Identifying Energy Savings Potential on Rooftop Commercial Units

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ABSTRACT

There has been only limited research on light commercial packaged HVAC units. Optimization of unit function, through review of refrigerant charge, system airflow, and controls can offer substantial savings in certain climates. However, a systematic enhanced maintenance protocol has apparently not been used widely in this sector.

This paper reports on efforts in the Pacific Northwest to develop a procedure that can be used to evaluate the performance of rooftop packaged heating/cooling systems and discusses results from applying the protocol to 30 rooftop units. Estimates of savings potential (based on detailed simulations) are also presented.

Introduction

Baseline surveys in the Pacific Northwest have found about 80% of new and existing commercial HVAC systems are pre-engineered packaged units (Baylon, et al, 2001). Medium-sized (5-20 cooling tons) rooftop packaged HVAC systems are commonly used for space conditioning in light commercial buildings. This equipment generally has a constant volume air handler with natural gas or a reversing valve (if a heat pump) to provide heating; a cooling coil and compressor for air conditioning; and a series of dampers and plenums to manage airflow and ventilation to the space served. The systems can be installed with economizers, which are meant to provide cooling to spaces using outdoor air when ambient conditions allow. Outside air economizers save cooling energy and are required by Pacific Northwest energy codes on units with 5 tons or more of cooling.

In our experience, HVAC service companies routinely perform relatively non-invasive preventive maintenance on rooftop units, including changing system filters, performing routine checks on system operation, and occasionally performing more involved assessments of refrigerant charge. Little work is done to assure proper airflow or proper operation of economizers, or to assess and mitigate the possible impacts of duct losses, which could be substantial in some cases.

A review of research on packaged HVAC systems suggests that a majority of these units have at least one significant operational deficiency, particularly units with an economizer cooling option. Other common problems that have been identified include incorrect refrigerant charge, inadequate evaporator airflow, duct leakage, and improper thermostat specification and scheduling. All of these elements were initially to be reviewed in this study, but ducts were not examined in detail because tools to evaluate their leakage are already more developed, and more effort was shifted toward development of an economizer evaluation procedure.

DOE-2.1E (Lawrence Berkeley Laboratory 1993) simulations have shown that economizers should be able to offset about half the cooling load in many areas west of the Cascades in the Pacific Northwest. By 1996, the economizer was mandated for all packaged rooftop systems larger than 5 tons of nominal cooling capacity (65,000 BTU/hr). Furthermore, the economizer has been a key factor in utility-sponsored conservation programs for the commercial sector over the last fifteen years.

Very little work has been done to develop and deliver hands-on protocols that can be used by HVAC technicians to characterize these systems and document energy efficiency improvements. The purpose of this research is to determine whether a protocol can be developed to address maintenance and optimization issues that could be incorporated into current HVAC technician practices for servicing and repairing rooftop units, and the potential impacts this would have on energy use and equipment efficiency.

There are only limited studies showing the potential energy savings from more aggressive maintenance in packaged units. Hewett et al. (1992) found savings on the order of 1900 kWh/yr for 17 Midwest rooftop sites that received refrigerant, airflow, and duct repairs. Houghton (1997) reported savings of about 25% attributable to maintenance of air filters, coils, compressors and outdoor air dampers (economizers). Delp et al. (1998) showed that, despite the assumption that duct losses in most commercial buildings are not important because the ducts are thought to be within the air and thermal barriers of the building, these assumptions are often incorrect

Only a few studies of economizer function have been undertaken. Two studies (Lunneberg, 1999; Davis Energy Group, 2001) used small samples, but found over 50% of economizers had at least one serious fault, with bad temperature sensors being the most common problem. Other efforts (e.g. Breuker et al. 2000; Pratt et al. 2000) have focused on monitoring and optimizing economizer function in the context of automated diagnostic systems.

This paper reports on the development of the field protocol, the results of the field study, and the challenges of transferring the protocol to HVAC technicians. Energy savings for various maintenance and repair measures are estimated based on short-term metering experiments and application of further DOE-2.1E modeling to units operating in the Eugene, OR climate.

Protocol Description and Development

Because a comprehensive rooftop protocol did not exist prior to the project, one function of the field review was to establish a usable protocol. The protocol would begin as a relatively lengthy research tool and be refined into a form that could be used by HVAC technicians as part of a service visit. Two service companies (three technicians) were involved in the project. The protocol focused primarily on refrigerant charge, airflow, and economizer operation, with evaluation of duct losses of secondary interest. (Ducts were characterized, in terms of their location inside or outside the building's air/thermal boundaries, but given the difficulties in measuring register airflow and duct leakage, duct performance was de-emphasized in this project.). Also of interest was system scheduling (thermostat settings and air handler operation).

Refrigerant Charge

Many researchers have noted the effect of improper charge on system efficiency and capacity. Equipment manufacturers and trade schools have clearly detailed the proper procedures to check refrigerant charge. However, service technicians often neglect to use the proper techniques, relying instead on rules-of-thumb that often are inaccurate.

Refrigerant charge was evaluated using a semi-automated version of the "Carrier Method" developed by Proctor Engineering Group (PEG) as their CheckMe!™ Program. This process allows contractors to call a toll free number and report ambient dry bulb temperature, supply and return temperatures (including return wet bulb temperature, which determines the evaporator's latent cooling load), and suction and discharge pressures and temperatures. If a charge adjustment is indicated, the technician is given a recommendation on the size of the adjustment.

The Carrier method (and other manufacturers' methods) assume the refrigerant coils are sufficiently clean to facilitate heat transfer. If an evaluation of charge is undertaken with dirty coils, faulty conclusions can occur. CheckMe!™ requires at least the outdoor coil be cleaned before checking charge. Coil cleaning is not commonly done in the Pacific Northwest and is priced as an optional maintenance item. A nozzle-type applicator with foaming cleanser was observed in this project to be much more effective than the pump sprayers, air compressors, or garden hoses used by some technicians, in terms of the reduction in system discharge pressure and compressor energy usage. Coil cleaning is an integral part of the procedure developed in this project.

Evaporator and Economizer Airflow

Evaporator and economizer airflow were evaluated using multiple TrueFlow™ Air Handler Flow Meters (flow plate), which is a tool recently introduced into the HVAC market. This device determines airflow by measuring pressure drop across a perforated plate and converting the pressure drop to flow. More commonly used methods such as sensible temperature split across the system heat exchanger have been shown to be inaccurate in a number of studies (e.g., Palmiter and Francisco 2001).

The protocol involves measuring both the economizer flow and air handler fan flow simultaneously, so as to get an estimate of the percentage of outdoor air under various economizer positions. Flow plates are inserted in place of the system filters and at the inlet of the economizer.

Manufacturers of air conditioning equipment have typically suggested that an airflow rate of 400 ft^3/min (CFM) per nominal ton of cooling is the desired airflow. Although manufacturers vary somewhat about this number, 400 CFM/ton is the generally agreed-upon benchmark for assessing whether airflow is adequate. Various laboratory and field researchers (e. g. Parker et al. 1997) have found that airflows of 350 and even 325 CFM/ton moderately degrade system capacity and efficiency.

Use of the TrueFlow™ plates is easy to understand; the main challenge to the technician on medium size packaged units is that multiple plates must often be installed to measure the airflow. This can be time-consuming in some cases, and there can occasionally be problems with air bypassing the plates. In most cases, however, some ingenuity can solve these problems. The technicians were very impressed with the ability of the plates to give direct measurements of flow, and commented especially on the usefulness of this measurement in installing new systems.

Economizer

The economizer portion of this project aimed broadly at five goals:

- determine the range of economizer types installed;
- develop a generalized protocol for assessing economizer operation;
- apply the protocol to assess the operational capabilities of installed economizers;
- determine optimal configuration of economizer logic and setpoints;
- estimate the energy and savings impacts of economizer assessment and repair.

The hope was that a field checklist could be developed that a service technician could follow to determine the health of the economizer. The checklist was to include characterization as well as functional tests. The functional operation verification aspect of this checklist proved to be the most challenging part of the project. The range of equipment found and the difficulty in performing some tests made the development of a generalized protocol elusive. At this point, the economizer portion of the protocol is still under development.

The protocol in its current form includes space for descriptive detail for the entire package including make, model and capacity. The individual sections develop information on refrigerant charge, airflow, duct characterization, and specific information for the economizer. The economizer information includes control type, sensor type and manufacturer information for the economizer and controls themselves.

Field Results

Field crews evaluated 30 units in 19 separate businesses, most of which were located in Eugene, Oregon. A small group of units were located in the Puget Sound area. Execution of the full protocol required an average of about 4 hours.

Not all parts of the final protocol were completed for each unit, since the protocol was under development throughout the project and because, in some cases, economizer troubleshooting took longer than average or was inconclusive. Toward the end of the field testing, it was felt that time was best spent getting the best understanding possible on economizers, so the flow and charge protocols, which were both well in hand, were sacrificed.

The equipment tested in this project ranged in size from 2.5 to 15 nominal tons of cooling, with the average being about 7 tons. The units ranged in age from the mid-1980s to very recent (i.e., installed in the year 2001). All units but one were unitary packaged systems. One split-system unit was included as part of the study: a 5-ton unit that used R-410A as its refrigerant. Six of the units had dual compressors; the rest had single compressors. Some units used natural gas for heat, some were heat pumps, and others supplied only air conditioning.

Most systems were constant volume; a few cases used zone dampers. Refrigerant charge evaluation was only done on units that could be maintained at a constant flow rate for the duration of the test (to give the evaporator the highest possible airflow); if a system was constantly changing airflow and mixed air temperature, such as is often the case with variable volume/variable temperature (VVT) systems, the charge evaluation could not be performed.

In reporting field results, we note the overall number of sites is relatively small, so it is useful to display and discuss individual results.

Refrigerant Charge

It was possible to attempt use of CheckMe!™ on 16 units; 14 had successful CheckMe!™ runs, in which a conclusive evaluation of charge was provided. The other two cases had insoluble compressor staging or zone damper problems.

Only five out of the 14 systems (36%) had the correct charge in their as-found configuration. This is in-line with findings of larger studies of residential air conditioners conducted by Proctor Engineering (e.g. Proctor et al. 1995).

In cases where the system needs an adjustment, CheckMe!™ provides a recommendation on the size of the adjustment. Recommendations are based on results of prior adjustments at the same cooling load, and are given in ounces of refrigerant to add or remove. Technicians are cautioned to treat the recommendations conservatively, especially since packaged units typically respond more rapidly to small adjustments than split systems (on which most of the data in the CheckMe!™ database has been collected).

Of the 14 successful CheckMe!™ runs, 7 initially returned results of overcharge with the average recommendation of removing 8 ounces of refrigerant. In two of these cases, the bakery and the pet grooming facility, the apparent overcharge was due to dirty coils; when the coils were cleaned, CheckMe!™ returned a result of proper charge. Our field results indicate that cleaning coils prior to performing CheckMe!™ is extremely important, which is now standard procedure when using the program. In the other five cases of overcharge, technicians were reluctant to make any changes in the system charge, so the system was left as found.

In four cases, the system was said to be undercharged by CheckMe!™. In one of these cases the system had a very severe leak in an after-market pressure controller. The controller was replaced and three pounds of refrigerant were added. After this change was made, the system was still undercharged, but it was left at this point to avoid further system problems, since the return ducts were seriously undersized (flow was about half of the recommended level).

Refrigerant was also added in unit D at the drug store. This unit was found to be about 20 ounces low, and 19 ounces were added. This shortage is fairly significant, and the contractor agreed with the CheckMe!™ assessment. After the refrigerant was added CheckMe!™ said that the charge was fine. No change was made in the other systems with reported low charge, as the recommendations were both the minimum 6 ounces that can be reported by CheckMe!™ and the contractors did not feel that adding refrigerant was justified.

Evaporator Airflow

System (evaporator) airflow was measured in 27 units. The results are shown in Table 1. The average flow was 304 cubic feet/minute – ton, corrected to standard air conditions (SCFM/ton). This flow was taken with the economizer in either a minimum air position or closed, whichever configuration provided the least outside air. System airflow ranged from 99 to 429 SCFM/ton. The case with the lowest flow was a VVT system in which we were unsuccessful in opening up more than 2 out of 7 air zones. About two-thirds of the units had airflow less than 350 SCFM/ton. It is interesting to note that the average was very close to what other researchers have found looking at larger sets of randomly selected data (e.g. Parker et al. 1997). Most studies of airflow have studied residential systems, but there is no difference in how system airflow affects refrigeration capacity and efficiency.

Table 1. Evaporator Airflow

Business/Unit	**Nominal Tons[1]**	**(SCFM)**	**(SCFM/ton)**
Shopping common area	5/5	1985	198
Restaurant	5	2008	402
Bakery	7.5	1915	255
Florist	5	1288	258
Pizza Shop	4	1047	262
Tanning salon - unit 1	5	1675	335
Tanning salon - unit 2	3	584	195
Tanning salon - unit 3	5	959	192
Research facility - unit B-8	6	1990	332
Drug store - unit C	4	1715	429
Drug store - unit D	5	2010	402
Pet grooming facility	6	2037	340
Pet veterinarian	4.5/3	2639	352
Pet store - unit 8	3	1057	352
Airport lower roof	10/5	1489	99
Airport upper roof	7.5	2712	362
School facility	2.5	777	311
Office building A - 2.5 ton	2.5	767	307
Office building A - 4 ton	4	1630	408
Office building A - 8.5 ton	4.5/4	2685	316
Office building B - 7.5 ton	7.5	2327	310
Office building B - 15 ton	15	5480	365
Travel agency - unit 1	7.5	1978	264
Travel agency - unit 2	7.5	1770	236
Travel agency - unit 3	7.5	1850	247
Athletic club	12.5	4492	359
Office building C	5	1610	322
Average	**6.6**	**1943**	**304**

1.Two numbers indicate sizes of first and second stages in dual compressor systems. For these cases, flow expressed in CFM/ton is based on the total available cooling. None of the units tested had a higher speed for the second stage.

Economizer Function

Table 2 summarizes the problems found with the economizers. Of the 23 economizers only 9 (less than 40%) were fully functional. Full functionality in this case means the outside air damper modulates to minimum when there is no call for cooling, the system can open to maximum outside air when there is a call for cooling, and there is no obvious problem with the damper actuator. The economizer checkout procedure was under development throughout the project, so the assessment of economizer function is conservative. Since sensor calibrations were checked in detail in only a very few cases, this potential fault is not included in the table.

Table 2. Summary of Diagnosed Economizer Problems

Business/Unit	Broken damper control	Damper installed fixed fully open	Off/Low ambient change-over[1]	Damper opens fully for compressor operation	Remote damper control[2]
Shopping common area			√		
Restaurant			√		
Bakery					
Florist					
Tanning salon - unit 1		√			
Pizza shop		√			
Research facility - unit B-8					
Drug store - unit C					
Drug store - unit D					
Pet grooming facility					√
Pet veterinarian					√
Pet store - unit 8					√
Airport lower roof					
School facility					
Office building A - 2.5 ton				√	
Office building A - 8.5 ton				√	
Office building B - 7.5 ton					
Office building B - 15 ton					
Travel agency - unit 1	√				
Travel agency - unit 2	√				
Travel agency - unit 3	√				
Shopping mall – unit 27			√		
Shopping mall – unit 10			√		
Total	**3**	**2**	**4**	**2**	**3**

1.Changes to compressor-only cooling at outdoor temperature of 40 F or even lower, so unit almost never uses outdoor air for cooling.
2.System was controlled by a remote modem so it was impossible to fully evaluate the economizer at the time of the field visit.

The vast majority of the systems tested used louvers and actuators. Only four units had slider dampers. All of these units were of the older Carrier Weathermaker type, and used microswitches for position control. Three of these were found to have broken microswitches that caused the dampers not to operate. Of these two were fixed closed at minimum position.

Two units were found to have been installed with the outdoor air dampers fixed in a fully open position. This meant much more air than needed for ventilation was introduced whenever the system air handler ran. In one case, 75% of the system flow always came from outdoors; in the other case, the outdoor air fraction was measured at about 50%. The accompanying contractor fixed these problems.

Of the 22 economizer systems that went through a full examination, 15 (68%) used dry bulb changeover controls. The remaining 7 used enthalpy changeover controls. None used differential control. Some of the units that have dry bulb controls had been originally installed with enthalpy controls, but when the sensor failed it was replaced with a dry bulb sensor. This is common practice in the Eugene area, and corresponds with the very low latent cooling load (whether by design or by chance is unclear).

On eight of the dry bulb units, changeover setpoint data were recorded. In three of these eight units the economizer was set to off, meaning it would never be used for cooling. In another, the setpoint was set to 40° F. While this does not preclude using the economizer for cooling, the number of hours in which it may be used for cooling will be exceedingly small. The setpoint at these units was changed to 60° F. In another case, a nominal apparent setpoint of 95° F was recorded, but it was later determined a snap disc-type control overrode this misleading setpoint.

Of the remaining four units with recorded dry bulb changeover settings, two were at the pet grooming facility and unit 8 of the pet store, which were at the same building. At this building the changeover did not appear to have any effect at any of the units tested, although the dampers all were found to be functional. Thermostat settings for this building were set at a central headquarters in Phoenix, AZ, and it is likely that the economizer settings are also controlled from this remote location.

The remaining two units with recorded dry bulb changeover setpoints both appeared to be working. This does not mean that we were able to verify that there were no problems (e.g. sensor calibrations), but none of the diagnostics performed revealed any fault.

Of the seven units with dry bulb changeover but no recorded setpoints, three were the travel agency units with broken microswitches, causing the economizers to be inoperable. One of the remaining four was the pet veterinarian, which was at the same pet store with the apparent control from Phoenix. The 2.5 ton unit at office building A did not have a damper problem, in that the damper was fully functional, but the damper went to fully open when the compressor came on. Replacement of the control board did not fix the problem.

Of the seven economizers with enthalpy sensor control, five did not show any specific problems. One of the remaining two was the unit with the louvers installed fully open. The final unit, the airport administration building, did not have an obvious way to assess the functionality of the economizer when the outdoor conditions were outside of its range. We made only one change on an enthalpy control (to a more aggressive setting which enabled more use of outside air for cooling).

Economizer Airflow

Airflow measurements through the economizer were made at 17 units in up to 3 different economizer configurations: economizer closed, economizer at minimum position, and economizer fully open. Measurements were made with the flow plates. Measurements with the economizer closed were intended primarily to determine whether there was significant bypass around the dampers. In general, when economizers were closed there was no measurable flow through the economizer.

Of much more interest was the fraction of outdoor air with the economizer at minimum position and with the economizer fully open (i.e., economizer being used for cooling). In addition to measuring the fraction of outdoor air in each of these situations, we wanted to investigate whether there was a significant change in system flow when the economizer was fully open. In cases where the flow rate does change significantly, a likely cause is that the duct resistance is substantially different from the resistance of the economizer.

Table 3 shows the results of this testing. The flow rates under each configuration are total system flow, with economizer flow represented as a percentage of the system flow. The final column shows the ratio of the system flow with the economizer fully open to the flow with the economizer at minimum position. Flow is in cubic feet per minute of standard air (SCFM).

Table 3. Economizer Airflow Results

	Minimum		Fully Open		Flow
	System (SCFM)	Outdoor (%)	System (SCFM)	Outdoor (%)	Open / Min.
Shopping common area	1985	13.9	2137	62.6	1.08
Restaurant	2008	0	2098	26.2	1.04
Bakery	1915	11.2	1995	53.3	1.04
Florist	1288	18.2	1342	63.5	1.04
Tanning salon - unit 1	1675	20.4	1360	73.4	0.81
Pizza shop	--	--	1075	74.5	--
Research facility - unit B-8	1990	17.1	1996	78.9	1.00
Drug store - unit C	1715	0	1589	92.7	0.93
Drug store - unit D	2010	0	1804	93.6	0.90
Pet grooming facility	2037	22.6	2138	62.0	1.05
Pet veterinarian	2639	0	2494	61.1	0.95
Pet store - unit 8	1057	31.9	1067	55.5	1.01
School facility	777	17.8	823	64.3	1.06
Office building A - 2.5 ton	767	91.9	767	91.9	--
Office building A - 8.5 ton	2685	54.2	--	--	--
Office building B - 7.5 ton	2327	9.2	2327	50.9	1.00
Office building B - 15 ton	--	--	5480	39.9	--
Travel agency - unit 1	1978	21.6	--	--	--
Average	**1803**	**20.6**	**1839**	**65.3**	**0.99**

The table shows that, on average, minimum position for 16 units provided about 20% of the total airflow. This corresponds to an average minimum economizer flow of about 320 SCFM. However, while there is cluster at the 10-25% range, there is a wide variation in measured flow. Incorrect damper positions were changed prior to testing, however, so no quantitative results of the as-found minimum setting are available.

On average, the units obtained about two-thirds of their air from outside when the economizers were fully open. This mean that if the economizer air dampers were fully open they could only deliver the stated portion of the total air flow, reducing the effectiveness of the economizer.

The vast majority of the units delivered in excess of 50% outdoor air with the economizers fully open, with only the restaurant and the 15 ton unit at office building B being below that level. About half of the units got 60-80% of their air from outdoors when the economizer was fully open, and only three had outdoor air over 90%. This is common, as many units are not designed to actually shut off the connection to the return ducts completely. The units that had over 90% probably were designed to shut down the return completely, and the portion of the air that was not from the economizer was likely bypass around that damper.

For the most part, system airflow did not change much when the economizer opened, usually less than 5%. There were only four units where measured flows changed by more than 5% between minimum and full-open economizer positions, and only one of these was greater than 8%. At the remaining unit, tanning salon unit 1, the measured flow changed by almost 20%, with the flow being significantly lower with the economizer fully open. It is unknown why the flow changed so dramatically at this unit.

Energy Savings Estimation

The sponsoring utility was obviously interested in the energy savings that could be attached to identifying and fixing various installation and operations problems. EWEB currently offers sizable incentives for installation of an economizer kit on new or existing package unit installations. They are interested in extending incentives to renovation of existing economizer systems. As part of the protocol, a number of measurements were taken on the units and, where possible, were associated with actual repairs. The most useful measurements turned out to be hand held readings, especially amp draw at the compressor before and after condenser coil cleaning (which results in a direct measurement of change in COP at the given ambient condition) and measurements of evaporator airflow (which could be compared with detailed studies of air conditioner performance as a function of evaporator airflow). Because the amount of measured data was modest, a set of DOE-2.1E simulations was run to estimate economizer-related savings. Refrigerant charge and evaporator airflow adjustment savings (expressed as a percent of each load) were estimated based on fieldwork done by Proctor et al. (1990).

Table 4 shows the estimated impact of maintenance measures attempted in this project. A total of 30 units were tested, but the number of units for which a measure was applicable could be substantially less, either because those characteristics were not reviewed or because (as with two of the units), no economizer was installed. Potential program impacts are a combination of the estimated savings and the probability that any unit might benefit from that repair. The percent savings associated with these measures are derived from the simulation results applied to the individual building type. This includes estimates of lighting and other occupancy effects on the cooling requirements in the building. The simulations represent an initial estimate that allowed the operating conditions present at the site visit to be translated into an overall annual impact on the cooling energy of the building. This should be viewed as an initial estimate that should be confirmed with more detailed evaluation.

The savings in Table 4 were developed independently for each measure noted. Thus the interaction between measures is not accounted for directly. To a first approximation the savings from a repair and optimization is the product of the percent savings from all measures applied. Savings estimates are mutually exclusive within each category: each individual measure would be applied as an alternative to the other mentioned.

Table 4. Estimated Savings By Measure

Measure	Savings (% of annual cooling)	Percent of units eligible for measure
Charge		
Repair 20% undercharge	11	7
Repair 10% undercharge	6	28
Flow		
Clean condenser coil	6	5
Repair evap. airflow problem	4	19
Economizer (60 F Change-Over)[1]		
Fix damper problem	26	15
Fix control problem	26	30
Economizer (55 F Change-Over)[2]		
Fix damper problem	14	10
Fix control problem	14	20
Economizer		
Changeover Setting (55 – 60 F)	11	37 (sensible)
Differential/integrated Control[3]	23	30 (enthalpy)

1.Measure is to go from a no-economizer condition to a 60 F changeover. Damper and control problems are called out individually because there is a different estimated incidence of each problem.
2.Measure as preceding but use 55 F as the changeover temperature from outside air to compressor-only cooling.
3.Integrated control allows simultaneous use of outside air and compressor.

The most significant savings are available from economizers; about 60% of the economizers reviewed were thought eligible for one or another of these energy saving measures. This is not to say that 60% of the economizers were dysfunctional, since in at least a third of the cases measures that involved improving the control or increasing the changeover set point did not imply that the units were not functioning; by adjusting these control points, considerable savings would be available. This does, of course, require a level of sophistication on the part of the technician to judge when such control changes might be appropriate.

In addition to economizer savings, other O&M measures such as charge adjustment, damper repair and coil cleaning can offer very cost effective savings although they are usually smaller than the economizer impacts.

Utility Program Impact

EWEB has been running an "Energy Smart Replacement" program that rebates outside air economizer installation at up to $750.00 per unit. Cost effectiveness and savings are based on proper operation and the research behind this paper was commissioned after industry sources (Lunneberg 1999) indicated there may be widespread problems with their operation. Based on verification received in the reported field work, EWEB now requires a check-out procedure for all rebated economizers and has reduced incentives to reflect the current industry condition. Incentives for economizer installations are now $150 per ton of cooling up to a maximum of $750.

EWEB plans to continue the research and protocol development, hopefully in conjunction with regional market transformation organizations and develop a retro-commissioning program targeted at smaller rooftop units. However, current field research with HVAC service contractors indicates that substantial variation exists in the controls for these units as installed in the field. Significant training will be required to familiarize the service contractors with the large number of commonly used control configurations.

Conclusions

This project resulted in development of a protocol to assess rooftop packaged unit function. The protocol was not transferred successfully to HVAC technicians so that they could use it without supervision, but it is likely more work will be done with this protocol and there will be more opportunities to train technicians. The dissimilarity of equipment and controls seen in the field will need to be addressed in contractor training to allow the protocol to be successfully completed in the field.

A significant minority of units had refrigerant charge deficiencies; suggested adjustments were, on average, relatively modest. Measured evaporator airflow averaged about 300 CFM/ton of cooling, which is similar to other studies' results for residential units. Savings of 5 to 10 percent on the cooling energy requirements were estimated for measures the corrected these deficiencies. Because the resistance from the service technicians, adjustments of refrigerant charge was thought to be a secondary priority for the development of a utility program.

Outdoor air delivered through the economizer system averaged about 20% of full system flow at minimum setting and about 65% at maximum setting. A wide range of minimum airflow was observed, which has both energy and air quality implications. Substantial savings could be available if damper settings can be optimized. Often these effects are not accessible since they are part of the initial manufacturing specifications.

Energy savings for repair of economizer faults offer the greatest potential energy savings in the Eugene climate. The complexity and variation of the economizer controls found in the field was a major barrier to development of a standardized economizer troubleshooting and repair procedure. Further research in this area is appropriate, perhaps leading to an HVAC industry market transformation effort.

While repair and optimization of outside air economizers was shown to be economically effective in simulation, the reality of the field is quite different. In fact the units operating incorrectly are probably contributing to increased energy use rather than savings. This sample set is not large enough to project a region-wide impact, but based on the poor level of operation reported here and elsewhere it may well be that the substantial investment in economizers is resulting in no net savings on balance. In cases where actual equipment malfunction exists, savings and benefits are clearly apparent. However, this sample also indicates that cost effective savings may be obtained by optimizing the performance of functional units through relatively simple procedures done as part of an HVAC service contractor's maintenance or repair visit. It is clear, even from this small sample, that a full checkout of economizer installation operation or retrofits is desirable where utilities are contributing incentives and expecting to receive load reductions. Further research in this area is important.

References

Baylon, D, M. Kennedy, S. Borrelli, 2001, *Baseline Characteristics of the Non-Residential Sector in Idaho, Montana, Oregon, and Washington*. Portland, OR: Northwest Energy Efficiency Alliance.

Breuker, M., T. Rossi, and J. Braun. 2000. "Smart Maintenance for Rooftop Units." Printed in *ASHRAE Journal*.

Davis Energy Group, 2001. *Specification of Energy Efficient Installation Practices for Commercial Unitary HVAC Systems.* Boston, MA: Consortium for Energy Efficiency.

Delp, W.W., N.E. Matson, E. Tschudy, M.P. Modera, and R.C. Diamond. 1998. *Field Investigation of Duct System Performance in California Light Commercial Buildings*. Lawrence Berkeley National Laboratory. *ASHRAE Transactions*, V. 104, Pt. 2.

Hewett, M., D. Bohac, R. Landry, T. Dunsworth, S. Englander, and G. Peterson. 1992. *Measured Energy and Demand Impacts of Efficiency Tune-ups for Small Commercial Cooling Systems.*

Houghton, D. 1997. *Operating and Maintaining Rooftop Air-conditioning Units*, E-source TU-97-2.

Lawrence Berkeley Laboratory. 1993. *DOE-2.1E Reference Manual*. National Technical Information Service.

Lunneberg, T. 1999. *When Good Economizers Go Bad*. E-source ER-99-34.

Palmiter, L. and P.W. Francisco. 2000. *Development of a Simple Device for Field Air Flow Measurement of Residential Air Handling Equipment: Phase II*. Final Report. Prepared for the U.S. Department of Energy by Ecotope, Inc.

Parker, D., J. Sherwin, R. Raustad, and D. Shirey. 1997. *Impact of Evaporator Coil Airflow in Residential Air-Conditioning Systems.* Florida Solar Energy Center. Presented at the 1997 ASHRAE Annual Meeting.

Pratt, R., Katipamula, S., Brambley, M., Blanc, S. 2000. *Field Results from Application of the Outdoor Air/Economizer Diagnostician for Commissioning and O&M*. In Proceedings of the 2000 National Conference on Building Commissioning.

Proctor, J., M. Blasnik and P. Downey. 1995. *Southern California Edison Coachella Valley Duct and HVAC Retrofit Efficiency Improvement Pilot Project.* Final Report. Prepared for SCE by Proctor Engineering Group.