Evaluation of Renewable Energy Alternatives for Highway Maintenance Facilities

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16. Abstract

A considerable annual energy budget is used for heating, lighting, cooling and operating ODOT maintenance facilities. Such facilities contain vehicle repair and garage bays, which are large open spaces with high heating demand in winter. The main goal of the project was to recommend renewable energy and energy efficiency strategies for ODOT maintenance facilities that will reduce energy costs and reduce greenhouse gas (GHG) emissions. The research team developed a 3-phases screening process for evaluating renewable energy technologies and developed a decision support tool for use in each phase.

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TABLE OF CONTENT

CHAPTER 1 - INTRODUCTION 1
1.1 Problem Statement 1
1.2 Research Objectives 1
1.3 Research Methodology 2
CHAPTER 2 - DATA COLLECTION AND ANALYSIS 4
2.1 Drawing Reviews of 2 ODOT Maintenance Facilities 4
Typical maintenance facility's functional characteristics 4
Heating and cooling 8
Ventilation 8
Process loads 8
2.2 ODOT Maintenance Facilities' Electricity Consumption Data 8
2.3 ODOT Maintenance Facilities' Gas Consumption Data 13
2.4 ODOT Maintenance Facilities Total Energy Consumption 15
2.5 Comparing ODOT Energy Consumption with Published Data 17
2.6 Correlation of Energy Consumption with Weather Data 19
CHAPTER 3 – LITERATURE REVIEW 23
3.1 Research Studies on Renewable Energy in Transportation Facilities 23
3.2 Renewable Energy Alternatives 24
3.2.1 Solar air heating 25
3.2.2 Grid connected photovoltaic systems 30
3.2.3 Grid connected wind turbine 33
3.2.4 Solar water heating systems 39
3.2.5 Ground source heat pump 41
3.2.6 Biomass heating systems 44
CHAPTER 4 – ON-SITE ASSESSMENT 47
4.1 Survey 47
4.1.1 Survey development 48
4.1.2 Representative opinions 48
4.1.3 Survey results 49
4.2 Site Visits 58
4.2.1 Objectives of site visits 59
4.2.2 Site visit procedures 62
4.2.3 Tools used during site visits 62

4.3 Energy Efficiency Opportunities 63
4.3.1 Heating quick fix strategies 63
4.3.2 Heating long term strategies 65
4.3.3 Lighting quick fix strategies 67
4.3.4 Lighting long term strategies 67
4.3.5 Equipment quick fix strategies........ 69
4.3.6 Operation strategies 69
4.4 Renewable Energy Opportunities 70
4.4.1 Photovoltaics........ 70
4.4.2 Solar air heating 72
4.4.3 Wind energy systems 73
CHAPTER 5 – BEST MANAGEMENT PRACTICES 74
5.1 Energy Efficiency 74
5.1.1 Thermal separation of functional areas........ 74
5.1.2 Daylight harvesting systems 78
5.1.3 Hydronic heating........ 78
5.1.4 Waste oil heater........ 78
5.2 RET Incentives........ 79
5.2.1 Business energy investment tax credit........ 80
5.2.2 Utility incentives........ 80
5.3 RET Project Procurement / Contracting Best Practices........ 81
5.3.1 Power purchasing agreements........ 81
5.3.2 Energy savings performance contracts 82
5.4 Renewable Energy Credits........ 82
5.5 RET Projects General Best Practices........ 83
5.6 Technology Specific Best Practices........ 84
5.6.1 PV systems........ 84
5.6.2 Solar air heating 85
5.6.3 Wind........ 85
5.6.4 Solar hot water 86
5.6.5 Biomass heating systems 87
5.6.6 Ground source heat pumps........ 88
CHAPTER 6 – DECISION MATRICES 89
6.1 State Level Decision Matrix 89

6.1.1 Evaluation criteria ... 92
6.2 State Level Evaluation of RETs ... 93
6.2.1 Solar air heating ... 93
6.2.2 Grid connected photovoltaic ... 97
6.2.3 Grid connected wind turbines ... 100
6.2.4. Biomass heating systems ... 103
6.2.5. Solar hot water ... 105
6.2.6 Ground source heat pumps ... 108
6.3 How to use the State-Level Decision matrix? ... 110
6.4 Site Level Decision Matrix ... 110
CHAPTER 7 – LIFE CYCLE COST ANALYSIS 113
7.1. RETScreen Software ... 113
7.2. LCCA for Solar Air Heating Systems ... 117
7.2.1. LCCA for Pike County Garage SAH system ... 117
7.2.2. LCCA for a new maintenance facility SAH system ... 122
7.3. LCCA for Grid Connected PV Systems ... 124
7.3.1. LCCA for Pike County Garage grid connected PV system ... 124
7.3.2. LCCA for Seneca County Garage grid connected PV system (no incentives) ... 126
7.3.3. LCCA for Seneca County Garage grid connected PV system (with incentives and SREC) ... 129
7.4. LCCA for Grid Connected Wind Energy Systems ... 131
7.4.1. LCCA for Seneca County Garage grid connected wind energy system (no incentives) ... 131
7.4.2. LCCA for Pike County Garage grid connected wind energy system (no incentives) ... 134
7.4.3. LCCA for Seneca County Garage grid connected PV system (with incentives and SREC) ... 136
CHAPTER 8 - CONCLUSIONS, RECOMMENDATIONS AND FUTURE RESEARCH 138
8.1 Conclusions ... 138
8.2 Recommendations ... 139
8.3 Future Research ... 140
REFERENCES 142
APPENDICES 145

LIST OF FIGURES

Figure 1.1. Project tasks and research deliverables........ 3

Figure 2.1. Maintenance area........ 5

Figure 2.2. Garage area........ 5

Figure 2.3. Office area may serve functions (offices, breakout rooms, conference rooms, and parts storage........ 6

Figure 2.4. Cold storage area........ 7

Figure 2.5. Truck washing area........ 7

Figure 2.6. Map of the Ohio Department of Transportation districts and the counties they contain........ 9

Figure 2.7. Pike county garage - monthly electrical energy consumption (kWh)........ 11

Figure 2.8. Pike county garage - monthly natural gas consumption (ccf)........ 15

Figure 2.9. Pike county garage – total monthly energy consumption (kWh)........ 16

Figure 2.10. Energy consumption by end use, vehicle service commercial buildings (Source CBECS 2003)........ 18

Figure 2.11. AHRAE climate regions (Source: ASHRAE)........ 19

Figure 2.12. Monthly heating degree days – Pike County Garage........ 20

Figure 2.13. Monthly cooling degree days, Pike County Garage........ 20

Figure 2.14. Heating degree days and natural gas consumption for Pike County Garage........ 21

Figure 2.15. Cooling degree days and electricity consumption for Pike County Garage........ 22

Figure 2.16. Heating degree days and electricity consumption for Pike County Garage........ 22

Figure 3.1. Components of a solar air heating system (RETScreen International, 2004)........ 26

Figure 3.2. Air flow in a SAH system (Conserval Engineering, 2012)........ 26

Figure 3.3. Schematic of SAH design that takes advantage of destratification energy savings (RETScreen International, 2004)........ 28

Figure 3.4. Estimated energy savings utilizing SAH (National Energy Renewable Lab, 2013)........ 29

Figure 3.5. Annual global solar radiation at a tilt angle equal to the latitude for Ohio (National Energy Renewable Lab, 2013)........ 32

Figure 3.6. Components of a wind turbine (RETScreen International, 2004)........ 34

Figure 3.7. Ohio 50 m wind resource availability (Source: NREL)........ 36

Figure 3.8. Obstacle clearance parameters for wind turbines (Source: http://www.smallwindtips.com/tag/tower-height/)........ 37

Figure 3.9. Horizontal axis turbine at ODOT Northwood outpost facility........ 38

Figure 3.10. Vertical-axis turbine. Source: http://www.windspireenergy.com/case-studies/missouri-department-of-transportation/attachment/mdot_2/ 38

Figure 3.11. Example of an active, closed-loop solar water heating system (source: http://www.solardev.com/FSEC-solar-heating.php) 40

Figure 3.12. Components of a ground source heat pump (RETScreen International, 2004) 42

Figure 3.13. Types of ground source heat pumps. From left to right: horizontal (looping), vertical, pond/lake and open-loop system (RETScreen International, 2004). 42

Figure 3.14. Biomass resource availability in Ohio (National Energy Renewable Lab, 2013) 45

Figure 4.1. Excerpt from the survey sent to ODOT facilities. 48

Figure 4.2. Radiant heaters provide space heating for the maintenance/garage area 51

Figure 4.3. Gas fired make up air units provide space heating for the maintenance/garage area 52

Figure 4.4. Gas fired furnace provide space heating for the office area 52

Figure 4.5. Outdoor electrical condensers provide space cooling for the office area 53

Figure 4.6. Water heating for sanitary uses is provided by a gas-fired water heater 53

Figure 4.7. Large exhaust fans provide ventilation to maintenance/garage areas 54

Figure 4.8. 400 W metal halide lamps used in the garage/maintenance area 54

Figure 4.9. Building mounted 175 W metal halide lamps are used for outdoor site lighting 55

Figure 4.10. T8-fluorescent lamps are typically used in the office area 55

Figure 4.11. Thermostat controls and occupancy sensors are used in office area to control HVAC equipment and lighting respectively. 56

Figure 4.12. Control panel for make up air units. 56

Figure 4.13. Dial control for setting radiant heaters' temperature. 57

Figure 4.14. Basic on/off switches are used to manually control lighting circuits 57

Figure 4.15, Typical process equipment used for vehicle repair and maintenance 58

Figure 4.16. Excerpt from the "Building Systems and Renewable Energy" form used during site visits. . 60

Figure 4.17. Major Equipment form used during site visits. 61

Figure 4.18. "Indoor Environmental Conditions Measurement" form used during site visits. 61

Figure 4.19. Tools and instruments used during site visits. 63

Figure 4.20. Vehicle exhaust reel 64

Figure 4.21. Infrared camera shot of a visited facility door displaying temperature differentiation indicating infiltration. 65

Figure 4.22. Thermal shot of a conference room show very low temperature because of excessive use of a/c system. 66

Figure 4.23. Example of a heat recovery ventilator (Greencheck, 2013). 66

Figure 4.24. Example of instances where unnecessary lighting was being used in unoccupied areas 67

Figure 4.25. Before and after pictures of a Trident Seafood facility where MH lamps were replaced with HIF lamps (Seattle Government- Energy Smart Services). 69

Figure 4.26. Fifth avenue outpost garage use HID fluorescent fixtures in the garage area. 69

Figure 4.27. Site layout of the Seneca County Garage. 71

Figure 4.28. Site layout of the Pike County Garage. 71

Figure 4.29. The southern facing wall of the Pike County Garage and a solar air heating system installed on a similar wall. 72

Figure 4.30. The southern wall of Seneca County Garage is shaded by an unconditioned storage area. ... 72

Figure 4.31. Location of the visited sites superimposed on the NREL wind resource map. 73

Figure 5.1. Several functional spaces with different heating requirements are combined in many existing ODOT facilities. 75

Figure 5.2. Maintenance area and garage area are thermally separated by a wall in the New Lucas County Garage. 76

Figure 5.3. A separate truck washing building is used in the New Lucas County Garage 76

Figure 5.4. Corrosion of structural steel and metal wall in truck washing area 77

Figure 5.5. Truck washing building in New Lucas County garage is constructed of CMU instead of structural steel to reduce corrosion problems. 77

Figure 5.6. Waste oil heater in New Lucas County Garage's maintenance area 79

Figure 6.1. State Level Decision Matrix, "RET Ranking NB" Tab 90

Figure 6.2. State Level Decision Matrix, "RET Ranking EB" Tab 90

Figure 6.3. State Level Decision Matrix, "RET General Info" Tab 91

Figure 6.4. State Level Decision Matrix, "Resources" Tab 91

Figure 6.5. State Level Decision Matrix, "Ranking Criteria" Tab 92

Figure 6.6. Brown collector on industrial building, Connecticut, USA. Photo credit Conserval Engineering. 94

Figure 6.7. Grey colored solar collect installed on part of the wall of a vehicle maintenance building Before (left) and after (right). Photo credit: US Army environmental command (source: http://aec.army.mil/usaec/sustainability/drumwall.pdf 95

Figure 6.8. An SAH collector installed on a gable wall on the BigHorn Home Improvement Center in Silverthorne, Colorado. Photo credit solarwall. http://solarwall.com/media/download_gallery/BigHorn-SolarWall.pdf 95

Figure 6.9. Simple payback for SAH systems that replaces gas heating (National Renewable Energy Laboratory, 2013) 96

Figure 6.10. Simple payback for a 10 kW system (National Renewable Energy Laboratory, 2013) 99

Figure 6.11. Installation of skylight glass laminated with PV cells at the Thoreau Center for Sustainable Development, Presidio National Park, San Francisco, California. (Credit: Lawrence Berkeley Lab) 100

Figure 6.12. Simple payback for a SWH system where gas is the fuel saved and not considering incentives (National Renewable Energy Laboratory, 2013) 107

Figure 6.13. Simple payback for a SWH system where electricity is the fuel saved and not considering incentives (National Renewable Energy Laboratory, 2013) 107

Figure 6.14. Site Level Decision Matrix, "Favorable Conditions" Tab 112

Figure 6.15. Site Level Decision Matrix, "Unfavorable Conditions" Tab 112

Figure 7.1. RETScreen Life Cycle Cost module. 114

Figure 7.2. RETScreen Financial Analysis module. 115

Figure 7.3. Plan view of Pike County Garage 119

Figure 7.4. South East wall where collector is assumed installed for the Pike County Garage SAH system LCCA 119

Figure 7.5. Cumulative cash flow graph for the Pike County Garage SAH system LCCA 122

Figure 7.6. Cumulative cash flow graph for a new facility SAH system LCCA 123

Figure 7.7. Cumulative cash flow graph for the Pike County PV project 126

Figure 7.8. Plan view of Seneca County Garage 127

Figure 7.9. Cumulative cash flow graph for the Seneca County PV project 129

Figure 7.10. Cumulative cash flow graph for the Seneca County PV project with incentives and SRECs 131

Figure 7.11. Cumulative cash flow graph for the Seneca County wind energy project 133

Figure 7.12. Cumulative cash flow graph for the Pike County wind energy project 135

Figure 7.13. Cumulative cash flow graph for the Seneca County wind energy project with incentives and RECs 137

LIST OF TABLES

Table 2.1. Pike County Garage's electricity consumption data 10

Table 2.2. Average monthly electricity usage and cost for Pike County Garage 12

Table 2.3. List of the 13 ODOT maintenance facilities chosen for in-depth analysis and their districts... 13

Table 2.4. Average monthly natural gas usage and cost for Pike County Garage 14

Table 2.5. Average and maximum monthly total energy consumption and cost for Pike County Garage . 17

Table 2.6. Average monthly consumption and cost of electricity and natural gas for Pike County Garage 17

Table 2.7. Average monthly consumption and cost of electricity and natural gas for Pike County Garage 17

Table 2.8. Comparison of published energy consumption data for ASHRAE regions 4 and 5 to Pike county garage energy consumption........ 19

Table 4.1. Facility space usage breakdown........ 49

Table 4.2. Summary of survey results for ODOT district 2........ 50

Table 4.3. Summary of survey results for ODOT district 6........ 50

Table 4.4. Summary of survey results for ODOT district 9........ 51

Table 4.5. Energy intensive process equipment used in ODOT facilities........ 57

Table 4.6. List and characteristics of the facilities selected for site visits. 59

Figure 5.4. Corrosion of structural steel and metal wall in truck washing area........ 77

Table 5.1. List of incentives offered by the AEP Ohio........ 81

Table 6.1. Useful lives of common RET systems. (Source: NREL)........ 93

Table 7.1. Design and financial parameters associated with the Pike County Garage SAH system LCCA 118

Table 7.2. Percent of month when heating is assumed required for the Pike County Garage SAH system LCCA........ 120

Table 7.3. Assumed operating days and hours for the Pike County Garage SAH system LCCA 120

Table 7.4. Energy savings associated with the Pike County Garage SAH system LCCA........ 120

Table 7.5. Financial indicators associated with the Pike County Garage SAH system LCCA........ 121

Table 7.6. Financial indicators associated with new facility SAH system LCCA 123

Table 7.7. Design and financial parameters associated with the Pike County Garage PV system 125

Table 7.8. Energy performance of the Pike County Garage PV system 125

Table 7.9. Financial indicators associated with the Pike County Garage PV system LCCA 126

Table 7.10. Design and financial parameters associated with the Seneca County Garage PV system 127

Table 7.11. Energy performance of the Seneca County Garage PV system 128
Table 7.12. Financial indicators associated with the Seneca County Garage PV system LCCA 128
Table 7.13. Design and financial parameters associated with the Seneca County Garage PV system with incentives and SRECs 130
Table 7.14. Financial Indicators associated with the Seneca County Garage PV system LCCA with incentives and SRECs 130
Table 7.15. Design and financial parameters associated with the Seneca County Garage Energy system 132
Table 7.16. Energy performance of the Seneca County Garage wind energy system 132
Table 7.17. Financial indicators associated with the Seneca County Garage wind energy system LCCA 133
Table 7.18. Design and financial parameters associated with the Pike County Garage wind energy system 134
Table 7.19. Energy performance of the Pike County Garage wind energy system 134
Table 7.20. Financial indicators associated with the Pike County Garage wind energy system LCCA... 135
Table 7.21. Design and financial parameters associated with the Seneca County Garage wind energy system with incentives and RECs 136
Table 7.22. Financial indicators associated with the Seneca County Garage wind energy system LCCA with incentives and RECs 137

CHAPTER 1 - INTRODUCTION

1.1 Problem Statement

A considerable annual energy budget is used for heating, lighting, cooling and operating ODOT maintenance facilities. Such facilities usually consists of vehicle repair bays, which are large, open spaces with high clearance, high ventilation demand, and high heating demand in winter. ODOT is trying to reduce its energy consumption to lower its bills and lower its environmental impact. Energy production from traditional, fossil fuel-based sources is a significant contributor to air pollution in the United States, releasing such pollutants as sulfur dioxide, nitrogen oxide, and carbon dioxide, which have widespread and adverse effects on human health and contribute to acid precipitation, smog, and greenhouse gases (GHG) emissions. Energy generation from renewable sources—such as solar, wind, and biomass—minimizes acid rain, smog, climate change, and human health problems resulting from air contaminants. In addition, using renewable resources avoids the consumption of fossil fuels, the production of nuclear waste, and the environmentally damaging operation of hydropower dams (US Green Building Council, 2009a).

Renewable energy technologies (RETs) have numerous applications and benefits; however, the success of their implementation is dependent on a detailed assessment of a variety of factors including physical, economic, and institutional (NCHRP, 2011). The need to reduce energy consumption in ODOT maintenance facilities coupled with the recent advancements in Renewable Energy Technologies (RET)s, present a unique opportunity to implement cost-effective energy efficiency and renewable energy strategies for these very important facilities.

1.2 Research Objectives

The proposed research aims to study and recommend best practices (BP) to maximize the cost effectiveness of implementing renewable energy technologies (RET) projects in ODOT highway maintenance facilities to reduce energy costs and reduce greenhouse gas (GHG) emissions. To accomplish this goal, the main research objectives of this study are to:

1. Collect data on Ohio renewable energy resources such as solar, wind, hydroelectric power, geothermal, biomass and ethanol and biodiesel fuels available at or near ODOT maintenance facilities and utilize this data to evaluate renewable energy production potential;
2. Collect data on ODOT maintenance facilities including site information and energy usage data and utilize this data for initial screening of appropriate RETs;
3. Conduct a comprehensive literature review on currently available RETs including solar, wind, geothermal, biomass, landfill gas, hydropower and passive building and site modifications to reduce energy costs and GHG emissions in highway maintenance facilities. The literature review will also examine the advantages and disadvantages of the various RETs and their potential applications for highway maintenance facilities;
4. Conduct on-site assessments of existing ODOT maintenance facilities to determine opportunities and challenges for effective implementation of RETs;

5. Investigate which RET alternatives might work for the various sites and determine which solution would maximize cost effectiveness and GHG reductions;
6. Develop a report detailing best practices for installing cost effective energy capture technologies at new and existing ODOT maintenance facilities while considering overall costs and payback figures of each of the suggested RETs;
7. Develop decisions matrices to help identify a short list of potential RET projects for each ODOT maintenance facility;
8. Develop a life cycle cost analysis (LCCA) methodology for the selection of the optimum RET project for a given maintenance facility. The LCCA will consider the initial RET capital cost, the operations and maintenance expenses, the return on investment (ROI), inflation, cost growth of grid-based electricity, and lifetime of equipment;

1.3 Research Methodology

The research team investigated and analyzed the applicability of renewable energy technologies (RET) to ODOT maintenance facilities and developed decision matrices for the selection of RETs. The research team conducted the research work in seven major tasks:

1. Collecting data on maintenance facilities' energy consumption and energy capture technologies currently employed in ODOT maintenance facilities.
2. Conducting a comprehensive literature review on renewable energy alternatives, their available resources in Ohio and their associated advantages/disadvantages.
3. Selecting case studies of ODOT maintenance facilities and conducting on site assessment.
4. Identifying and analyzing potential renewable energy best practices.
5. Developing Applicability Matrices for the selection of RET projects
6. Developing a Life Cycle Costing Analysis (LCCA) methodology for the evaluation of RET.
7. Making final recommendations for implementing RETs at ODOT maintenance facilities.

These research tasks and their deliverables are summarized in Figure 1.1. These research tasks and their deliverables are described in more detail in the following chapters, as shown in Figure 1.1

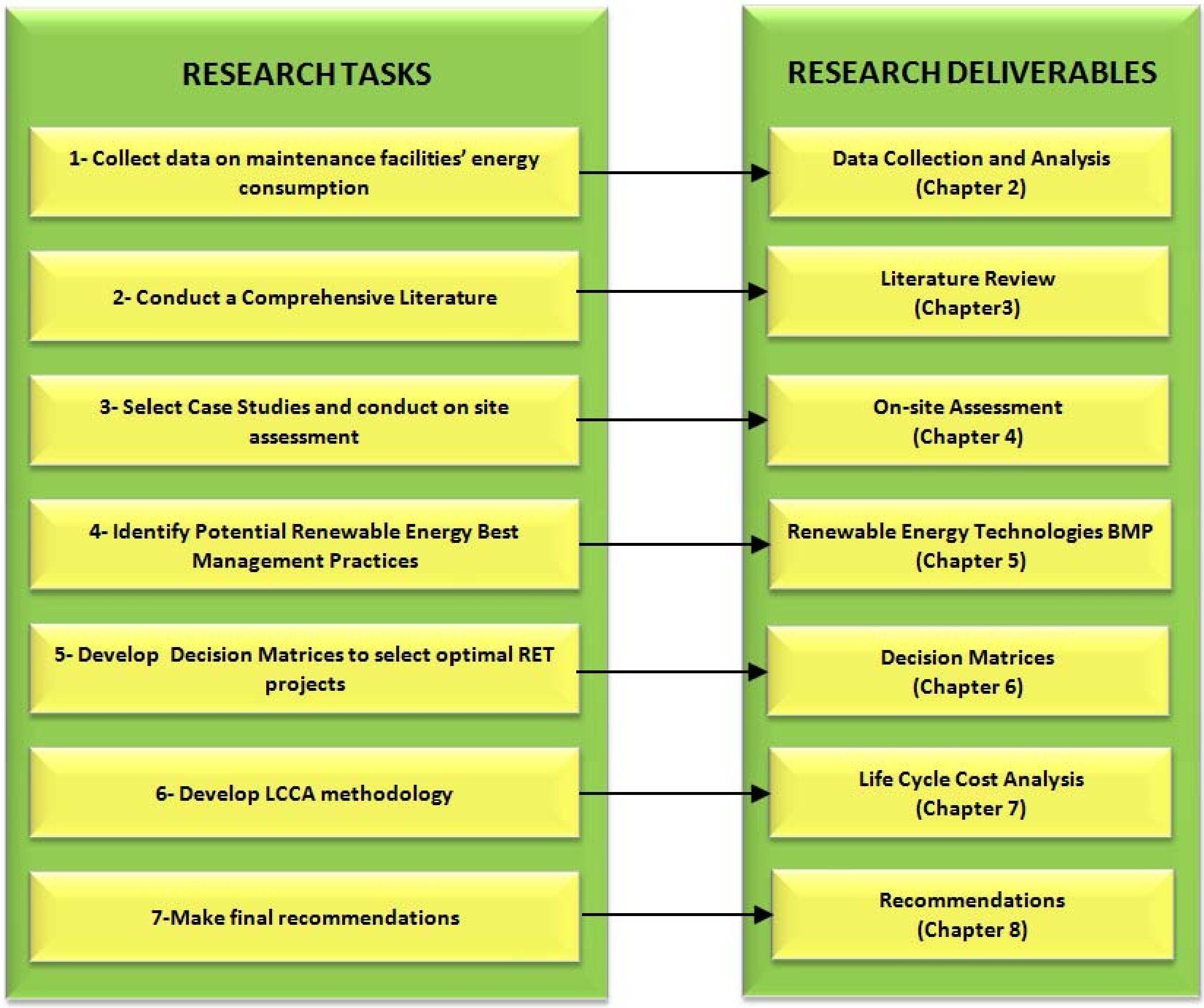


Figure 1.1. Project tasks and research deliverables

CHAPTER 2 - DATA COLLECTION AND ANALYSIS

It is very important to gather site-relevant data to analyze the merits of any renewable energy project (Federal Energy Management Program, 2010a). The research team collected and analyzed an extensive amount of detailed information about some of Ohio's existing highway maintenance facilities. The collected data included (1) utility bills, (2) energy usage and costs, (3) site location (address, longitude and latitude), (4) square footage, (5) typical number of occupants , (6) functional use (office, garage, warehouse), (7) unusual features, (8) age, condition of roof (9) atypical energy needs, (10) availability of land for renewable energy installations and (11) two complete sets of construction documents for two maintenance facilities. The data collected provided the research team with a general understanding of ODOT maintenance facilities and their energy consumption patterns.

The data collected was evaluated in several ways. The major goals of the evaluations were to (1) identify the major energy consuming systems in ODOT maintenance facilities; (2) analyze facilities' monthly energy usage profile to identify any seasonal variations, (3) compare monthly energy usage in ODOT maintenance facilities to published national/regional energy usage data, and (4) evaluate the relationship between monthly energy usage and outside weather conditions. The following sections discuss the outcomes of the various evaluations in more details.

2.1 Drawing Reviews of 2 ODOT Maintenance Facilities

A detailed review of two complete set of construction drawings provided by ODOT for two maintenance facilities (Williams County Garage and Seneca County Garage) was performed. Each drawing set included architectural, site, structural, mechanical and electrical drawings. The objective of the drawings' review process was to better understand the maintenance facility's functional characteristics and to identify the major energy consuming systems. The design review process has revealed the following:

Typical maintenance facility's functional characteristics

Review of the architectural drawings has revealed that ODOT maintenance facilities typically have 5 different types of functional areas; (1) maintenance area; (2) garage area; (3) office area; (4) cold storage area and (5) truck washing area.. Each of these areas has its own heating, cooling and lighting requirements.

The maintenance area as shown in Figure 2.1 typically has an indoor space for mechanics to work on vehicles and contains all the equipment and tools needed by a mechanic to perform the various required maintenance activities. These activities vary widely from simple maintenance and fluid changes for fleet cars and light trucks, to major overhauls of large equipment such as bucket loaders, graders, and snow plows. The maintenance area may include welding and bodywork areas depending on the type of work performed at the facility. The maintenance area is heated in the winter and typically not mechanically cooled in the summer. The maintenance area should be well lit to enable the mechanics to safely carry out their required activities.

Figure 2.1. Maintenance area.

The garage area as shown in Figure 2.2 typically includes space for indoor vehicle storage and parking. The garage area is typically mechanically heated in the winter and not mechanically cooled in the summer. The garage area should only be lit as trucks drive in and out of the garage; lights should be turned off when the trucks are just parked in the garage.

Figure 2.2. Garage area

The office area as shown in Figure 2.3 typically houses a number of personnel such as mechanics, supervisors, administrative staff and road maintenance crews. The office area also typically includes break rooms, parts storage, rest rooms, and showers. The area space is typically mechanically heated in the winter and mechanically cooled in the summer. The office area should be adequately lit; light should be turned off when space is not used.

Figure 2.3. Office area may serve functions (offices, breakout rooms, conference rooms, and parts storage.

The cold storage area as shown in Figure 2.4 is used to store equipment and materials that is not used in winter such as signs and barrels. The cold storage area is neither heated in the winter nor mechanically cooled in the summer.

Figure 2.4. Cold storage area

The truck washing area as shown in Figure 2.5 includes a wash bay that is primarily used for washing the salt trucks in winter to prolong their service lives.

Figure 2.5. Truck washing area

Heating and cooling

- The heating load of the maintenance facilities is significant due the large number of vehicle doors and the need to occasionally open the doors.
- The maintenance areas typically use radiant heaters or unit heaters.
- The administration spaces normally have a forced air unit serving them.
- Heat is primarily obtained by burning natural gas in the heating units.
- Space cooling is not provided except in the administrative areas.
- In some facilities, Heating and Cooling is controlled by programmable thermostats and occupancy sensors

Ventilation

- Maintenance facilities have high ventilation requirements to dilute exhaust from vehicles driving in and out of the facility.
- Ventilation is typically accomplished by an air handling unit supplying outdoor air and by exhaust systems that remove vehicle exhaust from the maintenance areas.
- In some facilities, the ventilation system is controlled by CO sensors.
- The restrooms have their own exhaust systems.

Process loads

- Equipment (process loads) found in ODOT maintenance facilities that use electricity include air compressors, hydraulic pumps for lifts, overhead cranes, welders, and other machine shop tools.

2.2 ODOT Maintenance Facilities’ Electricity Consumption Data

The analysis of electricity consumption of ODOT maintenance facilities was necessary to (1) develop a baseline for electricity consumption of these facilities; and (2) identify potential improvements for each facility. The main contributors to electricity consumption in ODOT maintenance facilities include: ventilation, lighting, process equipment, air conditioning, and vending machines.

ODOT Central office has provided the research team with electricity usage data for 50 of its maintenance facilities located throughout all twelve ODOT districts. Figure 2.6 shows a map for the 12 ODOT districts.

Figure 2.6. Map of the Ohio Department of Transportation districts and the counties they contain.

The 50 facilities were selected based on age and included the newest ODOT maintenance facilities. ODOT and the research team have decided to evaluate energy usage of the newest facilities as those facilities are less likely to be replaced in the near future and as such are good candidates for implementing renewable energy projects. The data provided by ODOT included electricity usage and costs, site location (address, longitude and latitude), square footage, utility, and age of the facilities. Table 2.1 includes the electricity consumption for one the ODOT garages, Pike County Garage.

Electricity (kWh)				
Start Date	**End Date**	**For Month**	**Energy Use**	**Energy Cost**
11/22/2011	12/22/2011	Dec-11	13,440	$1,543.43
10/21/2011	11/21/2011	Nov-11	12,720	$1,485.51
9/23/2011	10/20/2011	Oct-11	9,040	$1,218.17
8/24/2011	9/22/2011	Sep-11	10,880	$1,403.92
7/26/2011	8/23/2011	Aug-11	12,480	$1,566.68
6/24/2011	7/25/2011	Jul-11	12,800	$1,623.51
5/25/2011	6/23/2011	Jun-11	11,280	$1,302.21
4/26/2011	5/25/2011	May-11	10,320	$1,192.72
3/24/2011	4/25/2011	Apr-11	12,080	$1,412.80
2/24/2011	3/23/2011	Mar-11	11,520	$1,329.40
1/26/2011	2/23/2011	Feb-11	14,240	$1,643.22
12/23/2010	1/25/2011	Jan-11	20,400	$2,292.30
11/20/2010	12/22/2010	Dec-10	17,840	$2,040.41
10/23/2010	11/19/2010	Nov-10	10,960	$1,293.75
9/23/2010	10/22/2010	Oct-10	9,680	$1,127.97
8/25/2010	9/22/2010	Sep-10	12,800	$1,472.27
7/27/2010	8/24/2010	Aug-10	13,520	$1,544.80
6/24/2010	7/26/2010	Jul-10	14,720	$1,644.12
5/26/2010	6/23/2010	Jun-10	12,560	$1,440.31
4/24/2010	5/25/2010	May-10	9,360	$1,330.70
3/24/2010	4/23/2010	Apr-10	148	$1,378.33
2/24/2010	3/23/2010	Mar-10	13,760	$1,572.32
1/26/2010	2/23/2010	Feb-10	18,000	$2,044.17
12/23/2009	1/25/2010	Jan-10	18,560	$2,091.76

Table 2.1. Pike County Garage's electricity consumption data

Charts showing the monthly electrical energy consumption for each of the 50 maintenance facilities were developed. Figure 2.7 shows an example of such a chart for the Pike County Garage. A general observation for all facilities analyzed was that the December to March months consumed more electricity, signifying that electricity expenses associated with heating the facilities in the winter months were greater than the cooling demands in the summer months.

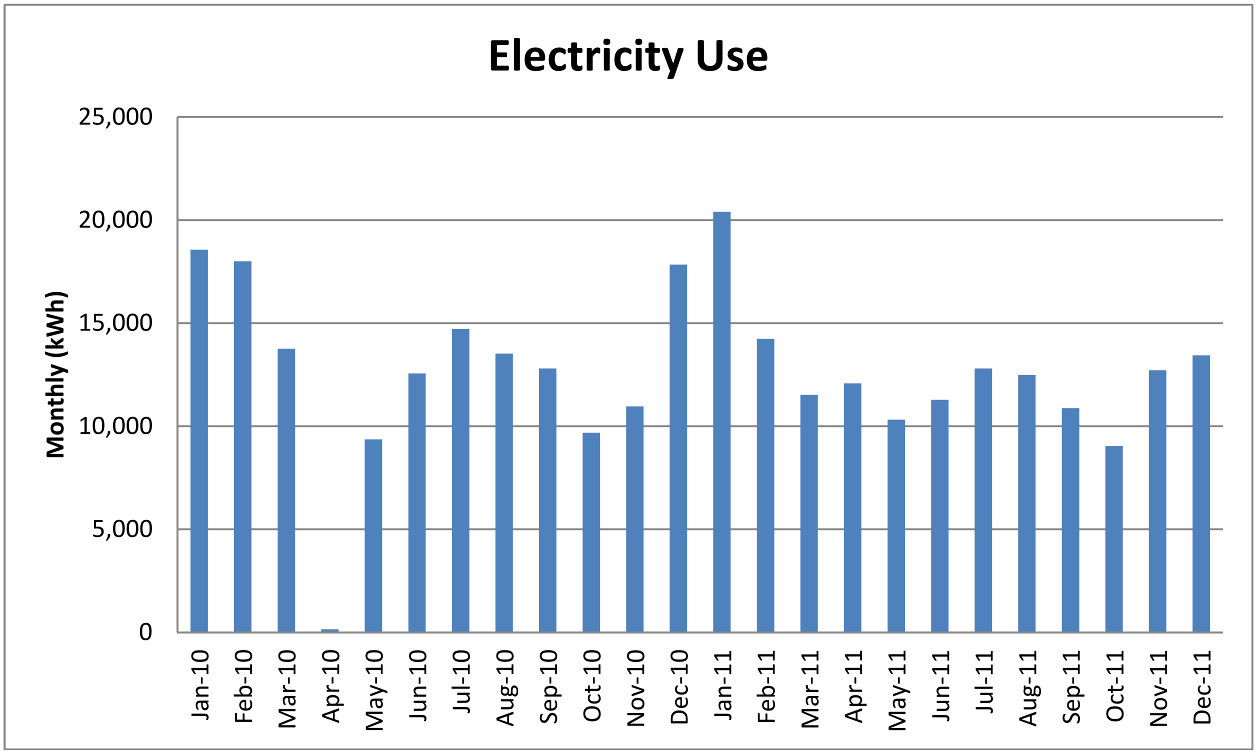


Figure 2.7. Pike county garage - monthly electrical energy consumption (kWh).

To allow for a comparison among the 50 maintenance facilities, the research team calculated and analyzed average monthly electrical energy and costs per square foot. Table 2.2 summarizes the results of this analysis and shows the following for each maintenance facility: (1) construction year; (2) square foot area; (3) ODOT district; (4) average monthly Kwh of electricity use; (5) average monthly Kwh of electricity used per square foot; (6) average monthly electricity cost; and (7) average monthly electricity cost per square foot.

As shown in Table 2.2, the average monthly electricity consumption per square foot for all 50 facilities is 0.4 kwh/sf/month. The average monthly electricity cost per square foot is \$0.05/sf/month. A careful examination of Table 2.2 will reveal that some facilities have extremely low electrical energy consumption; the research team has determined during the site visits that electrical energy consumption for those facilities was not reported accurately.

Facility	Built	Area (Sq Ft)	District	Average monthly kWh (electrcity)	Average Monthly kWh (electrcity)/sf	Average Monthly Electricity Cost	Avg. Monthly Electricity Cost/sf
Noble County County Garage	2012	10886	10	5,665	0.52	$ 464.05	$ 0.04
Holmes County Garage	2010	22600	11	1,556	0.07	$ 134.07	$ 0.01
Clinton County Garage	2009	32039	8	5,627	0.18	$ 541.27	$ 0.02
Pike County Garage	2009	22824	9	9,022	0.40	$ 1,456.80	$ 0.06
Logan County Garage	2008	22000	7	8,651	0.39	$ 877.50	$ 0.04
Marion County Garage	2007	11400	6	344	0.03	$ 1,419.66	$ 0.12
Ashtabula County Garage	2005	22000	4	21,271	0.97	$ 2,611.36	$ 0.12
Belmont County Garage	2005	18880	11	1,483	0.08	$ 221.81	$ 0.01
Fifth Avenue Outpost Garage	2005	5110	6	2,944	0.58	$ 1,017.01	$ 0.20
Hamilton County Garage (new)	2005	27500	8	23,489	0.85	$ 2,198.17	$ 0.08
Independence Garage	2005	6200	12	1,034	0.17	$ 637.89	$ 0.10
Wyandot County Garage	2005	20829	1	3,202	0.15	$ 450.52	$ 0.02
Fairfield County Garage	2005	18660	5	11,950	0.64	$ 1,104.96	$ 0.06
LAWRENCE COUNTY GARAGE	2005	22500	9	10,547	0.47	$ 1,095.59	$ 0.05
Auglaize County Garage	2002	22000	7	10,426	0.47	$ 1,117.42	$ 0.05
Franklin County Garage	2002	22307	6	7,447	0.33	$ 857.74	$ 0.04
Guernsey County Garage	2001	22000	5	13,023	0.59	$ 980.51	$ 0.04
Meigs County Garage	2001	22382	10	12,279	0.55	$ 2,638.11	$ 0.12
Montgomery County Garage	2001	22000	7	12,642	0.57	$ 1,229.38	$ 0.06
Morgan County Garage	2001	22000	10	12,959	0.59	$ 998.73	$ 0.05
Van Wert County Garage	2001	25008	1	178	0.01	$ 1,116.14	$ 0.04
Gallia County Garage	1999	21000	10	12,150	0.58	$ 1,311.36	$ 0.06
Champaign County Garage	1998	22000	7	10,899	0.50	$ 1,112.18	$ 0.05
Morrow County Garage	1998	22200	6	323	0.01	$ 1,249.38	$ 0.06
Scioto County Garage	1997	35000	9	8,511	0.24	$ 782.64	$ 0.02
Seneca County Garage	1997	36325	2	11,393	0.31	$ 990.09	$ 0.03
Williams County Garage	1997	36325	2	11,999	0.33	$ 1,123.67	$ 0.03
Milford Outpost Garage	1994	12460	8	5,952	0.48	$ 782.03	$ 0.06
Lake County Garage (New)	1993	33326	12	11,395	0.34	$ 2,226.94	$ 0.07
Delaware County Garage	1992	23760	6	8,160	0.34	$ 844.21	$ 0.04
Hocking County Garage	1992	15678	10	6,411	0.41	$ 510.44	$ 0.03
Muskingum County Garage	1992	16600	5	8,567	0.52	$ 654.00	$ 0.04
Butler County Garage	1991	27474	8	17,413	0.63	$ 1,891.44	$ 0.07
Defiance County Garage	1991	33800	1				
Northwood Outpost Garage	1991	31142	2	15,474	0.50	$ 1,846.80	$ 0.06
Ottawa County Garage	1991	28000	2	7,169	0.26	$ 727.63	$ 0.03
Ashland County Garage	1990	40083	3				
Mahoning County (Canfield) County	1990	29650	4	10,325	0.35	$ 1,003.22	$ 0.03
Shelby County Garage	1990	28140	7	17,491	0.62	$ 1,520.83	$ 0.05
Hancock County Garage	1989	31000	1	546	0.02	$ 1,075.31	$ 0.03
Mercer County Garage	1989	29000	7	11,743	0.40	$ 1,150.55	$ 0.04
Miami County Garage	1988	25000	7	13,040	0.52	$ 1,132.35	$ 0.05
Summit (Boston Heights) County Gar	1988	22110	4	16,542	0.75	$ 1,825.78	$ 0.08
Geauga County Garage	1987	16000	12	2,382	0.15	$ 669.23	$ 0.04
Knox County Garage	1986	15494	5	4,877	0.31	$ 369.55	$ 0.02
Wood County Garage	1986	18400	2	7,759	0.42	$ 654.23	$ 0.04
Erie County Garage	1985	14620	3	6,637	0.45	$ 609.02	$ 0.04
Hardin County Garage	1985	14620	1	179	0.01	$ 571.26	$ 0.04
Henry County Garage	1985	15200	2	6,328	0.42	$ 654.51	$ 0.04
Pickaway County Garage	1985	15132	6	7,784	0.51	$ 771.80	$ 0.05
Average					0.40		$ 0.05

Table 2.2. Average monthly electricity usage and cost for Pike County Garage

2.3 ODOT Maintenance Facilities' Gas Consumption Data

ODOT Districts 2, 6 and 9 have provided the research team with gas usage data for their maintenance facilities. The gas usage provided by these ODOT districts was for all their facilities for which the data was available. After comparing the electricity usage data and gas usage data, the research team has identified 13 maintenance facilities for which both gas and electricity usage data were provided. Those 13 facilities were studied in more detail and are listed in Table 2.3. Table 2.4 includes the natural gas consumption for one the ODOT garages, Pike County Garage.

District	Facility
2	Seneca County Garage
2	Williams County Garage
2	Ottawa County Garage
2	Wood County Garage
6	Marion County Garage
6	Fifth Avenue Outpost Garage
6	Franklin County Garage
6	Morrow County Garage
6	Delaware County Garage
6	Pickaway County Garage
9	Pike County Garage
9	Lawrence County Garage
9	Scioto County Garage

Table 2.3. List of the 13 ODOT maintenance facilities chosen for in-depth analysis and their districts.

Natural Gas (Ccf) (1ccf = 29.3kWh)				
Start Date	**End Date**	**For Month**	**N Gas Use (ccf)**	**Energy Cost**
8/2/2012	9/5/2012	Aug-12	26	$34.08
7/3/2012	8/2/2012	Jul-12	19	$29.51
6/4/2012	7/3/2012	Jun-12	19	$29.70
5/3/2012	6/4/2012	May-12	28	$33.87
4/3/2012	5/3/2012	Apr-12	67	$53.88
3/5/2012	4/3/2012	Mar-12	176	$121.71
2/3/2012	3/5/2012	Feb-12	1,142	$837.53
1/4/2012	2/3/2012	Jan-12	1,151	$842.31
12/5/2011	1/4/2012	Dec-11	1,114	$869.20
11/4/2011	12/3/2011	Nov-11	523	$419.88
10/4/2011	11/3/2011	Oct-11	337	$276.32
9/4/2011	10/3/2011	Sep-11	22	$35.61
8/4/2011	9/3/2011	Aug-11	40	$49.59
7/4/2011	8/3/2011	Jul-11	19	$33.09
6/4/2011	7/3/2011	Jun-11	17	$31.69
5/4/2011	6/3/2011	May-11	95	$103.69
4/4/2011	5/3/2011	Apr-11	178	$178.88
3/4/2011	4/3/2011	Mar-11	713	$644.52
2/4/2011	3/3/2011	Feb-11	1,180	$1,062.96
1/4/2011	2/3/2011	Jan-11	4,125	$3,914.37
12/4/2010	1/3/2011	Dec-10	1,189	$1,148.69
11/4/2010	12/3/2010	Nov-10	866	$821.40
10/5/2010	11/4/2010	Oct-10	99	$106.36
9/5/2010	10/4/2010	Sep-10	49	$63.32
8/5/2010	9/4/2010	Aug-10	24	$40.01
7/5/2010	8/4/2010	Jul-10	27	$41.86
6/5/2010	7/4/2010	Jun-10	41	$49.35
5/5/2010	6/4/2010	May-10	43	$44.21
4/6/2010	5/5/2010	Apr-10	90	$81.43
3/6/2010	4/5/2010	Mar-10	471	$369.45
2/4/2010	3/5/2010	Feb-10	2,085	$1,777.16

Table 2.4. Average monthly natural gas usage and cost for Pike County Garage

Charts showing the monthly natural gas consumption for each of the 13 facilities were developed. Figure 2.8 shows an example of such a chart for the Pike County Garage. A general observation for all facilities analyzed was that the December to March months consume the majority of natural gas to heat the facility in the winter. Only small amounts of natural gas are used in the summer months to provide hot water.

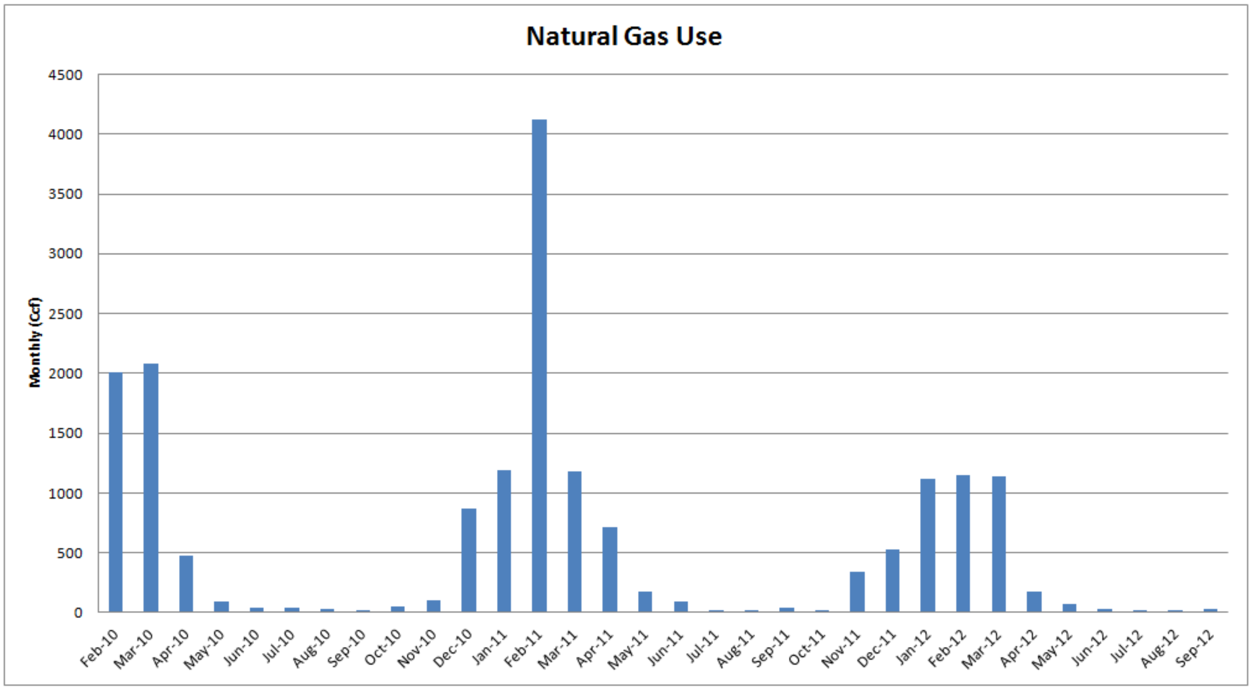


Figure 2.8. Pike county garage - monthly natural gas consumption (ccf).

2.4 ODOT Maintenance Facilities Total Energy Consumption

An analysis of the total energy consumption of the 13 facilities listed in Table 2.3 was performed. This was necessary to be able to compare the total energy consumed by these facilities to published data for comparable facilities as discussed in the following section. Since electricity consumption is typically reported in kWh where as natural gas consumption is typically reported in ccf (100 cubic feet), it was essential before calculating the total energy consumption to convert both electrical and natural gas consumption to a common unit. The common unit used was kWh and natural gas consumption in ccf was multiplied by a conversion factor (1ccf = 29.3 kWh) to determine the consumption in kWh.

Charts showing the total monthly energy consumption for each of the 13 facilities were developed. Figure 2.9 shows an example of such a chart for the Pike County Garage. Once again, a general observation for all facilities analyzed was that ODOT maintenance facilities use much more total energy in winter than in summer to meet heating requirements of the facilities.

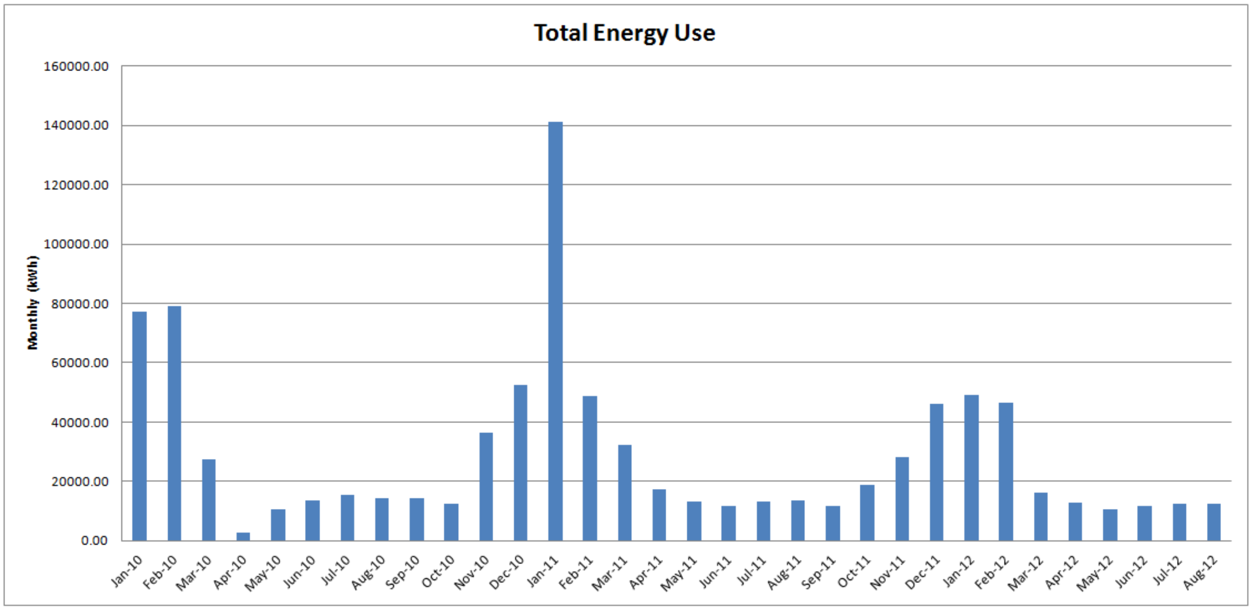


Figure 2.9. Pike county garage – total monthly energy consumption (kWh).

The analysis of total energy consumption for each ODOT facility also included calculating several performance indicators such as those shown in Tables 2.5, 2.6 and 2.7. Table 2.5 shows the average and maximum monthly total energy consumption for Pike County Garage. Table 2.6 shows the average monthly consumption and cost of electricity and natural gas for the Pike County Garage. Table 2.7 shows the percentage that electricity and natural gas account for - in terms of both energy (kWh) and cost ($) - for Pike County Garage. Analysis of Table 2.7 shows that although electricity account for 75% of the total energy cost, it only provides 43% of the total energy consumed. This trend was evident in all of the 13 facilities analyzed and can lead to the following conclusions:

- The source of most of the energy used in ODOT facilities is natural gas (57% for Pike County Garage). Natural gas is primarily used for space heating and hot water.
- Space heating requirements account for the majority of energy needs in ODOT maintenance facilities.
- The price of natural gas is relatively low compared to electricity. Since natural gas accounts for the majority of energy while it is only responsible for a small fraction of the total cost.
- With current low prices, ODOT facilities should continue using natural gas for space heating and hot water requirements if conventional fossil fuel based HVAC systems are to be used.
- A steep rise in natural gas price would have a large effect on the energy costs for ODOT facilities and would make renewable energy projects much more feasible.

Average total kWh (monthly)	28,838
Average kWh/sf (monthly)	1.263
Max kWh (month)	141,263
Max kWh/sf (month)	6.189
Average Cost (monthly)	$2,016.43
Average Cost/sf (monthly)	$0.09
Max Cost (month)	$6,206.67
Max Cost/sf (month)	$0.27

Table 2.5. Average and maximum monthly total energy consumption and cost for Pike County Garage

Average electric kWh (monthly)	12,290
Average electric kWh/sf (monthly)	0.538
Average electric cost (monthly)	$1,513.69
Average gas kWh (monthly)	16,548
Average gas kWh/sf (monthly)	0.725
Average gas cost (monthly)	$502.74

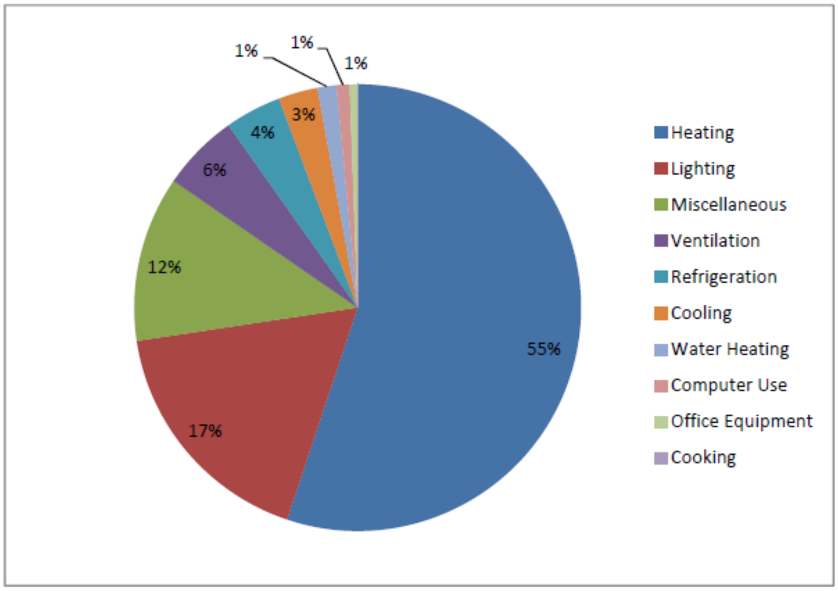
Table 2.6. Average monthly consumption and cost of electricity and natural gas for Pike County Garage

	Average monthly cost ($)		Average monthly Consumption (kWh)	
Natural Gas	503	25%	16,548	57%
Electricity	1,514	75%	12,290	43%
Total	$2,016.43		28,838	

Table 2.7. Average monthly consumption and cost of electricity and natural gas for Pike County Garage

2.5 Comparing ODOT Energy Consumption with Published Data

As discussed in (NCHRP, 2013) maintenance facilities have a number of unique attributes that contribute to an energy use profile that is quite unlike most other commercial buildings. For vehicle repair/service facilities, the 2003 Commercial Building Energy Consumption Survey (CBECS) identified the main drivers of energy use as heating and lighting, followed by process loads, which are categorized as "Miscellaneous" in Figure 2.10. Process loads are generally the equipment used in the servicing or repair of vehicles, including compressed air systems, welding, and any number of power tools used. The maintenance facilities typically have high ventilation demand, high heating demand in winter, and generally, no or little cooling in summer.



Source: CBECS 2003

Figure 2.10. Energy consumption by end use, vehicle service commercial buildings (Source CBECS 2003)

The energy consumption of a facility of any type will depend on its climate. So it is important when comparing actual energy consumption with published data to use data from similar climatic regions. The American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) has divided the US into climatic regions. Figure 2.11 shows the ASHRAE regions. A quick look at Figure 2.11 will reveal that most of ODOT maintenance facilities are in ASHRAE Region 5 while some are in ASHRAE Region 4.

Two sets of published energy consumption data for facilities that have similar energy use profile to highway maintenance facilities were used. One data set was developed by the 2003 Commercial Building Energy Consumption Survey (CBECS) and the second set was developed by the U.S. Army Corps of Engineers Construction Energy Research Laboratory (CERL) in conjunction with the National Energy Renewable Lab (NREL) (NCHRP, 2013). Table 2.8 shows published energy consumption data from both data sets for facilities in ASHRAE climate regions 4 and 5. Table 2.8 also shows calculated energy consumption data for Pike County Garage. As seen from Table 2.8, the Pike County Garage energy consumption is comparable to the values published by the NREL study.

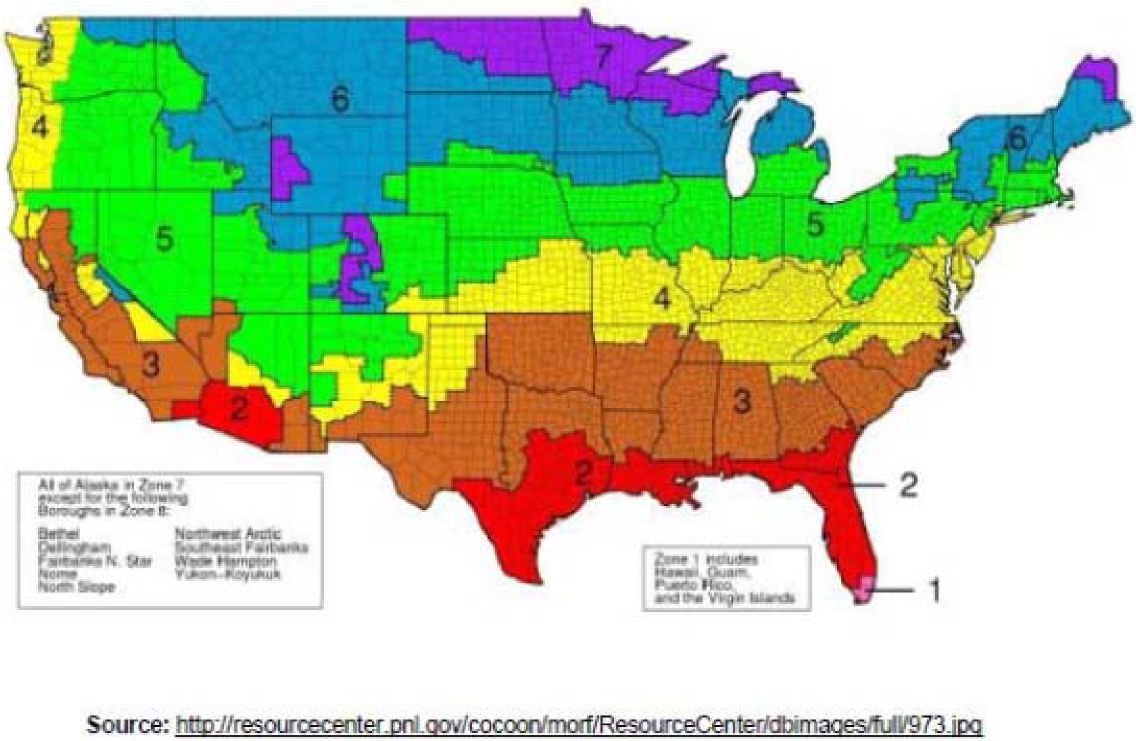


Figure 2.11. AHRAE climate regions (Source: ASHRAE)

Location	CBECS 2003		NREL		Pike County Energy Usage
	Baltimore, MD ASHRAE Region 4A	Chicago, IL ASHRAE Region 5A	Baltimore, MD ASHRAE Region 4A	Chicago, IL ASHRAE Region 5A	
kBtu/sf-year	92.90	99.88	54.85	67.85	51.71
kWh/m2-year	293.00	315.00	173.00	214.00	163.18
kWh/sf-year	27.22	29.26	16.07	19.88	15.16
kWh/sf-month	2.27	2.44	1.34	1.66	1.26

Table 2.8. Comparison of published energy consumption data for ASHRAE regions 4 and 5 to Pike county garage energy consumption.

2.6 Correlation of Energy Consumption with Weather Data

Because the literature indicated that most of the energy used by maintenance facilities was used on HVAC systems, it was important to collect weather data since weather impacts the energy consumption of HVAC systems. Weather data is widely reported in terms of heating degree days and cooling degree days. A heating degree day (HDD) is the number of degrees that a day's average temperature is below 65^{o} Fahrenheit. A cooling degree day (CDD) is the number of degrees that a day's average temperature is above 65^{o} Fahrenheit and people start to use air conditioning to cool their buildings.

To be able to correlate weather data with energy consumption, the research team collected weather data in terms of heating degree days and cooling degree days using the online resource "degreedays.net" for all 13 facilities evaluated. Figures 2.12 and 2.13 show the monthly heating degree days and cooling degree days for Pike County Garage respectively.

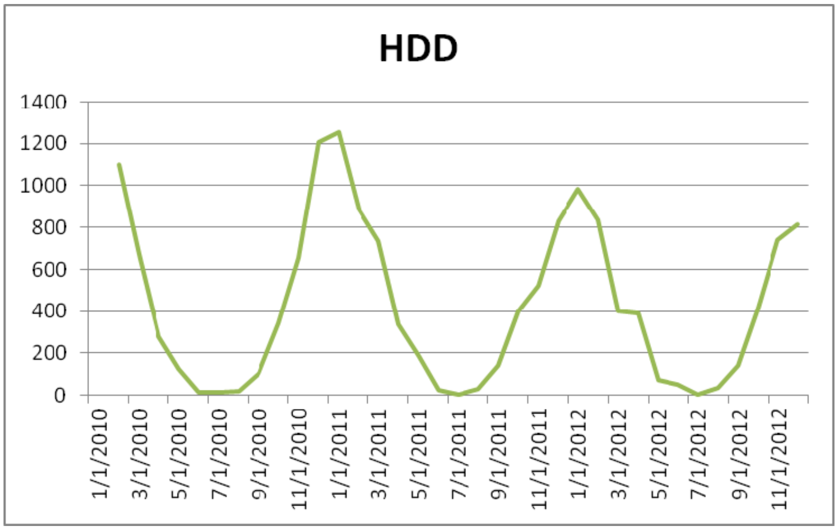


Figure 2.12. Monthly heating degree days – Pike County Garage

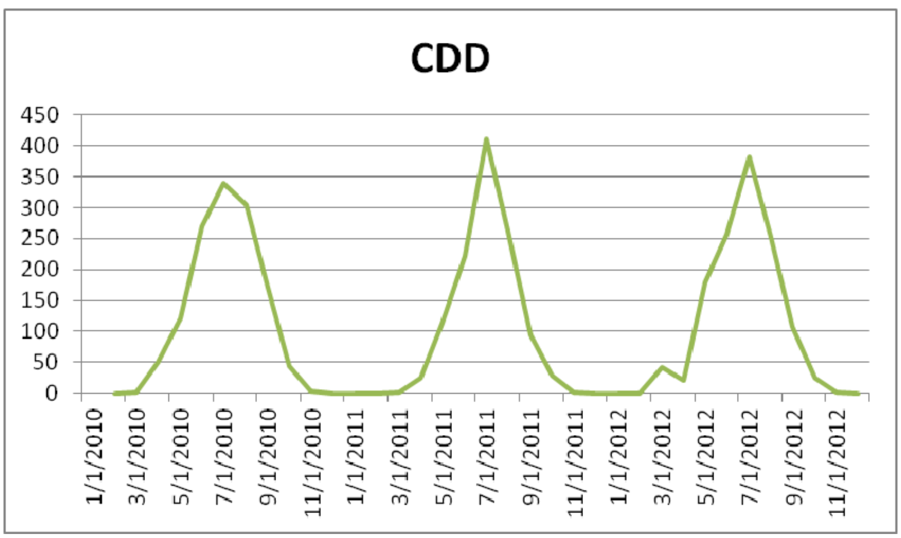


Figure 2.13. Monthly cooling degree days, Pike County Garage

The degree days' charts were then superimposed over the monthly energy use charts to identify any correlation between degree days and electricity and natural gas consumption. Figure 2.14 shows the heating degree days and natural gas consumption for Pike County Garage. Figure 2.15 shows the cooling degree days and electricity consumption for Pike County Garage and Figure 2.16 shows the heating degree days and electricity consumption for Pike County Garage.

The relationship displayed in Figures 2.14, 2.15 and 2.16 was consistent throughout the facilities. The natural gas consumption tends to follow the heating degree days trend steadily throughout the year. This was expected since natural gas is primarily used for space heating and hot water.

It was expected that the electricity consumption would follow the cooling degree days since the mechanical cooling is achieved with electrical air conditioning systems in the summer. However, as seen in Figure 2.15, the electricity consumption didn't follow the cooling degree days completely although in the summer, electricity slightly increase as the number of cooling degree days increase. When electricity consumption was plotted together with heating degree days as shown in Figure 2.16, it was noticed that electricity usage significantly increases with the increase in heating degree days in winter. A careful evaluation of the energy use profile of maintenance facilities has explained this trend; electricity is used more in the winter to run the exhaust fans used in building ventilation. These exhaust fans are not used in the summer since overhead doors are open in the summer to naturally ventilate the maintenance facilities.

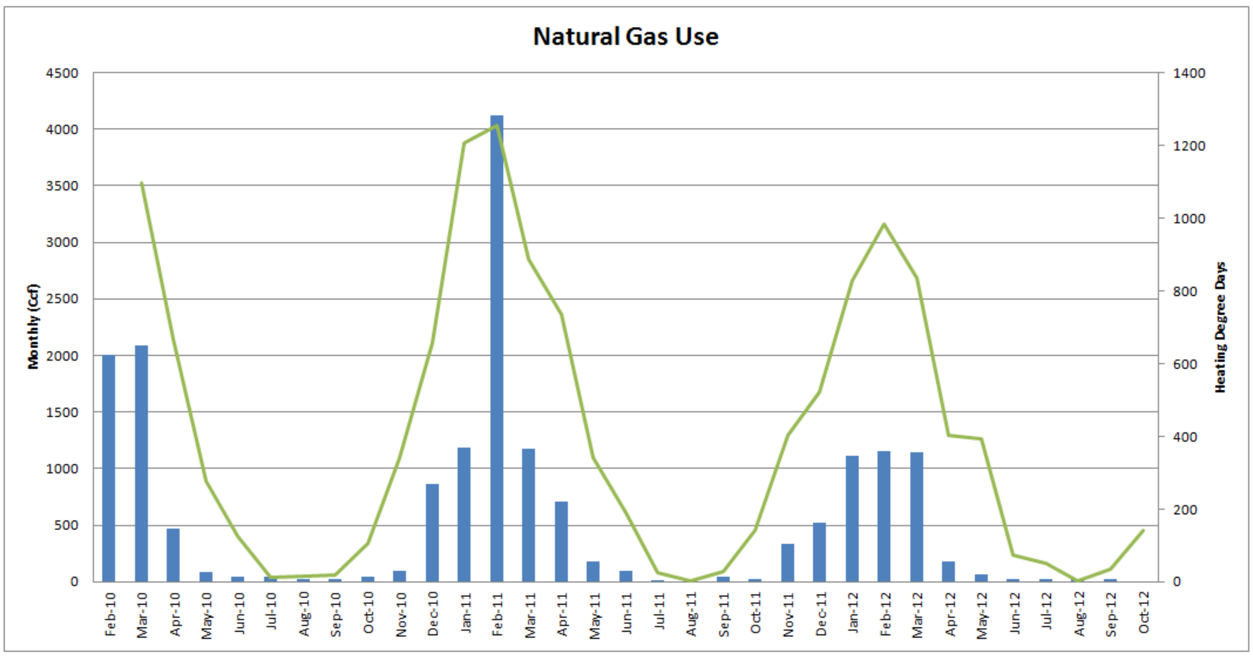


Figure 2.14. Heating degree days and natural gas consumption for Pike County Garage.

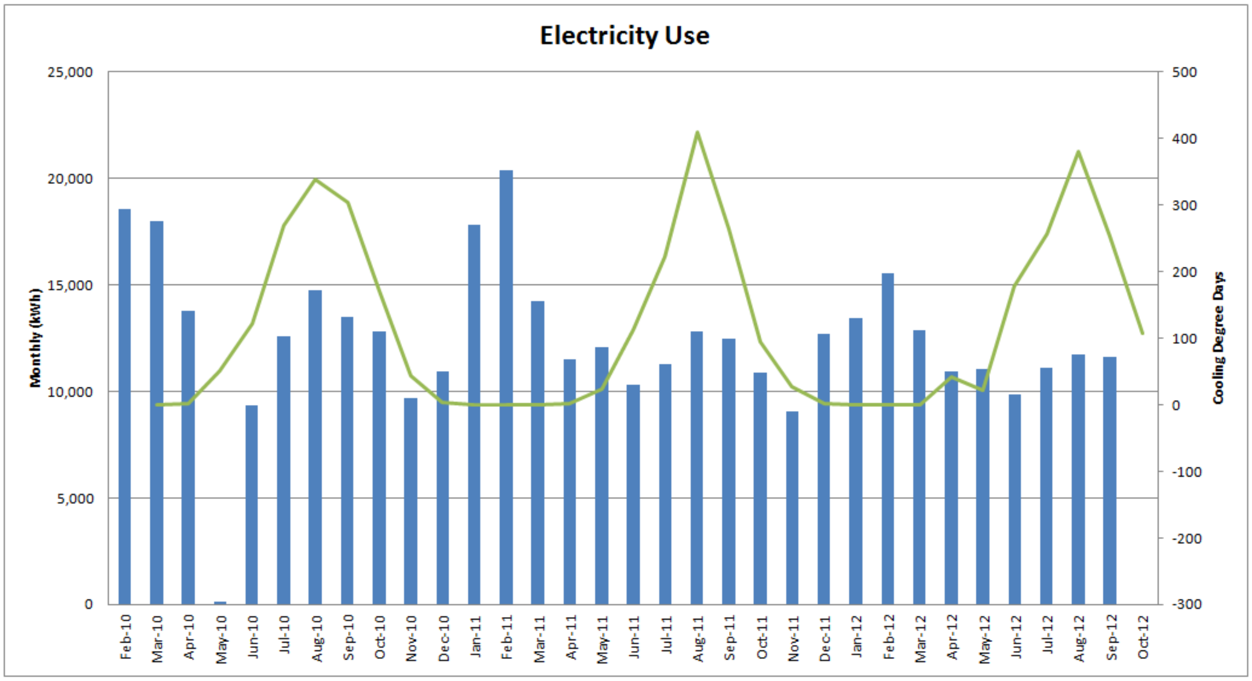


Figure 2.15. Cooling degree days and electricity consumption for Pike County Garage

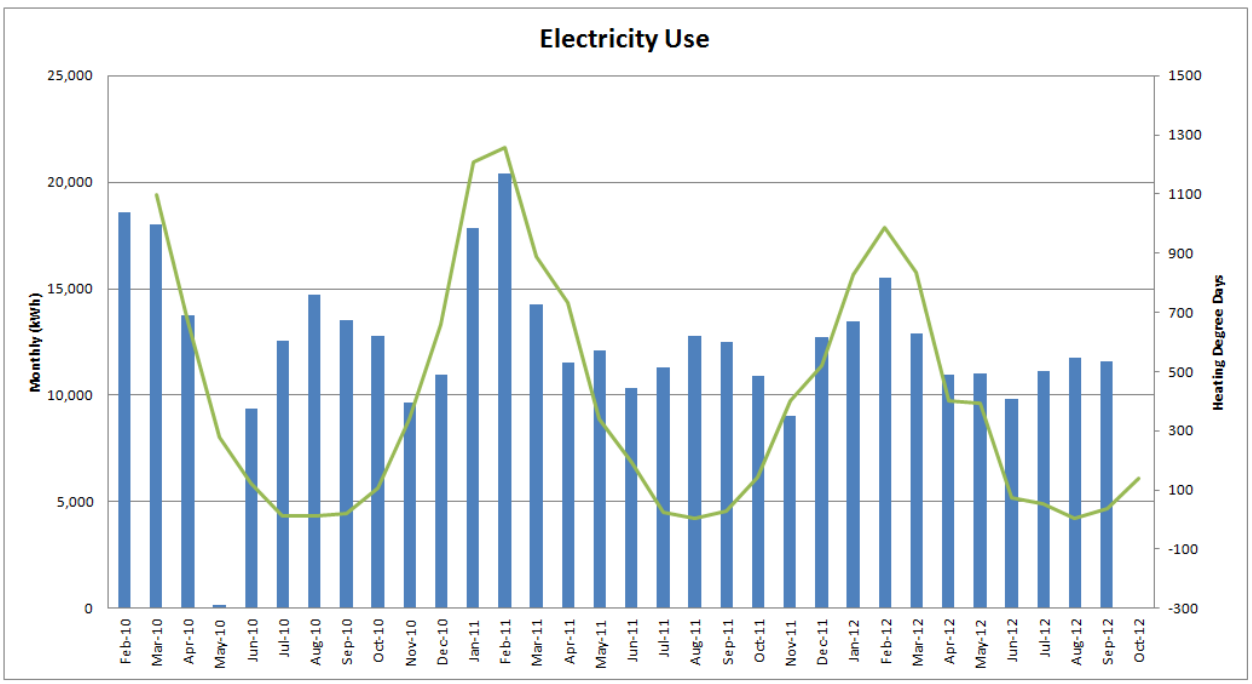


Figure 2.16. Heating degree days and electricity consumption for Pike County Garage.

CHAPTER 3 – LITERATURE REVIEW

The use of renewable energy technologies (RETs) has increased in recent years to reduce the consumption of fossil fuels and to protect the environment from their harmful effects. Generating electricity from fossil fuels, such as oil, natural gas, and coal, negatively affects the environment at each step of production and use, beginning with extraction and transportation, followed by refining and distribution, and ending with consumption (US Green Building Council, 2009a).

Renewable energy technologies provide more benign forms of energy and reduce green house gas (GHC) emissions from building energy use. Furthermore, renewable energy projects can help reduce energy costs associated with lighting, heating, cooling, and operating buildings. As global competition for fossil fuels accelerates, the rate of return on RETs improves. Currently, renewable power can be less expensive than traditional sources of power in some areas. Several federal, state, and utility incentives are available to reduce the initial cost of purchasing and installing renewable energy equipment. Net metering can offset on-site renewable energy costs because excess electricity generated on-site is sold back to the utility (US Green Building Council, 2009b), (NCHRP, 2011).

Recent federal energy policies have placed increased emphasis on increasing federal agencies' use of renewable energy and implementing renewable energy generation projects. President Obama signed Executive Order 13514 on October 5, 2009 with a goal to "establish an integrated strategy towards sustainability in the Federal Government and to make reduction of greenhouse gas emissions a priority for Federal agencies" (Executive Order 13514, 2009). EO 13514 sets requirements related to energy efficiency and GHG management that affect FHWA policy regarding business with federal and state partners. Compliance with EO 13514 provides a motivation for agencies including Ohio DOT to implement renewable energy projects. In addition, green building rating systems such as LEED rewards projects that utilize renewable energy sources (US Green Building Council, 2009a) (US Green Building Council, 2009b).

3.1 Research Studies on Renewable Energy in Transportation Facilities

Several research studies have been conducted to evaluate applicability of individual renewable energy technologies in transportation facilities. Sebnem conducted research at Ohio University to evaluate the performance of solar energy in a rest area located on Interstate Highway I-75 in Cincinnati. He monitored the effectiveness of the solar water heating system over a one year period and used life cycle cost analysis to compare the performance of conventional and solar water heating systems. He concluded that the solar system was able to cover 20% of the domestic hot water heating load throughout the year in 1991. He also estimated that the solar water heating system is more economical than the conventional system over a 20 year analysis period (Sebnem, 1992).

Chapman and Wiczkowski conducted a study for the Illinois Department of Transportation to evaluate the use of wind power for electricity generation at Illinois interstate highway rest areas, weigh stations, and team section buildings. The goal of their project was to determine the extent to which wind power could offset electricity costs, provide a reasonable return on investment, offset energy use, and provide educational opportunities. The study gathered and analyzed data on wind resources that are available at/near transportation facilities and evaluated the feasibility of using several commercially available wind turbines at these facilities. The cost of generating electricity using wind power was then estimated and compared to current electricity rates in Illinois. This study found that selected combinations of locations and wind turbines can provide electricity at competitive rates (Chapman & Wiczkowski, 2009).

Kreminski, Hirsh and Boand conducted a study for the Colorado Department of Transportation (CDOT) to evaluate the potential use of CDOT roadway right-of-way (ROW) and other transportation facilities for renewable energy production. They have estimated that the use of solar energy on CDOT ROW can generate approximately 55,500 GWh/year which is about 1% of Colorado's total 2007 electricity demand. They have also concluded that some CDOT facilities can make use of other sources of renewable energy including wind, geothermal, biomass and low impact hydro power (Kreminski, Hirsch, & Boand, 2011).

The objective of a recent NCHRP study was to develop technical and case study data on the use of solar or wind power as an alternative power source for a wide variety of transportation facilities (NCHRP, 2011). The study identified sources of information available that need to be accessed when evaluating viability of possible solar or wind applications and described a general design approach for locating RETs along the roadside, including what guidelines exist for locating structures within the actual right of way according to FHWA and AASHTO design manuals and guides. The study also explained how to apply Life Cycle Cost Analysis (LCCA) to DOT related RET systems.

A very recent NCHRP study developed a Renewable Energy Guide for Highway Maintenance Facilities (NCHRP, 2013). This national study of highway maintenance facilities and their renewable energy potential mirrored several of the goals of this research project. Its discussion of RETs and case studies from across the country helped to develop an understanding of which technologies would likely be good candidates and develop strategies for the analysis of Ohio facilities.

3.2 Renewable Energy Alternatives

The following RETs were researched to evaluate their economic feasibility in ODOT maintenance facilities:

- Solar photovoltaic systems for electricity generation
- Concentrating solar power for electricity generation
- Solar thermal for preheating ventilation air
- Solar thermal for water heating
- Wind turbines for electricity generation
- Passive solar heating
- Geothermal heat pumps
- Biomass and landfill Gas
- Hydropower

Based on the initial research, the following technologies were determined to be not practical for ODOT maintenance facilities:

- Concentrating solar power technologies produce electricity by concentrating the sun's energy using reflective devices, such as troughs or mirror panels, to reflect sunlight onto a receiver. The resulting high-temperature heat is used to power a conventional turbine to produce electricity. Concentrating solar power technologies are used on large scale solar power plants and are not feasible for ODOT maintenance facilities
- Passive solar heating involves the use of the building elements to capture and store solar thermal energy to meet heating demands. Passive solar heating works well for buildings that experience small air changes per hour (ACH). ODOT maintenance facilities have large ACH requirements because of high ventilation demands.
- Hydropower systems use hydro turbine generators to extract power from the movement of water between two different elevations. Site visits and survey results have determined the lack of hydropower resources at ODOT maintenance facilities.

The following sections discuss the various renewable energy technologies (RETs) that have been identified as potentially feasible in ODOT maintenance facilities. The discussion of these RETs includes a description of each RET; its efficiency; its associated costs; factors affecting its performance; and availability of its renewable resource in Ohio.

3.2.1 Solar air heating

<u>Description</u>

A solar air heating (SAH) system, also called solar ventilation air preheating and/or solar wall, is based on solar thermal energy and uses a solar heated surface to preheat ventilation air as it enters a building to lessen the energy burden of heating applications (U.S. Energy Information Administration, 2012). Solar air heating systems would benefit ODOT maintenance facilities since these facilities require large volumes of outdoor air to replace air contaminated from vehicles' exhausts, and vehicle repair and welding activities. By preheating ventilation air, SAH system reduces the consumption of conventional energy, such as natural gas or diesel fuel.

As shown in Figure 3.1, the SAH system consists of two parts: (1) a solar collector and (2) a fan and air distribution system. The most common style of collector for SAH is the transpired solar collector that is usually installed on the south facing wall in the form of a rain screen. The fan pulls ventilation air through the small holes in the dark colored solar collector into an air gap where the air becomes heated between the building's exterior wall and solar collector cover. Through convection, the heated air rises and is pulled into the buildings ventilation system and delivered throughout the building with the air distribution system. In the summer, a bypass damper is opened, avoiding an unnecessary load on the air-conditioning system. The bypass damper is controlled by an adjustable thermostat that senses outdoor temperature. The thermostat is typically set to open the damper when the outdoor temperature is warm enough to eliminate the need for heating (Enermodal Engineering Limited, 1997), (RETScreen International, 2004), (U.S. Energy Information Administration, 2012), (National Renewable Energy Laboratory, 1994). Figure 3.2 shows the flow of air in a SAH system.

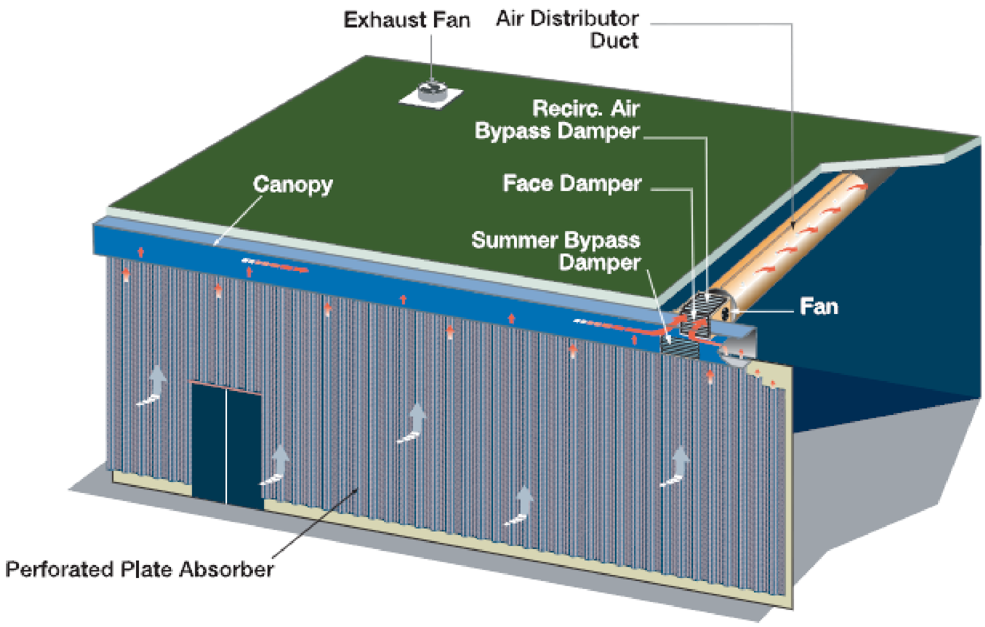


Figure 3.1. Components of a solar air heating system (RETScreen International, 2004)

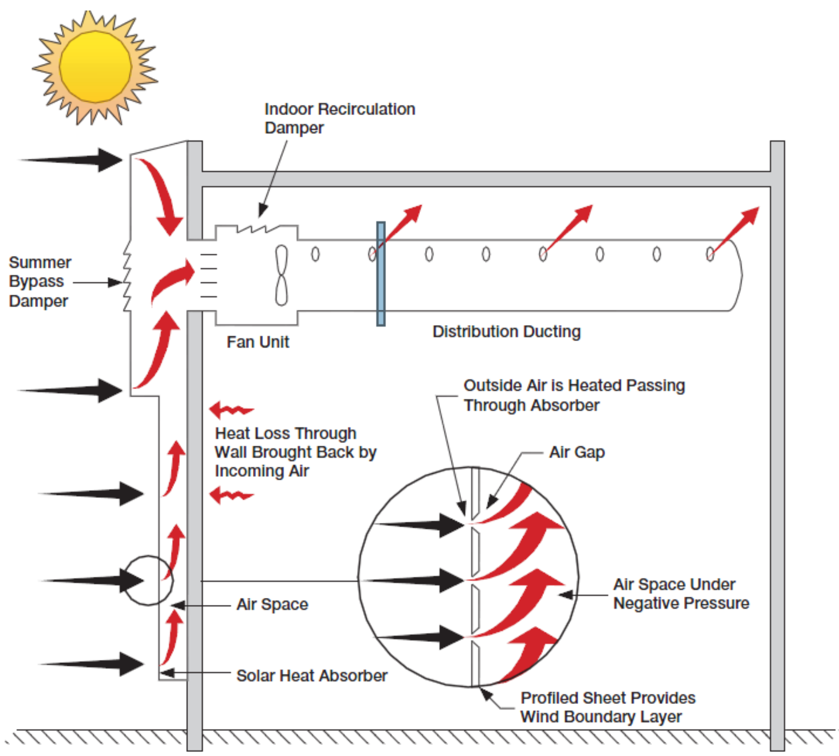


Figure 3.2. Air flow in a SAH system (Conserval Engineering, 2012)

Efficiency

Solar air heating systems save conventional energy in three different ways: (1) active solar energy gains; (2) building heat recapture savings; and (3) destratification savings. Depending on the type of building, only some of these savings may apply. All of these energy savings would apply to ODOT maintenance facilities, because of their wide-open configurations and high ceilings. The three modes of energy savings are further explained below (Enermodal Engineering Limited, 1997), (RETScreen International, 2004):

- Active solar energy gains: The SAH system preheats ventilation air as it enters a building to and reduces the consumption of conventional energy, such as natural gas or diesel fuel.
- Building heat recapture savings: The SAH system incorporates airspace between the cladding and the rest of the wall. This airspace provides extra insulation for the building. In addition, the building heat is recaptured by the airspace rather than being lost to the environment. Thus, a SAH system reduces heat losses through the wall on which it is installed.
- Destratification savings: In wide open buildings with large volumes, warm air rises and stays near the ceiling while cooler air stays below. When such stratification occurs, people at floor level are cold while heat is lost through the building roof. A SAH system installed in buildings experiencing stratification can be designed in a way that will mix solar preheated air with warm building ceiling air and deliver this air to the building as shown in Figure. This makes use of heat that would otherwise be lost through the ceiling or through roof-mounted exhaust vents. A properly designed solar air heating system that makes use of the hot air residing near the ceiling can completely replace conventional gas-fired make-up air heaters that would be installed to provide ventilation air with additional heat.

Figure 3.3 shows a schematic of a design of a SAH that takes advantage of destratification energy savings. In this design, dedicated ducts are used to distribute the solar-heated air around the ceiling. The ducting is typically made of flexible fabric with perforations to release air along the length of the duct near the ceiling. With such design, the air flow through the collector varies; a constant speed fan is combined with a recirculation damper system. The flow rate through the distribution ducts is constant, but the portion of this flow that is cool air drawn in through the solar air collector and the portion of this flow that is warm air drawn from within the building is continuously varied to achieve a specified mixed air temperature. The specified mixed air temperature is usually in the range of 15 to 18ºC. This is cooler than the desired building air temperature, so when this cool air is injected into the warm air near the building ceiling, the mixed air will be at the desired building temperature. Being cooler, this air will descend towards the floor. This achieves destratification and reduces the conventional heating required by the building (RETScreen International, 2004).

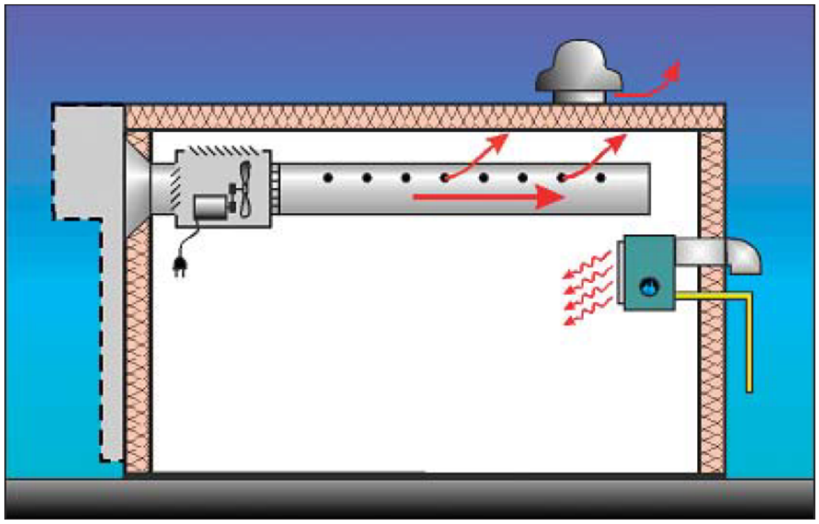


Figure 3.3. Schematic of SAH design that takes advantage of destratification energy savings (RETScreen International, 2004)

Factors affecting performance

The energy performance of a solar air heating system is influenced by a number of factors that include the amount of solar radiation hitting the solar collectors, the collector's orientation, the collector's color, the collector's size, shading of the collector and the number of hours that the solar air heating system is operating.

- The amount of solar radiation varies by location and climate. When evaluating a SAH project, a thorough analysis of available solar radiation is essential. The National Renewable Energy Lab (National Energy Renewable Lab, 2013) developed a variety of resources and tools to provide initial and detailed information on site-specific solar ventilation preheating projects. The NREL' s estimated energy savings utilizing SAH is shown in Figure 3.4. As shown in the Figure, most of Ohio should expect energy savings from SAH in the 200-400 kwh/m2 of wall/ year.

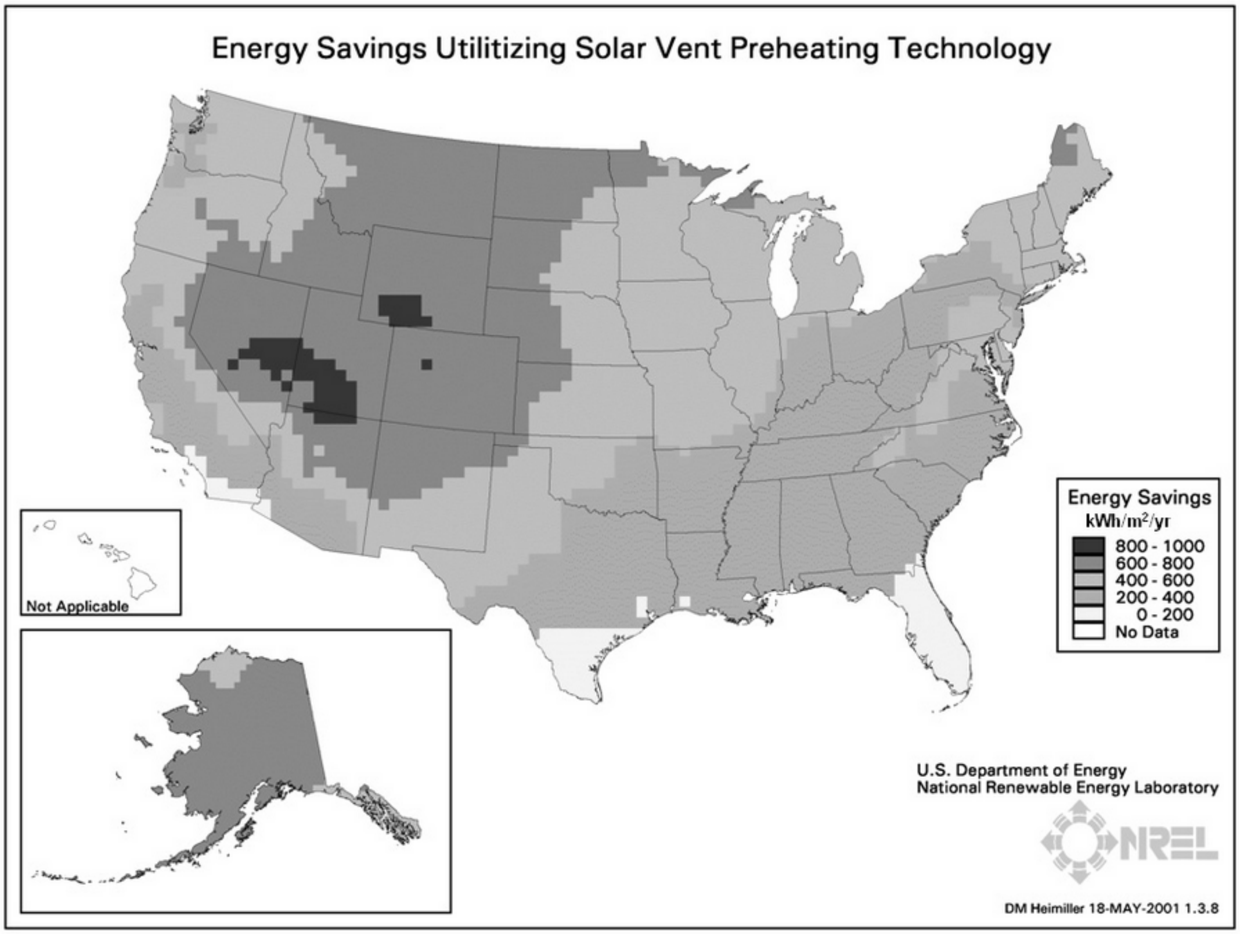


Figure 3.4. Estimated energy savings utilizing SAH (National Energy Renewable Lab, 2013)

- In the northern hemisphere, optimal performance is achieved for solar collectors that are south oriented. However, east and west-facing walls will still collect a reasonable amount of solar energy.
- The color of the collector should be dark, but it does not have to be black. Although black collectors will absorb more of the sun's energy than other colors, architectural considerations may dictate the use of other colors. Most dark colors can convert 80 to 95% of the sun's incident energy into heat, so changing from black to another dark color will not significantly reduce the collector output.
- The energy performance of SAH system improves the longer the building is occupied in the winter as the need for ventilation and solar air heating increases. This makes solar air heating more competitive in ODOT maintenance facilities where buildings are occupied for long hours on weekdays in winter and on some weekends and holidays in case of snow storms.
- Shading of the solar collector will reduce the energy performance of the SAH system. A shading analysis of the site should be performed to ensure that the performance is not significantly lowered due to shading.

Cost data
RETs' installation costs have an impact on their economic feasibility. Since RETs installation costs are decreasing as their technologies continue to improve, it is important to use the latest available cost information. NREL publishes RET installed cost information annually. The NREL 2012 report estimates that the mean installed cost of SAH system is $27/ft2. It should be noted that if the SAH is to be installed on a new project, the material and labor costs of regular cladding should be subtracted from the average installed cost since the collector replaces regular cladding. The cost of regular cladding is typically one third to one half of that of the purchase and installation cost of the collector (RETScreen International, 2004). Retrofit systems that may have significant integration costs (e.g. additional ductwork and fans) would price above the average installed cost.

According to NREL, there is no additional maintenance cost for the solar collectors which have the same maintenance requirements of the steel cladding they replace. However, there is an operating cost for the fan power required to draw intake air through the collector. This is estimated to be 1 Watt per square foot of collector when the system is operational.

3.2.2 Grid connected photovoltaic systems

Description
Photovoltaic (PV) systems convert sunlight into electricity. The main component of a PV system is a PV module or array made of individual PV cells. PV modules are integrated into systems designed for specific applications. The components added to the PV module constitute the "balance of system". For PV modules that are connected to the central grid, balance of system components typically include:

- Inverters - required to convert the direct current (DC) power produced by the PV module into alternating current (AC) power. AC power is used by many buildings' appliances and motors. Utility grids also use AC power and therefore grid-connected systems always require the use of an inverter.
- Structure - required to mount or install the PV modules. The structure should orient the PV modules in such a way that the modules will catch a reasonable amount of sunlight. The structure may be a tilted roof that, in the Northern Hemisphere, faces south.

Batteries are not necessary when the system is grid-connected. The major benefit of grid connected PV systems is that the utility is able to provide power during periods when there is no sunshine and the PV system output is not sufficient to meet the facility's loads. When the sun shines, the PV-generated electricity will power some or all of the loads in the building. This reduces the amount of electricity that the building owner must purchase from the grid. In an increasing number of areas, 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 (Leng, Dignard-Bailey, Bragagnolo, Tamizhmani, & Usher, 1996), (RETScreen International, 2004).

Efficiency
PV modules are rated on the basis of the power delivered under Standard Testing Conditions of 1 kW/m² of sunlight and a PV cell temperature of 25 degrees Celsius (°C). Their output measured

is expressed in terms of "peak Watt" (Wp) or nominal capacity. A 100 Wp array, for example, will furnish about 100 Watts of power if squarely oriented towards the sun at noon on a cool, clear spring day. When there is less sunshine, the array provides less power, but it is still called a 100 Wp array. At the vast majority of locations on the planet, a peak Watt of installed photovoltaic capacity oriented to catch the sun will generate between 800 and 2,000 Wh of energy per year (Leng, Dignard-Bailey, Bragagnolo, Tamizhmani, & Usher, 1996), (RETScreen International, 2004). For commercial buildings, the size of a PV system can be up to 100 kWp.

The capacity factor of a PV system is a good indication of the system's efficiency. The capacity factor is the ratio of the average power produced by the PV system over a year to its rated "nominal" power capacity. Typical values for photovoltaic system capacity factor range from 5 to 20%.

Factors affecting performance

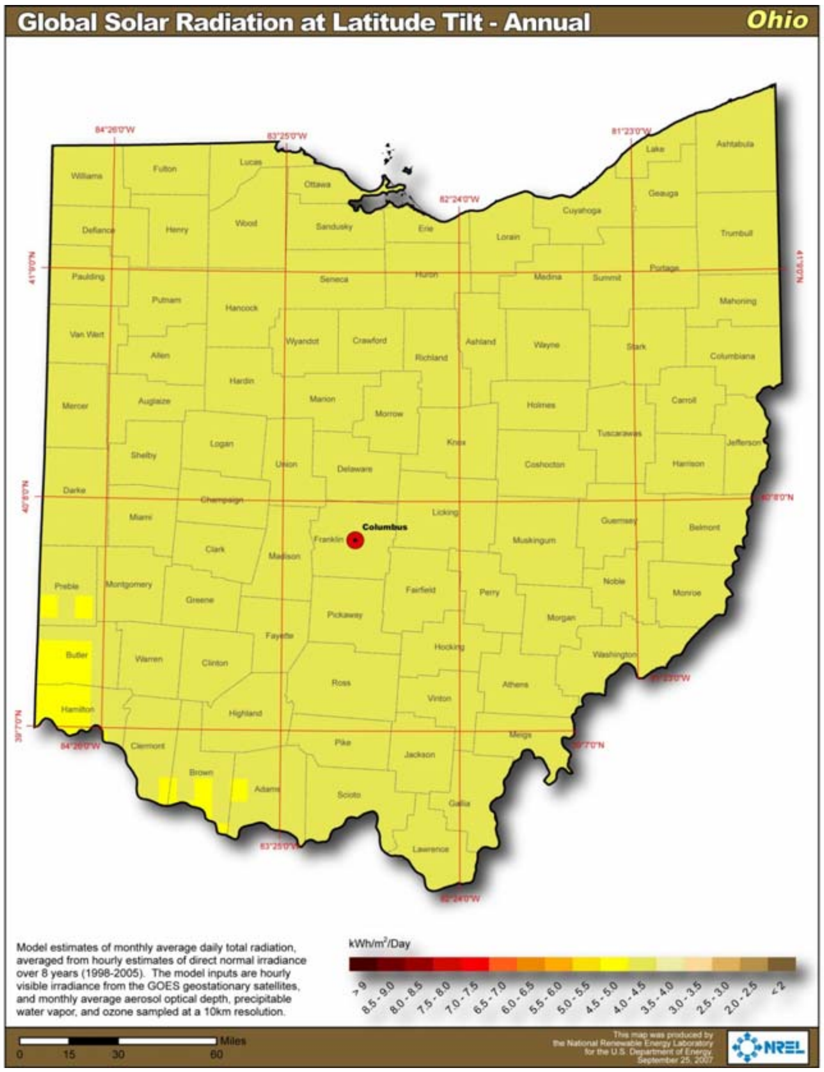
The energy performance of a photovoltaic system is influenced by a number of factors that include the amount of solar radiation hitting the solar collectors, the collector type, the slope and the orientation of the collector, shading and the solar tracking mode.

The amount of solar radiation varies by location and climate. When evaluating a PV project, a thorough analysis of available solar radiation is required. The National Renewable Energy Lab (National Energy Renewable Lab, 2013) developed a variety of resources and tools to provide initial and detailed information on site-specific solar radiation. Figure 3.5 shows the annual global solar radiation in Ohio at a tilt angle equal to the latitude. It is clear from Figure 3.5 that there is a modest solar resource available everywhere in Ohio.

The dominant type of PV module is based on crystalline silicon (c-Si) materials —either monocrystalline or polycrystalline. Amorphous silicon (a-Si)-based PV modules are also available that can be applied to flexible substrates such as metal roofing materials. Amorphous Silican PV modules tend to have lower efficiencies and somewhat lower costs per unit area. Other materials that are used in PV modules include cadmium sulfide (CdS), copper-indium-(di)selenide (CIS), cadmium telluride (CdTe), copper-indium-gallium-(di)selenide (CIGS). These are classified as "thin film" PV modules, because they require less semiconductor materials than crystalline silicon PV modules. The principal advantage of thin film PV modules is lower cost, and the ability to be applied to various substrates. In general, the efficiencies of thin film PV modules (11%) are higher than amorphous crystalline PV modules (7%), but lower than crystalline PV modules (14%) (NCHRP, 2013). The efficiency of the PV modules becomes more important when the area available for PV mounting is limited; the higher the efficiency, the less area that is needed.

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. Tilt angles of +/- 10 degrees from latitude, and orientations of +/- 30 degrees from true south do not significantly change performance (NCHRP, 2013). Some arrays are mounted on racks that move throughout the day to keep the array oriented towards the sun. These moving racks or "trackers" can increase the output of the array by 20 to 50%. However, they add moving parts and complexity to the photovoltaic system.

It is important to avoid shading of the PV modules since it may greatly reduce the PV system's output. Shading of PV modules from roof mounted equipment, building parapets and landscape elements should be analyzed. Sun path charts can be used to check for obstructions that could shade the solar modules during the course of the year. The University of Oregon's Solar Radiation Monitoring Laboratory provides a tool for generating sun charts for specific locations (University of Oregon, 2007). Shading of crystalline silicon PV modules particularly should be avoided as 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 (Leng, Dignard-Bailey, Bragagnolo, Tamizhmani, & Usher, 1996), (RETScreen International, 2004).



<u>Figure 3.5. Annual global solar radiation at a tilt angle equal to the latitude for Ohio (National Energy Renewable Lab, 2013)</u>

Cost data

PV system costs have been rapidly decreasing over the past few years so it is important to use the latest available cost information when conducting an economic analysis. NREL publishes RET installed cost information annually. The NREL 2012 report estimates that the mean installed cost of PV systems (10-100 kW) is $4,425/kW. According to NREL, the mean annual maintenance cost for these systems is $24/kW/year (National Renewable Energy Laboratory, 2012a). For grid connected roof mounted PV systems, the purchase of the array accounts for about 60% of the total cost of installing and operating the system over its entire lifetime. The inverter is responsible for about 15% of the life-cycle cost, and installation another 10% (RETScreen International, 2004).

3.2.3 Grid connected wind turbine

Description

Wind turbines produce electricity using the renewable kinetic energy from the wind. In grid connected wind turbines systems, the system feeds electrical energy directly into the electric utility grid. The major components of modern wind energy systems are show in Figure 3.6 and consist of the following (Rangi, Templin, Carpentier, & Argue, 1992) :

- Rotor, with 2 or 3 blades, which converts the wind energy into mechanical energy onto the rotor shaft;
- Gearbox to match the slowly turning rotor shaft to the electric generator. The gearbox is used to increase the rotational speed of the shaft between the rotor and the generator. In many wind turbines, such as the one shown in Figure 3.6, the gearbox and generator are located in a nacelle, mounted atop the tower;
- Tall tower which supports the rotor high above the ground to capture the higher wind speeds;
- Solid foundation to prevent the wind turbine from blowing over in high winds conditions
- Control system to start and stop the wind turbine and to monitor proper operation of the machinery.

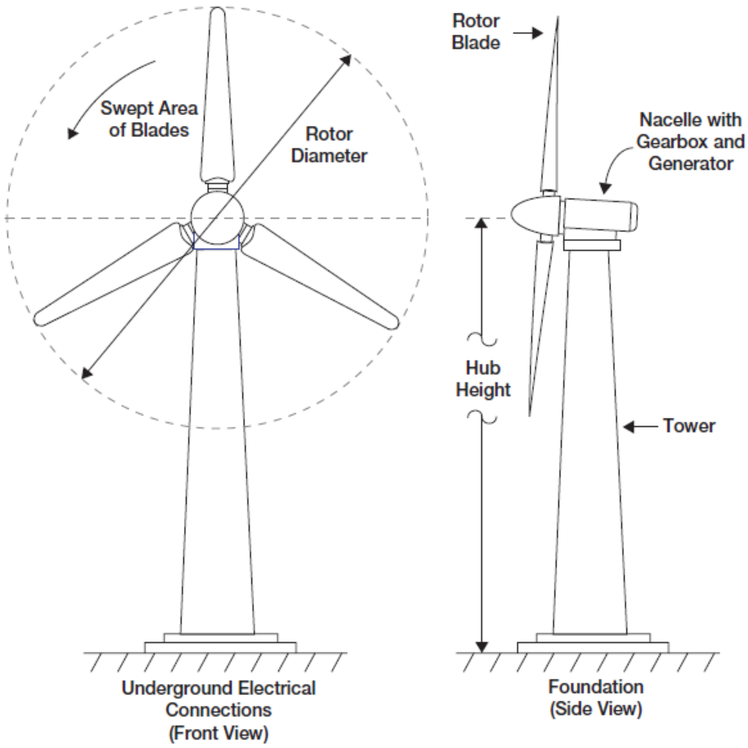


Figure 3.6. Components of a wind turbine (RETScreen International, 2004)

The controls operate the wind energy system automatically. An anemometer continuously measures wind speed. When the wind speed is high enough to overcome friction in the wind turbine drive train (about 4 m/s), the controls allow the rotor to rotate, producing power. Power output increases rapidly as the wind speed rises. The wind speed at which rated power is reached is called the rated wind speed of the turbine, and is usually a strong wind of about 15 m/s. Eventually, if the wind speed increases further, the control system shuts the wind turbine down to prevent damage to the machinery. This typically occurs when the wind speed reaches 25 m/s.

Efficiency

The size of a turbine is expresses in terms of its rated capacity in kW. The rated capacity is reached at the rated wind speed. Grid connected wind turbines are available in different rated capacities. While turbines installed, owned, and operated individually range from about 10 to 100 kW, turbines in wind farms are 1 MW or more. Turbines in the 10 to 100 kW range would be practical for highway maintenance facilities. Many municipalities, such as schools or government facilities, have successfully completed projects in this capacity range (NCHRP, 2013).

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 percentage of the energy that the turbine would produce if it could run at full rated capacity every hour of the year. Capacity factors can vary widely from much less than 20% to well over 30%, depending on the wind resource and the design of the turbine. This is why accurate resource assessment and optimized turbine siting are so critical for a successful project. A typical

CF for a large wind turbine installation in a site with good wind resource is about 30-40% (NCHRP, 2013). Small turbine projects typically, but not always, have a lower CF (in the 20-30% range).

Factors affecting performance
The energy performance of a wind power system is influenced by a number of factors that include the wind speed, the wind turbine power capacity, the type of wind turbine (i.e. vertical axis or horizontal axis, site terrain and nearby obstructions.

Wind speed
The performance of a wind turbine depends on the wind velocity. Not all areas are suitable for an installation of a wind turbine. Generally it is assumed that wind energy can be economically viable if wind speeds are higher than 4 m/s, measured at an altitude of 10 meters, or about 9 to 10 mph at 30 feet (RETScreen International, 2004). The energy generated by the wind turbine is not linearly related to the wind speed, but rather increases in proportion to the cube of the wind speed. This means that when the wind speed is doubled, 8 times more energy is generated. Thus, a good wind resource is critical to the success of a commercial wind energy project. The wind resource should be strong, steady with few periods of calm and few storm periods when wind speeds are too high to be used by the turbine. The amount of wind varies by location and climate. The National Renewable Energy Lab (National Energy Renewable Lab, 2013) developed a variety of resources and tools to provide initial information on solar resources. Figure 3.7 shows the Ohio 50m wind resource availability and also 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. The figure shows that, on a state level, the largest amount of opportunities for developing wind energy in the Ohio are found in the northern and north-western part of the state. It is important to note that since wind varies considerably, even over small areas, a proper wind resource assessment at the site should be performed during the feasibility study.

Terrain and Obstructions
Site terrain and nearby obstacles can affect the wind turbines' energy performance. The most favorable wind turbine location at a given site is typically at the highest elevation, has the smoothest land cover, and has few obstructions in the direction of the prevailing wind. Western or southwestern exposures are generally desirable inland. There must be sufficient land area for the wind turbine to provide adequate buffer between the turbine and nearby physical obstacles such as structures, and trees. Such obstacles can decrease wind speeds and increase turbulence that leads to greater fatigue failure of turbines. As shown in Figure 3.8, obstacle clearance guidelines recommend that the bottom of the turbine's rotor sweep should be sited at least 30 feet above obstacles within 500 feet of the turbine to avoid turbulent airflows (The Cadmus Group, 2012). Terrain is considered in analysis through Wind Shear Value. Table 3.1 shows different types of terrain and their associated wind shear values. One should note that the higher the shear value, the smaller the energy output of the turbine.

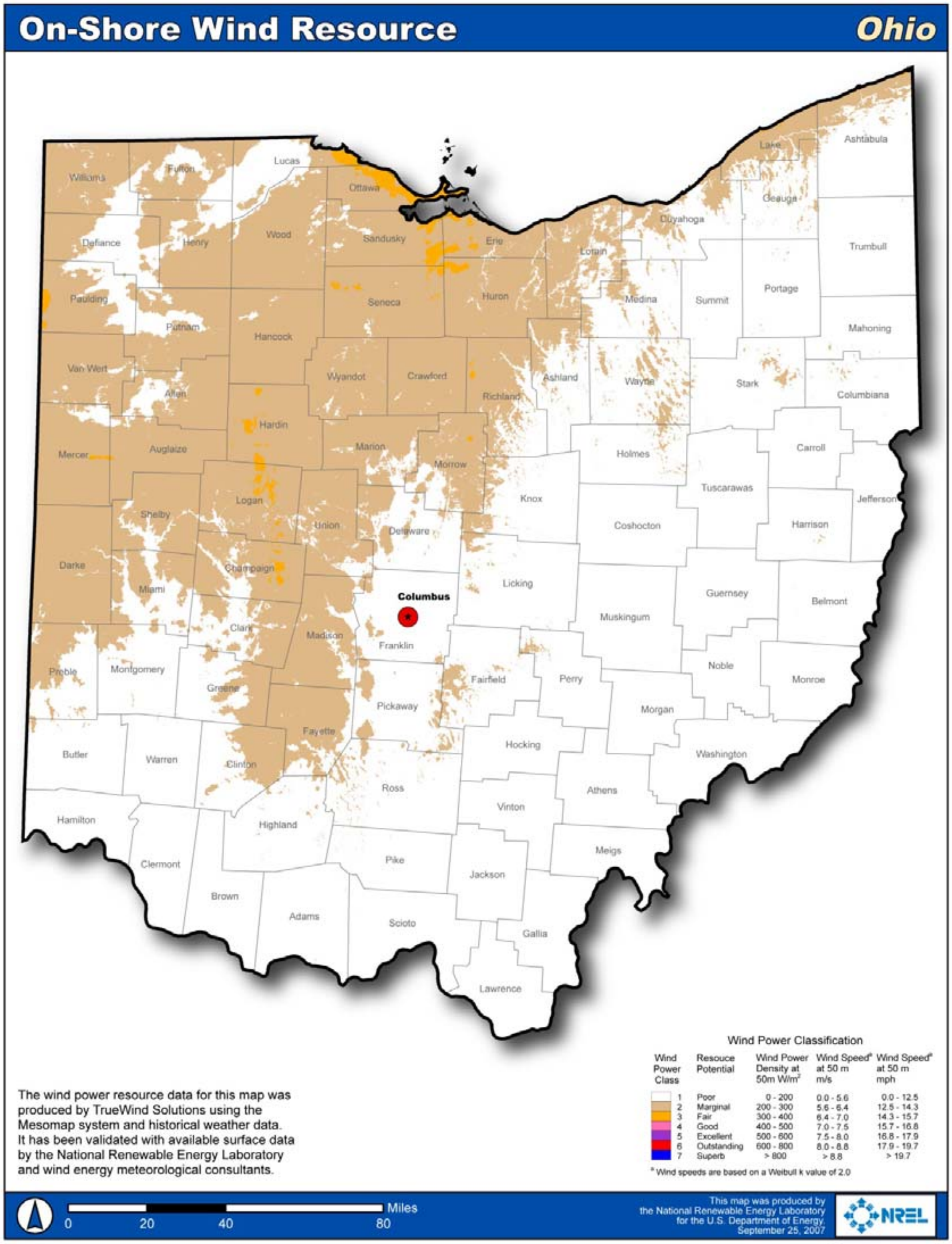


Figure 3.7. Ohio 50 m wind resource availability (Source: NREL)

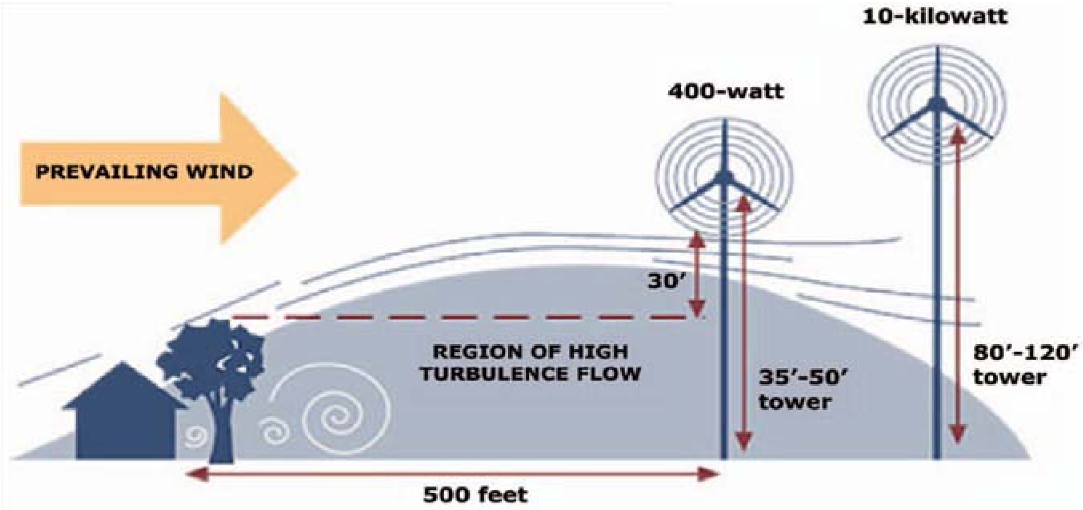


Figure 3.8. Obstacle clearance parameters for wind turbines (Source: http://www.smallwindtips.com/tag/tower-height/)

Land Cover Type	DSAT Terrain Roughness Category	Wind Shear Value (α)
a. Ice, open pavement, snow, level beach, water	Ice or pavement	0.08
b. Grass	Cut grass	0.15
c. Agricultural	Cropland/agricultural	0.21
d. Scattered	Scattered trees and hills	0.29
e. Sparse	Sparse forest	0.34
f. Suburban	Scattered buildings and suburban	0.34
g. Dense forest (50-100ft)	Dense forest	0.44
h. Urban	Urban	0.44

Table 3.1 Different types of terrain and their associated wind shear values (The Cadmus Group, 2012).

Type of wind turbine

Wind turbines are characterized by the axis around which the rotor blades rotate. The wind energy market has adopted the horizontal axis turbine as shown in Figure 3.9, for the vast majority of installations. Vertical-axis turbines as shown in Figure 3.10, are less efficient than horizontal-axis turbines but accept wind forces equally from all directions (Federal Energy Managment Program , 2009). Although they permit the generator, gearbox, and other components to be situated near ground level, where they can be easily maintained, vertical axis turbines are relatively rare. Figure 3.10 shows an example of a vertical axis wind turbine.

Figure 3.9. Horizontal axis turbine at ODOT Northwood outpost facility

Figure 3.10. Vertical-axis turbine. Source: http://www.windspireenergy.com/case-studies/missouri-department-of-transportation/attachment/mdot_2/

Tower height

Wind speed typically increases with height above the ground, so when discussing wind speeds, the height of the wind speed measurement must be specified. At minimum, the annual average wind speed for a wind energy project should exceed 4 m/s, or 14 km/h, at a height of 10 m above the ground; commercial wind farms are usually sited at locations with average wind speeds significantly higher than this.

Cost data

There is a steep declining unit cost curve ($/kW) as the size of a wind turbine and wind project increases. NREL publishes RET installed cost information annually. The NREL 2012 report estimates that the mean installed cost of Wind energy systems is $6,066/kW for systems that are 10 kW to 100 kW in capacity. According to NREL, the mean annual maintenance cost for these systems is $44/kW/year (National Renewable Energy Laboratory , 2010b). In addition to the initial costs and the regular operation and maintenance costs, there will be the costs associated with major equipment repair. It can be expected that over the lifetime of the turbine at least one major component, costing 20 to 25% of the initial costs, will need replacement. Rotor blades and gearboxes are the components most likely to need attention (RETScreen International, 2004).

3.2.4 Solar water heating systems

Description

A solar water heating (SWH) system uses the sun to heat a fluid in solar collectors, which are generally mounted on the roof. The heated water is then stored in a hot water storage tank similar to a conventional gas or electric water tank. In almost all climates a conventional backup system is necessary to make sure the water is heated up to the desired temperature. A SWH system typically uses one of two types of collectors: (1) Flat-plate collectors, and (2) Evacuated-tube collectors. Flat-plate collectors are the most commonly used solar collectors. The evacuated tube solar collectors provide higher temperature water and are more efficient in colder ambient conditions than flat plate solar collectors (Federal Energy Managment Program , 2009).

Solar water heating systems can be configured in a number of different ways, and the components they contain vary from system to system. A closed-loop solar water heating system as shown in Figure 3.11 is commonly used in Ohio, where the possibility of freezing is prevalent. This system uses a heat exchanger, which transfers the heat from the hot fluid coming from the collectors to the domestic water. The solar-heated water is kept in a hot water storage tank, which permits the system to store heat from sunny periods for use during non-sunny periods of up to several days. In solar systems that are not designed to meet the entire hot water demand year-round, a conventional gas or electric water heater in the hot water tank will raise the temperature of the water to the desired level. In this closed loop system, the fluid in the solar collectors remains completely separate from the domestic hot water. This permits the addition of antifreeze, such as glycol, to the collector loop. In cold climates, another way to protect the system against freezing is the use of a drain-back tank: the heat transfer fluid is pumped up from a tank in the heat exchanger to the collectors, and then drains back down to the heat exchanger by gravity. During freezing periods, the system is not operated and all water drains from the collectors (RETScreen International, 2004)

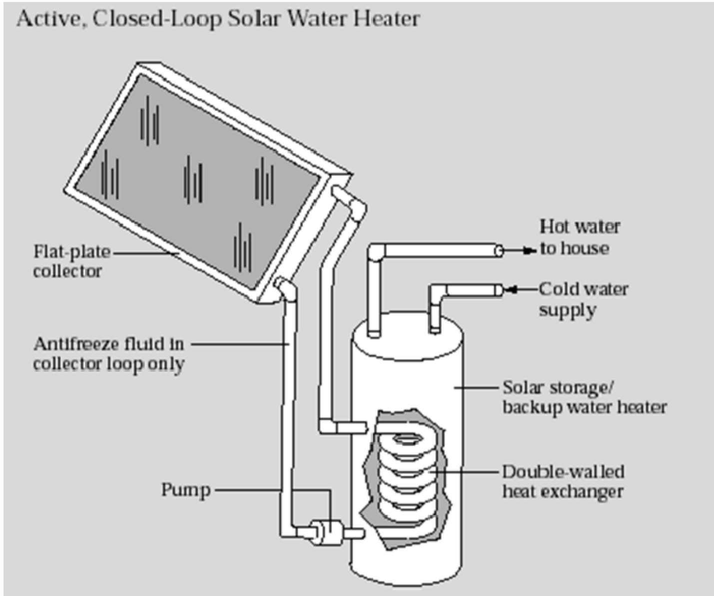


Figure 3.11. Example of an active, closed-loop solar water heating system (source: http://www.solardev.com/FSEC-solar-heating.php)

Factors affecting performance

The energy performance of a solar water heating system is influenced by a number of factors that include the amount of solar radiation hitting the solar collectors, the slope and the azimuth (physical orientation) of the solar collector, the collector type (e.g. flat plate or evacuated tube), and the collector. Performance also depends on the incoming temperature of the water. The colder the water, the more efficiently the system operates. It is important to properly size the SHW system to improve its cost effectiveness. A larger than needed system will generate hot water in excess of the daily demand, and is therefore wasted. The amount of wasted hot water is also affected by the hot water storage capacity of the system.

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. In general tilt angles of +/- 10 degrees from latitude, and orientations of +/- 30 degrees from true south do not appreciably change performance (NCHRP, 2013). It is essential to avoid shadow on the SHW collectors. Even a small line of shadow falling on a SHW collector will reduce its output.

Cost data

NREL publishes RET installed cost information annually. The NREL 2012 report estimates that the mean installed cost of SWH is $137/ft2 of collector. According to NREL, the mean annual maintenance cost for these systems is 0.5 to 1.0 % initial installed cost/year (National Renewable Energy Laboratory, 2012b).

3.2.5 Ground source heat pump

Description

A ground source heat pump (GSHP) is a green and sustainable technology that utilizes the earth's energy to help heat and cool buildings. Ground source heat pumps operate similarly to air source heat pumps, but use the heat in the ground, groundwater, or surface bodies of water, such as ponds, lakes or streams, as the heat source/sink. They have a large advantage over air source heat pumps, in that they don't suffer from low performance in winter when air temperatures fall below about 40 degrees Fahrenheit. The relatively constant and higher winter-time temperature of the earth, as opposed to the variable air temperatures, is what makes geothermal heat pumps more efficient than air source heat pumps for heating. The temperature of the air changes significantly with seasons; however, the temperature inside the earth is much more stable. Therefore, the ground is warmer than the outside air in the winter and cooler than the outside air in the summer. GSHPs use this concept to provide a mechanism to use renewable underground energy as a source of heating and cooling. This technology provides heating or cooling by moving heat from/to earth rather than creating heat as in traditional furnaces. In the winter, this system extracts heat from earth and uses it to heat buildings. In the summer, this system takes the heat from the building and dumps it into the ground (El-Rayes, Liu, & Abdallah, 2011). Properly sized and installed GSHP systems can reduce energy consumption by over 40 percent (NCHRP, 2013).

As shown in Figure 3.12, a ground-source heat pump system has three major components: (1) a heat exchanger that transfer heat into or out of the ground or water body, (2) a heat pump, and (3) an interior heating or cooling distribution system. The heat exchanger may be buried in the ground, in which case it is called a ground-coupled system, or submerged in a lake or pond, in which case it is called a surface water system. The heat exchanger is made of underground loops of high-strength polyethylene pipes filled either with water in regions with temperature ranges above water freezing point or anti-freeze in northern regions of the U.S. The heat transfer fluid circulates in the pipes and into the heat pump unit inside the building. The circulating fluid extracts or discharges heat from or into the ground in order to heat or cool the building. Eventually, the ventilation ducts or the distribution system is used to distribute heating or cooling throughout the building (El-Rayes, Liu, & Abdallah, 2011). For larger commercial buildings there are usually multiple heat pumps (perhaps one for each zone) attached to the heat exchanger through a building loop. This provides greater control of the conditions of each zone, and even heat exchange between zones. For example, sunny rooms can extract excess heat and redistribute it to cooler areas of the building.

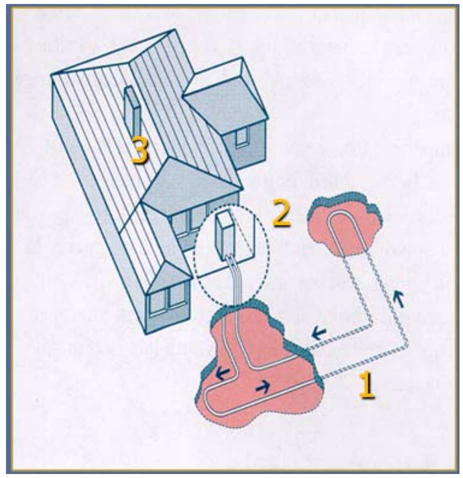


Figure 3.12. Components of a ground source heat pump (RETScreen International, 2004)

As shown in Figure 3.13, four types of geothermal HVAC systems are available which are classified based on the configuration of the underground loops used as the heat exchanger. Three of these (horizontal, vertical, and pond/lake) are closed-loop systems. The fourth type is the open-loop system. In close loop systems, the heat transfer fluid flows from the heat pump, located inside the building, around the outdoor heat exchanger, and back to the heat pump. In the open loop system, the heat transfer fluid is groundwater that is drawn from a well, which is fed to the heat pump and then flows back into the ground.

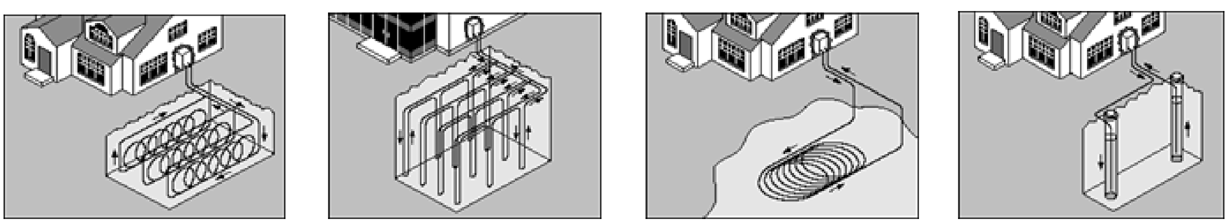


Figure 3.13. Types of ground source heat pumps. From left to right: horizontal (looping), vertical, pond/lake and open-loop system (RETScreen International, 2004).

Adequate selection of which type of GSHP to use depends on the climate, soil conditions, available land, and local installation costs at the site (El-Rayes, Liu, & Abdallah, 2011).

- The horizontal system is most cost-effective for residential installations and small commercial buildings, particularly for new construction where sufficient land is available. In the horizontal system, the underground pipes are buried, usually between 1 and 2 m below the surface, in one or more horizontal trenches. Supply and return headers connect the trenches in parallel. The pipes may be laid straight in the trench or a looping pipe allowing more pipes in a shorter trench could be used. In typical horizontal heat exchangers about 35 to 55 m of pipes are installed per kW of heating and cooling capacity.
- The vertical system is suitable for large commercial buildings and schools because it requires less land area. The vertical system makes most sense where land area is limited, where disruption of the landscape must be minimized, and when the ground is rocky near

the surface and therefore trenching would be difficult. Heat transfer occurs in a series of vertical boreholes drilled 45 to 150 m into the ground. The heat exchanger pipe runs down to the bottom of the hole and then back to the surface. Of the four methods, vertical well fields extract the most amount of energy from the smallest area of land.

- The pond/lake system uses a supply line pipe that is run underground from the building to a water body and coiled into circles. This system may be the lowest cost option if the site has an adequate water body. The water body should meet minimum volume, depth, and quality criteria. This will ensure adequate heat source availability and prevent the possibility of icing of the coils.
- The open-loop system uses water from wells or surface water bodies as the heat exchange fluid that circulates directly through the GSHP system. Once it has circulated through the system, the water returns back to the ground fluid source. This system is only practical where there is an adequate supply of relatively clean water, and all local codes and regulations are met.

<u>Efficiency</u>

The GSHP requires electricity to run the compressor, fans, circulation pumps, and controls, but the heating or cooling energy provided by the system is generally four times the electrical energy consumed. This 400% efficient operation compares favorably with electrical resistance heating, which cannot exceed 100% efficiency, and reduces electricity consumption compared to conventional air conditioners and air-source heat pumps by 30 to 70% for heating and 20 to 50% for cooling. The heating efficiency of GSHPs is indicated by the coefficient of performance (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 (NCHRP, 2013). When compared to even the most efficient gas technologies, ground-source heat pumps can save significant quantities of energy (RETScreen International, 2004).

<u>Factors affecting performance</u>

The energy performance of a ground source heat pump (GSHP) system is influenced by a number of factors that includes the heat pump capacity, the heating seasonal efficiency and/or the cooling seasonal coefficient of performance (COP), as well as the ground heat exchanger (GHX) type (i.e. horizontal or vertical ground-coupled closed loop or groundwater) and length, as well as the site conditions such as the soil type and the earth temperature. Another important factor that affects the GSHP performance is the size and the type of the heating and cooling load.

<u>Cost data</u>

The geothermal heat pump costs approximately $2,500 per ton of capacity (California Energy Commission, 2008). The underground loop varies in cost according to the loop system and type of soil. The average horizontal loop system cost is $2,750 per ton of capacity while, the average vertical loop system cost is $3,200 per ton of capacity (Kozlowski, 2007). The construction cost of the underground loop heat exchanger varies significantly with the soil type. The underground loop has a very long lifetime and the piping materials usually have a long warranty period of up to 55 years. With quality and proper installation, the underground loop has a life expectancy of over 100 years. Once the underground loop is installed, it won't have to be replaced for a very long time, even if the heat pump needs replacing after 20+ years.

The maintenance cost of GSHP systems is estimated as annual expenses per square footage of the building. The annual average maintenance cost of GSHP systems is $0.13/SF/year (Bloomquist, 2001). The heat pump will need to be replaced after 20 years of installation with the same installation cost of $2,500 per ton of capacity.

For new construction, if the project is not getting a GSHP, it would still need a conventional heating and cooling system. The cost of the conventional system should be subtracted from the cost of GSHP when conducting a feasibility analysis for a new project. On existing buildings where conventional heating and cooling systems already exist, their costs cannot be subtracted and as a result the payback period is going to be longer.

3.2.6 Biomass heating systems

Description

A biomass heating system burns organic matter to generate heat. This heat is transported and used wherever it is needed for the ventilation and space heating requirements of a building. Biomass heating systems differ from conventional wood-burning stoves and fireplaces in that they typically control the mix of air and fuel in order to maximize efficiency and minimize emissions, and they include a heat distribution system to transport heat from the site of combustion to the heat load.

Factors affecting performance

A wide range of low-cost matter can be used as biomass feedstock. This includes wood and wood residues in chunk, sawdust, chip, or pellet form; agricultural residues such as straw, husks, animal litter, and manure; fast-growing energy crops grown specifically for biomass combustion, and municipal solid waste.

The type of biomass that should be used will vary with what is available as a supply. A major consideration is proximity to a reliable supplier for this renewable resource. Figure 3.14 shows a biomass resource map developed by NREL that provides a general idea of the amount of biomass available in Ohio.

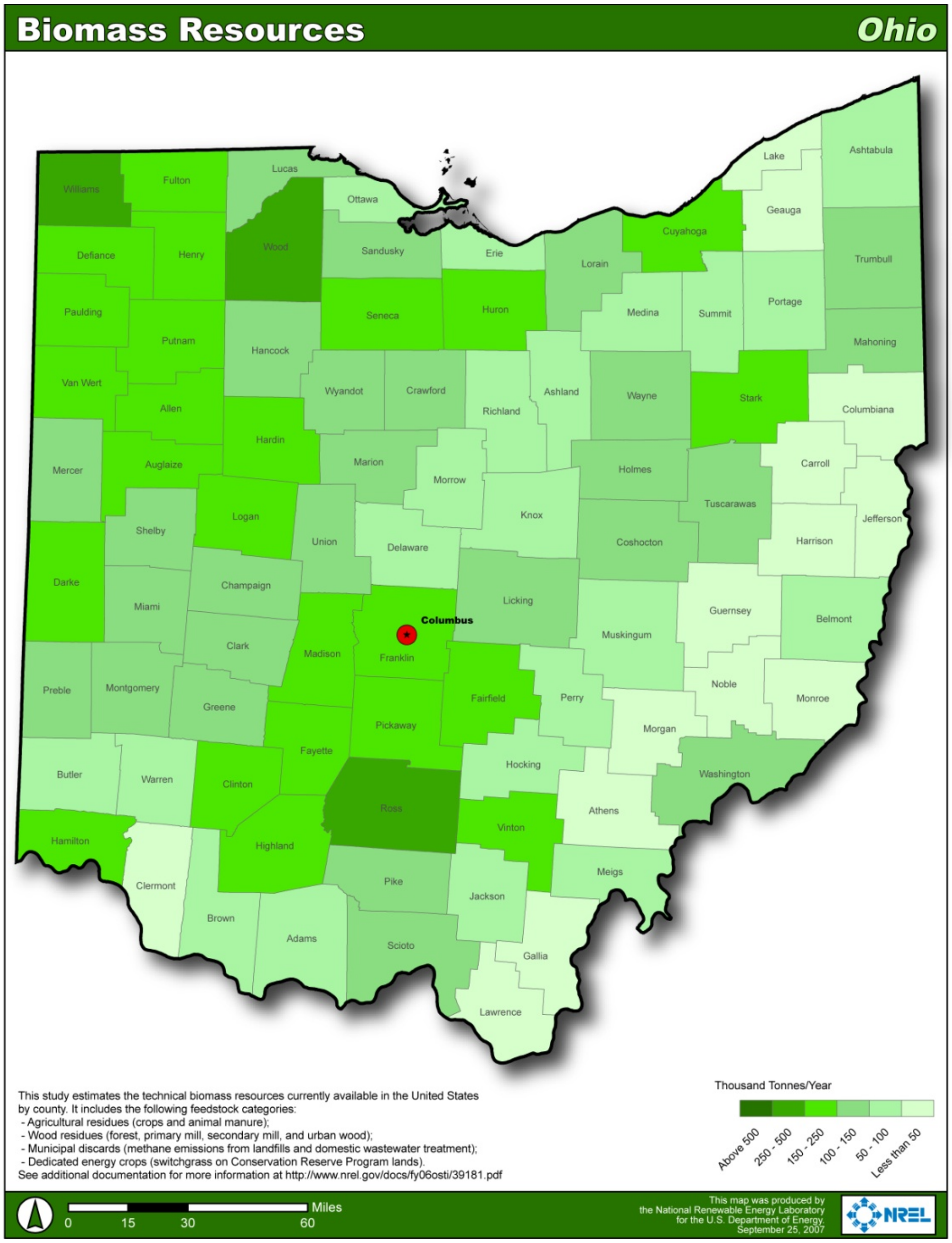


Figure 3.14. Biomass resource availability in Ohio (National Energy Renewable Lab, 2013)

Biomass furnaces/boilers that use either pellets or wood chips are the most common biomass heat equipment. Equipment efficiencies range from 70% - 85%. Pellets cost about $200/ton and have a heat content of about16 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 (NCHRP, 2013).

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 pre-treatment or clean-up 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 (NCHRP, 2013).

CHAPTER 4 – ON-SITE ASSESSMENT

4.1 Survey

After the initial data collection and analysis, a more detailed study of individual facilities was completed. This was done in the form of a survey sent to the 13 selected facilities and site visits to 5 of the facilities. The survey was developed to determine what types of equipment were used in facilities and how frequently they were used, as well as if any forms of energy efficient measures were being utilized. A draft survey was initially sent out to select ODOT personnel for feedback and then a final version with comments incorporated was sent to the 13 facilities. The surveys were submitted to the heads of each of the three districts to then be passed on to a facility representative for each maintenance facility to complete and return. Each facility representatives answered questions in several categories about the characteristics, conditions, and usage frequency of the facility and its equipment. These questions were organized into the following sections in the survey:

1. General Facility Information
2. Occupants/ Facility Manager Opinions
3. Metering and Emergency Generator Information
4. Heating Equipment
5. Cooling Equipment
6. Lighting System
7. Building Systems Controls
8. Energy Consuming Equipment Conditions and O&M procedures
9. Energy Efficiency and Conservation
10. Renewable Technologies

An excerpt of the survey is shown in Figure 4.1 and the complete survey is included in Appendix A.

General Facility Information			
Facility Name:			
ODOT Region:			
Address:			
Facility Representative:			
Phone:		Email:	

1.	What is the building square footage?							
2.	What is the size of the overall facility site? (Acres)							
3.	When was the building built?							
4.	What approximate percentage of the facility do the following spaces account for?							
	Offices:		Garage:		Storage:		Other (please specify):	
5.	What is the average number of daily occupants?							
6.	What is the average weekly occupancy and operation time?					Days/ week:		
	(In terms of hours per day and days per week)					Hours/day:		
7.	Has the Facility ever been formally commissioned and/or audited for energy use? If so when was the last time? Please provide details below.							

Figure 4.1. Excerpt from the survey sent to ODOT facilities.

4.1.1 Survey development

The survey questions were chosen based on the researchers' judgment of importance towards conducting a low level energy audit of these facilities. Importance was determined from studying different energy audit plans, such as the FEMP Commissioning for Existing Federal Buildings on demand training (Federal Energy Management Program, 2012a) and Commissioning for Federal Facilities guide (Federal Energy Management Program, 2012b). Energy audit plans and guides were ideal for highlighting the types of questions to ask because the intentions of the research mirror the goals of commissioning which are to (1) provide a safe and healthy facility, (2) improve energy performance and minimize energy consumption, and (3) reduce operating costs (Federal Energy Management Program, 2012b). Questions in the survey concerning RETs were developed based on what was learned about the factors affecting RETs from the literature review.

4.1.2 Representative opinions

In addition to gathering details about the characteristics and energy usages of individual facilities, the survey also allowed for the facility representatives to express their opinions about their facilities conditions and mechanisms. The representatives were asked to rank the condition levels of different building aspects, such as lighting quality and noise levels, and to list some of the most common complaints heard. The researchers felt it was important to consider the opinions of the people who have daily experience with the facilities and their equipment as they would know best what the common issues were.

4.1.3 Survey results

The survey received a 100 percent response record and led to several findings about the facilities. From the General Facility Information section of the survey it was found that the average facility consists primarily of garage/maintenance space, making up about 72 percent of a facility. The remaining space was split almost equally between office and storage space at about 16 and 12 percent respectively. There were some facilities that did not fit this model, for example several had little or no storage space reported. It was also found that the typical facility supports on average about 25 daily occupants or employees and is operating about 40 hours per week. It also indicated that none of the facilities had been formally commissioned or audited for energy use. Table 4.1 shows how the space usage details based on survey results.

District	Facility		Usage				Hours/ Week	Occupants
			Offices	Garage	Storage			
2	Seneca County Garage		N/A	N/A	N/A		40	23
2	Williams County Garage		N/A	N/A	N/A		40	24
2	Ottawa County Garage		N/A	N/A	N/A		40	22
2	Wood County Garage		3.5	95	1.5		42.5	26
6	Marion County Garage		10	80	10		42.5	22
6	Fifth Ave County Garage		10	90	0		40	21
6	Franklin County Garage		10	80	10		42.5	19
6	Morrow County Garage		25	50	25		40	20
6	Delaware County Garage		25	50	25		40	20
6	Pickaway County Garage		25	50	25		40	20
9	Pike County Garage		18	64	18		45	25
9	Lawrence County Garage		15	84	1		40	30
9	Scioto County Garage		18	80	2		40	30
	Average		**16.0**	**72.3**	**11.8**		**41.3**	**25.0**

Table 4.1. Facility space usage breakdown.

Typical type of building systems were identified from the survey results and are discussed in the following subsections. The surveys also indicated that the participating facilities have not implemented any energy efficiency projects with the exception of some energy efficient lighting upgrades. Furthermore, the surveys have indicated that none of the 13 facilities have implemented any renewable technologies but many demonstrated interest in hearing ideas and pursuing RET options. Tables 4.2, 4.3, and 4.4 summarize results from the completed surveys for ODOT districts 2, 6, and 9 respectively.

Facility	Built	Area (Sq Ft)	Energy Use Indices Jan 2010 to Jan2012			Hours/ Week	Occupants	Building Control Systems	Energy Efficiency	Heating Systems	Cooling systems
			Total Energy kWh/sf	Electric kWH/sf	Gas kWH/sf						
Seneca County Garage	1997	36325	0.95	0.27	0.68	40	23	No	None	Gas Fired Furnace, Standard Radiant Heaters	Condenser
Williams County Garage	1997	36325	0.82	0.34	0.47	40	24	No	None	Gas Fired Furnace, Standard Radiant Heaters	Condenser
Ottawa County Garage	1991	28000	0.85	0.53	0.32	40	22	Occupancy, Thermostat	None	Gas Fired Make up Air Unit, Standard Radiant Heaters,	Condenser
Wood County Garage	1986	18400	1.72	0.41	1.31	42.5	26	No	None	Standard Radiant Heaters, Boilers, Waste Oil Burner	Condenser / Split AC Unit

Table 4.2. Summary of survey results for ODOT district 2.

Facility	Built	Area (Sq Ft)	Energy Use Indices Jan 2010 to Jan2012			Hours/ Week	Occupants	Building Control Systems	Energy Efficiency	Heating Systems	Cooling systems
			Total Energy kWh/sf	Electric kWH/sf	Gas kWH/sf						
Marion County Garage	2007	11400	1.79	0.03	1.77	42.5	22	Thermostats, CO Sensors	Lighting	Gas Fired Furnace, Standard Radiant Heaters	Condenser
Fifth Ave County Garage	2005	5110	7.91	0.02	7.89	40	21	Thermostats, CO Sensors	Lighting	Gas Fired Furnace, Standard Radiant Heaters	Condenser
Franklin County Garage	2002	22307	1.61	0.39	1.22	42.5	19	None	Lighting	Gas Fired Furnace, Standard Radiant Heaters	Condenser
Morrow County Garage	1998	22200	0.64	0.01	0.63	40	20	Photo Sensors, Thermostats, CO Sensors	None	Gas Fired Make up Air Unit, Gas Fired Furnace, Standard Radiant Heaters	Condenser
Delaware County Garage	1992	23760	1.53	0.54	0.98	40	20	Photo Sensors, Thermostats	None	Gas Fired Make up Air Unit, Gas Fired Furnace, Standard Radiant Heaters	Condenser
Pickaway County Garage	1985	15132	1.69	0.40	1.28	40	20	Photo Sensors, Thermostats	None	Gas Fired Make up Air Unit, Gas Fired Furnace, Standard Radiant Heaters	Condenser

Table 4.3. Summary of survey results for ODOT district 6.

Facility	Built	Area (Sq Ft)	Energy Use Indices Jan 2010 to Jan2012			Hours/ Week	Occupants	Building Control Systems	Energy Efficiency	Heating Systems	Cooling systems
			Total Energy kWh/sf	Electric kWH/sf	Gas kWH/sf						
Pike County Garage	2009	22824	1.26	0.54	0.73	45	25	Occupancy sensors for Thermostat, CO	Lighting	Gas Fired Make up Air Unit, Gas Fired Furnace, Standard Radiant Heaters	Condenser, Central Air
Lawrence County Garage	2005	22500	1.26	0.58	0.67	40	30	No	Lighting	Gas Fired Make up Air Unit, Gas Fired Furnace, Standard Radiant Heaters	Condenser, Central Air, Window AC
Scioto County Garage	1997	35000	1.18	0.50	0.68	40	30	No	None	Gas Fired Make up Air Unit, Gas Fired Furnace, Standard Radiant Heaters	Condenser

Table 4.4. Summary of survey results for ODOT district 9.

4.1.3.1 Typical mechanical systems

Survey results indicated that the heating equipment typically used in the maintenance/garage area is a combination of standard radiant heaters as shown in Figure 4.2, and gas fired make up air units as shown in Figure 4.3. For the office area, a gas fired furnace as shown in Figure 4.4 is typically used to provide heating. The cooling equipment used for the office area is typically a split central air system with outside condenser unit(s) as shown in Figure 4.5, and occasionally window A/C units are used. Water heating for sanitary uses is typically provided by a gas fired water heater as shown in Figure 4.6. Large exhaust fans are used to provide adequate volume of outdoor air to meet ventilation code requirements as shown in Figure 4.7.

Figure 4.2. Radiant heaters provide space heating for the maintenance/garage area

Figure 4.3. Gas fired make up air units provide space heating for the maintenance/garage area

Figure 4.4. Gas fired furnace provide space heating for the office area

Figure 4.5. Outdoor electrical condensers provide space cooling for the office area

Figure 4.6. Water heating for sanitary uses is provided by a gas-fired water heater

Figure 4.7. Large exhaust fans provide ventilation to maintenance/garage areas

4.1.3.2 Typical lighting systems

400 W Metal halide lamps are typically used in the garage/maintenance areas as shown in Figure 4.8. 175 W metal halide lamps are used for outdoor site lighting as shown in Figure 4.9. T8-fluorescent lamps are typically used in the office area as shown in Figure 4.10.

Figure 4.8. 400 W metal halide lamps used in the garage/maintenance area

Figure 4.9. Building mounted 175 W metal halide lamps are used for outdoor site lighting

Figure 4.10. T8-fluorescent lamps are typically used in the office area

4.1.3.3 Typical building control systems

The Building Systems Controls as reported in the surveys were very basic. As shown in Figure 4.11, in the office area, thermostat controls are typically used for controlling HVAC equipment; and in some facilities occupancy sensors are used to turn off light when no one is using the room.

Figure 4.11. Thermostat controls and occupancy sensors are used in office area to control HVAC equipment and lighting respectively.

In the maintenance/garage areas, a control panel as shown in Figure 4.12 controls the make up air units and a simple dial control is used to set the radiant heaters' temperature as shown in Figure 4.13. Basic on/off switches as shown in Figure 4.14 are used to manually turn the various lighting circuits on and off.

Figure 4.12. Control panel for make up air units.

Figure 4.13. Dial control for setting radiant heaters' temperature.

Figure 4.14. Basic on/off switches are used to manually control lighting circuits

4.1.3.4 Typical process equipment used

As shown in Figure 4.15, maintenance bays have a number of equipment used by the mechanics for vehicle repair and maintenance. These energy consuming equipment include cranes, monorails, vehicle lifts, air compressors, pressure washers, saws and grinders. As shown in Table 4.5 some of the equipment has large motors that consume large amounts of energy when in use.

Equipment	Energy source	Motor Capacity
Vehicle Lift Console	Electricity	20 HP
3 Ton Crane	Electricity	8.3 HP
1 Ton Monorail	Electricity	2.94 HP
Pressure Washer	Electricity and Gas	7.5 HP

Table 4.5. Energy intensive process equipment used in ODOT facilities.

Figure 4.15, Typical process equipment used for vehicle repair and maintenance

4.2 Site Visits

Based on the survey results, 5 ODOT maintenance facilities were selected for further detailed analysis that included site visits. The first 4 of the 5 facilities were chosen to represent different sizes and ages of buildings from across the three ODOT districts participating in the research. Characteristics of the selected facilities are shown in Table 4.6. ODOT personnel suggested that the research team visit the fifth facility, the New Lucas County Garage that was recently completely, to document energy efficiency measures utilized.

Facility	District	Year Built	Square Footage	Site Acres
Pike County Garage	9	2008	27,857	10
Seneca County Garage	2	1997	36,325	12
Fifth Avenue Outpost Garage	6	2005	5,110	4
Franklin County Garage	6	2002	22,307	9
New Lucas County Garage	2	2013	-	16

Table 4.6. List and characteristics of the facilities selected for site visits.

4.2.1 Objectives of site visits

The objectives of the site visits were to (1) review the as built facility drawings to identify major energy consuming equipment, (2) walk the building and site with facility personnel who are familiar with existing systems and review the usage of lighting, HVAC, building envelope, and equipment, and (3) evaluate the feasibility of the building/site for implementing renewable energy strategies. Forms were developed for the site visits to facilitate the procedures and keep record of the measurements. The forms completed were a "Building Systems and Renewable Energy" form, "Major Equipment" form, and "Indoor Environmental Conditions Measurements" form. Excerpts from the forms are shown in Figures 4.16 to 4.18. The complete forms are included in Appendix B. We designed the "Building Systems and Renewable Energy" form in a way that facility personnel will be able to continue to perform the necessary site evaluation long after the research project is completed. Such a continuous evaluation is essential to ensuring energy efficiency.

General Facility Information			
Facility Name:			
ODOT Region:		Date:	
Address:			
Facility Representative:			
Phone:	Email:		
1. What are the facility operating hours?			

Building Envelope					
#	Check Point Description				Corrective Action Request / Comments
1	Are doors/windows kept closed during heating and cooling season?	YES	NO	N/A	
2	Are building walls too hot/cold candidate for insulation?	YES	NO	N/A	Location:
3	Is weather stripping found to be adequate around windows/doors? (reduce air leak)	YES	NO	N/A	
4	Are windows types adequate (e.g. single pane, double pane, high performance windows?	YES	NO	N/A	Location:
5	Are windows placed correctly? (i.e. majority of windows facing south)?	YES	NO	N/A	
6	Are there signs of deterioration of building envelope (siding deterioration, masonry fluorescence, window fogging, and	YES	NO	N/A	Location:

Figure 4.16. Excerpt from the “Building Systems and Renewable Energy” form used during site visits.

Misc. Equipment								Williams County						
Equipment	HP	Number	Phase	volt	Wire			HP	Phase	Number	volt	Wire		
Air Compressor								15	3	1	208			
Vehicle Lift Console								20	3	1	208			
3 Ton Crane								8.3	3	1	208			
Pressure Washer								7.5	3	1	208			
1 Ton Monorail								2.94	3	1	208			
OH Doors								0.75	1	6	120			
Vehicle Exhaust Reel								0.33	1	2	120			
Grinder									1	1	208			
Truck Tire Changer									1	1	120			
Ice Machine									1	1	120			
Air Dryer									1	1	120			
Parts Washer									1	1	120			
Band Saw									1	1	120			
Shop press									1	2	120			
Fuel Island									3	1	208	#12		
Salt dome									3	1	208	#6		
Calcium Tank									1	1	208			

Figure 4.17. Major Equipment form used during site visits.

Location	Temperature	Relative Humidity	CO2(ppm)	Light level (fc)	CO

Figure 4.18. "Indoor Environmental Conditions Measurement" form used during site visits.

4.2.2 Site visit procedures

The site visits began with a review of the buildings' plans and drawings so that the researchers could identify the major energy-consuming equipment in the buildings. The "Major Equipment" form was used to record the details of equipment found in the drawings. Following the review of the buildings' drawings, a tour of the facility buildings and features was performed with representatives of the facility. Facility representatives who were familiar with the existing systems were extremely helpful in providing information and answering questions about the facilities. Throughout the tours pictures of the facilities were taken and notes and recordings made on the "Building Systems and Renewable Energy" form. The final objective of the visit was evaluating the feasibility of the building/site for implementing energy efficient and renewable energy strategies. This was accomplished by taking numerous measurements and readings throughout the buildings and sites. Measurements of temperature, relative humidity, carbon monoxide levels, carbon dioxide levels, and lighting levels were made in each room of the buildings, both office and garage areas, as well as outdoor readings for base levels. Infrared thermometer readings and an infrared camera were also used throughout the buildings at locations that were susceptible to insulation failures and leaks. A range finder was also used to check the relative heights of site features that could be limiting obstructions to RETs, such as trees and neighboring buildings. The readings collected were recorded on the Measurement forms.

4.2.3 Tools used during site visits

A variety of tools and instruments were used throughout the site visits to make the measurements and observations about the facilities. The tools are displayed in Figure 4.19. They include: EXTECH Heavy Duty Light Meter, EXTECH Carbon Monoxide Meter, TSI IAQ-Calc Carbon Dioxide Meter, Kestrel 4100 Temperature and Humidity Meter, Nikon Prostaff3 Range Finder, FLUKE Infrared Thermometer, FLIR Infrared Camera, and EXTECH Environmental All Purpose Meter.

Figure 4.19. Tools and instruments used during site visits.

4.3 Energy Efficiency Opportunities

Based on the observations and measurements made at the site visits, along with the background information gathered from the surveys and data collection, several energy efficiency opportunities have been identified. 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 potential 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 (NCHRP, 2013) Energy efficiency opportunities have been identified for the heating and lighting systems, process equipment, and operation procedures. The energy efficiency opportunities have been catergorized as quick fixes or long term solutions. Quick fixes are those that would not require any substantial costs and could be achieved even with simple workforce behavioral changes. Long term fixes are those that would require medium to large costs and typically include major equipment replacement.

4.3.1 Heating quick fix strategies

At 55 percent of total energy usage, heating accounts for the largest portion of the total energy cost in a maintenance facility (U.S. Department of Energy, 2012). Therefore, energy efficiency measures that would reduce heating energy requirements should be carefully considered in ODOT maintenance facilities.

Some of the quick fixes involve the proper usage of equipment as intended in the design such as:

- When available, vehicle exhaust reels as shown in Figure 4.20, should be used in winter to limit Carbon monoxide (CO) generation. Increased CO generation is not healthy for the workers and will require that the large exhaust fans in the garage be turned on. The fans will consume additional electrical energy and will also turn on the gas-fired make up air units consuming more natural gas. During some of the site visits, it was reported that the exhaust reels were sometimes not used. It is important to convey to the workforce the importance of proper use of the exhaust reels not only for reducing energy demand, but more importantly for reducing health hazards associated with Carbon Monoxide.

Figure 4.20. Vehicle exhaust reel

- When available, CO sensors controlling the exhaust fans should be used as intended and not overridden. Overriding the sensors keep the exhaust fans on longer than necessary and use unnecessary energy. In addition, when the exhaust fans work more than needed, they cause negative pressure in the building and cause uncomfortable cold air draft in the office areas.
- HVAC controls should be used effectively in ODOT maintenance facilities. The site visits have revealed that properly using existing HVAC control systems can have a significant impact on reducing energy consumption by:
    - Using weekend and night setbacks on HVAC in offices or conditioned buildings

    - Looking for unoccupied areas being heated or cooled, and switching off heating or cooling.
    - Checking that heating controls are not set too high or cooling controls set too low.
- HVAC systems should be properly maintained and filters should be replaced regularly for good operation and to avoid energy waste.
- Infiltration should be controlled by replacing worn weather-stripping and caulking to ensure windows and doors are airtight. Infiltration should be controlled on both exterior doors and windows, and the doors between the office and garage sections of buildings. Figure 4.21 shows an infrared camera shot that shows how a door at a visited facility has temperature differences at the bottom of the door which indicates that cold air from the mechanically cooled office space is leaking in large quantities to the warmer, un-cooled garage space.

Figure 4.21. Infrared camera shot of a visited facility door displaying temperature differentiation indicating infiltration.

4.3.2 Heating long term strategies

4.3.2.1 Testing and balancing of the HVAC system in the office areas

During the site visits, some facility personnel complained of the inconsistency of temperatures from room to room. Either that the room furthest from HVAC is hot while the closest to HVAC is freezing or that the room furthest from the furnace is cold while the closest to furnace is too hot. Figure 4.8 shows an infrared picture of a conference room in Pike County garage. The picture was taken in late spring 2013. The conference room is closest to the HVAC system. As shown in the picture, even though the conference room is only occasionally used for meetings and is empty most of the time, the “unbalanced” HVAC systems is keeping the average room temperature very cold (69.4 ^{o} F). Balancing the HVAC system does not only reduce the energy consumption of the system, but also improves the comfort of the employees.

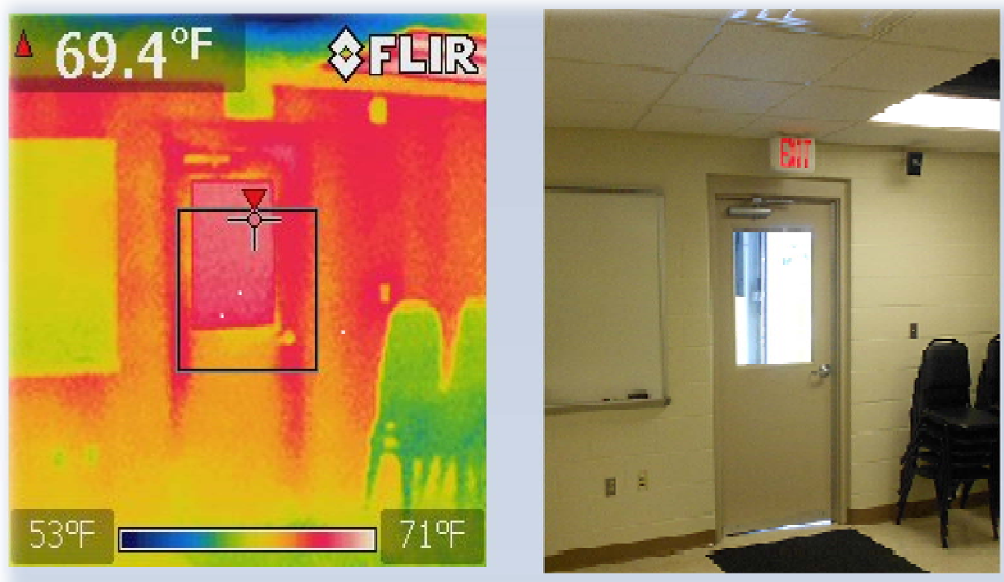


Figure 4.22. Thermal shot of a conference room show very low temperature because of excessive use of a/c system.

4.3.2.2 Heat recovery

Another long term fix is the installation of a heat recovery ventilator (HRV). On cold winter days, a HRV unit significantly helps heat the outdoor air coming into the building. The warm exhaust air (return air) heats up the plate heat exchanger on the way out of the building. When the cold outdoor air hits the warm plate heat exchanger, it gets conditioned up to 70% of the way to the return air temperature. An example of a HRV system is shown in Figure 4.23. Another way of introducing heat to air before it enters the building is through the use of a solar air heater. Also called solar air ventilation, these systems use conventional steel siding to absorb solar radiation. This technology is considered a renewable energy technology and is discussed in more details in Chapters 3, 5 and 6.

Figure 4.23. Example of a heat recovery ventilator (Greencheck, 2013).

4.3.2.3 Use efficient HVAC equipment

Another long term strategy for reducing energy required for heating is to choose more efficient heating and cooling systems. This strategy is most cost feasible when existing equipment have reached their service lives and need replacement. In this case, it is recommended to choose high efficiency condensing furnaces and unit heaters (92+ efficiency) and high efficiency air conditioners (EER 11.5+ for larger units, SEER 14+ for smaller units).

4.3.3 Lighting quick fix strategies

Lighting, at 17 percent, accounts for a large portion of the total energy cost in a maintenance facility (U.S. Department of Energy, 2012). The use of efficient lamps, fixtures, and modern lighting controls can save money and improve working conditions. Some of the quick fixes that can be done to improve lighting efficiency include switching off unnecessary lights and utilizing day lighting whenever possible. It was observed on some of the site visits that the garage doors in the summer are frequently left open and daylight is used instead of electrical lighting. This is a good practice that should be encouraged in all facilities.

However, it was also observed on some visited sites as shown in Figure 4.24, that many lighting fixtures were left on unnecessarily in unoccupied spaces. These areas can greatly benefit from occupancy sensors that would turn light off automatically when the space is unoccupied. Low cost occupancy sensors can be installed to turn light off when no one is in room. This is particularly useful for ODOT maintenance facilities because highway workers are in and out of the facilities frequently throughout the day. Dimmers could also be used to reduce lighting levels when not needed. Dimmers are relatively inexpensive to install. Another more expensive lighting control strategy include the use of photo sensors to turn electric light off when there is enough daylight present in the room.

Figure 4.24. Example of instances where unnecessary lighting was being used in unoccupied areas

4.3.4 Lighting long term strategies

Replace standard metal halide (MH) with high-intensity fluorescent (HIF) lights

Metal halide lamps are used quite extensively at ODOT maintenance facilities for lighting indoor spaces with high ceilings. In recent years, manufacturers have begun offering fluorescent fixtures designed to replace MH fixtures in high-bay applications. The fixtures house two, three, four, six or eight T8 or T5HO lamps to provide various levels of light output. A six-lamp F32T8HO fixture can replace a 400W standard MH fixture and save about 50 percent on energy while producing about 16 percent less maintained light output. However, the HIF lamps will produce more light output than depreciated MH lamps. (lightingtaxdeduction.org, 2013) (ROI Energy, 2013) (Galitsky & Worrell, 2008).

HIF lighting offers many advantages over MH lighting in high-bay applications including:

- Higher efficiency: Energy savings up to 50%
- Higher lumen maintenance: Although the initial lumen output of a Metal Halide fixture may be quite high, metal halide fixtures are known for their poor lumen maintenance. The average 400w Metal Halide fixture emits only 65% of its initial lumens by the time it hits mean lamp life (40% of total lamp life or 8000 hours) and as low as 40% of its initial lumens by the end of lamp life. HIF lamps, on the other hand, have superior lumen maintenance, and maintain 90-94% of their initial lumens through the end of lamp life. (Optimum Lighting, 2013)
- With HIF lighting, when one lamp fails, the fixture will still produce light until it is convenient to change the failed lamp, whereas if a metal halide lamp fails, the entire space it was lighting will become darkened
- Longer lamp life: HIF fluorescent lamps last longer than MH lamps
- Better color rendering ability: color rendering is the ability to judge an object's color
- HIF lamps provide more uniform lighting, less shadows and less glare. Better lit facilities help increase worker morale & improve productivity
- HIF lamps are easily dimmable due to their instant on and re-strike capability. Dimming controls such as occupancy sensors, photocells and scheduling systems that are impractical for MH can save significant energy in HIF systems.

Disadvantages of HIF lamps include inability to start and operate efficiently at extremely cold temperatures. This is not a major issue for ODOT maintenance facilities since the maintenance/garage areas where HID fluorescent lamps are recommended are heated in the winter. Figure 4.25 shows a before and after picture of a lighting retrofit project that replaced MH lamps with HIF lamps in a high bay area. It should be noted that some of the visited ODOT maintenance facilities have already changed their MH lamps to HIF lamps as shown in Figure 4.26.

Figure 4.25. Before and after pictures of a Trident Seafood facility where MH lamps were replaced with HIF lamps (Seattle Government- Energy Smart Services).

Figure 4.26. Fifth avenue outpost garage use HID fluorescent fixtures in the garage area.

4.3.5 Equipment quick fix strategies

Mechanics at ODOT maintenance facilities use several compressed air tools. Compressed air for these tools is provided by an air compressor. To save electrical energy, it is important that the air compressor be checked on a regular basis to ensure that it is free of leaks. Leaks in the compressed air system will increase the compressor run times and waste electrical energy.

4.3.6 Operation strategies

Facilities can significantly reduce their energy consumption if their users are motivated and educated about proper procedures for operating them. Some examples of simple tasks ODOT employees can do are outlined below:

- In the winter, do not leave overhead doors open longer than necessary. If this problem exists, an automatic control strategy that interlocks the overhead doors with the heaters can be implemented. In this case the heaters will not run when the overhead doors are open.
- Switch off unnecessary lights; rely on daylighting whenever possible.
- Use weekend and night setbacks on HVAC systems.
- Report leaks of water, steam, and compressed air and ensure they are repaired quickly. The best time to check for leaks is a quiet time like the weekend.
- Look for unoccupied areas being heated or cooled, and switch off heating or cooling.
- Check that heating controls are not set too high or cooling controls set too low. Sometimes when heating set points are too high, windows and doors are often left open to lower temperatures instead of lowering the heating set point.
- Carry out regular maintenance of energy-consuming equipment.
- Encourage other environment-friendly habits, such as recycling and using recycled or "green" materials.

4.4 Renewable Energy Opportunities

One objective of the site visits was to evaluate the feasibility of the visited sites for implementing the 3 most promising RETs for ODOT maintenance facilities as identified by the research; namely solar air heating systems, grid connected PV systems and grid connected wind energy systems. The site visits revealed several opportunities for implementing some of these RETs on existing ODOT facilities. These opportunities are discussed below and are further analyzed in Chapter 7 using life cycle cost assessment techniques.

4.4.1 Photovoltaics

The Seneca County Garage has good potential for photovoltaic technologies. The site layout is shown in Figure 4.27. The main building's roof slope is oriented due south which offers the prefect configuration for roof mounted PV modules. The building's roof on the southern side is also very large as it is extended by an attached un-conditioned storage area against the southern wall. A larger roof area means more flexibility in sizing and installing a PV system. The building and land areas at the site had no major shading obstructions which is crucial to ensuring a consistent level of available solar radiation.

The Pike County Garage, on the other hand, is not a good candidate for a roof-mounted PV installation. Figure 4.28 shows the site layout of the garage. The main building's roof area slopes primarily east and west which would significantly reduce the solar radiation collected by the PV modules. As shown in Figure 4.28, Pike County Garage does have a small storage building with a roof sloping south-east. This would be a better orientation for mounting the PV modules. However the roof area of the storage building is small and can potentially limit the size of the PV system.

Figure 4.27. Site layout of the Seneca County Garage.

Figure 4.28. Site layout of the Pike County Garage.

4.4.2 Solar air heating

The Pike County Garage has good potential for installing a solar air heating system. As shown in Figure 4.28, the southern wall is just slightly off perfect south and as such, provides a good orientation for installing a solar wall. While the southern wall is relatively small compared to the east and west wall, it does not have any shading obstructions. The southern wall also is directly against the garage portion of the building and so warm air from the solar collector will directly enter into the garage. Figure 4.29 shows an elevation of the southern wall. It also shows a solar air heating system installed on a similar wall.

Figure 4.29. The southern facing wall of the Pike County Garage and a solar air heating system installed on a similar wall.

The Seneca County Garage, on the other hand, is not a good candidate for a solar air heating system. Although, the building has a long south facing wall, as shown in Figure 4.27, the wall is shaded by an attached unconditioned storage area as shown Figure 4.30.

Figure 4.30. The southern wall of Seneca County Garage is shaded by an unconditioned storage area.

4.4.3 Wind energy systems

The cost-effectiveness of grid connected wind energy systems significantly depends on the wind speed. To determine which of the visited sites has is a good candidate for wind energy systems, the location of the 5 visited sites were superimposed on the NREL wind resource map as shown in Figure 4.31. The Seneca County Garage was the only facility that has decent level of wind resources. An LCCA for a wind turbine project installed at the Seneca County Garage was performed and is discussed in Chapter 7.

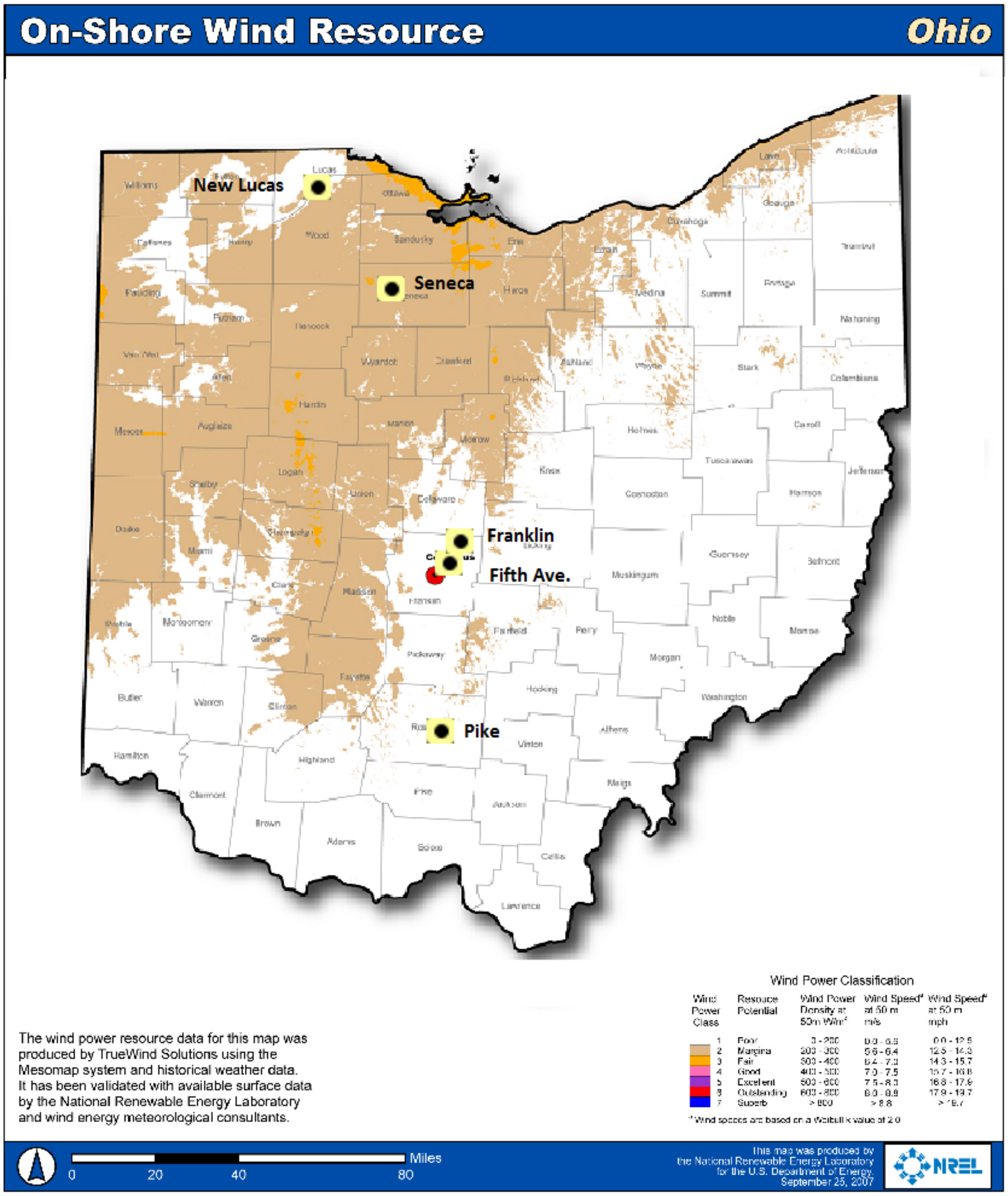


Figure 4.31. Location of the visited sites superimposed on the NREL wind resource map.

CHAPTER 5 – BEST MANAGEMENT PRACTICES

5.1 Energy Efficiency

Energy efficiency strategies that reduce a facility's energy load should precede the incorporation of any RETs in order to maximize return on investment in renewable energy systems. The reduced facility's energy loads allow the energy produced by the RET to be a larger percentage of the overall facility demand. Energy efficiency measures also typically have a higher return on investment than RET projects and so more financially feasible opportunities may be found from considering them first. Several energy efficiency strategies were recommended for the visited existing ODOT maintenance facilities in Chapter 4. In addition to these strategies there are some energy efficiency strategies that are only feasible in new facilities and are discussed in the following subsections.

5.1.1 Thermal separation of functional areas

As discussed in chapter 2, ODOT maintenance facilities typically have 5 different types of functional areas; (1) maintenance area; (2) garage area; (3) office area; (4) cold storage area and (5) truck washing area. Each of these areas has its own heating, cooling and lighting requirements. In many of the existing ODOT facilities, as shown in Figure 5.1, three of these functional spaces; (1) maintenance area, (2) garage area and (3) truck washing area, are combined into one large area. As a result these three functional areas are heated to the same temperatures using the same HVAC equipment even though they have different heating requirements. For example, the maintenance area should be heated in the winter to a comfortable temperature (70^o to 72^o F) that enables the mechanics to safely and comfortably carry out their required activities. On the other hand, the garage space, which typically represent the largest space in ODOT maintenance facility should only be heated to (50^o or 55^o F) and it would still achieve the intended objective of melting the snow and ice off of trucks to protect them from rust, prolong their service lives and ensure a more efficient snow/ice clearing operations in the winter. When these two areas are combined, the more stringent heating requirements (in this case for the maintenance area) have to be used for both areas. As a result, the large garage area is heated unnecessarily to (70^o - 72^o F) where it only needs heating to (50^o or 55^o F).

Figure 5.1. Several functional spaces with different heating requirements are combined in many existing ODOT facilities.

By thermally separating the different functional areas, a significant amount of energy used for heating the facility could be saved. This strategy has been adopted in the "New Lucas" County Garage as shown in Figures 5.2 and 5.3. Separating the truck washing area from the rest of the facility had an added benefit of reducing corrosion effect of the used wash water that is mixed with salt. Such salt-mixed water caused corrosion of structural steel in some of the visited facilities as shown in Figure 5.4. Some ODOT facility personnel also reported that the salt mixed water caused rusting of their personal vehicles.

Another good practice related to the truck washing area that the New Lucas County garage implemented is that they constructed the truck washing building using concrete masonry units (CMU) instead of structural steel and steel exterior walls as shown in Figure 5.5 to prevent early deterioration of steel elements. On the other hand, it seems that the height of the maintenance area of the New Lucas County garage is a little higher than needed as shown in Figure 5.2. This unnecessary addition to the height increases the volume of air that needs to be heated in the winter and would increase energy demand. It is important to share among all ODOT districts both the best practices and lessons learned to improve the design and construction of planned maintenance facilities.

Figure 5.2. Maintenance area and garage area are thermally separated by a wall in the New Lucas County Garage.

Figure 5.3. A separate truck washing building is used in the New Lucas County Garage

Figure 5.4. Corrosion of structural steel and metal wall in truck washing area

Figure 5.5. Truck washing building in New Lucas County garage is constructed of CMU instead of structural steel to reduce corrosion problems.

5.1.2 Daylight harvesting systems

Daylight harvesting systems reduce the use of electrical lighting when natural daylight is available. Daylight harvesting systems use photo sensors to detect the light level and send a signal to the lighting control system that in turns switch off or dim fixtures if enough daylight is reaching the space. Daylight harvesting can reduce energy used for electrical lighting by 20-60 percent (Galasiu, Newsham, Suvagau, & Sander, 2007). To make better use of daylight harvesting in new buildings, it is necessary to install additional windows, skylights, and light tubes to allow more sunlight into the day lit space. 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. Daylighting also offers the opportunity for more building occupants to have views to the building exterior. Initial costs to include daylight strategies are minimal and may only require rearrangement of already planned glazing, revisions to glazing materials or potentially adding some shading elements.

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 (NCHRP, 2013). Due to the complex nature of daylighting system design, a thorough analysis is required for any daylighting design solution. Such an analysis should include the use of daylight simulation software programs to predict system performance.

5.1.3 Hydronic heating

This strategy is only feasible for new buildings as the installation into an existing building would be complex and expensive. In a hydronic radiant heating system, space heating is provided by hot water supplied through pipes embedded in floors. The uniform temperature distribution from floor heating increases comfort and reduces room air temperature stratification. Radiant floor heating systems provide the same comfort level in the working zone at a lower room air temperature during the heating season. This results in reduced ventilation and infiltration losses (Zhivov, Herron, & Liesen, 2009). A hydronic radiant floor heating system also has benefits specific to maintenance garages. One of these is that during winter months a floor heater would melt the snow and ice off of trucks much faster as trucks would be much closer to the heat source than they are from the typical standard radiant heaters on the ceiling. The workers would also feel warmer because of their proximity to the heat source.

5.1.4 Waste oil heater

Another best practice used in the New Lucas County Garage is the use of waste oil heater as shown in Figure 5.6. One gallon of waste oil has the same heat content as 1.4 ccf of natural gas. Annual cost savings resulting from using a waste oil heater can be calculated knowing the following:

- C_g = Cost of natural gas ($/ccf)
- V_{wo} = Volume of waste oil generated each year by facility (Gallons)
- R_{wo} = Revenue generated from selling used oil, if any ($/Gallon)

Annual savings = $V_{wo} * ((1.4 * C_g) - R_{wo})$
For example if:

- C_g = Cost of natural gas = $1/ccf (typical current cost for ODOT facilities)
- V_{wo} = Volume of waste oil generated each year by facility = 500 Gallons (assumed)
- R_{wo} = Revenue generated from selling used oil $0.5/Gallon (assumed)

Then the annual savings from using a waste oil heater would be $450.

Figure 5.6. Waste oil heater in New Lucas County Garage's maintenance area

5.2 RET Incentives

The feasibility study of an RET should include all the potential incentives that would help the economics of the project. The Federal government offer incentives to encourage renewable energy projects, including grant programs, and tax incentives (NCHRP, 2013) . The economics of renewable energy projects are often dependent on these incentives as they can greatly reduce the upfront and annual costs. As a state agency, ODOT may be ineligible for many of these federal incentives. Private developers, however, can take advantage of the tax credits, grants, and other federal incentives that drive the renewable energy markets. This becomes a key consideration in deciding whether to fund projects directly or enter into a contract with a third party to be able to take advantage of federal incentives (Stoltenberg & Partyka, 2010). There are several contracting options and they are discussed in section 5.3.

Most states have incentive programs in place to help offset costs and promote energy efficiency strategies and renewable energy technologies. Available programs and policies vary from state to state. There are several resources that compile incentives and their details and allow specific locations to identify potential programs. A Database of State Incentives for Renewable Energy (DSIRE) is available at dsireusa.org which includes summaries and details for incentive programs by state, as well as information on federal incentives (U.S. Department of Energy, 2013). This information can be beneficial in determining which incentives apply specifically to

ODOT facilities and help estimate any economic impact on the project. It is also important to check the time limitations on the incentives. Some incentives have set expiration dates or have slowly decreasing credits and offers year by year. Before planning on receiving an incentive it is a good practice to confirm that it will still be offered when the project is completed and that the project can still apply for it. The DSIRE information is typically up to date, but it's still always a good idea to verify the status and availability of incentives with the administering agency, organization, or utility (Stoltenberg & Partyka, 2010).

Other sources compile incentives that are only available in Ohio. Energize Ohio, a program run by The Ohio State University, provides a searchable database of energy efficiency and renewable energy incentives for Ohio that can be filtered to meet specific needs (Ohio State University, 2011). Energize Ohio allows incentives to be identified based on county, authority sector, utility provider and incentive type. The Green Energy Ohio website (Green Energy Ohio, 2013) also compiles another list of incentives available in Ohio and provides a list of Ohio's renewable energy installers.

5.2.1 Business energy investment tax credit

One example of a well established project incentive is the Business Energy Investment Tax Credit (ITC). The business energy investment tax credit is a Federal corporate tax credit which is available to projects throughout the country. The credit is available for eligible systems that are placed into service by December 31, 2016. This credit is worth 30 percent of up-front expenditures for renewable energy technologies including solar, fuel cells, and small wind, and 10 percent of expenditures for some other technologies, such as geothermal (NCHRP, 2013). The tax credit is awarded to either the original builder or user of the renewable energy system. The applicable sectors for the ITC are commercial, industrial, utility, and agricultural, so a state agency would require a power purchasing agreement or other arrangement with a third-party as discussed in section 5.3 in order to take advantage of it (NCHRP, 2013).

5.2.2 Utility incentives

Utility companies sometimes offer incentives that are the simplest to obtain. Companies typically have well established programs with clear guidelines and requirements for qualifying for the incentives. Table 5.1 shows a list of eligible incentives from the DSIRE database for customers served by the American Electric Power company (U.S. Department of Energy, 2013). AEP Ohio is the utility of record for three of the visited facilities, and 14 of the 50 facilities for which electricity use was analyzed.

Incentive Name	Available Funding	Technology	Specific Requirements	DSIRE Link
AEP Ohio - Renewable Energy Credit (REC) Purchase Program	Solar: $262.5/REC Wind: $34/REC (* Program expired on July 15, 2013, but a future similar program may take its place)	Photovoltaic, Wind	AEP Customer. Solar/Wind systems max rated capacity of 100kW. Installed after Jan 1, 1998	Link
Commercial Custom Project Rebate Program	$0.08/kWh + $100/kW (50% of cost up to $300,000)	Energy Efficient Building Equipment	Equipment must be new and not covered by other AEP incentive	Link
Commercial Energy Efficiency Rebate Program	Various Rebates by Equipment	Energy Efficient Building Equipment	Equipment must be new	Link
Commercial New Construction Energy Efficiency Rebate Program	Various Rebates (Max: 50% of cost up to $50,000)	Energy Efficient Building Equipment	Equipment must be new	Link
Commercial Self Direct Rebate Program	Up to$450,000/business entity, $225,000/project	Energy Efficient Building Equipment	Equipment must be new. Must use more than 700,000kWh. Projects Since 2008	Link
Renewable Energy Technology Program	Solar: $1.50/Watt, Wind: $0.275/kWh. Max: Res Sol:50% or $12000, NonRes Sol:50% or $75000, Res Wind: 50% or $7500, NonRes Wind:40% or $12000	Photovoltaic, Wind	Customers must use the AEP net metering, and all equipment must comply with AEP Requirements.	Link

Table 5.1. List of incentives offered by the AEP Ohio.

5.3 RET Project Procurement / Contracting Best Practices

As previously mentioned, a state agency such as ODOT would need to enter into a contract with a third party to be able to take advantage of many of the federal tax incentives, and grants that drive the renewable energy market. There are several contracting options that ODOT can use including:

- Power purchase agreements
- Energy savings performance contracts

These contracting options are explained in more detail in the following subsections.

5.3.1 Power purchasing agreements

Power purchase agreements (PPAs) have been used to finance solar projects since 2003 and they are now driving most commercial PV installations. A PPA works on the basis of a private developer (typically a group consisting of developers, construction companies, and finance companies) agreeing to fund, install, own, operate, and maintain customer-sited (behind the meter) PV system. The customer signs an agreement to purchase the produced electricity from the developer through a long term contract (10 to 30 years) with specified energy prices. Payment is based on actual energy (kilowatt-hours) generated from the PV modules and consumed by the site. (Stoltenberg & Partyka, 2010). PPAs are currently legal in over 20 states, one of which is Ohio (NCHRP, 2013) . A PPA allows a facility pursuing a renewable energy system to place all capital costs on the developer and allows the facility to pay for the use of the technology over an extended period. The facility also avoids maintenance and operations responsibilities. Furthermore, for ODOT facilities, PPAs allow a RET project to take advantage of incentives that they would normally not be able to, such as the business energy investment tax credit, which leads to reduced energy costs. When PPA contracts expire they are typically either renewed for similar terms, the renewable system is purchased by the customer, or the technology is removed from the site. A public works building in Denver Colorado utilized a PPA for a 102 kW photovoltaic system (Stoltenberg & Partyka, 2010).

5.3.2 Energy savings performance contracts

Energy savings performance contracts (ESPC) have a long history of use in the federal sector and for financing energy efficiency projects. 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. 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 (NCHRP, 2013). These contracts are recommended for renewable energy projects only if energy-efficiency measures also are being performed (Stoltenberg & Partyka, 2010).

5.4 Renewable Energy Credits

A renewable energy credit (REC), also referred to as a renewable energy certificate or green tag, is created for each megawatt-hour (1 MWh, or 1000 kilowatt-hours) of renewable electricity generated and delivered to the power grid. When electricity is generated by a renewable source such as wind and/or solar, two things are created: (1) the actual electricity and (2) the environmental benefits associated with the fact that the electricity was produced without burning fossil fuels. RECs are used to account for and track the environmental benefits of the electricity generated from renewable sources. RECs can be sold or purchased and are typically bought for the purpose of supporting renewable energy and/or to help meet any renewable energy requirements. These requirements typically fall under a renewable portfolio standard (RPS). Ohio has an RPS that requires electric distribution utilities and electric services companies to secure a portion of their electricity supplies from alternative energy resources. By the year 2025, 25 percent of the electricity sold by each utility or electric services company within Ohio must be generated from alternative energy sources. At least 12.5 percent must be generated from renewable energy resources, including wind, hydro, biomass and at least 0.5 percent solar. The remainder can be generated from advanced energy resources, including nuclear, clean coal and certain types of fuel cells. In addition, at least one half of the renewable energy used must be generated at facilities located in Ohio (PUCO, 2013). One way that electric distribution utilities can comply with Ohio RPS is through the purchase of the RECs created by applicable commercial and/or institutional RET projects.

The RECs created by solar PV projects are referred to as Solar REC or SREC. SRECs generally have greater value than other RECs. SRECs can completely change the economic viability of a PV project. Stoltenberg and Partyka reported on a PV project that was evaluated in 2003 but was not economically feasible. Three years later (2006), a state RPS requiring that a percentage of the utility's electricity come from solar power was passed. The RPS essentially required a utility to buy SRECs, which sold for a premium of $0.24 per kWh. The project changed from an unacceptable investment to a good investment. (Stoltenberg & Partyka, 2010)

SRECs can be used for up to five years from the time they are produced, and there are two methods to sell them. The first is called spot market sales where SRECs are sold every time it is convenient to sell, but the price of the sale is subject to market price. The second method to sell SRECs is called long-term sales where an organization selling SRECs will enter into a contract and the price of each SREC will be constant throughout the contract period. The price of long-term SREC sales is normally lower than the price of spot market SREC sales, but they provide revenue stability (Stuart & Phillips, Veteran's Glass City Skyway Solar Array Field Demonstration, 2012). Stuart and Phillips researched SREC to determine if they can be used to generate revenue from Veteran's Glass City Skyway Solar Array (VGCS). They have explained that the process of certifying a site to be eligible to sell SRECs consist of three steps (1) the site must be certified by the Public Utilities Commission of Ohio (PUCO), (2) the solar array must be registered with the Pennsylvania New Jersey Maryland Interconnection LLC - Generation Attribute Tracking System (PJM-GATS) and (3) once the SRECs are registered with PJM-GATS, they can be sold through a REC broker. Stuart and Phillips indicated that a revenue grade energy meter must be used to be certified by PUCO and PJM-GATs. The cost the meter used for the VGCS project was approximately $2,500.

The prices of RECs have been going down. In 2012, Stuart and Phillips estimated the value of SRECs to be $225-325 / Mwh. Currently SRECs are selling for $100-$200 depending on US region and wind RECs are selling for $5 - $6 (Good Energy, 2013)

5.5 RET Projects General Best Practices

There are several general steps and practices that can be taken to ensure the quality and efficiency of RET projects. The majority of these best practice measures should be part of the pre-design and design phases of projects and are outlined below (NCHRP, 2013).

- Renewable energy consultants and commissioning agents should be included on the project as early as possible.
- Establish the objectives of the RET project, such as determining what percentage of energy generation from renewable resources is needed.
- Utilize energy modeling strategies to develop a full understanding of the energy needs of the buildings.
- Implement energy monitoring processes and equipment to keep records and evaluate RETs' performance.

- Ensure that designers and project members are familiar and experienced with all aspects of the RETs and energy efficiency strategies being considered.
- Consider whole building design processes and strategies for new building or buildings undergoing major renovations to ascertain the highest performance and efficiencies out of RET projects.
- Research into the site areas environmental limitations, zoning and permitting restrictions, and other regulatory issues. These issues should be checked early on as they can be a significant factor in the practicality of a project (NCHRP, 2013).
- Check with the utility companies to determine any restrictions for renewable energy generation, and/or incentive programs and opportunities.
- Integrate Solar Ready design principles so that the building can add solar energy equipment in the future. This is for circumstances when technologies are not deemed currently feasible but show potential for future feasibility. Solar ready strategies include (Lissell, 2009):
    - Roof slope oriented southward.
    - Potential solar panel locations should be clear of any major shading obstructions.
    - Roof should be designed with the capability of supporting the additional weight of solar panels and mounting equipment.
    - Maintenance access of future PV modules should be well planned.
    - Roof area should be mostly unobstructed to allow adequate space for future installations.
    - Space is designated for the future installation of all additional necessary equipment for RET systems, such as inverters, wiring and storage tanks.

It is good practice to ensure all contractors and installers have the proper training and experience to work on projects to help avoid potential performance issues. Similarly facility staff that will interact with project equipment should be well trained on the appropriate procedures, settings and calibrations, and maintenance requirements. Another good practice is to perform regular commissioning of buildings and the equipment. This helps control the quality and efficiency of RET systems and to catch any issues or performance flaws as quickly as possible.

5.6 Technology Specific Best Practices

Each renewable energy technology is different and will have different performance levels for different sites. These performance levels and efficiencies will be significantly impacted by their appropriate implementation and the careful considerations of the best practices for each technology.

5.6.1 PV systems

PV systems technology is very flexible and well developed. There are many different ways of installing systems and different locations where the PV modules can be placed. Ohio has relatively good levels of available solar radiation, but individual sites should be carefully checked with various tools and resources, such as the NREL resource maps and sun charts. As long as a site has the potential for south facing PV panels and has no major shading concerns it is likely that it could include an efficient PV project. There are several available financial incentives for PV systems which when used, make PV projects much more financially appealing. Some best practices to follow when selecting and implementing PV systems include (NCHRP, 2013):

- If power purchase agreements are used as described in section 5.3.1, ensure that PPA contract terms are properly negotiated. Use lessons learned from other state/federal agencies.
- If net metering is allowed, determine if there are any system size restrictions and how much the utility will pay for the excess electricity.
- Ensure that the PV project is eligible to sell SRECs and determine potential revenues.
- When possible, install inverters in shaded or cooler areas
- Ensure that vendor products are readily available. Ask for experience/history of meeting delivery times. Ensure that firm has demonstrated experience installing PV systems
- PV modules should not be shaded during the hours of 9 AM to 4PM or longer.
- Minimize roof penetrations
- Consider high wind loads if any during design of PV modules mounting system
- Account for snow loads and snow interference with electricity generation during winter months.
- Meet module access and fire code requirements by leaving space around roof systems. These are typically in the range of 4 to 6 feet around the perimeter of solar modules.
- Include monitoring equipment to keep track of energy outputs.

5.6.2 Solar air heating

Buildings with high walls and large amounts of open space, such as ODOT maintenance facilities, particularly benefit from the reduced heating demands resulting from solar air heating systems. The main limiting factors for solar air heating systems are the orientation of the wall and the presence of any shading obstructions. Some best practices to follow when designing and implementing solar air heating systems include (NCHRP, 2013):

- The color of the collector should be dark, but it does not have to be black. Most dark colors will not significantly reduce the collector output and thus provide flexibility to the design team for integrating the collector with the architectural design.
- Solar collector walls should not be shaded during the hours of 9 AM to 4PM or longer.
- Ensure that the air intake for the solar wall is not near areas with potentially contaminated air.
- Ensure that the fan operation is linked to the fire protection system, such that it will shut off if a fire alarm is activated
- Install monitoring equipment to find out energy supplied by the system.

5.6.3 Wind

A grid connected wind energy system can be feasible in ODOT facilities when there is adequate wind speeds at the site, ample land to provide buffer between the turbine and surrounding structures, a smooth land cover to reduce turbulence that may cause fatigue failure of turbines and where local zoning and environmental regulations allow for properly sized turbine towers to be installed. Some best practices to follow when designing and implementing wind energy systems include (NCHRP, 2013):

- If power purchase agreements are used as described in section 5.3.1, ensure that PPA contract terms are properly negotiated. Use lessons learned from other state/federal agencies.
- If net metering is allowed, determine if there are any system size restrictions and how much the utility will pay for the excess electricity.
- Ensure that the wind energy project is eligible to sell RECs and determine potential revenues.
- A good wind resource is essential to a successful wind project. The average cost of generating electricity from a wind turbine falls dramatically with increasing average wind speed. Since wind resource is far more site-specific than solar, it is important that a thorough assessment of wind resources be performed to reveal how hard the wind blows and from which directions. An accurate estimate of the wind speed at a site is very difficult to arrive at without a long term record of measurements. Wind data should be collected using meteorological equipment such as an anemometer for one year at the site, if local data is not available. Time can be reduced if the data can be correlated with other data from nearby projects and sites. In case of large wind turbines, wind site assessment should include the use of meteorological towers to collect wind data for a year. Meteorological towers should be at a height equal to the approximate hub height of the rotor.
- Determine if special approvals are needed. Once a site for a wind project has been selected, an environmental assessment must be conducted and regulatory approval obtained. Such assessment should ensure that the local population supports wind energy, and that an affordable connection can be made to transmission or distribution lines.
- Ensure that the turbine is not located in the path of migratory birds or in areas with bat populations. Consultation with appropriate agencies or experts to determine level of risk and the potential for successful mitigation approaches.
- Research zoning and regulatory issues and ensure turbine generator meets requirements for height, set back distances from roads and buildings, noise, and visibility.
- If proposed wind turbine is near an airport or military installations, ensure that there is no potential for interference with radar equipment.
- Ensure that turbine blades are at least 30 feet above and 500 feet away from any interfering obstructions.
- Use monitoring equipment to keep records of wind speeds and energy outputs.
- Ensure that vendor products are readily available. Ask for experience/history of meeting delivery times. Ensure that firm has demonstrated experience installing PV systems
- Explore cooperative projects between facilities at an offsite location to acquire a better wind resource or to avoid environmental or restriction concerns.

5.6.4 Solar hot water

Solar water heating systems can be used to provide warm or hot water in any climate. Although they reduce the use of fossil fuels and reduce the emissions of harmful gasses such as CO2, SOx, NOx, they are currently not very economically feasible for ODOT maintenance facilities. ODOT facilities typically use relatively cheap natural gas to fulfill their water heating requirements. If the use of financial incentives makes a solar hot water feasible for an ODOT maintenance facility, then the following best practices should be considered to increase the likelihood of project's success (NCHRP, 2013):

- Ensure that vendor products are readily available. Ask for experience/history of meeting delivery times. Ensure that firm has demonstrated experience installing SHW systems
- Ensure that solar collectors are properly oriented. 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. In general tilt angles of +/- 10 degrees from latitude, and orientations of +/- 30 degrees from true south do not appreciably change performance
- Solar collectors should not be shaded during the hours of 9 AM to 4PM or longer.
- Minimize roof penetrations
- Include monitoring equipment to keep track of energy outputs.
- Ensure overheating and thermal expansion precautions have been met.
- Include monitoring controls for temperatures and flow levels.
- Ensure that all system components (collector, storage and backup system) are placed near to each other
- Ensure that pipe carrying hot water are well insulated

5.6.5 Biomass heating systems

Biomass heating systems can provide heat for ODOT maintenance facilities that have the space necessary for fuel delivery, storage, and handling and that are located in areas where there is a reliable and inexpensive source of bio-fuels. Compared with fossil fuel-fired systems, biomass heating plants are physically larger, have higher initial costs, and require more operator involvement. But when heating loads are high over a considerable fraction of the year, the reduced fuel costs and reduced emissions of greenhouse gases and acid rain-causing compounds may make biomass heating systems attractive. When the above conditions exist and a biomass heating system is deemed feasible for an ODOT maintenance facility, then the following best practices should be considered to increase the likelihood of project's success:

- A major consideration in the design of a biomass heating system is the sizing of the biomass combustion system. Two approaches are commonly used (1) peak load design and (2) base load design. In peak load design, the biomass heating system is large enough to meet the maximum heat load that will occur. In base load design, it is only large enough to meet the base load that occurs during typical operation. Peak load design maximizes the use of biofuels and minimizes the use of fossil fuels. This can be advantageous when the cost of fossil fuel is very high. But the biomass combustion system required to meet the peak load will be larger and more expensive. In addition, it will often operate at a loading well below its nominal capacity and results in reduced efficiency and increased emissions. Base load design typically permits a much smaller and cheaper biomass heating system. Yet, because it satisfies the base load, most of the annual energy requirements are met by the biomass system. This arrangement can be very cost-effective and because the system operates at or near its design load most of the time, efficiency is high and emissions are reduced. However, a conventional peak heating system is required, and fossil fuel consumption is higher (RETScreen International, 2004). While the best approach will depend on the nature of the installation, ODOT maintenance facilities would likely benefit more from using the base load approach.

- Determine if special environmental approvals are needed. There may be a need for additional pollution control equipment for particulate control.
- Ensure that there is enough space to accommodate the regular delivery of biofuel. Such a space should be accessible by truck and large enough vehicles to turn around and for other necessary equipment to operate.
- Since the long term economic feasibility significantly depends on the price of the biofuel used. It is important to have a reliable long-term contract for purchasing bio-fuel at a stable price. To ensure a reliable, secure supply, the supplier must be chosen carefully.
- Unlike fossil fuels, which are standard products available from a wide range of suppliers, biomass fuels vary in their quality and consistency. Because of this variability, it is important to assess a potential biomass fuel supply for moisture content, ash content, and heating value. Most biomass fuels contain moisture; the more it contains, the heavier it will be during handling and transport and the less efficiently it will burn due to the need to convert the water to steam. Wet biomass fuels can also lead to higher emissions of carbon monoxide and unburned hydrocarbons in low temperature biomass combustion systems and is subject to biological activity during storage (RETScreen International, 2004). Thus it is important to ensure that the quality of the biomass fuel is acceptable and available on a long-term basis at a price that is competitive with fossil fuels.

5.6.6 Ground source heat pumps

Although GSHP systems are very energy efficient, they are not very practical for use in ODOT maintenance facilities for two reasons; (1) the heating load and cooling load in ODOT maintenance facilities vary significantly, and (2) heating is the dominant energy requirement on ODOT maintenance facilities and is provided through low-cost natural gas. ODOT facilities should consider GSHPs on new facilities only if generous financial incentives are available from electric utilities. In this case, it is recommended that the GSHP be sized to provide heating/cooling for the office area only and that the following best practices be considered (NCHRP, 2013):

- Review environmental permitting requirements particularly if an open loop system is considered as the underground heat exchanger.
- Ensure that the thermal properties of the ground/heat source are well known. This may require drilling test wells and taking soil samples.
- Use thermally enhanced grout in boreholes to improve heat transfer with the soil and improve performance.
- Ensure that installer has demonstrated experience installing GSHP systems

CHAPTER 6 – DECISION MATRICES

Two decision matrices (a State Level Matrix and a Site Level Matrix) were developed to assist ODOT decision makers with identifying RET projects that are capable of maximizing the green performance of their facilities while complying with limited budgets. The decision matrices are further described in the following sections

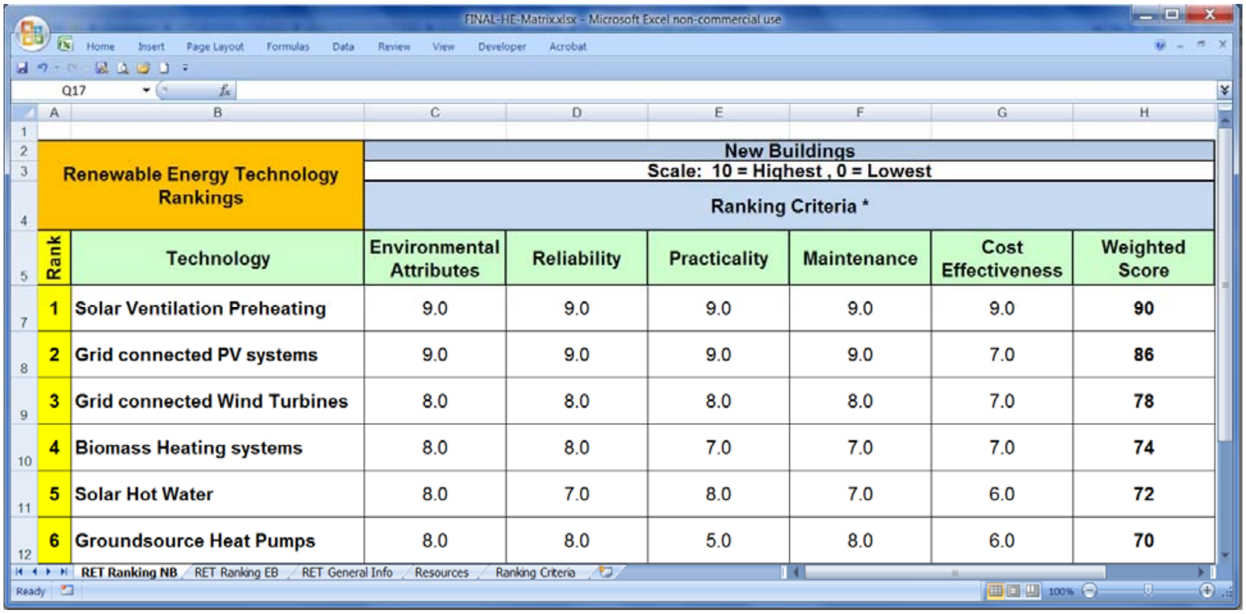
6.1 State Level Decision Matrix

The State Level matrix provides a high level comparison of RETs and ranks them based on their overall applicability in highway maintenance facilities in Ohio. This matrix provides an initial screening mechanism without considering specific site conditions, energy usage patterns or facilities goals. It also provides easy access to information, resources, tools and case studies to help evaluate applicability of renewable energy projects and to increase overall energy savings and GHG reduction potential of RET investments.

The research team used an excel spreadsheet to develop the state level matrix. The spreadsheet consists of several tabs as follow:

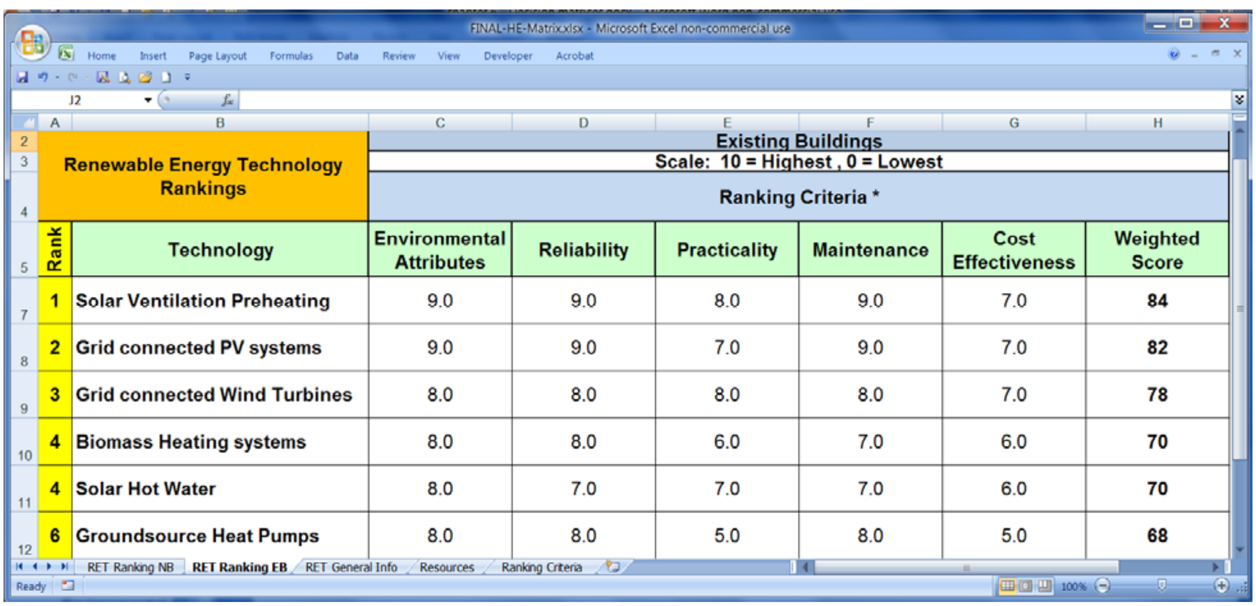
- The first tab of the matrix spreadsheet "RET Ranking NB" as shown in Figure 6.1 contains a list of all RETs evaluated, scores with regards to the various ranking criteria, an overall weighted score and rank (compared to other RETs weighted score) for new buildings.
- The second tab of the matrix spreadsheet "RET Ranking EB" as shown in Figure 6.2 is similar to the first tab and contains a list of all RETs evaluated, scores with regards to the various ranking criteria, an overall weighted score and rank (compared to other RETs weighted score) for existing buildings. There was a need for including a separate tab for evaluating existing buildings since the feasibility of implementing RET technologies in ODOT maintenance facilities will depend on whether the RET technology is implemented on a new project or as a retrofit to an existing project. For example, solar air heating is most cost-effective when employed in new construction since the collector replaces some form of regular building cladding, reducing the net cost of the solar system. Thus SAH has a higher score for cost effectiveness in "RET Ranking NB" than it does in "RET Ranking EB"
- The third tab of the matrix "RET General Info" as illustrated in Figure 6.3 contains a discussion of how each RET alternative performs against each evaluation criteria. It was important to include this discussion so that the decision maker using the matrix understands how the research team arrived at the score assigned to each RET alternative for each criterion. This tab also includes additional guidance information on how the feasibility of a given RET will vary based on whether the project is new construction or a retrofit of an existing building.
- The fourth tab of the matrix "Resources" as illustrated in Figure 6.4 contains listings of manufacturers; and links to technology briefs, case studies, and reports.
- The fifth tab "Ranking criteria" as illustrated in Figure 6.5 contains more detail on the ranking criteria and the weights assigned to each criteria. As shown in Figure 6.5, the research team assigned equal weights to each of the five evaluation criteria (20%). However, the decision maker using the matrix can easily change the weights to match his/her project's specific conditions. This will obviously change the overall score for

each RET in the “RET Ranking NB” and the “RET Ranking EB” tabs. The user can use the Excel functionality to easily sort the RETs based on the changes.



Renewable Energy Technology Rankings		New Buildings Scale: 10 = Highest , 0 = Lowest Ranking Criteria *					
Rank	Technology	Environmental Attributes	Reliability	Practicality	Maintenance	Cost Effectiveness	Weighted Score
1	Solar Ventilation Preheating	9.0	9.0	9.0	9.0	9.0	90
2	Grid connected PV systems	9.0	9.0	9.0	9.0	7.0	86
3	Grid connected Wind Turbines	8.0	8.0	8.0	8.0	7.0	78
4	Biomass Heating systems	8.0	8.0	7.0	7.0	7.0	74
5	Solar Hot Water	8.0	7.0	8.0	7.0	6.0	72
6	Groundsource Heat Pumps	8.0	8.0	5.0	8.0	6.0	70

Figure 6.1. State Level Decision Matrix, “RET Ranking NB” Tab



Renewable Energy Technology Rankings		Existing Buildings Scale: 10 = Highest , 0 = Lowest Ranking Criteria *					
Rank	Technology	Environmental Attributes	Reliability	Practicality	Maintenance	Cost Effectiveness	Weighted Score
1	Solar Ventilation Preheating	9.0	9.0	8.0	9.0	7.0	84
2	Grid connected PV systems	9.0	9.0	7.0	9.0	7.0	82
3	Grid connected Wind Turbines	8.0	8.0	8.0	8.0	7.0	78
4	Biomass Heating systems	8.0	8.0	6.0	7.0	6.0	70
4	Solar Hot Water	8.0	7.0	7.0	7.0	6.0	70
6	Groundsource Heat Pumps	8.0	8.0	5.0	8.0	5.0	68

Figure 6.2. State Level Decision Matrix, “RET Ranking EB” Tab

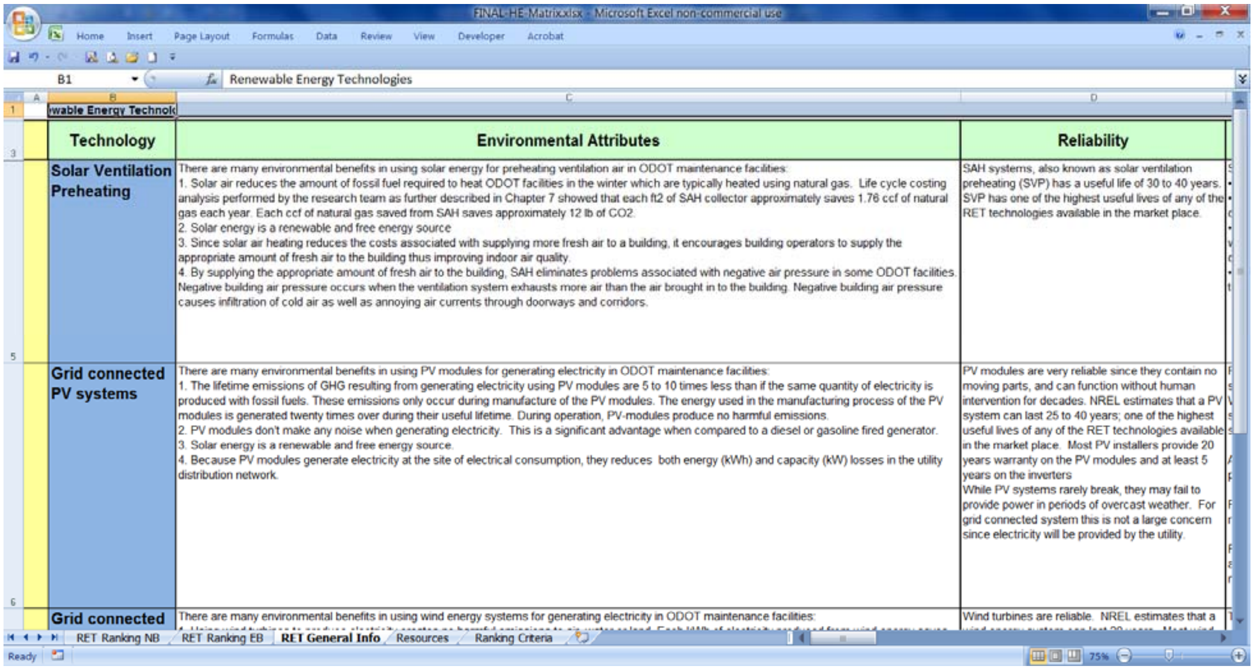


Figure 6.3. State Level Decision Matrix, “RET General Info” Tab

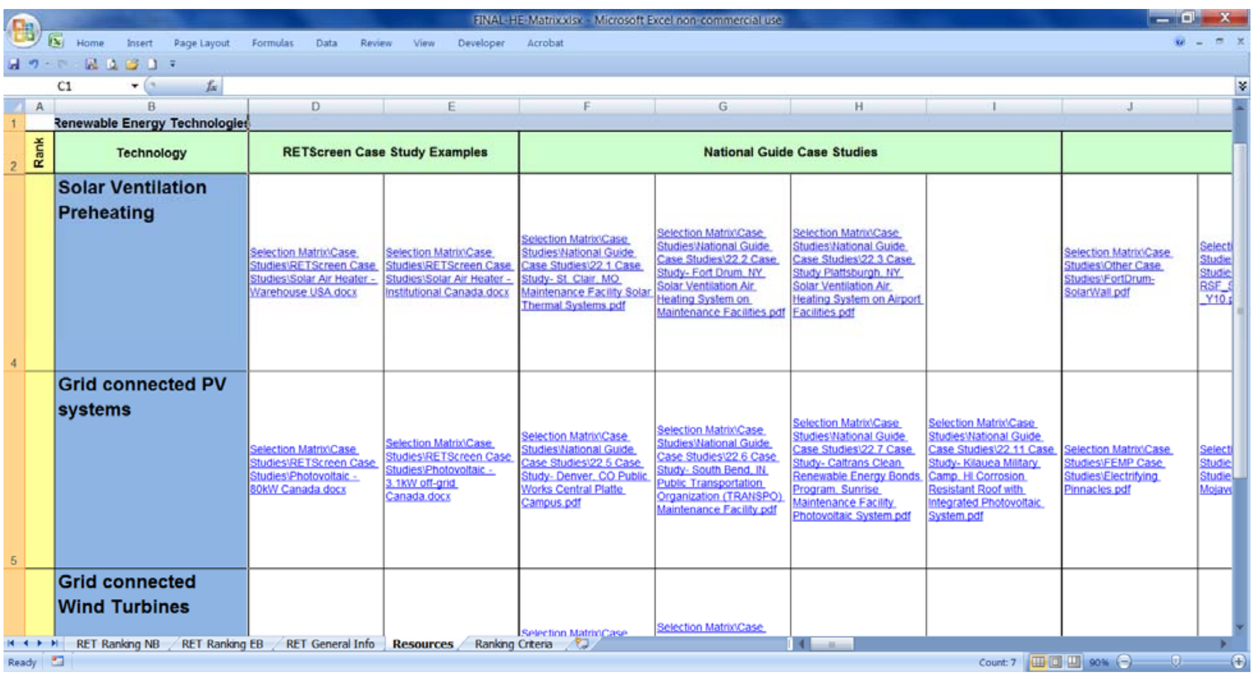


Figure 6.4. State Level Decision Matrix, “Resources” Tab

B	C	D	E	F	G	H
ODOT - RET Selection - Ranking Criteria						
Score Weight	**20%**	**20%**	**20%**	**20%**	**20%**	**100%**
Criteria Category	**Environmental Attributes**	**Reliability**	**Practicality**	**Maintenance**	**Cost Effectiveness**	**Total**
What was considered in each category?	We considered the emissions reduction potential of the RET. We evaluated both (1) emissions emitted during the manufacturing process of the RET components and (2) emissions eliminated during the expected life of the RET. We also considered other environmental impacts such as site disturbance, ground water pollution, noise pollution, and social impacts.	We considered the maturity of the technology, its typical useful life, typical warranties on the technology and its components, and its consistency (e.g. ability to meet requirements without interruption).	We considered ease of construction and installation, special code/zoning requirements, availability of renewable resources in Ohio, and whether technology matches ODOT maintenance facilities' energy demands' patterns.	We considered the complexity of required maintenance activities and whether special expertise is needed to perform such activities or they can be performed by ODOT maintenance personnel. We also looked at frequency of maintenance activities required and their associated costs.	We looked at the economic feasibility. We considered not only initial cost but total life cycle cost. We also looked at factors that have an impact on cost effectiveness.	The sum of all the weights assigned to each crieterion should equal 100T

Figure 6.5. State Level Decision Matrix, "Ranking Criteria" Tab

6.1.1 Evaluation criteria

The state level matrix compares different RET alternatives and ranks them based on 5 criteria: (1) environmental attributes, (2) reliability, (3) practicality,(4) maintenance, (5) cost effectiveness. The following paragraphs explain in further detail, what the research team considered when assigning scores for a given RET under each criterion:

- Environmental attributes: We considered the emissions reduction potential of the RET. We evaluated both (1) emissions emitted during the manufacturing process of the RET components and (2) emissions eliminated during the expected life of the RET. We also considered other environmental impacts such as site disturbance, ground water pollution, noise pollution, and social impacts.
- Reliability: We considered the maturity of the technology, its typical useful life, typical warranties on the technology and its components, and its consistency (e.g. ability to meet requirements without interruption).
- Practicality: We considered ease of construction/installation, special code/zoning requirements, availability of renewable resources in Ohio, and whether technology matches ODOT maintenance facilities' energy demands' patterns.
- Maintenance: We considered the complexity of required maintenance activities and whether special expertise is needed to perform such activities or they can be performed

by ODOT maintenance personnel. We also looked at frequency of maintenance activities required and their associated costs.

- Cost effectiveness: We looked at the economic feasibility. We considered not only initial cost but total life cycle cost. We also looked at factors that have an impact on cost effectiveness.

6.2 State Level Evaluation of RETs

The research team studied in detail how various RETs perform against each evaluation criterion. The following sections present the outcome of this effort and is intended to help the decision maker using the matrix understand the logic behind each score.

6.2.1 Solar air heating

Environmental attributes

There are many environmental benefits in using solar energy for preheating ventilation air in ODOT maintenance facilities:

1. Solar air reduces the amount of fossil fuel required to heat ODOT facilities in the winter which are typically heated using natural gas. Life cycle costing analysis performed by the research team as further described in Chapter 7 showed that each ft2 of SAH collector approximately saves 1.76 ccf of natural gas each year. Each ccf of natural gas saved from SAH saves approximately 12 lb of CO2.
2. Solar energy is a renewable and free energy source
3. Since solar air heating reduces the costs associated with supplying more fresh air to a building, it encourages building operators to supply the appropriate amount of fresh air to the building thus improving indoor air quality.
4. By supplying the appropriate amount of fresh air to the building, SAH eliminates problems associated with negative air pressure in some ODOT facilities. Negative building air pressure occurs when the ventilation system exhausts more air than the air brought in to the building. Negative building air pressure causes infiltration of cold air as well as annoying air currents through doorways and corridors.

Reliability

SAH systems, also known as solar ventilation preheating (SVP) has a useful life of 30 to 40 years. As shown in Table 6.1, SVP has one of the highest useful lives of any of the RET technologies available in the market place.

System Useful Life	Years
PV	25 to 40
Wind	20
Biomass combustion Combined Heat and Power	20 to 30
Biomass heat	20 to 30
SWH	10 to 25
SVP	30 to 40

Table 6.1. Useful lives of common RET systems. (Source: NREL)

Practicality
SAH systems are very practical as they are:

- Easy to construct since there are no storage tanks or heat exchangers involved, which reduces complexity and costs.
- The solar collector can be installed on walls of different configurations as shown in Figures 6.6 to 6.8. It can be installed on the entire wall or on part of the wall. Although it is easier to install a solar collector on a wall that has now windows or doors, wall openings can be accommodated.
- The amount of solar energy collected by the SAH system correlates well with ODOT heating demands; the vertical solar collector catches more sun during the winter, when the sun is low in the sky. Heating demands increase significantly in the winter in ODOT facilities because of the cold weather and longer hours of operation in case of snow storms.
- The color of the collector should be dark, but it does not have to be black. Most dark colors will not significantly reduce the collector output and thus provide flexibility to the design team for integrating the collector with the architectural design. Figure 6.6 shows an industrial system in Connecticut that uses a brown colored collector, and accommodates numerous doors and windows.

Figure 6.6. Brown collector on industrial building, Connecticut, USA. Photo credit Conserval Engineering.

Figure 6.7. Grey colored solar collect installed on part of the wall of a vehicle maintenance building Before (left) and after (right). Photo credit: US Army environmental command (source: http://aec.army.mil/usaec/sustainability/drumwall.pdf

Figure 6.8. An SAH collector installed on a gable wall on the BigHorn Home Improvement Center in Silverthorne, Colorado. Photo credit solarwall. http://solarwall.com/media/download_gallery/BigHorn-SolarWall.pdf

Maintenance

Solar air heating systems require little additional maintenance. The steel collector has the same maintenance requirements of the steel cladding it replaces, and can be repainted if necessary. The summer bypass damper is operated similar to other dampers in the ventilation system. Building ventilation fans need the same maintenance regardless of whether they draw air through a solar collector or a regular intake. The flow of warm air dries the space behind the collector, making it an unwelcoming environment for insects. The flow rate per unit area of collector is too low to draw dirt, pollen, dust, and snow towards the wall. Thus they do not clog the collector's perforations and do not significantly lower the efficiency of the collector (RETScreen 2004)

Cost effectiveness

Properly designed and installed SAH systems have one of the shortest payback periods of any of the available RET technologies when incentives are not considered. The NREL map in Figure 6.9 shows the simple payback (without incentives) for SAH systems in different areas of the US. On new projects, SAH systems may have simple payback periods as low as two to five years depending on the cost of the energy source they replace. The solar air heating system will last for decades, and continue to generate savings after it has paid back its initial costs.

Solar air heating is most cost-effective when employed in new construction where the collector replace some of the regular building cladding and allows the use of less expensive wall cladding material as a backing, reducing the net cost of the solar system. Also on new projects, the building ventilation system will be designed and situated so as to facilitate integration of the solar collector, avoiding additional ducting and fans. The next most cost-effective application of SAH is on retrofit projects that aim to renovate or repair an existing exterior wall, improve interior air quality, or eliminate negative air pressure problems. On these retrofit projects, the SAH system will benefit from the cladding credit, but may require minor modifications to the existing ventilation system.

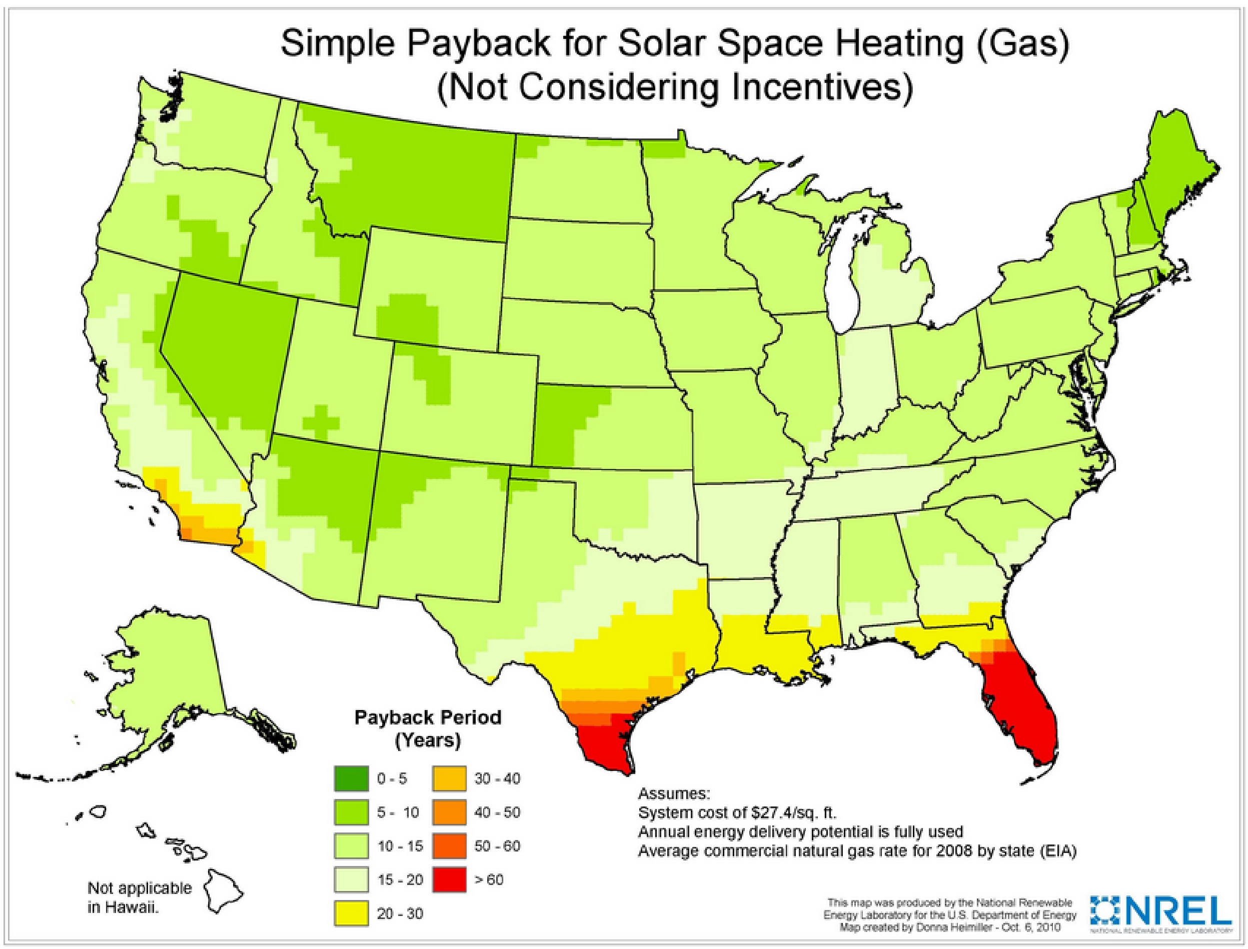


Figure 6.9. Simple payback for SAH systems that replaces gas heating (National Renewable Energy Laboratory, 2013)

New vs. existing buildings

As discussed above, solar air heating is most cost-effective when employed in new construction. In new construction, since the collector function as weather cladding for the building, it replaces regular cladding and thus the material and labor costs of regular cladding should be subtracted from the SAH system’s total cost. The cost of regular cladding is typically one third to one half of that of the purchase and installation cost of the collector. For existing buildings, the cost of additional ducting could be avoided if the intake for the building ventilation system is located near the wall on which the solar collector is installed.

Conclusion

Solar air heating is a cost-effective technology for heating ODOT maintenance facilities. Energy savings resulting from SAH systems are the sum of solar energy actively collected, building heat recapture savings, and destratification savings. The amount of solar energy collected by the SAH system correlates well with ODOT heating season; a strong solar resource is available during the winter when ventilation air heating is required since the vertical solar collector catches more sun during the winter, when the sun is low in the sky. Solar air heating collectors do not just provide energy benefits - they also serve as weather cladding. SAH systems feed into the intake of conventional building ventilation systems. They are most financially attractive in new construction and retrofit applications aimed at repairing an existing wall, improving air quality, or eliminating negative air pressure problems.

6.2.2 Grid connected photovoltaic

Environmental attributes

There are many environmental benefits in using PV modules for generating electricity in ODOT maintenance facilities:

1. The lifetime emissions of GHG resulting from generating electricity using PV modules are 5 to 10 times less than if the same quantity of electricity is produced with fossil fuels. These emissions only occur during manufacture of the PV modules. The energy used in the manufacturing process of the PV modules is generated twenty times over during their useful lifetime. During operation, PV-modules produce no harmful emissions.
2. PV modules don’t make any noise when generating electricity. This is a significant advantage when compared to a diesel or gasoline fired generator.
3. Solar energy is a renewable and free energy source.
4. Because PV modules generate electricity at the site of electrical consumption, they reduce both energy (kWh) and capacity (kW) losses in the utility distribution network.

Reliability

PV modules are very reliable since they contain no moving parts, and can function without human intervention for decades. As was previously indicated in Table 6.1, NREL estimates that a PV system can last 25 to 40 years; one of the highest useful lives of any of the RET technologies available in the market place. Most PV installers provide 20 years warranty on the PV modules and at least 5 years on the inverters (NCHRP 2013)

While PV systems rarely break, they may fail to provide power or have inconsistent power generation in periods of overcast weather. For grid connected system this is not a large concern since electricity will be provided by the utility.

Practicality
PV is a simple technology that can be easily installed in ODOT maintenance facilities. PV modules can easily be mounted on the roof of a structure. Roof mounted PV systems are very practical in ODOT maintenance facilities since they typically have large roof areas. They can also be mounted on the ground or on the building walls. When mounting PV modules on the roof of an existing building it is important to ensure that the roof is able support the additional weights of the modules and support structures and that the roof's life is at least as long as the expected life of the PV modules. Roof mounted PV modules are more practical in new construction projects since roof life is typically longer than in existing projects. On existing projects, roof mounted PV systems may not be practical if the roof slope is oriented east or west.

Another advantage of a PV system is its modularity. PV is a scalable technology that can be put into place quickly and in any increment desired. PVs' modularity permits the owners to start with a small system and add capacity over the years, in response to changes in the demand for electricity or the availability of capital.

For ODOT facilities, the solar load correlation is negative since sunny periods coincide with lower than average electric loads during the summer. Although this is not a major concern for grid connected PV modules, it should be taken into consideration when sizing the PV system in order to not oversize the system.

PV systems are very suitable for distributed integration with the utility grid because of the simplicity of these systems, their modularity and reliability. The distributed approach is potentially more suitable for Photovoltaics since it overcomes a major disadvantage of centralized PV power plants, in that distributed systems can be mounted on roofs and facades, whereas the cost of a large tract of land for a central PV power plant can be very significant.

Maintenance
PV systems contain few components and have very basic operating and maintenance procedures. The PV system, unlike wind turbines, bio mass systems or generators, is simple, very reliable, and can be maintained by people who have no background in power systems. This is particularly important for ODOT maintenance facilities which may not have adequate staff with proper expertise to operate complex power systems.

Cost effectiveness
Without financial incentives grid connected PV systems often have paybacks of 20 years or more, depending on the price of electricity saved. The NREL map in Figure 6.10 shows the simple payback (without incentives) for a 10 kW PV system in different areas of the US (National Renewable Energy Laboratory, 2013). Simple payback periods are expected to decrease in the future as PV system costs continue to decrease and electricity rates continue to increase. It is important to use the most recent costs of PV modules when evaluating their economic feasibility.

PV systems are much more feasible by taking advantage of available financial incentives and by selling solar renewable energy credits as described in Chapter 5; payback periods can be as low as 6 years. The net cost of PV installations can also be reduced by using the modules to replace part of the building facade or roof, thereby saving on the cost of conventional materials as shown in Figure 6.11. Such installations are referred to as building integrated photovoltaic (BIPV). Several PV manufacturers produce BIPV modules which can be incorporated into buildings as standard building components such as roofing tiles and curtain walls. This helps reduce the relative cost of the PV power system by the cost of the conventional building materials. A large cost advantage of PV system in general is that the sun, the fuel for PV systems, is free, and thus protected from the price volatility that is always a concern with fossil fuels.

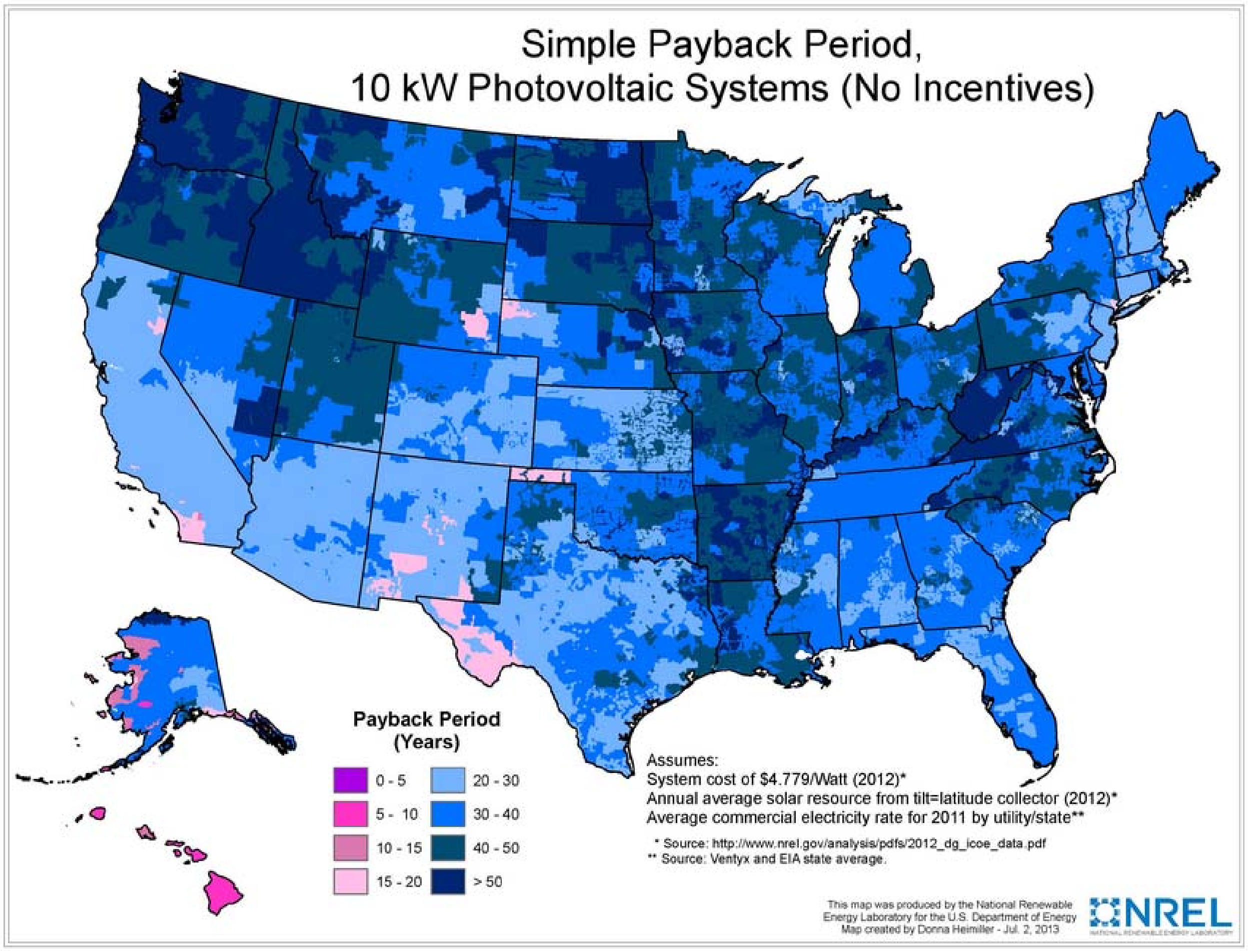


Figure 6.10. Simple payback for a 10 kW system (National Renewable Energy Laboratory, 2013)

Figure 6.11. Installation of skylight glass laminated with PV cells at the Thoreau Center for Sustainable Development, Presidio National Park, San Francisco, California. (Credit: Lawrence Berkeley Lab)

New vs. existing buildings
Grid connected PV systems can successfully be implemented on both new and existing buildings. PV systems have some advantages when employed in new construction since the building can be oriented due to south to optimize the PV system's energy performance. Also on new projects, if BIPV systems are used, the BIPV modules will replace some conventional building materials and will reduce the net cost of the BIPV system. On existing buildings, for roof-mounted PV installations, the roof should be in good condition. It should be able to support the additional weight of the modules and should last for the expected service life of the PV modules.

Conclusion
The capital costs of PV systems are high, but their operating and maintenance costs are very low. The use of financial incentive and the ability to sell SREC can significantly improve the economic feasibility of grid connected PV systems. Intangible benefits of PV systems are often more important than costs. The environmental benefits of the technology, its minimal noise and visual pollution compared to generators and electric lines, and its modularity and simplicity may make it the power system of choice.

6.2.3 Grid connected wind turbines

Environmental attributes

There are many environmental benefits in using wind energy systems for generating electricity in ODOT maintenance facilities:

1. Using wind turbines to produce electricity creates no harmful emissions to air, water or land. Each kWh of electricity produced from wind energy saves approximately .65 kg of CO_2. The energy needed to produce the turbine is recovered by that turbine in three months if the wind velocity is 7 m/s.
2. Wind energy is a renewable and free energy source.

3. Because wind energy systems generate electricity at the site of electrical consumption, they reduce both energy (kWh) and capacity (kW) losses in the utility distribution network.

On the other hand, there may be some environmental concerns related to wind energy systems. These include:

1. Noise: Neighbors may potentially complain of noise. Unless the maintenance facility is very close to 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 (NCHRP, 2013).
2. Visual obstructions: If neighbors support wind energy, they are less likely to object to a turbine that obstructs their view.
3. Possible interference with radar systems if turbine is close to airports and military installations.
4. Possible interference with the path of migratory birds and bat population: Appropriate agencies should be consulted to determine level of risk and the potential for successful mitigation approaches.
5. Sites with dense forests may require clearing of trees within a 500 ft of proposed wind turbine location to reduce turbulent airflow.

Reliability

Wind turbines are reliable. As was previously indicated in Table 6.1, NREL estimates that a wind energy system can last 20 years. Most wind energy systems' installers provide 5 years warranties on the system and its components (NCHRP, 2013). Reliable operation requires some additional maintenance. Typically PV systems have higher warranties and longer useful lives.

Practicality

There are several reasons that wind energy systems are practical for ODOT maintenance facilities, especially those located in rural area:

1. ODOT maintenance facilities located in rural areas have ample land and as such are suitable for wind energy systems which require sufficient land area to provide adequate buffer between the turbine and surrounding structures.
2. Winds tend to be stronger during the day than the night and stronger during the winter than the summer. Thus, the times of stronger winds tend to coincide with periods of elevated electricity demand in ODOT maintenance facilities.
3. Construction of wind turbines can be completed in a short time

On the other hand, there are some issues related to wind energy systems that may make them less practical for some ODOT maintenance facilities. These include:

1. ODOT facilities in urban areas typically don't have ample land area to provide adequate buffer between the turbine and surrounding structures
2. ODOT facilities in urban areas have several neighbors who may object to the turbine's noise and/or visual obstruction

3. The wind resource assessment and approvals for a wind turbine are often the longest activities in the development of the wind energy project and may significantly delay the completion of the project.

Maintenance

Although wind turbines are reliable, they require regular inspections and maintenance. The operator of the wind turbine must have a plan in place for conducting the required regular inspections and maintenance. Otherwise, even the most robust and reliable turbine will eventually fail. Maintenance requirements vary among manufacturers. Some turbines require more maintenance activities than others. It is recommended that ODOT install turbines that have minimal maintenance requirements and that spare products are readily available. 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, etc.), there are some safety risks associated with performing the functions at the tower heights (NCHRP, 2013).

Cost effectiveness

The capital costs of wind energy systems are high. Without financial incentives, these systems have payback periods of 15 – 25 years (NCHRP, 2013). The economic feasibility of a wind energy system can be significantly improved by taking advantage of available financial incentives and by selling renewable energy credits as described in Chapter 4. It should be noted however that the monetary value of renewable energy credits (REC) associated with wind energy is much lower than a solar renewable energy credit (SREC). Where the wind REC is currently valued at $5-$6 / MWH, the solar REC is valued at $100-$200/MWH. A major cost advantage of wind energy systems is that the wind, the fuel for wind turbines, is free, and thus protected from the price volatility that is always a concern with fossil fuels.

New vs. existing buildings

Wind energy systems can be effectively equally installed on both new and existing facilities as long as there is sufficient land area and enough wind. Since wind turbines are typically mounted on the ground, the condition of the existing building won't have an impact on the turbine installation. As such, wind turbines can potentially be more feasible on some ODOT existing facilities if the condition of the roof on those facilities is not adequate for proper mounting of PV modules and/or if buildings on those facilities are going to be replaced before the useful life of the PV system.

Conclusion

A grid connected wind energy system can be feasible in ODOT facilities when there is ample land to provide buffer between the turbine and surrounding structures, where there is a smooth land cover to reduce turbulence that may cause fatigue failure of turbines and where local zoning and environmental regulations allow for properly sized turbine towers to be installed. Since the energy in the wind increases in proportion to the cube of the wind speed, high average wind speeds are essential to profitable wind project development. In addition, government or utility production credits significantly improve the profitability of on-grid wind projects.

6.2.4. Biomass heating systems

Environmental attributes

There are many environmental benefits in using biomass systems for providing heat in ODOT maintenance facilities:

1. Growing biomass removes the same amount of carbon from the atmosphere as is released during combustion, so there are zero net emissions of greenhouse gases.
2. Most biofuels have negligible sulfur content and thus do not contribute to acid rain.
3. Biomass that is harvested in a sustainable manner is considered a renewable energy resource since it will last indefinitely.
4. Because biomass heating usually makes use of fuel that is available locally and because it requires considerable labor to operate and maintain the system, it creates local jobs. Biomass heating supports these local jobs rather than capital-intensive industries, such as oil extraction, that may be located far from the heating plant.
5. Biomass heating often uses waste products, such as byproducts from lumber mills or agricultural processing. These waste products are transformed from liability to resource.

On the other hand, biomass combustion does generate some emissions that can affect local air quality and may be subject to regulation. These include particulates (also known as soot), carbon monoxide, sulfur oxides, and low levels of carcinogens. These emissions and the regulations that apply will depend on the type of fuel as well as the size and nature of the combustion system. Also, unlike other renewable sources, biomass is not free.

Reliability

Biomass heating systems are reliable. As was previously indicated in Table 6.1, NREL estimates that a biomass heating system can last 20 to 30 years. Reliable operation requires special attention to fire safety, air quality standards, ash disposal options, and general safety issues. These requirements should be investigated at the initiation of the project.

Practicality

There are several reasons that biomass heating systems are practical for ODOT maintenance facilities, especially those located in rural area:

1. Biomass heating systems require far more space than comparable fossil fuel-fired systems. ODOT maintenance facilities in rural areas tend to have the space necessary for fuel delivery, storage, and handling.
2. Biomass is more practical if there in s adequate supply of fuel resources. In rural areas, there is typically a wide range of low-cost matter that can be used as biomass feedstock. This includes agricultural residues such as straw, husks, animal litter, and manure.
3. Substantial fuel savings must be achieved in order to offset the high initial costs and annual labor requirements of the biomass heating system. In general, ODOT maintenance facilities have a very high heating load in the winter and can thus provide required fuel savings.

On the other hand, there are some issues related to biomass systems that may make them less practical for some ODOT maintenance facilities. These include:

1. Depending on the biomass fuel used, a biomass heating system may require the construction of a separate building to house the system as well as costly fuel handling systems.
2. The operating and maintenance costs of the biomass system are also much higher than those of a fossil fuel fired system.
3. ODOT facilities in urban areas typically don't have ample land area to provide the space necessary for fuel delivery, storage, and handling.
4. Emission generated by biomass combustion may be subject to stricter air quality regulation in ODOT facilities in urban areas.
5. Facilities that both generate biomass residues and need heat are typically the best candidates for biomass heating. If the biomass residues and by-products have no high-value alternative use, or need to be disposed of, they can be a very low cost fuel. Since maintenance facilities do not generate biomass residue but generate waste oil, it is more practical to use waste oil burners as discussed in Chapter 5- Best management practices.

<u>Maintenance</u>
Biomass heating systems generally require more attention than fossil fuel-fired heating systems. They require committed operators throughout the heating season. Biomass fuel must be produced and loaded into feed hoppers or fuel storage, ash must be removed regularly from the burner or ash bins, and system function must be monitored closely. Failure to dedicate reliable people to biomass system operation can result in a shutdown and force a switch to a fossil fuel-fired system with higher fuel costs.

<u>Cost effectiveness</u>
Biomass combustion systems have high initial costs but very low fuel costs. The initial costs of biomass systems can be as high as four times that of fossil fuel fired system (RETScreen International, 2004). The biomass system may require the construction of a separate building to house the system as well as costly fuel handling systems whereas the fossil-fuel fired system can be situated in a corner of the building itself. The operating and maintenance costs of the biomass system are also much higher than those of the fossil fuel fired system. But if the biomass system uses very low cost fuel (e.g. wood chips from a local sawmill), it can easily be the least cost option in the long term.

The price of the biofuel depends on the source and the local availability. If the source is a waste product that must be disposed of, it may have a negative cost since tipping fees are reduced. Residuals, such as bark from a saw mill, which do not need to be disposed of but have no alternative use, are available at no cost. By-products, such as shavings and sawdust, have a low-value alternative use and therefore will be available at a low cost. Biomass harvested or purpose-grown specifically for use as a bio-fuel will have higher costs, and prepared fuels, such as wood pellets and briquettes, may cost more than fossil fuels. A reliable long-term supply of bio-fuel at a stable price is essential. The price of the bio-fuel will be influenced by possible alternative uses. For example, the price of waste wood bark may jump if it begins to be used in landscaping.

Long-term contracts should be sought and to ensure a reliable, secure supply, the supplier must be chosen carefully. (RETScreen International, 2004).

New vs. existing buildings
Biomass heating is most cost-effective when employed in new construction. In new construction, the biomass heating system replaces the conventional fossil-fuel fired system and thus the material and labor costs associated with the conventional system should be subtracted from the biomass heating system's total cost. In addition, new construction offer better opportunities for designing and implementing the additional space required for handling the biofuel. Such required space typically include (1) a fuel receiving area; accessible by truck, with enough space for vehicles to turn around and, if necessary, mobile loaders and other equipment to operate and (2) a fuel storage space.

Conclusion
Biomass heating systems can provide heat for ODOT maintenance facilities that have the space necessary for fuel delivery, storage, and handling and that are located in areas where there is a reliable and inexpensive source of bio-fuels. Compared with fossil fuel-fired systems, biomass heating plants are physically larger, have higher initial costs, and require more operator involvement. But when heating loads are high over a considerable fraction of the year, the reduced fuel costs and reduced emissions of greenhouse gases and acid rain-causing compounds may make biomass heating systems attractive.

6.2.5. Solar hot water

Environmental attributes
Environmental benefits associated with using solar thermal energy for heating water in ODOT maintenance facilities include:

1. The use of solar energy for water heating reduces the use of fossil fuels. It thus reduces the emissions of harmful gasses such as CO_2, SO_x, NO_x.
2. Solar thermal energy is a renewable and free energy source.

To prevent health problems (such as the legionella bacteria), the water of the storage boiler must be kept at above 60 °C and many building codes require a conventional water heater as a backup to the solar water heating system. Such requirement increase the initial cost of the SWH system and reduces its economic feasibility.

Reliability
Solar hot water systems are reliable. As was previously indicated in Table 6.1, NREL estimates that a solar hot water system can last 10 to 25 years. Reliable operation requires some additional maintenance. Typically PV systems have higher warranties and longer useful lives.

Practicality
Solar collectors are relatively simple and fitted to roofs or facades of new and existing buildings. There needs to be adequate area for the collectors, and if roof mounted, structural loads imposed by the collectors must be considered. 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

(NCHRP, 2013). Many building codes require a conventional water heater backup to consistently the temperature of the stored water at above 60 °C in order to prevent health problems.

In ODOT maintenance facilities, hot water is used for sanitary uses in bathrooms and kitchens, and for washing vehicles in wash bay areas. In ODOT existing facilities that the research team visited, there were two separate systems that provided the hot water needed; (1) a gas fired conventional hot water system is used to provide hot water for sanitary uses and (2) a gas fire pressure washer is used for washing vehicles. For a SWH system to be practical in ODOT maintenance facilities, it should be able to fulfill both water heating requirements.
Solar water heating has been successfully used for car washes requiring large quantities of warm or hot water. It is not very practical if the SWH is only used to provide hot water for the bathrooms, showers and kitchen areas as it was reported by some ODOT facility representatives that there is typically not too much demand for hot water in these areas. A lower usage means an extended return on investment for the SWH system.

Maintenance
Although SWH are reliable, they require regular inspections and maintenance. While the burden of maintenance is not particularly high and is similar to that required of other plumbing systems, the system cannot be ignored. The operator of a solar water heating system must be committed to regular maintenance and timely repairs. An operator lacking this commitment may soon have a broken or leaky system. If in-house staffs maintain the SWH system, they should be adequately trained.

Cost effectiveness
There is a substantial extra initial cost associated with a SWH system, particularly when a conventional water heater is required as a backup. Without financial incentives SWH systems often have paybacks of 40 years or more assuming natural gas is the fuel saved; which is typical in ODOT maintenance facilities. If electricity is the fuel saved, payback is typically less. The NREL map in Figure 6.12 shows the simple payback for a SWH system where gas is the fuel saved and not considering incentives in different areas of the US (National Renewable Energy Laboratory, 2013). The NREL map in Figure 6.13 shows the simple payback for a SWH system where electricity is the fuel saved and not considering incentives (National Renewable Energy Laboratory, 2013).

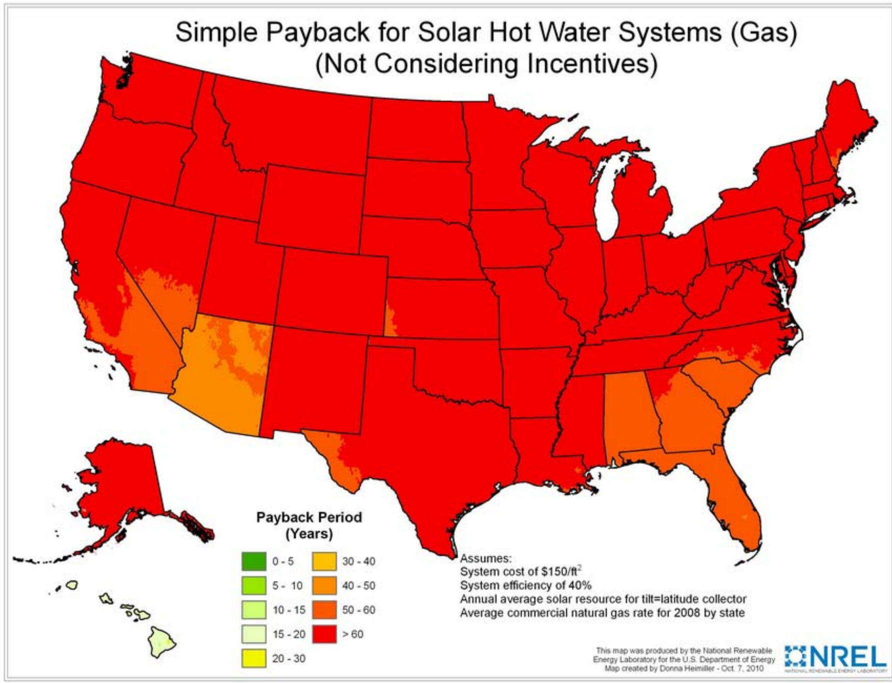


Figure 6.12. Simple payback for a SWH system where gas is the fuel saved and not considering incentives (National Renewable Energy Laboratory, 2013)

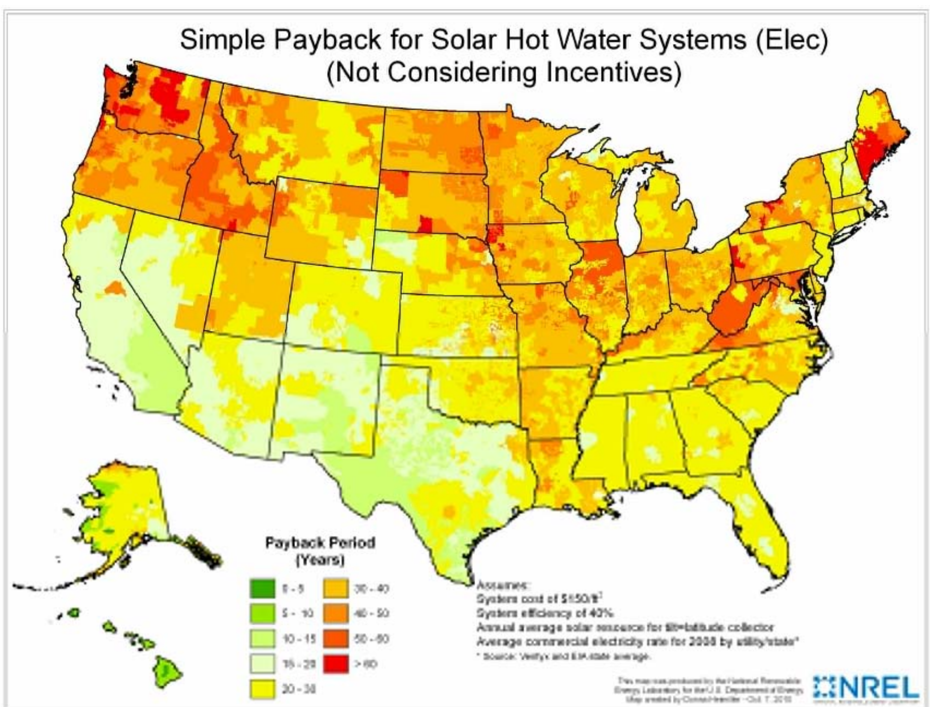


Figure 6.13. Simple payback for a SWH system where electricity is the fuel saved and not considering incentives (National Renewable Energy Laboratory, 2013)

The economic feasibility of a SWH system can be significantly improved by taking advantage of available financial incentives as described in Chapter 4. It should be noted however that currently there are typically less incentives for SWH systems where gas is the fuel saved. In addition, since SWH don't generate electricity, there are no additional revenues from selling RECs. A major cost advantage of SWH systems is that the sun, the fuel for these systems, is free, and thus protected from the price volatility that is always a concern with fossil fuels.

New vs. existing buildings

SWH systems can successfully be implemented on both new and existing buildings. SWH systems have some advantages when employed in new construction since the building can be oriented due to south to optimize the SWH system's energy performance. On existing buildings, there may be some minor "additional-interface" retrofit work required for the implementation of a SWH such as additional piping from the solar collector to existing hot water tanks. Also on existing buildings, for roof-mounted solar collectors, the roof should be in good condition. It should be able to support the additional weight of the solar collectors and should last for the expected service life of the SWH system.

Conclusion

Solar water heating systems can be used to provide warm or hot water in any climate. Although they reduce the use of fossil fuels and reduce the emissions of harmful gasses such as CO2, SOx, NOx, they are currently not very economically feasible for ODOT maintenance facilities. ODOT facilities typically use relatively cheap natural gas to fulfill their water heating requirements.

6.2.6 Ground source heat pumps

Environmental attributes

Ground source heat pumps are among the most energy efficient heating and cooling systems available today. They use less energy and produce fewer emissions than conventional heating/cooling systems. When compared to even the most efficient gas technologies, ground-source heat pumps can save significant quantities of energy (RETScreen International, 2004).

On the other hand, there may be some environmental concerns related to ground source heat pump systems. These include:

- GSHP use refrigerants. Refrigerants' leaks are a major cause of ozone depletion. To reduce this potentially negative environmental program, refrigerants should be selected with zero ozone depletion potential and low global warming potential.
- GSHP use electricity to run: Although they use less electricity to run, the energy they need is not completely free.
- Using an open loop system as the ground heat exchanger may potentially contaminate ground water.
- Installation of the underground heat exchanger pipes disrupts the site and existing landscape.

Reliability

GSHP systems are reliable. The underground loop has a very long lifetime and the piping materials usually have a long warranty period of up to 55 years. With quality and proper installation, the underground loop has a life expectancy of over 100 years. The heat pumps often last 20 years or more. Once the underground loop is installed, it won't have to be replaced for a very long time, even if the heat pump needs replacing after 20 years.

Practicality

The main reason that GSHPs may not be very practical for ODOT facilities is that the heating and cooling loads for those facilities vary considerably. ODOT facilities have a high heating load in the winter and, because the garage/maintenance areas are not cooled, a low cooling load in the summer. GSHPs are much more feasible on projects that require both heating and cooling. On these projects, the GSHP is operating year-round and generates larger energy savings to compensate for its higher initial costs.

One option of overcoming this issue on ODOT maintenance facility is to design/install a GSHP that will only provide the heating and cooling needs for the office area. The office area is typically heated in the winter and cooled in the summer. This, however, will require additional heating systems for the rest of the ODOT facility. Considering that the office area's heating load is only a small part of the total facility's heating load, this option will not have a significant impact on the total facility's fossil-fuel consumption and/or reduction in greenhouse gas emissions.

Maintenance

Ground-source heat pumps' maintenance costs are generally lower than those of conventional systems. A properly built geothermal system can readily provide 20 years of reliable heating and cooling, with minimal maintenance. GSHPs have relatively few moving parts, and all moving parts are indoors.

Cost effectiveness

There is a substantial extra initial cost associated with a GSHP system because of the additional cost associated with the need to excavate the site and install the underground heat exchanger pipes. GSHPs are most cost-effective where both heating and cooling is needed over the course of the year as this permits the GSHP to operate year-round and to generate larger energy savings to compensate for its higher initial costs. Since on ODOT facilities, there is no need to cool the maintenance/garage areas in the summer, GSHPs are less economically attractive. Furthermore, since on ODOT facilities the dominant energy requirement results from heating and since heating requirements are typically provided by low cost gas, GSHPs are even more less attractive.

GSHPs are even less cost-effective when employed in existing facilities. When employed in new construction, the GSHP system would replace a conventional HVAC system and thus the material and labor costs associated with the conventional system should be subtracted from the GSHP system's total cost. Existing facilities do not have this advantage since the investment in conventional HVAC systems has already been made.

New vs. existing buildings

The GSHP payback period in case of an existing project is larger than in the case of a new project. When performing the economic analysis of the GSHP for a new project, the initial cost of the system is calculated as the difference between the cost of GSHP and the cost of the traditional heating system. Since, for new projects, the cost of the traditional heating system is an "avoided" cost that won't be incurred. In general the GSHP is most cost-effective in new construction, especially since this facilitates trenching and drilling, or when an existing heating and cooling system has reached the end of its life and must be replaced.

Conclusion

Although GSHP systems are very energy efficient, they are not very practical for use in ODOT maintenance facilities for two reasons; (1) the heating load and cooling load in ODOT maintenance facilities vary significantly, and (2) heating is the dominant energy requirement on ODOT maintenance facilities and is provided through low-cost natural gas. ODOT facilities should consider GSHPs on new facilities only if generous financial incentives are available from electric utilities. In this case, it is recommended that the GSHP be sized to provide heating/cooling for the office area only.

6.3 How to use the State-Level Decision matrix?

As discussed above, the fifth tab "Ranking criteria" of the state level decision matrix shown in Figure 6.5 contains the weights assigned to each criterion. The research team assigned equal weights to each of the five evaluation criterion (20%). It is recommended however that the decision maker evaluate whether assigning equal weights to all criteria apply to the project he/she is evaluating. For example, if a decision maker knows that he/she has access to an experienced maintenance staff (either internally or through a third party) which is capable of effectively taking care of any maintenance issues that may arise, then he/she should reduce the weight assigned to the maintenance criterion since maintenance is not going to be an issue. If on the other hand, the facility is located in an area where experienced maintenance personnel are not readily available and any maintenance issue may lead to operational problems, than the decision maker should increase the weight assigned to the maintenance criterion in order to select a system that requires less maintenance. Changing the weights assigned to each criterion will obviously change the overall score for each RET in the "RET Ranking NB" and the "RET Ranking EB" tabs. The user can use the Excel functionality to easily sort the RETs based on the changes.

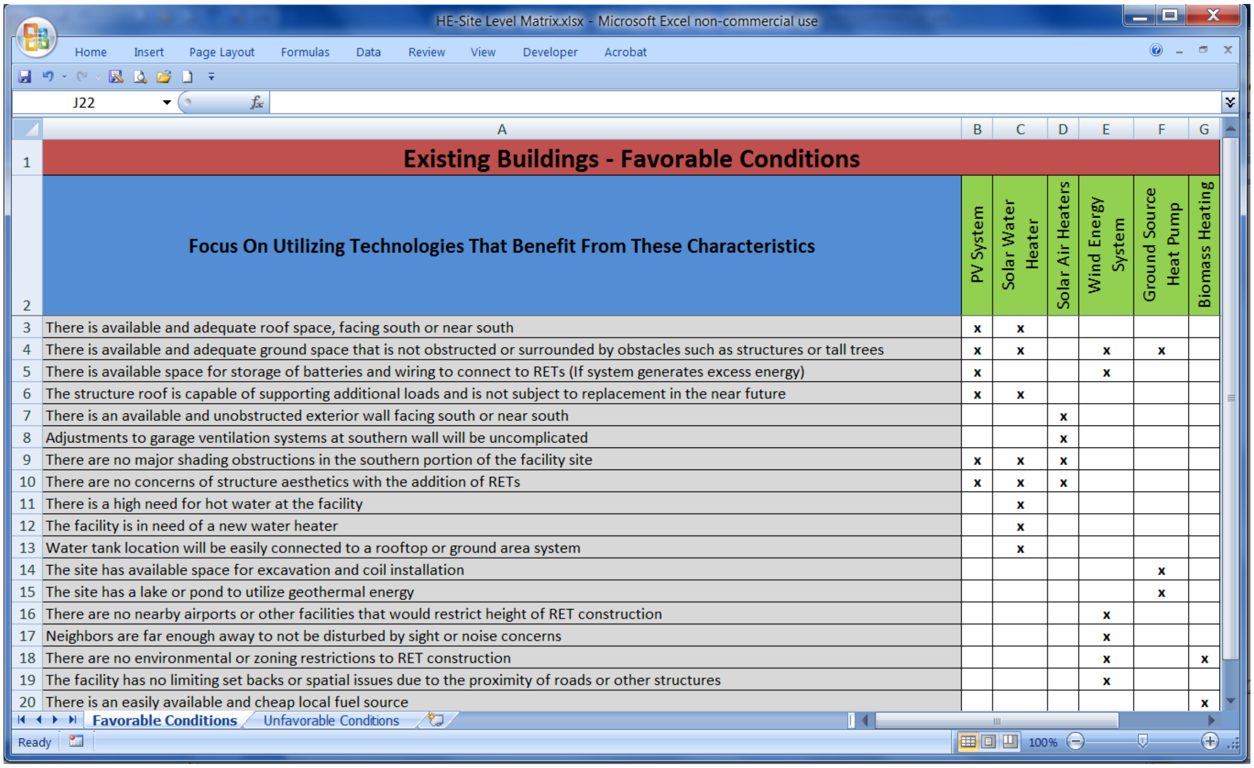
Once the weights assigned to each criterion have been adjusted and a new ranking of the RETs established, the decision maker should use the site level decision matrix to evaluate if the top 3 RETs from the state matrix are good candidates at the project level and deserve further evaluation using life cycle costing assessment techniques as described in Chapter 7. This is particularly important when evaluating an RET for an existing maintenance facility since the optimal selection will significantly depend on existing conditions and can only be determined by a site level analysis.

6.4 Site Level Decision Matrix

As discussed above, the state level matrix provides an overall ranking of the studied RETs as they generally apply to highway maintenance facilities in Ohio. It should be noted however that a RET may have a high overall ranking in the State level matrix, yet it is not suitable for a particular project. For example, installing a large wind turbine to generate electricity from renewable wind energy may have a high overall ranking in Ohio but may not be suitable for an urban highway maintenance facility or not suitable for a facility where the majority of energy used is in the form of natural gas.

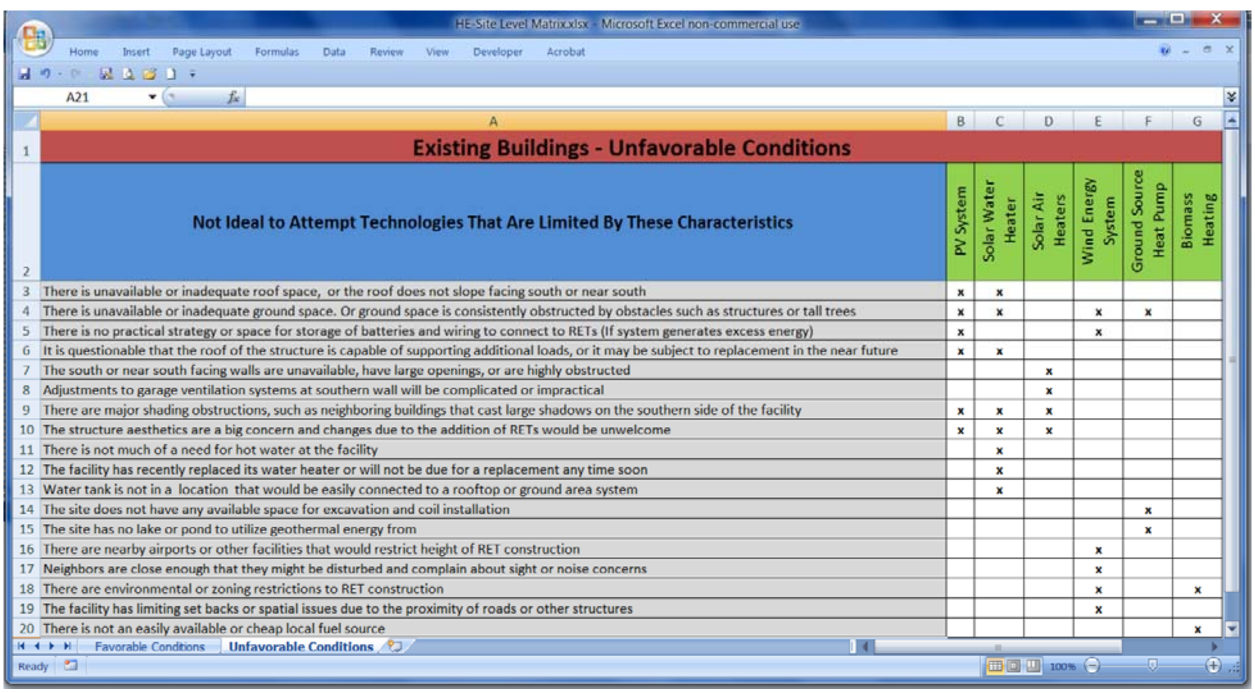
The site level matrix provides guidance for when a particular RET should and should not be selected under various specific site conditions, energy usage patterns and facilities goals. The research team used an excel spreadsheet to develop the site level matrix. The spreadsheet consists of two tabs for favorable conditions (Figure 6.14) and unfavorable conditions (Figure 6.15). The research team considered the following specific project conditions:

- Future expansion: for example, if a facility would like to add more renewable energy capacity in the future, than a project with solar panels is a good candidate.
- Site characteristics: For example, if the site contains large trees that shade the roof and the occupants would like to keep the trees then roof- mounted PV panels are not a good selection.
- Project Schedule: If project team wants a fast schedule for RET implementation than a project with large wind turbines is not a good candidate. For large wind turbines, 50 m or taller, meteorological (MET) towers are erected to determine the site wind's resources and the MET studies are often 1 year and longer.
- Energy usage: For example, if the source of most of the energy used is natural gas for heating than a large wind turbine is not applicable.
- Implementation Difficulty: ease of retrofit, disruption to operations or occupants, and degree of maintenance required.
- Customer Acceptance – potential to help meet energy goals, to improve quality and improved aesthetics, potential for occupant complaints, and demonstrated history of success: for example, if noise is to be avoided , don't select wind turbines



	Existing Buildings - Favorable Conditions						
2	Focus On Utilizing Technologies That Benefit From These Characteristics	PV System	Solar Water Heater	Solar Air Heaters	Wind Energy System	Ground Source Heat Pump	Biomass Heating
3	There is available and adequate roof space, facing south or near south	x	x				
4	There is available and adequate ground space that is not obstructed or surrounded by obstacles such as structures or tall trees	x	x		x	x	
5	There is available space for storage of batteries and wiring to connect to RETs (If system generates excess energy)	x			x		
6	The structure roof is capable of supporting additional loads and is not subject to replacement in the near future	x	x				
7	There is an available and unobstructed exterior wall facing south or near south			x			
8	Adjustments to garage ventilation systems at southern wall will be uncomplicated			x			
9	There are no major shading obstructions in the southern portion of the facility site	x	x	x			
10	There are no concerns of structure aesthetics with the addition of RETs	x	x	x			
11	There is a high need for hot water at the facility		x				
12	The facility is in need of a new water heater		x				
13	Water tank location will be easily connected to a rooftop or ground area system		x				
14	The site has available space for excavation and coil installation					x	
15	The site has a lake or pond to utilize geothermal energy					x	
16	There are no nearby airports or other facilities that would restrict height of RET construction				x		
17	Neighbors are far enough away to not be disturbed by sight or noise concerns				x		
18	There are no environmental or zoning restrictions to RET construction				x		x
19	The facility has no limiting set backs or spatial issues due to the proximity of roads or other structures				x		
20	There is an easily available and cheap local fuel source						x

Figure 6.14. Site Level Decision Matrix, "Favorable Conditions" Tab



	Existing Buildings - Unfavorable Conditions						
2	Not Ideal to Attempt Technologies That Are Limited By These Characteristics	PV System	Solar Water Heater	Solar Air Heaters	Wind Energy System	Ground Source Heat Pump	Biomass Heating
3	There is unavailable or inadequate roof space, or the roof does not slope facing south or near south	x	x				
4	There is unavailable or inadequate ground space. Or ground space is consistently obstructed by obstacles such as structures or tall trees	x	x		x	x	
5	There is no practical strategy or space for storage of batteries and wiring to connect to RETs (If system generates excess energy)	x			x		
6	It is questionable that the roof of the structure is capable of supporting additional loads, or it may be subject to replacement in the near future	x	x				
7	The south or near south facing walls are unavailable, have large openings, or are highly obstructed			x			
8	Adjustments to garage ventilation systems at southern wall will be complicated or impractical			x			
9	There are major shading obstructions, such as neighboring buildings that cast large shadows on the southern side of the facility	x	x	x			
10	The structure aesthetics are a big concern and changes due to the addition of RETs would be unwelcome	x	x	x			
11	There is not much of a need for hot water at the facility		x				
12	The facility has recently replaced its water heater or will not be due for a replacement any time soon		x				
13	Water tank is not in a location that would be easily connected to a rooftop or ground area system		x				
14	The site does not have any available space for excavation and coil installation					x	
15	The site has no lake or pond to utilize geothermal energy from					x	
16	There are nearby airports or other facilities that would restrict height of RET construction				x		
17	Neighbors are close enough that they might be disturbed and complain about sight or noise concerns				x		
18	There are environmental or zoning restrictions to RET construction				x		x
19	The facility has limiting set backs or spatial issues due to the proximity of roads or other structures				x		
20	There is not an easily available or cheap local fuel source						x

Figure 6.15. Site Level Decision Matrix, "Unfavorable Conditions" Tab

CHAPTER 7 – LIFE CYCLE COST ANALYSIS

Life-Cycle Cost Analysis (LCCA) is an economical method for evaluating product alternatives where all costs associated with an alternative throughout its life cycle are considered. LCCA is suitable for evaluating building upgrades and design alternatives that satisfy the same requirements of performance. These performance requirements include occupant comfort, adherence to codes and engineering standards, system reliability, and aesthetics considerations. LCCA is also suitable for comparing new technologies with existing/current technologies in order to estimate net savings, payback periods as well as potential benefits that could be achieved by applying these new technologies (El-Rayes, Liu, & Abdallah, 2011). The LCCA has a distinct advantage over the simple payback model by taking cost of money into account in a systematic and consistent manner (NCHRP, 2011).

This chapter includes results from several LCC analyses performed for the 3 most promising RETs for ODOT maintenance facilities as identified by the research; namely solar air heating systems, grid connected PV systems and grid connected wind energy systems. The LCC results include simple payback, potential environmental benefits in terms of reduction in carbon foot print, and return on investment (ROI), also known as internal rate of return. The LCCA methodology used accounts for the total costs including initial, maintenance, operation, energy, and repair of the RET over a specified study period. The study period is selected as the anticipated life of the RET. The LCCA methodology also accounts for energy price escalation, as well as the time value of money via discounting. The initial costs may include any capital investment for land acquisition, construction, and/or equipments needed for the facility. The energy costs are calculated based on consumption, current rates, and price projection. Replacement costs are calculated based on the estimated life of the RET and the length of the study period. In order to calculate the life cycle cost (LCC), all the aforementioned costs are converted to present values based on a reasonable discount/interest rate. The purpose of the LCCA is to choose the best alternative that provides the lowest LCC of all alternatives and consistent with the required quality and functionality. The RETScreen software was used to perform the LCC analyses. RETScreen is described in more detail in the following section.

7.1. RETScreen Software

RETScreen (Renewable Energy Technology Screening software) conducts detailed LCCA analysis for projects and performs prefeasibility and, feasibility studies to compare traditional energy sources to Renewable Energy Technology (RET) alternatives. RETScreen helps quickly and accurately evaluate whether a proposed clean energy project passed an initial screening for financial viability and is worth further consideration. RETscreen reduces the cost of doing prefeasibility and feasibility studies and enables more potential projects to be screened, so that resources can be allocated to those that have the most promise (RETScreen International, 2004). The software is available on the RETScreen Website for download, free-of-charge (http://www.retscreen.net).

RETScreen's LCCA model is very powerful and is capable of (1) considering all life cycle costs associated with design alternatives (2) accounting for various financial parameters and (3) performing several financial analyses.

The life cycle costs that can be considered by RETScreen are shown in Figure 7.1 for a sample Wind Turbine project. As shown in Figure 7.1, RETscreen can consider detailed initial cost including development, design and construction costs. It can also consider annual costs such as maintenance, energy consumption and operation; and future costs such as replacement costs.

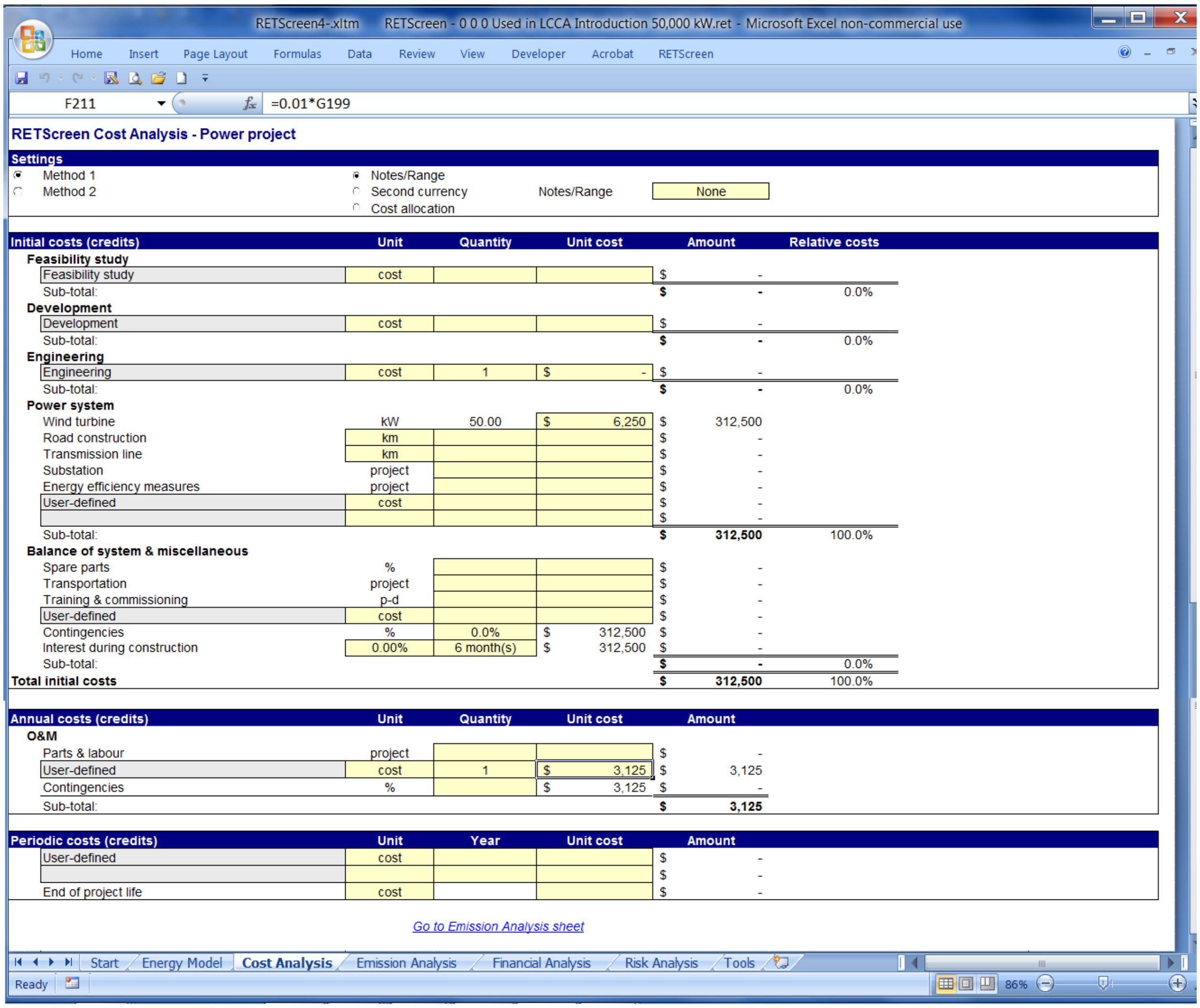


Figure 7.1. RETScreen Life Cycle Cost module.

Figure 7.2 show the financial parameters that can be considered by RETScreen. These include incentives, rebates, inflation rate, fuel escalation rate, debt ratio, debt interest rate, rate of electricity exported to grid, equipment depreciation for tax purposes, and greenhouse gas reduction income.

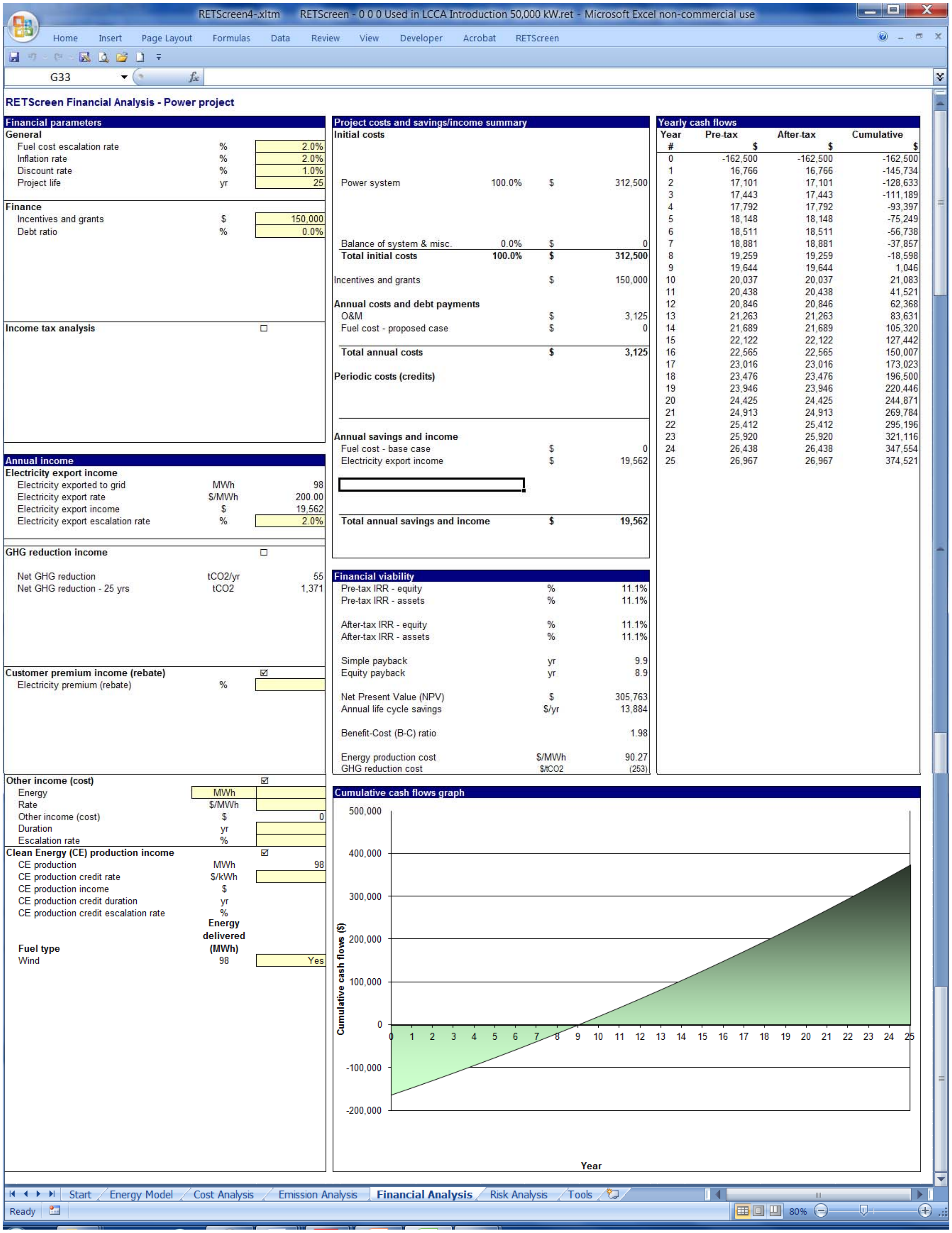


Figure 7.2. RETScreen Financial Analysis module.

Also as illustrated in Figure 7.2, RETScreen calculates a suite of financial indicators to assess the life cycle cost feasibility of the project. These financial indicators include simple payback, equity payback, internal rate of return (IRR), and net present value (NPV). As shown in Figure 7.2, RETScreen also displays a cumulative cash flow graph. For the sample wind turbine project, the initial investment is paid off in year 9.

The following paragraphs describe the financial indicators used in LCCA in more detail (RETScreen International, 2004):

- The internal rate of return (IRR) on equity (%) represents the true interest yield provided by the project equity over its life. It is calculated using the yearly cash flows and the project life. It is also referred to as the return on equity (ROE) or return on investment (ROI) or the time-adjusted rate of return. It is calculated by finding the discount rate that causes the net present value of the equity to be equal to zero. Hence, it is not necessary to establish the discount rate of an organization to use this indicator. An organization interested in a project can compare the internal rate of return to its required rate of return (often, the cost of capital). If the internal rate of return is equal to or greater than the required rate of return of the organization, then the project will likely be considered financially acceptable. If it is less than the required rate of return, the project is typically rejected. An organization may have multiple required rates of return that will vary according to the perceived risk of the projects. The most significant advantage of using the internal rate of return indicator to evaluate a project is that the outcome does not depend on a discount rate that is specific to a given organization.
- The simple payback (year), represents the length of time that it takes for a proposed project to recover its own initial cost, out of the income or savings it generates. The basic principle of the simple payback method is that the more quickly the cost of an investment can be recovered, the more desirable is the investment. A negative payback period would indicate that the annual costs incurred are higher than the annual savings generated. The disadvantage of simple payback method is that it does not consider the time value of money, or the impact of inflation on the costs. RETScreen uses the total initial costs, the total annual costs (excluding debt payments) and the total annual savings and income to calculate the simple payback. The calculation includes any initial cost incentives and grants.
- The equity payback represents the length of time that it takes a project's owner to recoup his/her own initial investment (equity) out of the project cash flows generated. The equity payback considers project cash flows from its inception as well as the leverage (level of debt) of the project. The equity payback is typically a better indicator of the project merits than the simple payback as it considers the time value of money.
- The Net Present Value (NPV) of the project is the value of all future cash flows, discounted at the discount rate, in today's currency. Under the NPV method, the present value of all cash inflows is compared against the present value of all cash outflows associated with an investment project. The difference between the present values of these cash flows, called the NPV determines whether or not the project is a financially acceptable investment. Positive NPV values indicate a potentially feasible project. In using the net present value method, it is necessary to choose a rate for discounting cash flows to present value.

- The annual life cycle savings is the levelized yearly savings having exactly the same life and net present value as the project. The annual life cycle savings are calculated using the net present value, the discount rate and the project life.
- The net Benefit-Cost (B-C) ratio is the ratio of the net benefits to costs of the project. Net benefits represent the present value of annual income and savings less annual costs, while the project's cost is defined as the project's equity. B-C ratios greater than 1 indicate profitable projects.
- The GHG reduction cost is calculated by dividing the annual life cycle savings of the project by the net GHG reduction per year, averaged over the project life.

It is important to note that different decision-makers use different financial indicators to assess the life cycle cost feasibility of their projects. For example, an investor might seek a return-on-investment in excess of 8%, and a company might want a positive net present value at a discount rate of 10%. On the other hand, the payback period is often used by individuals or small firms that may be cash poor. When a firm is cash poor, a project with a short payback period, but a low rate of return, might be preferred over another project with a high rate of return, but a long payback period. In this case, the small organization typically needs a faster repayment of its cash investment. What is considered an acceptable payback would also depend on the project's owner. An institutional owner typically accepts payback periods in the 5 to 10 year range, whereas a private owner may require a payback period of 5 years or less.

7.2. LCCA for Solar Air Heating Systems

A solar air heating (SAH) system, also called solar ventilation air preheating and/or solar wall uses a solar heated surface to preheat ventilation air as it enters a building to lessen the energy burden of heating applications. For wide open buildings with high ceilings such as those encountered in most ODOT maintenance facilities, energy savings resulting from SAH systems are the sum of solar energy actively collected, building heat recapture savings, and destratification savings. Solar air heating collectors do not just provide energy benefits, they also serve as weather cladding. Since the cost-effectiveness of SAH systems depends on whether the project is new construction or a retrofit of an existing building, two LCCAs of solar air heating systems are discussed in the following subsections. The first is for a proposed retrofit of the Pike county garage and the second is for a proposed new facility.

7.2.1. LCCA for Pike County Garage SAH system

Pike County Garage was constructed in 2008. The research team has concluded after visiting the garage that it can benefit from a SAH system installed on its South East wall. In order to perform LCC analysis for a solar air heating system in Pike County Garage, the system need to be designed to estimate its size and expected performance. The energy performance of a solar air heating system is influenced by a number of factors that include the design airflow rate (the amount of outdoor air supplied when the system is operating), amount of solar radiation hitting the solar collectors, average wind speed for each month, the collector's orientation, and the number of hours that the solar air heating system is operating. The RETScreen software already includes a large database of solar radiation and wind data from around the world so the user needs only to enter design air flow rate, collector's orientation and the number of hours of operation for calculating the recommended area of the solar collector.

In addition to design parameters, the LCCA also requires an estimate of life cycle costs (LCC) associated with the SAH system. For a SAH system, these LCC components include initial cost, service life, fuel replaced, fuel unit cost, and fuel escalation rate. Table 7.1 summarizes both the design and economic parameters used to conduct the LCCA analysis for a SAH system for the Pike County Garage. The initial cost of the solar wall and its service life were obtained from The National Energy Renewable lab (NREL) data. NREL publishes a yearly report that includes mean costs for renewable energy projects and their service lives (National Renewable Energy Laboratory, 2012a). It was assumed that the solar collector would be installed on the south east wall of the Pike County Garage shown in Figure 7.3. The azimuth of the south east wall is 15^o. The azimuth is the angle between the projection, on a horizontal plane, of the normal to the surface and the local meridian, with zero due south. The preferred orientation of the solar wall in the Northern Hemisphere is south, in which case the azimuth angle is 0°. Figure 7.4 shows a picture of the south east wall where the SAH system's collector would be installed. The RETScreen calculated area of the collector (1346 ft2) can easily fit on the wall.

Design airflow rate	12958	cfm
Solar wall area	1346	ft2
Solar Wall Orientation (Azimuth)	15	o
Fuel replaced	Gas	
Gas cost ($/ccf)	1	$/ccf
Fuel escalation rate	5%	
Inflation rate	2%	
Discount rate	2%	
Project Life	30	years
Incentives	0	$
Cost $/sf of solar wall	25	$/sf
Total initial cost of solar wall	33637	$
Credit EB	0	$
facility area	2120	m2

Table 7.1. Design and financial parameters associated with the Pike County Garage SAH system LCCA

Figure 7.3. Plan view of Pike County Garage


Figure 7.4. South East wall where collector is assumed installed for the Pike County Garage SAH system LCCA

It was assumed that the Pike County garage will require heating from November to March and it will sometimes be heated in April, May, September, and October as shown in Table 7.2. When the Pike County Garage is not heated, the Garage overhead doors are open and the SAH system's bypass damper is also open to avoid heating the garage and maintenance area needlessly.

Table 7.3 shows the assumed number of days per week during weekdays and weekends that the system is in operation and the average number of hours per day during weekdays and weekends that the system is in operation. The number of hours per day that a building ventilation system operates usually depends on the length of time people are in the building.

January	100%	100%
February	100%	100%
March	100%	100%
April	75%	75%
May	50%	50%
June	0%	0%
July	0%	0%
August	0%	0%
September	50%	50%
October	75%	75%
November	100%	100%
December	100%	100%

Table 7.2. Percent of month when heating is assumed required for the Pike County Garage SAH system LCCA

Operating days per week - weekdays	d/w	5	5
Operating hours per day - weekdays	h/d	9	9
Operating days per week - weekends	d/w	2	2
Operating hours per day - weekends	h/d	2	2

Table 7.3. Assumed operating days and hours for the Pike County Garage SAH system LCCA

RETScreen calculates the energy consumption for both the base case (where gas fired make up air units are used in conjunction with Infrared heaters to heat the facility) and the proposed case (where a solar wall is used in conjunction with infrared heaters to heat the facility). The results of the energy analysis are shown in Table 7.4; the proposed SAH system uses 4099 ccf of natural gas annually where as the base design uses 6844 ccf of natural gas. The annual fuel savings are $2720.64/year.

		Base case	Proposed case
Total Annual Energy used for heating	MWh	151.36	90.65
Fuel type		Natural gas -ccf	Natural gas - ccf
Seasonal efficiency		0.75	0.75
Fuel consumption - annual	ccf	6844.17	4099.06
Fuel rate	$/ccf	0.99	0.99
Annual Fuel cost	$	6783.18	4062.54
Annual Fuel savings	$		2720.64

Table 7.4. Energy savings associated with the Pike County Garage SAH system LCCA

Based on the energy savings associated with the solar wall, RETScreen calculates various financial indicators to assess the life cycle cost feasibility of the project as shown in Table 7.5. The simple payback is 12.4 years. The simple payback represents the length of time that it takes for a proposed project to recover its own initial cost, out of the income or savings it generates. The equity payback is 9.5 years. The equity payback represents the length of time that it takes a project's owner to recoup his/her own initial investment (equity) out of the project cash flows generated. Unlike the simple payback, the equity payback considers the time value of money and the impact of inflation on the costs and is typically a better indicator of the project merits than the simple payback. The internal rate of return (IRR) on equity for this project is 12.4%. The IRR represents the true interest yield provided by the project equity over its life and is relatively good considering the low interest rate conditions in the current financial markets. The Net Present Value (NPV) of this project is $98,343. The fact that the project has a positive NPV indicates a potentially feasible project. The annual life cycle savings for this project is $4,391/year over the life cycle of the project (30 years) and the net Benefit-Cost (B-C) ratio is 3.92. Both the positive annual life cycle savings and a B-C ratio that is much greater than 1 indicate a potentially feasible project. The proposed SAH system would reduce Greenhouse Gas emissions by 14 tons of CO2 annually and since the proposed project has a positive annual life cycle savings of $4,391, the associated cost of reducing a GHG emission is negative (-$4,391/14 = - 313 $/tCO2). This is a very good indication that the proposed project would not only cut GHG emissions, but would do that while saving money over the life cycle of the project.

Total initial cost of solar wall	33637	$
simple payback	12.4	years
Equity payback	9.5	years
IRR equity	12.4	%
Net Present Value	98,343	$
Annual Life Cycle savings $/yr	4391	$/year
Benefit/ Cost ratio	3.92	
GHG reduction cost ($/tCO2)	-313	$/tCO2
Net Annual GHG reduction	14	tCO2/year
Net GHG reduction (30 years)	435	tCO2

Table 7.5. Financial indicators associated with the Pike County Garage SAH system LCCA

Figure 7.5 shows the cumulative cash flow graph for the proposed SAH project. As shown in the Figure, the initial investment is paid off after 9.5 years.

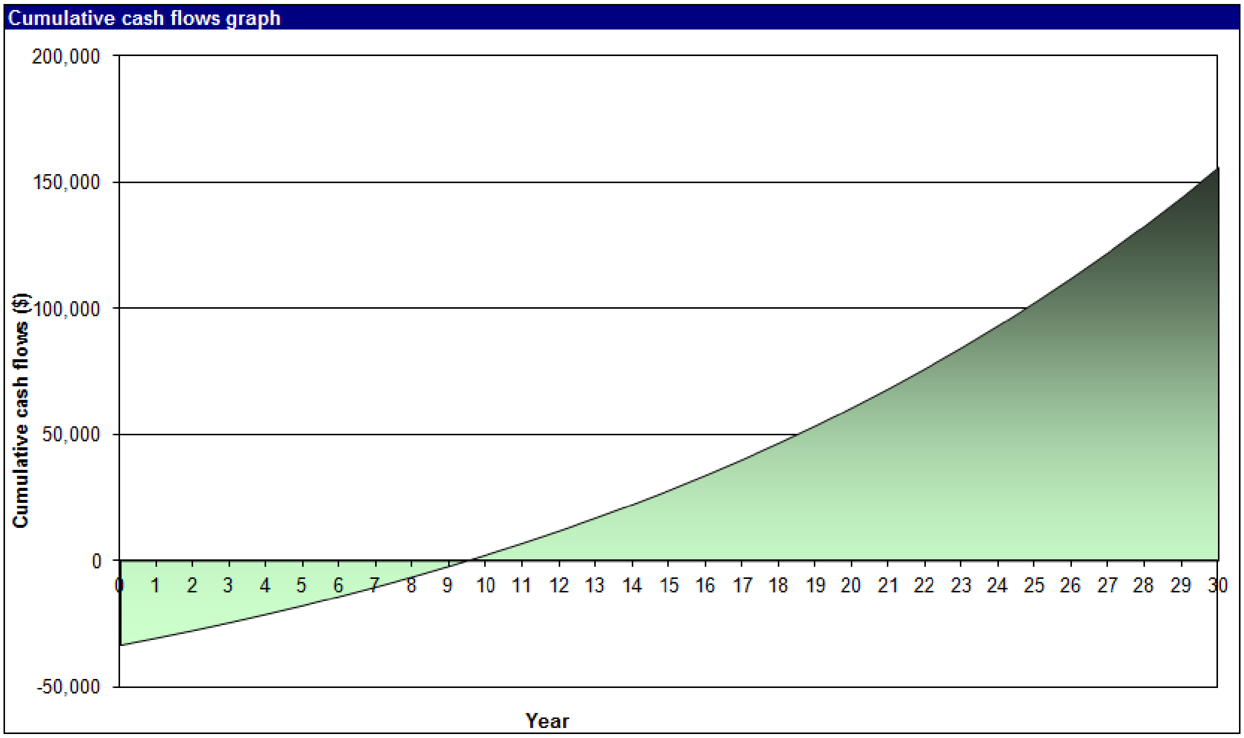


Figure 7.5. Cumulative cash flow graph for the Pike County Garage SAH system LCCA

7.2.2. LCCA for a new maintenance facility SAH system

As discussed in Chapters 3 and 6, when SAH systems are employed in new construction, they are much more cost-effective since the cost of the regular building cladding that is replaced by the collector is subtracted from the collector's initial cost. The cost of regular cladding is typically one third to one half of that of the collector (RETScreen 2004). Also on new projects, the building ventilation system is designed and situated so as to facilitate integration of the solar collector, avoiding additional ducting and fans.

For the LCCA analysis discussed in this section, it was assumed that a new ODOT maintenance facility with similar configuration as the Pike county garage will be constructed. As such, all the design, economic and operation parameters summarized in Tables 7.1, 7.2 and 7.3 would apply for the new facility with the exception of the initial unit cost ($/sf) of the solar wall. For the new facility, and to be conservative, it was assumed that the cost of regular cladding is one third of the collector's cost. Based on this, the initial unit cost of the SAH system ($/sf) used in the LCCA for the new facility was calculated to be ($25/sf of wall *2/3 = $16.67/sf of collector). Since the initial unit cost was the only difference between the analysis described in this section and the LCCA for the Pike county garage described in section 7.2.1, the energy savings as shown in Table 7.4 didn't change. However, the financial indicators have changed significantly and are shown in Table 7.6.

Total initial cost of solar wall	22429	$
simple payback	8.2	years
Equity payback	6.8	years
IRR equity	17.3	%
Net Present Value	109,551	$
Annual Life Cycle savings $/yr	4891	$/year
Benefit/ Cost ratio	5.88	
GHG reduction cost ($/tCO2)	-349	$/tCO2
Net Annual GHG reduction	14	tCO2/year
Net GHG reduction (30 years)	435	tCO2

Table 7.6. Financial indicators associated with new facility SAH system LCCA

As shown in Table 7.6, the financial indicators associated with the new facility's SAH system are all much more attractive. The simple payback is 8.2 years. The equity payback is 6.8 years. The internal rate of return (IRR) on equity is 17.3%. The Net Present Value is $109,551. The annual life cycle savings is $4,891/year over the life cycle of the project (30 years) and the net Benefit-Cost (B-C) ratio is 5.88. Figure 7.6 shows the cumulative cash flow graph for the new facility's SAH project. As shown in the Figure, the initial investment is paid off after 6.8 years.

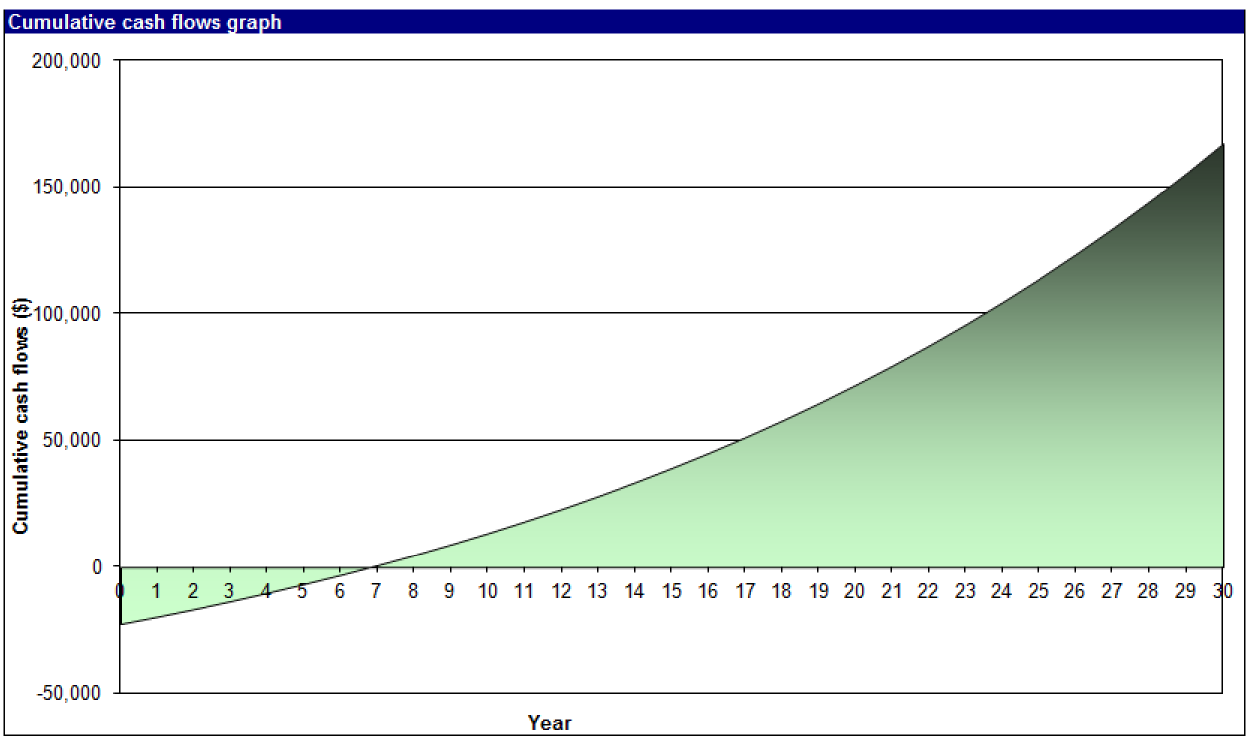


Figure 7.6. Cumulative cash flow graph for a new facility SAH system LCCA

7.3. LCCA for Grid Connected PV Systems

A grid connected PV system located on a facility generates electricity from sunshine. When there is no sunshine and the PV system output is not sufficient to meet the facility's loads, electricity is provided by the utility's grid. When the sun shines, the PV-generated electricity powers some or all of the loads in the building. This reduces the amount of electricity that the facility's owner must purchase from the grid. Where net metering is available, electricity that is in excess of the facility's requirements is sold to the utility. Since the cost-effectiveness of grid connected PV systems depends on the proper orientation of the PV modules, two LCCA of grid connected PV systems are discussed in the following subsections. The first LCCA is for a proposed retrofit of the Pike county garage where the roof is not properly oriented for optimal PV performance. The second is for a proposed retrofit of the Seneca county garage where the roof is properly oriented for optimal PV performance. In both LCCAs, financial incentives were not considered. A third LCCA that considers financial incentives was completed for the proposed retrofit of Seneca county garage.

7.3.1. LCCA for Pike County Garage grid connected PV system

Pike County Garage was constructed in 2008. A plan view of Pike county garage was shown in Figure 7.3. From Figure 7.3, it is clear that mounting PV modules on the east side of the roof of the Garage/office building will not result in optimal PV performance. The azimuth of the PV modules in this case will be 65^o. The azimuth is the angle between the projection, on a horizontal plane, of the normal to the surface and the local meridian, with zero due South. As was discussed in Chapter 3, optimal performance of PV modules occurs when the azimuth of PV modules is within the +/- 30^o range.

In order to perform a LCC analysis for a grid connected PV system in Pike County Garage, the system need to be designed to estimate its size and expected performance. The energy performance of a grid connected PV system is influenced by a number of factors that include the amount of solar radiation hitting the PV modules, the PV module's nominal capacity, and the collector's orientation and tilt angle. The RETScreen software already includes a large database of solar radiation from around the world so the user needs only enter the PV module's nominal capacity, the collector's orientation and tilt angle. The LCCA was performed for a 20kW PV system. Although a system of this size is not enough to provide all the electricity needed for the facility, it is a size that is good to start with. As was mentioned previously in Chapter 6, a major advantage of a PV system is its modularity that permits the owner to start with a small system and add capacity over the years, in response to changes in the demand for electricity or the availability of capital.

In addition to design parameters, the LCCA also requires an estimate of life cycle costs (LCC) associated with the grid connected PV system. These LCC components include initial cost, replacement cost, maintenance cost, service life, electricity export rate, and electricity escalation rate. Table 7.7 summarizes both the design and economic parameters used to conduct the LCCA analysis for the Pike County Garage's 20 kW PV system. Input from local PV installers have indicated that current prices for PV modules are about $3000/kW of nominal capacity and that annual maintenance costs are about $20/kW/year. As mentioned above, it was assumed that the PV modules would be installed on the east wall of the Pike County Garage. The azimuth of the east wall is 65^o. It was also assumed that the PV modules will be installed parallel to the roof and thus the tilt angle is 35^o. RETScreen also has a built in database of PV modules, their manufacturers, and their nominal efficiencies. A Sunpower "mono-Si - SPR-210-BLK" that has a nominal efficiency of 16.9% was used in this LCCA. Nominal module efficiency depends primarily on the type of cell used (mono-Si, poly-Si, a-Si, CdTe, CIS, spherical-Si) but also varies from manufacturer to manufacturer, depending on the manufacturing processes used. Based on the above inputs, RETScreen calculates the required area of the PV modules to be (1270 ft2) which can easily fit on the roof's east side.

PV nominal kW	20	kW
Cost $/KW	3,000	$
Annual maintenance $/kW	20	$/kW
Inverter replacement cost in years 10,20	10,000	$
Electricity cost ($/kwh)	0.13	
Azimuth	65	o
Tilt	35	o
Electricity escalation rate	5%	
Inflation rate	2%	
Discount rate	2%	
Project Life	30	years
Incentives	0	
SREC ($/kwh)	0	$/kWh
Calculated area for PV modules	1270	sf

Table 7.7. Design and financial parameters associated with the Pike County Garage PV system

RETScreen calculates the energy generated annually and the capacity factor as shown in Table 7.8. The capacity factor is the ratio of the average power produced by the power system over a year to its rated power capacity.

Capacity factor	%	12.7%
Annual electricity generated	MWh	22.254

Table 7.8. Energy performance of the Pike County Garage PV system

Based on the energy performance of the PV system, RETScreen calculates various financial indicators to assess the life cycle cost feasibility of the project as shown in Table 7.9. The simple payback is 24.1 years. The equity payback is 17.3 years. The internal rate of return (IRR) on equity for this project is 4.5%. All these financial indicators point to a modest return on an investment. The Net Present Value (NPV) of this project is $38,343. The annual life cycle savings for this project is $1,712/year over the life cycle of the project (30 years) and the net Benefit-Cost (B-C) ratio is 1.64. Both the small annual life cycle savings and a B-C ratio that is just greater than 1 indicate a potentially feasible project but with very modest financial returns. The proposed PV system would reduce Greenhouse Gas emissions by 12 tons of CO_2 annually and since the proposed project has a positive annual life cycle savings of $1,266, the associated cost of reducing a GHG emission is negative (-$1,266/12 = - 143 $/tCO2).

Total initial cost of PV system	60000	$
Simple payback	24.1	years
Equity payback	17.3	years
IRR equity	5.2	%
Net Present Value	38,343	$
Annual Life Cycle savings $/yr	1712	$/yar
Benefit/ Cost ratio	1.64	
GHG reduction cost ($/tCO2)	-143	$/tCO2
Net Annual GHG reduction	12	tCO2/year
Net GHG reduction (30 years)	360	tCO2

Table 7.9. Financial indicators associated with the Pike County Garage PV system LCCA

Figure 7.7 shows the cumulative cash flow graph for the proposed PV project. As shown in the Figure, the initial investment is paid off after 17.3 years.

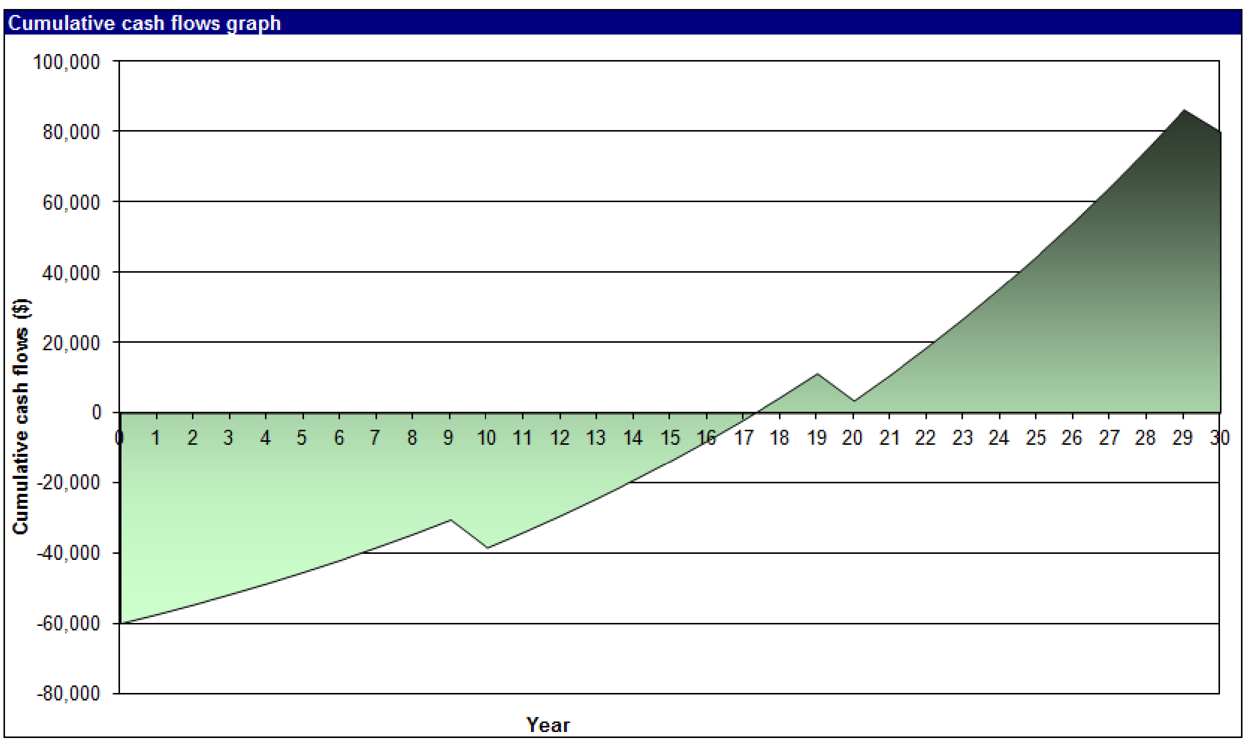


Figure 7.7. Cumulative cash flow graph for the Pike County PV project

7.3.2. LCCA for Seneca County Garage grid connected PV system (no incentives)

As discussed in Chapters 3 and 6, the cost-effectiveness of grid connected PV systems depends on the proper orientation of the PV modules. Figure 7.8 is a plan view of Seneca county garage.

It shows that the roof is properly oriented towards the south. The azimuth of the PV modules in this case is 0^{o}.

Figure 7.8. Plan view of Seneca County Garage

The proposed PV system for Seneca County garage is similar to the PV system proposed for Pike County garage in Section 7.3.1. As such, all the design, and economic parameters in Table 7.7 would apply for the Seneca county garage's system with the exception of the location (Tiffin, OH) and azimuth of the PV modules (0^{o}). The design and economic parameters for the Seneca county garage's PV system are summarized in Table 7.10.

PV nominal kW	20	kW
Cost $/KW	3,000	$
Annual maintenance $/kW	20	$/kW
Inverter replacement cost in years 10,20	10,000	$
Electricity cost ($/kwh)	0.13	
Azimuth	0	o
Tilt	35	o
Electricity escalation rate	5%	
Inflation rate	2%	
Discount rate	2%	
Project Life	30	years
Incentives	0	
SREC ($/kwh)	0	$/kWh
Calculated area for PV modules	1270	sf

Table 7.10. Design and financial parameters associated with the Seneca County Garage PV system

As shown in Table 7.10, RETScreen calculates the required area of the PV modules to be (1270 ft2) which is the same area of the Pike County's proposed PV system. The area of the PV modules depends on the nominal efficiency of the modules. A Sunpower "mono-Si - SPR-210-BLK" that has a nominal efficiency of 16.9% was also used in this LCCA. Although the area, type and nominal efficiency of the PV modules are the same for Pike County and Seneca County, the energy generated by the Seneca county system as calculated by RETScreen is different and is shown in Table 7.11. The same PV system, oriented properly will generate 11.4% ((24.8-22.254)/22.254) more electricity.

Capacity factor	%	14.2%
Annual electricity generated	MWh	24.8

Table 7.11. Energy performance of the Seneca County Garage PV system

Because of the increase in electricity production, the financial indicators have slightly improved and are shown in Table 7.12. The simple payback is 21.2 years. The equity payback is 16 years. The internal rate of return (IRR) on equity for this project is 6.3%. The Net Present Value (NPV) of this project is $54,402. The annual life cycle savings for this project is $2,429/year over the life cycle of the project (30 years) and the net Benefit-Cost (B-C) ratio is 1.91. The proposed PV system would reduce Greenhouse Gas emissions by 14 tons of CO2 annually and since the proposed project has a positive annual life cycle savings of $2,429, the associated cost of reducing a GHG emission is negative (- 174 $/tCO2). Although all the financial indicators have improved, the proposed project would still yield modest financial returns.

Total initial cost of PV system	60000	$
Simple payback	21.2	years
Equity payback	16	years
IRR equity	6.3	%
Net Present Value	54,402	$
Annual Life Cycle savings $/yr	2,429	$/year
Benefit/ Cost ratio	1.91	
GHG reduction cost ($/tCO2)	-174	$/tCO2
Net Annual GHG reduction	14	tCO2/year
Net GHG reduction (30 years)	420	tCO2

Table 7.12. Financial indicators associated with the Seneca County Garage PV system LCCA

Figure 7.9 shows the cumulative cash flow graph for the proposed PV project. As shown in the Figure, the initial investment is paid off after 16 years.

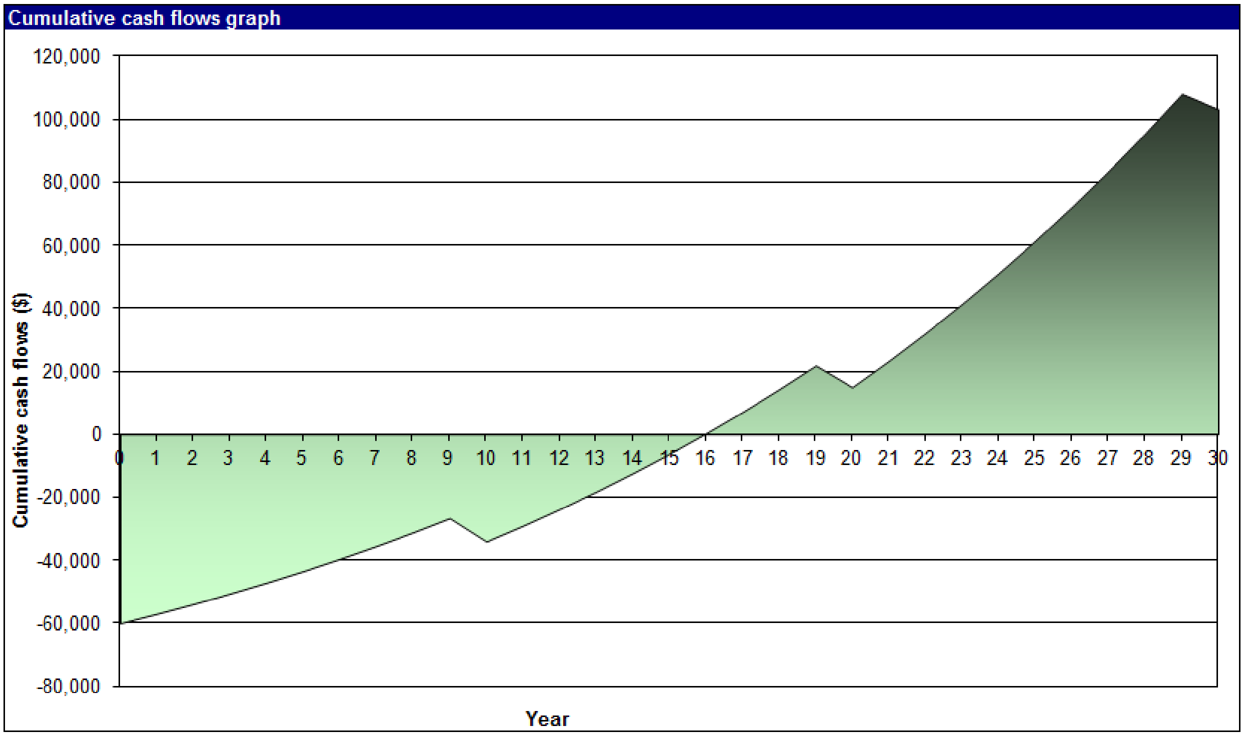


Figure 7.9. Cumulative cash flow graph for the Seneca County PV project

7.3.3. LCCA for Seneca County Garage grid connected PV system (with incentives and SREC)

The use of financial incentives and the ability to sell SRECs can significantly improve the economic feasibility of grid connected PV systems but will require special arrangements since ODOT as a state agency may be ineligible for many of the federal incentives. Such arrangements as discussed in Chapter 5 include involving a third party to take advantage of all available incentives/tax credits and certifying the PV system with the proper agencies.

The PV system evaluated in this case is exactly the same as the system evaluated in section 7.3.2 for Seneca County garage with the exception that financial incentives and SREC are considered in this analysis. It was assumed, that a third party would contract with ODOT through a power purchase agreement as described in Chapter 5. The third party would be able to apply for the Business Energy Investment Tax Credit which is worth 30 percent of upfront expenditures for PV system. It was also assumed that the project will certify the PV system with the proper agencies and be able to sell SREC at $100/Mwh. The design and economic parameters for the Seneca county garage's PV system with incentives and SRECs are summarized in Table 7.13.

PV nominal kW	20	kW
Cost $/KW	3,000	$
Annual maintenance $/kW	20	$/kW
Inverter replacement cost in years 10,20	10,000	$
Electricity cost ($/kwh)	0.13	
Azimuth	0	o
Tilt	35	o
Electricity escalation rate	5%	
Inflation rate	2%	
Discount rate	2%	
Project Life	30	years
Incentives	30%	
SREC ($/kwh)	.10	$/kWh
Calculated area for PV modules	1270	sf

Table 7.13. Design and financial parameters associated with the Seneca County Garage PV system with incentives and SRECs

Because of the financial incentives and the additional revenues generated from SRECs, the financial indicators have significantly improved and are shown in Table 7.14. The simple payback is 7.9 years. The equity payback is 6.5 years. The internal rate of return (IRR) on equity for this project is 17%. The Net Present Value (NPV) of this project is $193,711. The annual life cycle savings for this project is $8,605/year over the life cycle of the project (30 years) and the net Benefit-Cost (B-C) ratio is 4.21. The proposed PV system would reduce Greenhouse Gas emissions by 14 tons of CO2 annually and since the proposed project has a positive annual life cycle savings of $8,605, the associated cost of reducing a GHG emission is negative (- 619 $/tCO2). All the financial indicators have significantly improved and the proposed project is very attractive financially because of the incentives and SRECs.

Total initial cost of PV system	60000	$
Simple payback	7.9	years
Equity payback	6.5	years
IRR equity	17	%
Net Present Value	193,711	$
Annual Life Cycle savings $/yr	8605	$/year
Benefit/ Cost ratio	4.21	
GHG reduction cost ($/tCO2)	-619	$/tCO2
Net Annual GHG reduction	14	tCO2/year
Net GHG reduction (30 years)	420	tCO2

Table 7.14. Financial Indicators associated with the Seneca County Garage PV system LCCA with incentives and SRECs

Figure 7.10 shows the cumulative cash flow graph for the proposed PV project with incentives and SRECs. As shown in the Figure, the initial investment is paid off after 6.5 years.

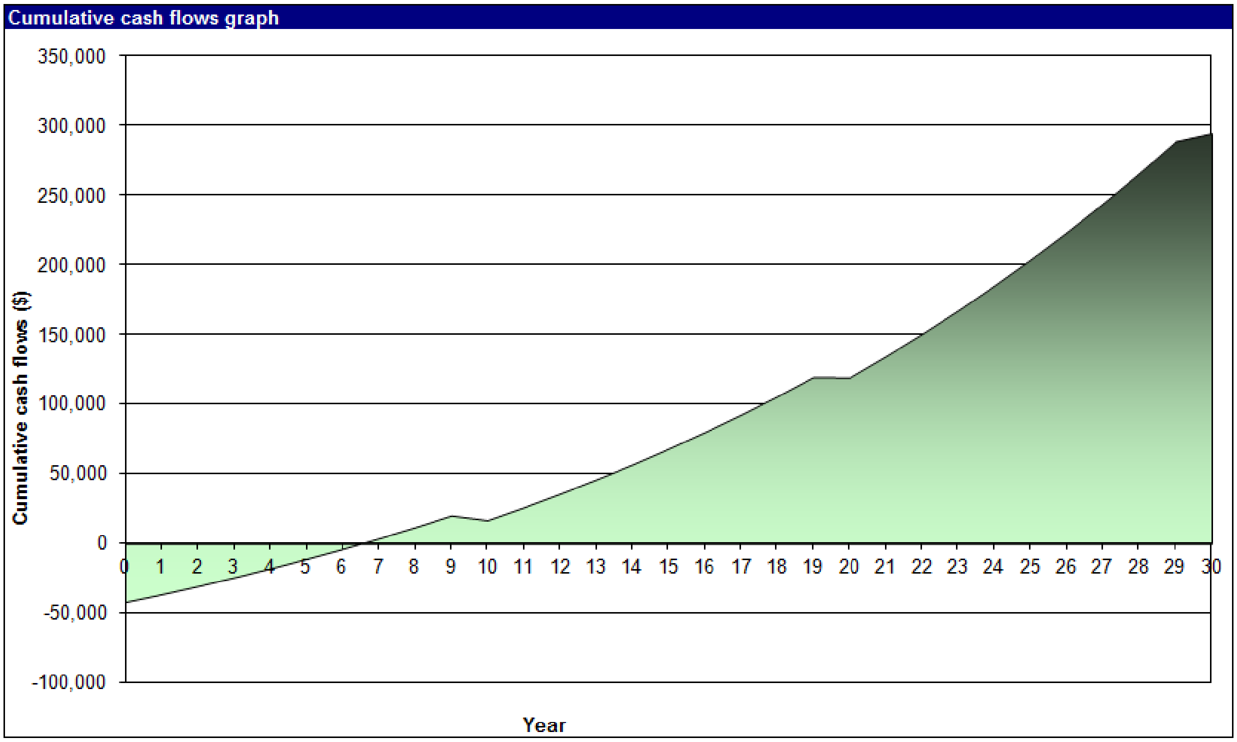


Figure 7.10. Cumulative cash flow graph for the Seneca County PV project with incentives and SRECs

7.4. LCCA for Grid Connected Wind Energy Systems

A grid connected wind energy system located on a facility generates electricity from the wind kinetic energy. In grid connected wind turbines systems, the system feeds electrical energy directly into the electric utility grid. Since the cost-effectiveness of grid connected wind energy systems significantly depends on the wind speed, two LCCA of grid connected wind energy systems are discussed in the following subsections. The first LCCA is for a proposed installation at the Seneca county garage where the wind resources are fair (i.e. wind speed at 50 m = 6.8 m/sec) for optimal PV performance. The second is for a proposed installation at the Pike county garage where the wind resources are poor (i.e. wind speed at 50 m = 4.0 m/sec). In both LCCAs, financial incentives were not considered. A third LCCA that considers financial incentives was completed for the proposed installation at Seneca county garage.

7.4.1. LCCA for Seneca County Garage grid connected wind energy system (no incentives)

In order to perform a LCC analysis for a grid connected wind energy system at Seneca County Garage, the system need to be designed to estimate its size and expected performance. The energy performance of a grid connected wind energy system is influenced by a number of factors that include the wind speed, the wind turbine height, terrain (considered in the analysis through the wind shear value), and the turbine's nominal capacity. The LCCA was performed for a 50kW wind energy system. A system of this size is expected to provide most of the electricity needed for the facility.

In addition to design parameters, the LCCA also requires an estimate of life cycle costs (LCC) associated with the grid connected wind energy system. These LCC components include initial cost, replacement cost, maintenance cost, service life, electricity export rate, and electricity escalation rate. Table 7.15 summarizes both the design and economic parameters used to conduct the LCCA analysis for the Seneca County Garage's 50 kW wind energy system. From the NREL wind resource map, average wind speed at 50m was assumed to be 6.8 m/s. RETScreen has a built in database of wind turbines, their manufacturers, and their nominal efficiencies. A 50 kW ReDriven was selected. The turbine height was assumed 85 ft.

Wind turbine nominal kW	50	kW
Cost $/KW	6,000	$
Annual maintenance $/kW	40	$/kW
Inverter replacement cost in years 10,20	15,000	$
Electricity cost ($/kwh)	0.13	
Wind speed at 50 m	6.8	m/sec
Wind shear value	0.12	
Electricity escalation rate	5%	
Inflation rate	2%	
Discount rate	2%	
Project Life	30	years
Incentives	0	
REC ($/kwh)	0	$/kWh

Table 7.15. Design and financial parameters associated with the Seneca County Garage Energy system

RETScreen calculates the energy generated annually and the capacity factor as shown in Table 7.16. The capacity factor is the ratio of the average power produced by the power system over a year to its rated power capacity.

Capacity factor	%	25.2%
Annual electricity generated	MWh	110

Table 7.16. Energy performance of the Seneca County Garage wind energy system

Based on the energy performance of the wind energy system, RETScreen calculates various financial indicators to assess the life cycle cost feasibility of the project as shown in Table 7.17. The simple payback is 24.3 years. The equity payback is 16 years. The internal rate of return (IRR) on equity for this project is 6.4%. All these financial indicators point to a modest return on an investment. The Net Present Value (NPV) of this project is $291,327. The annual life cycle savings for this project is $13008/year over the life cycle of the project (30 years) and the net Benefit-Cost (B-C) ratio is 1.64. A B-C ratio that is just greater than 1 indicate a potentially feasible project but with very modest financial returns. The proposed wind energy system would reduce Greenhouse Gas emissions by 62 tons of CO2 annually and since the proposed project has a positive annual life cycle savings of $13008, the associated cost of reducing a GHG emission is negative (- 1084 $/tCO2).

Total initial cost of PV system	300000	$
Simple payback	24.3	years
Equity payback	16	years
IRR equity	6.4	%
Net Present Value	291,327	$
Annual Life Cycle savings $/yr	13008	$/yar
Benefit/ Cost ratio	1.97	
GHG reduction cost ($/tCO2)	-1084	$/tCO2
Net Annual GHG reduction	62	tCO2/year
Net GHG reduction (30 years)	1860	tCO2

Table 7.17. Financial indicators associated with the Seneca County Garage wind energy system LCCA

Figure 7.11 shows the cumulative cash flow graph for the proposed wind energy project. As shown in the Figure, the initial investment is paid off after 16 years.

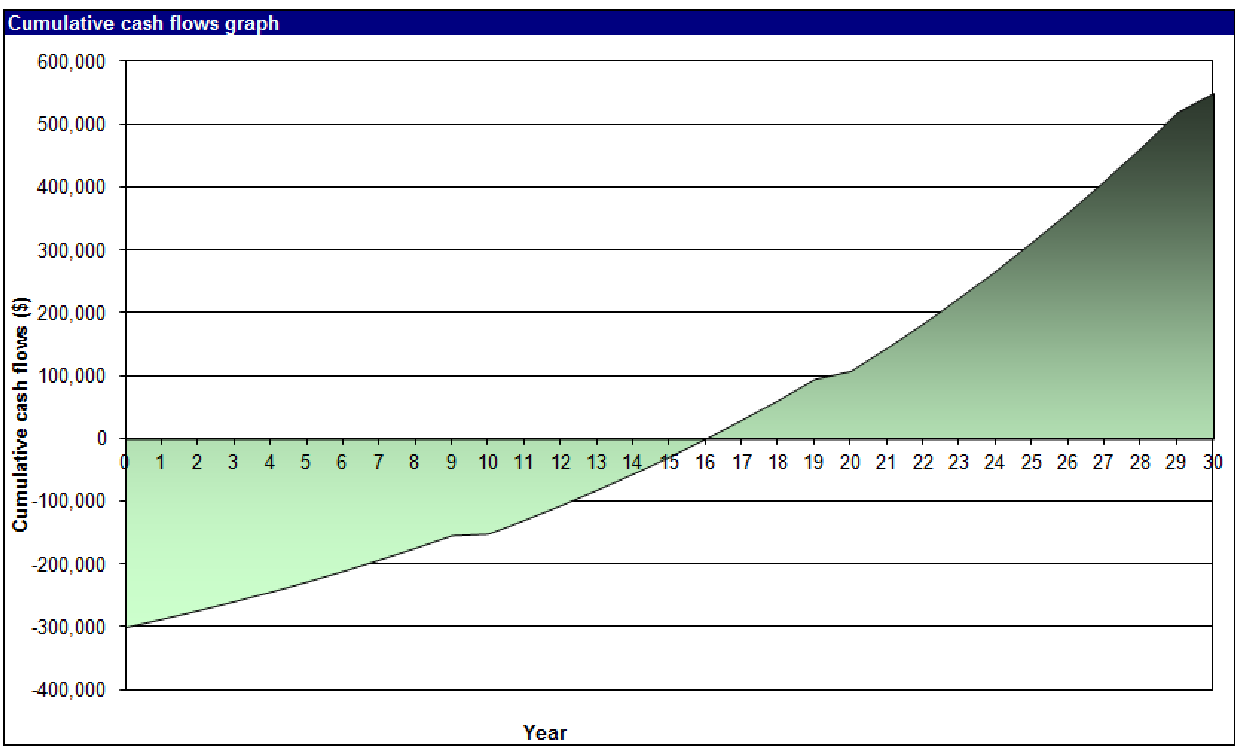


Figure 7.11. Cumulative cash flow graph for the Seneca County wind energy project

7.4.2. LCCA for Pike County Garage grid connected wind energy system (no incentives)

As discussed in Chapters 3 and 6, the cost-effectiveness of grid connected wind energy systems significantly depends on the wind speed. From the NREL resource map, it was determined that the wind speed at the Pike County garage is 4.0 m/sec at 50 m which is significantly less than that at Seneca County Garage.

The proposed wind energy system for Pike County garage is similar to the wind energy system proposed for Seneca County garage in Section 7.4.1. As such, all the design, and economic parameters in Table 7.15 would apply for the Pike county garage's system with the exception of the wind speed. The design and economic parameters for the Pike county garage's wind energy system are summarized in Table 7.18.

Wind turbine nominal kW	50	kW
Cost $/KW	6,000	$
Annual maintenance $/kW	40	$/kW
Inverter replacement cost in years 10,20	15,000	$
Electricity cost ($/kwh)	0.13	
Wind speed at 50 m	4	m/sec
Wind shear value	0.12	
Electricity escalation rate	5%	
Inflation rate	2%	
Discount rate	2%	
Project Life	30	years
Incentives	0	
REC ($/kwh)	0	$/kWh

Table 7.18. Design and financial parameters associated with the Pike County Garage wind energy system

Because of the poor wind resources at the Pike county garage, the energy generated by the system as calculated by RETScreen has significantly decreased and is shown in Table 7.19. The same wind energy system, installed in an area with poor wind resources will generate 72% ((110-31)/110) less electricity.

Capacity factor	%	7.1%
Annual electricity generated	MWh	31

Table 7.19. Energy performance of the Pike County Garage wind energy system

Because of the poor wind resources, the project is not economically feasible. The financial indicators are shown in Table 7.20.

Total initial cost of PV system	300000	$
Simple payback	146.7	years
Equity payback	> project	years
IRR equity	-4	%
Net Present Value	-208,791	$
Annual Life Cycle savings $/yr	-9323	$/yar
Benefit/ Cost ratio	0.3	
GHG reduction cost ($/tCO2)	548	$/tCO2
Net Annual GHG reduction	17	tCO2/year
Net GHG reduction (30 years)	510	tCO2

Table 7.20. Financial indicators associated with the Pike County Garage wind energy system LCCA

Figure 7.12 shows the cumulative cash flow graph for the proposed PV project. As shown in the Figure, the initial investment will never be paid off during the life of the project and the project is not feasible.

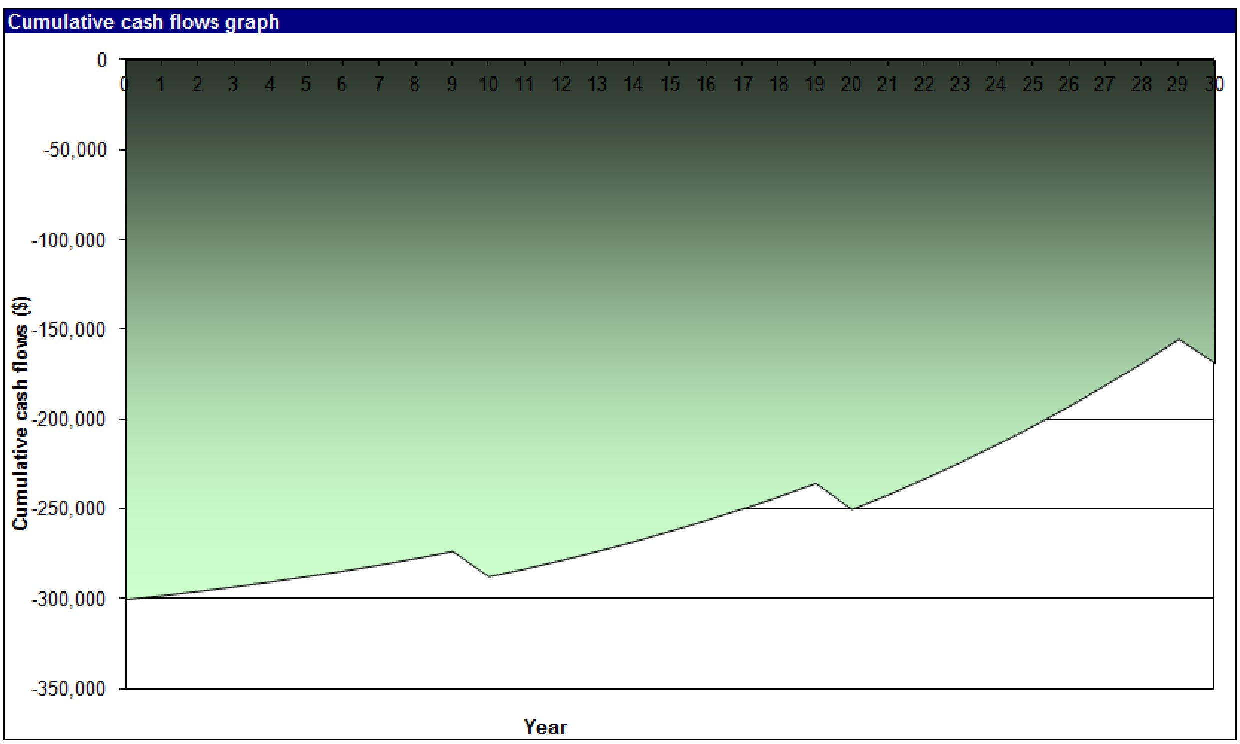


Figure 7.12. Cumulative cash flow graph for the Pike County wind energy project

7.4.3. LCCA for Seneca County Garage grid connected PV system (with incentives and SREC)

The use of financial incentives and the ability to sell RECs can improve the economic feasibility of grid connected wind energy systems but not to the same degree as PV systems since the value of RECs from wind generated power is considerably less than SREC as discussed in Chapter 5. Using financial incentives for wind projects will also require special arrangements since ODOT as a state agency may be ineligible for many of the federal incentives. Such arrangements as discussed in Chapter 5 include involving a third party to take advantage of all available incentives/tax credits and certifying the wind system with the proper agencies.

The wind energy system evaluated in this case is exactly the same as the system evaluated in section 7.4.1 for Seneca County garage with the exception that financial incentives and REC are considered in this analysis. It was assumed, that a third party would contract with ODOT through a power purchase agreement as described in Chapter 5. The third party would be able to apply for the Business Energy Investment Tax Credit which is worth 30 percent of upfront expenditures for the wind energy system. It was also assumed that the project will certify the wind energy system with the proper agencies and be able to sell RECs at $5/Mwh. The design and economic parameters for the Seneca county garage's wind energy system with incentives and RECs are summarized in Table 7.21.

Wind turbine nominal kW	50	kW
Cost $/KW	6,000	$
Annual maintenance $/kW	40	$/kW
Inverter replacement cost in years 10,20	15,000	$
Electricity cost ($/kwh)	0.13	
Wind speed at 50 m	6.8	m/sec
Wind shear value	0.12	
Electricity escalation rate	5%	
Inflation rate	2%	
Discount rate	2%	
Project Life	30	years
Incentives	30	%
REC ($/kwh)	5	$/kWh

Table 7.21. Design and financial parameters associated with the Seneca County Garage wind energy system with incentives and RECs

Because of the financial incentives and the additional revenues generated from RECs, the financial indicators have significantly improved and are shown in Table 7.22. The simple payback is 16.3 years. The equity payback is 12.3 years. The internal rate of return (IRR) on equity for this project is 9.6%. The Net Present Value (NPV) of this project is $408,109. The annual life cycle savings for this project is $18,222/year over the life cycle of the project (30 years) and the net Benefit-Cost (B-C) ratio is 2.36. All the financial indicators have significantly improved and the proposed project is reasonably attractive financially because of the incentives and RECs.

Total initial cost of PV system	300000	$
Simple payback	16.3	years
Equity payback	12.3	years
IRR equity	9.6	%
Net Present Value	408,109	$
Annual Life Cycle savings $/yr	18222	$/yar
Benefit/ Cost ratio	2.36	
GHG reduction cost ($/tCO2)	-294	$/tCO2
Net Annual GHG reduction	62	tCO2/year
Net GHG reduction (30 years)	1860	tCO2

Table 7.22. Financial indicators associated with the Seneca County Garage wind energy system LCCA with incentives and RECs

Figure 7.13 shows the cumulative cash flow graph for the proposed wind energy project with incentives and RECs. As shown in the Figure, the initial investment is paid off after 12.3 years.

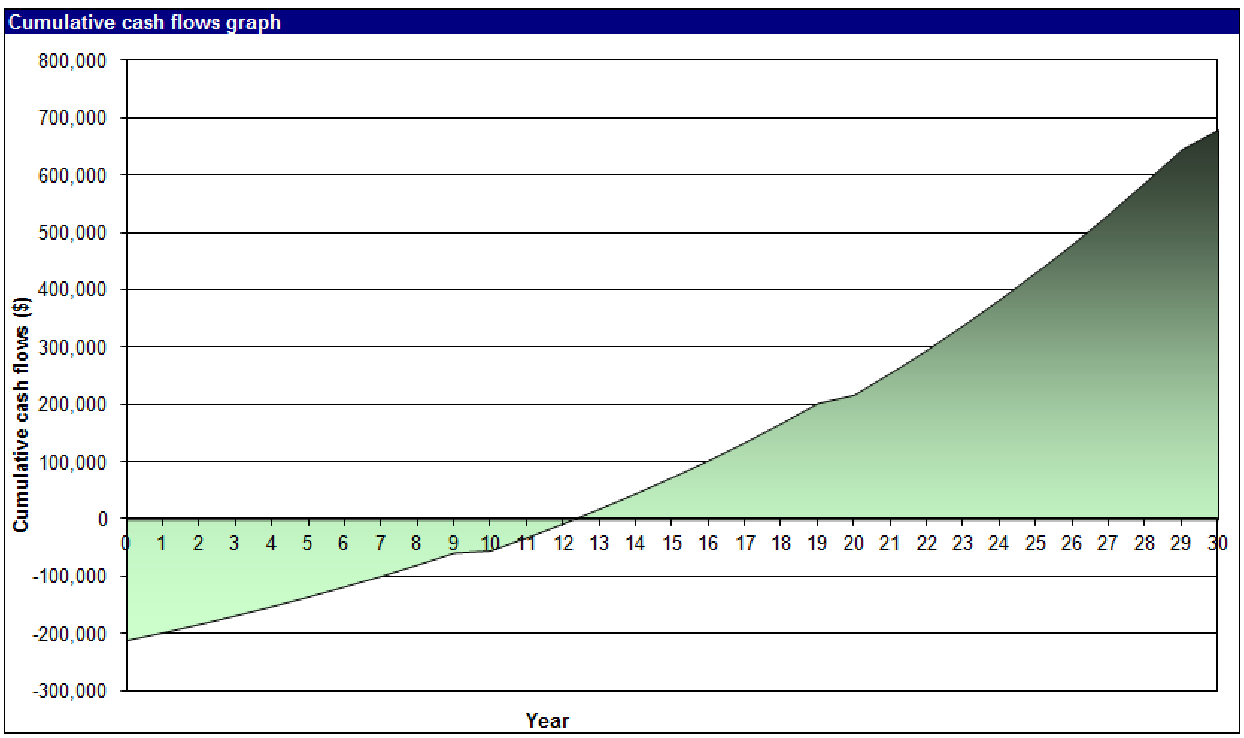


Figure 7.13. Cumulative cash flow graph for the Seneca County wind energy project with incentives and RECs

CHAPTER 8 - CONCLUSIONS, RECOMMENDATIONS AND FUTURE RESEARCH

8.1 Conclusions

The main objective of the research was to recommend strategies for ODOT maintenance facilities that will reduce current energy costs, reduce greenhouse gas (GHG) emissions and reduce potential future energy costs increases resulting from fossil fuel price volatility. The research methodology included an analysis of energy consumption data from 50 ODOT maintenance facilities, followed by a survey of 13 facilities and on-site assessment of 5 facilities.

The research concluded that there are several factors which influence the feasibility of a RET project. These factors can be categorized into 3 categories: (1) statewide/institutional factors, (2) project physical factors, and (3) project financial factors. To be able to effectively assess the 3 categories of factors, the research team developed a 3-phases screening/evaluation process and developed a decision support tool for use in each phase.

The first phase of the screening/evaluation process is performed at the state level and considers the statewide/ institutional factors that are similar throughout Ohio. These factors for example include energy prices and facilities' energy use profiles. Compared to other states, energy prices in Ohio are reasonable. Although good for Ohioans, reasonable energy prices make RET projects less feasible and make energy efficiency projects more practical. Similarly energy use profiles for ODOT maintenance facilities are comparable; with space heating accounting for the majority of the energy demand. Therefore any energy efficiency or RET project should first consider reducing heating requirements. The research team developed and used a state level decision matrix to rank RET projects at the state level. The state level matrix compares different RET alternatives and ranks them based on 5 criteria: (1) environmental attributes, (2) reliability, (3) practicality, (4) maintenance, and (5) cost effectiveness. Since the feasibility of implementing RET technologies depends on whether the project is a new project or a retrofit, two state level decision matrices were developed; one for new construction projects and the other for existing buildings. The state level matrices also provide easy access to information, resources, tools and case studies of RET projects.

The second phase of the screening/evaluation process considers the project physical factors. These factors include building orientation, solar radiation, wind speed, shading from trees, terrain, condition of roof, and zoning requirements. The research team developed a site level decision matrix for use in the second phase of evaluation. The site level matrix provides guidance on when a particular RET should and should not be selected under various specific site conditions and project goals.

The third phase of the screening/evaluation process uses a Life Cycle Costing Assessment (LCCA) methodology to determine the economic feasibility of a RET project that passed the first two screening phases. The LCCA considers the project financial factors that may have an impact on the economic feasibility. These factors include initial costs, incentives, maintenance and replacement costs. The LCCA calculates a suite of financial indicators to assess the profitability of the project.

The research team has determined that the source of most of the energy used in ODOT maintenance facilities is natural gas and that space heating which accounts for the majority of energy needs are provided by natural gas. Natural gas prices are currently low but a sharp increase in their prices will significantly increase ODOT energy bills. Because electricity prices are currently more expensive than natural gas, RETs that reduce electricity consumption were generally found to be more economically feasible under present market conditions. These systems include solar photovoltaic and wind turbines. An exception to this general rule is the use of solar air heaters particularly if implemented on new construction projects. Although a solar air heater reduces consumption of relatively inexpensive natural gas, its reasonable initial cost makes it one of the most feasible renewable energy technologies for ODOT maintenance facilities.

The research has recommended several energy efficiency strategies for existing and new ODOT facilities. Energy efficiency strategies often have a quicker payback and higher return on investment than renewable energy projects and will lead to lower energy costs and reduced greenhouse gas emissions. Energy efficiency strategies have been identified for the heating and lighting systems, process equipment, and operation procedures. The energy efficiency strategies have been categorized as quick fixes or long term solutions. Quick fixes are those that would not require any substantial costs and could sometimes be achieved just with simple workforce behavioral changes. Long term fixes are those that would require some capital investment and typically include equipment replacement.

As to renewable energy strategies, the research team has found that solar air heating (SAH) and solar photovoltaic (PV) systems, in general, have the best potential in ODOT maintenance facilities. SAH systems reduce energy required for space heating which is currently provided by natural gas and as such their use can be a hedge against future increases in natural gas prices. SAH systems are most financially attractive in new construction where simple payback periods can be as low as 8 years. The capital costs of PV systems are high, but their operation and maintenance costs are very low. Typical payback periods for PV systems in Ohio are 25-30 years without considering financial incentives and/or selling solar renewable energy credits (SREC)s. The use of financial incentives and the ability to sell SRECs can significantly improve the economic feasibility of grid connected PV systems and reduce their payback periods to 7 years, but will require special arrangements. Such arrangements include involving a third party to take advantage of available incentives/tax credits and certifying the PV system with the proper agencies. A large cost advantage of PV systems in general is that the sun, the fuel for PV systems, is free, and thus protected from the price volatility that is always a concern with fossil fuels. Wind energy systems also have a similar advantage since the wind is free. However wind energy systems’ performance significantly depends on wind speeds which are adequate only in some parts of Ohio, and they are more complex to maintain compared to PV systems.

8.2 Recommendations

There are several benefits to implementing the recommended RET systems as early as possible. As these systems become more prevalent, the economic values of the renewable energy credit (REC) they generate decrease and the financial incentives offered by utilities expire.

Furthermore, there is currently a 30% tax credit for eligible RET systems that are placed into service by December 31, 2016. Although ODOT as a state agency is not eligible for this tax credit, it can still indirectly take advantage of it by involving a private developer through a power purchase agreement (PPA) as discussed in Chapter 5.

It should be emphasized that the economic feasibility of an RET which depends on several project physical and financial factors can only be established through a detailed LCCA analysis. Results from several LCCA studies for RET implementations on existing ODOT facilities were performed and included in Chapter 7. However, it is important to perform a "new" detailed LCCA analysis for any RET project other than those included in Chapter 7. The research team recommends using the RETScreen software for the LCCA evaluation.

8.3 Future Research

Some recommended energy efficiency strategies included in the report can't be evaluated using RETScreen and require energy modeling and daylight modeling software for proper evaluation. These strategies include the thermal separation of functional areas and the use of daylighting strategies. They are only applicable to new buildings but can potentially reduce energy consumption significantly. The use of energy modeling and daylight modeling were beyond the scope of this project and the research team recommends a second phase of the project where such software is utilized for proper assessment.

If power purchase agreements and alternative financing options are used as recommended in Chapter 5, it is important to develop best practices for ODOT to use based on experiences of other state, federal agencies. Such best practices would be developed in Phase 2 of the research.

The research team also recommends that the University of Cincinnati continue working with ODOT on a regular basis to analyze energy consumption data for the following reasons:

1. Ensure the data is complete: Several monthly electrical consumption data for some facilities were missing. A regular review will ensure that all data is provided in a timely manner.
2. Identify any negative trends in energy consumption in a timely manner and resolve the underlying issues to eliminate unnecessary costs
3. Ensure that implemented energy efficiency and/or renewable energy strategies are achieving anticipated results: On some of the facilities visited, although some energy efficiency control strategies were available (such as carbon monoxide sensors controlling the ventilation fans), the facilities used large amounts of energy because these controls were manually overridden.
4. Provide support when detailed LCCA evaluations are needed for proposed projects.
5. Provide support when energy modeling and daylighting studies are needed during the design of new facilities.
6. ODOT maintenance facilities consume a significant amount of energy to meet their heating, lighting, cooling and operation demands. There are 88 counties in Ohio. All counties have a county garage and some counties have additional outpost garages. Data collection has revealed that the average monthly utility bill for the facilities included in

the research is currently around $2,000/month. Based on the number of garages and the average monthly utility bill for the facilities evaluated, the UC research team estimates the total annual energy bill for ODOT maintenance facilities to be more than $2,000,000/year. The proposed UC involvement will cost less than 2% of this annual budget and is expected to save much more than it costs.

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APPENDICES

Appendix A - Facility Survey

General Facility Information			
Facility Name:			
ODOT Region:			
Address:			
Facility Representative:			
Phone:		Email:	

1.	What is the building square footage?							
2.	What is the size of the overall facility site? (Acres)							
3.	When was the building built?							
4.	What approximate percentage of the facility do the following spaces account for?							
	Offices:		Garage:		Storage:		Other (please specify):	
5.	What is the average number of daily occupants?							
6.	What is the average weekly occupancy and operation time? (In terms of hours per day and days per week)						Days/ week:	
							Hours/day:	
7.	Has the Facility ever been formally commissioned and/or audited for energy use? If so when was the last time? Please provide details below.							

Occupants/ Facility Manager Opinions					
1.	How do you rank the building's overall comfort level?				
	1 (Worst)	2	3	4	5 (Best)
2.	How do you rank the building's lighting quality?				
	1 (Worst)	2	3	4	5 (Best)
3.	How do you rank the building's noise levels?				
	1 (Worst)	2	3	4	5 (Best)
4.	How do you rank the indoor air quality inside the building:				
	1 (Worst)	2	3	4	5 (Best)
5.	How do you rank the building's typical temperature level in terms of comfort:				
	1 (Worst)	2	3	4	5 (Best)
6.	What are some of the most common complaints from the building occupants?				
7.	Who/what organization provides facilities maintenance? (In house or contracted?)				
8.	Do you have up-to-date drawings of the buildings' layout, mechanical, and electrical systems that can be made available at the start of the site visit?				YES NO

Metering and Emergency Generator Information		
1.	How many separate electricity meters serve the facility?	
	How many are "smart" meters?	
	How many are standard meters?	
2.	How many separate gas meters serve the facility?	
3.	Does an emergency generator serve the facility?	
	If so, what is the capacity?	
	If so, is the generator used to control peak demand?	

Heating Equipment

Which of the following equipment is used for heating? Please check all that applies and indicate which area(s) of the facility the equipment heats (i.e.office, garage, storage, others)

	Equipment	Check (√) all that applies	Area of building heated by equipment (garage, office, storage, others)
	Gas Fired Make up air Unit		
	Gas Fired Furnace		
	Standard Efficiency Radiant heaters		
	High Efficiency Radiant heaters		
	Hydronic Radiant floor heating		
	Boilers		
	Steam radiators		
	Hot water radiation units		
	Air source Heat pump		
	Geothermal Heat pump		
	Others : (Please list below)		

Cooling Equipment

Which of the following equipment is used for cooling? Please check all that applies and indicate which area(s) of the facility the equipment cools (i.e.office, garage, storage, others)

	Equipment	Check (√) all that applies	Area of building cooled by equipment (garage, office, storage, others)
	Condenser		
	Cooling tower		
	Chiller		
	Window Air Conditioning unit		
	Split Air Conditioning unit		
	Air source Heat pump		
	Roof top unit		
	Others : (Please list below)		

Lighting System

Which of the following lamp types is used for lighting? Please check all that applies and indicate where on the facility/**site** the lamp type is used (i.e.**site**, office, garage, storage, others)

	Fixture		Check (√) all that applies	Area of facility/site where fixture is used (site, garage, office, storage, others)
	Mercury Vapor lamps			
	Metal Halide lamps			
	Pulse start Metal Halide lamps			
	High Pressure Sodium lamps			
	Low Pressure Sodium lamps			
	T12- fluorescent with magnetic ballast			
	T12- fluorescent with electronic ballast			
	T8- fluorescent lamps			
	Super T8- fluorescent lamps			
	T5- fluorescent lamps			
	T5HO- fluorescent lamps			
	Compact fluorescent lamps			
	Incandescent lamps			
	Tungsten-Halogen lamps			
	LED lamps			
	Induction lamps			
	Others : (Please list below)			

Building Systems Controls

1.	Does the facility have an **Energy Management and Control System (EMCS)**? [If you have an outside contractor that provides maintenance services to your facility's EMCS, that contractor may be able to provide assistance in completing this survey]		YES	NO
		If so, when was the system installed?		
		If so, what type (pneumatic, electric, Direct Digital Control)?		
2.	Does your facility use **occupancy sensors** to turn light on/off?		YES	NO
3.	Does your facility have a **lighting control system** that allows the user to remotely switch ALL light (on/off), operate dimmers and schedule space lighting levels from a single location?		YES	NO
4.	Does your facility use **photo sensors** to dim electric fixtures when there is enough daylight?		YES	NO
5.	Does your facility use **programmable thermostats** to reduce heating and cooling during unoccupied hours?		YES	NO
6.	Does your facility use **occupancy sensors** to control HVAC thermostat settings?		YES	NO
7.	Does your facility adjust thermostat settings for change in seasons?		YES	NO
8.	Are garage area exhaust fans controlled by **CO sensors**?		YES	NO
9.	Does your facility use **Variable Speed Drives (VSD)** on Fans and/or pumps?		YES	NO

Energy Consuming Equipment Conditions and O&M procedures

1.	Is there any particular energy consuming equipment that has exceeded or is near exceeding its useful life? Please specify below	
2.	When were the buildings' major HVAC components installed? Are they part of the original system?	
3.	When was the last time the buildings' HVAC was tested and balanced?	
4.	Does your facility keep a maintenance schedule for replacing air filters and/or maintaining heating/cooling coils?	YES NO
5.	Does the facility perform flue gas analysis on a regular basis to ensure proper air to fuel ratio for gas fired heating equipment?	YES NO
6.	Does the facility perform vibration analysis on a regular basis to assess existing equipment conditions?	YES NO

Energy Efficiency and Conservation

1. Have any of the following energy conservation measures been implemented within the last five years? Please check (√) all that applies

Energy Efficient Lighting		Energy recovery ventilators	
Lighting Controls		High Efficiency fans	
Occupancy Sensors		High Efficiency motors	
HVAC Controls Retrofit		Close Capture Evacuation System for Vehicle Exhaust Fumes	
Major HVAC Renovations		Other: (please specify)	
Vestibules with air locks		Other: (please specify)	

2.	Has the building envelope been thoroughly inspected (for air leakage, thermal performance, R-Value, etc.)? If so when was it last performed?
3.	Does the facility utilize any form of natural lighting? (Daylighting)
4.	Does the facility currently take advantage of any discount or rebate programs provided by utilities or other organizations? If so, please provide details.

Renewable Technologies				
1.	Have any of the following renewable energy measures been implemented in your facility? Please check (√) all that applies			
	Geothermal Heat pumps		Solar hot water heating	
	Bio mass power		Bio mass heat	
	Wind turbines		Hydroelectric	
	Solar air ventilation (Solar walls)		Passive Solar Heating	
	Photovoltaics (Solar panels to generate electricity)		Other: (please specify)	
2.	Have any renewable energy measures or systems been considered or discussed for future implementation? (If so, please provide details)			
3.	Are there large areas of unused land on the facility property? (If so, what percentage of the sites area is unused?)			
4.	What percentage of the facility and parking areas receive consistent sunlight?			

Appendix B - Building Systems and Renewable Energy Form

General Facility Information

Facility Name:	Pike County Maintenance Facility	
ODOT Region:	9	Date: May 29, 2013
Address:	5591 Wakefield Mound Rd , Seal, OH 45661	
Facility Representative:	Ed Lightle	
Phone: 740-289-2650	Ed.Lightle@dot.state.oh.us	

1.	What are the facility operating hours?	

Building Envelope

#	Check Point Description		Corrective Action Request / Comments
1	Are doors/windows kept closed during heating and cooling season?	YES NO N/A	
2	Are building walls too hot/cold candidate for insulation?	YES NO N/A	Location:
3	Is weather stripping found to be adequate around windows/doors? (reduce air leak)	YES NO N/A	
4	Are windows types adequate (e.g. single pane, double pane, high performance windows?	YES NO N/A	Location:
5	Are windows placed correctly? (i.e. majority of windows facing south)?	YES NO N/A	
6	Are there signs of deterioration of building envelope (siding deterioration, masonry fluorescence, window fogging, and wet spots)	YES NO N/A	Location:
7	Did the thermal imager indicate leaks in the building (by significant temperature difference)?	YES NO N/A	Location:
8	Did the thermal imager detect cold spots in a wall that may be caused by sections of missing insulation, wet insulation, or a missing air barrier?	YES NO N/A	Location:
9	Are there window coverings to block sun where needed	YES NO N/A	

#	Check Point Description				Corrective Action Request / Comments
10	Are different areas of facility adequately separated? Are separation doors closed?	YES	NO	N/A	
11	Are windows properly caulked and free of cracks?	YES	NO	N/A	
12	Are there deciduous plants to shade southern and western sides of buildings?	YES	NO	N/A	
13	General Comments				

Lighting Systems

#	Check Point Description				Corrective Action Request / Comments
1	Did Light meter indicate inadequate illuminance level?	YES	NO	N/A	Location:
2	Does illuminance level change significantly throughout the day in some areas (because of daylighting)?	YES	NO	N/A	Location:
3	Do lamp types properly match application?	YES	NO	N/A	Location:
4	Is light control system type adequate for all locations (manual, schedule, occupancy sensors, photocell, daylight)?	YES	NO	N/A	Location:
5	Are magnetic ballasts used in some areas of the facility?	YES	NO	N/A	Location:
6	Are the operating hours of the various lamps adequate?	YES	NO	N/A	
7	Is the light control system layout adequate?	YES	NO	N/A	
8	Are lamps dimmable	YES	NO	N/A	
9	Would you like to install local switches for more control for very large area & lights?	YES	NO	N/A	

10	Would you like to delamp/deactivate extra lights & fixtures	YES	NO	N/A	Location: Qty:
11	Is lighting only used when needed?	YES	NO	N/A	
12	Is lighting on after hours & weekend used only when needed?	YES	NO	N/A	
13	What percentage of lights is being shut off during after hours/weekends?	YES	NO	N/A	
14	Are there any special Lighting needs/concerns where?	YES	NO	N/A	
15	What do you hear most often regarding lights in this building?				
16	Do you need light switch stickers to remind people to turn off lights when not in use?	YES	NO	N/A	Location: Qty:
17	Are Exit signs LEDs?	YES	NO	N/A	Location: Qty:
18	General Comments				

Heating, Ventilation and Air Conditioning Systems

#	Check Point Description				Corrective Action Request / Comments
1	If heating/cooling control is accomplished from central computer, does the computer schedule match your occupancy?	YES	NO	N/A	
2	Do temperature/humidity readings conform to heating/cooling set points?	YES	NO	N/A	Location:
3	Are air velocity readings adequate?	YES	NO	N/A	
4	Are CO2 readings adequate?	YES	NO	N/A	Location:

5	Are <u>CO readings</u> adequate?	YES NO N/A	
6	Is HVAC control system type adequate for all locations (manual, schedule, occupancy sensors, CO sensors, EMS)?	YES NO N/A	
7	Are time clock schedules for starting and stopping equipment adequate?	YES NO N/A	
8	Are heating thermostats set to maintain 68°F or lower?	YES NO N/A	
9	Is air conditioning (A/C) set for75°F and shut down during unoccupied hours?	YES NO N/A	
10	Are there many fans or portable electric space heaters used by occupants?	YES NO N/A	Type Location
11	Are exhaust fans shut off during unoccupied hours?	YES NO N/A	
12	What do you hear most often regarding this building heating/cooling & comfort?		
13	Is welding hood closed when not in use?	YES NO N/A	
14	Are electronics located away from thermostats?	YES NO N/A	
15	Are thermostats/return air vents not blocked?	YES NO N/A	
16	Are timers set appropriately for make up air units?	YES NO N/A	
17	General Comments		

#	Facility Equipment / Miscellaneous				
#	Check Point Description				Corrective Action Request / Comments
1	Do you have very large (>1HP) fans or motors operating in this building?	YES	NO	N/A	Location:
2	Are motors energy efficient (0.91 (for 10 hp motors) to 0.95 (for 50 hp motors)?	YES	NO	N/A	Location:
3	Are computers OFF at the end of the work day, not just sleep mode?	YES	NO	N/A	
4	Are copying machines shut off, or on sleep mode, at the end of the work day?	YES	NO	N/A	Location:
5	Are fax machines shut off, or on sleep mode, at the end of the work day?	YES	NO	N/A	
6	Are there any leaking faucets?	YES	NO	N/A	Location:
7	Are energy awareness materials displayed throughout the building?	YES	NO	N/A	Location:
8	Is compressed air on only when needed?	YES	NO	N/A	
9	Are leaks in compressed air regularly checked/fixed?	YES	NO	N/A	
10	Measured hot water temperature is excessive (above 115 F)	YES	NO	N/A	
11	Hot water tank is insulated?	YES	NO	N/A	
12	Recommendations/Ideas to Save Energy at this Facility				

PV feasibility					
#	Check Point Description				Corrective Action Request / Comments
1	Is there adequate roof, or ground space available to install solar collectors?	YES	NO	N/A	Location:
2	Will the solar collector receive consistent sunlight? (At least 9AM to 4PM for ideal results) Use sun path charts	YES	NO	N/A	
3	Are there shading obstructions that will restrict solar collection?	YES	NO	N/A	
4	Can the solar collectors be positioned facing southward?	YES	NO	N/A	Best possible orientation/location:
5	Will angled collector surfaces be possible?	YES	NO	N/A	
6	Will Installation of a collector to a building surface be difficult?	YES	NO	N/A	Complications:
7	Is there available space for storage of batteries? (If system generates excess energy)	YES	NO	N/A	
8	Will heavy snow or wind loads pose difficulty for roof systems?	YES	NO	N/A	Complications:
9	if roof mounted, can the roof supports structural loads imposed by the collectors?	YES	NO	N/A	
10	Is roof slope ideal?	YES	NO	N/A	
11	Is maintenance access to proposed collectors diffictult?	YES	NO	N/A	
12	Is net metering available?	YES	NO	N/A	
13	Is roof good for 20 years?	YES	NO	N/A	

14	General Comments: PV on parking lot		

Solar Air Heater Feasibility

#	Check Point Description		Corrective Action Request / Comments
1	Is there adequate wall space available to install solar collectors?	YES NO N/A	Location:
2	Will the solar collector receive consistent sunlight? (At least 9AM to 4PM for ideal results) Use Sun Charts to check during the heating seasons	YES NO N/A	
3	Are there shading obstructions that will restrict solar collection?	YES NO N/A	
4	Can the solar collectors be positioned facing southward?	YES NO N/A	Best possible orientation:
5	Will Installation of a collector to a building surface be difficult?	YES NO N/A	Complications:
6	Will ventilation through the ceiling area be difficult or require major adjustments?	YES NO N/A	Complications:
7	Are the facilities air flow ventilation demands known? What are they?	YES NO N/A	Air flow demands:
8	Does the proposed area for intake air have the possibility of drawing from contaminated air sources (e.g., vehicle exhaust, etc.).	YES NO N/A	
9	Will a dark color of the transpired wall integrate well with existing colors?	YES NO N/A	
10	General Comments		

Solar Hot Water Feasibility			
#	Check Point Description		Corrective Action Request / Comments
1	Is there adequate roof space available to install solar collectors?	YES NO N/A	Location:
2	Will the solar collector receive consistent sunlight? (At least 9AM to 4PM for ideal results)	YES NO N/A	
3	Can roof structure supports additional panel weight?	YES NO N/A	
4	Can the solar collectors be positioned facing southward?	YES NO N/A	Best possible orientation:
5	Is roof good for 20 years?	YES NO N/A	
6	Is roof pitch steep enough for drain back systems?	YES NO N/A	
7	Is there adequate spacing for piping and plumbing connections?	YES NO N/A	
8	Is there a high frequency of freezing during winter months at the location?	YES NO N/A	
9	Will replacement water heaters or storage tanks be required? Will space for them be an issue?	YES NO N/A	
10	Will Installation of a collector to a building surface be difficult?	YES NO N/A	Complications:
11	Will angled collector surfaces be possible?	YES NO N/A	
12	Is existing hot water tank close to a good location on the roof where the panels can be installed?	YES NO N/A	
13	Are there unshaded areas on the roof?	YES NO N/A	

14	Is there a high demand for hot water use in the facility?	YES NO N/A	
15	General Comments		

Wind Feasibility

#	Check Point Description		Corrective Action Request / Comments
1	Does the facility site have the available area to install a wind turbine?	YES NO N/A	Location:
2	Is there enough land to construct towers at least 30 feet above and 300 feet away from any obstruction (structures, large trees, or land formations) to avoid turbulent airflows? Turbulent flow leads to greater fatigue failure of turbines? Also if turbine is close to buildings, noise may be a big issue.	YES NO N/A	
3	Are there any known zoning or regulatory restrictions at the site?	YES NO N/A	
4	Is the available space outside of any setback restrictions of any roads or other structures?	YES NO N/A	
5	What is the proximity of the site to any airports?	YES NO N/A	
6	Is wind data known for the site? If not, check into temporary meteorological towers.	YES NO N/A	
7	Are there any other known height restrictions?	YES NO N/A	
8	Is there available space for storage of batteries? (If system generates excess energy)	YES NO N/A	
9	Is it possible to share the generated energy between multiple sites?	YES NO N/A	

10	Might neighbors object to a turbine that obstructs their view or is noisy?	YES NO N/A	
11	Are there potential benefits from terrain features such as hilltops and ridges that can accelerate wind speeds?	YES NO N/A	
12	Could the placement of a turbine on site create shadows on buildings that can result from rotating turbine blades when the sun is at certain angles during the year? Use Sun Charts.	YES NO N/A	
13	Will the turbine be located in the path of migratory birds / bat populations ?	YES NO N/A	
14	Is there a potential for interference with radar at military installations and other airports.	YES NO N/A	
15	General Comments		

Hydro Power

#	Check Point Description		Corrective Action Request / Comments
1	Does the site contain a small, constantly flowing, natural water feature?	YES NO N/A	Location:
2	Does the hydro source have a steady flow? What is the size of the source? What is the Hydraulic head?	YES NO N/A	Size: Head:
3	Is there adequate space for the turbine, generator and other equipment?	YES NO N/A	
4	Does the source ever have any form of seasonal flooding or drought?	YES NO N/A	
5	General Comments		

Daylight Feasibility

#	Check Point Description		Corrective Action Request / Comments
1	Are there north and south facing walls with large window spaces, or the opportunity for them?	YES NO N/A	
2	Are there windows in need of replacement or opportunities for renovation?	YES NO N/A	
3	Is there an opportunity for rooftop renovation to allow for options such as skylights?	YES NO N/A	
4	Does the exterior of the building allow for shading surfaces to control seasonal sunlight?	YES NO N/A	
5	Are there existing building controls that can be applied to a daylight system? (Dimming, etc)	YES NO N/A	Existing Components:
6	Are there exterior obstructions shading the north or south facing windows and walls?	YES NO N/A	
7	General Comments		

Passive Heating

#	Check Point Description		Corrective Action Request / Comments
1	Are there north and south facing walls with large window spaces, or the opportunity for them?	YES NO N/A	
2	Are there windows in need of replacement or opportunities for renovation?	YES NO N/A	Location:
3	Is there an opportunity for rooftop renovation to allow for options such as skylights?	YES NO N/A	
4	Does the exterior of the building allow for shading surfaces to control seasonal sunlight?	YES NO N/A	Location:
5	Are there existing building controls that can be applied to a system? (Monitoring, etc)	YES NO N/A	Existing Components:

6	Are there exterior obstructions shading the north or south facing windows and walls?	YES NO N/A	
7	General Comments		

Geothermal Feasibility

#	Check Point Description		Corrective Action Request / Comments
1	Is there available open space for excavation and installation of coils?	YES NO N/A	Horizontal or vertical?: Location:
2	Does the site have a lake or pond to utilize geothermal energy from?	YES NO N/A	Location?
3	Are there any known zoning or regulatory restrictions at the site? (Especially water sources)	YES NO N/A	
4	Do records of soil characteristics and conditions exist?	YES NO N/A	
5	General Comments		