The Premium Economizer: An Idea Whose Time Has Come

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ABSTRACT

Several field studies have found that more than half of outside air economizers on packaged rooftop cooling units are not providing optimal savings, either because dampers or controls have failed, changeover is set incorrectly, or the improper type of controls for the local climate have been installed. Analysis of economizer operation indicates that, at best, only one-third of potential savings is being achieved. Eugene Water & Electric Board (EWEB) has developed "premium" economizer requirements that result in increased economizer savings in the field. Meeting the stricter requirements is rewarded by larger utility rebates.

A brief literature review of packaged rooftop cooling unit studies is followed by results from a full cooling season field test of ten packaged units equipped with either standard or premium outside air economizers. Extended field monitoring shows that properly operating premium economizers provide more savings than standard economizers. Results also show that better commissioning is required to improve economizer reliability. Three years of utility program experience in providing rebates for a "premium" economizer are also discussed.

Introduction

Packaged rooftop units provide air-conditioning, ventilation, and heating for about 45% of the floor space in the United States (EIA 1998). In the West, 12% of buildings report having outside air economizers installed (Lunneberg 1999). An outside air economizer is a set of components that allows the use of outside air for cooling instead of operating a mechanical refrigeration compressor. The Fifth NW Power Plan estimated that in the commercial sector, rooftop heating ventilating and air-conditioning (HVAC) improvements would contribute 16.7% of retrofit savings and economizers provide a large share of that savings (NPCC 2005).

Often dubbed "free cooling," the outside air economizer shows great savings potential in theoretical energy simulations. The actual performance has been much less than ideal as discussed in the literature review. This paper explores extended monitoring of an improved economizer specification to verify that savings can actually be increased. Daily performance results indicate that the time has come to implement this 30-year old premium economizer technology. The paper also discusses program implementation history and recommended program improvements to increase the reliability of savings from outside air economizers.

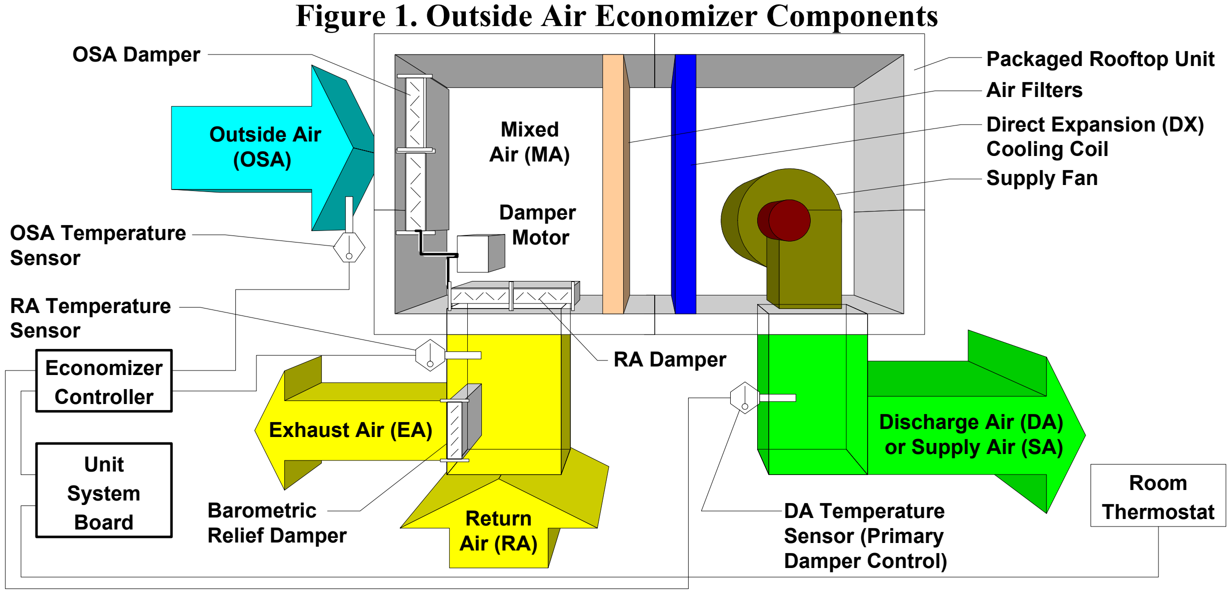
Literature and Program Review

Several field studies have found that more than half of outside air economizers are not providing optimal savings, either because dampers or controls have failed, changeover is set incorrectly, or the improper type of controls for the local climate have been installed. The New Buildings Institute completed a fairly recent compilation of western rooftop field studies (Cowan 2004). Summarized data from four field studies in California and the Northwest (covering more than 500 packaged rooftop HVAC units) showed that outside air economizers displayed problems in 64% of the units. Economizers were also noted as having great savings potential. These field studies may have been inspired by an early report that all was not well in the economizer world (Lunneberg 1999). Efforts to improve the situation have focused on three areas: (1) improving service for rooftop units including proper economizer adjustment (EMI 2004), (2) encouraging manufacturers to develop a more reliable and efficient rooftop unit including economizer enhancements (Jacobs, Higgins & Shwom 2004), and (3) developing a reliable and workable solution as a retrofit to existing units and as an upgrade to units being installed with today's technology (Hart 2004). This paper focuses on the third area; although conclusions indicate that more functional testing or commissioning follow up will be necessary to improve retrofit reliability.

Outside Air Economizer Saving Principles

An outside air economizer uses cool outside air instead of mechanical cooling. Where there are cooling loads simultaneous with cool outside air, significant savings can be achieved. An economizer schematic with components is shown in Figure 1. Over the years, numerous economizer control strategies have been developed. Many attributes can be adjusted to change the operation, effectiveness, cost, and potential savings of an outside air economizer. These attributes are briefly explained below. More comprehensive explanations and illustrations can be found in EWEB program literature (Hart 2004).

Figure 1. Outside Air Economizer Components



Economizer Configuration

Typically, packaged rooftop HVAC units have outside air (OSA) and return air (RA) dampers. Barometric relief dampers usually provide relief of building air pressure. Damper actuators are typically fully modulating and can drive dampers to any position (measured as percent open). The primary damper control is typically a proportional controller and temperature sensor that maintains air between 50ºF and 56ºF. The primary control sensor can be located in either the mixed air (MA) position or the discharge air (DA) position.[1]

Economizer Activation

Most packaged HVAC units have "coordinated" activation. The economizer is activated on an actual call for cooling from the space thermostat. Some older sequences use a fixed mixed air temperature control, resulting in excessive heating energy use.

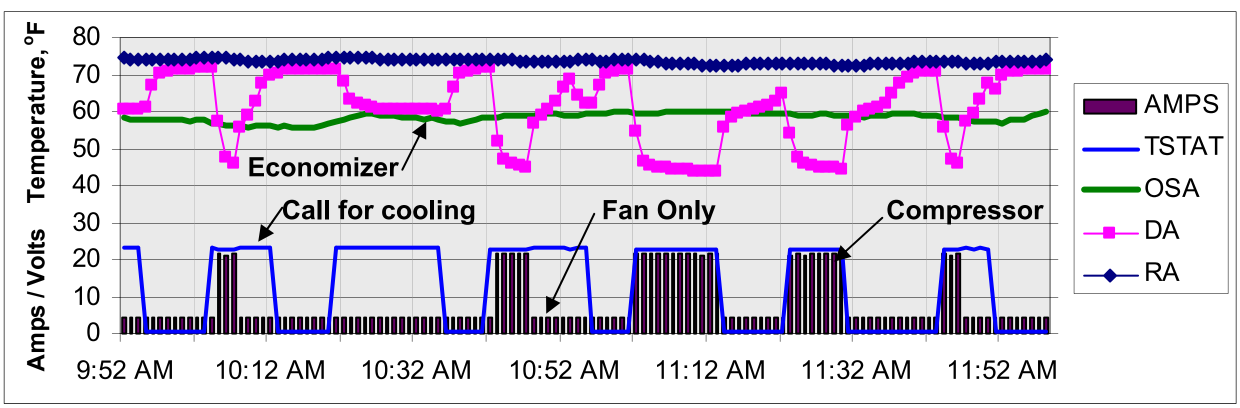
Changeover

The OSA high limit or "changeover" sequence determines when is it too hot or humid outside to use the economizer. Changeover type is distinguished by both mode and sensor type. The sensor type should match the climate. Two types of sensors are available:

- Dry-bulb sensors measure temperature only. Recommended for the western U.S.
- Enthalpy sensors adjust for the heat energy of moisture in air. Recommended for the more humid eastern U.S. More accurate enthalpy control requires separate dry-bulb and humidity or dew-point sensors. Less accurate combined enthalpy sensors are typical.

The mode of changeover control can be a single sensor (OSA only) or a set of differential or comparative sensors (OSA vs. RA) sensors. The single sensor requires field setting of the changeover point by the technician. A sample of monitoring results from a single-sensor changeover equipped rooftop unit is shown in Figure 2. Even though the approximately 15ºF difference between outside and return air could meet the cooling demand during the time period shown, the mechanical cooling compressor is used most of the time. Note that once the outside air temperature approaches the 60ºF changeover setpoint, the economizer is locked out and the compressor takes over.

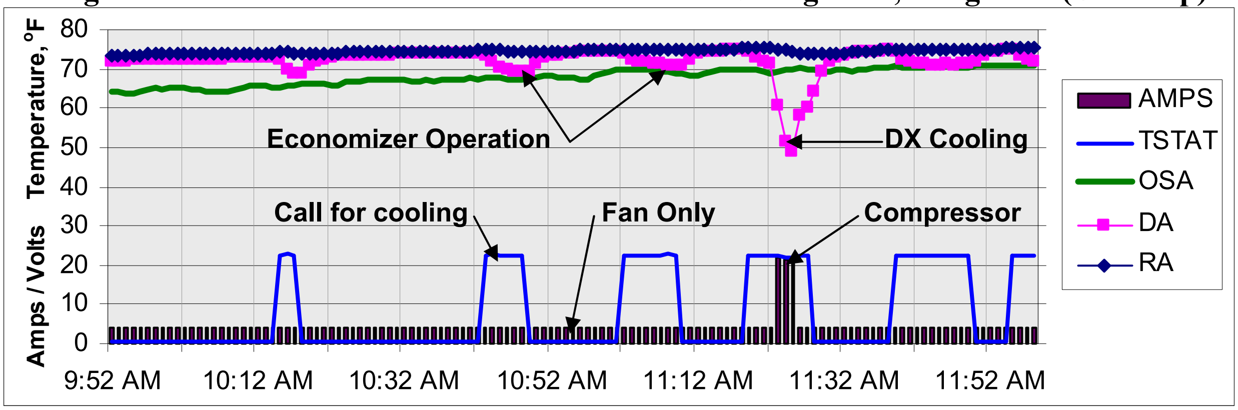
Figure 2. Standard Economizer, Single-Sensor Changeover, Non-Integrated (Unit A7s)



[1] One point of confusion is that manufacturers often call the main control sensor a "mixed air" sensor. Mixed air is the proper primary sensor location for fully modulating chilled water coils, but to maintain comfort and avoid coil icing with a direct-expansion cooling system, the primary sensor should be located downstream of the cooling coil in the discharge air position.

A differential changeover uses outside air until it is warmer (or has greater enthalpy) than return air. Differential changeover allows the economizer to take better advantage of integration strategies discussed below. Differential changeover takes the guesswork out of field adjustments and provides a more reliable economizer changeover. Most economizer controllers have the logic for differential control and just need a return air sensor to upgrade to differential control. In Figure 3, monitored results of a rooftop unit with differential changeover are shown. With a relatively high outside air temperature, the economizer cycles several times during the morning. The compressor operates only once when the second stage of cooling is activated.

Figure 3. Premium Economizer with Differential Changeover, Integrated (Unit A8p)



Level of Integration

Integration means that an economizer is "capable of providing partial cooling even when additional mechanical cooling is required to meet the remainder of the cooling load" (ASHRAE 2004, 38). Integration can be partially implemented; five discrete levels of integration exist, including the "non-integrated" case. The first two levels use a single-stage cooling thermostat, while the final three require a dedicated thermostat stage for the economizer:

- Non-integrated or exclusive operation: Below the changeover setting, only the economizer operates. Above the changeover setting, only mechanical cooling operates.
- Time-delay integration: On a call for cooling, the economizer operates for a set time (typically 5 minutes), then if there is still a need for cooling, the cooling coil operates. The dampers return to minimum ventilation at the end of the call for cooling.
- Alternating integration: This is the best integration that can be achieved with a single-stage direct-expansion cooling unit. The first cooling stage activates the economizer. When the second stage is activated the cooling compressor operates and the economizer dampers reduce OSA to avoid comfort problems from discharge air that is too cold.
- Partial integration: With a multiple-stage or variable-speed compressor direct-expansion cooling unit, integration is improved, since these systems provide partial cooling. The partial mechanical cooling provides less temperature drop so that when the compressor is on, the economizer can use a lower outside air temperature and do more outside air cooling than in alternating integration. The smaller the first stage of mechanical cooling is relative to total cooling capacity, the greater the savings from economizer operation.

- Full integration: A hydronic chilled-water cooling coil can be modulated to any cooling output. This allows the economizer to be fully open when additional cooling is required. Full integration also requires a differential changeover strategy.

Technology Definition: Western Premium Economizer

The Western Premium outside air economizer uses readily available technology—that is almost 30 years old—to provide a system that increases the savings when compared with the "standard" economizer that is typically provided in today's HVAC market place. To avoid confusion with manufacturers who may have different specifications for a "premium" economizer, EWEB uses the term "Western Premium Economizer" (WPE) to specify an integrated economizer with a dry-bulb differential changeover. Table 1 shows a summary of standard and Western Premium Economizer features, as well as the specifications for the better than standard economizer that was monitored in this study. Most rooftop equipment manufacturers can meet the WPE specification, but the correct components must be specified.

Table 1. Economizer Attributes

Attribute	Typical "Standard"	Monitored "Standard"	Western Premium
Configuration	Modulating RA/OA dampers, no relief	Modulating RA/OA dampers, barometric relief	Modulating RA/OA dampers, barometric relief
Activation	Single stage cooling	Single stage cooling	Two Stage Cooling
Changeover	Snap Disc 55ºF OSA dry-bulb	Settable 60ºF OSA dry-bulb	Differential dry-bulb
Integration	None: either econo or cool	None: either econo or cool	Alternating integration
Ventilation minimum	"eyeball" estimate	CO_2 meter used once to set at site "A," eyeball at site "B."	Set using measured temperatures to calculate outside air fraction.

Improved Economizer Integration

Increased savings results from improving the integration of the economizer with mechanical cooling. "Standard" economizers typically have no integration. Maximizing integration is important because there are many occupied hours during the year when OSA is in the 55ºF to 70ºF range where integration increases economizer savings. New lighting technologies and flat-screen computer displays are putting less heat into the space, reducing the need for cooling when outside air is below 55ºF. Lower internal loads mean that it is even more important that economizer operation be integrated with the mechanical cooling operation.

Fundamental economizer requirements. EWEB provides rebates for both standard economizers and Western Premium outside air economizers. There are several fundamental requirements that apply to both:

- Fully modulating damper motor with modulating control.
- Coordinated control: the economizer is only active when there is a call for cooling.
- Relief air and modulating return air damper. Relief air can be provided with a barometric damper in the return air duct, a motorized exhaust air damper, or an exhaust fan.
- Minimum outside ventilation air measurement. Part of the documented checkout includes verifying the minimum OSA setpoint by measuring the temperature of the mixed air, return air, and outside air to calculate the percentage of outside air. While not technically part of the economizer strategy for cooling, paying attention to when and how

much ventilation air is used can save energy. Excessive ventilation air increases heating and cooling energy use when not economizing.

Western premium economizer requirements. Western Premium Economizers will provide greater savings because they provide alternating or partial integration. In addition to the fundamental requirements, Western Premium Economizers have these requirements:

- Dedicated thermostat stage for economizer. To get the most benefit, the economizer needs to provide cooling first, before the cooling compressor is engaged.
- Differential changeover. Most economizer controllers have differential logic built in; the addition of a dry-bulb return air sensor increases savings.
- Dry-bulb changeover. In the western climate, high humidity rarely occurs near changeover temperatures.[2] For most occupancies, dry-bulb sensors are required in the western U.S. due to higher expected reliability[3] and lower cost. If the specification were applied in the more humid eastern U.S., enthalpy sensors would be appropriate.
- Primary control placement. For a direct-expansion (DX) cooling coil, the primary damper control temperature sensor should be located after the cooling coil to maintain comfort.
- Low-ambient OSA compressor lockout. This control stops the compressor from operating when the outside air is below setpoint (55ºF to 60ºF recommended, 50ºF minimum). Many economizers have undetected failures. With the low-ambient compressor lock out, an economizer failure may result in a high temperature comfort complaint and service request so the economizer is more likely to get needed service.
- Installer training. For Western Premium Economizer installations, a lead installer from the contractor must have attended the EWEB orientation session, plus either (a) both basic and advanced EWEB economizer classes or (b) manufacturer training that covers economizer field installation and controls for the brand of economizer installed.

Field Test Methodology

The approach was to find several packaged rooftop units with standard economizers where customers would allow monitoring. EWEB paid for retrofit of half the units to meet the WPE specification. One-minute data from June through October of 2005 for five standard and five premium units were used for analysis. Standard units were monitored in the condition found. Premium units received the contractor checkout and documentation as required by the program, but no further commissioning or special functional testing was applied.

Site Conditions

Units were selected on two buildings in Eugene, Oregon. Building "A" is a medical clinic built in 1992 and is in generally good condition. The rooftop units are shown in Figure 4.

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[2] There are no humid (moist) climate sites in the western U.S. according to ASHRAE 90.1-2004 climate zones (ASHRAE 2004).

[3] While no published reliability studies were found, dry-bulb sensors are expected to be more reliable than enthalpy sensors based on anecdotal remarks by several contractors and field investigators.

Building "B" is a former credit union branch that has been converted for office use by a security company. It was built in 1985 and is in generally good condition.

Monitoring Approach

Data loggers were set to collect data at one-minute intervals. Architectural Energy Corporation manufactured all equipment used for long-term remote monitoring. Temperature sensors were checked before field placement to verify accuracy.[4] The overall system architecture consists of local micro data loggers, connected to a multiplex router connected to a modem and a phone line. Most loggers were located next to the fan housing, inside the unit as shown in Figure 5. The monitored points of a typical heat pump include:

- Discharge air (DA): located after the cooling coil, either before or after supply fan.
- Return air (RA): located about 2 feet down the return duct before the mixing section.
- Compressor & Fan Amp draw: a current transformer is placed on the load side of the HVAC unit power supply. This allows differentiation between compressor power and fan power. Where not possible,[5] only the compressor is monitored.
- Thermostat signal for stage one cooling (TSTAT): The voltage signal between 24-volt common and the Y1 thermostat terminal was monitored.
- Outside air (OSA): At each building three sensors were located in different locations.[6]

Figure 4. Rooftop of Building "A"

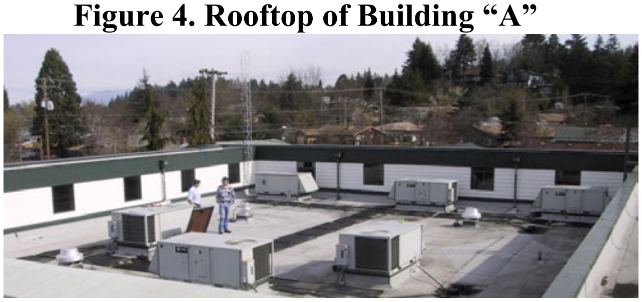
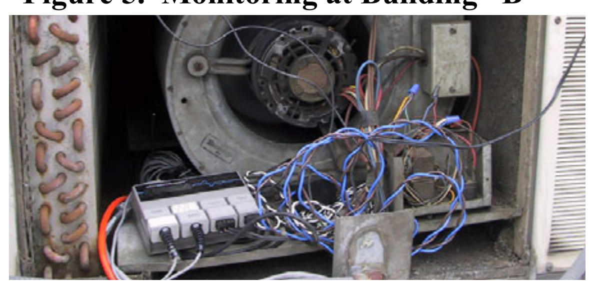


Figure 5. Monitoring at Building "B"



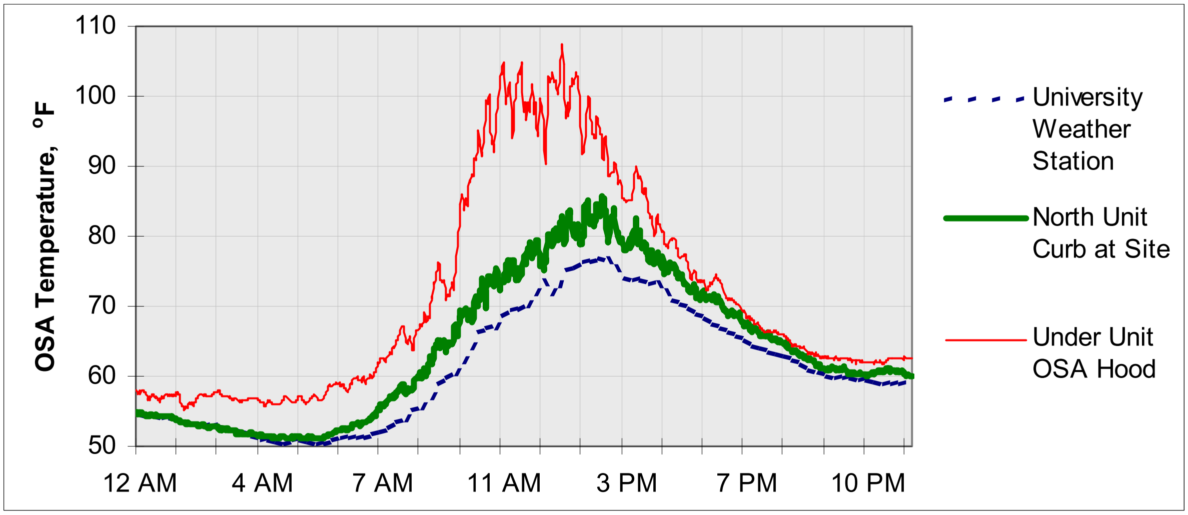
OSA sensor location issues. Figure 6 shows the comparison of readings from a sensor under the OSA hood, a site sensor on the north unit curb, and a local weather station. Monitoring of 6 outside air temperature sensors (3 at each site) revealed a high degree of temperature reading variability.

[4] The standard deviation of sensor readings during checking was 0.22ºF, with maximum/minimum deviations of +0.44/-0.35ºF.

[5] For units B1 and B5 where fan current measurements could not be collected, fan operating hours were estimated to be 8:00 am to 5:00 pm plus whenever the compressor cycled outside those hours.

[6] The sensor locations are inside OSA hoods of various orientations, inside unit frames near factory-placed OSA sensors, and at the roof curb on the north side of a unit. The north roof curb sensor was used for the OSA reference at each site.

Figure 6. Outside Air Sensor Variation Due to Location



OSA sensors inside the economizer hood may be inaccurate due to hood orientation, solar gain, or building exhaust air entrainment. Simultaneous temperature difference between sensors at each site was sometimes more than 25ºF and the median temperature spread for June through mid-July was 5.5ºF at site "A" and 7.9ºF at site "B." Since economizer control logic is dependant upon accurate OSA readings, sensor location deserves more research attention.

Field Test Results

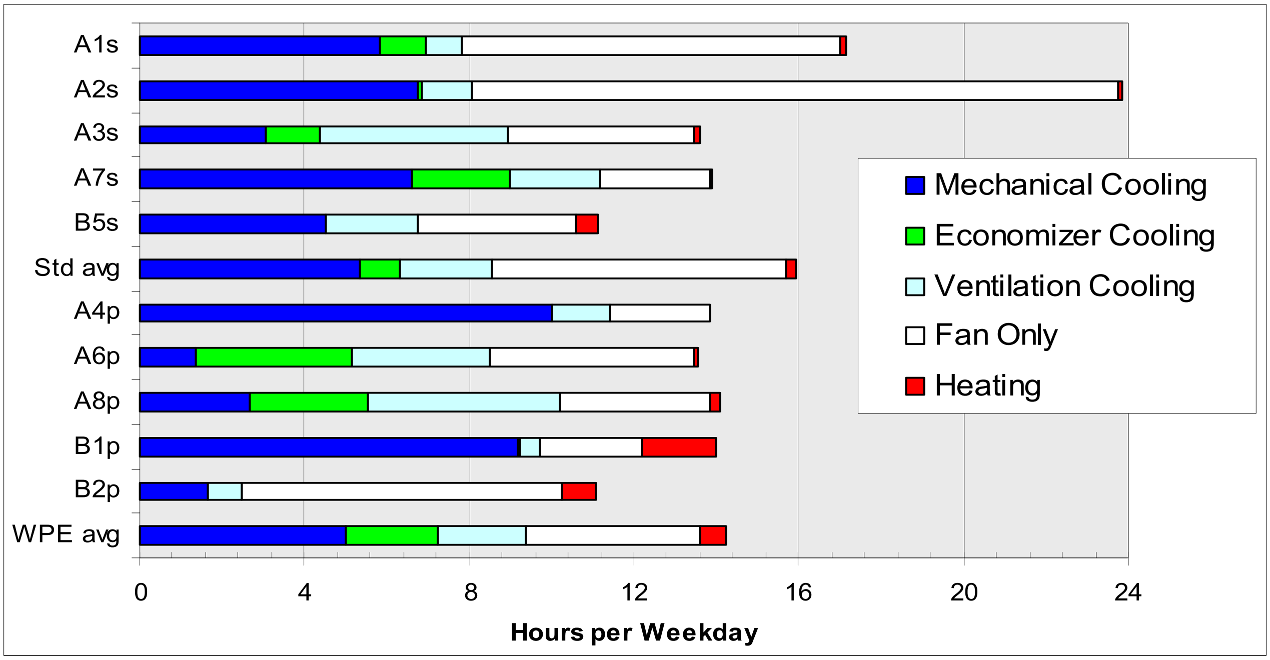
The nearly seven million data points were analyzed to determine when the units were operating in cooling or economizer modes. The unit tag prefix indicates site and the suffix indicates economizer type: "s" for standard (std) and "p" for WPE. The average weekday operation by mode[7] from June 2005 through October 2005 is shown in Figure 7. The share of total sensible cooling (on a degree-hour[8] basis) provided by the economizer[9] is shown in Table 2.

From the results shown it is apparent that most of the units do not have successful economizer operation. While failures are expected for the existing economizer units that were in the 10- to 20-year life range, it is disappointing that contractor training and a specified field checkout did not result in better reliability for Western Premium Economizers just two years after installation. The current inspection process is limited to checking that parts are all present with a visual check for any obvious errors; the inspector does not cycle the economizer to verify functionality. Troubleshooting the failed premium economizers after monitoring revealed that a

[7] Economizer cooling is only credited when the thermostat calls for cooling. Ventilation cooling effect is separately calculated since it will vary based on ventilation air minimum settings and would be provided by a unit without an economizer.
[8] Sensible cooling degree hours are calculated each minute as (RA – DA)/60 then summed for the mode analyzed.
[9] Economizer share (%) of cooling degree hours is used for comparison, as it is independent of cooling loads, unit size, or hours of cooling operation. The percentage share of economizer cooling is the economizer cooling provided compared to the sum of economizer and mechanical cooling. A larger "economizer share of sensible cooling" indicates more savings.

functional test and thermostat inspection would have discovered the failure in all cases.[10] This indicates that an independent quality assurance process is needed to improve reliability.

Figure 7. Individual Unit Average Weekday Runtime by Mode



Does "Premium" Save More?

The two best performing units from each group were compared to determine if there was significant additional savings from a Western Premium Economizer. The share of economizer cooling provided seasonally is shown in Figure 8, while daily results are shown in Figure 9.

When the two best performing economizers of each type are compared there is a gross reduction in sensible mechanical cooling of 18.1% from the standard to the premium economizer. A statistical analysis of daily results is detailed in Table 3, and the average daily mechanical cooling is found to be significantly less for properly working Western Premium Economizers when either groups or individual units are compared.

[10] Unit **A4p** was installed with the incorrect discharge air sensor (wrong resistance). Changeover sensors and other operation were correct. There was a comfort complaint due to the outside air lockout, and the heat pump activation relay was changed; however, the incorrect sensor was not detected and the lockout was set to a higher level rendering it ineffective. Unit **B1p** was found to have no problems with economizer operation; however, the unit thermostat had reset to factory defaults (78°F cooling) because the backup battery was dead. Two units served the sky lit atrium and the other unit (with a cooling setting of 72°F) carried the entire cooling load below changeover temperatures, resulting in no economizer cooling for unit B1p. Unit **B2p** was locked in changeover, probably due to a bad controller. The sensors tested correct, and the damper actuator operated correctly.

Table 2. Individual Unit Cooling Load and Economizer Operation

Unit Tag A/B = building "s" = standard "p" = premium	Cooling Size (Tons)	Degree-Hours of Sensible Cooling (Independent of unit CFM) Economizer Cooling	Mechanical Cooling	Total Sensible Cooling	Ventilation Cooling Effect (not in Total)	Percent Cooling by Economizer (5 months)
A1s	3	708	9,936	10,644	217	6.7%
A2s	4	78	11,197	11,276	417	0.7%
A3s	4	1,298	5,891	7,189	1,636	18.1%
A7s	5	3,070	14,030	17,100	786	18.0%
B5s	2	3	7,977	7,980	905	0.0%
Standard Average		**1,032**	**9,806**	**10,838**	**792**	**8.7%**
A4p	4	0	24,897	24,897	514	0.0%
A6p	4	1,942	2,739	4,681	892	41.5%
A8p	5	1,643	5,124	6,767	1,801	24.3%
B1p	2	20	25,246	25,266	248	0.1%
B2p	7.5	0	3,241	3,241	246	0.0%
Premium Average		**721**	**12,249**	**12,970**	**740**	**13.2%**

Figure 8. Economizer Cooling Share

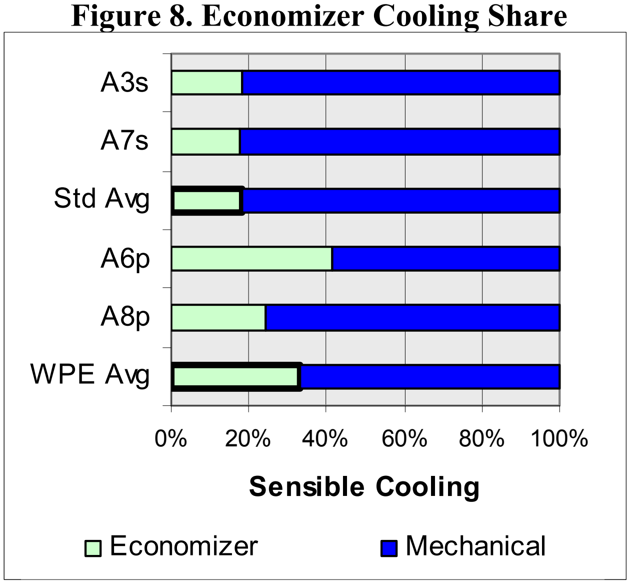
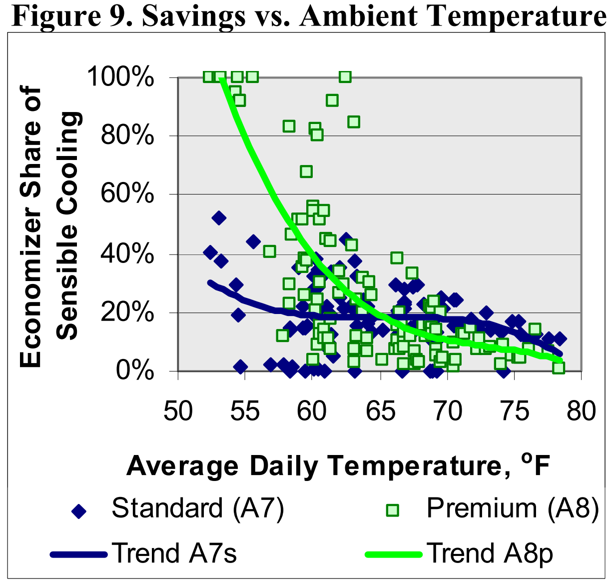


Figure 9. Savings vs. Ambient Temperature



While the unit sample is quite small, the mechanical cooling varied daily due to changes in internal load, occupants, outside temperature, and solar gain. The varying daily performance of standard[11] vs. premium economizers can be compared as a larger sample of weekday results (n=109). Both group and unit comparisons show a significant reduction in mechanical cooling when a Western Premium Economizer is used. The hypothesis that the WPE group saved 10% of mechanical cooling over the standard group was also found to be significant at the 0.05 level.

[11] The properly working standard economizers monitored were more efficient than a typical standard economizer as shown in Table 1. Most standard economizers would have fewer hours of economizer operation than the standard units monitored.

Table 3. *t*-Test of Daily Sensible Mechanical Cooling Degree Hours[12]

Groups/Units Compared		Mean Daily Cooling[13]		n[14]	Hypothesis[15]	Savings	P[16]	Result
Std: A3, A7	WPE: A6, A8	67.21	55.01	218	H_0: $\mu > 0$	18.1%	0.00006	Significantly Different
Std: A3, A7	WPE: A6, A8	67.21	55.01	218	H_a: $\mu = -6.7$	10.0%	0.0396	Savings is Significant
A3s	A6p	67.16	47.96	109	H_0: $\mu > 0$	28.6%	0.0004	Significantly Different
A7s	A8p	67.25	62.06	109	H_0: $\mu > 0$	7.7%	0.0259	Significantly Different

Program Experience

EWEB's Energy Smart Replacement Program began in the Spring of 1999. The program helps customers upgrade to more efficient HVAC products, especially when equipment failed in hot weather. HVAC contractors were the primary delivery point for the program via cash rebates they would pass on to their customers for efficient HVAC units. Figure 10 shows the increase in Western Premium installations since the specification was introduced. The history of EWEB economizer rebates is summarized as follows:

- In 1999 an economizer installation received a fixed rebate of $750. Some installations had a small cooling load or were very small units such as 1 or 2 tons.
- In 2002 the economizer incentive was limited to $150 per ton up to $750 maximum and required a short checklist filled out by the installing technician.
- Midway through 2002 EWEB teamed with Ecotope to provide a class for contractors covering the basics of an economizer and the preferred installation technique.
- In 2003 the "standard economizer" rebate was reduced to $75 per ton up to $375 maximum. The "premium economizer" specification was added with a rebate of $150 per ton up to $750 maximum. The economizer checklist was expanded.
- In mid-2003 the economizer checklist revealed some discrepancies. Random field review of premium economizer installations found that very few actually matched the information the technician had supplied on the economizer checklist.
- In early 2004 the classes were expanded to help contractors better understand the Western Premium Economizer requirements. All premium economizer installations received inspections prior to payment.
- In 2005, 90% of economizers that were inspected had the correct components installed.

EWEB conducted 84 field inspections of Western Premium Economizers over the last three years. The frequency (n) of discrepancies discovered is listed in Table 4. While most problems were minor, more than 80% of the time there was more than one problem. In most cases, contractors corrected the situation and received the higher WPE rebate.

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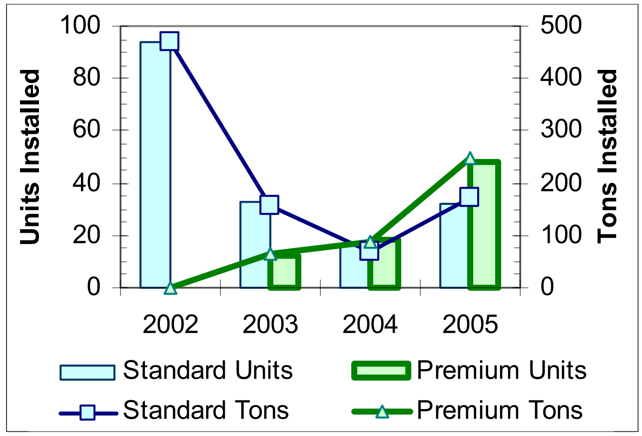
12 Standard and premium daily mechanical cooling is compared with *t*-tests, pairing data from the same day.
13 The daily mechanical cooling load of properly operating standard (Std, on left) and premium (WPE, on right) units are compared by standardizing daily mechanical cooling degree-hours to eliminate the impact of unit seasonal load variation.
14 The number of daily (weekday) data occurrences for each sample is represented by "n."
15 Hypothesis: "H_0" indicates the difference in sample means (μ) is greater than 0; "H_a" indicates the sample mean for the WPE has 10% less mechanical cooling than the standard economizer.
16 "P" is the fractional probability that each hypothesis is false.

Table 4. Economizer Discrepancies

Discrepancy with WPE specification	n
No ambient cooling compressor lockout	20
Incorrect ambient compressor lockout	1
No return air sensor	22
Incorrect OSA or RA sensor (enthalpy)	20
Incorrect OSA changeover sensor setting	12
Sensors wired incorrectly	8
No relief air	2
Economizer Completely Disabled	4

Figure 10. WPE vs. Standard Economizers



Conclusions

While the unit sample size was quite limited, there were some important lessons learned from this preliminary extended cooling season field study.

- The failure rate for the upgrades was much higher than expected, with three of the five premium economizers failing to operate properly. Since the lack of economizer operation occurred throughout the data period, and none of the units went from good to bad, this indicates that problems existed with the original installation. A simple visual inspection of the parts was not adequate to ensure proper operation.
- While one service call was triggered, the low ambient compressor lockout was not adequate to provide quality assurance. The field results did indicate that the lockout could be set at a higher ambient temperature than found for most cases. When set down to 50°F, the lockout was not an effective diagnostic indicator of economizer failure.
- When daily results from the two working premium units were compared with the two best working standard units, the units meeting the premium specification delivered a significantly greater savings. The unit sample set is too small to determine the magnitude of savings or reliability, but the daily performance indicates that the Western Premium Economizer is likely to have increased savings compared to a standard economizer.
- Outside air sensor locations can be problematic, and may result in changeover from economizer to compressor cooling occurring too early.

Recommendations

The following recommendations result from this study.

- Develop an active quality assurance component to be completed in conjunction with the economizer upgrade. At a minimum this would include an intervention by the inspector to activate cooling and defeat the changeover if necessary to verify functional operation of the economizer and a thermostat inspection.
- Revise the Western Premium Economizer specification to require the compressor lockout be set at 60°F with special exceptions set no lower than 55°F. Pursuit of other retrofit or upgrade diagnostic options would also be worthwhile.

- Further investigation of a larger sample set of packaged rooftop economizers to determine increased savings from the Western Premium Economizer specification is expected to be worthwhile.
- Some experimentation in an extended sample should be undertaken with various outside air sensor placements. A short vertical mast made from conduit above the unit with an inexpensive radiation shield or a vented box low on the north side of the unit could dramatically improve the accuracy of the outside air signal.

References

[ASHRAE] American Society of Heating Refrigerating and Air-Conditioning Engineers. 2004. *ASHRAE Standard 90.1-2004: Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta, Ga.: ASHRAE.

Cowan, A. 2004. *Review of Recent Commercial Roof Top Unit Field Studies in the Pacific Northwest and California*. White Salmon, Wash.: New Buildings Institute. Available Online: www.newbuildings.org/downloads/NWPCC_SmallHVAC_Report_R3_.pdf.

[EIA] U.S. Energy Information Administration. 1998. *1995 Commercial Buildings Characteristics.* Washington, D.C.: EIA. Available online: www.eia.doe.gov/emeu/cbecs/.

[EMI] Energy Market Innovations, Inc. 2004. *Market Progress Evaluation Report, of the Small Commercial HVAC Pilot Program.* Report #E04-135. Portland, Oreg.: Northwest Energy Efficiency Alliance. Available online: www.nwalliance.org/resources/reports/135.pdf.

Hart, R. 2004. "EWEB Outside Air Economizer Requirements Background." Eugene Water & Electric Board (EWEB) Program Literature. Eugene, Oreg.: EWEB. Available online: www.eweb.org/business/energy/programs/replacements/economizers/ econo_premium.pdf.

Jacobs, P., C. Higgins and R. Shwom. 2004. "Upstream Solutions to Downstream Problems: Working with the HVAC and Efficiency Communities to Improve Field Performance of Small Commercial Rooftop Units." In *Proceedings of the 2004 Summer Study on Energy Efficiency in Buildings,* 6:219-230. Washington, D.C.: American Council for an Energy-Efficient Economy.

Lunneberg, T. 1999. *When Good Economizers Go Bad: Keeping This Air-Side Energy Saver on the Upside.* ER-99-14. Boulder, Colo.: E SOURCE, INC.

[NPCC] Northwest Power and Conservation Council. 2005. *The Fifth Northwest Electric Power and Conservation Plan.* Council Document 2005-07. Portland, Oreg.: NPCC Available online: www.nwcouncil.org/energy/powerplan/plan.