Persistence of O&M Energy-Efficiency Measures

Energy Trust of Oregon

Date: October 19, 2017

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1 EXECUTIVE SUMMARY

1.1 Background

Energy Trust of Oregon's (Energy Trust) Production Efficiency (PE) and Building Efficiency (BE) programs provide incentives for a variety of measures that are based on participating industrial customers' behavioral changes. Custom operations and maintenance (O&M) and Strategic Energy Management (SEM) O&M actions are Energy Trust's primary nonresidential offerings with behavioral components. Because there is little documentation on the persistence of savings from O&M, Energy Trust currently assumes that the savings persist for an average of three years after intervention.

Measure lifetime has a tremendous impact on the cost effectiveness of these measures: being off by one year in either direction may have a large impact and could influence Energy Trust's investment decisions. For these reasons, Energy Trust hired DNV GL to perform focused research into the persistence of O&M savings to obtain a more accurate estimate of measure lifetimes. This document represents the final deliverable for that research effort.

1.2 Research goal and objectives

The primary goal of the industrial O&M persistence research is to provide better estimates of measure lifetimes for these behavioral measures. Research objectives include:

- Obtain common definitions of the types of behavioral O&M actions and categorize them by end use (e.g., boiler, compressed air, etc.)
- Determine which behavioral O&M actions are the most prevalent and are responsible for the bulk of ex ante savings
- Obtain estimates of measure lifetime for specific actions based on a literature review
- Identify specific actions that have limited supporting documentation on their persistence that would warrant further research

1.3 Research approach

DNV GL conducted a detailed literature review and analysis to characterize the types of O&M measures and associated energy saving actions to identify the types of measures or actions that have reasonable persistence. We selected a list of 68 common measures for this study and included the following measure groups: heating, ventilation and air conditioning (HVAC); compressed air and compressed air programs, waste water treatment plant (WWTP) aeration blowers, boilers, steam traps, chillers and cooling towers, air abatement, process ovens, lighting, refrigerated spaces, and refrigeration warehouses.

For each measure, we reviewed the available literature to identify existing estimates and support development of new estimates of savings persistence. Because little data is available on persistence, the team developed a method to assess persistence in the absence of literature values, categorizing measure as follows:

- Low persistence - impacted by human control and control strategies (1 year)
- Mid-range persistence - changes to measure are possible but changes usually planned (2 years)
- Highest persistence - generally more difficult to change or revert back to inefficient condition (3 years)

We assigned a persistence period to each measure based on the literature review and the above categorization approach. Additionally, we assigned estimates of relative savings of high, medium, and low based on the identified savings from literature. We provide detailed tables with information about each measure (see Appendix A-M).

1.4 Findings and Conclusions

Our research validates Energy Trust's current assumption of a 3-year average for persistence of O&M measures. Of the 68 measures we reviewed, we assessed that more than half had 3-year persistence or greater (59%).

The measures generally fell into two categories: maintenance (repairs, cleaning, routine checks) and controls (adjusting and optimizing schedules, set points, and control schedules). Repairs have a high persistence; maintenance cleaning and checking is a repetitive activity. Persistence of controls and optimization measures are dependent on the potential for the controls to be revised or overridden, reducing the efficiency gains.

Energy Trust can use the results of this research effort as a basis for prioritizing inclusion of O&M measures. For example, measures related to control strategies for equipment sequencing, staging and loading, have both high savings and high persistence. Other high savings measures include reducing air compressor loading, boiler combustion controls, compressed air annual maintenance program, and HVAC equipment scheduling. The research also provides a convenient summary of measure issues and a robust reference list.

Energy Trust of Oregon

MEMO

Date: June 26, 2018
To: Board of Directors
From: Lindsey Diercksen, Senior Program Manager, Industry & Agriculture
Phil Degens, Evaluation Manager
Subject: Staff Response to the Persistence of O&M Energy-Efficiency Measures Study

The study helps validate the use of a three-year measure life that is being used for industrial and commercial operation and maintenance (O&M) energy-efficiency measures. The study identified that the lifetime of O&M measures has not been researched in a comprehensive manner and that there is little actual field data available on this topic.

O&M measure life could benefit from additional research. A recent study by Puget Sound Energy of its Industrial Systems Optimization Program found that 97 percent of O&M actions were still in place six to 30 months after being implemented. These findings provide further indication that Energy Trust's use of a three-year measure life is conservative, and might be too low. Energy Trust is in the process of commissioning a study to look at the long-term retention of industrial O&M measures, with results of the study expected to be available in 2019.

2 INTRODUCTION

Energy Trust of Oregon provides incentives for measures that are based on behavioral changes in the industrial sector, including O&M measures for their Production Efficiency program. For O&M measures, Energy Trust has assumed an average 3-year lifetime. The measure lifetime determines the cost-effectiveness, which in turn can influence business decisions regarding investments for the programs. Focused research on measure persistence allows a more accurate assessment of measure lifetimes.

2.1 Overview

Currently, there is little documentation on the persistence of O&M savings to support measure life claims for Strategic Energy Management (SEM) and O&M Programs.

To address the need for information on persistence, Energy Trust contracted DNV GL to conduct research to characterize the types of O&M measures and energy saving actions implemented through commercial and industrial programs at Energy Trust, and define the types of measures or actions that have reasonable persistence and can be claimed through the program. This document is designed to:

- Ascertain the what the current practices are for estimating measure lives (persistence) of O&M measures
- Identify the typical value of the energy savings claims
- Determine the program or other aspects that drive or support the measure life

For O&M measures, Energy Trust has assumed an average 3-year lifetime (where average means half the measures persist more and half less than the average of 3 years).

The research objectives of the evaluation are as follows:

- Obtain common definitions of what actions are defined as behavioral for O&M and categorize them (e.g. boiler, compressed air, etc.)
- Determine which behavioral O&M actions are the most prevalent and are responsible for the bulk of the ex ante savings
- Obtain estimates based on a literature review of the measure lifetime of specific actions
- Identify any specific actions that would warrant further research

This study focused on measures that could be performed on equipment in place and currently operating at a facility, where a change in behavior, maintenance or operations could improve efficiency. Typical measures included optimizing and adjusting operational schedules, equipment set points, and control settings; cleaning equipment components to minimize clogging and improve flow, changing filters, and repairing leaks. It did not consider measures that would require new equipment or control systems, such as re-sizing to improve efficiency.

2.2 Organization of this Report

We have organized the remainder of this report as follows:

- Section 3 provides an overview of our approach to developing the industrial O&M measure persistence workbook
- Section 4 provides a high-level summary of key findings from the research and reviews DNV GL's recommendations regarding which end-uses and/or measures Energy Trust should consider for further efforts to improve persistence estimates

- Section 5 provides the complete list of references we consulted in support of this research.
- Following section 5 are a series of appendices. Appendix A lists the individual measures in order of persistence. Appendices B through M provide key tables from the industrial O&M measure persistence workbook and example standard operating procedures (SOP) for the measure group. We provide one appendix per measure group.

3 APPROACH

The primary approach to this research began with developing a list of measures and then conducting literature research related to persistence and energy savings for each measure. We developed the initial list of measures based on three sources: common O&M measures in the Production Efficiency program measures, DNV GL experience, and the appearance of measures in Technical Reference Manuals (TRM) and other references from the Northwest and other regions. The following end use measure groups are included: HVAC, compressed air and compressed air programs, waste water treatment plant aeration blowers, boilers, steam traps, chillers and cooling towers, air abatement, process ovens, lighting, refrigerated spaces, and refrigeration warehouses.

The literature review focused on published sources, with a preference for independent organizations such as government and utility or regional energy efficiency organizations, rather than trade literature. In addition to published reports and guidance, we included information from case studies, fact sheets, and blogs from technical experts. We also identified example standard operating procedures (SOP) to better assess appropriate maintenance practices. SOPs at industrial facilities describe required actions for facility and equipment operations staff. Although often site-specific, SOPs provide guidance that is applicable to energy efficiency measures and publicly available examples from vendors and public agencies were obtained. The SOPs that were obtained provide useful reference material for developing or adding to site-specific SOPs. They also can be used as a guide for future evaluation. These are provided in the appendices in their entirety.

We reviewed the preliminary list of measures with Energy Trust staff and refined it to focus the research on measures common in Energy Trust projects. The list is consistent with common O&M measures observed in energy efficiency programs around the country. Although our research focused on industrial measures, many are applicable to commercial buildings as well. We selected a total of 68 measures and organized them into tables by measure group. Each table includes data regarding average persistence (in years), risk to persistence, cost, and maintenance needs. A list of all the measures is provided in Appendix A.

In the first phase of research, DNV GL observed that little information was available in the literature regarding persistence of O&M measures. We found numerous documents referencing best practices, case studies, guidelines for effective maintenance and equipment upkeep as well as example standard operating procedures (SOPs). However, few studies tracked long-term performance and persistence of O&M measures. The few that did look at longitudinal persistence were not focused on the industrial sector.

Because of this lack of information, DNV GL developed an approach to assessing persistence in the absence of relevant literature. We categorized measures as follows:

- Low persistence - impacted by human control and control strategies (1 year)
- Mid-range persistence – changes to measure are possible but changes usually planned (2 years)
- Highest persistence - generally more difficult to change or revert back to inefficient condition (3 years)

DNV GL assessed persistence based on these measure categories where there was not a literature source for persistence. Where a literature source was available and suggested more than 3 years, we assigned measures to “3+” years. Observed ranges in literature are identified in the tables (Appendices B through M).

We organized the information into tables and collected information regarding the measure group, the measure itself, and maintenance attention needed. DNV GL identified risks to persistence and factors that could result in lower persistence, such as whether set points or controls were easy to override. We also included required actions to protect persistence, such as maintaining records of maintenance actions and enforcing SOPs.

Savings information—often rules of thumb or percent improvement—provide an indication of the significance of savings, depending on equipment size. DNV GL attempted to get average savings, when multiple references are available. Many values in the literature are case studies. However, there was sufficient information to indicate which measures are most significant in terms of savings. Based on the research, we assigned each measure a high, medium, and low savings-level. This takes into account commonly observed sizes of equipment for these measures. For example, Wastewater Treatment Plant (WWTP) aeration blowers are typically over 200 hp; a small percent improvement yields more significant savings than a measure for a 20 hp pump. Actual savings will depend on the unique equipment and operational characteristics at a specific installation.

Table 1 lists the fields in each table, along with an explanation and an example. Appendices B through M provide the completed persistence tables.

Table 1. Explanation of fields and sources in the persistence tables

Field in Each Measure Group Table*	Example Field inputs, from HVAC Measure Group	Explanation of Field	Data Sources for Field
End Use	All HVAC systems – rooftop units (RTUs), air handlers, split systems	Describes the equipment where the measure occurs. Left out in the table if the same as the caption title	Energy Trust and DNV GL experience, TRMs, other references
Measure name	Equipment scheduling	Name of the identified measure	Energy Trust and DNV GL experience, TRMs, literature
Expanded Measure Includes	Occupied/ unoccupied scheduling	Provides additional explanation of the measure; this field not required for all measure groups.	Energy Trust and DNV GL experience; TRMs, literature
Persistence	1-year	Estimated persistence.	Source as identified, or categorized from 1 to 3 years based on the estimated ease of converting to the inefficient condition. Also, based on literature review.
Risks To Persistence	Schedule changes to made to conform with actual occupancy. No warnings to EMS indicating HVAC equipment is in manual [override] mode.	Lists factors that have the potential to limit persistence. For example, if warnings indicate when the equipment is in override mode, there is less likelihood that an operator will change the setting and eliminate the savings	Based on literature review
Required Task To Obtain Persistence	Schedule operation according to occupancy	This identifies actions necessary for the measure to continue operating.	Based on references in the bibliography and SOPs

Field in Each Measure Group Table*	Example Field inputs, from HVAC Measure Group	Explanation of Field	Data Sources for Field
Maintenance Requirements	Change times/schedules as needed	Maintenance requirements to keep the measure functional; in the example maintenance is needed to make updates if schedules shift	Standard operating procedures, researched documents such as reports and vendor information
Implementation Cost	Variable on size of facility. Generally fixed plus T&M	Cost identified as low, medium, or high, or variable depending on size of facility	Based on literature review
Average savings (%)	10% - 20% (Building efficiency initiative 2011; Murphy, ASHRAE 2009)	Savings as a percent of the consumption of the equipment or other metrics as described	References are provided
Primary Variables	Total connected kW load and occupancy schedules	Lists key variables for assessing savings	Identified from literature and DNV GL experience
Savings and Cost Verification Ability	Very good. Easy process to track changes made to occupied/unoccupied schedules.	Identifies ease or difficulty of verifying savings and costs	Assessed based on the ease of finding information and performing savings analysis

* Note that there is also an optional comment field in some tables.

4 SUMMARY OF FINDINGS AND RECOMMENDATIONS

This section includes highlights of the research results.

4.1 Key findings

Of the 68 measures reviewed, we assessed that more than half had 3 or more years of persistence (59%). This validates Energy Trust's use of 3 years' persistence for O&M measures as appropriate for SEM and O&M programs. Table 2 shows the number of years of persistence for the measures in each measure group. Appendix A provides a detailed list of the measures organized by persistence and measure group.

Table 2. Quantity of measures in each measure group by persistence (in years)

Measure Group	Persistence (years)				Total Measures
	1	2	3	> 3	
Air abatement	1	2	3	0	6
Air compressor	0	1	0	4	5
Boiler	1	2	2	2	7
HVAC	3	2	1	1	7
Lighting	1	0	1	4	6
Process oven	2	2	0	3	7
Refrigerated spaces	0	1	0	2	3
Refrigerated warehouses	0	0	0	7	7
Steam	0	0	0	1	1
Wastewater treatment plant (WWTP)	2	1	0	4	7
Compressed air leak repair program	1	0	0	1	2
Chiller systems	2	4	4	0	10
Total Measures	**13**	**15**	**11**	**29**	**68**

In a recently completed evaluation of an O&M program (DNV GL 2017b), the verification of completed measures was over 95%, despite there being 6 months to 2.5 years between the evaluation and the completion of program years. Although less than 3 years had elapsed, the level of continuity suggests that the measure persistence was more than 3 years. This further supports the use of 3 years or greater persistence for behavior based programs.

Our detailed review of the measures suggested that there are two typical broad measure types: maintenance measures and controls measures. These can be further categorized into activities such as adjustment/optimization, controls, cleaning, maintenance, and repairs (or new parts) as shown in Table 3. Our research suggests that the most prevalent measure type involves control systems (over 60%). These measures can be further characterized in terms of either maintenance of the controls or adjustment/optimization of the controls. Cleaning, routine maintenance (outside of controls), and repairs account for nearly 40% of the measures.

Table 3. Description of measures

Measure Activity	Description	Example	Total Measures	Percent of Total
Adjustment/optimization	Adjust schedules, sequencing, staging, controls, valves for efficiency	Sequencing blowers for load at a WWTP	22	32%
Controls	Control maintenance, set point adjustments	Maintain chiller controls	20	12%
Cleaning	Removing debris, scale, dirt, and eliminating blockages in equipment and transfer systems	Boiler tube cleaning	8	29%
Maintenance	Regular service to maintain operation as designed	Compressed air leak repair program	7	10%
Repair/new parts	Repairing leaks in hoses, pipes, and fittings; repairing seals and insulation, upgrading lights	Insulation repair	11	16%
Total			**68**	**100%**

When we consider the persistence of measures in each of these categories (Table 4), we find that maintenance and cleaning measures tend to be more short term, while repairs are expected to persist beyond 3 years. The controls measures—whether optimizing the existing system or maintaining it with minor adjustments—vary in persistence based on the potential for humans to override the adjustments. Table 4, which shows the persistence of the different categories, provides additional insight into the type of measures that have the most persistence. Straightforward repairs to leaks, nozzles, valves, and equipment have high persistence. Controls and optimization measures range in persistence, depending on the potential for the controls to be revised to the detriment of the efficiency. Maintenance and cleaning needs to be performed at regular intervals; the measures identified need attention at three years or less.

Table 4. Persistence by measure activity

Measure Activity	Persistence (years)				Total Measures
	1	2	3	> 3	
Adjustment/optimization	4	7	3	8	22
Controls	2	7	1	10	20
Cleaning	4	0	4	0	8
Maintenance	3	1	3	0	7
Repair/ new parts	0	0	0	11	11
Total	**13**	**15**	**11**	**29**	**68**

The combination of savings and persistence suggests which measures to prioritize. For example, the longest persistence and highest savings measures include:

- Air compressor leak repair, both as an individual measure and as a leak repair program
- Repairs to minimize open blowing of compressed air
- On/off and load control strategies for air compressors
- Boiler controls
- Compressor controls and compressor staging at refrigerated warehouses
- At wastewater treatment plants, sequencing and staging blowers for proper load
- Replacing incandescent light bulbs

4.2 Recommendations

Based on the research, DNV GL recommends the following:

- **Update research on existing measures with high savings.** Perform limited updates strategically, focusing on potentially high savings measures. Additional methods to quickly quantify savings would support identification of measures in program audits and training. Similarly, confirming persistence supports Energy Trust's investment decisions.

- **Collect additional data during programs to confirm or update research.** DNV GL recommends tracking the completed measures as an indication of persistence and savings value. Specifically, Energy Trust programs could develop and compile site-specific lists of measures identified, completed, and subsequently checked/confirmed operational. Maintaining the documentation over several years would allow confirmation of persistence in the field. Energy Trust could track performance over time with current and past participants. This could include a comparison of persistence of the measure with activities such as logging routine maintenance, repairs, system changes, and calibrations. This would demonstrate persistence by the program.

- **Research additional measures.** Although this list addresses many common measures, many more O&M opportunities exist. Expanding the list of measures can guide program implementers to high priority measures and increase savings.

- **Address risk to persistence programmatically.** Persistence can improve when procedures and controls minimize the potential for behavior that reduces energy efficiency. For example, the program can encourage the codification of controls strategies and maintenance practices in SOPs and observed work practices, or by making it physically difficult to make changes through locks, permission requirements, and hard-wired solutions. We recommend Energy Trust develop procedures and actions to improve persistence, using the detailed results of the research.

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APPENDIX A. PERSISTENCE OF REVIEWED MEASURES

Table 5. Persistence and relative savings value of individual measures reviewed

Persistence (years)	Measure Group	Measure	Savings ranking
1	Air abatement	High-efficiency filters	L
	Boiler	Combustion controls	H
	Chiller systems	Clear clogged spray nozzles	L
		Improve air flow	L
	Compressed Air Leak Repair Program	Compressed air annual maintenance program	H
	HVAC	Condenser coil cleaning	M
		Economizer repair	L
		Equipment scheduling	H
	Lighting	Occupancy Sensor Controls (Wall Switch)	M
	Process Oven	Shutdown scheduling	M
		Temperature reduction	H
	WWTP	Aeration diffuser maintenance to maintain proper flow	M
		Eliminate flow restrictions to maintain proper flow	M
2	Air abatement	Run-time reduction	M
		Set minimal idle speed or off times	M
	Air compressor	Reduce operating pressure (PSI)	H
	Boiler	Maintain boiler blowdown controls	L
		Multiple boiler controls	H
	Chiller systems	Condenser water set-point control maintenance	L
		Maintain chiller controls	M
		Maintain VFD operation	L
		Wet bulb approach control	M
	HVAC	Economizer repair	L

Persistence (years)	Measure Group	Measure	Savings ranking
		Maintain temp controls	M
	Process Oven	Burner tuning	M
		Lower Explosive Limit (LEL) Monitor	L
	Refrigerated Spaces	Defrost Scheduling	M
	WWTP	Check placement of Dissolved Oxygen probe	H
3	Air abatement	Duct gate and valve adjustment	L
		Optimize cleaning strategy	L
		Zone isolation	L
	Boiler	Boiler Controls	H
		Tube cleaning	M
	Chiller systems	Keep oil from refrigerant	L
		Purge air from condenser	M
		Reducing scale or fouling	L
		Remove scale deposits	M
	HVAC	Maintain refrigerant Charge	L
	Lighting	Incorporate lighting into centralized building control	M
3+	Air compressor	Leak repair	H
		Maintain zone Isolation	M
		Minimize open blowing; install engineered nozzles and air-solenoid valves.	H
		On/off and load control strategies. Compressor sequencing.	H
	Boiler	Insulation adjustment/repair	M
		Optimize condensate system operation	M
	Compressed Air Leak Repair Program	Compressed Air Leak Repair Program	H
	HVAC	Economizer repair	L
	Lighting	De-lamp	M
		Lighting Controls - Ceiling sensors, high bay sensors, EMS/digital controls.	M

Persistence (years)	Measure Group	Measure	Savings ranking
		Replace Incandescent bulbs	H
		Use lower wattage lamps	M
	Process Oven	Insulation adjustment/repair	M
		Product pre-conditioning	M
		Seal Oven Openings	L
	Refrigerated Spaces	Evaporator Fans Controls	M
		Repair Door seals	M
	Refrigerated warehouses	Compressor staging	H

APPENDIX B. HVAC MEASURES

HVAC O&M includes maintaining refrigerant charge, coil cleaning, and temperature control for all systems. Control O&M applies to multiple air-handling units. Economizer O&M applies to air-handlers and rooftop units that provide heating and cooling with outside air ventilation.

Table 6. Persistence of HVAC system measures

End Use	Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maint. Require-ments	Implement-ation Cost	Average savings (%)	Primary Variables	Applicable Equipment	Savings and Cost Verification Ability
All HVAC systems – rooftop units (RTUs), air handlers, and split systems	Equipment scheduling	Occupied unoccupied scheduling	1 year	Schedule changes to made to conform with actual occupancy. No warnings to energy-management system (EMS) indicating HVAC equipment is in manual (override) mode.	Schedule operation according to occupancy	Change times/schedules as needed	Variable on size of facility. Generally fixed plus time and materials	10% - 20% (Building efficiency initiative 2011; Murphy, ASHRAE 2009)	Total connected kW load and occupancy schedules	Any HVAC unit where an occupied unoccupied schedule can be implemented through a setback thermostat or EMS control	Very good. Easy process to track changes made to occupied/unoccupied schedules.

End Use	Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maint. Require-ments	Implement-ation Cost	Average savings (%)	Primary Variables	Applicable Equipment	Savings and Cost Verification Ability
HVAC condensing units	Condenser coil cleaning	Removing dirt, dust, and debris from exchanger surfaces.	1 year	Debris and blockages build up from lack of routine inspection. Inspection schedule frequency determined by environment.	Visual observation	Annual service	Variable on size of facility. Generally fixed plus time and materials	CA 2017 study (DNV GL) found 51 kW/ton averaged across modeled building types and all CA climate zones based on modeling a 4.6% change in EIR, 1.1% change in cooling capacity, and 1% change in sizing ratio. Estimated 0.8% annual energy savings.	Unit size, capacity, efficiency, and percent obstruction	All exterior condensing units. Most commonly applies to small ground mounted split system condensers.	Very good. Consists of log of visual inspections and maintenance logs.
Applies to all RTUs and air-handling units providing ventilation	Economiz-er repair	Optimizing ventilation air, system requires precise humidity control or similar complexities	1 year (Vermont Technical Resource Manual [TRM] 70% persistence over 14-year measure life) and Moser 2013.	This applies to complicated economizer systems like dual bulb enthalpy and for systems that require precise humidity control. Many components to maintain and calibrate.	Maintain dampers, actuators, dry-bulb/wet-bulb sensors	Annual service	Variable on size of facility. Generally fixed plus time and materials	Economizer repair savings varies widely based on “broken” condition, trade offs with fresh air/ free cooling/ excessive outdoor air (DNV GL 2017 study)	Unit size, capacity, efficiency, and percent reduction	Rooftop units and air handling units with outside air dampers and ventilation air requirements.	Moderate. Requires EMS alarms to warn of operation outside required setpoints.

End Use	Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maint. Require-ments	Implement-ation Cost	Average savings (%)	Primary Variables	Applicable Equipment	Savings and Cost Verification Ability
Applies to all RTUs and air-handling units providing ventilation	Economiz-er repair	Optimizing ventilation air, includes enthalpy sensors and moderate complexity	2 years (Vermont TRM 70% persistence over 14-year measure life) and Moser 2013	Persistence can be impacted by failure to maintain and calibrate enthalpy sensors and controls in non-critical applications.	Maintain dampers, actuators, dry-bulb/wet-bulb sensors	Annual service	Variable on size of facility. Generally fixed plus time and materials	Economizer repair savings varies widely based on “broken” condition, trade offs with fresh air/ free cooling/ excessive outdoor air (DNV GL 2017 study)	Unit size, capacity, efficiency, and percent reduction	Rooftop units and air handling units with outside air dampers and ventilation air requirements.	Moderate. Requires EMS alarms to warn of operation outside required setpoints.
Applies to all RTUs and air-handling units providing ventilation	Economiz-er repair	Optimizing ventilation air, simple control system	3 years (Vermont TRM 70% persistence over 14-year measure life) and Moser 2013	Applies to dry-bulb economizers. Damper, actuator, and linkage maintenance common to all three economizer modes.	Maintain dampers, actuators, and dry-bulb/wet-bulb sensors	Annual service	Variable on size of facility. Generally fixed plus time and materials	Economizer repair savings varies widely based on “broken” condition, trade offs with fresh air/ free cooling/ excessive outdoor air (DNV GL 2017 study)	Unit size, capacity, efficiency, and percent reduction	Rooftop units and air handling units with outside air dampers and ventilation air requirements.	Moderate. Requires EMS alarms to warn of operation outside required setpoints.

End Use	Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maint. Require-ments	Implement-ation Cost	Average savings (%)	Primary Variables	Applicable Equipment	Savings and Cost Verification Ability
Applies to all facilities and all heating/ cooling equipment (primarily temp control)	Maintain temp controls	Thermostats, outdoor air-temp reset, heat/cool coil temps	2 years (Massachusetts TRM assumes 100% persistence with a 15-year measure life (10-year retrofit)	2-years for setback thermostats. High level of human interaction and override potential. 3-years for facilities with EMS and in-house or contract service.	Maintain and repair controls	Annual service	Variable on size of facility. Generally fixed plus time and materials	1% per degree F per 8-hour period (Honeywell rule-of-thumb)	Total connected kW load and occupancy schedules	All equipment with room thermostats.	Very good. Requires notation from servicing report.
HVAC Compressors	Maintain refrigerant Charge	Maintain required refrigerant amount	3 years	Annual charge measurement part of annual maintenance. Historically, refrigerant levels do not change once charged except for severe equipment damage or equipment failure. Charge would be considered "maintained" if equipment is replaced or failures resolved.	Test refrigerant level	Annual service	Variable on size of facility. Generally fixed plus time and materials	80 kWh/year/unit (based upon 12,997 units in DNV GL study for CPUC). About 25% of refrigerant charge in supermark-ets is lost each year. PhaseOutFacts.org	Unit size, design efficiency, and percent of on-site charge	All HVAC refrigeration compressors.	

Notes:

Current list does not differentiate between office/administrative areas and temperature/humidity sensitive production areas
TRM review: Measures include refrigerant charge, economizer, duct sealing, thermostats
Literature review: Mostly industry best practices. Savings estimates primarily from utility program measures. O&M costs not defined.
Activities to improve persistence:
Maintain HVAC trends for key parameters from EMS logs and incorporate specific maintenance items in work orders/logs

- Address specific requirements for process. O&M requirements likely will be more stringent for process critical HVAC systems, and have priority over non-critical HVAC systems.

EXAMPLE HVAC SOP

Source: BBJ Environmental Solutions, HVAC Maintenance Checklist. http://www.bbjenviro.com/resource-article/hvac-maintenance/

Maintaining HVAC systems is critical to demonstrate that you are following the industry's "standard of care." HVAC maintenance will help protect your building occupants from unnecessary exposure to IAQ issues and help protect you from potential litigation.

There are some other very good reasons HVAC maintenance, including:

Lower utility costs.
Increase the service life of the HVAC equipment (reduce replacement costs).
Greater comfort for the building's occupants.

Common best practices for HVAC maintenance and maintaining a hygienic HVAC system follow. See all BBJ Environmental HVAC Maintenance solutions here.

Select Best Filter Capacity

Filters, and their ability to remove microorganisms can be best understood by using ASHRAE's standard (52.2-1999) which assigns an efficiency rating to filters called a MERV. The higher the MERV rating the more efficient the filter is in removing small particles. Generally speaking, a MERV rating of 11 or above is recommended.

Filter type can also make a difference in indoor air quality. Pleated filters made of cotton/synthetic fabrics may cost a little more, but the fabric can boost efficiency and the pleats increase the effective area.

Replace Filters (every 1—6 months)

Filters capture dust that can become a food source for mold and, depending on the filter, many of the spores themselves. Filters are made to be replaced frequently. Intervals should be one to six months, depending on the dirt load. You may need to visually inspect filters at monthly intervals before you can assign an established replacement frequency.

One tip for easy maintenance is to install easy to open panels to gain access to the filters and coils.

Clean Evaporator and Condenser Coils (once or twice a year)

Evaporator coils which are continually damp provide one of the best places for mold to grow. In addition to the constant dampness, the supply side of the coil is in contact with warm, humid outside air and the dirt that gets past filters contains the nutrients that mold requires to grow.

The condenser coil, exposed to unfiltered outdoor air, suffers considerable degradation due to dirt. While the condenser coil does not affect indoor air quality, cleaning this coil the same time the evaporator coil is cleaned will improve energy efficiency.

Coils soiled with microbial growth are particularly difficult to clean. Bacterial metabolism creates a sticky waste, which creates a biofilm that locks particles to the growing organism. Some molds develop long branches, or hyphae, that help to further cement the mass together. A quality cleaning solution with an appropriate dwell time is necessary to effectively remove all microorganisms.

Built up fungal growth is difficult to clean from metal surfaces. Technicians can be tempted to use an aggressive (high acid or caustic) cleaner. Such overly aggressive cleaners can damage metal surfaces. Damage can range from pitting of surfaces that interferes with rapid flow of condensate from fin surfaces to accelerated structural deterioration of components. Residues from such cleaners can also contaminate the indoor air if not fully rinsed.

Products like BBJ's Power Coil Clean are specifically formulated to attack the particulates that hold biofilms together without damaging the HVAC equipment. Once we keep the biofilm from growing back (see treatment section), a less aggressive coil cleaner like BBJ's MicroCoil Clean can be used to rid the system of dirt through routine cleanings.

Keeping the coils clean through frequent maintenance and appropriate treatments (see next section) will dramatically reduce the time required to complete this job.

As previously mentioned, energy savings is another reason to keep coils clean. A study completed by Pacific Gas & Electric indicates that the efficiency of a 10-ton package unit can be improved 16% simply by cleaning the evaporator and condenser coils. This can entirely offset the labor and product cost of cleaning the coil.

Treat Coils (after every cleaning)

Mold grows very quickly and a coil, once cleaned, can become fowled again in short order. Antimicrobial treatments, like BBJ MicroBiocide® for HVAC Systems, disrupts the reproductive cycle of mold spores and therefore inhibits the growth of mold.

The entire air handler should be treated once it is cleaned to make sure the unit remains free of microorganisms between cleanings.

Inspect Area Around Air Intake (twice annually)

Water can pool around air handlers, particularly those mounted on the roof. As with any place where water exists, mold can grow. Mold near the air intake will increase the likelihood that spores are sucked into the ventilation system. Make sure there is no standing water around the air handler.

Fix Leaks in Cabinet and Supply Duct (annually)

Annual checkups should include a survey of air leaks and corrective action such as replacing screws or latches, and patching or replacing gaskets. Cabinet and duct integrity is particularly important on the supply-air side, where high pressure can force air out a small crack.

Clean and Adjust Dampers (annually)

One of the most common problems with commercial HVAC equipment is improper damper operation. A study of 13 units conducted by PG&E found not one with properly operating dampers. This can negatively affect indoor air quality and also increases utility consumption.

Operating properly, dampers keep the compressor from running when outside air temperature is below 60 degrees Fahrenheit. But unless they are kept clean and well-lubricated they stick, robbing the unit of free cooling potential (if closed) or overloading the cooling coil with too much hot outside air (if open).

During servicing, moveable surfaces should be cleaned and lubricated. As long as a service technician is on the roof, this should take about 15 minutes.

After cleaning and lubrication, a damper should be run through its full range. Tools can generate electrical control signals to drive the actuator, or the economizer set-point can be manipulated at the control panel. Afterward the set-point should be checked.

Inspect Fan, Bearings, and Belts (twice annually)

While proper operation of fans, bearings and belts have minimal impact on indoor air quality, it only makes sense to include this step as a best practice in preventative maintenance. Avoiding the emergency of a unit that has shut down (usually on the hottest day of the year) will make best utilization of your HVAC labor force.

Impeller blades on a forward curved fan can fill up with dirt, lowering efficiency and air flow. Cleaning the blades on a small fan can take an hour or more; cleaning larger fans, especially those with multiple wheels on a single shaft, can be a major project.

Many HVAC technicians have found fan motors running in the wrong direction. Because they still supply perhaps 50 percent of rated flow even running backwards, this may not be readily apparent. The most common cause is switched wire leads on the motor. Clear labels on the fan housing, pulleys, motor, and wires can help prevent this problem.

Newer fans have self-lubricating bearings (sealed-cassette ball bearing cartridges preloaded with grease). When they finally fail, typically after several years of service, the bearing cassette must be replaced. Signs of impending failure are excessive noise, vibration, or heat emanating from the bearing.

Conventional greased ball bearings are occasionally found in packaged units. Their most common problem is over greasing, which can be as damaging as under-greasing.

Improperly adjusted belts rob the drivetrain of power, create noise, and must be replaced sooner than well-adjusted belts. Belts should be aligned to prevent lateral wear. Proper tension should be maintained; loose belts slip on the pulley wheels, causing torque loss and rapid wear. Belts that are too tight put an excessive load on the motor and fan shaft bearings, causing early failure of the bearings and/or belts.

Clean Air Ducts (Inspect every 2 years)

There is no real consensus regarding the frequency of cleaning supply and return air ducts. It will depend on the maintenance of the HVAC system (a well-maintained system will put a lower dirt load into the ducts) and the use of the building. The North American Duct Clearers Association (NADCA) recommends inspecting supply side and return air ducts every two years (annually in hospitals). If the inspection reveals contamination, the ducts should be cleaned.

This is clearly a job for a professional contractor. You may want to contact NADCA (www.nadca.com) for referrals. Members of this association subscribe to specialized training an industry code of ethics.

Quality Assurance Audits (on-going)

There are many ways for today’s facility managers confirm that best practices to deliver good indoor air quality are in place. These include:

Look up. As you walk through your facility, pay attention to the air vents. This very simple inspection can help you determine if mold or other pollutants are entering your occupied space.

Follow your nose. The presence of mold often creates a “musty” odor. Tuning in your sense of smell to the air flowing through your facility could alert you to pending trouble.

Ask building occupants. Use periodic random surveys to keep in touch with your building occupants. This can be done through “desk drops” (leaving surveys on employees’ desks after hours, or through the e-mail system.

Listen to your building’s occupants. People’s complaints may be an indication of an indoor air quality issue.

Confirm record keeping. Record keeping ideas in the “Toolbox” section of this manual. If you choose to use any of these, make sure you routinely inspect them to make sure they are up to date.

Testing devices. Swab tests of the HVAC system can provide a clear indication of the systems’ cleanliness. They can detect the level of microbial growth. Maintaining a history of readings can provide confirmation the system is clean or a warning that more attention is required.

APPENDIX C. COMPRESSED AIR MEASURES

The compressed air measures apply to both single compressor and multiple compressor systems and are for single stand-alone repairs. Compressed air is used in process and manufacturing, pneumatic systems, air tools, and other applications. O&M opportunities include system pressure reductions, compressed air leak repairs, staging and control of multiple compressor systems, maintenance of equipment, and distribution system optimization.

Table 7. Persistence of compressed air measures

Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implemen-tation Cost	Average savings (%)	Primary Variables	Savings and Cost Verification Ability	Comments	Applicable Equipment
Reduce operating pressure (pounds per square inch or psi)	2 years Source: MidAmerican Energy	Risk is pressure may be allowed to drift higher than needed. Required pressure is a function of work done. Work is not static and can change over time. Pressures may need to be increased or decreased with changes in equipment or task.	Monitor discharge pressures, SCFM, and compressed air requirements	Monthly observation	Low	1.0% per 2-psi reduction (decrease of 10 psi = 5.0%-8.0% reduction National Grid, Gas & Electric Energy Efficiency Opportunities guidebook)	Pressure and operating hours	Poor. Small pressure changes can be masked by other factors.	Persistence is dependent upon plant and production requirements. These are variable and can change. If loads/comp-air is fixed, then persistence can extend indefinitely.	Single compressor and multiple compressor plants

Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implemen-tation Cost	Average savings (%)	Primary Variables	Savings and Cost Verification Ability	Comments	Applicable Equipment
On/off and load control strategies. Compressor sequencing.	3+ years	Savings linked with proper control settings. Controls are subject to manual overrides and operational sensors. Must be reviewed and maintained.	Maintain local controls, review pressure at tasks	Quarterly control set-point review	Low to Medium (medium costs for replacement of more sophisticated controls)	0.60 kW/hp/ Hour, assumes an 80% load factor (DNV GL calculation)	kW and operating hours	Good. Savings should be consistent over time.	These assumptions are for controlling/ modulating compressed air output for both single and multiple compressor systems. This does not include sequencing/ staging multiple compressors which is addressed below.	Single compressor and multiple compressor plants

Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implemen-tation Cost	Average savings (%)	Primary Variables	Savings and Cost Verification Ability	Comments	Applicable Equipment
Leak repair	3 years	Once repaired, the device/fitting should not leak again unless in high impact area.	Leak detection plan. New leaks, not necessarily at the repaired device, will occur over time. Some leaks are audible and can be identified through a walk-through. Other leaks are silent and require ultrasonic detection. The cost-effective balance between an O&M service contract for ultrasonics and potential savings needs to be determined.	Annual site or third-party plan, repair large audible leaks when possible in interim	Medium to high	20%-30% total compressor usage (D'Antonio et al. 2001)	Pressure, size of leak, annual operating hours, plant efficiency	Very good depending upon the total capacity of all leaks.	3-year persistence at individual leaks. 3+ years persistence with leak prevention program.	Single compressor and multiple compressor plants

Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implemen-tation Cost	Average savings (%)	Primary Variables	Savings and Cost Verification Ability	Comments	Applicable Equipment
Minimize open blowing; install engineered nozzles and air-solenoid valves.	3+ years	This installs equipment that replaces a constant stream of open compressed air. Once installed, these devices are rarely removed.	Training personnel on proper use. Maintain/ install blow off devices and solenoids	Semi annual	Low to Medium	20%-35% of system power (Hofherr 2009)	Pre/post CFM, pressure, operating hours	Can be difficult. Depends upon total open blow offs eliminated. Can be masked by other factors.	A common example of this is an open pipe blowing compressed air to remove debris from a drilling process for example. Compressed air blows across the cutting surface continuously. A solenoid valve is installed which opens the pipe when the drill operator engages the drill. The pipe is closed for the rest of the time. Savings are calculated as a leak. The number of times the machine is used is also a variable. Once installed, the solenoid will continue working leading to the longer persistence.	Single compressor and multiple compressor plants

Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implemen-tation Cost	Average savings (%)	Primary Variables	Savings and Cost Verification Ability	Comments	Applicable Equipment
Maintain zone isolation	3+ years	This installs equipment that replaces a constant stream of open compressed air. Once installed, these devices are rarely removed. The isolation valves are designed to create smaller and more efficient sub-systems. A compressor may be used as backup when another fails. The intent of the measure is make sure the isolation valve is closed once the failed compressor is brought online. Don't want temporary overrides becoming permanent.	Maintain existing zone values and monitor line pressures.	Semi-annual review of plant requirements and operation of installed valves and controls.	Low to Medium	0.60 kW/HP/ Hour	kW and operating hours	Can be very good if zone allocation is significant.	Valves and controls can be installed to isolate parts of a system that operates less than the main system. This can also include isolating loads and selecting which of multiple compressor plants is best suited for the final task. Finally, it can entail finding a large or different load at the end of a piping header and installing a dedicated compressor for that load (large capital project).	Multiple compressor plants

Notes:

- TRM review: only minor O&M related compressed air measures observed. Little consistency between TRMs.
- Literature review: extensive plans outlining measures but very limited O&M savings estimates. O&M implementation/maintenance costs poorly defined in literature reviewed.

Key activities for improving persistence:

- Maintain compressed air plant maintenance log
- Enter daily/monthly/weekly/annual data as required
- Obtain data from EMS, process control system, or local controls
- Persistence savings can exceed 3 years with verification of conditions.

Example Compressed Air SOP

US Department of Energy Office of Industrial Technologies. Maintenance of Compressed Air Systems for Peak Performance (Compressed Air Systems Fact Sheet #5).
https://www.compressedairchallenge.org/library/factsheets/factsheet05.pdf

Basic Maintenance Checklist

Inlet Filter Cartridges. Inspect and clean or replace per manufacturer specifications. Required frequency is often related to operating conditions. Dirty filters increase energy consumption.

Drain Traps. Clean out debris and check operation periodically.

Compressor Lubricant Level. Inspect daily and top off or replace per manufacturer specifications. Change lubricant filter per manufacturer specifications.

Air Lubricant Separator (Lubricant-injected Rotary Screw Compressors). Change per manufacturer specifications, or when pressure drop exceeds 10 psid, whichever is less.

Lubricant Selection. Select compressor and electric motor lubricant per manufacturer specifications.

Belt Condition. Check belts for wear and check/adjust tension per manufacturer specifications.

Operating Temperature. Verify that operating temperature is per manufacturer specification.

Air Line Filters. Replace particulate and lubricant removal elements when pressure drop exceeds 2 to 3 psid. Inspect all elements at least annually regardless of pressure drop indication.

Water Cooling System. For water-cooled systems, check water quality (especially pH and total dissolved solids), flow, and temperature, and clean/replace filters and heat exchangers per manufacturer specifications.

System Leaks. Check lines (especially joints), fittings, clamps, valves, hoses, disconnects, regulators, filters, lubricators, gauge connections, and end-use equipment for leaks.

System Cleanliness. Check system for compressor and motor lubricant leaks and cleanliness.

APPENDIX D. COMPRESSED AIR MONITORING PROGRAM MEASURES

This measure group is for compressed air programs that address an entire system compressed air system.

Table 8. Persistence of compressed air monitoring program measures

End Use	Common Problem Areas	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables
Compressed air leak repair program	Couplings, hoses, tubes, fittings, pressure regulators, traps, shut-off valves, pipe joints, disconnects, threaded seals, site-specific equipment	3+ years	Implements a procedure to repair leakage that increases operating costs over time. Once repaired, savings can persist without further verification.	See example guidance: A) ComEd leak repair guidance B) Installation and use of in-house monitoring system	See: A)) ComEd leak repair guidance B) Leak repair selection protocols (Baker 2017)	Based upon compressed air system size and complexity (ComEd repair program pays $12/hp up to $12,000)	10% annual cost avoidance (Pohlmann 2005)	Pressure, size of leak, annual operating hours, plant efficiency

End Use	Common Problem Areas	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables
Compressed-air annual maintenance program	Replace filters, maintain oil pressure, optimize system drainage, maintain proper dryer dew point temperature, check and clean plugs and valves, maintain proper lubrication.	1 year	These are routine annual maintenance items that can decrease system efficiency over time. These are usually the manufacturer's required maintenance routines. Some required tasks must be done semi-annually or quarterly. Persistence will drop if procedures are not adhered to.	Follow installed equipment maintenance guidelines.	Maintain local controls, review pressure at tasks	Annual maintenance contract or in-house staff	1% of annual operating cost based upon 2-psi increase in pressure per year due to increased resistance (Kaeser Compressors Energy Savings in Compressed Air Systems)	System pressure and annual operating hours

Notes:

The annual saturation percentage of compressed air leaks was not identified during the program and literature searches. The size and capacity of new leaks is size dependent.

Literature review: Extensive plans outlining measures but very limited O&M savings estimates. O&M implementation/maintenance costs poorly defined.

Activities to improve persistence:

- Develop appropriate guidelines and require compliance

Example Guidance for a Compressed Air Program

Source: ComEd Compressed Air Leak Repair Requirements for participants (https://www.comed.com/WaysToSave/ForYourBusiness/Documents/CompressedAirLeakRepairApplication.pdf)

1. Leak surveys must be performed at the customer's facility by a Trade Ally or qualified contractor
2. Leak locations must be identified with a numbered tag that is clear and visible
3. Tags must remain in place for at least 30 days after submission of the application. This allows program representatives to verify leak repairs if necessary
4. One leak must be repaired for every five horsepower of non-backup air compressors
5. At least 50 percent of the total identified leak volume must be repaired
6. All leaks must be repaired if less than one leak per five horsepower of non-backup air compressors is identified
7. If all leaks are required to be repaired, and an individual leak is determined to be irreparable or cost prohibitive to repair; the customer may submit a written explanation and may be allowed to opt out of repairing that leak
8. Itemized and dated invoices must be submitted for the leak survey (showing contractor names, survey date survey cost); and for leak repairs (showing contractor name, itemized repair list and cost)
9. Must submit completed leak survey report (Excel file) with detailed system and leak repair information.

Example Guidance: Prioritizing Leak Repairs

Source: Leak repair selection protocols (Baker 2017)

To be efficient, leaks scheduled for repair should be prioritized by measured volume and ease of repair. This prioritization delivers the best return on time and effort. Larger leaks are more audible, increasing awareness and accountability to repair the obvious energy waste. Larger leaks may be repaired to correct a performance issue, not to deliver energy savings.

To provide a simple prioritized summary of leaks from each assessment, recorded leaks are sorted by volume and summarized. The data compiled by individual leak assessment and total recorded leaks for all assessments consistently follow an 80/70 relationship, where 80% of the total volume can be eliminated by repairing 70% of the leaks.

APPENDIX E. AERATION BLOWER MEASURES

Aeration blowers are the largest consumers of electricity (>60%) in wastewater treatment plants (WWTPs) (NYSERDA undated) The next largest electrical end-users in a wastewater treatment plant (WWTP) is pumps.

Table 9. Persistence of aeration blower measures

End Use	Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maint. Requirements	Implement-ation Cost	Average savings (%)	Primary variables	Savings and Cost Verification Ability
WWTP Aeration blower	Sequencing and staging multiple blowers for proper load	3+ years	3-years based upon setting staging blowers to load. Once set, staging changes only if load changes. Some sites may require semi-annual set points to compensate for seasonal flow capacities.	Monitor flow through SCADA or logs	Weekly or as dictated by flow	Low	0.60 kW/hp/hour, assuming 80% load (DNV GL calc)	Total blower HP annual operation	Moderate
WWTP Aeration blower	Aeration diffuser maintenance to maintain proper flow	1 year	Annual maintenance is required to clean fouling and scaling, keeps pores open, and maintains membranes.	Maintain and replace per manufacturers' specs	Per specifications	Low to moderate	kWh/M3 wastewater - site specific conditions - 2010 UCLA whitepaper	Wastewater flow and fouling rate	Moderate
WWTP Aeration blower	Identify and repair piping leaks to maintain proper flow	3+ years	3-years - once repaired new leaks are not expected at that device.	Visual observation	Weekly	Low	Detailed document search has these savings as site specific	Wastewater flow capacity, size, location of leak	Moderate
WWTP Aeration blower	Eliminate flow restrictions to maintain proper flow	1 year	1-year is the routine clearing of debris and restrictions from normal usage.	Visual observation	Weekly	Low	kWh/M3 wastewater, site-specific conditions (Stenstrom 2010)	Wastewater flow and fouling rate	Moderate

End Use	Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maint. Requirements	Implement-ation Cost	Average savings (%)	Primary variables	Savings and Cost Verification Ability
WWTP Aeration blower	Check placement of dissolved oxygen probe	2 years	Probe placement dependent upon system load and capacity. Improper placement leads to excessive bubbler operation. Persistence of 2-years due to need for possible failure/recalibration.	Maintain and replace per manufacturers' specs	Per specifications	Low	Detailed document search has these savings as site specific	Wastewater flow and fouling rate	Moderate
WWTP Aeration basins	Reduce number of aeration basin and digester mixers	3+ years	Load specific. Once set operation is fixed upon capacity.	Monitor flow through SCADA or logs	Weekly or as dictated by flow	Low to moderate	0.60 kW/HP/Hour, assuming 80% load (DNV GL calculation)	Total blower HP annual operation	Moderate
WWTP Sludge heating	Maintain optimum heating temperature (controls)	3+ years	Controls measure. Requires calibration and monitoring. Sludge loads and moisture content is dependent upon the dewatering equipment and technology.	Maintain/reset control based upon sludge chemistry	Annually	Low	Detailed document search has these savings as site specific. Dewaterings can be either dry bed or mechanical. Equipment can be filter presses, belt filter presses, vacuum filters, and centrifuges.	Sludge moisture content, furnace temperatures, annual hours	Moderate

Notes:

- TRM review: not included in any TRM
- Literature review: Mostly industry best practices, without savings or O&M costs estimated.

Activities to improve persistence:

- Utilize existing documentation; WWTP may already have a SOP manual specific to their operation
- For O&M/SEM, maintain measure spreadsheet with SCADA and observational entries.

Aeration Blower SOP

Source: Florida Department of Environmental Protection Division of Recreation and Parks. Bahia Honda State Park Wastewater Treatment Facility Plant: Standard Operating Procedures Manual.
http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiAgP_Lk_rVAhWJ5yYKHZ4nDlIQFggmMAA&url=http%3A%2F%2Fmyflorida.com%2Fapps%2Fvbs%2Fvbs_pdf.download_file%3Fp_file%3DF23404_AttachmentKSOPManual.pdf&usg=AFQjCNHgyBw3oZTC8tp2DQYgxE7KRomFfw

SECTION 4 - OPERATIONAL PROCEDURES:

4.1 OPERATIONAL PROCEDURES

The treatment process needs to be checked. As the flows change, the characteristics of the sewage changes which requires adjustments in operations. Operational tests are necessary to determine the characteristics of the mixed liquor in each stage of treatment so proper treatment adjustments can be made.

A. Characteristics of The Mixed Liquor

1. Color: The mixed liquor at first will have a dark gray appearance blending to a light brown and later to a light chocolate or a dark brown.
2. Odor: When the mixed liquor has the lighter colors, it gives off an odor similar to dish water and possibly a fresh grease or lard odor. As the color changes to dark brown, the liquor will have a slight earthy odor.
3. Flocculation: After the aeration tanks have been in operation, the solids will adhere and form a floc. As floc forms, it is carried to the settling tank. The liquid in the settling tank is not turbulent and the floc being heavier than the liquid, settles to the bottom of the tank.
4. Sludge: The solids or floc is called “activated sludge”. This sludge is active and is returned to the aeration tanks a food for the aerobic bacteria. The sludge, if allowed to remain in the settling tank will become septic and rise to the surface.

SECTION 5 - CHECKS, TESTS, RECORDS, AND REPORTING:

5.1 CHECKS, TESTS, RECORDS AND REPORTING

During plant operations, the operator should be on the alert and observe each phase of treatment and immediately correct any malfunction. The Plant records should be maintained at the Park Office & at each Train.

5.1.1 CHECKS

1. Trash and sand accumulated in the influent chamber is to be checked for excessive buildup. Remove sand and trash when necessary.
2. Aeration tanks should have a smooth rolling action. Frothing or foaming is generally caused by excessive air producing a violent, turbulent action. Check floc for formation, size, and settlement.
3. Scum and/or grease should be removed from the settling tanks and promptly taken to a disposal point. The sides of the settling tanks should be scraped and the removed solids pushed downward so that they may be picked up by the sludge pump and returned to the aeration tanks or the sludge holding tank.
4. Sludge holding tank is to be checked for volume and excess sludge drawn-off when necessary.
5. Chlorination unit to be checked for operation.
6. The stilling well should be checked each day. Solids should be collected and disposed in a covered container and disposed of in a sanitary landfill.

It is realized that Operators in some sewage treatment plants have little equipment to perform elaborate laboratory tests; however, by observation, an alert operator can determine irregularities in the operations. In addition to visual observation, the following tests will be helpful in determining the efficiency of the operations. All testing shall be performed in accordance with the permit requirement and must be performed by using approved

FDEP or EPA methods.

1. Dissolved Oxygen:

This test enables the operator to calculate the plant loading and to determine if adjustments in the air supply should be made. Water normally contains oxygen in solution; and when the maximum amount of oxygen is contained in solution, the water is saturated. This dissolved oxygen is consumed by the bacteria creating a deficiency in the oxygen supply. The amount of dissolved oxygen in liquid is expressed in parts per million (PPM). This test may be done by using the Dissolved Oxygen Test Kit. Generally, 1-2 ppm of DO is preferred in the aeration tanks within 10-minutes of blower startup. Less than 0.2 mg/L of DO should be in the anoxic tank.

2. Carbonaceous Biochemical Oxygen Demand (CBOD 5) - This test must be performed by an approved lab.: This lab test takes 5 days and gives a direct measure of oxidizable materials and describes the concentration or strength of sewage entering and leaving the plant. Also, this test can help to evaluate the plant's operating efficiency, and whether additional aeration is needed during periods of high BOD. The 5-day B.O.D. denotes the treatment required. The CBOD 5 is the preferred test because it is nitrogen limited. The oxygen content of sewage is rapidly used up by the oxidation process of the micro-organisms. The CBOD is a measure of the oxygen required to stabilize the sewage and is expressed in milligrams per liter, 5-day B.O.D.

This test is done under controlled conditions and is done in a laboratory. BOD tests should be taken of the influent and effluent as required by permit.

3. Settleability:

This test for settleable solids can be done quickly and it indicates the percent (%) of settleable solids in the mixed liquor in the aeration tank. If compared with the effluent sample test, the comparative results will show how the sludge settles. Visual inspections and laboratory tests is the basis of determining the degree of treatment being attained and corrective measures to improve the treatment. As an expedient to making some of the sludge tests, two (2) quart Mason Jars may be used (Figure No. 8) instead of some of the more expensive or 1000 ml graduated cylinders. If Mason Jars are used, they should be graduated in 10 equal spaces as shown.

A grab sample shall be taken from the outlet end of the last aeration tank/basin prior to entering the settling tank (A coffee can, fastened to a broom handle, works well for obtaining samples). Use the clear liquid from the top of the container (Graduated cylinder/Mason Jar) used to collect grab sample. On a graduated cylinder markings are present on the sides, however when using a glass jar a tape is placed and marked in 10 equal spaces. Number from 10 at the top, to 0 at the bottom.

Care must be taken to obtain the sample slowly so that it will be a true representative of the prevailing conditions. Do not include surface scum in the sample. Keep the sampler below the aeration liquid level surface (perhaps 2 feet) and remove it after the surface scum has been pushed away. Pour the sample into the jar, along the inclined sides, if a graduated cylinder is used, so that it does not splash and receive further aeration, at this point. Observe the time (30-minutes) allowed for the sample to set in the container. After a 30-minute settling period, the sample color and odor can be checked.

Other duties can be carried out while the sample settling period is taking place. The setteables within the sample should begin separating immediately and be well on the way in 10-minutes if everything is operating properly. A good indicator for the plant's operation will be if 20% to 40% of the sample's solids material have settled within the timed 30-minute period allowed to settle. This will vary as the solids content in the aeration tank (MLSS) varies.

The plant operator should develop a schedule which permits adequate time to take samples at a pre-determined time of a day, so that the flow and temperature will be similar, and thereby, give a good running comparison of grab samples.

3a. Mixed Liquor Suspended Solids

Periodically the MLSS should be tested by a laboratory. Twice a year is recommended as a minimum and more often if process problems are apparent. Generally, MLSS between 2,700-4,000 are acceptable. Higher values indicate wasting is needed, lower indicates insufficient solids are in the plant.

The laboratory should also check the percent Volatile: 70% is a normal value.

APPENDIX F. BOILERS

Boiler O&M measures include oil and gas fired boilers in HVAC applications. This includes both steam and hydronic fire-tube and water-tube units. High temperature hot water generators and dedicated process boilers are not included.

Table 10. Persistence of boilers

Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Imple-mentation Cost	Average savings (%)	Primary Variables	Savings and Cost Verification Ability
Combustion controls	O_2 trim, reduce excess air, check burner flames, optimize combustion efficiency	1 year	Controls measure. Many variables that can change. These are part of annual maintenance checklists. Gas only burners. Dual fuel burners (oil) have additional maintenance components.	Maintain equipment and remediate as needed.	Annual servicing. Semi-annual for large 8,760 plants.	Based upon facility	Efficiency can be increased 1% for each 10% reduction in excess air or 40F reduction in stack temp. (DOE Energy Tips)	Annual operating hours, fuel type, CO2, O2, and temperature	Moderate - requires solid baseline and per annualized per/unit variable
Boiler Controls	Heating hot water reset (controls that regulate hot water supply temperature according to outside air), outdoor air-temperature lockout controls, combustion air pre-heat control	3 years	These are not directly controlling burner firing or are combustion dependent. They are less susceptible to manual override	Maintain equipment and remediate as needed.	Annual service contract	Based upon facility	2% of a facility's total energy use with a 5-month simple payback (EPA 2003)	Boiler capacity, heating loads, outdoor air temperature	Moderate - requires solid baseline and per annualized per/unit variable

Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Imple-mentation Cost	Average savings (%)	Primary Variables	Savings and Cost Verification Ability
Multiple boiler controls	Sequencing, staging, select most efficient boiler	2+ years	Multiple boilers must be sequenced/staged for optimum operation. Boilers with proper size and burner turn ratios must be selected. Building/system/ process loads can change overtime. Persistence is achieved when boiler sequencing is done to meet current requirements in a timely fashion.	Maintain equipment and remediate as needed.	Annual service contract	Based upon facility	+/- 7% of heating energy. Average simple payback <2 years (EPA 2003)	Incremental heating loads, boiler capacities, boiler efficiencies	Moderate - requires solid baseline and post annualized per/unit variable. For example, baseline is one boiler always leading; post condition allows optimizing multiple boilers to operate at most efficient point for each.
Tube cleaning	Increase heat transfer ability	3 years	Persistence based upon rate of fouling. 3-years only if automatic boiler water treatment equipment is in place. 1-year with no treatment equipment.	Implement boiler water treatment plan and do chemical testing.	Annual service contract and periodic tests	Based upon facility	Maximum 2.0% water-tube boilers & 5.0% fire-tube boilers (1-mm scale = 2.0% reduction) (Bhatia 2012)	Type and thickness of scale, boiler type, annual operating hours, total boiler capacity	Moderate - requires solid baseline and post annualized per/unit variable

Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Imple-mentation Cost	Average savings (%)	Primary Variables	Savings and Cost Verification Ability
Insulation adjustment /repair	reposition or fix existing insulation	3+ years	This is analogous to "repair steam and compressed air leaks". Damaged and missing insulation should be repaired in a timely fashion.	Annual observation	Annual service contract	Based upon facility	50 btuh/hr/liner foot of pipe/inch diameter/100 psi steam (unlagged heating surface 1-lb steam/hour/ft 2/100psi)	Device surface area, fluid/steam temperature, operating hours, insulation R-value	Moderate - requires solid baseline and post annualized per/unit variable
Maintain boiler blowdown controls	Maintain controls	2 years	This is for the maintenance of existing controls. Blowdown capacity and frequency should be reviewed and verified for optimum blowdown.	Annual service	Annual service contract	Based upon facility	2% of blowdown rate (Cahill 2009)	Size of boiler, annual operating hours, blowdown capacity.	Moderate - requires solid baseline and post annualized per/unit variable
Optimize condensate system operation	Monitor condensate and makeup water amounts	3+years	This is a controls and monitoring measure. Condensate return GPM and boiler water makeup GPM are monitored along with condensate return temperatures. The monitoring process identifies condensate leaks and provides remediation pathways.	Annual observation	Annual service contract	Based upon facility	Up to 10% boiler operating cost (Bhatia 2012)	Percent of condensate return, condensate temperature, annual operating hours, makeup water temperature.	Moderate - requires solid baseline and post annualized per/unit variable

Notes:

TRM review: minor boiler references in TRMs

Literature review: mostly industry best practices. No savings estimates given. O&M costs not defined.

Create and maintain boiler plant logs.

Incorporate maintenance/review tasks into work logs and procedures.

Boiler manufacturers' publish daily/weekly/monthly/annual operating and maintenance guidelines. A Cleaver Brooks Guideline is presented in the Boiler SOP Checklist TAB.

Custom checklists should be created according to the unique requirements of each facility. Requirements may become more aggressive as process loads become more complex.

Overall persistence can be 3 years plus with adequate reporting.

Boiler SOP

Source: Cleaver Brooks Boiler Room Guide CB-7853

Daily Maintenance

1. Check water level. An unstable water level can indicate several problems such as excessive solids or water treatment, contamination from oil, overload or control malfunction. Ensure there is water in the gauge glass every time you enter the boiler room. See additional information later in this chapter.
2. Blow down boiler. Blow down the boiler in accordance with the recommendation of your feedwater consultant. A water quality and chemical treatment program will dictate frequency of boiler blowdown.
3. Blow down the water level controls to purge the float bowl of possible sediment accumulation. Operating conditions will dictate frequency of this check. See information later in this chapter.
4. Check combustion visually. Look at the flame to see if something has changed. Changes may be an indication that a problem is developing.
5. Treat water according to the established program. Add chemicals and take tests as outlined by your chemical feedwater consultant. See information later in this chapter.
6. Record boiler operating pressure or temperature. An excessive steam or water temperature drop will alert you to excessive loading on the boiler.
7. Record feedwater pressure and temperature. A change in pressure or temperature may indicate a problem is developing with your feed pump(s), deaerator or packaged feed system.
8. Record stack temperature. Changes in stack temperatures could indicate the boiler is sooting, scaling or there is a problem with baffles or refractory.
9. Record oil pressure and temperature. Changes in pressure and/or temperature could have an effect on combustion in the boiler and could indicate a problem in the oil regulators or oil heater.
10. Record oil atomizing pressure. Changes in pressure could have an effect on combustion in the boiler.
11. Record gas pressure. Changes in pressure could have an effect on combustion in the boiler and indicate a problem in the gas delivery system.
12. Check general boiler/burner operation. Maintaining top efficiency is the simple and basic reason for having operating personnel. Is anything different than it was the day before? If so, why?
13. Record boiler water supply and return temperatures. On hot water boilers, record these temperatures to assist in detecting system changes.
14. Record makeup water usage. Excessive makeup water could be an indication of system problems in both steam and hot water systems.
15. Check auxiliary equipment. There is a vast difference between “is it running” and “is it running properly.” Take nothing for granted, as auxiliary equipment can shut down your operation.

Weekly Maintenance

1. Check for tight closing of fuel valves. Check to ensure fuel does not flow through the fuel valve(s) when the burner is shut off.
2. Check fuel and air linkages. Check to ensure that all set screws on linkages are tight and are securely holding the linkage in place.
3. Check indicating lights and alarms. Check for burned out or loose light bulbs. Also check to ensure the appropriate shut down condition.

4. Check operating and limit controls. Check to ensure these controls shut the burner down at their predetermined set point. Settings should be verified by checking actual pressures and temperatures on the boiler gauges.
5. Check safety and interlock controls. Check to ensure these controls shut the burner down at their predetermined set point. Settings should be verified by checking actual pressures and temperatures on the boiler gauges.
6. Check operation of water level controls. Stop the boiler feed pump and allow the control to stop the boiler under normal low fire conditions. See your operating manual for a more detailed procedure. See information later in this chapter.
7. Check for leaks, noise, vibration, unusual conditions, etc. Checking for these items is a cost effective way to detect system operational changes. Small problems can be corrected before they become large problems.
8. Check operation of all motors. By developing a routine, any change in operation or bearing temperature will usually be caught in time to avoid a failure.
9. Check lubricating levels. Check levels of any oil bath filters, oil level in air/oil tank, oilers on pumps, etc. Add oil in accordance with the manufacturer's recommendations.
10. Check the flame scanner assembly. Using the appropriate meter, check the flame signal strength at the program relay flame amplifier. Ensure the scanner assembly is clean and dry.
11. Check packing glands on all pumps and metering devices. Proper tension on packing glands will extend life of the equipment.
12. Check gauge glass. Ensure there are no cracks or etching in the glass or leakage around the packing.

Monthly Maintenance

1. Inspect burner operation. Do a visual inspection of the pilot flame, main burner flame throughout the firing range, free movement of linkages and general burner operation.
2. Analyze combustion. Take the flue gas analysis over the entire firing range, comparing the combustion analysis and stack temperature readings with previous month.
3. Check cams. Inspect the cam springs for scoring, tightness of set screws, free movement, alignment of cam followers and other related parts.
4. Check for flue gas leaks. Ensure something hasn't changed in the breeching, stack or overall system that allows flue gas to be drawn into the boiler room.
5. 5. Inspect for hot spots. Inspect the boiler to ensure no hot spots are developing on the outside of the boiler. Hot spots can indicate a refractory failure or baffle failure, which could cause improper gas flow through the boiler or the cooling lines could be plugged or disconnected.
6. Review boiler blowdown to determine that a waste of treated water is not occurring. Check water treatment and testing procedures with your feedwater consultant. See additional information later in this chapter.
7. Check all combustion air supply inlets to the boiler room and burner to ensure sufficient air is being supplied.
8. Check all filter elements. Clean or replace as needed. On "self-cleaning" filters, make certain that impurities are flushed or discharged from filter body.
9. Check the fuel system to make certain that strainers, vacuum gauges, pressure gauges and pumps are properly cared for.

10. Check all belt drives for possible failure. Tighten V-belt sheaves and make certain that belts operate with proper tension.
11. Check lubrication requirements of all bearing supported equipment. Do not over-lubricate electric motors.

Semi-Annual Maintenance

1. Clean low water cutoff (s). Remove the head assembly or probes and inspect and clean out any sediment or contamination in the column or piping. Determine why sediment or contamination condition exists. See additional information later in this chapter.
2. Check oil preheaters by removing the heating element and inspect for sludge or scale.
3. Repair refractory. Immediately upon opening the fireside areas, give the refractories an inspection and start repairs as soon as possible. Read and follow refractory repair instructions.
4. Clean oil pump strainer and filter. Ensure they are not plugged, thus reducing the flow of the required oil to the burner.
5. Clean air cleaner and air/oil tank. Inspect and clean out any sediment or contamination. Add oil in accordance with the manufacturer's recommendations.
6. Check pump coupling alignment. Check alignment of all couplings to ensure the tolerances are within the manufacturers recommendations.
7. Reset Combustion. The entire combustion process should be carefully checked, O2 readings taken and necessary burner adjustments made. Make certain the readings are recorded and used as a basis of comparison for future tests. Combustion adjustments should only be made by those thoroughly familiar with all aspects of burner adjustment and combustion.
8. Inspect mercury switches. Inspect mercury switches for contamination, loss of mercury, and cracked or broken wires. Replace if any of these conditions are found.

Annual Maintenance

Note: Annual maintenance should be coordinated with the annual pressure vessel inspection performed by insurance or government groups. Establish a firm procedure with all outside inspection groups so that your equipment will be in a proper state of readiness. As a matter of routine, establish a procedure using good safety practices whenever a boiler is taken off the line. Disconnect all power supplies and lock switches in the off position. Whenever there is more than one boiler connected to a common header establish a routine procedure of locking the header valve on any unit that is down for cleaning or inspection, close any flue gas outlet dampers, and all pieces of equipment required to isolate the boiler.

1. Clean fireside surfaces by brush or use a powerful vacuum cleaner to remove soot. After the cleaning process and if boiler is to be left open, it is advisable to spray all fireside surfaces with some type of corrosion preventative.
2. Clean breeching. Inspect breeching and stack and remove any soot build up.
3. Clean waterside surfaces. Remove all handhole and manway plates, inspection plugs from water column tees and crosses and float assemblies from water columns. Thoroughly wash all waterside surfaces.
4. Check oil storage tanks. Oil storage tanks should be inspected for sludge and water accumulation. Keep the tank filled with oil to prevent condensation during summertime.
5. Check fluid levels on all hydraulic valves. If any leakage is apparent, take positive corrective action immediately.

6. Check gauge glass for possible replacement. If internal erosion at water level is noted, replace with new glass and gaskets. On all unattended boilers, the gauge glass mounting should be of the safety style with stop checks in case of glass breakage.
7. Remove and recondition safety valves. Have them reconditioned by an authorized safety valve facility. The safety valve is an important device yet possibly receives less attention than any other device. See additional information later in this chapter.
8. If oil fuels are used, check on the condition of the fuel pump. Fuel pumps wear out and the annual inspection time is the opportune time to rebuild or replace them.
9. Boiler feed pumps. Strainers should be reconditioned. Feed pump elements wear and must be replaced. Sometimes a review of the condensate return system and chemical feed arrangement will reveal causes of short pump life. See additional information later in this chapter.
10. Condensate receivers should be emptied and washed out. Make an internal inspection, if possible. If the receiver has a make-up valve mounted, it should be overhauled and checked for proper operation.
11. Chemical feed systems should be completely emptied, flushed, and reconditioned. Metering valves or pumps should be reconditioned at that time.
12. Tighten all electrical terminals. All terminals should be checked for tightness, particularly on starters and movable relays.
13. Check deaerator or boiler feed systems. Inspect them to ensure they are not contaminated, corrosion is not taking place and that the lining has not deteriorated and fallen off. Check all other mechanical aspects of the equipment. See information later in this chapter.
14. Check linkages. Check to ensure the linkage ball connectors have not worn out. Worn connectors can cause inconstancy in the linkage movement and result in unrepeatable excess air levels in the combustion process.

APPENDIX G. STEAM TRAPS

Implement an on-going steam trap repair/replace program to eliminate increased energy usage over time.

Table 11. Persistence of steam traps

End Use	Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables	Verification Ability
Steam	Steam trap replacement	5 years	Persistence is predicated upon an industry average of 20% annual steam trap mortality	Implement steam trap maintenance program	Annual testing, More frequent with high pressure	Varies by site - fixed cost plus cost per trap	Example: 211 LB/HR per 100 psi per 1/4" opening [US DOE Energy Tips: STEAM]	Steam pressure, trap quantity, size of leak, annual operating hours	Need site specific savings variable based upon pressure

Notes:

TRM review: Minor steam trap references in TRMs

Literature review: Many detailed charts defining savings after leak sizes happen. Predictive O&M savings need to be further defined along with steam trap maintenance plan costs.

SOP: Guidance for inspections are available (http://www.uesystems.com/wp-content/uploads/2012/08/steam-trap-inspection-guide.pdf)

APPENDIX H. CHILLER AND COOLING TOWER MEASURES

These measures are linked with centrifugal and direct expansion [Dx] chiller operation for HVAC applications. Also included is cooling tower O&M and pump control O&M. Commercial and industrial refrigeration O&M is handled separately.

Table 12. Persistence of chiller and cooling tower measures

End Use	Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables
Space Cooling - Chiller	Maintain chiller controls	Chilled water reset, condenser water reset, outdoor-air temperature (OAT) lockout	2 years	Controls dependent. Requires replacement, repair, calibration. Some human interaction possible. Also, requires timely changes to OAT in response to changed conditions within a facility.	Maintain controls, sensors, and set points. Monitor flow/temperature.	Annual service contract	Varies by site (size, quantity)	2°F to 3°F CHW temp increase can get 3% - 5% savings	Controls set points, annual cooling hours, chiller size and efficiency
Space Cooling - Chiller	Reducing scale or fouling	Improve heat transfer	3 years	3 years+ with automatic water treatment program; 2 years without automatic treatment	Implement water treatment program	Annual service & testing	Varies by site (size, quantity)	0.9% per each 0.01" deposit (The Apex Solution 2013)	Thickness of scale, annual cooling hours

End Use	Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables
Chiller	Purge air from condenser	Maintain flow	3 years	Part of annual maintenance checklist. Savings persist once identified and repaired.	Monitor flow and temperatures	Annual contract	Varies by site (size, quantity)	3.0% per psi air (The Apex solution 2013)	Controls set points, annual cooling hours, chiller size and efficiency, air intrusion
Chiller	Keep oil from refrigerant	Maintaining system integrity	3 years	Part of annual maintenance checklist. Savings persist once identified and repaired.	Repair leaks in system	Annual contract	Varies by site (size, quantity)	2.0% loss per 1.0% oil intrusion (The Apex solution 2013)	Controls set points, annual cooling hours, chiller size and efficiency, oil intrusion
Cooling Tower	Wet-bulb approach control	Controlling cooling towers for optimal system performance	2 years	Controls dependent. Requires replacement, repair, calibration. Human interaction susceptible.	Monitor flow and temperatures	Annual contract	Varies by site (size, quantity)	2.6% to 8.5% savings (Crowther, ASHRAE Journal 2014)	Size and capacity of cooling tower, total fan HP, annual cooling hours, percent obstruction
Cooling Tower	Remove scale deposits	Improve and optimize heat transfer	3 years	3 years with automatic water treatment program; 1 year without automatic treatment.	Observation and cleaning	Annual contract	Varies by site (size, quantity)	2.6% to 8.5% savings (Crowther 2004). 1/32" scale increases cost 7% and reduces refrigeration capacity by 1%. (Weimar 2009)	Size and capacity of cooling tower, total fan HP, annual cooling hours, percent obstruction

End Use	Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables
Cooling Tower	Clear clogged spray nozzles	Uneven heat transfer and flow	1 year	Persistence diminishes if observation and remediation is not timely.	Observation and cleaning	Annual contract	Varies by site (size, quantity)	Chiller consumes 2.5% to 3.5% more per degree of condenser temperature. (US Department of Energy [DOE] Federal Energy Management Program [FEMP] 2010).	Size and capacity of cooling tower, total fan HP, annual cooling hours, percent obstruction
Cooling Tower	Improve air flow	Debris or blockage to tower air	1 year	Required annual maintenance per manufacturers'' specifications. 1-year in dirty environment. 2-years in other environments.	Observation and cleaning	Annual contract	Varies by site (size, quantity)	Chiller consumes 2.5% to 3.5% more per degree of condenser temperature. (DOE FEMP 2010).	Size and capacity of cooling tower, total fan HP, annual cooling hours, percent obstruction
Cooling Tower	Condenser water set-point control maintenance	Allows efficient chiller operation	2 years	Controls dependent. Requires replacement, repair, calibration. Human interaction susceptible.	Annual service	Annual contract	Varies by site (size, quantity)	0.18 kWh/ft2 (Joyce 2011)	Size and capacity of cooling tower, total fan HP, annual cooling hours, chiller efficiency

End Use	Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables
Pumps	Maintain VFD operation	Maintain variable flow	2 years	Controls dependent. Requires replacement, repair, calibration. Human interaction susceptible.	Look for override conditions, failed valves	Monthly observation and service contract	Varies by site (size and quantity)	Variable with chillers and HVAC equipment	HVAC and chiller requirements

Notes:

Current list does not differentiate between dedicated HVAC chillers, dedicated process chillers, and mixed use plants

TRM review: minor chiller references in TRMs. Average TRM measure life is 3-5 years

Literature review: mostly industry best practices, with no savings estimates or O&M costs.

Activities to minimize risk to persistence

Establish daily/weekly/monthly/annual chiller log protocols

Confirm readings through EMS/SCADA/Digital control data

Maintenance procedures may be more stringent for process chillers with more frequent servicing requirements

Chiller and Cooling Tower SOP

Source: Graham, Kevin M. Facilitiesnet: 5 Steps to Chiller Efficiency. http://www.facilitiesnet.com/hvac/article/5-Steps-to-Chiller-Efficiency-Facility-Management-HVAC-Feature--2192

Step 1: Maintain a Daily Operating Log

Chiller operators should document chiller performance daily with an accurate and detailed log, comparing this performance with design and start-up data to detect problems or inefficient control set points. This process allows the operator to assemble a history of operating conditions, which can be reviewed and analyzed to determine trends and provide advanced warning of potential problems.

For example, if machine operators notice a gradual increase in condensing pressure during a month's time, they can consult the daily operating log and systematically check and correct the possible cause of this condition, such as fouled condenser tubes or non-condensables.

Chiller manufacturers can provide a list of recommended data points specific to equipment upon request. Operators can take data readings daily, once per shift at about the same time. Today's chillers are controlled via microprocessor controls, so managers can automate this process using microprocessor-controlled building automation systems.

Step 2: Keep Tubes Clean

One large potential hindrance to desired chiller performance is heat-transfer efficiency. Chiller performance and efficiency relate directly to its ability to transfer heat, which begins with clean evaporator and condenser tubes. Large chillers contain several miles of tubing in their heat exchangers, so keeping these large surfaces clean is essential for maintaining high-efficiency performance.

Chiller efficiency deteriorates as tubes become fouled, when mud, algae, sludge, scale, or contaminants accumulate on the waterside of heat-transfer surfaces. The rate of fouling depends on the system type — open or closed — as well as on water quality, cleanliness, and temperature.

Most chiller manufacturers recommend cleaning condenser tubes annually, since they typically are part of an open system, and they recommend cleaning evaporator tubes once every three years for closed systems. But if the evaporator is part of an open system, they recommend periodic inspection and cleaning.

Managers can consider two primary methods for cleaning tubes:

Mechanical cleaning removes mud, algae, sludge, and loose materials from smooth-bore tubes and consists of removing the water-box covers, brushing the tubes and flushing with clean water. For internally enhanced tubes, managers should consult the chiller manufacturer for mechanical-cleaning recommendations.

Chemical cleaning removes scale. Most chiller manufacturers recommend consulting with a local water-treatment supplier to determine the proper chemical solution required. A thorough mechanical cleaning should always follow a chemical cleaning.

New chillers feature automatic tube-brushing systems, which can be retrofit onto existing chillers. These systems use small, nylon-bristled brushes that flow through the tubes for cleaning. A custom-manufactured, four-way reversing valve is installed in condenser water-piping system, and every six hours, the system automatically reverses the flow through the condenser tubes for about 30 seconds.

Coupled with proper water treatment, these systems virtually eliminate fouling within the chiller and maintain design-approach temperatures. These systems typically show payback periods of less than two years.

Step 3: Ensure a Leak-free Unit

Manufacturers recommend quarterly tests of compressors for leaks. Low-pressure chillers using either CFC-11, which has been phased out, or HCFC-123 have sections of their refrigeration systems that operate at sub-atmospheric pressure. Although these chillers are the most common in today's facilities, it is difficult to create a perfectly sealed machine, and leaks allow air and moisture, commonly referred to as non-condensables, to enter the unit.

Once in the chiller, non-condensables become trapped in the condenser, increasing condensing pressure and compressor-power requirements and reducing efficiency and overall cooling capacity. Low-pressure chillers have high-efficiency purge units that remove non-condensables to maintain design-condensing pressure and promote efficient operation. One chiller manufacturer estimates that 1 psi of air in a condenser equates to a 3 percent loss in chiller efficiency.

Moisture in a chiller also can create acids that corrode motor windings and bearings and create rust inside the shell. Small rust particles called fines float in the vessels and get trapped inside heat-exchanger tubes. Fines on tubes decrease the unit's heat-transfer effectiveness and overall efficiency. Left unchecked, they can lead to costly tube repairs.

The best way to monitor leaks in a low-pressure chiller is to track purge-unit runtime and the amount of moisture accumulation at the purge unit. If either of these figures is too high, the unit has leaks. Other indications of air in the system include increased head pressure and condensing temperature.

High-pressure chillers using CFC-12, HFC-134a, or HCFC-22 operate at pressures well above atmospheric pressure, and leaks in these types of chillers release potentially hazardous refrigerants into the environment. Environmental regulations limit the amount of annual refrigerant leaks.

Leaks also results in a lower refrigerant charge and other operational problems, such as lower evaporator pressure, which can cause the compressor to work harder to produce a lower cooling capacity. For positive-pressure chillers, technicians should monitor the refrigerant charge level and evaporator pressure to detect leaks.

Step 4: Sustain Proper Water Treatment

Most chillers use water for heat transfer, so the water must be properly treated to prevent scale, corrosion and biological growth. A one-time chemical treatment is required for closed-water systems, which are typical of chilled-water systems connected to the chiller evaporator.

Open systems typically are used for condenser-water systems connected to the chiller condenser. Condenser systems that use sources such as cooling towers require continuous chemical water treatment. Managers should work with a chemical-treatment vendor familiar with local water supplies and can provide full-service maintenance for all facility water systems.

Scale should not be a problem if the vendor maintains proper chemical treatment of the evaporator and condenser-water systems. The presence of scale in the condenser or evaporator tubes indicates improperly treated water. The vendor needs to test water quality every three months and correct the water treatment program, which should aid in cleaning the chiller tubes.

Also, all systems strainers should be cleaned every three months. Sand filters and side-stream filters for condenser-water systems are very effective at maintaining clean water, if properly maintained. To determine when cleaning is required, technicians should monitor pressure drop at the filters and refer to manufacturer recommendations on cleaning. Filters should be cleaned quarterly, regardless of pressure drop.

Maintenance of strainers and filters limits chiller-tube erosion caused by sand or other small particles moving at high velocities. Erosion and tube pitting decreases overall heat-transfer effectiveness and decreases efficiency. If uncorrected, these conditions can lead to plugged tubes or catastrophic tube failure.

Technicians should inspect chilled-water and condenser-water piping systems annually for evidence of corrosion and erosion. Most manufacturers recommend eddy-current inspection of heat-exchanger tubes, including an electromagnetic procedure for evaluating tube-wall thickness, every three-five years.

Step 5: Analyze Oil and Refrigerant

Annual chemical analysis of oil and refrigerant can aid in detect chiller-contamination problems before they become serious. Testing consists of spectrometric chemical analysis to determine contaminants, including moisture, acids, and metals, which hamper performance and efficiency. A qualified chemical laboratory specializing in HVAC equipment must perform the analysis. Most manufacturers provide annual oil and refrigerant analysis services.

Technicians should take an oil sample while the chiller is operating. The oil should be changed only if indicated by oil analysis. Technicians also should monitor oil filters for pressure drop and change them during a recommended oil change or if pressure drop is outside of tolerance.

Oil analysis can help detect other chiller problems. For example, high moisture content in the oil can signal problems with the purge unit, and changes in oil characteristics can signal the development of unacceptable compressor wear.

Managers use refrigerant testing to determine contaminants that might lead to reliability and efficiency problems. One main contaminant is oil that migrates into the refrigerant. One chiller manufacturer estimates there is a 2 percent loss in chiller efficiency for every 1 percent oil found in the refrigerant, and it is not uncommon to find 10 percent oil in older chillers' refrigerant. Based on this estimate, such contamination can lead to a substantial 20 percent decrease in efficiency. The bottom line — testing can pay large dividends.

Maintenance Schedule as provided by www.eere.energy.gov

Basic Steps for Optimized Performance:
Inspect the chiller quarterly
Routinely check for refrigerant leaks
Confirm compressor operating pressures are within a reasonable range
Check all motor voltages & amps
Check all electrical starters, contactors and relays
Check all hot gas and unloader operations
To reach maximum efficiency, use superheat and sub-cooling temperature readings

Line readings from Discharge lines should also be obtained

For a custom maintenance schedule for your specific product, please contact a Cooling Technology, Inc representative and they will be happy to discuss our maintenance packages with you.

Daily Maintenance Check List for Chillers

Description Comment
Chiller use & Sequencing Turn off or sequence unnecessary chillers
Overall Visual Inspection Complete overall visual inspection to be sure all equipment is operating and that safety systems are in place
Check Set points Check all setpoint for proper setting and function

Monthly Maintenance Check List for Chillers

Description Comment
Evaporator and Condenser Coil Fouling Assess evaporator and condenser coil fouling as required
Compressor Motor Temperature Check temperature per manufacturer’s specifications
Leak Testing Conduct leak testing on all compressor fittings, oil pump joints and fittings, and relief valves
Check all Insulation Check insulation for condition and appropriateness
Control Operations
Verify proper control function including:

- Hot gas bypass
- Liquid injection

Semi – Annually Maintenance Check List for Chillers

Description Comment
Check Chiller Lockout Points Check settings for manufacturer’s specifications

Annual Maintenance Check List for Chillers

Description Comment
Compressor Motor & Assembly Check all alignments to specification. Check all seals and provide lubrication where necessary.
Compressor Oil System Conduct analysis on oil & change as necessary Check oil pump and seals Check oil heater and thermostat Check all strainers, valves, etc.
Electrical Connections Check all electrical connections and terminals for contact and tightness
Water Flows Assess proper water flow in evaporator and condenser
Check Refrigerant Level and Condition Record amounts and address leakage issues.

APPENDIX I. AIR ABATEMENT MEASURES

Air abatement pertains to dust and waste collection systems. These are specialized systems associated with industrial and manufacturing facilities. There is a wide variety of types of systems.

Table 13. Persistence of air abatement measures

Measure Name	Persistence	SOP Applicability	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables	Savings and Cost Verification Ability
Duct gate and valve adjustment	3 years	Site specific	Savings based upon installed equipment	Observation or digital control	Semi-Annual Real time change as needed	Site dependent	These are exclusively custom measures in TRMs. No rule-of thumb savings identified.	Total connected kW, per adjustment or change in operation, annual operating hours, cycling load factors, etc.	Need to establish per unit avoided cost
Run-time reduction	2 years	Site specific	Savings based upon control settings. Human interaction and override susceptible.	Observation or digital control	Semi-Annual Real time change as needed	Site dependent	These are exclusively custom measures in TRMs. No rule-of thumb savings identified.	Total connected kW, per adjustment or change in operation, annual operating hours, cycling load factors, etc.	Need to establish per unit avoided cost
Set minimal idle speed or off times	2 years	Site specific	Savings based upon control settings. Human interaction and override susceptible.	Observation or digital control	Annual	Site dependent	These are exclusively custom measures in TRMs. No rule-of thumb savings identified.	Total connected kW, per adjustment or change in operation, annual operating hours, cycling load factors, etc.	Need to establish per unit avoided cost

Measure Name	Persistence	SOP Applicability	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables	Savings and Cost Verification Ability
Zone isolation	3 years	Site specific	Savings based upon installed equipment	Observation or digital control	Annual	Site dependent	These are exclusively custom measures in TRMs. No rule-of thumb savings identified.	Total connected kW, per adjustment or change in operation, annual operating hours, cycling load factors, etc.	Need to establish per unit avoided cost
High-efficiency filters	1 year	Site specific	Persistence maintained with specified schedules.	Manufacturer Specifications	Per manufacturer specifications	Site dependent	These are exclusively custom measures in TRMs. No rule-of thumb savings identified.	Total connected kW, per adjustment or change in operation, annual operating hours, cycling load factors, etc.	Need to establish per unit avoided cost
Optimize cleaning strategy	3 years	Site specific	Maintain per manufacturers' specifications and facility operation.	Manufacturer specifications	Per manufacture specifications	Site dependent	These are exclusively custom measures in TRMs. No rule-of thumb savings identified.	Total connected kW, per adjustment or change in operation, annual operating hours, cycling load factors, etc.	Need to establish per unit avoided cost

Notes:

TRM review: not included in any TRM.

Literature review: These are mostly industry best practices without savings or O&M cost estimates.

Activities to minimize risk to persistence:

- O&M measures require a maintenance log customized for the specific operation.

- Compliance can be verified through maintenance log trends for EMS or process control systems.
- O&M for air abatement may be set by the manufacturer.

Because of the wide variety of equipment, no relevant SOP found.

APPENDIX J. PROCESS OVEN MEASURES

Process ovens are direct fired ovens that serve a manufacturing or process load. These are natural gas fired or electric resistance units.

Table 14. Persistence of process oven measures

Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables	Cost and Savings Verification Ability
Insulation adjustment /repair	3+ years	This measure repairs/replaces existing insulation. Savings persists once insulation is repaired.	Visual inspection	Annual inspection	Site dependent	These are exclusively custom measures in TRMs and equipment can be custom made for the facility. No rule-of thumb savings identified.	Oven temperature, size of uninsulated device, R-value, annual operating hours	Site dependent
Shutdown scheduling	1 year	Controls. Variable usage. Persistence is dependent with scheduling to actual production which can change quickly.	Inspect and maintain controls	Semi-Annual Real time as needed	Site dependent	These are exclusively custom measures in TRMs and equipment can be custom made for the facility. No rule-of thumb savings identified.	Size and efficiency of oven, operating temperature curves, annual operating hours, oven efficiency.	Site dependent

Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables	Cost and Savings Verification Ability
Temp reduction	1 year	Controls. Temperatures can change as product lines change and new products are added. Operation may reflect seasonal production variables. Temperatures must correspond with production parameters for each specific product.	Inspect and maintain controls	Semi-Annual Real time as needed	Site dependent	These are exclusively custom measures in TRMs and equipment can be custom made for the facility. No rule-of thumb savings identified.	Size and efficiency of oven, operating temperature curves, annual operating hours, oven efficiency.	Site dependent
Burner tuning	2 years	Process combustion efficiency is more "manufacturer design" driven when compared with HVAC furnaces.	Combustion testing monitoring	Semi-Annual Real time as needed	Site dependent	These are exclusively custom measures in TRMs and equipment can be custom made for the facility. No rule-of thumb savings identified.	CO2, O2, stack temperature, turn down ratios annual operating hours	Site dependent
Seal Oven Openings	3+ years	Savings consistent with proper operation opening gates and leak repairs.	Maintain closure controls	Semi-Annual Real time as needed	Site dependent	These are exclusively custom measures in TRMs and equipment can be custom made for the facility. No rule-of thumb savings identified.	Size of required opening per schedule production, oven temperature, annual operating hours, excess air percentage	Site dependent

Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables	Cost and Savings Verification Ability
Lower Explosive Limit (LEL) Monitor	2 years	Controls, but process dependent. Less variables and human interaction.	Inspect and maintain controls	Quarterly	Site dependent	These are exclusively custom measures in TRMs and equipment can be custom made for the facility. No rule-of thumb savings identified.	Required LEL levels, annual operating hours, oven efficiency	Site dependent
Product pre-conditioning	3+ years	Consistent once in place.	Inspect and maintain controls	Semi-Annual Real time as needed	Site dependent	These are exclusively custom measures in TRMs and equipment can be custom made for the facility. No rule-of thumb savings identified.	Temperature and moisture content of material, pound of product, oven temperature, oven efficiency	Site dependent

Notes:

TRM review: - not included in any TRM

Literature review: These are mostly industry best practices without savings or O&M cost estimates..

Activities to minimize risk to persistence:

- Set up logs that confirm operation conforms with manufacturing specifications
- Maintain logs that show that observation checklists are being maintained
- Repair/remediation plan is implemented

Process Oven SOP

Rottman Murphy, Renee. Process Heating: 10 Tips for Oven Maintenance. http://www.process-heating.com/articles/83563-10-tips-for-oven-maintenance

To keep your oven operating at its peak performance, follow these maintenance tips.

Whether an oven is used in a tension test or an annealing application, every oven owner should perform routine maintenance checks to keep the oven at peak condition.

Everyone knows that maintenance is important for product longevity and performance. Your vehicle is an obvious example of this -- especially if you have ever found yourself calling AAA for roadside assistance on a rainy night.

Ovens for testing, laboratory and process applications are no exception. Whether an oven is used in a tension test or an annealing application, every oven owner needs a checklist to help keep the oven at peak condition. And, ovens that have mounting assemblies or special cooling have even more maintenance issues.

TIP 1: Maintain the Blower

The blower motor is one of the most important oven features. Proper lubrication is a must if it is a sleeve-bearing motor, according to "Dayton Fractional HP Motors Installation and Maintenance Information Manual." If the blower motor is equipped with oil cups, lubricate with five drops of SAE 20 non-detergent oil at six-month intervals. Ball-bearing motors or motors pre-lubricated at the factory do not require lubrication, according to Dayton. Apply the oil at the front and back of the motor where there are lubrication ports in the housing. Always refer to manufacturer's instructions when oiling your oven's motor.

The blower motor in figure 1 requires regular re-oiling. Arrows point to where the application ports are located. Figure 2 shows a ball-bearing motor that does not require periodic re-oiling; this type of motor normally has a sealed housing. Over-lubrication is strongly discouraged.

The risk of premature oven stoppage is reduced if the blower motor is kept free of dirt and other debris. Loose blanket insulation from the oven and other foreign materials may get caught in the blower assembly and create an unbalanced state in the motor. Vacuuming or using an air jet can keep vent openings clean.

Also, check the blower wheel and extension shaft set screws periodically, especially if it is a continuous-duty unit. Tighten the screws as required. Verify that the general blower motor mounting is secure. Make sure that the mounting screws are snug, but do not overtighten because this might crush the isolation or resilient washers. The isolation washers are located behind the mounting plate and mounting screws (figure 2), between the plate and oven. Always replace the washers when damaged.

TIP 2: Consider Oven Location and Avoid Restricted Airflow

The physical location of the oven is another important consideration. Do not place the oven where the airflow around the blower motor is blocked. Be careful where the specimen or product is placed inside the oven. Restricting the air inlets and outlets (figure 3) reduces airflow through the entire oven, resulting in premature element failure and poor performance.

TIP 3: Use Correct Power

Operating on reduced power can result in poor performance. A classic example of this problem is operating a 240 VAC oven on 208 VAC, which results in a 20 percent power reduction. If you experience unsatisfactory operating conditions because of reduced power, correct with a buck-boost transformer.

TIP 4: Check Your Heating Elements

Burnt out heating elements result in reduced power and loss of performance. If oven performance drops off or it takes longer than normal to heat up, then check the elements. One way is to check the resistance of individual elements with a digital multimeter. For safety reasons, always first turn off power to the control system. Once the power is off, systematically disconnect each element from the circuit, connect the voltmeter across the leads, and set the meter to ohms. A high reading (infinity) would indicate a burnt-out element; a low reading (below 100 ohms) would indicate a normal or good element.

A second method is an amperage check of elements. This involves a clip-on ammeter to check the current draw. To begin, clip the meter around one of the leads going to the bank of elements. If both leads are attached at the same time, each one will cancel out the other. Turn system power "on" and set the temperature controller for 100 percent output. If the current draw is lower by more than 10 percent of the data label rating, you should check each element independently and systematically.

When checking individual elements, manually set the controller to 100 percent. Be sure only one lead at a time is attached to an ammeter. No current reading indicates a possible bad element. After each reading, return controller output to 0 percent to avoid overheating the oven. Finally, perform a resistance check on the element to verify a failed element.

Depending on the type of elements used in the oven, different replacement instructions normally apply. One item to always remember is that power must be disconnected from the oven before replacing the heating elements. Failure to do this simple procedure may result in personal injury or death.

TIP 5: Check Your Thermocouples

If the oven shuts off because of a sensor break, the oven temperature sensor or its wiring may be at fault. There could be two problems that need correcting. The first is an open/broken thermocouple or a broken extension lead. The second type, which occurs less frequently, is a shorted lead outside of the oven.

The first malfunction most often occurs on the bead, where the two wires of the thermocouple meet at the sensing unit inside the oven. Remove the thermocouple from the oven and visually inspect the thermocouple wires for cracks or breaks, especially at the tip of the thermocouple or bead. Use an ohm meter connected across the thermocouple leads to check for continuity on the thermocouple. Before using the meter, disconnect the thermocouple from the control system.

A broken extension lead may be as obvious as a break at the connector outside the oven or hidden in the middle of the lead. To fix a break at the connector, strip back and connect at the end of the lead. An ohm meter is needed to find a break in the lead's center. Use the meter to check for continuity through the leads. If discontinuity is noted, repair by simply replacing the extension lead with the same type of lead.

If the oven controller reads ambient (room temperature) even though the oven is obviously hot, this may indicate a shorted thermocouple where two thermocouple wires (leads) are touching. When the bare wires make prolonged contact, this creates the cold junction described above. To repair, simply separate the leads.

If you need to replace the entire thermocouple, replace it with the exact same type of thermocouple that was previously used in the oven. When replacing, bend the new thermocouple to match the original configuration. Observe the polarity. If the temperature reading drops as the oven temperature rises, the polarity of the thermocouple is reversed. Correct this polarity problem by stopping the heating process and reversing the thermocouple. If the temperature reading rises as the oven temperature rises, continue the heating process.

TIP 6: Plug Unnecessary Heat Losses

If your oven is equipped with a light, always use a port plug in the light socket when not using the light, even when operating the light socket within the oven's temperature rating (figure 4). The light socket may have a temperature rating that is less than the rating of your oven, especially a high temperature oven. Using a port plug in the light socket reduces heat loss and prevents the socket from malfunctioning from the heat. Always replace the port plug when cracked or damaged.

TIP 7: Inspect Door Gaskets and Port Inserts

Inspect the gaskets on the oven door and other port inserts periodically for breaks, torn gaskets and missing sections. If you feel heat escaping from the oven, there is likely to be torn gaskets.

TIP 8: Check Mounting and Slide Assemblies

Ovens designed for materials testing may require special mounting. Mounting and slide assemblies need to be checked on a regular basis to ensure that all locking devices operate properly.

TIP 9: Use Water-Cooled Accessories Intelligently

If you tap very briefly on a hot iron, you may not get burnt. But, if you keep your hand on it for a longer time, there is enough time for heat transfer, and you will get burnt. This analogy is similar to what occurs with too rapid of a water flow in cooling accessories. When using water-cooled accessories, avoid excessive water flow rates. Too high of a flow rate does not allow enough time for heat to be removed from the load train or retort. Failure to remove enough heat from the load train or retort could damage retort seals, accessories or a transducer, if present.

TIP 10: Cool Correctly

In those applications that require it, cryogenic cooling is the preferred method of bringing an oven to a low temperature. Cryogenic cooling is effective if you follow a few tips. When installing and using CO2 or LN2 with solenoid valves:

Do not use regulators between the CO2 siphon tank or LN2 tank and oven.
Avoid using manifolds. Changes in the cross section of the liquid path can result in solidifying the liquid.
Do not exceed the pressure rating of the solenoid valve.
Use proper ventilation when cooling. The operator's life you could save might be your own.

Choosing an oven and its accessories is often a daunting process. From the blower motor and elements to port plugs, oven maintenance is vital to oven longevity and operator safety. Nothing guarantees the eternal life of any product, but by following these 10 tips, you will understand some things to look for when planning your next oven purchase.

APPENDIX K. LIGHTING MEASURES

Lighting O&M can include all interior and exterior fixture types. Specific controls are described in the measures.

Table 15. Persistence of lighting measures

Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables	Verification Ability
Occupancy sensor controls (wall switch)	1 year. The average estimated useful life (EUL) in six TRMs is 10-years.	Large potential to use as wall switch. High level of human interaction and override.	Maintain/repair controls	Annual replacement	Per control	13% to 90% from Hubble documentation depending on space type (10% - 50% LBNL Design Guide)	Total connected kW and pre/post operating hours, number of controls	Easy - power or time-of-use (TOU) logger based
Lighting controls - ceiling sensors, high bay sensors, EMS/digital controls.	3 years. The average EUL in six TRMs is 10-years.	Less override and human interference in operation. EMS would require trending logs.	Maintain/repair controls	Annual replacement	Per control	13% to 90% from Hubble documentation depending on space type (10% - 50% LBNL Design Guide)	Total connected kW and pre/post operating hours, number of controls	Easy - power or TOU logger based
De-lamp	3 years. The average EUL in six TRMs is 10-years.	Once removed, less likely to be installed unless area usage changes.	Remove lamps	One time removal	Per fixture	Savings percentage is site and space specific. The rule of thumb given is two 4' lamps are required for every 64 FT1	Total connected kW and pre/post operating hours, number of controls	Easy - power or TOU logger based

Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables	Verification Ability
Incorporate lighting into centralized building control	3 years	Trending required for verification	Identify circuits and establish schedules	High capital cost to control contactors	TBD This may not be O&M. High capital cost	35%-40% (Facilitiesnet 2011)	Total connected kW and pre/post operating hours, number of controls	Easy - power or TOU logger based
Use lower wattage lamps	3 years. The average EUL in three TRMs 10.5-years.	Once replaced less likely to be installed unless area usage changes.	Identify over lit areas	One time replacement	Per fixture	Savings percentage is site and space specific. The rule of thumb given is two 4' lamps are REQUIRED for every 64 FT^2	Pre and post wattage per fixture, total number of fixtures, annual operating hours	Easy - power or TOU logger based

Measure Name	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables	Verification Ability
Replace Incandescent bulbs	3 years (average EUL 4 TRMs 8-years)	Once replaced less likely to be installed unless area usage changes.	Identify incandescent bulb locations	Upgrade fixture	Per fixture	Divide Incandescent lamp wattage by 4 to estimate CFL wattage (For LEDs Lumen to Watt comparison Incandescents 10-17 lumens per watt, halogens 12-22 lumens/Watt, LED (White) 400-100 lumens per watt. At high end, LEDs are 4x more efficient than halogens). Phillips about to introduce 200 lumen per watt 4'LED - projected savings of 50% over T8 lighting systems.	Pre and post wattage per fixture, total number of fixtures, annual operating hours	Easy - power or TOU logger based

Notes:

TRM review: - included in several TRMS - Savings approach varies- lifetime varies

Literature review: - many lighting O&M guides but no cost consensus.

No specific SOP identified. Guidance available from LBNL Design Guides.(http://ateam.lbl.gov/Design-Guide/DGHtm/lighting.htm)

APPENDIX L. REFRIGERATED SPACE MEASURES

This includes low, medium, and high-temperature refrigerated showcases and walk-in coolers. These cases and coolers can either be piped to a central refrigeration plant or self-contained units with DX compressors.

Table 16. Persistence of refrigerated space measures

End Use	Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables
Refrigerated Spaces	Defrost Scheduling	Optimize defrost times	2 years (average EUL in two TRMs is 11-years)	Persistence applies to electric resistance and hot gas bypass. Persistence depends on timer settings and maintaining humidity controls.	Maintain defrost controls and timers	Annual contract	Per Unit	Up to 6.0% (per NATIONAL GRID media trade guidebook)	Connected defrost kW, pre/post defrost schedules
Refrigerated Space Doors	Repair Door seals	Minimize air leak to showcases	+3 years (4-year EUL in one TRM)	Savings consistent once repaired.	Repair/replace broken worn seals	As needed upon inspection	Per Unit	4 to 22 kWh per linear foot of gasket (Rauss 2008)	Linear feet of bad seal, case temperature. Refrigeration efficiency
Refrigerated Spaces	Evaporator Fans Controls	Stage and cycle evaporator fans	+3 years (15-year lifetime per Vermont TRM)	Maintain controls that optimize evaporator fan operation.	Maintain fan controls	Annual contract	Per Unit	30% 0f fan usage (Washington State University), 13% to 59%	Fan kW, pre/post operating hours, compressor efficiency

Notes:

TRM review: Observed in several TRMs; primarily evaporator fan controls, door heaters, and defrost schedules

Literature review: limited cost information available.

Refrigerated showcases not part of industrial projects

Refrigerated warehouses, cryogenic chambers, and other refrigerated spaces are industrial end uses

SOP for refrigerated warehouses applies to these measures.

APPENDIX M. REFRIGERATION PLANT MEASURES

These O&M measure apply to multiple compressor systems in commercial and industrial facilities. They include ammonia systems and zeotropic chlorofluorocarbons.

Table 17. Persistence of refrigeration plant measures

Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables
Compressor staging	Optimize plant operation	3 years (12.5 year EUL in two TRM refrigeration plant measures)	Controls strategies are not changed when plant loads change.	Maintain chiller plant controls	Annual	Site specific	30-50% (per NATIONAL GRID media trade guidebook)	Total plant kW, operating hours
Discharge pressure reduction	Compressor controls	3 years (12.5 year EUL in two TRM refrigeration plant measures)	Controls strategies are not changed when plant loads change.	Maintain chiller plant controls	Annual	Site specific	0.5% reduction for every 1-psig decrease	Total plant kW, operating hours
Raise suction pressure	Compressor controls	3 years (12.5 year EUL in two TRM refrigeration plant measures)	Controls strategies are not changed when plant loads change.	Maintain chiller plant controls	Annual	Site specific	Power reduced by 2% for each 1-psi increase in suction pressure (Singh for Emerson)	Total plant kW, operating hours

Measure Name	Expanded Measure Includes	Persistence	Risks to Persistence	Required Task to Obtain Persistence	Maintenance Requirements	Implementation Cost	Average savings (%)	Primary Variables
Cooling tower control tuning	Optimize tower operation	3 years (12.5 year EUL in two TRM refrigeration plant measures)	Controls strategies are not changed when plant loads change.	Maintain chiller plant controls	Annual	Site specific	Considered custom measure - limited data - most references are for HVAC not refrigerated plants	Total plant kW, operating hours
Maintain compressor control	Compressor controls	3 years (12.5 year EUL in two TRM refrigeration plant measures)	Controls strategies are not changed when plant loads change.	Maintain chiller plant controls	Annual	Site specific	7%–12% based upon local and system configuration (Singh for Emerson)	Total plant kW, operating hours
Smart or liquid defrost runtime	Compressor controls	3 years (12.5 year EUL in two TRM refrigeration plant measures)	Controls strategies are not changed when plant loads change.	Maintain chiller plant controls	Annual	Site specific	Considered custom measure - many variables	Total plant kW, operating hours
Suction temperature - set to float	Compressor controls	3 years (12.5 year EUL in two TRM refrigeration plant measures)	Controls strategies are not changed when plant loads change.	Maintain chiller plant controls	Annual	Site specific	Up to 8% (Singh for Emerson)	Total plant kW, operating hours

Notes:

TRM review: Measures found in several TRMs: primarily, evaporator fan controls, door heaters, and defrost schedules

Literature review: limited cost data available

These measures are site specific. Persistence is dependent upon maintaining required control set points. Refrigeration systems are crucial to operations and are often highly controlled and maintained. The issue becomes O&M for energy efficiency, which may be outside of their internal requirements.

Activities to minimize risk to persistence:

- Implement and maintain chiller plant logs
- Record data from EMS or refrigeration control systems
- Set up remediation plan.

Refrigeration Plant SOP

Source: Maxon, Steve. Preventive Maintenance: Keeping Refrigeration Equipment in Shape. http://www.achrnews.com/articles/98243-preventive-maintenance-keeping-refrigeration-equipment-in-shape

All mechanical equipment needs periodic service to keep it in the best operating condition. Good service can mean the difference between a few mechanical malfunctions or continuous problems.

The following is a guide to developing a comprehensive preventive maintenance program.

To properly maintain a system, all the major components should be included in the maintenance schedule. These include the evaporator(s), compressor unit, and condenser.

For this article, only air-cooled condensing units will be discussed. Units with water-cooled condensers or towers require specific inspection methods, but the other components of those systems can be considered within the context of this article.

Evaporators

Check the evaporators monthly for proper defrosting. Ice accumulation on the evaporator coil can cause inefficiencies in the operation of the system, and can be detrimental to the coil surface itself.

Every six months:

1. Tighten all electrical connections in the electrical panel.

   - Check for frayed wiring insulation and corroded terminals, and make certain all spade connections are tight.

2. Check fan motors and blades.

   - Do the blades turn freely? Check the blades for unusual wear patterns or stress fractures. Clean the surface of each fan blade. Replace any worn blades and tighten the fan set screws.
   - On motors with lubrication fittings, apply the correct lubricant. Replace any motor that is hard to rotate or has worn bearings.

3. Check all defrost heaters.

   - Make certain heaters are in the correct position for maximum heat transfer to the evaporator coil. Follow the manufacturer's recommendations.
   - Check each heater for correct amp draw.
   - Check the voltage at each heater terminal.

- Make certain the heater terminals are in good condition.

4. Clean the drain pan and check for proper drainage.

   - All foreign material should be removed from the drain pan. The pan should drain freely.
   - The drain line should be free-draining with visible slope away from the evaporator.
   - Check the drain line heater in applications below freezing.

5. Clean the evaporator coil surface.

   - The coil should be washed periodically to remove dust and other foreign materials that might have been drawn into the fins. A commercial-grade cleaning foam can be used. Follow the label directions of the appropriate cleaner to clean refrigerant coils.

Compressor Units

<u>Every six months:</u>

1. Tighten all electrical connections.

   - Check for frayed wiring insulation and corroded terminals. Replace damaged wiring.
   - Make certain all spade connections are tight.

2. Check all electrical components.

   - Electrical contactors should be inspected closely for worn and pitted contact points. The points should be cleaned and polished. Check for any discoloration in the conductors, which may indicate a loose wire or a dangerous overcurrent condition. Any foreign material found in the contactor should be removed.
   - Inspect the defrost timer motor. Clean the contact points and lubricate the gears of the clock. Make certain the entire clock mechanism rotates freely.
   - Check all relays for worn points; replace relay if necessary.
   - Check the electrical connections inside the compressor electrical box.

3. Check the operation of the control system.

   - Check all pressure controls for proper operation and set points.
   - Check the safety controls. Make certain the oil safety and high pressure controls are functioning.
   - Check the operation of the room temperature thermostat. Make certain the liquid line solenoid valve closes completely and the compressor pumps down and cycles off.

4. Check the oil level in the compressor.

   - The oil level should be at or between one-third and two-thirds of the sight glass.
   - Check the operation of the crankcase heater.

5. Check the operation of the defrost controls.

   - Under most conditions, the timer should initiate the defrost. Make certain the defrost termination temperature control stops the defrost cycle and allows the evaporator fans approximately 2 min of delay time before restart.

6. Check the condition of refrigerant line insulation.

   - Open, torn, or waterlogged insulation provides little benefit to the system. If the insulation is in poor condition, replace it.

7. Check for the proper refrigerant level in the system.

   - The liquid line sight glass should be clear and full of liquid refrigerant during normal operation. If not, find and repair the leak, then charge enough refrigerant into the system to maintain a clear sight glass.

8. Check the system superheat at the condensing unit.

   - Suction superheat should be checked at the compressor as follows:

     a) Measure the suction pressure at the suction service valve of the compressor and determine the saturation temperature corresponding to this pressure from a temperature-pressure chart.
     b) Measure the suction temperature of the suction line about 1 foot back from the compressor using an accurate thermometer.
     c) Subtract the saturated temperature from the actual suction line temperature. The difference is superheat.

   - Too low a suction superheat can result in liquid being returned to the compressor. This causes dilution of the oil and eventual failure of the bearings, rings or, possibly, valve failure.
   - Too high a suction superheat will result in excessive discharge temperatures, which cause the oil to break down and result in piston ring wear and piston and cylinder wall damage.
   - For maximum system capacity, suction superheat should be kept as low as practical. (Heatcraft recommends the superheat at the compressor be no lower than 30Â°F.) If adjustments to the suction superheat need to be made, the expansion valve at the evaporator should be adjusted. Follow the manufacturer’s recommendations.

9. Check all capillary and super hose lines for signs of wear.

   - Make certain all capillary and super hose lines are secure and do not rub against objects that can cause refrigerant leaks.

10. Replace all missing valve caps and unit covers.

Condensers

Every six months (sooner if local conditions cause clogging or fouling of air passages through the finned surface), perform the following:

1. The condenser coil should be cleaned and washed.

   - Clean periodically with a brush, vacuum cleaner, pressurized water, or commercially available coil cleaning foam. If a foam cleaner is used, it should not be acid based. Follow the label directions of the appropriate cleaner.

2. Check the operation of the condenser fans.

   - Check that each fan freely rotates.
   - Tighten all fan set screws.
   - Check the fan blades for signs of stress or other wear features. If any unusual wear is seen, replace the blade.
   - Lubricate the motors if applicable. (Most condenser motors are permanently sealed and do not require lubricating.) Replace any motor that is worn.

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