HVACR Protocols and Training for a DER World

Joe Schmutzler, Chair, Western HVAC Performance Alliance Inc.

ABSTRACT

With the increasing complexity of Heating, Ventilation, Air Conditioning, and Refrigeration (HVACR) systems, quality HVACR education and training is becoming ever more important. Add to this the introduction of Distributed Energy Resources (DER) and increasing customer engagement in energy markets, an HVACR technician's role is central to an optimized commercial and industrial building's performance. Proper understanding and maintenance of these systems provides not only energy and comfort benefits but ensures that demand reductions are available when called upon. It is also incredibly important that technicians and maintenance staff fully understand how systems operate together so that they do not disconnect necessary equipment, but also know how to properly maintain various components as a system. The next generation of HVACR training programs will need to develop quality instruction methodologies for both new trainees as well as existing maintenance staff seeking to maintain their certifications.

Many educational and industry organizations are striving to fill this need, but an integrated approach that provides for a continuous learning methodology stands the best chance of achieving an optimal result for the HVACR industry. In order to achieve this result, it will be necessary for HVACR technicians to regularly update their training, and for educational organizations to stay on top of changes in the industry to meet the needs of their students in a timely manner. The Western HVAC Performance Alliance Inc. (WHPA) is working with manufacturers, educational organizations, energy utilities, and research institutions to find processes that can maximize training that achieves the goals of efficiency, comfort, and low cost.

Introduction

HVACR maintenance as long been an issue that the energy efficiency sector has worked to improve in order make certain that these systems operate in an optimal fashion in order to reduce energy consumption and demand. An emerging factor in this market is the need for HVACR systems to interact with grid signals in order to reduce load at specified times, or possibly increase demand in the future as excess generation starts to become more common with higher percentage of renewable energy penetrations on the grid. A well-educated workforce that receives regular updates to their training and has the proper tools in order properly diagnose and maintain this equipment will be necessary to achieve the full benefits of grid-interactive systems. Maintenance issues will be especially important for small to medium commercial space that look to participate in DR programs and other energy markets given that almost all these locations have outside firms managing service and maintenance.

Quality maintenance protocols will be a necessary part of the training for HVACR technicians, but also for reference while performing onsite maintenance. The protocols referenced in this document were developed by WHPA volunteers over a number of years reflecting a wide scope of industry expertise and backgrounds. The input reflected the experience of researchers, manufacturers, and implementation staff regarding proper maintenance programs. As training is always of limited duration it is of utmost importance that technicians have simple and easy reference materials to refer to during the service of the HVACR equipment.

Background

HVACR systems accounted for 54% of commercial building energy usage in the United State in the most recent Commercial Building Energy Consumption Survey (CBECS) by the Energy Information Agency (EIA 2016) as shown in Figure 1. While a good proportion of commercial heating is provided by non-electric sources, the majority is still electric heat (EIA 2016) providing a sizeable load that could be curtailed or moved if needed to allow these to provide various grid services. The interest in electrifying heating systems will increase the use of electricity in building systems, especially in the residential and small business markets that often have the greatest need for quality maintenance and service. Other loads such as lighting and water heating are often brought under a building Energy Management System that is often managed by the same staff who oversee the HVACR equipment, as shown in Figure 1.

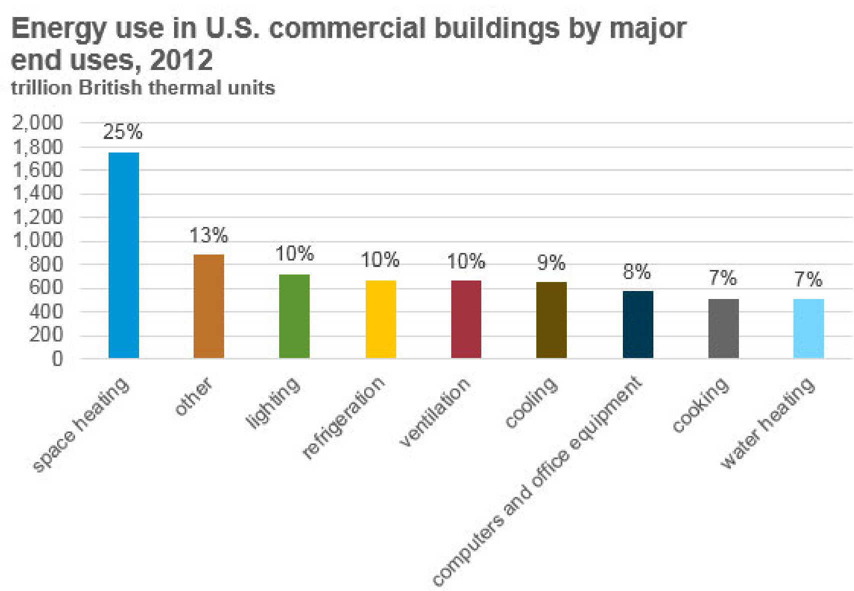

Figure 1. Energy use in US commercial buildings by major end uses, 2012. *Source*: EIA 2016.

Proper maintenance is well understood by the industry to reduce HVACR energy use, but there are benefits to a well performing system for DERs. The Pacific Gas and Electric Company (PG&E) Automated Demand Response technology incentive program mandates a load shed test prior to participating in the Demand Response events. This helps to verify the actual potential for shedding load, but also to verify that the HVAC equipment is operating properly and can provide the committed load reduction. If it shown during this test that the HVAC unit does perform as was assumed during the initial review, the equipment will need to be repaired and another load shed test completed to confirm the committed kW can be realized. According to the program implementation firm, Energy Solutions, this has happened to customers in the past and the HVAC units had to be serviced to bring them up to proper operation to pass the load shed test and demonstrate that the committed load shed kW could be achieved. (C. Riker, 2019) However, according to a commercial DR provider, “In general we do not impose any maintenance stipulations within our contracts- that steps outside of our boundaries a bit. Although we see issues from a controls/connectivity/setpoints/calibration standpoint via poor performance in a DR test/event, customers are generally motivated to repair these given their earning potential.” (N.Soles, 2019)

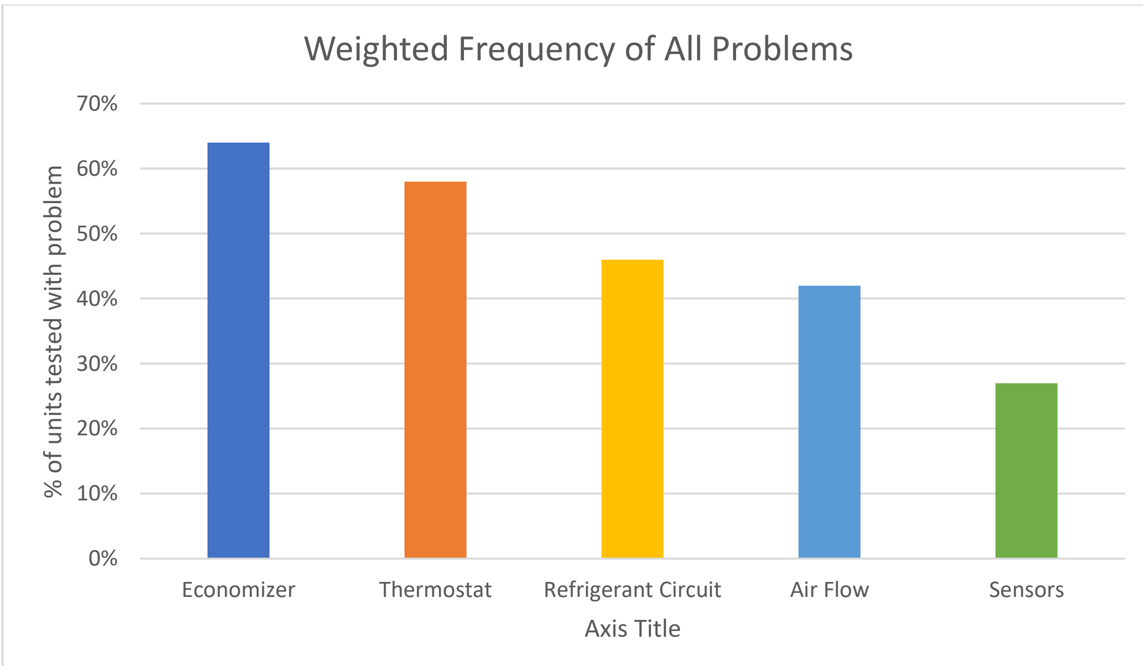

Figure 2. Weight average for All Programs – Frequency of Problems. *Source:* NPCC, 2004

The Northeast Power Coordinating Council (NPCC 2004) previous studies have found that refrigerant circuit problems are found on almost half of all HVAC units, as shown in Figure 2, which could undermine the actual capabilities of the units to perform as desired during a DR event. Economizer and airflow problems would also cause an issue with tenant comfort that could impact long-term participation in the program and reduce total program capacity during the season. Thermostat problems could range from improper setpoints that affect the impact on the tenants during the DR call, to not being able to control the HVAC unit properly to maintain comfort. Sensor issues may not impact the HVAC unit capability to setback during an event but could confuse the unit and have it turn the compressors on early or have temperatures get too high in the space and cause comfort issues for the tenants. All of these issues can help to undermine the HVAC unit’s ability to perform during the Demand Response event.

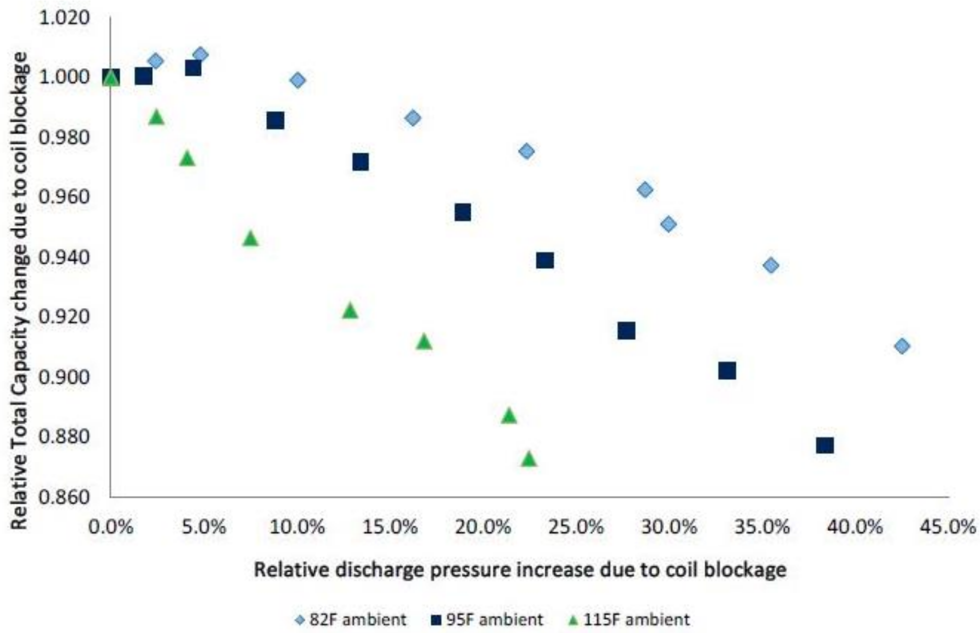

Figure 3. Relative discharge pressure increase due to coil blockage. *Source:* CPUC 2017

According to the CPUC's Laboratory HVAC testing Research Study conducted in 2017, refrigerant circuit issues could impact unit effective cooling capacity while still drawing the same kW. It has been found that, especially at higher temperatures, relative unit capacity starts to fall off as temperature rises and the percentage of coil blockage increases as shown in Figure 3. This would very easily impact the ability of the HVAC units to meet the cooling needs of the space. If the customer is implementing a DR methodology wherein they turn off compressors on a certain percentage of units, this would effectively increase that value beyond what was expected and would increase the risk that the HVAC units would not be able to meet the cooling needs of the space. (CPUC, 2017)

Proper maintenance can therefore be seen as a risk management tool to help alleviate concerns that demand reductions will not be available when called upon by the utility or system operator. (NPCC, 2004). This necessitates the need for not only properly maintenance training, but more importantly for proper protocols/processes to be in place before training takes place.

Implementation of Maintenance Programs

If the industry is to get to the point of being able to manage loads to aid the electric grid, putting proper practices in place will be a necessary step. For large commercial buildings, this is not as large of an issue as many already have onsite staff and large enough loads that they are often targets for outreach for Demand Response providers and the electric utilities themselves. However, the results of a large survey of California HVAC service contractors conducted by EMI Consulting found that the small to medium commercial sector is a large percentage of total energy usage that is much less likely to receive regular check-ups within the year in Figure 4. (California Measurement Advisory Council (CALMAC), 2012).

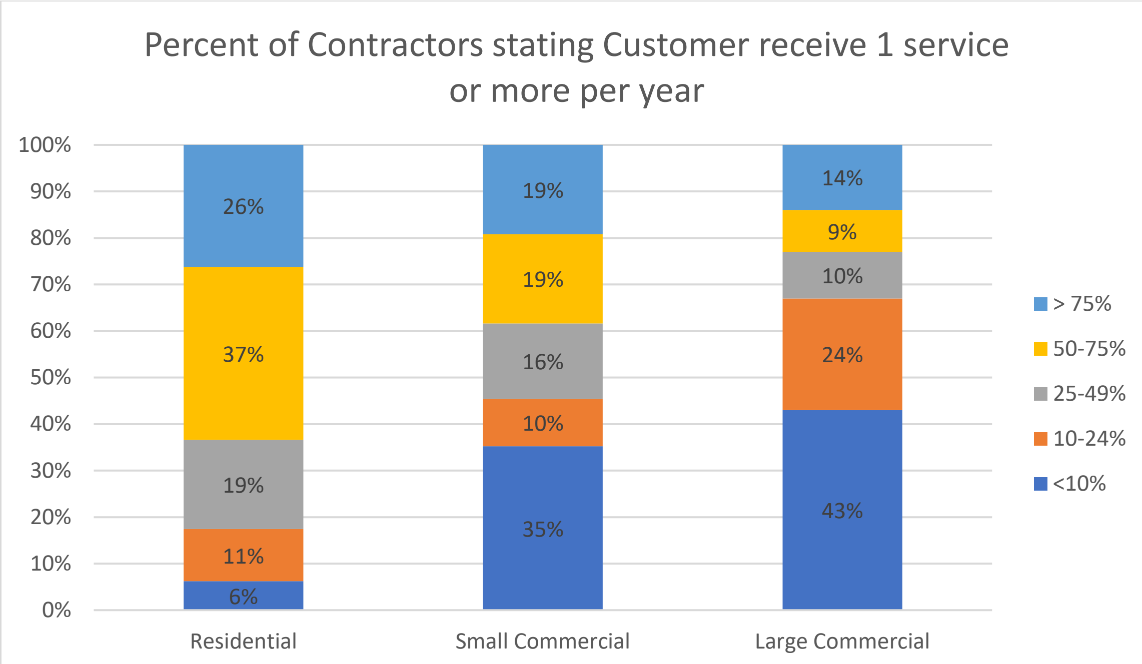

Figure 4. Maintenance Contractors' Reports of the Percentage of Customers who have at least One HVAC Check-Up per Year. *Source:* CALMAC 2012. *Note:* Survey participants indicate that 10 tons is considered the change point for moving from small to large commercial.

There also does not seem to be a good definition among contractors of what "quality maintenance" would be when servicing their units. Responses to a large survey of California HVAC service contractors also found very little agreement among participants as to what would constitute this level of maintenance. Many of the higher rated options were just vague notions with no specific details about what constituted quality maintenance as shown in Table 1. (CALMAC 2012)

Table 1. Contractors' Definition of Quality Maintenance

Task	Residential (n = 109)	Small Commercial (n = 110)	Large Commercial (n = 92)	Total (n = 311)
General Mention of Inspections/Testing	13%	21%	11%	15%
'Complete' or 'Proper' - Doing a Job the 'Right Way'	7%	14%	15%	12%
Inspecting Air Filters	14%	11%	1%	9%
Using a Checklist	9%	10%	7%	9%
Communicating Findings to the Customer	9%	8%	8%	8%
Peak/Optimum Performance	7%	8%	9%	8%
Inspecting Ductwork	10%	9%	2%	7%
Checking Refrigerant Charge	13%	5%	1%	7%
Customer is Satisfied	9%	5%	8%	7%
Inspecting Electrical Components	10%	6%	1%	6%
Inspecting Condensing Coil	10%	7%	0%	6%
Manufacturer Specifications	5%	4%	7%	5%
Cleaning the System	6%	8%	1%	5%

Contractors' Definition of Quality Maintenance. *Source:* CALMAC 2012. *Note:* Only shows responses for criteria mentioned by at least 5% of respondents. Multiple responses accepted.

WHPA Recommended HVAC Maintenance Protocols

As a precursor to training development, the WHPA's Committee on Quality Maintenance developed a service standard to be used by contractors and technicians in the field for HVAC systems that would also be potentially relevant to Refrigeration equipment as well. The required processes for inspection and maintenance of HVAC systems described in this Standard shall be implemented through a facility maintenance program: the plan under which maintenance actions shall be taken toward achievement of a set of objectives. This facility maintenance program shall be defined to preserve the condition of the HVAC systems and components in a manner that enables the systems to, at a minimum, provide the intended thermal comfort and energy efficiency and help to achieve the intended indoor air quality required for the facility.

The building owner shall be responsible for meeting the requirements of this standard. The owner may designate other parties that shall be authorized and contractually obligated to fulfill the owner's responsibility.

The facility maintenance program shall contain, at a minimum, the following essential elements, which are described below as part of ASHRAE/ACCA Standard 180:

4.1 Prepare for Facility Maintenance Program

4.1.1 Inventory Items to be Inspected and Maintained in Facility Maintenance Program

4.1.2 Define Facility Maintenance Program Requirements

4.1.3 Define Facility Performance Objectives

4.1.4 Create Maintenance Plan for Each System or Component

4.1.5 Create Facility Maintenance Program Requirements Document

4.2 Conduct Facility Maintenance Program

4.2.1 Authorize Facility Maintenance Program

4.2.2 Execute Facility Maintenance Program

4.3 Periodically Review Facility Maintenance Program

4.3.1 Periodically Provide Documentation of Facility Maintenance Program

4.3.2 Periodically Review Facility Maintenance Program

4.1 Prepare for Facility Maintenance Program

4.1.1 Inventory Items to be Inspected and Maintained in the Facility Maintenance Program. All HVAC systems or components that impact the facility's performance shall be inventoried. This list shall uniquely identify each system or component. It shall provide sufficient detail to allow establishment of appropriate condition indicators, inspection tasks and frequencies, the party responsible to perform the inspections and required actions in the event that unacceptable conditions are detected.

4.1.2 Define Facility Maintenance Program Requirements. One of the key elements of a high-quality facility maintenance program is to engage in dialogue between interested stakeholders to define the scope and contents of the program. In some form of decision-making process, facility performance objectives, and requirements for documentation, and periodic review shall be established and documented. For each system or component, maintenance plan requirements shall be established and documented, including tasks and frequencies, condition indicators, and required actions. Deliberations and ultimate decisions shall be documented.

4.1.3 Define Facility Performance Objectives. Objectives for the performance of the facility shall be established and documented. At a minimum, these objectives shall incorporate thermal comfort, energy efficiency, and indoor air quality metrics. Facility Performance Objectives shall be established for the facility as a whole, or for individual systems or components (so long as each system or component has at least the minimum required objectives). The metrics for reporting performance, targets, methods for assessing that performance, and the source of the facility performance objectives shall be established and documented.

4.1.4 Create Maintenance Plan for Each System or Component. For each system or component, a maintenance plan shall be included in the Facility Maintenance Program Requirements Document, describing the required tasks, the condition indicator(s) and the required actions specific to each task, the associated condition indicators (including both methods for assessment and criteria for acceptability), and the actions to be taken upon detection of unacceptable performance or conditions. The plans shall be defined specifically to meet the size, design, scope and complexity of the system or component.

4.1.4.1 Establish Inspection and Maintenance Tasks. Required inspection and maintenance tasks for each system or component shall be established and documented. This requirement shall include, for each system or component, the element to be inspected or maintained, a brief description of the required inspection or maintenance activity, and identification of the parties responsible for performing and authorizing the task.

4.1.4.2 Establish Frequencies for Each Task. The required frequency of inspection and maintenance tasks for the system or component shall be established and documented.

4.1.4.3 Establish Condition Indicators for Each Task. Required indicators of unacceptable conditions for each inspection and maintenance task shall be established and documented. Each indicator shall include two parts: the method of assessment to be used to measure or observe conditions that could lead to failure or performance degradation, and the criteria used to gauge whether or not the conditions are acceptable.

4.1.4.4 Establish Required Actions for Each Task. Actions required to be taken in the event of detection of unacceptable conditions shall be established and documented.

4.1.5 Create Facility Maintenance Program Requirements Document. A document describing all of the facility maintenance program plans and requirements shall be created. Any changes to the facility maintenance program shall be documented in a revision of this document.

4.2 Conduct Facility Maintenance Program

4.2.1 Authorize Facility Maintenance Program. Upon definition of the facility maintenance program, the responsible party shall authorize its execution.

4.2.2 Execute Facility Maintenance Program. All required activities laid out in the Facility Maintenance Program Requirements Document shall be performed as defined.

4.3 Periodically Review Facility Maintenance Program

4.3.1 Periodically Provide Documentation of Facility Maintenance Program. An inspection and maintenance documentation package shall be defined for the overall facility maintenance program. This documentation shall include, at a minimum. the Facility Maintenance Program Requirements Document, results of reviews, any recommendations made through the program, a customer-facing report that facilitates decision-making, and backup data that documents the program. Documentation shall contain sufficient record detail to support decision-making and archiving of actions. Documentation may be electronic or on paper (electronic is preferred), the format shall allow for easy access by all appropriate parties, and it shall be well organized, clearly labeled, and archived. At a minimum, required documents shall consist of the following:

- Readily accessible emergency information including emergency staff and/or agency notification procedures,
- Inventory of systems or components with associated condition indicators,
- Verification that demonstrates implementation of the maintenance plan, and
- Verification of progress towards meeting the facility performance objectives.

4.3.2 Periodically Review Facility Maintenance Program. The facility maintenance program shall be reviewed to evaluate its success and to ensure that expectations are being met. Possible needs for modification to the facility maintenance program shall be considered in this review.

The review shall be conducted at least annually, or more frequently if there are changes to the facility, such as: modifications to the facility that impact facility performance objectives, changes to its function or use in a way that impacts performance, changes to systems or components, the facility or one or more systems or components are found to be incapable of achieving their facility performance objectives, or upon documented recommendation from the maintenance provider.

The process for this review shall be laid out in the Facility Maintenance Program Requirements Document, and shall include, at a minimum, the following steps:

4.3.2.1 Measure and Summarize Results of Facility Maintenance Program. The means to measure or summarize the following shall be established and documented:

- Performance of the facility (according to assessment of performance objective metrics defined above)
- Responses to unacceptable conditions
- Documentation received
- Tasks carried out and their frequencies for included systems and components.

- Condition of systems and components

4.3.2.2 Compare with Expectations for Facility Maintenance Program. The measurements and summaries above shall be compared with the expectations for:

- Facility Performance Objectives
- Response to unacceptable conditions
- Documentation
- Level of effort for tasks carried out and their frequencies for all systems and components.
- Criteria that define unacceptable conditions.

4.3.2.3 Investigate Possible Causes for Each Discrepancy. Should there be any discrepancies between the measurements and summaries and the expectations, possible causes shall be investigated. Examples of possible causes include poor field practice, insufficient time budgeted for tasks, required component repairs are not made, underlying design issues are causing successive failures, systems or components are obsolete, conditions outside of the system or component are causing failure, climate related or operational issues are present, or equipment is shut down for repairs.

4.3.2.4 Consider Revisions to the Facility Maintenance Program for Each Discrepancy. If the results of the investigation indicate that the facility might benefit from maintenance changes, revisions to the facility maintenance program shall be considered. Changes may be made to any element of the facility maintenance program—facility performance objectives, inspection and maintenance tasks and frequencies, condition indicators (including method of assessment and criteria), response to unacceptable conditions, or documentation. All decisions made in these situations shall be well justified, well documented, and authorized.

Consideration of revisions to the facility maintenance program shall be mandatory, but the revisions themselves are optional, except in the specific case of unacceptable conditions that are detected in several subsequent inspections. Changes made in these situations shall, at a minimum, include one or more of the following:

- The unacceptable condition shall be remedied,
- The required inspection and maintenance frequencies shall be increased, or
- Some other aspects of the facility maintenance program shall be modified.

In any case, modifications shall be allowed only if the facility performance objectives still include the minimum required facility performance objectives defined in this Standard (energy efficiency, thermal comfort, and indoor air quality), the facility maintenance program is still designed to achieve the (new or revised) facility performance objectives, and the minimum allowed tasks and task frequencies are still met.. All other requirements of Standard 180 shall still be met.

The facility maintenance program shall be reauthorized upon any changes to the Facility Maintenance Program Requirements Document.

4.3.2.5 Reevaluate the Facility Maintenance Program for Each Revision. If the facility maintenance program is modified, the effectiveness of the modification shall be evaluated, and a follow-up review may be requested before the next annual review. (WHPA, 2016)

WHPA Reviewed Protocol for Refrigeration Components

At the 2015 WHPA in-person meeting, the following protocol was reviewed for submittal to Southern California Edison (SCE) for a possible refrigeration maintenance protocol. Further follow-up with SCE indicated a strong interest in developing this further to include in existing programs.

1. Objectives
    a. To propose an open and effective refrigeration cycle analysis methodology
    b. Create a framework that establishes the common components of the solution
    c. Provide for opportunities for different technology providers to fill in "details" and provide a mechanism for continuous improvement within the framework
    d. Provide a way to evaluate the different "details" provided by different parties
2. Approach
    a. Establish a solution framework
    b. Provide approved solution components
    c. Identify solution component evaluation criteria
    d. Provide advice for considering the evaluation criteria
3. Establish a solution framework
    a. The approach shall consider the equipment types being evaluated. The minimum equipment type factors that shall be considered are:
        i. Condenser design - it shall work for air cooled equipment
        ii. Evaporator design - it shall work for constant air volume direct expansion (DX) equipment
        iii. Metering device type - it shall work with TxV and fixed orifice equipment
        iv. Refrigerant type - it shall work with R-22 and R-410a refrigerants
        v. The design efficiency of the equipment - is shall work over the range of design efficiencies currently used in the field for non-residential comfort cooling
    b. The approach shall specify applicable test conditions and important procedures including:
        i. Range of condenser and evaporator inlet air conditions
        ii. Testing units with multiple circuits
        iii. Testing compressors with unloaders
        iv. Testing units with low ambient condenser fan controls
        v. Testing units with outdoor air ventilation including economizers
    c. That approach shall involve measuring the driving conditions under which the equipment is being evaluated. The minimum driving conditions that shall be considered are:
        i. Condenser inlet dry-bulb temperature (CIDB) or outdoor ambient temperature (AMB)
        ii. Evaporator inlet dry-bulb temperature (EIDB)
        iii. Evaporator inlet wet-bulb temperature (EIWB)

d. That approach shall involve measurements that are impacted by unit performance. The minimum performance measurements that shall be considered are:
   i. Low-side refrigerant pressure (SP)
   ii. High-side refrigerant pressure (LP) or (DP)
   iii. Suction-line refrigerant temperature (ST)
   iv. Liquid-line refrigerant temperature (LT)
e. The approach shall calculate performance indices (PIs), based on the measurements. The minimum calculated performance indices are:
   i. Evaporating temperature (ET)
   ii. Superheat (SH)
   iii. Subcooling (SC)
   iv. Condensing temperature over ambient (COA)
f. The approach shall provide "no fault" value expectations of the PIs for appropriate equipment type and driving conditions.
g. The approach shall calculate the variance of the calculated PIs relative to the "no fault" expectations for the PIs. (ΔET, ΔSH, ΔSC, ΔCOA)
h. The approach shall determine if ΔCOA and ΔET is acceptable or not. If not, service is required to correct this problem before refrigerant charge refinement is appropriate (next step).
i. If the ΔCOA and the ΔET are acceptable, refine charge based on ΔSH and ΔSC while maintaining acceptable ΔCOA and ΔET.

4. Provide approved solution components
   a. A "no fault" model that provides expected values of the PIs for appropriate equipment type and driving conditions
   b. Boundary in the ΔCOA and ΔET space that separates "acceptable" from "unacceptable" performance (Tier 1 fault detection)
   c. Refrigerant charge refinement algorithm based on ΔSH and ΔSC (Tier 2 fault detection)
5. Identify solution component evaluation criteria
   a. "No fault" model
      i. Must consider these equipment properties:
         1. Expansion device (e.g. TxV, Fixed Orifice)
         2. Rated efficiency
      ii. Must consider well established SH goal value dependence on driving conditions for fixed orifice units in an acceptable way
      iii. Must provide SC goal values appropriate for the preponderance of TxV units encountered
      iv. Must make a case that the "no fault" model performs well based on some combination of:
         1. Lab test data
         2. Manufacturers data
         3. Simulation results

v. Show that the proposed “no fault” model works reasonably well for the range of equipment types and driving conditions expected to be tested

b. Fault detection algorithms
    i. Show that the proposed Tier 1 and Tier 2 fault detection algorithms identify the following cases as “faults”
    ii. ET and SH are ok but SC and COA are low, which may be caused by a combination of insufficient low-side heat transfer compensated by insufficient charge
    iii. ET and SH are ok but SC and COA are high, which may be caused by a combination a refrigerant flow restriction compensated by excessive charge
    iv. Show that when the following faults are introduced at some reasonable level, the performance is judged “unacceptable”
        1. Too much or too little refrigerant charge
        2. Too large or too small restriction to refrigerant flow
        3. Too much or too little low-side heat transfer
        4. Too much or too little high-side heat transfer
        5. Inefficient compressor
        6. Non-condensables (contaminants) in the refrigerant or inappropriate fractionalization of non-azeotropic refrigerants

6. Provide advice for considering the evaluation criteria
    i. If the criteria are deemed too aggressive to be practical given the current state of the art, the criteria could be deemed acceptable if:
    ii. There is a recognition of the limitation per the specification
    iii. There is an openness to work towards a better solution or at least a willingness to adopt a better solution when one becomes available.

(WHPA, 2015)

Conclusions

Given the current level of quality maintenance in the HVACR sector, the training protocols in this document are just a starting point in the move toward the development of training that will marry the technical capacity and capability of field technicians with the ability to also communicate with and educate the customer throughout the process. The protocols also lay the foundation for this a sector to regularly provide quality outcomes for their customers.

The energy efficiency sector has long recognized proper maintenance as an avenue for kWh, kW, and therm savings. However, as we move into a world where customer loads are seen as a potential source of grid management it is imperative that HVACR service quality improves in order to help de-risk Demand Response programs and maximize benefits of this sector. Poorly maintained systems will reduce the physical capabilities of the HVACR systems, but also increase the likelihood of customer intervention to maintain comfort levels during a DR event. Proper understanding of these various demands will be needed if the industry is to fully realize the potential offered by this market.

References

CALMAC (California Measurement Advisory Council). 2012. California HVAC Contractor & Technician Behavior Study. San Francisco, CA.

CPUC (California Public Utilities Commission). 2017. Laboratory HVAC Testing Research for 2013-14 (HVAC5): An Introduction and Data Dictionary. San Francisco, CA.

EIA (Energy Information Agency). 2016. 2012 Commercial Building Energy Consumption Survey (CBECS). Washington, DC: EIA. https://www.eia.gov/consumption/commercial/

Northwest Power and Conservation Council (NPCC). 2004. Review of Recent Commercial Roof Top Unit Field Studies in the Pacific Northwest and California. Portland, OR

WHPA (Western HVAC Performance Alliance). 2016. Proposed changes to standard document. San Anselmo, CA.

WHPA (Western HVAC Performance Alliance). 2015. Open Specification Proposal. San Anselmo, CA.

(C. Riker, associate director, Energy Solutions, pers. comm., March 5, 2019).

(N. Soles, national accounts executive, CPower Energy Management, pers. Comm., March 14, 2019)