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REVIEW OF RECENT COMMERCIAL ROOF TOP UNIT FIELD STUDIES IN THE PACIFIC NORTHWEST AND CALIFORNIA

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Introduction

New Buildings Institute contracted with Northwest Power and Conservation Council (NW Council) to collect data from previously completed research projects, field tests and programs in the Northwest and around the country, synthesize those results and identify recommended next steps. The primary objective is to present the aggregated results of four recent investigations into the efficiency and operational problems of packaged rooftop heating, ventilation and air conditioning units (RTU). Secondarily the report suggests recommendations for programmatic approaches to capture RTU savings potential and for further research and analysis needed to develop programmatic approaches and estimated savings for those approaches. The scope of this project did not include analysis regarding energy savings potential, cost effectiveness, or costs and benefits of possible solutions.

Field studies from the following utilities and agencies in this report include: Eugene Water and Electric Board (EWEB), Puget Sound Energy (PSE), Northwest Energy Efficiency Alliance (NEEA) and the California Energy Commission (CEC). Ecotope performed the EWEB and PSE studies. The NEEA program was run by Portland Energy Conservation Inc. (PECI), and the CEC program was managed by New Buildings Institute, with the research performed by Architectural Energy Corporation.

Summary

All of the field studies found similar problems occurring with similar frequencies. Combining the results provides an overview of the commonalities between the study results, recognizing that these are broad statements and that there were some differences in the exact definitions of each of the problem categories between the studies.

For the purpose of this report, the combined findings are described per key problem area, and charts at the end of this section show the approximate weighted average findings (weighted by number of rooftop HVAC units) and range of energy savings reported for all the studies. A total of 503 rooftop HVAC units, at 181 commercial buildings sites in 5 states were investigated between the four field studies. Results are reported from the entire sample, or a subset of the sample depending on data availability as noted. It is important to note that the reported energy savings estimates vary in calculation methods and assumptions.

Characterization of the Field Studies

Table 1 summarizes key characteristics of the field studies reviewed.

Table 1. Field Studies Key Characteristics

Source	Nuber of sites	Number of Rooftop Units	Tons of Cooling	Location	Time Frame
EWEB	19	30	210	Eugene, OR	2001
PSE	15	118	1279	Puget Sound Region, WA	2003-2004
NEEA Phase I	39	65	447	ID, MT, WA	2002
Phase II	33	75	436	ID, MT, OR, WA	2003-2004
CEC	75	215	1355	CA	2001-2002
Total	181	503	3727		

Problem Areas

Refrigerant Charge

Refrigerant charge was found to be out of range on an average of 46 percent of the units tested. This is based upon the charge being more than 5 percent over or under the unit specifications.

The most common method used to check the refrigerant charge is the CheckMe! [1] tool. Obtaining refrigerant charge readings has been troublesome due to weather conditions not allowing for valid readings, improper testing by the technician and a general reluctance of field personal to perform the tests.

For all of the projects, estimates of energy savings associated with correcting the refrigerant charge range from 5 to 11 percent of the cooling energy and are highly dependent upon how far out of spec the charge is.

Economizer

Economizers were failed or required adjustment on an average of 64 percent of the units for all of the studies.

Common failure modes include:

- Broken, frozen or missing drive system components
- Outside air or mixed air sensor failure
- Faulty repairs
- Low changeover temperature setpoint
- Use of a single-stage cooling thermostat

[1] CheckMe! is a diagnostic and tune-up service developed by Proctor Engineering Group. CheckMe! provides refrigerant charge by testing superheat and subcooling (or approach) temperatures.

Estimates of energy savings associated with repairing a failed economizer range from 14 to 40 percent of the cooling energy between the different studies. The low-end estimate is for adjustments to a functioning economizer and high-end estimate corresponds to repairing a broken economizer.

Airflow

The airflow was found to be out-of-range on an average of 42 percent of the units. This is based on out-of-range being defined as lower than 300 CFM/ton of cooling capacity compared with industry efficiency ratings based on an assumed airflow of 400 CFM/ton.

TrueFlow[2] grids were used to measure the airflow. Unit geometry can prevent the use of the grids in some cases and make it a time consuming process in many cases.

For all of the projects, estimates of energy savings associated with the correcting airflow range averaged around 10 percent of the cooling energy.

Thermostats

Problems were found with the thermostats on an average of 58 percent of the units. Thermostat problems include:

- Improper thermostat (single-stage cooling only)
- Cycling fans during occupied periods
- Continuous fans during unoccupied periods
- Improperly installed resistors
- No nighttime setup or setback

Savings estimates vary greatly depending upon the failure mode. In the case of cycling fans during occupied periods, correcting this so fans run continuously during occupied periods (as required by code) will cause the energy use to go up but will improve the ventilation and indoor air quality. Savings from thermostat corrections range up to 40 percent. The highest savings occur when the thermostat is preventing the economizer from operating.

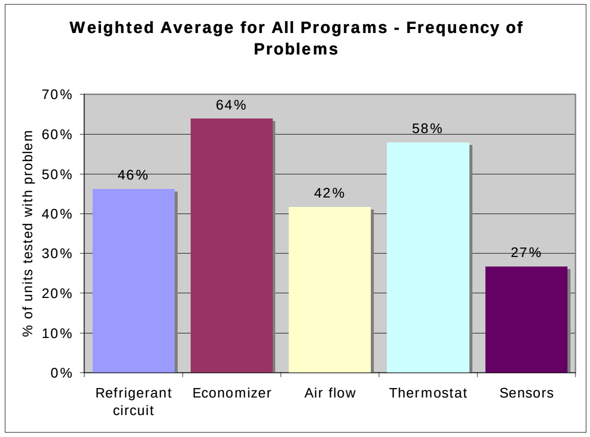
Sensors

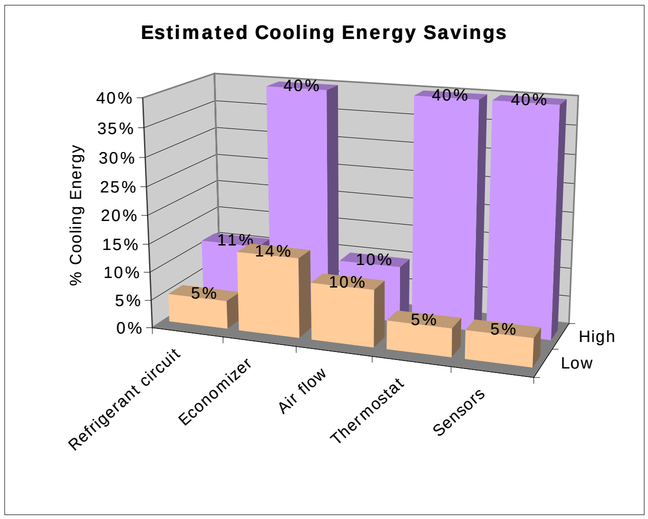
Sensors were problematic in approximately 20 percent of the units. Problems included:

- Failed sensors
- Snap discs that cannot be calibrated or adjusted.
- Broken wires

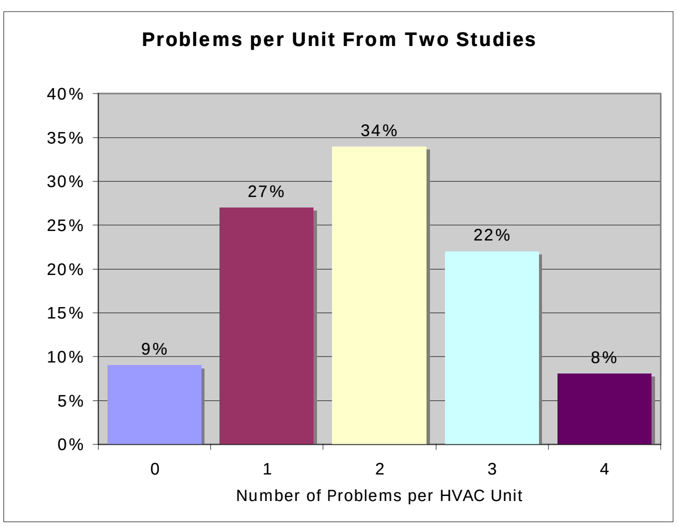
As with thermostats, the energy savings for repairing failed sensors varies greatly. Savings may be modest by replacing a snap disk to one that raises the economizer changeover setpoint or may be on the order of 40 percent if it enables a nonfunctioning economizer.

[2] The TrueFlow Air Handler Flow Meter provides an accurate (+/- 7 percent) measurement of airflow through air handlers. The system uses acrylic plates that temporarily replace the filter in the air handler distribution system during the airflow measurement process.





Problems per unit for the PSE and the PECI were combined and are shown below. Problems per unit could not be extracted from the EWEB and the PIER field surveys. The average number of problems per unit is 1.9. The variation by age or cooling capacity is minimal as is shown in the PSE and PECI results.



Energy savings estimates are for the correction of the problem independent of other performance areas. Clearly, the savings per problem, if corrected, is not cumulative. Problems and solutions are interactive.

Conclusions

In addition to providing frequency of problems, the review of these four studies provided additional insights that should inform future efforts and program development. Following are conclusions based on the review of the field test results:

- Problems with sensors are well understood. Dry-bulb temperature sensors are more reliable than enthalpy sensors and should be recommended here in the Northwest. Northwest climate conditions do not require enthalpy sensors. Snap disks should also not be used, as they do not provide any means of adjustment or calibration.
- Properly functioning economizers and thermostats offer the greatest potential for energy savings. The energy savings available from a properly functioning economizer have resulted in economizers being required in nearly all energy codes, but these savings are not being achieved in the majority of the units tested. Economizer failures are common in all systems regardless of age. The PIER study only looked at units 4 years old or newer and reported results consistent with the other studies were older units were tested.
- The testing and correcting of refrigerant charge variations in the field is difficult to implement, and the savings are less than in other problem areas. The use of thermostatic expansion valves instead of fixed orifice devices can reduce losses due to charge variations.
- The interaction of the economizer and controllers is not well understood. In the field it is often difficult to determine whether the economizer is working correctly due to the differences between economizers and controllers and the many modes of operation.
- Many of the problems discovered by these studies are specification and installation problems. The initial specification of improper sensors and thermostats followed by inadequate and untested system installations have resulted in many systems not operating correctly from their initial startup.

Solution Approaches

None of the studies have documented results of the energy impact from proposed solutions at this stage. Nonetheless, the frequency of significant energy wasting problems is large. Several approaches are underway to try to improve RTU performance by correcting these problems. The adoption of these approaches validates the severity of the problems, the priority of addressing RTU problems, and the importance of attempting reasonable solutions that will have a strong likelihood of improving efficiency and performance. Following is a summary of the approaches currently underway. The programs have each taken different approaches to addressing the problems found in their initial field studies and can be categorized as follows:

- System Specifications - New or replacement system upgrades
- Component Specifications - Economizer replacement
- Service Protocols - System and economizer service and repair

EWEB Western Premium Economizer

The EWEB Western Premium Economizer program addresses the operation and reliability of economizers through the development of specifications. EWEB estimates that upgrading economizers to it's "Western Premium" specification will double the savings of a basic economizer as specified and installed using standard practice. The Western Premium program addresses new systems as well as economizer replacements. Following are the Western Premium Economizer requirements.

- Fully modulating damper motor
- Proportional damper control
- Coordinated control
- Relief air and return air damper
- Documented checkout
- Minimum outside ventilation air measurement
- Installer training
- Dedicated thermostat stage for economizer
- Differential changeover
- Dry-bulb changeover
- Primary control placement
- Low-ambient OSA compressor lockout
- Minimum airflow

CEC PIER HVAC Fault Detection & Diagnostics Program

The CEC has funded the Advanced Automated HVAC Fault Detection and Diagnostics (FDD) Commercialization Program with goals to develop and demonstrate advanced fault detection and diagnostic methods and measurement equipment for cooling, heating and ventilating systems; more advanced and fault-resistant HVAC equipment; and to work directly with manufacturers in order to implement improvements and innovations in new commercially available equipment.

Two of the projects in the FDD program are specific to rooftop package units. The Rooftop Unit Diagnostics project is developing refrigeration cycle diagnostics and economizer, demand control ventilation (DCV) and control system diagnostics. The project goal is to supply the marketplace with a product offering by August 2006 that provides important diagnostic and performance information with a compelling business proposition for achieving significant energy and demand savings in commercial buildings.

The second project in the CEC Pier program is the Advanced Rooftop Unit (ARTU) project will develop, test and demonstrate an ARTU prototype of 5-ton cooling capacity that addresses many of the energy and ventilation problems found in commercial building mechanical systems. Features of the ARTU will include improved outdoor air control, improved economizer reliability, diagnostics and troubleshooting capability, and fault-tolerant design.

California Title 24 Acceptance Testing

California has adopted Acceptance Testing into the 2005 Title 24 nonresidential codes. Acceptance Testing addresses problems that occur during installation by requiring contractors to install and test their equipment verifying that it functions in accordance with applicable standards and related construction documents. Parts of the field Acceptance Testing requirement are waived for units that have an economizer installed by the original equipment manufacturer (OEM) due the PIER findings that units with an OEM economizers did not exhibit the frequency of problems of field installed units.

PSE Premium Service Program

PSE is now marketing the Premium Service protocol as a conservation program. PSE currently has between 400 and 600 units in the program. They continue to refine the protocol to achieve a balance between optimum energy efficiency and market value (cost) of the service.

Consortium for Energy Efficiency

The Consortium for Energy Efficiency (CEE) is currently working on a set of specifications for an advanced package rooftop unit that was drafted in the CEC PIER Small HVAC project. The specifications contain three tiers of performance for new and replacement RTUs. Tier 1 is a set of specifications that are all currently available on the market and provide an immediate basis for utilities to upgrade program requirements. Tier 2 includes Tier 1 plus the additional design features that are part of the CEC PIER Advanced Rooftop Unit project. Tier 3 is a proposed performance-based measurement for future specification development.

The specifications focus on system reliability and maintaining rated efficiency of the unit over its life. For economizers, the specification requires a factory-installed, certified and run-tested economizer prior to leaving the factory.

Recommendations

Solutions to the problems lie at the manufacturer level, design and construction phase, and during O&M. In dealing with rooftop package units, conservation programs of the past have focused primarily on energy efficiency ratings and on an economizer requirement. The field studies have shown that RTUs are not performing at the level expected by those programs. Problems are evident in every phase of the RTU lifecycle including: manufacturing, design and specification, installation and O&M. Complete and economical solutions to all of the problems with RTUs will require addressing issues at each of these levels.

Based on the greatest improvement potential for the least investment and market barriers, we believe the priority intervention point is during new and change out specifications. Ordering equipment with improved features will reduce the trickle down affect of problems experienced at both installation and operations and maintenance. The need to address problems at O&M point in the chain is also critical, but the investment levels and barriers increase as you move away from the manufacturer and specifier. The recommendations below offer areas to pursue at the new and replacement point as well as further investigation into O&M solutions.

Recommendations for next steps the region could investigate to increase confidence in specifications or approaches that could be adopted by the RTF include the following:

Development of Specifications for a Northwest RTU

Many of the problems found in the field can be prevented with proper specifications. The EWEB Western Premium Economizer program is a good first step in this direction and can be applied to new as well existing rooftop units. The CEC PIER FDD Program that includes the Advanced Packaged Rooftop Unit project and the CEE Specifications for an Advanced Package Rooftop Unit also address issues related to specifications to prevent problems at startup. The Rooftop Unit Diagnostics project, also part of the FDD program includes diagnostic and performance information with a technician interface at the unit for diagnostic information and immediate feedback on repair effectiveness.

Development of a Northwest Advanced Rooftop Specification would require further research into these existing models, drafting of the best combination of features responsive to Northwest conditions, and review of the specifications by utilities and the Regional Technical Forum. Ultimately, the region would have a voluntary specification that could be adopted by efficiency programs and promoted directly with designers and contractors.

Require Acceptance Testing

Acceptance testing of RTUs can help insure that the units are properly installed with control points and thermostats correctly set. The EWEB Western Premium Economizer program addresses this with advanced documented checkout requirements, and California has implemented this as part of their nonresidential energy code.

Since Acceptance Testing protocols exist through these examples, and national development and implementation expertise lies with local firms the development of a draft regional procedure for consideration would not be an extensive new research area. Requirements for Acceptance Testing of RTUs could be a part of Northwest new commercial construction efficiency programs.

Economizer and Controls – Monitoring and Research

Economizer and control problems often go undetected due to a lack of understanding of their operation. A better understanding of these components through field monitoring and research may lead to simpler service protocols that will enhance the effectiveness of maintenance and service.

- Additional Field Investigation of Control Problems

Additional information from field research on controls would help inform and direct Northwest efforts to address roof top unit efficiency. The Institute can not estimate the scope, cost or confidence of results from research into this area, but believes it is an area of priority for additional information and potential for savings.

- Support and Gain Field Statistics from Service Based Solutions.

Monitoring of the PSE Premium Service program will provide the necessary data to evaluate the cost effectiveness of enhanced service programs. This is important in light of the on-going fine-tuning of the service protocols. Feedback from this program may also provide information directly from service contractors regarding new equipment specifications that would solve some of the O&M problems they encounter and attempt to repair.

Recommendations Summary

This investigation of NW RTU studies identifies several problem areas and potential savings. Recommendations have been made for potential solutions at each stage of the RTU lifecycle from manufacturing to O&M. The prioritizing and the development of a Scope of Work to apply these recommendations would be best achieved by re-convening and directing regional RTU experts. Discussions focused on each recommendation and on potential field research scopes and costs would help define Scopes of Work, savings estimates, and the necessary budget required to implement the various recommendations.

Field Studies

This section of the report describes the general approach of each program, the protocol used and the field findings. The findings are organized around the following five key problem areas: Thermostats, Economizers, Refrigerant Charge, Airflow and Sensors.

PSE – Premium Service Small Commercial Rooftops Pilot Incentive Program

Overview

This program was a pilot project funded by PSE to test a service protocol to increase the efficiency of existing rooftop units and be cost effective in the marketplace.

Over 14 months during 2003 and the first quarter of 2004, 115 package rooftop units at 13 locations, for a total of 1,279 total tons of cooling, were serviced under the pilot incentive program. The primary use was office and retail at 41 percent each, with athletic clubs making up the remainder. The program is ongoing and it is expected to include 400 sites by January 2005.

The most common unit size was 5 tons (25 units total), for approximately ten percent of the installed capacity. Fifty-nine percent of the installed capacity consisted of 38 units between 15 and 25 tons. Natural gas was the primary means of heating at 64 percent of the units (54 percent of the tonnage.). All electric accounted for 21 percent and heat pumps accounted for 15 percent of the units. No data was provided on the age of the units.

Protocol

The protocol varied during the course of the program. Items in the protocol relevant to energy savings opportunities are unit type (gas heat, heat pump, all electric), unit size, thermostat characteristics, economizer component performance, evaporator airflow, outside air factions (at both minimum and maximum settings), coil condition, refrigerant charge, and major repairs identified and/or performed.

Findings

The results were presented in a Microsoft Excel spreadsheet. Due to the evolving nature of the protocol and the experience of the technician in using the protocol there are many holes in the database that affect its completeness. The following results are extracted from the spreadsheet and are a reasonable summary of the component findings for this pilot,

Refrigerant Charge

Checking the refrigerant charge was problematic in nature due to the following reasons:

1. Cold outdoor conditions during visit
2. Failure to enable all cooling stages during the test
3. Technician confusion

The charge checking protocol has been changed, and new data is expected from ongoing field tests.

Economizer

More than half of the units reported some economizer problem. Economizer sensors were bad on 20 percent of the units. Typical failure was the outside air sensor, but the mixed and return air sensors are also included. The economizer changeover temperature was adjusted on 33 percent of the units that could be adjusted. In approximately 15 percent of the units a snap disc was used. Snap discs are non-adjustable and require a replacement in order to adjust the temperature that determines the changeover temperature. The snap discs were not replaced during the field service.

The economizer controller was replaced on 14 percent of the units. Other repairs including rewiring, damper linkage and binding dampers were performed on 16 percent of the units.

Airflow

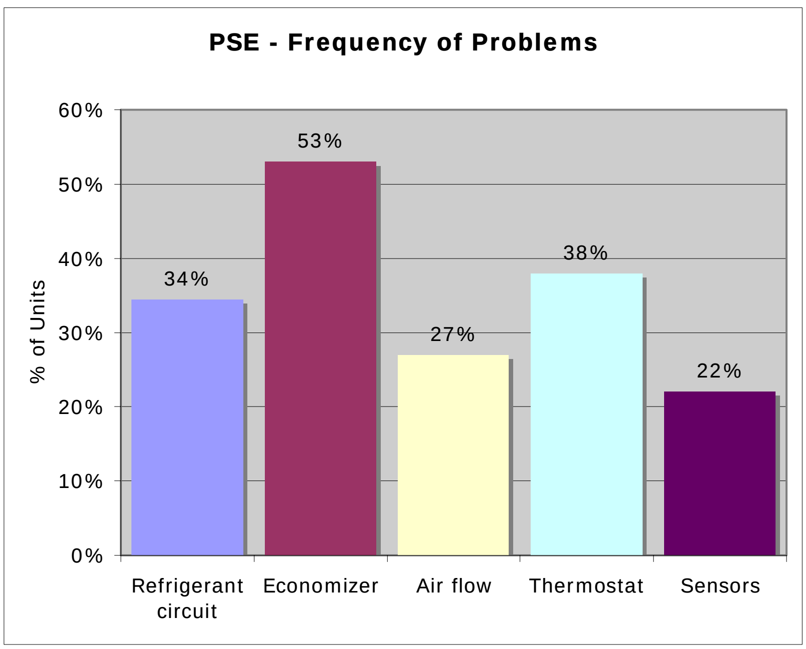
Average evaporator airflow was 304 CFM/ton with a range from 99-420 CFM/ton. Additionally, 27 percent of units had 300 CFM/ton or less of airflow.

Thermostats

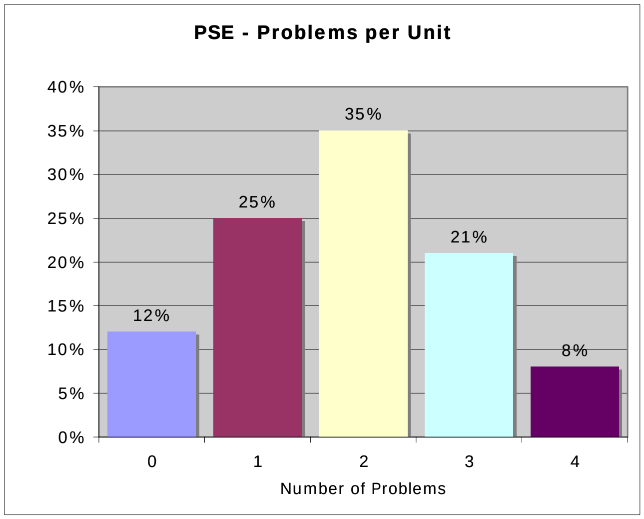
Twenty-two percent of the thermostats had a positive adjustment made. Thirty-six percent were not adjusted. No data was reported for 42%. A positive adjustment is any combination of: setting the heating point lower, setting the cooling point higher and decreasing the number of occupied hours. The actual settings observed were not recorded, nor were the new settings. No negative adjustments were recorded.

Sensors

Sensors required replacement or rewiring on 22 percent of the units.



Many of the units had multiple problems with the average at 1.9 problems per units. The average number of problems per unit varies by only +/- 0.1 across units of different cooing capacity.



EWEB – Western Premium Economizer Program

Overview

During the summer and early fall of 2001, EWEB tested a field protocol on commercial buildings. The goals of the project were to evaluate the performance of packaged units and use this information to improve system efficiency and evaluate energy savings opportunities and their cost effectiveness. HVAC service technicians assisted in the testing of the protocol in an effort to train them to deliver this enhanced service.

No electronic database exists for this work. All summaries and reports were developed directly from the paper copies completed in the field.

A total of 35 units were evaluated, ranging in size from 2.5 to 15 tons of cooling. The age of the units and heating type was not provided.

Protocol

As with the PSE field surveys, the protocol varied and was non-uniform as it was developed during the course of the program. Basic elements of the protocol included evaporator airflow, system refrigerant charge, assessing the type and function of the economizer and reviewing the performance of the duct system.

Findings

Refrigerant Charge

Refrigerant charge evaluation was carried out on 14 units using the CheckMe! program developed by Proctor Engineering. Four units were undercharged and three units were overcharged. Two additional units were thought to be overcharged, but the reading was in error due to a dirty condenser coil. After cleaning the coil the reading shown a correct charge.

Economizer

Economizers are estimated to be non-operational in 30 percent of EWEB's service territory. Repairing these units and upgrading to a dry-bulb changeover setting of 60F was estimated by EWEB to reduce cooling energy by 25 percent, again based on simulations.

Economizer changeover temperature setpoints were found to be set too low. The study reported these non-aggressive levels (55^o F or cooler) could be changed to a more aggressive level (60^o F). The EWEB study estimated that this is the situation for 35 percent of EWEB's service territory. Energy savings are estimated to be 10 percent of cooling, based on DOE2.1E simulations.

Airflow

Airflow was measured on 27 units with the TrueFlow device, which enables direct assessment of airflow. Average evaporator airflow was 304 CFM/ton with a range from 99-420 CFM/ton.

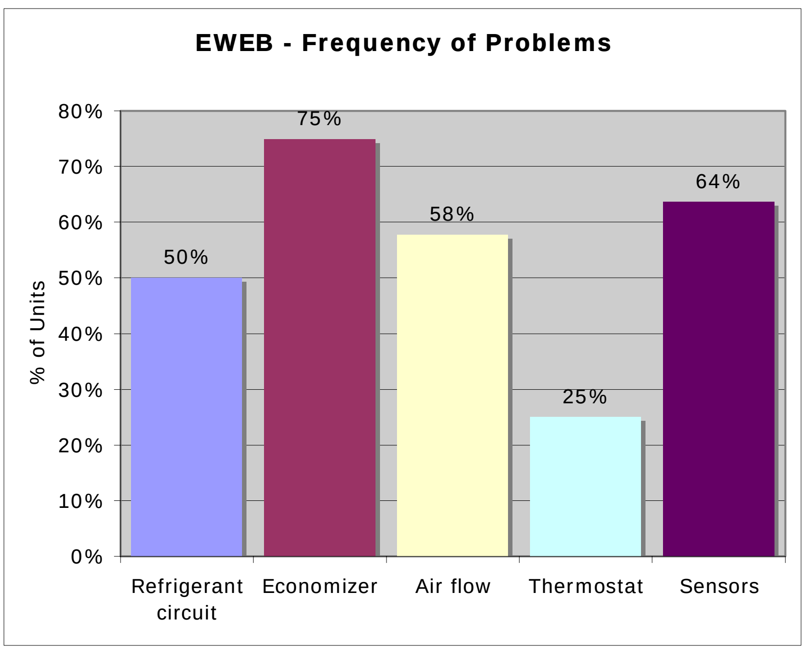
The average minimum outside airflow was around 20 percent of the full system, but the range was from 0 percent to 92 percent. The maximum outside airflow averaged only 65 percent of full system airflow.

Thermostats

The thermostats on 25 percent of the units were single-stage only on units with economizers. Rooftop package units with an economizer require a two-stage cooling setpoint thermostat even when the compressor does not have any stage capability. Temperature setpoints and fan schedules were not reported, although they were part of the protocol.

Sensors

Sensor were found to need adjustment or replacment on 23 percent of the units with economizers.



The raw data was not proved for this study therefore the number of problems per unit could not be determined.

PECI/NEEA – Small Commercial HVAC O&M Pilot Project

Overview

The goal of the Small Commercial HVAC O&M Pilot Project program was to optimize the performance and energy efficiency of rooftop packaged units up to 15 tons through the development of an enhanced service offering for RTUs. The enhanced service offering, referred to as AirCare Plus, was intended for service companies to offer to their customers as a reasonably priced and attractive upgraded maintenance service. The program was managed by PECI for the Northwest Energy Efficiency Alliance.

The program was designed to have two pilot phases followed by a regional program launch. Phase I of the program started in 2002. Phase II ran from February 2003 to February 2004. Phase I included 59 field tests located throughout the Northwest. Phase II was a market test based on the results of Phase I with a goal of 250 sales. Actual sales for Phase II were 125 units with 78 units serviced and 37 units monitored.

Protocol

The Small Commercial HVAC O&M Pilot Project was unique in that all procedures were programmed into a PalmPilot eliminating the need for a pencil and clipboard in the field and providing automated interface with the database. During Phase I, the CheckMe! tool was used to test refrigerant charge but was changed in Phase II to the Honeywell Service Assistant when going to the all-digital approach. Basic protocol areas were building, thermostat, unit, economizer, airflow and charge.

Findings

Phase I findings are based on 59 total units, and Phase II findings are based on the first 69 units serviced.

Refrigerant Charge

Phase I: Seventy-two percent of the units had a problem with the refrigerant circuit with 50 percent of the total circuits needing a charge correction. The primary problem was incorrect charge in 80 percent of the problem circuits. The most common condition was under charged in 52 percent of the problem units. Other conditions included overcharge, leak or flat (fully discharged) circuit, dirty condensing coil, and condensing coil airflow and refrigerant flow restriction.

Phase II: Adjustments were recommended on 43 percent of the units. Of the units recommend for adjustment, 17 percent were adjusted which corresponds to 7 percent of all the units.

Economizer

Phase I: Economizer problems were found in 65 percent of the units. Thirty-seven percent of the units had failed economizers, and 50 percent of the units needed changeover temperature setting changes. Individual failures included: use of a single-stage cooling thermostat, actuator or controller failure, outside air sensor failure, seized-up drive system, incorrect setup of the economizer during installation, wiring problem, sensor failure and broken or missing linkage components.

Phase II: Adjustments were recommended on 74 percent of the units. Of the units recommend for adjustment, 78 percent were adjusted which corresponds to 58 percent of all the units.

Airflow

Phase I: The airflow was found to be a problem in 62 percent of the units with 56 percent of these units more than 50 cfm lower than the manufacturer's suggested airflow rate of 400 cfm.

Phase II: Adjustments were recommended on 48 percent of the units. Of the units recommend for adjustment, 70 percent were adjusted which corresponds to 33 percent of all the units.

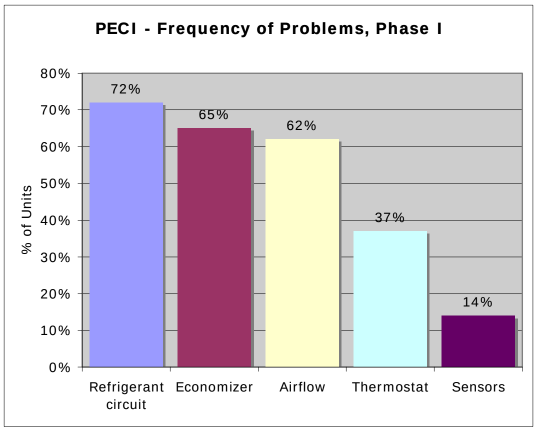
Thermostats

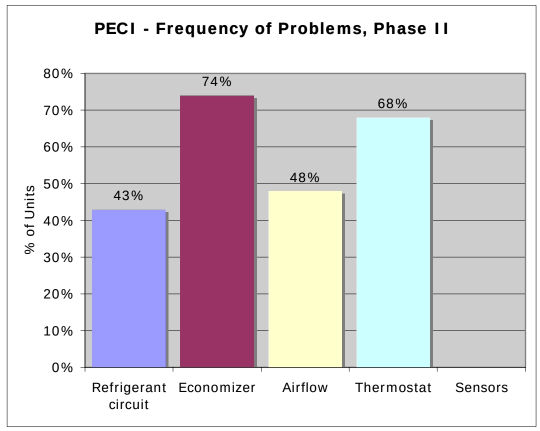
Phase I: Problems were found in 37 percent of the thermostats.

Phase II: Adjustments were recommended on 68 percent of the units. Of the units recommend for adjustment, 46 percent were adjusted which corresponds to 32 percent of all the units.

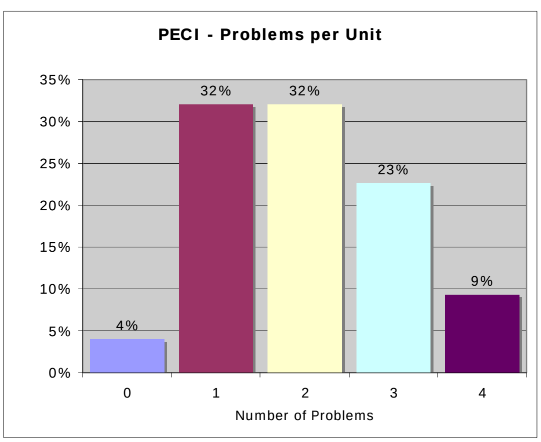
Sensors

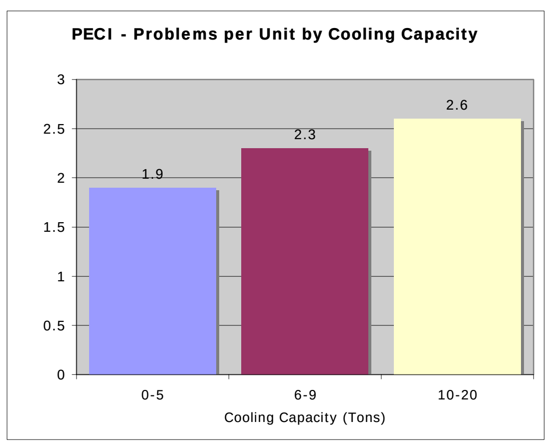
Sensor failures or calibration errors were reported in 14 percent of all units.





Many of the units had multiple problems with the average at 2.0 problems per units. The average number of problems per unit varies by only +/- 0.2 across units of varying age. The average varies more by the capacity of the units with the larger units showing more problems.





CEC PIER – Integrated Design of Small HVAC Systems

Overview

The goal of the CEC Public Interest Energy Research (PIER) Integrated Design of Small HVAC Systems project, conducted from early 2001 through 2003, was to identify problems with small HVAC systems that prevent them from reaching their full efficiency potential and to suggest potential solutions and develop market connections. The focus was on new commercial buildings, four years or newer in age, and on single-package AC units with rated capacity of 10 tons or less.

During field-testing, 215 rooftop units were surveyed on 75 newly constructed commercial buildings throughout California. A maximum of four units were surveyed per building. All data gathered were entered into a Microsoft Access database.

Protocol

Initial on-site surveys collected information sufficient to develop DOE-2 models on each space surveyed. Data included building shell, lighting and internal loads, and operating schedules.

The second level of data collection included a one-time test of fan rate and power during each mode of operation (standby, fan-only, cooling stage one and cooling stage two if applicable), economizer functional testing and refrigerant charge.

Level three consisted of 2-3 weeks of short-term monitoring. Included were fan controls, economizer operation and power measurements for model calibration

Findings

Refrigerant Charge

Refrigerant charge was tested by measuring superheat and subcooling. The evaluation was performed using the CheckMe! program developed by Proctor Engineering. Forty-six percent of the units did not pass the refrigerant charge test.

Economizer

Economizers tested failed in 64 percent of the units. Of these units, 24 percent would not move at all, 29 percent did not respond to the cold spray test, and 10 percent displayed poor operation during short-term monitoring.

Airflow

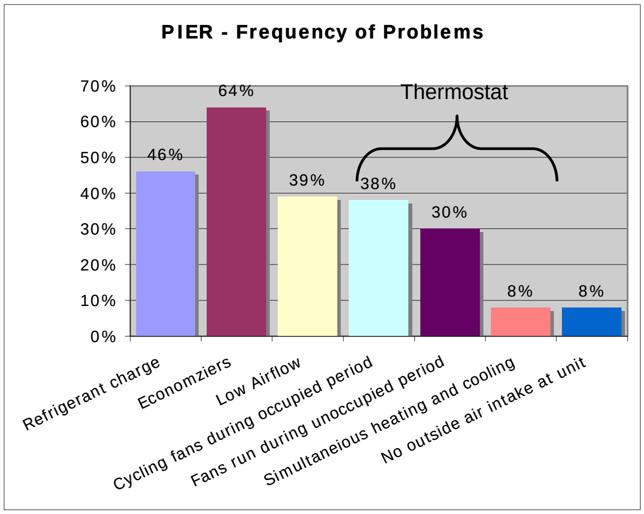
Airflow testing was performed using TrueFlow grids. Thirty-nine percent of the units had low airflow with less than 300 CFM/ton and average airflow of 325 CFM/ton.

Thermostats

System fans were found to be cycling on and off with calls for heating or cooling in 38 percent of units tested. The cycling of fans during occupied periods saves energy, but at the cost of poor indoor air quality and does not meet typical code requirements for outside air requirements. Fans were found to be running continuously during unoccupied periods in 30 percent of the units. Fan operation during unoccupied times is an opportunity to save energy through thermostat setback and fan cycling.

Sensors

Sensor data were not reported independently but are embedded in the results of various categories



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