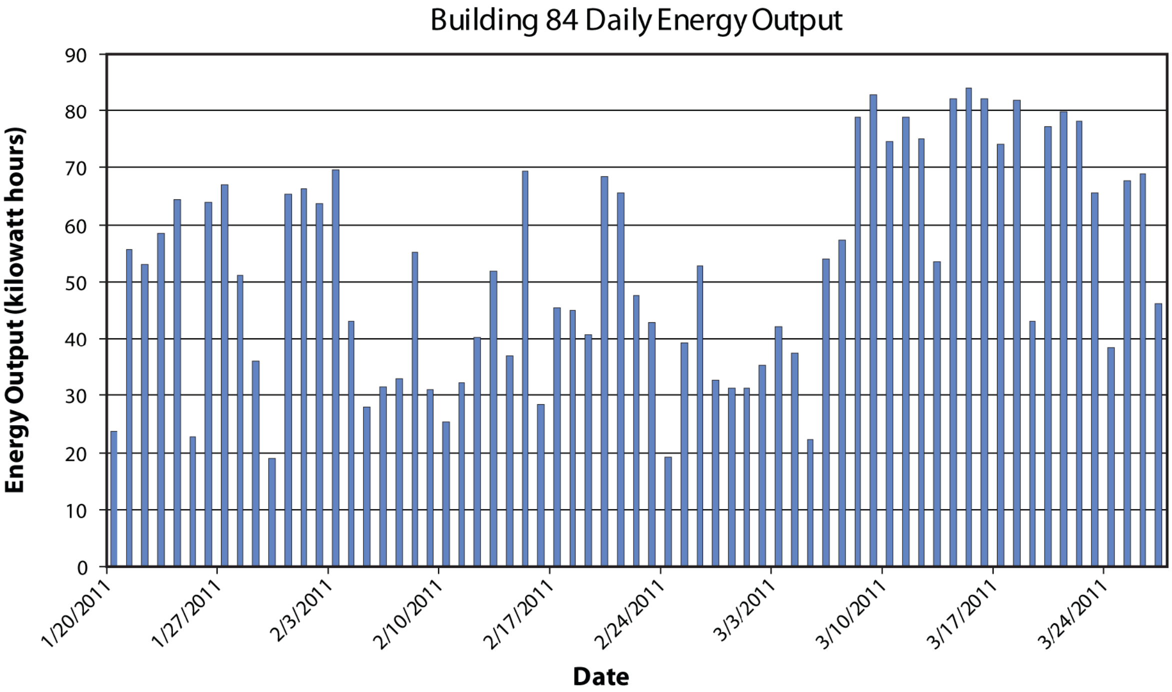
Photovoltaic System

- PV system type: thin-film amorphous silicon
- PV system rated capacity: 15 kW
- PV system area: 2,860 ft^2
- System cost: $195,674
- Annual energy saved: 19,128 kWh
- Annual energy operating cost savings: $6,729 (elec. @ $0.3518/kWh)
- Economics: 29 years (payback period)
- Applicability: buildings that have metal roofs

The daily electricity output of the photovoltaic system from January 20, 2011, to March 24, 2011, is shown in Figure 22-67.

22.11.4 Lessons Learned

- The permitting process is a critical-path item, and more likely to be a cause of delay than technical or construction issues. This is especially true in situations (like this one) where there are multiple parties responsible for taking necessary actions or providing necessary information, some of whom have no vested interest in the project.
- If breaks occur in the material's surface, the cells are extremely vulnerable to intra-cell corrosion. This vulnerability within the cells dictates that any breaks should be sealed at once, even if this sealing occurs at a cost of reduced operational efficiency of that particular cell.



Source: Materials and Structures Branch of the Construction Engineering Research Laboratory–Engineer Research and Development Center.

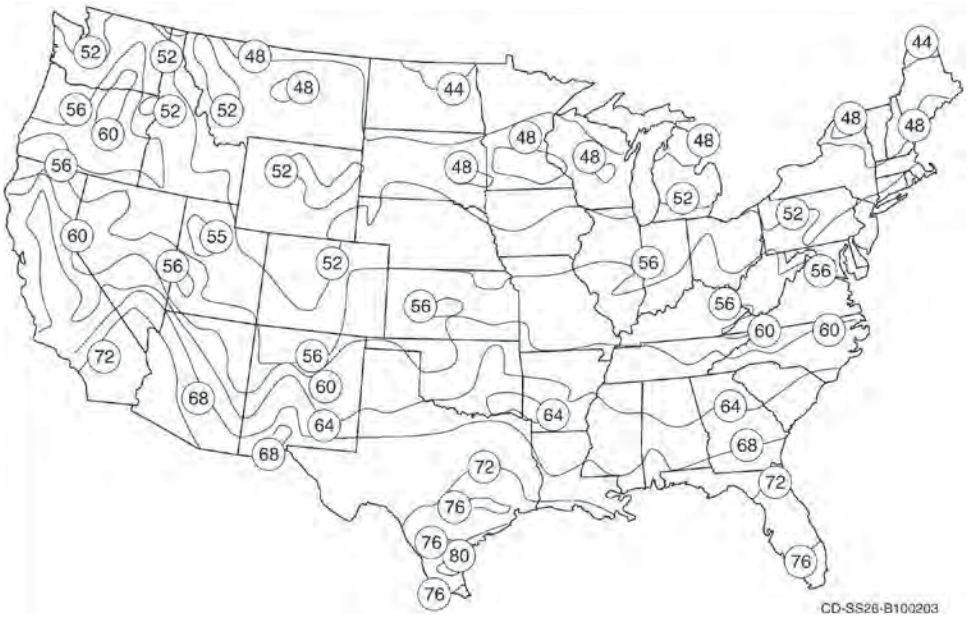
Figure 22-67. System electricity output.

APPENDIX A

Hot Water Load Estimation

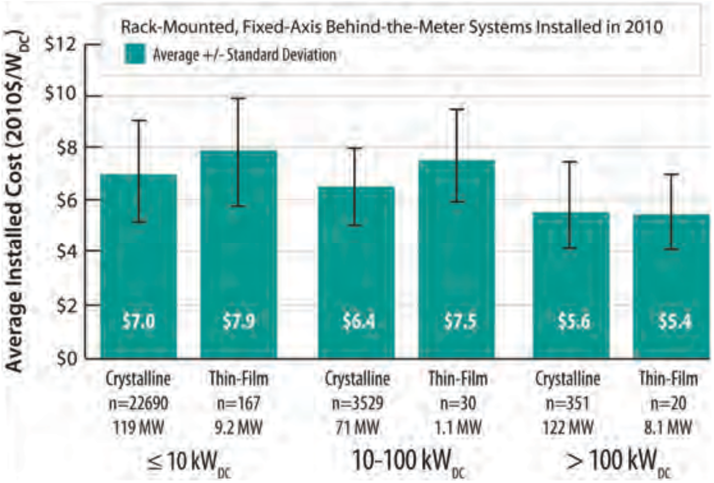
Hot water heating loads can be determined from knowledge of the quantity of hot water required, the delivery temperature of the hot water, and the temperature of the cold water input, as follows:

- Annual hot water (Btu) = annual gallons × 1.0 Btu/lb-°F × 8.33 lbs/gal × (T_{out}–T_{in}), where T_{out} and T_{in} are the delivery and input temperatures in degrees Fahrenheit, and annual gallons is the amount of hot water used annually in gallons. The cold water input temperatures can be approximated from maps of groundwater (see Figure A-1)



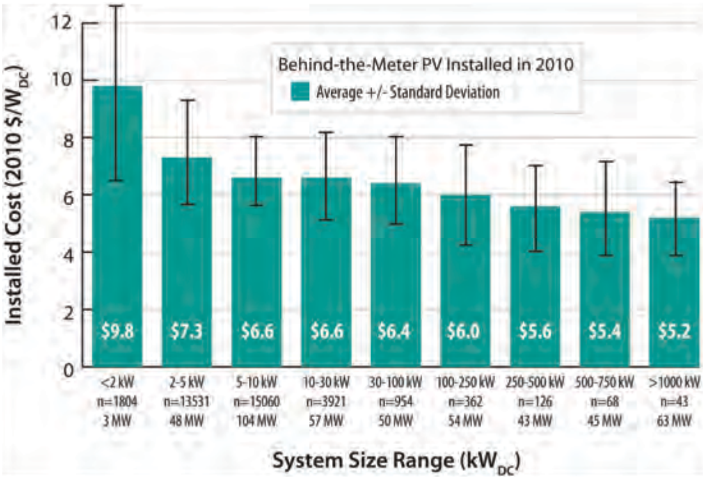
Source: DOE FEMP: Federal Technology Alert: Solar Water Heating.

Figure A-1. Groundwater temperature in degrees Fahrenheit in wells ranging from 50 ft to 150 ft in depth.



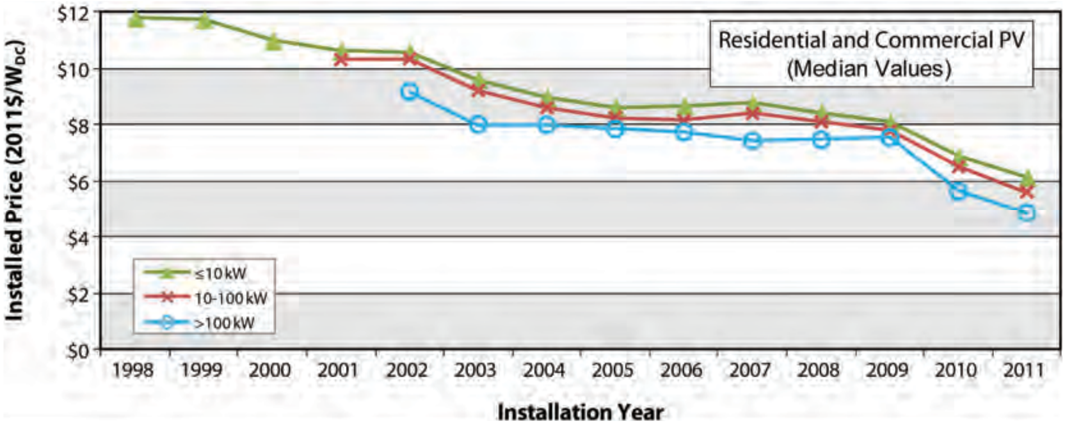
Source: *2010 Solar Technologies Market Report*, 2011, p. 67, http://www.nrel.gov/docs/fy12osti/51847.pdf.

Figure A-2. Photovoltaic system cost data by module type.



Source: *2010 Solar Technologies Market Report*, 2011, p. 66, http://www.nrel.gov/docs/fy12osti/51847.pdf.

Figure A-3. Photovoltaic system cost data.



Source: Barbose, Darghouth, and Wiser, 2012.

Figure A-4. Photovoltaic system cost trend.

Table A-1. Biomass—wood chip/pellet cost data (backup).

Parameter	Wood Chips	Bulk Wood Pellets	Propane
Fuel cost	$50/ton	$200/ton	$2.50/gal
Fuel heat content	12.2 MMBtu/ton	16.4 MMBtu/ton	92,000 Btu/gal
Fuel consumed	49 tons	37 tons	7,000 gal
Annual fuel cost (513 MMBtu)	$2,800	$7,400	$17,500
System O&M cost	$1,500	$1,500	$500
First year cost savings	$13,900	$9,400	n/a
Simple system payback	8 years	11 years	n/a
Total cost savings over 15 years vs. propane[1]	$168,000	$82,400	n/a

[1] Inflation rate trend for propane is 5.25% and for wood fuel is 3.25%; existing propane boiler is assumed to be 80% efficient, and wood boiler is 85% efficient.

Source: Containerized Wood Boiler Case Study, http://www.actbioenergy.com/brochure/Containerized%20Wood%20Boiler%20Case%20Study.pdf.

Glossary[102]

Absorber: the component of a solar thermal collector that absorbs solar radiation and converts it to heat, or, as in a solar photovoltaic device, the material that readily absorbs photons to generate charge carriers (free electrons or holes).

Active Solar Heater: a solar water or space heating system that use pumps or fans to circulate the fluid (water or heat transfer fluid like diluted antifreeze) from the solar collectors to a storage tank subsystem.

Air Collector: in solar heating systems, a type of solar collector in which air is heated in the collector.

Albedo: the ratio of light on a surface to light reflected from it. For sunlight this is the same as solar reflectance. Light-colored surfaces have relatively high albedos and are effective in applications such as *cool roofs.*

Alternating Current: a type of electrical current, the direction of which is reversed at regular intervals or cycles; in the United States the standard is 120 reversals or 60 cycles per second; typically abbreviated as AC.

Angle of Incidence: in reference to solar energy systems, the angle at which direct sunlight strikes a surface; the angle between the direction of the sun and the perpendicular to the surface. Sunlight with an incident angle of 90 degrees tends to be absorbed, while lower angles tend to be reflected.

Angle of Inclination: in reference to solar energy systems, the angle that a solar collector is positioned above horizontal.

Antifreeze Solution: a fluid, such as methanol, ethylene glycol, or propylene glycol, added to engine coolant or used in solar heating systems as a heat transfer fluid, to protect the system from freezing.

Antireflection Coating: a thin coating of a material applied to a photovoltaic cell surface that reduces the light reflection and increases light transmission.

Aperture: an opening; in solar collectors, the area through which solar radiation is admitted and directed to the absorber.

Array (Solar): any number of solar photovoltaic modules or solar thermal collectors or reflectors connected together to provide electrical or thermal energy.

Average Wind Speed (or Velocity): the mean wind speed over a specified period of time.

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[102] The DOE/EERE energy terms glossary (http://www1.eere.energy.gov/site_administration/glossary.html) was a major source; other definitions supplied by the authors.

Azimuth (Solar): the angle between true south and the point on the horizon directly below the sun.

Balance-of-System: in a renewable energy system, refers to all components other than the mechanism used to harvest the resource (such as solar collectors, photovoltaic panels, or a wind turbine).

Batch Heater: this simple passive solar hot water system consists of one or more storage tanks placed in an insulated box that has a glazed side facing the sun. A batch heater is mounted on the ground or on the roof. Some batch heaters use selective surfaces on the tank(s). These surfaces absorb sun well but inhibit radiative loss. Also known as *bread box systems* or *integral collector storage systems.*

Battery: an electric energy storage device composed of one or more electrolyte cells.

Biogas: a combustible gas created by anaerobic decomposition of organic material, composed primarily of methane, carbon dioxide, and hydrogen sulfide.

Biomass: as defined by the Energy Security Act (PL 96-294) of 1980, "any organic matter which is available on a renewable basis, including agricultural crops and agricultural wastes and residues, wood and wood wastes and residues, animal wastes, municipal wastes, and aquatic plants."

Biomass Energy: energy produced by the conversion of biomass directly to heat or to a liquid or gas that can be converted to energy.

Biomass Fuel: biomass converted directly to energy or converted to liquid or gaseous fuels such as ethanol, methanol, methane, and hydrogen.

Biomass Gasification: the conversion of biomass into a gas, by biogasification or thermal gasification, in which hydrogen is produced from high-temperature gasifying and low-temperature pyrolysis of biomass.

Building Envelope: the structural elements (walls, roof, floor, foundation) of a building that encloses conditioned space; the building shell.

Capacity Factor: the ratio of the actual annual electricity produced by a power generator to the annual electricity that could have been generated assuming the generator was operating at its nameplate or design output rating for all hours of the year. Capacity factors of solar electric power and wind power systems tend to be lower (0.2 to 0.3) than conventionally fueled generators due to the variability of the renewable resource. Renewable electricity systems can use energy storage to increase their capacity factors.

Central Receiver Solar Power Plants: also known as *power towers,* these use fields of two-axis tracking mirrors known as heliostats. Each heliostat is individually positioned by a computer control system to reflect the sun's rays to a tower-mounted thermal receiver. The effect of many heliostats reflecting to a common point creates the combined energy of thousands of suns, which produces high-temperature thermal energy. In the receiver, molten nitrate salts absorb the heat energy. The hot salt is then used to boil water to steam, which is sent to a conventional steam turbine generator to produce electricity.

Charge Controller: an electronic device that regulates the electrical charge stored in batteries so that unsafe overcharge conditions for the batteries are avoided.

Clerestory: a window located high in a wall near the eaves that allows daylight into a building interior; may be used for ventilation and solar heat gain.

Closed-Loop Geothermal Heat Pump Systems: closed-loop (also known as *indirect*) systems circulate a solution of water and antifreeze through a series of sealed loops of piping. Once the heat has been transferred into or out of the solution, the solution is recirculated. The loops can be installed in the ground horizontally or vertically, or they can be placed in a body of water such as a pond. See *horizontal ground loop, vertical ground loop, Slinky ground loop,* and *surface water loop* for more information on the different types of closed-loop geothermal heat pump systems.

Combined Heat and Power: an electric power generation system that also provides heating through the capture of waste heat from the power generation process.

Cooling Degree Day: a value used to estimate interior air cooling requirements (load) calculated as the number of degrees per day (over a specified period) that the daily average temperature is above 65°F (or some other, specified base temperature). The daily average temperature is the mean of the maximum and minimum temperatures recorded for a specific location for a 24-hour period.

Current Dollars: the value or purchasing power of a dollar that has not been reduced to a common basis of constant purchasing power but instead reflects anticipated future inflation; when used in computations, the assumed inflation rate must be stated.

Darrieus (Wind) Machine: a type of vertical-axis wind machine that has long, thin blades in the shape of loops connected to the top and bottom of the axle; often called an *eggbeater windmill.*

Degree Day: a unit for measuring the extent that the outdoor daily average temperature (the mean of the maximum and minimum daily dry-bulb temperatures) falls below (in the case of heating, see *heating degree day*) or falls above (in the case of cooling, see *cooling degree day*) an assumed base temperature, normally taken as 65°F unless otherwise stated. One degree day is counted for each degree below (for heating) or above (for cooling) the base for each calendar day on which the temperature goes below or above the base.

Diffuse Solar Radiation: sunlight scattered by atmospheric particles and gases so that it arrives at the earth's surface from all directions and cannot be focused.

Direct-Beam Radiation: solar radiation that arrives in a straight line from the sun.

Direct Gain: the process by which sunlight directly enters a building through the windows and is absorbed and stored in massive floors or walls.

Direct Solar Water Heater: these systems use water as the fluid that is circulated through the collector to the storage tank. Also known as *open-loop* systems.

Discounting: a method of financial and economic analysis used to determine present and future values of investments or expenses.

Distributed Generation: a term used by the power industry to describe localized or on-site power generation.

Domestic Hot Water: water heated for residential washing, bathing, and so forth.

Double-Wall Heat Exchanger: a heat exchanger in a solar water heating system that has two distinct walls between the heat transfer fluid and the domestic water to ensure that there is no mixing of the two.

Downwind Wind Turbine: a horizontal-axis wind turbine in which the rotor is downwind of the tower.

Drain-Back (Solar) Systems: a closed-loop solar heating system in which the heat transfer fluid in the collector loop drains into a tank or reservoir whenever the booster pump stops to protect the collector loop from freezing.

Drain-Down (Solar) Systems: an open-loop solar heating system in which the heat transfer fluid from the collector loop and the piping drain into a drain whenever freezing conditions occur.

Emissivity: the ratio of the radiant energy (heat) leaving (being emitted by) a surface to that of a black body at the same temperature and with the same area; expressed as a number between 0 and 1.

Energy Conservation: the use of less energy by reducing the output requirements of an energy system. An example is a reduction in the temperature set point for a thermostat that results in reduced heating energy requirements. A reduction in lighting energy by strategically reducing or turning off lights is another example of energy conservation.

Energy Efficiency: the use of less energy for a given output through reductions in a system's energy losses. For example, a higher efficiency boiler or furnace will require less fuel to meet the same heating requirement as a less efficient boiler or furnace.

Energy Intensity: the relative extent that energy is required for a process. Examples of energy intensity are the energy requirement per unit of product manufactured or per dollar of investment or per hour of labor or per unit floor area of facility.

Evacuated-Tube Collector: a solar collector made up of rows of parallel, evacuated glass tubes. Each tube consists of a glass outer tube and an inner tube, or absorber. The absorber is covered with a selective coating that absorbs solar energy well but inhibits radiative heat loss. The air is withdrawn (evacuated) from the space between the tubes to form a vacuum, which eliminates conductive and convective heat loss. Evacuated-tube collectors are used for active solar thermal systems.

Fenestration: the arrangement or layout of windows in a building.

Flat Plate Solar Thermal/Heating Collectors: large, flat boxes with glass covers and dark-colored metal plates inside that absorb and transfer solar energy to a heat transfer fluid. This is the most common type of collector used in solar hot water and space heating systems.

Flywheel: a massive disk that, when coupled to a generator, can be used to convert electrical energy into kinetic energy for storing the electricity for later use.

Foot Candle: the illumination on a 1-ft^2 surface on which there is a uniform light flux distribution of 1 lumen (lumen/square foot).

Francis Turbine: a type of hydropower turbine that contains a runner that has water passages through it formed by curved vanes or blades. As the water passes through the runner and over the curved surfaces, it causes rotation of the runner. The rotational motion is transmitted by a shaft to a generator.

Fresnel Lens: an optical device for concentrating light that is made of concentric rings that are faced at different angles so that light falling on any ring is focused to the same point.

Fuel Cell: an electrochemical device that converts chemical energy directly into electricity.

Full Sun: the amount of power density in sunlight received at the earth's surface at noon on a clear day (about 1,000 W/m^2).

Geothermal Energy: energy produced by the internal heat of the earth; geothermal heat sources include hydrothermal convective systems, pressurized water reservoirs, hot dry rocks, manual gradients, and magma. Geothermal energy can be used directly for heating or to produce electric power.

Geothermal Heat Pump: a type of heat pump that uses the ground, groundwater, or ponds as a heat source and heat sink, rather than outside air. Ground or water temperatures are more constant and are warmer in winter and cooler in summer than air temperatures. Geothermal heat pumps operate more efficiently than conventional or air-source heat pumps.

Gigawatt (GW): a unit of power equal to 1 billion watts; 1 million kilowatts, or 1,000 megawatts.

Glazing: transparent or translucent material (glass or plastic) used to admit light and/or to reduce heat loss; used for building windows, skylights, or greenhouses, or for covering the aperture of a solar collector.

Green Certificates: represent the environmental attributes of power produced from renewable resources. By separating the environmental attributes from the power, clean power generators are able to sell the electricity they produce to power providers at a competitive market value. The additional revenue generated by the sale of the green certificates covers the above-market costs associated with producing power made from renewable energy sources. Also known as *green tags, renewable energy certificates*, and *tradable renewable certificates.*

Ground Loop: in geothermal heat pump systems, a series of fluid-filled plastic pipes buried in the ground or placed in a body of water near a building. The fluid within the pipes is used to transfer heat between the building and the ground (or water) in order to heat and cool the building.

Ground Reflection: solar radiation reflected from the ground onto a solar collector.

Ground-Source Heat Pump: (See *Geothermal Heat Pump*)

Horizontal Ground Loop: in this type of closed-loop geothermal heat pump installation, the fluid-filled plastic heat exchanger pipes are laid out in a plane parallel to the ground surface. The most common layouts either use two pipes, one buried at 6 ft and the other at 4 ft, or two pipes placed side-by-side at 5 ft in the ground in a 2-ft-wide trench. The trenches must be at least 4 ft deep. Horizontal ground loops are generally most cost-effective for residential installations, particularly for new construction where sufficient land is available. Also see *closed-loop geothermal heat pump systems.*

Hub Height: the height above the ground that a horizontal-axis wind turbine's hub is located.

Hybrid System: a renewable energy system that includes two different types of technologies that produce the same type of energy (e.g., a wind turbine and a solar photovoltaic array combined to meet a power demand).

Hydroelectric Power Plant: a power plant that produces electricity by the force of water falling through a hydro turbine that spins a generator.

Impulse Turbine: a turbine that is driven by high-velocity jets of water or steam from a nozzle directed to vanes or buckets attached to a wheel. (A *Pelton wheel* is an impulse hydro turbine.)

Incident Solar Radiation: the amount of solar radiation striking a surface per unit of time and area.

Indirect Solar Gain System: a passive solar heating system in which the sun warms a heat storage element, and the heat is distributed to the interior space by convection, conduction, and radiation.

Indirect Solar Water Heater: these systems circulate fluids other than water (such as diluted antifreeze) through the collector. The collected heat is transferred to the household water supply using a heat exchanger. Also known as *closed-loop* systems.

Insolation: the solar power density incident on a surface of stated area and orientation, usually expressed as watts per square meter or Btu per square foot per hour.

Integral Collector Storage System: this simple passive solar hot water system consists of one or more storage tanks placed in an insulated box that has a glazed side facing the sun. An integral collector storage system is mounted on the ground or on the roof. Some systems use selective surfaces on the tank(s). These surfaces absorb sun well but inhibit radiative loss. Also known as *bread box systems* or *batch heaters.*

Inverter: a device that converts direct current electricity (from, for example, a solar photovoltaic module or array) to alternating current for use directly to operate appliances or to supply power to an electricity grid.

Irradiance: the direct, diffuse, and reflected solar radiation that strikes a surface.

Isolated Solar Gain System: a type of passive solar heating system where heat is collected in one area for use in another.

Kaplan Turbine: a type of turbine that has two blades whose pitch is adjustable. The turbine may have gates to control the angle of the fluid flow into the blades.

Kilowatt-hour: a unit or measure of electricity supply or consumption of 1,000 watts over the period of 1 hour; equivalent to 3,412 Btu.

Load Management: to influence the demand on a power source.

Load Profile or Shape: a curve on a chart showing power (kW) supplied (on the horizontal axis) plotted against time of occurrence (on the vertical axis) to illustrate the variance in a load in a specified time period.

Load Shedding: turning off or disconnecting loads to limit peak demand.

Load Shifting: a load management objective that moves loads from on-peak periods to off-peak periods.

Local Solar Time: a system of astronomical time in which the sun crosses the true north–south meridian at noon and which differs from local time according to longitude, time zone, and equation of time.

Low-E Coatings and (Window) Films: a coating applied to the surface of the glazing of a window to reduce heat transfer through the window.

Low-Emissivity Windows and (Window) Films: energy-efficient windows that have a coating or film applied to the surface of the glass to reduce heat transfer through the window.

Low-Flow Solar Water Heating Systems: the flow rate in these systems is ⅛ to ⅕ the rate of most solar water heating systems. The low-flow systems take advantage of stratification in the storage tank and theoretically allow for the use of smaller diameter piping to and from the collector and a smaller pump.

Lumen: a measure of the intensity of visible light given off by a light source. It is equal to the quantity of light (luminous flux) in a solid angle of one steradian by a uniform point source of one candela intensity.

Mean Power Output (of a Wind Turbine): the average power output of a wind energy conversion system at a given mean wind speed based on a Rayleigh frequency distribution.

Mean Wind Speed: the arithmetic wind speed over a specified time period and height above the ground (the majority of U.S. National Weather Service anemometers are at 20 ft (6.1 m).

Megawatt: 1,000 kilowatts or 1 million watts; standard measure of electric power plant generating capacity.

Megawatt-hour: 1,000 kilowatt-hours or 1 million watt-hours.

Microclimate: the local climate of specific place or habitat, as influenced by landscape features.

Multijunction Device: a high-efficiency photovoltaic device containing two or more cell junctions, each of which is optimized for a particular part of the solar spectrum.

Nacelle: the cover for the gear box, drive train, generator, and other components of a wind turbine.

Natural Cooling: space cooling achieved by shading, natural (unassisted, as opposed to forced) ventilation, conduction control, radiation, and evaporation; also called *passive cooling.*

Natural Draft: draft that is caused by temperature differences in the air.

Natural Ventilation: ventilation that is created by the differences in the distribution of air pressures around a building. Air moves from areas of high pressure to areas of low pressure, with gravity and wind pressure affecting the airflow. The placement and control of doors and windows alters natural ventilation patterns.

Net Metering: the practice of using a single meter to measure consumption and generation of electricity by a small generation facility (such as a house with a wind system or solar photovoltaic system). The net energy produced or consumed is purchased from or sold to the power provider, respectively.

Net Present Value: the net value of an investment accounting for all cash flows over a specified time period and using discounting.

Net Zero Energy Building: a building that derives enough energy from on-site renewable resources to totally offset any purchased energy from the utility or other off-site sources to meet its energy requirements on an annual basis. Also called *zero net energy building*.

One-Axis Tracking: a system capable of rotating about one axis.

One Sun: the maximum value of natural solar insolation.

On-Peak Energy: energy supplied during periods of relatively high demand, as specified by the supplier.

On-Site Generation: generation of energy at the location where all or most of it will be used.

Open-Loop Geothermal Heat Pump System: open-loop (also known as *direct*) systems circulate water drawn from a ground or surface water source. Once the heat has been transferred into or out of the water, the water is returned to a well or surface discharge (instead of being recirculated through the system). This option is practical where there is an adequate supply of relatively clean water, and all local codes and regulations regarding groundwater discharge are met.

Orientation: the alignment of a building along a given axis to face a specific geographical direction. The alignment of a solar collector, in number of degrees east or west of true south.

Panel (Solar): a term generally applied to individual solar collectors and typically to solar photovoltaic collectors or modules.

Parabolic Dish: a solar energy conversion device that has a bowl-shaped dish covered with a highly reflective surface that tracks the sun and concentrates sunlight on a fixed absorber, thereby achieving high temperatures, for process heating or to operate a heat engine to produce power or electricity.

Parabolic Trough: a solar energy conversion device that uses a trough covered with a highly reflective surface to focus sunlight onto a linear absorber containing a working fluid that can be used for medium temperature space or process heat or to operate a steam turbine for power or electricity generation.

Passive Cooling: to allow or augment the natural movement of cooler air from exterior, shaded areas of a building through or around a building; also called *natural cooling*.

Passive Solar (Building) Design: a building design that uses elements of a building to heat and cool a building without the use of mechanical equipment. The principal elements include proper building orientation, proper window sizing and placement, design of window overhangs to reduce summer heat gain and ensure winter heat gain, and proper sizing of thermal energy storage mass (for example a Trombe wall or masonry tiles). The heat is distributed primarily by natural convection and radiation, though fans can also be used to circulate room air or ensure proper ventilation.

Passive Solar Heater: a solar water or space heating system in which solar energy is collected and/or moved by natural convection without using pumps or fans. Passive systems are typically integral collector storage (or batch collectors) or thermosiphon systems. The major advantage of these systems is that they do not use controls, pumps, sensors, or other mechanical parts, so little or no maintenance is required over the lifetime of the system.

Passive Solar Home: a house built using passive solar design techniques.

Payback Period: the amount of time required before the savings resulting from a system is equal to the system cost.

Peak Demand/Load: the maximum energy demand or load in a specified time period.

Peak Shifting: the process of moving existing loads to off-peak periods.

Peak Sun Hours: the equivalent number of hours per day when solar irradiance averages 1 kW/m^2. For example, 6 peak sun hours means that the energy received during total daylight hours equals the energy that would have been received had the irradiance for 6 hours been 1 kW/m^2.

Peak Watt: a unit used to rate the performance of solar PV cells, modules, or arrays; the maximum nominal output of a PV device, in watts under standardized test conditions, usually 1000 watts per square meter of sunlight, with other conditions, such as temperature, specified.

Peak Wind Speed: the maximum instantaneous wind speed (or velocity) that occurs within a specific period of time or interval.

Pellets: solid fuels made from primarily wood sawdust that is compacted under high pressure to form small pellets (about the size of rabbit feed) for use in a pellet stove.

Pellet Stove: a space heating device that burns pellets; pellet stoves are more efficient, clean burning, and easier to operate than conventional cord wood burning appliances.

Pelton Turbine: a type of impulse hydropower turbine where water passes through nozzles and strikes cups arranged on the periphery of a runner, or wheel, which causes the runner to rotate, producing mechanical energy. The runner is fixed on a shaft, and the rotational motion of the turbine is transmitted by the shaft to a generator. Generally used for high-head, low-flow applications.

Penstock: a component of a hydropower plant; a pipe that delivers water to the turbine.

Photovoltaic (Solar) Module or Panel: a solar photovoltaic product that generally consists of groups of PV cells electrically connected together to produce a specified power output under standard test conditions, mounted on a substrate, sealed with an encapsulant, and covered with a protective glazing. May be further mounted on an aluminum frame. A junction box on the back or underside of the module is used to allow for connecting the module circuit conductors to external conductors.

Photovoltaic (Solar) System: a complete PV power system composed of the module (or array) and balance-of-system components including the array supports, electrical conductors/wiring, fuses, safety disconnects, grounds, charge controllers, inverters, and battery storage.

Pitch Control: a method of controlling a wind turbine's speed by varying the orientation, or pitch, of the blades and thereby altering its aerodynamics and efficiency.

Polycrystalline: a semiconductor (photovoltaic) material composed of variously oriented, small, individual crystals.

Projected Area: the net south-facing glazing area projected on a vertical plane. Also, the solid area covered at any instant by a wind turbine's blades from the perspective of the direction of the wind stream (as opposed to the swept area).

Propeller (Hydro) Turbine: a turbine that has a runner with attached blades, similar to a propeller used to drive a ship. As water passes over the curved propeller blades, it causes rotation of the shaft.

Pumped Storage Facility: a type of power generating facility that pumps water to a storage reservoir during off-peak periods and uses the stored water (by allowing it to fall through a hydro turbine) to generate power during peak periods. The pumping energy is typically supplied by lower cost base power capacity, and the peaking power capacity is of greater value, even though there is a net loss of power in the process.

Pyranometer: a device used to measure total incident solar radiation (direct-beam, diffuse, and reflected radiation) per unit time per unit area.

Pyrolysis: the transformation of a compound or material into one or more substances by heat alone (without oxidation). Often called destructive distillation. Pyrolysis of biomass is the thermal degradation of the material in the absence of reacting gases, and occurs prior to or simultaneously with gasification reactions in a gasifier. Pyrolysis products consist of gases, liquids, and char, generally. The liquid fraction of pyrolized biomass consists of an insoluble viscous tar and pyroligneous acids (acetic acid, methanol, acetone, esters, aldehydes, and furfural). The distribution of pyrolysis products varies depending on the feedstock composition, heating rate, temperature, and pressure.

Radiative Cooling: the process of cooling by which a heat-absorbing medium absorbs heat from one source and radiates the heat away.

Renewable Energy: energy derived from resources that are regenerative or for all practical purposes cannot be depleted. Types of renewable energy resources include moving water (hydro, tidal, and wave power), thermal gradients in ocean water, biomass, geothermal energy, solar energy, and wind energy. Municipal solid waste is also sometimes considered a renewable energy resource.

Renewable Energy Certificates: a certificate representing the environmental attributes (e.g., greenhouse gas avoided) associated with a specified quantity of electricity generated from renewable energy systems. See *green certificates.*

Roof Pond: a solar energy collection device consisting of containers of water located on a roof that absorb solar energy during the day so that the heat can be used at night or that cools a building by evaporation at night.

Selective Absorber: a solar absorber surface that has high absorbance at wavelengths corresponding to those of the solar spectrum and low emittance in the infrared range.

Selective Surface Coating: a material with high absorbance and low emittance properties applied to or on solar absorber surfaces.

Solar Air Heater: a type of solar thermal system where air is heated in a collector and either transferred directly to the interior space or to a storage medium such as a rock bin.

Solar Array: a group of solar collectors or solar modules connected together.

Solar Azimuth: the angle between the sun's apparent position in the sky and true south, as measured on a horizontal plane.

Solar Cell: a solar photovoltaic device with a specified area.

Solar Collector: a device used to collect, absorb, and transfer solar energy to a working fluid. Flat plate collectors are the most common type of collectors used for solar water or pool heating systems. In the case of a photovoltaic system, the solar collector could be crystalline silicon panels or thin-film roof shingles, for example.

Solar Constant: the average amount of solar radiation that reaches the earth's upper atmosphere on a surface perpendicular to the sun's rays; equal to 1,353 watts per square meter or 492 Btu per square foot.

Solar Cooling: the use of solar thermal energy or solar electricity to power a cooling appliance. There are five basic types of solar cooling technologies: absorption cooling, which can use solar thermal energy to vaporize the refrigerant; desiccant cooling, which can use solar thermal energy to regenerate (dry) the desiccant; vapor-compression cooling, which can use solar thermal energy to operate a Rankine-cycle heat engine; evaporative coolers (swamp coolers); and heat pumps and air conditioners that can be powered by solar photovoltaic systems.

Solar Declination: the apparent angle of the sun north or south of the earth's equatorial plane. The earth's rotation on its axis causes a daily change in the declination.

Solar Energy: electromagnetic energy transmitted from the sun (solar radiation). The amount that reaches the earth is equal to one billionth of the total solar energy generated, or the equivalent of about 420 trillion kilowatt-hours.

Solar Fraction: the percentage of a building's seasonal energy requirements that can be met by a solar energy device(s) or system(s).

Solar Module (Panel): a solar photovoltaic device that produces a specified power output under defined test conditions, usually composed of groups of solar cells connected in series, in parallel, or in series–parallel combinations.

Solar Noon: the time of the day, at a specific location, when the sun reaches its highest apparent point in the sky; equal to true, or due, geographic south.

Solar Radiation: a general term for the visible and near visible (ultraviolet and near-infrared) electromagnetic radiation that is emitted by the sun. It has a spectral, or wavelength, distribution that corresponds to different energy levels; short-wavelength radiation has a higher energy than long-wavelength radiation.

Solar Thermal Electric Systems: solar energy conversion technologies that convert solar energy to electricity by heating a working fluid to power a turbine that drives a generator. Examples of these systems include central receiver systems, parabolic dishes, and solar troughs.

Solar Thermal Parabolic Dishes: a solar thermal technology that uses a modular mirror system that approximates a parabola and incorporates two-axis tracking to focus the sunlight onto receivers located at the focal point of each dish. The mirror system typically is made from a number of mirror facets, either glass or polymer mirror, or can consist of a single stretched membrane using a polymer mirror. The concentrated sunlight may be used directly by a Stirling, Rankine, or Brayton cycle heat engine at the focal point of the receiver or to heat a working fluid that is piped to a central engine. The primary applications include remote electrification, water pumping, and grid-connected generation.

Solar Thermal Systems: solar energy systems that collect or absorb solar energy for useful purposes. Can be used to generate high-temperature heat (for electricity production and/or process heat), medium-temperature heat (for process and space/water heating and electricity generation), and low-temperature heat (for water and space heating and cooling).

Solar Time: the period marked by successive crossing of the earth's meridian by the sun; the hour angle of the sun at a point of observance (apparent time) is corrected to true (solar) time by taking into account the variation in the earth's orbit and rate of rotation. Solar time and local standard time are usually different for any specific location.

Solar Transmittance: the amount of solar energy that passes through a glazing material, expressed as a percentage.

Solar Trough Systems (see also Parabolic Trough): a type of solar thermal system where sunlight is concentrated by a curved reflector onto a pipe containing a working fluid that can be used for process heat or to produce electricity. The world's largest solar thermal electric power plants use solar trough technology. They are located in California, and have a combined electricity generating capacity of 240,000 kW.

Stagnation Temperature: a condition that can occur in a solar collector if the working fluid does not circulate when sun is shining on the collector.

Stall: in reference to a wind turbine, a condition when the rotor stops turning.

Storage Tank: the tank of a water heater.

Sun Path Diagram: a circular projection of the sky vault onto a flat diagram used to determine solar positions and shading effects of landscape features on a solar energy system.

Sun Space: a room or small structure attached to the side of a house that uses large amount of south-facing glass (in the northern hemisphere) to maximize winter heat gains. The sun heats the space to provide solar heating. This heat can also be used in adjacent areas if vents, windows, doors, or other openings are available on the common wall between the sun space and the building.

Sun-Tempered Building: a building that is elongated in the east-west direction, with the majority of the windows on the south side. The area of the windows is generally limited to about 7% of the total floor area. A sun-tempered design has no added thermal mass beyond what is already in the framing, wall board, and so on. Insulation levels are generally high.

Surface Water Loop: in this type of closed-loop geothermal heat pump installation, the fluid-filled plastic heat exchanger pipes are coiled into circles and submerged at least 8 ft below the surface of a body of surface water such as a pond or lake. The coils should only be placed in a water source that meets minimum volume, depth, and quality criteria. Also see *closed-loop geothermal heat pump systems.*

Swept Area: in reference to a wind energy conversion device, the area through which the rotor blades spin, as seen when directly facing the center of the rotor blades.

Tempering Valve: a valve used to mix heated water with cold in a heating system to provide a desired water temperature for end use.

Thermosiphon: the natural, convective movement of air or water due to differences in temperature. In solar passive design, a thermosiphon collector can be constructed and attached to a hose to deliver heat to the home by the continuous pattern of the convective loop (or thermosiphon).

Thermosiphon System: this passive solar hot water system relies on warm water rising, a phenomenon known as natural convection, to circulate water through the collectors and to the tank. In this type of installation, the tank must be above the collector. As water in the collector heats, it becomes lighter and rises naturally into the tank above. Meanwhile, cooler water in the tank flows down pipes to the bottom of the collector, causing circulation throughout the system. The storage tank is attached to the top of the collector so that thermosiphoning can occur.

Thin-Film: a layer of semiconductor material, such as copper indium diselenide or gallium arsenide, a few microns or less in thickness, used to make solar photovoltaic cells.

Tilt Angle (of a Solar Collector or Module): the angle at which a solar collector or module is set to face the sun relative to a horizontal position. The tilt angle can be set or adjusted to maximize seasonal or annual energy collection.

Ton (of Air Conditioning): a unit of air cooling capacity; 12,000 Btu per hour.

Tracking Solar Array: a solar energy array that follows the path of the sun to maximize the solar radiation incident on the PV surface. The two most common orientations are (1) one axis, where the array tracks the sun east to west and (2) two-axis tracking, where the array points directly at the sun at all times. Two-axis tracking arrays capture the maximum possible daily energy.

Transpired Solar Collector: an unglazed solar collector that uses a perforated corrugated metal absorber. Outside air is drawn across the collector and is warmed by the absorber. The air is used to preheat ventilation air within the building (also known as an *unglazed transpired collector*).

Trombe Wall: a wall with high thermal mass and an exterior layer of glass that is used to store solar energy passively in a solar building. The wall absorbs solar energy and transfers it to the space behind the wall by means of radiation and by convection currents moving through spaces under, in front of, and on top of the wall.

True South: the direction, at any point on the earth that is geographically in the northern hemisphere, facing toward the South Pole of the earth. Essentially a line extending from the point on the horizon to the highest point that the sun reaches on any day (solar noon) in the sky.

Unglazed Solar Collector: a solar thermal collector that has an absorber that does not have a glazed covering. Solar swimming pool heater systems usually use unglazed collectors because they circulate relatively large volumes of water through the collector and capture nearly 80% of the solar energy available.

Vertical-Axis Wind Turbine: a type of wind turbine in which the axis of rotation is perpendicular to the wind stream and the ground.

Vertical Ground Loop: in this type of closed-loop geothermal heat pump installation, the fluid-filled plastic heat exchanger pipes are laid out in a plane perpendicular to the ground surface. For a vertical system, holes (approximately 4 in. in diameter) are drilled about 20 ft apart and 100 ft to 400 ft deep. Into these holes go two pipes that are connected at the bottom with a U-bend to form a loop. The vertical loops are connected with horizontal pipe (i.e., manifold), placed in trenches, and connected to the heat pump in the building. Large commercial buildings and schools often use vertical systems because the land area required for horizontal ground loops would be prohibitive. Vertical loops are also used where the soil is too shallow for trenching, or for existing buildings, because they minimize the disturbance to landscaping. Also see *closed-loop geothermal heat pump systems.*

Water-Source Heat Pump: a type of (geothermal) heat pump that uses well (ground) or surface water as a heat source. Water has a more stable seasonal temperature than air, thus making for a more efficient heat source.

Water Turbine: a turbine that uses water pressure to rotate its blades; the primary types are the Pelton wheel, for high heads (pressure); the Francis turbine, for low to medium heads; and the Kaplan, for a wide range of heads. Primarily used to power an electric generator.

Wind Energy: energy available from the movement of the wind across a landscape caused by the heating of the atmosphere, earth, and oceans by the sun.

Wind Energy Conversion System (WECS) or Device: an apparatus for converting the energy available in the wind to mechanical energy that can be used to power machinery (grain mills, water pumps) and to operate an electrical generator.

Wind Generator: a WECS designed to produce electricity.

Wind Power Curve: a graph representing the relationship between the power available from the wind and the wind speed. The power from the wind increases proportionally with the cube of the wind speed.

Wind Power Profile: the change in the power available in the wind due to changes in the wind speed or velocity profile; the wind power profile is proportional to the cube of the wind speed profile.

Wind Rose: a diagram that indicates the average percentage of time that the wind blows from different directions, on a monthly or annual basis.

Wind Speed: the rate of flow of the wind undisturbed by obstacles.

Wind Speed Duration Curve: a graph that indicates the distribution of wind speeds as a function of the cumulative number of hours that the wind speed exceeds a given wind speed in a year.

Wind Speed Frequency Curve: a curve that indicates the number of hours per year that specific wind speeds occur.

Wind Speed Profile: a profile of how the wind speed changes with height above the surface of the ground or water.

Wind Turbine: a wind energy conversion device that produces electricity; typically has one, two, or three blades.

Wind Turbine Rated Capacity: the amount of power a wind turbine can produce at its rated wind speed (e.g., 100 kW at 20 mph). The rated wind speed generally corresponds to the point at which the conversion efficiency is near its maximum. Because of the variability of the wind, the amount of energy a wind turbine actually produces is a function of the capacity factor (e.g., a wind turbine produces 20% to 35% of its rated capacity over a year).

Zero Energy Building: a building that derives all its energy from on-site renewable resources and does not require energy purchases from off-site sources.

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Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation