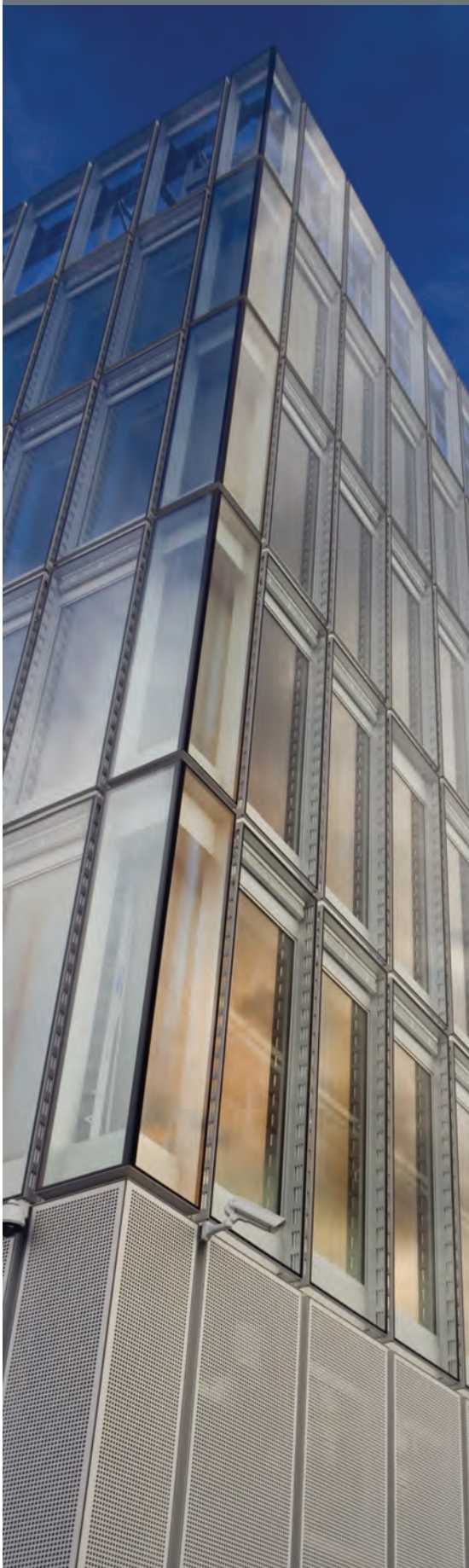


Release 3.0

Operations & Maintenance Best Practices

A Guide to Achieving Operational Efficiency

August 2010



Release 3.0

Operations & Maintenance

Best Practices

A Guide to Achieving Operational Efficiency

G. P. Sullivan^(a)

R. Pugh

A. P. Melendez

W. D. Hunt

August 2010

Prepared by
Pacific Northwest National Laboratory
for the Federal Energy Management Program
U.S. Department of Energy

^(a) Efficiency Solutions, LLC

Disclaimer

This report was sponsored by the United States Department of Energy, Office of Energy Efficiency and Renewable Energy, Federal Energy Management Program. Neither the United States Government nor any agency or contractor thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency or contractor thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency or contractor thereof.

Preface

This Operations and Maintenance (O&M) Best Practices Guide was developed under the direction of the U.S. Department of Energy's Federal Energy Management Program (FEMP). The mission of FEMP is to facilitate the Federal Government's implementation of sound, cost-effective energy management and investment practices to enhance the nation's energy security and environmental stewardship. Each of these activities is directly related to achieving requirements set forth in:

- The *Energy Policy Act of 2005*, which established a number of energy and water management goals for Federal facilities and fleets and also amended portions of the National Energy Conservation Policy Act (NECPA).
- Executive Order 13423, *Strengthening Federal Environmental, Energy, and Transportation Management* (signed in January 2007). This set more challenging goals than EPCA 2005 and superseded existing executive orders 13123 and 13149.
- The *Energy Independence and Security Act of 2007*, which further established energy, water, and building commissioning management goals and requirements and also amended portions of EPCA 2005 and NECPA. EISA was signed into law in December 2007.
- Executive Order 13514, *Federal Leadership in Environmental, Energy and Economic Performance* (signed in October of 2009) directs Federal agencies to further address energy, water, and operational efficiency beyond E.O. 13423 with targeted goals and actions.

Release 3.0 of this guide provides updates to Release 2.0 in the areas of O&M technologies, equipment performance, and costs. This new release also addresses water use and the impacts that recommended O&M practices can have on water efficiency.

Overall, this guide highlights O&M programs targeting energy and water efficiency that are estimated to save 5% to 20% on energy bills without a significant capital investment. Depending on the Federal site, these savings can represent thousands to hundreds-of-thousands dollars each year, and many can be achieved with minimal cash outlays. In addition to energy/resource savings, a well-run O&M program will:

- Increase the safety of all staff, as properly maintained equipment is safer equipment.
- Ensure the comfort, health, and safety of building occupants through properly functioning equipment providing a healthy indoor environment.
- Confirm the design life expectancy of equipment is achieved.
- Facilitate the compliance with the above-mentioned Acts and Orders as well as Federal legislation such as the *Clean Air Act* and the *Clean Water Act*, as well as expected carbon mitigation legislation.

The focus of this guide is to provide the Federal O&M/Energy manager and practitioner with information and actions aimed at achieving these savings and benefits.

Acknowledgments

This report is the result of numerous people working to achieve a common goal of improving operations and maintenance and energy/water efficiency across the Federal sector. The authors wish to acknowledge the contribution and valuable assistance provided by the staff of the Federal Energy Management Program (FEMP). Specifically, we would like to thank Ab Ream and Shawn Herrera, FEMP Program Managers, for their leadership and support of the FEMP Operations and Maintenance program.

In addition, the authors would like to recognize Bill Sandusky of the Pacific Northwest National Laboratory (PNNL) for his continued commitment and recognition of the resource savings potential of O&M to the Federal sector. Also from PNNL, Eric Richman and Carol Jones, and Hayden McKay of Hayden McKay Lighting Design, Inc. for their work on the Lighting section of this document.

Beth Shearer, of Beth Shearer and Associates, provided a conscientious review of material provided in this version of the document. She provided invaluable comments and suggestions to improve the quality of the document.

Finally, the authors would like to extend their appreciation to PNNL's document production team – Dave Payson and Elaine Schneider – for the conscientious, team-oriented, and high quality assistance they brought to this version of the document.

Contents

Preface.....	iii
Acknowledgments	v
Chapter 1 Introduction and Overview.....	1.1
1.1 About This Guide	1.1
1.2 Target Audience.....	1.2
1.3 Organization and Maintenance of the Document.....	1.2
Chapter 2 Why O&M?.....	2.1
2.1 Introduction	2.1
2.2 Definitions	2.1
2.3 Motivation	2.1
2.4 O&M Potential, Energy Savings, and Beyond	2.3
2.5 References	2.6
Chapter 3 O&M Management.....	3.1
3.1 Introduction	3.1
3.2 Developing the Structure	3.1
3.3 Obtain Management Support	3.3
3.3.1 The O&M Mission Statement.....	3.3
3.4 Measuring the Quality of Your O&M Program	3.4
3.5 Selling O&M to Management	3.5
3.6 Program Implementation	3.6
3.7 Program Persistence.....	3.6
3.8 O&M Contracting	3.6
3.8.1 O&M Contract Types.....	3.8
3.8.2 Contract Incentives	3.9
3.9 O&M: The ESPC Perspective.....	3.12
3.9.1 O&M Needs for Verified and Persistent Savings	3.12
3.9.2 Determination and Verification of O&M Savings in ESPCs	3.14
3.10 References	3.15
Chapter 4 Computerized Maintenance Management System	4.1
4.1 Introduction	4.1
4.2 CMMS Needs Assessment	4.1
4.3 CMMS Capabilities.....	4.1
4.4 CMMS Benefits	4.3
4.5 CMMS Resources.....	4.3
4.6 Reference	4.3

Chapter 5 Types of Maintenance Programs 5.1

5.1 Introduction 5.1

5.2 Reactive Maintenance 5.2

5.3 Preventive Maintenance 5.3

5.4 Predictive Maintenance 5.4

5.5 Reliability Centered Maintenance..... 5.5

5.6 How to Initiate Reliability Centered Maintenance..... 5.6

5.7 References..... 5.9

Chapter 6 Predictive Maintenance Technologies 6.1

6.1 Introduction 6.1

6.2 Thermography 6.2

6.2.1 Introduction 6.2

6.2.2 Types of Equipment 6.2

6.2.3 System Applications 6.4

6.2.3.1 Electrical System Applications..... 6.4

6.2.3.2 Mechanical System Applications 6.5

6.2.3.3 Roof Thermography 6.8

6.2.4 Equipment Cost/Payback 6.8

6.2.5 Training Availability 6.9

6.2.6 Case Studies 6.9

6.2.7 Resources..... 6.10

6.2.7.1 Infrared Service Companies..... 6.11

6.2.7.2 Infrared Internet Resource Sites 6.11

6.3 Lubricant and Wear Particle Analysis 6.12

6.3.1 Introduction 6.12

6.3.2 Test Types 6.13

6.3.3 Types of Equipment 6.15

6.3.4 System Applications 6.15

6.3.5 Equipment Cost/Payback 6.16

6.3.6 Training Availability 6.16

6.3.7 Case Studies 6.16

6.3.8 References/Resources 6.17

6.3.8.1 Analysis Equipment Resources 6.17

6.3.8.2 Oil Analysis Laboratories..... 6.17

6.3.8.3 Internet Resource Sites 6.18

6.4 Ultrasonic Analysis..... 6.19

6.4.1 Introduction 6.19

6.4.2 Types of Equipment 6.20

6.4.3 System Applications 6.21

6.4.3.1 Pressure/Vacuum Leaks..... 6.21

6.4.3.2 Mechanical Applications..... 6.21

6.4.3.3 Electrical Applications..... 6.22

6.4.4 Equipment Cost/Payback 6.22

6.4.5 Training Availability 6.22

6.4.6 Case Studies 6.23

6.4.7 References/Resources 6.23

6.4.7.1	Equipment Resources	6.23
6.4.7.2	Service Companies.....	6.24
6.4.7.3	Internet Resource Sites	6.24
6.5	Vibration Analysis.....	6.25
6.5.1	Introduction	6.25
6.5.2	Types of Equipment	6.26
6.5.3	System Applications	6.27
6.5.4	Equipment Cost/Payback.....	6.28
6.5.5	Training Availability	6.28
6.5.6	Case Studies	6.28
6.5.7	References/Resources	6.28
6.5.7.1	Training Equipment Resources.....	6.29
6.5.7.2	Service Companies.....	6.29
6.5.7.3	Training/Internet Resource Sites.....	6.29
6.6	Motor Analysis	6.30
6.6.1	Introduction	6.30
6.6.2	Motor Analysis Test.....	6.30
6.6.2.1	Electrical Surge Comparison.....	6.30
6.6.2.2	Motor Current Signature Analysis	6.30
6.6.3	System Applications	6.31
6.6.4	Equipment Cost/Payback.....	6.31
6.6.5	Training Availability	6.31
6.6.6	References/Resources	6.32
6.6.6.1	Equipment Resources	6.32
6.6.6.2	Service Companies.....	6.32
6.6.6.3	Internet Site Resources	6.32
6.7	Performance Trending.....	6.33
6.7.1	Introduction	6.33
6.7.2	How to Establish a Performance Trending Program	6.33
6.7.3	System Applications	6.34
6.7.4	Equipment Cost/Payback.....	6.34
6.7.5	Training Availability	6.34
6.7.6	Case Studies	6.35
6.8	References.....	6.35
Chapter 7 Commissioning Existing Buildings.....		7.1
7.1	Introduction	7.1
7.2	Definitions	7.2
7.3	Typical Findings from Existing Building Commissioning	7.4
7.5	Tracking Commissioning Benefits	7.6
7.6	The Commissioning Process	7.7
7.7	Commissioning Provider Qualifications	7.8
7.8	The Future of Building Commissioning.....	7.8
7.9	Case Studies.....	7.9
7.9.1	System Shutdown During Unoccupied Periods.....	7.9
7.9.2	In-House Recommissioning at a DOE National Laboratory.....	7.10

7.10	Additional Resources	7.12
7.11	References.....	7.12
Chapter 8 Metering for Operations and Maintenance		8.1
8.1	Introduction	8.1
8.2	Importance of Metering and the Business Case.....	8.2
8.3	Metering Applications	8.3
8.4	Metering Approaches.....	8.4
	8.4.1 One-Time/Spot Measurements.....	8.4
	8.4.2 Run-Time Measurements.....	8.5
	8.4.3 Short-Term Measurements/Monitoring	8.5
	8.4.4 Long-Term Measurements/Monitoring	8.6
	8.4.5 The Metering Hierarchy	8.6
8.5	Metering System Components.....	8.7
	8.5.1 Meters.....	8.7
	8.5.2 Data Collection.....	8.8
	8.5.3 Data Storage.....	8.8
	8.5.4 Data Analysis	8.9
8.6	Metering Economics.....	8.9
8.7	Metering Financing Options	8.11
	8.7.1 Metering Financing Hierarchy	8.11
8.8	Steps in Meter Planning.....	8.13
	8.8.1 Establish Program Goals and Objectives	8.13
	8.8.2 Identify Needs to Support Selected Analysis Approaches.....	8.13
	8.8.3 Develop and Apply Evaluation Criteria	8.14
	8.8.4 Implementation, Design, and Installation.....	8.15
	8.8.5 Performance Validation and Persistence.....	8.15
8.9	Case Study – General Services Administration’s Kastenmeier Federal Courthouse	8.15
8.10	References.....	8.18
Chapter 9 O&M Ideas for Major Equipment Types		9.1
9.1	Introduction	9.1
	9.1.1 Lock and Tag.....	9.1
9.2	Boilers	9.3
	9.2.1 Introduction	9.3
	9.2.2.1 Fire-Tube Boilers.....	9.3
	9.2.2.2 Water-Tube Boilers.....	9.3
	9.2.2.3 Electric Boilers	9.4
	9.2.3 Key Components	9.5
	9.2.3.1 Critical Components	9.5
	9.2.3.2 Other Components	9.7
	9.2.4 Safety Issues	9.8
	9.2.5.1 Efficiency, Safety, and Life of the Equipment.....	9.9
	9.2.5.2 Boiler Energy Best Practices.....	9.9
	9.2.5 Cost and Energy/Water Efficiency	9.9
	9.2.5.1 Efficiency, Safety, and Life of the Equipment.....	9.9
	9.2.5.2 Boiler Energy Best Practices.....	9.9

9.2.6	Maintenance of Boilers	9.12
9.2.7	Diagnostic Tools	9.12
9.2.8	Available Software Tools.....	9.13
9.2.9	Relevant Operational/Energy Efficiency Measures.....	9.14
9.2.9.1	Boiler Measure #1: Boiler Loading, Sequencing, Scheduling, and Control.....	9.14
9.2.9.2	Boiler Measure #2: Boiler Combustion Efficiency	9.17
9.2.9.3	Boiler Measure #3: Trending Boiler Stack Temperature.....	9.20
9.2.9.4	Opportunity Identification.....	9.20
9.2.10	Boiler Rules of Thumb	9.24
9.2.10.1	Boiler Water-Use Best Practices	9.25
9.2.11	Case Studies.....	9.26
9.2.12	Boiler Checklist, Sample Boiler Maintenance Log, and Water Quality Test	9.26
9.2.13	References.....	9.32
9.3	Steam Traps.....	9.34
9.3.1	Introduction	9.34
9.3.2	Types of Steam Traps.....	9.34
9.3.2.1	Mechanical Steam Trap.....	9.34
9.3.2.2	Thermostatic Steam Trap	9.35
9.3.2.3	Thermodynamic Steam Traps.....	9.36
9.3.2.4	Other Steam Traps.....	9.37
9.3.3	Safety Issues.....	9.37
9.3.4.1	Other Costs	9.37
9.3.4	Cost and Energy Efficiency	9.37
9.3.5	Maintenance of Steam Traps.....	9.39
9.3.5.1	Characteristics of Steam Trap Failure	9.39
9.3.6	Performance Assessment.....	9.41
9.3.7	Diagnostic Equipment.....	9.43
9.3.8	Relevant Operational/Energy Efficiency Measures.....	9.43
9.3.8.1	Steam Trap Water-Use Best Practices.....	9.45
9.3.9	Case Studies	9.45
9.3.10	Steam Traps Checklist	9.47
9.3.11	References.....	9.47
9.4	Chillers	9.48
9.4.1	Introduction	9.48
9.4.2	Types of Chillers	9.48
9.4.2.1	Mechanical Compression Chiller	9.48
9.4.2.2	Absorption Chiller.....	9.49
9.4.3	Key Components.....	9.49
9.4.3.1	Mechanical Compression Chillers.....	9.49
9.4.3.2	Absorption Chiller.....	9.49
9.4.4	Safety Issues.....	9.50
9.4.5	Cost and Energy Efficiency.....	9.50
9.4.6	Maintenance of Chillers.....	9.50
9.4.7	Diagnostic Tools	9.52
9.4.8	Available Software Tool.....	9.52
9.4.9	Relevant Operational/Energy Efficiency Measures	9.53
9.4.9.1	Chiller Water-Use Best Practices	9.57
9.4.10	Chillers Checklist.....	9.57
9.4.11	Sample Chiller Operation Log	9.59

9.4.12	References.....	9.60
9.5	Cooling Towers	9.61
9.5.1	Introduction	9.61
9.5.2	Types of Cooling Towers.....	9.61
9.5.3	Key Components	9.62
9.5.4	Safety Issues	9.62
9.5.5	Cost and Energy Efficiency.....	9.63
9.5.6	Maintenance of Cooling Towers.....	9.63
9.5.7	Common Causes of Cooling Towers Poor Performance.....	9.64
9.5.8	Diagnostic Tools.....	9.64
9.5.8.1	Cooling Tower Water-Use Best Practices	9.64
9.5.8.2	Operations and Maintenance Opportunities	9.66
9.5.8.3	Retrofit Opportunities	9.67
9.5.9	Cooling Towers Checklist.....	9.68
9.5.10	References.....	9.69
9.6	Energy Management/Building Automation Systems	9.70
9.6.1	Introduction	9.70
9.6.2	System Types	9.70
9.6.3	Key Components	9.71
9.6.4	Safety Issues	9.71
9.6.5	Cost and Efficiency	9.71
9.6.6	Maintenance.....	9.71
9.6.7	Diagnostic Equipment	9.72
9.6.8	Relevant Operational/Energy Efficiency Measures	9.72
9.6.9	Case Studies.....	9.77
9.6.10	Building Controls Checklist.....	9.80
9.6.11	References.....	9.81
9.7	Air Handling Systems	9.82
9.7.1	Introduction	9.82
9.7.2	Types of Air Handling Systems.....	9.82
9.7.3	Key Components	9.82
9.7.4	Cost and Energy Efficiency.....	9.82
9.7.5	Maintenance	9.83
9.7.5.1	Diagnostic Tools	9.83
9.7.5.2	Case Study	9.83
9.7.6	Air Handling System Checklists.....	9.84
9.7.7	References.....	9.86
9.8	Fans	9.87
9.8.1	Introduction	9.87
9.8.2	Types of Fans.....	9.87
9.8.2.1	Axial Fan.....	9.87
9.8.2.2	Centrifugal Fans	9.88
9.8.3	Key Components	9.89
9.8.4	Safety Issues.....	9.89
9.8.5	Cost and Energy Efficiency.....	9.89
9.8.6	Maintenance of Fans	9.89
9.8.7	Diagnostic Tools.....	9.90
9.8.8	Available Software Tools	9.90

9.8.9	Relevant Operational/Energy Efficiency Measures	9.91
9.8.10	Case Studies.....	9.93
9.8.11	Fans Checklist	9.94
9.8.12	References.....	9.95
9.9	Pumps	9.96
9.9.1	Introduction	9.96
9.9.2	Types of Pumps.....	9.97
9.9.2.1	Dynamic Pump (Centrifugal Pump)	9.97
9.9.2.2	Positive Displacement Pump	9.97
9.9.3	Key Components.....	9.98
9.9.3.1	Centrifugal Pump	9.98
9.9.3.2	Positive Displacement Pumps	9.98
9.9.4	Safety Issues.....	9.99
9.9.5	Cost and Energy Efficiency	9.100
9.9.6	Maintenance of Pumps.....	9.100
9.9.7	Diagnostic Tools	9.101
9.9.8	Available Software Tools.....	9.102
9.9.9	Relevant Operational/Energy Efficiency Measures	9.102
9.9.9.1	Pump System Water-Use Best Practices	9.105
9.9.10	Case Study.....	9.105
9.9.11	Pumps Checklist	9.107
9.9.12	References.....	9.108
9.10	Motors	9.109
9.10.1	Introduction	9.109
9.10.2	Types of Motors	9.109
9.10.2.1	DC Motors	9.109
9.10.2.2	AC Motors.....	9.110
9.10.3	Key Components.....	9.110
9.10.3.1	DC Motor	9.110
9.10.3.2	AC Motor.....	9.111
9.10.4	Safety Issues.....	9.112
9.10.5	Cost and Energy Efficiency	9.112
9.10.6	Maintenance of Motors.....	9.113
9.10.7	Diagnostic Equipment	9.114
9.10.8	Available Software Tools	9.114
9.10.9	Relevant Operational/Energy Efficient Measures	9.115
9.10.10	Electric Motors Checklist.....	9.118
9.10.11	References.....	9.119
9.11	Air Compressors	9.120
9.11.1	Introduction	9.120
9.11.2	Types of Air Compressors.....	9.120
9.11.2.1	Positive Displacement.....	9.120
9.11.2.2	Centrifugal Compressor	9.121
9.11.3	Key Components.....	9.121
9.11.4	Safety Issues.....	9.122
9.11.4.1	General Safety Requirements for Compressed Air.....	9.122
9.11.5	Cost and Energy Efficiency	9.123
9.11.5.1	Identify the Electrical Cost of Compressed Air.....	9.123

9.11.5.2	Waste Heat Recovered from Compressors can be Used for Heating.....	9.124
9.11.5.3	Use of Flow Controllers	9.125
9.11.5.4	Importance of Maintenance to Energy Savings.....	9.125
9.11.5.5	Leak Evaluation Procedure	9.125
9.11.6	Maintenance of Air Compressors.....	9.126
9.11.6.1	General Requirements for a Safe and Efficient Air Compressor	9.126
9.11.7	Diagnostic Tools.....	9.128
9.11.8	Available Software Tools	9.128
9.11.9	Relevant Operational/Energy Efficiency Measures	9.129
9.11.9.1	Air Compressor Water-Use Best Practices.....	9.129
9.11.10	Case Study	9.131
9.11.11	Air Compressors Checklist.....	9.132
9.11.12	References.....	9.133
9.12	Lighting.....	9.135
9.12.1	Introduction	9.135
9.12.2	Systems and Components	9.135
9.12.2.1	Light Sources	9.135
9.12.2.2	Ballasts, Transformers, and Power Packs.....	9.138
9.12.2.3	Luminaire Housing	9.139
9.12.2.4	Lighting Control Devices	9.140
9.12.3	Safety Issues	9.146
9.12.3.1	Electrical and Equipment Safety	9.146
9.12.3.2	Hazardous Materials Handling	9.147
9.12.4	Energy Efficiency, Savings, and Cost	9.148
9.12.4.1	Planned versus Reactive Maintenance.....	9.148
9.12.4.2	Response to Complaints	9.150
9.12.4.3	Retrofit versus Redesign.....	9.150
9.12.4.4	Energy Codes	9.153
9.12.5	Maintenance Procedures	9.153
9.12.5.1	Commissioning	9.153
9.12.5.2	Common Causes of Poor Performance.....	9.154
9.12.5.3	Cleaning.....	9.154
9.12.5.4	Lamp and Ballast Troubleshooting.....	9.155
9.12.5.5	Lighting Controls Calibration and Troubleshooting.....	9.156
9.12.5.6	Diagnostic Tools	9.157
9.12.5.7	Economics.....	9.159
9.12.6	Lighting Checklist.....	9.160
9.12.7	References.....	9.161
Chapter 10	O&M Frontiers.....	10.1
10.1	ACRx Handtool/Honeywell HVAC Service Assistant	10.1
10.2	Decision Support for O&M.....	10.2
10.3	ENFORMA® Portable Diagnostic Solutions.....	10.2
10.4	Performance and Continuous Re-Commissioning Analysis Tool.....	10.3
10.5	Energy Expert	10.4
10.6	Reference	10.4
Chapter 11	Ten Steps to Operational Efficiency	11.1

Appendix A – Glossary of Common Terms A.1

Appendix B – FEMP Contact List..... B.1

Appendix C – Resources for Energy and Facilities Professionals..... C.1

Appendix D – Suggestions for Additions or Revisions D.1

Figures

2.4.1 Effect of adequate and timely maintenance and repairs on the service life 2.5

5.1.1 Component failure rate over time for component population 5.1

6.2.1 Typical IR spot thermometer 6.2

6.2.3 Temperature is used in defining belt problems..... 6.3

6.2.2 Internal house wall..... 6.4

6.2.4 Air breaker problem 6.5

6.2.5 Overloaded contacts show different temperature profiles indicating one contact seeing much greater load, a potentially unsafe situation. 6.5

6.2.6 IR scans of multiple electric motors can highlight those with hot bearings indicating an imbalance or wear problem. 6.6

6.2.7 Possible gearbox problem indicated by white area defined by arrow..... 6.6

6.2.8 Seized conveyer belt roller as indicated by elevated temperatures in belt/roller..... 6.6

6.2.9 Inoperable steam heaters seen by cooler blue areas when compared to the operating heaters warmer red or orange colors. 6.6

6.2.11 When trended, IR scans of single bearings provide a useful indicator of wear and eventual need for replacement..... 6.7

6.2.10 IR scans of boiler can highlight those areas where the refractory has broken down leading to costly heat loss..... 6.7

6.2.12 Steam or hot water distribution system leaks and/or underground line location can be defined with IR. 6.7

6.5.1 Vibration severity chart 6.25

6.5.2 FFT – Example of graph breaking down vibration level at different frequencies 6.26

6.5.3 Typical vibration transducers 6.26

6.7.1 Boiler Cycling Frequency Data 6.37

7.4.1 Construction Phase CX costs..... 7.5

7.9.1 Whole-building electricity use before and after night shutdown program..... 7.10

7.9.2 PNNL EMSL building energy performance by fiscal year 7.11

8.1.1 Typical utility socket-type meter..... 8.1

8.4.1 Electric metering hierarchy..... 8.7

8.5.1 Typical electrical sub panel used in long-term monitoring 8.8

8.7.1 The metering financing hierarchy 8.12

8.8.1 Development process for meter system planning 8.14

8.9.1	Installed wireless monitoring system for WBE-based system.....	8.17
8.9.2	Sample screen capture for a generic building showing an alarm or high-energy using condition.....	8.18
8.9.3	Data from the monitoring device provides a comparison of 2 days of electricity.....	8.18
9.1.1	Typical folding lock and tag scissor clamp	9.2
9.2.1	Horizontal return fire-tube boiler.....	9.3
9.2.3	Electric boiler	9.4
9.2.2	Longitudinal-drum water-tube boiler.....	9.4
9.2.4	Adapted from 1999 National Board of Boiler and Pressure Vessel Inspectors incident report summary.	9.8
9.2.5	Effect of fouling on water side.....	9.9
9.2.6	Combustion analyzer.....	9.18
9.2.7	Example locations – combustion analysis.....	9.18
9.2.8	Boiler tube – scale deposit.....	9.21
9.2.9	Boiler tube – failure (rupture).....	9.21
9.2.10	Feed-water pipe – oxygen pitting.....	9.22
9.2.12	Condensate pipe – oxygen pitting	9.22
9.2.14	Boiler energy losses versus scale thickness.....	9.22
9.2.11	Boiler tube – failure (rupture).....	9.22
9.2.13	Condensate pipe – acidic corrosion.....	9.22
9.3.1	Inverted bucket steam trap	9.34
9.3.2	Bimetallic steam trap	9.35
9.3.3	Bellows steam trap.....	9.35
9.3.5	Disc steam trap.....	9.36
9.3.4	Float and thermostatic steam trap	9.36
9.3.6	Energy loss from leaking steam traps.....	9.38
9.3.7	Live steam (left) versus flash steam (right).....	9.41
9.3.8	Failed gasket on blind flange.....	9.45
9.4.1	Typical chiller plant	9.48
9.5.2	Direct or open cooling tower	9.61
9.5.1	Cooling tower.....	9.61
9.6.1	General Services Administration’s Custom House, Philadelphia, PA.....	9.77
9.7.1	Cooling coil requiring cleaning	9.84
9.7.2	Damper quick fix – not recommended.....	9.84
9.8.1	Propeller direct-drive fan (front and rear view).	9.84
9.8.2	Propeller belt-drive fan (front and rear view).	9.87
9.8.3	Tube-axial fan.....	9.87
9.8.4	Vane axial fan.....	9.88
9.8.5	Centrifugal fan	9.88
9.9.1	Technology tree for pumps.....	9.88
9.9.2	Rotary lobe pump	9.96
9.9.3	Positive displacement pumps.	9.97
9.9.4	Centrifugal pump.	9.98
9.9.5	Schematic of pump and relief valve.....	9.99
9.9.7	Retrofit cost savings (\$5,800 annually).	9.106
9.9.6	Pump system energy use and savings.....	9.106

9.10.1 DC motor.....	9.109
9.10.2 AC motor.....	9.110
9.10.3 Parts of a direct current motor.....	9.111
9.10.4 Parts of an alternating current motor.....	9.111
9.11.1 Rotary screw compressor.....	9.120
9.11.2. Typical single acting two-stage compressor.....	9.121
9.11.3 Helical-lobe rotors.....	9.122
9.12.1 Fluorescent lamp/ballast efficacy.....	9.138
9.12.2 Wall-box occupancy sensor uses hidden internal dip-switches to set manual-on, auto-off.....	9.141
9.12.3 Photosensor and fluorescent dimming ballast for continuous daylight dimming.....	9.145
9.12.4 Repair and rewiring must be done by a licensed electrician.....	9.146
9.12.5 Fluorescent lamp mortality curve.....	9.149
9.12.6 Lighting uniformity and fixture spacing criteria.....	9.151
9.12.8 Calibrations for controls.....	9.156
9.12.7 Ceiling occupancy sensor.....	9.157

Tables

3.1.1 Industry O&M metrics and benchmarks.....	3.5
3.2.2 Overview of key O&M issues, timing, and supporting documents.....	3.13
5.5.1 Reliability centered maintenance element applications.....	5.6
6.1.1 Common predictive technology applications.....	6.1
7.1.1 Commissioning type consideration by facility condition.....	7.1
9.2.1 Boiler cycling energy loss.....	9.14
9.2.2 Optimum excess air.....	9.17
9.2.3 Recommended limits for boiler-water concentrations.....	9.21
9.3.1 Steam trap discharge rate.....	9.43
9.6.1 Custom House demand reduction and savings 2005-2006.....	9.79
9.8.1 Fan-flow control comparison.....	9.92
9.11.4 Steam trap discharge rate.....	9.129
9.11.5 Compressed air leaks – cost per year assuming \$0.05/kWh.....	9.131

EERE Information Center
1-877-EERE-INF (1-877-337-3463)
www.eere.energy.gov/informationcenter

U.S. DEPARTMENT OF
ENERGY | Energy Efficiency &
Renewable Energy

PNNL-19634 • August 2010

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.

