Lessons Learned from Field Observations of Commercial Sector HVAC Technician Behavior and Laboratory Testing

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ABSTRACT

This paper provides lessons learned from field observations of commercial sector HVAC technician behavior and laboratory tests of a 7.5-ton dual-compressor packaged unit with an economizer. Observations were conducted to evaluate and improve California commercial HVAC maintenance programs. The programs provide incentives for rinsing coils with water, adjusting airflow, testing/repairing economizers, adjusting/installing thermostats, or installing notched v-belts. Most of these measures are performed during normal preventative maintenance without incentives. Incentives are also provided for enrolling customers and establishing three-year maintenance agreements. Observations indicate that programs provide training on how to enter data into the program database, but don't provide sufficient training, tools, protocols, or feedback for technicians to improve energy efficiency. Field observations indicate a lack of understanding regarding how to properly diagnose faults and implement repairs. The problem appears to be with program design, implementation, protocols, and data collection and not with technicians who are working within established program parameters. The programs should be redesigned to provide more effective training, tools, protocols, and data collection. Laboratory tests were conducted to understand the impacts of observed faults. Tests indicate minimum outdoor airflow is 15% with economizer dampers closed. With dampers open from 10 to 30% efficiency is reduced by 5 to 62% compared to closed dampers. Tests of laboratory-optimal refrigerant charge indicate efficiency improvements of 7 to 26%, but superheat and suction temperatures are outside manufacturer specifications. Laboratory tests of +40% overcharge achieves manufacturer specifications, but causes a 14% reduction to a 2% increase in efficiency depending on damper position.

Introduction

Commercial and residential HVAC energy consumption in the United States accounts for 30% of average summer peak-day electricity loads, 22% of total electricity use, and 73% of total natural gas use in buildings (USEIA 2003, 2009). A 2002 study published by the Hewlett Foundation indicates that improved HVAC installation and maintenance represents one of the largest achievable opportunities for energy efficiency savings (Rufo 2002). Independent laboratory tests indicate that HVAC installation and maintenance faults can reduce energy efficiency performance by more than 76% (Mowris 2011). Evaluation results of HVAC installation and maintenance programs in California from 2006 through 2009 have shown very little achieved savings (KEMA 2010). This paper provides lessons learned from field observations of technician behavior in order to improve commercial HVAC maintenance programs. The paper also provides laboratory test results of a 7.5-ton two-compressor commercial packaged unit with an economizer and varying damper positions, refrigerant charge, and airflow.[1] The program market share of this unit is approximately 15%.[2] The 7.5-ton unit has six fixed-orifice metering devices on the header of each circuit. The unit was fully instrumented and tested in an AHRI-certified laboratory per ANSI/AHRI Standard 210/240-2008 and ANSI/AHRI 340/360-2007.

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[1] Laboratory tests are one component of an impact evaluation of HVAC maintenance programs. These tests are in process. A ton is a unit of cooling capacity equivalent to 12,000 British thermal units (Btu) per hour. The Btu is the energy required to raise one pound (lb) of water one degree Fahrenheit (°F).
[2] Program market share is based on 2010-12 tracking data.

Background

Commercial HVAC maintenance programs have failed to achieve potential savings (Hunt et al. 2010, KEMA 2010). Programs have historically failed to provide sufficient in-field technical training, proper measurement tools and procedures, diagnostic software, ride-along technical inspections, or feedback to track improvement. Programs have generally focused on simple measures such as coil cleaning, refrigerant charge adjustments, or economizer testing which are typically performed incorrectly. Improper measurement tools and procedures along with simple superheat (SH) or subcooling (SC) diagnostic methods cause misdiagnosis of faults. Technicians accidentally contaminate systems with non-condensable air and water vapor when attaching hoses to measure refrigerant pressure. Some technicians add refrigerant to systems using reclaimed refrigerant in violation of US EPA 608 regulations for handling of fluorocarbon refrigerants (USEPA 2003).

Field observations of commercial sector HVAC technicians indicate a lack of understanding regarding how to perform HVAC maintenance procedures to improve energy efficiency. Observations indicate that many technicians do not clean coils or diagnose and correct refrigerant charge and economizers per manufacturer instructions (Carrier 2005, Carrier 2010, Lennox 2008). Observed technicians did not maintain vacuum pumps or perform evacuations properly to prevent or eliminate non condensables and restrictions per manufacturer instructions (JB 2007, ASHRAE 2010). Lack of understanding of HVAC craftsmanship and fundamentals causes technicians to perform suboptimal maintenance and installation which reduces energy efficiency.

Methodology

The following four types of field observations were conducted: 1) pre-maintenance observations conducted at sites on commercial packaged air conditioning systems scheduled for service by participating technicians, 2) ride-along observations conducted while maintenance services were being performed by participating technicians, 3) post-maintenance observations conducted after program services were performed, and 4) observations of units that did not participate in the program.[3] Data loggers were installed on randomly selected units at each of the participant sites to measure time-series electricity use, weather data, refrigerant temperature and pressure, outdoor air, return air, mixed air, and supply air temperatures. In addition, supply airflow and outdoor damper airflow measurements were made on each unit before and after maintenance services were performed. Acid tests were performed on most refrigerant circuits along with spot measurements and observations all of which were recorded. Make, model, serial numbers, digital photographs, and measurements for each unit were collected. Educational training, experience, certification, tools, equipment, procedures, and technician diagnostic protocols were also recorded. Data collected during on-site field observations and interviews are used to evaluate behavior of technicians participating in the program and program data. Observation data are also used to evaluate participant and non-participant unit characteristics regarding faults that were identified during the observations.

Field Observation Results

Field observations were conducted of 73 participant air conditioning circuits and 22 non-participant circuits.[4] Pre-maintenance observations of circuits identified 707 issues or 9.7 issues per

[3] Observations are in progress and more observation activities are planned.
[4] Most packaged units have independent refrigerant circuits comprised of a separate compressor, evaporator coil, condenser coil, metering device, and refrigerant lines. Units larger than 5 tons can have 2 or more circuits.

circuit. Post-maintenance observations of 55 circuits identified 567 faults or 10.3 faults per circuit (18 have not been observed). During field observations participating technicians correctly diagnosed and repaired 52 out of 707 faults including installing 45 new air filter sets and 2 new contactors, securing 2 panels, restoring operation of 1 compressor, and correcting 2 blower fans from 24-hour operation. The most important maintenance faults impacting energy efficiency are improper damper position, compressor failure, refrigerant leaks, condenser fan failures, 24-hour blower-motor operation, belt-drive tension/alignment, non-condensables, restrictions, refrigerant charge, contamination, evaporator airflow, condenser coil blockage, economizer malfunction, and wiring. Faults per circuit increased by 6% based on ex-post observations of technicians servicing 55 circuits. Observations of 22 non-participant circuits identified 72 faults or 3.3 faults per circuit. Fewer non-participant faults were identified due to not having economizers which contribute 50% of faults, fewer belt-driven fans which contribute 10% of faults, and only evaluating refrigerant charge on 10 units which contribute 7% of faults.

Approximately 92% of technicians surveyed have issues with tools or procedures in terms of performing maintenance services. Approximately 50% did not have EPA low-loss fittings on their refrigerant hoses. Technicians that did have low-loss fittings did not purge their hoses of air and water vapor prior to attaching to Schrader valves. One technician used contaminated refrigerant from a reclaim tank to add refrigerant, which is a violation of US EPA 608 regulations (USEPA 2002). These faults cause non-condensables or contaminants to enter the system when adding refrigerant or attaching hoses. None of the observed technicians used proper tools or procedures to measure relative humidity, airflow, economizer operation, damper position, coil cleaning, or fan belts. Technicians did not check or install fan belts with proper tension or alignment which causes reduced airflow, efficiency, and premature failure. One technician increased minimum outdoor air damper position from closed to 1-finger open. Three did not repair broken open dampers, and none of the technicians performed economizer repairs while being observed.

Participating contractors are required to meet program eligibility requirements.[5] The programs provide training to contractors, technicians, sales, and administrative staff on how to market the program and enter data into the online program database system. Participating customers in the statewide programs must sign a three-year maintenance agreement with qualified contractors. Customers who sign up and whose contract is approved by the statewide program receive incentives. Contractors receive incentives for enrolling customers in three-year maintenance agreements and performing maintenance services. The statewide commercial HVAC maintenance programs are based on the ACCA 180 Standard which lists 30 inspection/maintenance tasks for Rooftop Units (see table 5-20 of ANSI/ASHRAE/ACCA 2008). In order to receive incentives for measures in one program, contractors must enter data into a program database for each cooling service assessment (CSA) and bring the unit up to the program assumed performance "baseline." The baseline is not defined in terms of maintenance tasks technicians need to perform to diagnose and repair deficiencies in order to improve energy efficiency.[6] Observations indicate that technicians do not test, diagnose or repair all deficiencies in order to bring units up to a performance baseline. The CSA includes 40 or more maintenance tasks–30% more than ACCA 180. The data collection software includes approximately 220 to 250 questions and 310 to 350 fields of data per unit. Data collection requirements were expanded in 2013 to include each circuit. Observations of training and technicians found that it can take an additional 2 to 4 hours to enter data for one unit into the program database.

[5] C-20 license, consistent financial profitability, insurance requirements, minimum 5-years business experience with no outstanding claims with the Better Business Bureau, minimum of three technicians who meet the program qualifications, customer and supplier references, on-staff engineering support, and preventative maintenance scheduling system. One large property management customer without a C-20 license is participating in the program using their maintenance employees.

[6] According to one program "bringing a unit to baseline" means the contractor has completed all CSA tasks, required repairs, and maintenance to make the unit operate efficiently.

The programs are implemented in three utility service areas with three statewide programs and two local programs. The local programs do not require three-year maintenance agreements and are not based on the ACCA 180 Standard. Data loggers were installed on 44 units in two service areas to monitor pre and post-load impacts. Pre- and post-observations of program participants were conducted of technicians performing maintenance on units with data loggers. The study was designed to accept observation bias of master technicians in order to observe methods used to perform maintenance and fully understand changes that would be recorded on data loggers. The study was not designed to address all potential forms of bias. Failure to notify the evaluation team prior to contractors performing program services introduced "sample" and "follow-up" bias (Sica 2004). This occurred for work performed by two contractors on 4 units, not observed in one program. Therefore, only 82% of that program's pre- and post-metering data logger sample had observations of technicians performing work on monitored units. For the data logger sample the study attempted to work cooperatively with each program implementer to recruit contractors who received the largest share of incentives. One program recruited contractors for data logging who performed 100% of work. The other program recruited contractors for data logging who received less than 13% of total incentives. This introduced "sample" and "referral" bias.

Program trainers in one service area intervened to assist technicians with data collection during EM&V observations conducted in 2012 and 2013. During another observation in the same service area, program personnel intervened and stopped observations of a technician who was in the middle of repairing a 10-ton heat pump unit with data loggers installed. One circuit was overcharged and had high condenser saturation over ambient temperature indicating the presence of non-condensables or condenser heat transfer issues. The unit also had partially closed return dampers, missing economizer dampers, and approximately 50% outdoor air 24-hours per day which reduces efficiency by 12 to 125%. Observations of how technicians diagnose and repair units with multiple faults are critical to the research study. Interventions by program personnel during EM&V observations will introduce examination bias into the research study.[7] Bias will distort the data and produce results that are not representative of the target population. An important goal in study design is to produce results that can be extrapolated to the target population (Sica 2004). Future EM&V studies should work cooperatively with program personnel to mitigate bias.

One statewide program design claims that "error checking and fraud prevention" are performed using "real-time error checking and trend analysis algorithms to alert the technician of data entry errors" which "allows the technician to correct errors while at the jobsite, preventing the need for costly return trips."[8] The program also claims to check each incentive application. Observations indicate that technicians in this program enter CSA data on paper forms. Contractor office personnel use technician supplied paper forms to enter CSA data into the program database about 30 to 180 days after work is completed. In 2013 the program attempted to require technicians to enter on-site CSA data directly into the program database software. One technician was observed doing this, but it took too much time and the technician indicated he was reverting back to using paper forms.

Interim field observation results indicate that 85% of technicians previously performed maintenance measures in the same way. Technicians in statewide programs provided the following comments: data collection process is difficult to understand and complete, tasks are out of order, there are too many irrelevant questions, and too much time is required to collect and enter data. The average statewide participant satisfaction score for data collection is 4.3 +/- 1.8. Local program participants had no complaints and provided higher average satisfaction scores for data collection of 9.0 +/- 0.9. Twenty-three percent of technicians are unfamiliar with the ACCA 180 Standard. Most of these are local

[7] Study examination bias refers to the exclusion of technically limited or incomplete studies or the inclusion of only participants who are deemed competent to produce a technically adequate examination.

[8] The trend analysis is supposed to allow the program implementer to identify technicians who are attempting to game the system through a multi-dimensional analysis that compares measure mix, maintenance timing (using time stamps as the technician is prompted through the ACCA 180 protocol) and audit history (contractor track record).

program participants. All participants indicated that quality maintenance is important. Seventy-three percent of participants indicated they had pre-existing maintenance agreements with customers to perform quarterly, semi-annually or annual maintenance. Those that did not have pre-existing maintenance agreements are in local programs. The average statewide participant satisfaction score for training is 6.9 +/- 1.7, and the average local participant satisfaction score for training is 9.8 +/- 0.3. The average statewide participant satisfaction score for incentives is 5.8 +/- 1.5, and the average local participant satisfaction score for incentives is 6.4 +/- 1.4. The average statewide participant overall satisfaction score is 6.4 +/- 2.1, and average local participant overall satisfaction score is 9.0 +/- 0.8. The sixth largest participant in one of the statewide programs in terms of incentives is a customer and not a contractor. Employees of this participant perform maintenance services on units they own that are 60-tons or larger with on-board diagnostics communicating with an energy management system (EMS). While large units may meet the program eligibility requirements, they are not covered by the energy savings work paper which focuses on units with no on-board diagnostics or EMS controls. Seventy-one percent of participants indicated that they test and repair economizers. Observed technicians did not test or repair economizers, and most observed units have economizers.

The evaluation study obtained paperwork for 17 units from the on-site observation sample. The program implementer provided data submitted by the contractor from the program database for these 17 units. Comparisons of technician paperwork to the program database found issues with incorrect entries for temperatures, pressures, required subcooling, and required superheat. Some programs do not collect pre- and post-data for each circuit so it is impossible to fully understand if any errors are occurring. Some of the programs do not perform ride-along inspections or in-field training on each measure. Therefore, it is difficult to evaluate data entry errors by technicians or office personnel due to the way the programs are implemented. Additional efforts will be made by the evaluation team to obtain paperwork after site observations are completed to evaluate data entry errors for the programs.

Fault Detection Diagnosis and Repair

Correct fault detection diagnosis (FDD) and repair are important for HVAC maintenance. If technicians cannot correctly perform FDD and repairs, then it will be impossible for HVAC maintenance programs to realize *ex ante* savings. Two studies indicate problems correctly identifying faults using the California Energy Commission (CEC) refrigerant charge and airflow (RCA) protocol (Mowris 2011a, Braun 2013). Braun indicated that the CEC RCA protocol identifies faults in 46% of cases without faults, misdiagnoses in 25% of cases with faults, and does not detect faults in 32-55% of cases with faults. Mowris indicated that the CEC RCA protocol does not identify severe non-condensable and restriction faults in 17.8% of cases with faults. Mowris provided recommendations to enhance the CEC RCA protocol including field measurement instrument accuracy standards, procedures to prevent contamination, and diagnostic protocols to differentiate non-condensables and restrictions from refrigerant charge faults.

Are technicians correctly following a poor protocol or are errors compounding due to incorrectly implementing a poor protocol? The evaluation found problems with both issues in addition to lack of awareness and training regarding manufacturer protocols provided in installation manuals (Carrier 2005). The current CEC RCA protocol is based on at least three manufacturers' SH, SC, and proper airflow protocols which have been available for decades (Carrier 1986, Carrier 1998, Trane 1996, York 1991). These protocols are provided by manufacturers to help technicians evaluate proper RCA when no other faults are present. They are not designed to diagnose non-condensables, restrictions, heat transfer issues, static pressure, or outdoor air damper position.

FDD of outdoor airflow through economizer or make-up air dampers is not evaluated by program technicians and not included in efficiency tests used to rate packaged units. The following "rule-of-thumb" is assumed by most technicians: closed dampers 2% outdoor air (OA), 1-finger 10%

OA, 2-fingers 20% OA, 3-fingers 30% OA, and fully open 100% OA.[9] Approximately 74% of units observed in the programs have economizer or make-up air dampers set to one or more fingers open. Observations at a site with small packaged units found 75% of make-up air dampers fully open.

Laboratory Tests

Table 1 provides laboratory tests of the relative energy efficiency ratio (EER*) versus outdoor air damper position for a 7.5-ton two-compressor packaged unit and airflow of 3,000 standard cubic feet per minute (cfm).[10] Indoor (ID) conditions were 75°F drybulb/62°F wetbulb for all tests. Outdoor (OD) conditions vary as follows: 95°F drybulb/75°F wetbulb, 82°F drybulb/68°F wetbulb, and 115°F drybulb/80°F wetbulb. The laboratory tests were performed with no economizer installed and with an ASHRAE 90.1 compliant economizer rated at 10 cfm/ft^2 or 67.1 cfm outdoor air leakage with closed dampers per ANSI/AMCA Standard 500-D-12 (ANSI/AMCA 2012). The actual outdoor air leakage with closed dampers was 462 cfm or seven times greater than the 67.1 cfm rated leakage (**Table 1**).

Table 1. Relative Efficiency (EER*) versus Outdoor Air Damper Position for 7.5-ton Unit

Test	Outdoor Air %	Outdoor Air (cfm)	EER* 95/75°F OD 75/62°F ID	EER* 82/68°F OD 75/62°F ID	EER* 115/80°F OD 75/62°F ID
No Economizer Factory Charge AHRI Rating	4.5	135	10.0	12.0	7.5
Closed Economizer Dampers (Rated at 10 cfm/ft^2)	15.4	462	6.4	8.7	3.7
Economizer Dampers Open 1 Finger "10% OA"	19.5	585	5.7	8.3	2.9
Economizer Dampers Open 2 Fingers "20% OA"	23.2	696	5.1	8.0	2.1
Economizer Dampers Open 3 Fingers "30% OA"	30.1	903	4.5	7.8	1.4
Economizer Dampers Fully Open	62.1	1577	1.9	6.6	-1.4

Source: Intertek, Plano, TX

Table 1 shows that with economizer dampers closed the 7.5-ton unit is 38 to 104% less efficient than the same unit tested without an economizer per the ANSI/AHRI 340/360 and ANSI/AHRI 210/240 test procedures (ANSI/AHRI 2007, ANSI/AHRI 2008, Carrier 2001).[11] With economizer dampers open from 10 to 30% (1 to 3 fingers) efficiency is reduced by 5 to 62% compared to closed dampers. Laboratory tests indicate closed dampers provide 15.4% outdoor air, 1-finger open provides 19.5%, 2-fingers open provides 23.2%, 3-fingers open provides 30.1%, and fully open provides 62.1%. Fully open dampers can reduce efficiency by 24 to 139% compared to closed dampers. Space heating efficiency is also impacted by the minimum damper position. The program provided three training videos about economizers. The trainer recommended 3-fingers open to achieve 15% outdoor air, but this will reduce cooling efficiency by 11 to 62% compared to closed dampers.

Table 2 provides laboratory test results of economizer efficiency (EER*) and cooling capacity versus outdoor air conditions. Indoor return air conditions are constant for all tests at 75°F drybulb and 62°F wetbulb. Outdoor conditions vary from 70°F drybulb and 60°F (70/60) wetbulb to 65/57, 60/54 and 55/51. The economizer fan-only yields negative savings relative to 1st-stage cooling with dampers closed at 70/60 and 65/57. At 60/54 the economizer fan-only improves efficiency by 49.1% and economizer plus 1st-stage cooling improves efficiency by 44.2% compared to dampers closed. At 55/51 the economizer fan-only improves efficiency by 75.5% and economizer plus 1st-stage cooling improves efficiency by 50.3% compared to dampers closed.

[9] One-finger open is approximately 0.7 inches (1.8 cm), 2-fingers is 1.3 inches (3.3 cm), and 3-fingers is 2 inches (5.1 cm).
[10] Relative EER* is the cooling capacity in thousand Btu per hour (kBtuh) divided by total air conditioner electric power (kW) including indoor fan, outdoor condensing fan, compressor, and controls. This is not the manufacturer EER rating.
[11] Manufacturer EER ratings based on the AHRI 340/360 do not include cabinet or economizer outdoor air damper leakage.

Table 2. Economizer Efficiency and Cooling Capacity versus Outdoor Temperature

Description	Outdoor DB/WB (F)	Indoor DB/WB (F)	EER*	Cool Cap (kBtuh)	Efficiency Improvement
Economizer fan only	70/60	75/62	1.50	3,632	-83.1%
Economizer plus 1st Stage Cooling	70/60	75/62	10.13	47,147	13.8%
Dampers Closed 1st Stage Cooling	70/60	75/62	8.90	41,093	
Economizer fan only	65/57	75/62	9.01	14,098	-11.7%
Economizer plus 1st Stage Cooling	65/57	75/62	12.94	58,232	26.9%
Dampers Closed 1st Stage Cooling	65/57	75/62	10.20	45,490	
Economizer fan only	60/54	75/62	16.94	26,647	49.1%
Economizer plus 1st Stage Cooling	60/54	75/62	16.38	70,845	44.2%
Dampers Closed 1st Stage Cooling	60/54	75/62	11.36	48,979	
Economizer fan only	55/51	75/62	21.90	34,510	75.5%
Economizer plus 1st Stage Cooling	55/51	75/62	18.76	78,694	50.3%
Dampers Closed 1st Stage Cooling	55/51	75/62	12.48	52,144	

Source: Intertek, Plano, TX

Table 3 provides estimated economizer annual cooling energy savings for economizer fan-only, economizer plus 1st-stage cooling, and total economizer cooling.[12] The table shows the fraction of annual building cooling load for a typical small office building at outdoor temperature bins corresponding to economizer operation. The building cooling load was compared to the economizer cooling output in each bin to allocate load to the economizer fan-only versus economizer plus 1st-stage cooling. Economizer savings at each bin from the lab tests are combined with the annual cooling fractions to estimate annual cooling energy savings. The total estimated economizer savings are 13.4%, economizer fan-only savings are 2.4%, and economizer plus 1st-stage cooling savings are 11.0%. Economizer fan-only operation at outdoor conditions of 70/60 and 65/57 produces negative savings relative to 1st-stage cooling with dampers closed. This is offset by savings from economizer plus 1st-stage cooling. Eighty-two percent of economizer energy savings are from 1st-stage cooling indicating the importance of integrating mechanical cooling and economizer control strategies. Additional economizer tests will be performed on packaged units from other manufacturers.

Table 3. Estimated Economizer Annual Cooling Energy Savings

Description	Outdoor DB/WB (F)	Efficiency Improvement	Annual Building Cooling Load	Economizer Fan-Only Savings	Economizer + 1st-Stage Cooling Savings	Total Economizer Cooling Savings
Economizer fan only	70/60	-83.1%	1.0%	-0.8%		-0.8%
Economizer plus 1st Stage Cooling	70/60	13.8%	12.4%		1.7%	1.7%
Economizer fan only	65/57	-11.7%	2.6%	-0.3%		-0.3%
Economizer plus 1st Stage Cooling	65/57	26.9%	10.6%		2.9%	2.9%
Economizer fan only	60/54	49.1%	2.7%	1.3%		1.3%
Economizer plus 1st Stage Cooling	60/54	44.2%	7.1%		3.2%	3.2%
Economizer fan only	55/51	75.5%	2.9%	2.2%		2.2%
Economizer plus 1st Stage Cooling	55/51	50.3%	6.5%		3.3%	3.3%
Total				**2.4%**	**11.0%**	**13.4%**

The programs do not provide training or incentives to improve energy efficiency based on minimum outdoor air damper position. While programs provide incentives for repairing non-functional economizers, none of the technicians performed economizer repairs while being observed. Participating technicians in one statewide program received incentives for 1,136 economizer tests in 2010-12. A total of 438 repair incentives were paid for wiring, damper motor, sensor/controller, and linkage repairs.

[12] Annual building cooling load is based on DOE-2 simulations of DEER prototype small office building in Sacramento, CA.

Although it is not indicated in the tracking data an individual unit was likely to have required multiple repairs. Assuming all repaired units received new sensors, we estimate repairs were made on 148 units or 13%. In another program, 11 out of 16 economizers at one site were reported as repaired, but only 5 are still working one year later and 11 are not working. Four economizers have closed dampers, ten have dampers open to 1 finger, and two have dampers open to 1.5 fingers.

It can be more expensive to repair a broken economizer than to install a new one. Many parts for old economizers with analog sensors and controllers are no longer manufactured or available from distributors.[13] New economizers have improved digital sensors and controllers with on-board diagnostics and are relatively easy to install.[14] The 2010-12 statewide programs offered incentives to decommission non-functional economizers. If economizer dampers are closed when units are decommissioned efficiency can be improved by 5 to 140% depending on pre-existing damper position. Laboratory tests indicate that closed damper leakage will provide sufficient outdoor air to meet code ventilation requirements for many building occupancies.

Table 4 provides laboratory test results of relative efficiency (EER*) versus refrigerant charge and outdoor air damper position for the 7.5-ton two-compressor packaged unit. The laboratory “optimal” charge of 8.59 pounds (lb) in circuit 1 (c1) and 10.35 lb in circuit 2 (c2) was established with no economizer using manufacturer charging charts (Carrier 2005).[15] For optimal charge the measured ST is within +/-5°F of manufacturer specifications. Under charge of -20 to -40% reduces efficiency by 8 to 60% for closed dampers and 8 to 96% for 1-finger open relative to optimal charge. Tests of +20 to +40% over charge relative to optimal charge indicate a 3% increase to a 9% reduction in efficiency for closed dampers and 32% increase to a 17% reduction in efficiency for 1-finger open.

Table 4. Relative Efficiency versus Refrigerant Charge and Outdoor Air Damper Position

Test	Refrig. Charge c1/c2 (lb)	Airflow (cfm)	EER* 95/75°F OD 75/62°F ID	EER* 82/68°F OD 75/62°F ID	EER* 115/80°F OD 75/62°F ID
No Economizer AHRI Rated Efficiency	7.6/8.1	3000	10	12	7.5
Laboratory Optimal Charge Closed Damper	8.59/10.35	2500	6.0	8.5	3.2
-20% Charge Closed Damper (~Factory Charge)	7.07/8.73	2500	5.3	7.9	2.9
-40% Charge Closed Damper	5.55/7.11	2500	3.3	5.8	1.3
+20% Charge Closed Damper	10.11/11.97	2500	6.0	8.7	3.2
+40% Charge Closed Damper	11.63/13.59	2500	5.8	8.7	2.9
Laboratory Optimal Charge 1-Finger Open	8.59/10.35	2500	5.1	8.2	2.5
-20% Charge 1-Finger Open (~Factory Charge)	7.07/8.73	2500	4.4	7.5	1.8
-40% Charge 1-Finger Open	5.55/7.11	2500	2.3	5.5	0.1
+20% Charge 1-Finger Open	10.11/11.97	2500	5.2	8.3	2.2
+40% Charge 1-Finger Open	11.63/13.59	2500	5.1	8.4	2.0

Source: Intertek, Plano, TX

Test data indicates that circuit 1 superheat and suction temperatures are within manufacturer specifications for all damper positions. Circuit 2 superheat and suction temperatures are +25 to +33°F above manufacturer specifications indicating an undercharge condition from the perspective of technicians diagnosing refrigerant charge. Circuit 2 receives more warm outdoor air and less cool return since it is above circuit 1 and more aligned with the dampers. This increases the cooling load on circuit 2 relative to circuit 1 as indicated by superheat and suction temperatures that are greater than manufacturer targets. Laboratory tests of +40% over charge yield superheat and suction temperatures within manufacturer specifications for both circuits, but this causes a 14% reduction to a 2% increase in

[13] The programs provide incentives of $1,125 to $1,485 to repair broken economizers.
[14] See http://www.micrometl.com/economizers.aspx and http://beyondinnovation.honeywell.com/products/jade.
[15] The 8.59 lb circuit 1 optimal charge is 13% greater than 7.6 lb factory charge. The 10.35 lb circuit 2 optimal charge is 28% greater than 8.1 lb factory charge. Total optimal charge is 18.94 lb which is 20% greater than 15.7 lb total factory.

efficiency depending on damper position. Overcharging causes liquid refrigerant to flood the compressor at startup or when refrigerant incompletely vaporizes in the evaporator and enters compressor cylinders during operation (Tomczyk 1995). Repeated flooding during normal off cycles or excessive flooding during steady-state operation can dilute oil in the compressor causing inadequate bearing lubrication and premature failure (Emerson 2013).

Table 5 provides laboratory test results of relative efficiency (EER*) versus airflow and outdoor air damper position for the 7.5-ton two-compressor packaged unit. Compared to optimal refrigerant charge and airflow (RCA) and closed damper position, low airflow of 16 to 33% reduces efficiency by 2 to 23%. For 1-finger open damper position, low airflow reduces efficiency by 1 to 24%.

Table 5. Relative Efficiency versus Airflow and Outdoor Air Damper Position

Test	Refrig. Charge c1/c2 (lb)	Airflow (cfm)	EER* 95/75 OD 75/62 ID	EER* 82/68 OD 75/62 ID	EER* 115/80 OD 75/62 ID
No Economizer Factory Charge AHRI Rating	7.6/8.1	3000	10.0	12.0	7.5
Laboratory Optimal RCA Closed Damper	8.59/10.35	3000	6.4	8.7	3.7
16% Low Airflow Closed Damper	8.59/10.35	2500	6.0	8.5	3.2
33% Low Airflow Closed Damper	8.59/10.35	2000	5.6	8.4	2.9
Laboratory Optimal RCA 1-Finger Open	8.59/10.35	3000	5.7	8.3	2.9
16% Low Airflow 1-Finger Open	8.59/10.35	2500	5.1	8.2	2.5
33% Low Airflow 1-Finger Open	8.59/10.35	2000	5.0	8.0	2.2

Source: Intertek, Plano, TX

Discussion

Observations indicate that technicians participating in commercial sector HVAC programs lack tools, training, and procedures to correctly identify and perform FDD repairs to achieve energy savings. The programs provide training on how to enter data into the program database, but do not provide sufficient training, tools, protocols, or feedback for technicians to improve energy efficiency. Technicians are not properly repairing many economizers. In one program more than 50% of repairs are not working one year later. The problem appears to be with program design, implementation, protocols, and data collection and not with technicians who are working within established program parameters. Mistakes are often made by technicians or office personnel when entering data into the statewide program database which requires answering 220 to 250 questions per unit to receive incentives. Most questions address maintenance activities that do not save energy. Without the program technicians indicated that they would not answer so many questions to perform maintenance services. The programs should be redesigned to provide more effective energy efficiency measures, training, tools, protocols, and data collection focused on energy efficiency measures. Incentives should be provided for measures with the highest probable applicability, repair rate, and savings.

Laboratory tests for a 7.5-ton packaged unit with an economizer indicate that minimum outdoor airflow is 15.4% with closed dampers. Efficiency is reduced by 38 to 104% compared to the same unit tested without an economizer. With economizer dampers open from 10 to 30% efficiency is reduced by 5 to 62% compared to closed dampers. Eighty-two percent of economizer energy savings are from 1st-stage cooling indicating the importance of integrating mechanical cooling and economizer control strategies. Integrating mechanical cooling and economizer control strategies is important to save energy. Laboratory tests of optimal refrigerant charge and 16% low airflow indicate efficiency improvements of 7 to 26%, but circuit 2 superheat and suction temperatures are outside manufacturer specifications. Tests of +40% over charge achieves the manufacturer specifications, but causes a 14% reduction to a 2% increase in efficiency depending on damper position. Tests of 16 to 33% low airflow indicate a 2 to 24% reduction in efficiency depending on damper position. Programs should provide incentives for measuring outdoor airflow and reducing minimum outdoor air damper position to code levels on economizers and make-up air units to save cooling and heating energy. HVAC manufacturers, industry associations, state licensing boards, and USDOE can help by supporting improved equipment efficiency ratings, technician competency standards, FDD protocols, and field measurement instrument standards.

Conclusions

Pre-maintenance observations of commercial air conditioning circuits identified 9.7 faults per circuit. Observations conducted during and after maintenance services were performed identified 10.3 faults per circuit, an increase of 6%. Participating technicians correctly diagnosed and repaired 7.4% of faults. Approximately 92% of technicians have issues with tools or procedures. None had proper tools to evaluate economizers or outdoor air damper position. Approximately 50% did not have EPA low-loss fittings on their refrigerant hoses. Those that did have low-loss fittings did not purge hoses of air and water vapor prior to attaching to Schrader valves. These faults cause non-condensables or contaminants to enter the system when adding refrigerant or attaching hoses. Technicians did not use proper tools or procedures to measure relative humidity, airflow, economizer operation, damper position, coil cleaning, or fan belts. Most technicians did not install fan belts with proper tension or alignment which causes reduced airflow, efficiency, and premature failure.

Current programs do not provide sufficient training on proper FDD and repair. Programs provide incentives to contractors for some maintenance services already provided within standard maintenance contracts. The programs also provide incentives for adding or removing refrigerant charge without diagnosing other faults such as restrictions or non-condensables. Studies by Braun and Mowris indicate problems correctly identifying faults using the CEC RCA protocol which is not designed to diagnose non condensables, restrictions, or other faults. Observed technicians contaminated the refrigerant system with non-condensables due to not purging hoses. One observed technician increased minimum outdoor air damper position from closed to 1-finger open. Three observed technicians did not repair broken open dampers. None of the technicians performed economizer repairs while being observed. Laboratory tests of economizer dampers open from 10 to 30% indicate efficiency is reduced by 5 to 62% compared to closed dampers which deliver 15% outdoor air per ASHRAE 62.1. Eighty-two percent of economizer energy savings are from 1st-stage cooling indicating the importance of integrating mechanical cooling with economizer controls. Tests of laboratory-optimal charge compared to factory charge found efficiency improvements of 7 to 26%, but circuit 2 superheat and suction temperatures are outside manufacturer specifications. Laboratory tests of +40% over charge achieves the manufacturer specifications, but causes a 14% reduction to a 2% increase in efficiency depending on damper position.

Observations indicate that technicians participating in commercial HVAC maintenance programs lack tools, training, and procedures to correctly identify faults and perform repairs to achieve energy savings. Observations of training classes indicate that the statewide programs provide training on how to enter data into the program database, but do not provide sufficient training, tools, protocols, or feedback for technicians to improve energy efficiency. Field observations of technicians indicate a lack of understanding regarding how to properly diagnose faults and implement repairs to save energy. Observations indicate that technicians do not test, diagnose or repair all deficiencies. In one of the statewide programs this would be required in order to bring units up to the performance baseline. The programs assume there are no significant industry issues with respect to technicians achieving the performance baseline and improving energy efficiency. Observations indicate this is not the case. Technicians are not properly repairing very many economizers. In one program more than 50% of repairs are not working one year later. The problem appears to be with program design, implementation, protocols, and data collection and not with technicians who are working within established program parameters. The programs should begin exploring program design changes to improve training, tools, protocols, and data collection.

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