

## Up on the Roof: From the Past to the Future

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### ABSTRACT

Unitary packaged rooftop HVAC units provide heating and cooling for more than 40% of commercial building space. While unit efficiency has advanced dramatically over the past 30 years, analysis of high-efficiency unit market share shows that progress is slowing. Incremental increases in EER and SEER are shrinking, while the investment in physical materials needed to achieve coil efficiency improvements are becoming more expensive. In addition to base efficiency, a variety of items and dynamic effects like field installation, outside air economizers, control configuration, fan energy during ventilation, and cycle effects impact efficiency. Studies have shown problems in these areas and their negative and positive impacts are not reflected in EER, HSPF and SEER testing.

An advanced rooftop unit has been prototyped that includes energy-saving technologies beyond steady-state efficiency. Efficient technologies include variable speed fans, demand controlled ventilation, premium economizers, evaporative assist for condenser cooling, ventilation lockout during warm up, and a quality assurance installation. Proper application of these measures can save 30% to 48% of HVAC energy use, depending on region. This compares favorably to a 13- to 15-SEER upgrade that saves only 2% to 7%. Yet a nationally-accepted testing procedure has not been established to reflect the value of these measures, so manufacturers have little incentive to include them. An outline is proposed for a new test protocol that moves beyond steady-state efficiency and considers total energy use that can be used as a benchmark by utility programs, CEE, and Energy Star and as a marketing tool for manufacturers.

### Introduction

Throughout the United States, more than 40% of commercial building space is served by unitary packaged rooftop HVAC units, representing about one quad of annual energy use (TIAX 2003). Most of these units are small packaged rooftop units with single-stage direct expansion cooling. Two-thirds of units are in the 3- to 5-ton cooling range, with only 15% of units larger than 10-tons (Jacobs et al. 2003). In the Pacific Northwest, 265 MWa of potential conservation have been identified in commercial HVAC measures (NPCC 2005). A portion of these potential savings can be met with improved efficiency units, but we are approaching the point of diminishing returns as far as steady-state unit efficiency improvement measured by HSPF, SEER and EER.<sup>1</sup> As the research described here shows, non-steady-state regional measure savings ranges from 5 to 25 times the savings of an upgrade from SEER-13 to SEER-15.

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<sup>1</sup> EER (Energy Efficiency Ratio), SEER (Seasonal EER), and HSPF (Heating Seasonal Performance Factor) are described in American Refrigeration Institute (ARI) Standards 210/240 and 340/360.

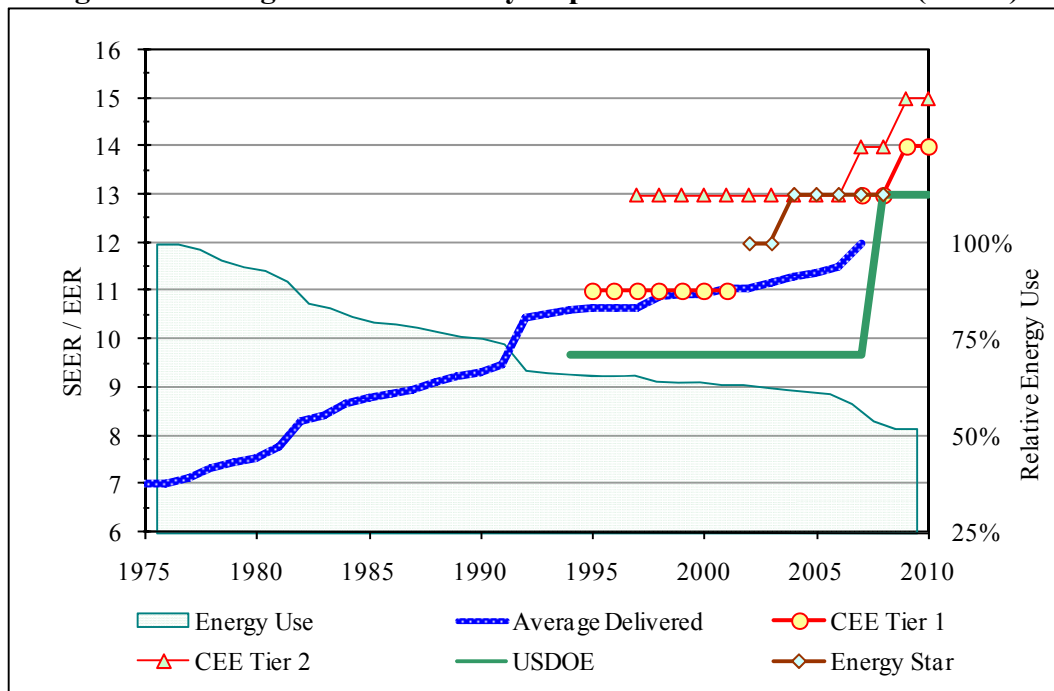
If we are to achieve significant energy savings in new and retrofit commercial HVAC, we will have to move beyond steady-state efficiency improvements and capture other methods of savings such as evaporative pre-cooling and comprehensive ventilation control enhancements. Packaged units have been found to have significant operational problems, with a cross section of studies showing a high percentage of problems (Cowan 2004). This indicates a need for better installation and commissioning as well as development of more robust equipment. There is also an opportunity to save significant energy by improving controls and in-field performance.

Ideally, an efficiency organization would set in-field efficiency targets that captured equipment and installation attributes that would support the HVAC industry in delivering true in-field performance. Establishing a laboratory rating procedure that recognizes the efficiency potential of non-steady-state technologies would be a rational first step and is the focus of this paper. This paper reviews the history of steady-state efficiency improvements, reviews problems found with rooftop units in the field, and demonstrates that a large potential savings exists beyond steady-state efficiency improvement. The authors conclude by echoing a call from other quarters to develop a total efficiency lab testing method that will capture efficiency improvements from a broad range of measures (Jacobs et al. 2003; Kavanaugh 2002).

## History of Rooftop Packaged Unit Efficiency Trends

Since the oil embargo of 1973, the efficiency of packaged unitary air conditioners has almost doubled. The history of actual weighted average shipped units along with minimum and target standards are shown in Figure 1 (ARI 2004).

**Figure 1. Packaged Unit Efficiency Improvement & Standards (SEER)**



SEER for unitary air conditioners under 65,000 Btu/hr; EER for 1975-1980.

Due to the relatively large energy savings and peak demand reduction potential of improving rooftop unit performance, utilities and other voluntary efficiency programs have

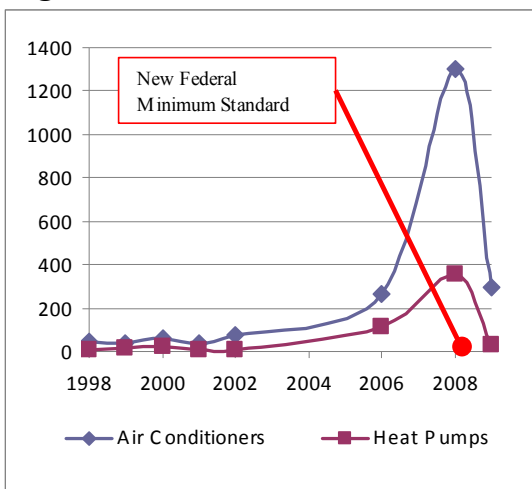
targeted this equipment in programs for many years. These programs have conventionally promoted equipment that attains high ratings using the standard DOE performance metrics of SEER, EER and HSPF.<sup>2</sup> The required performance for equipment to qualify for incentives has steadily increased during the last decade.

In 1994, the federal minimum standard for unitary packaged equipment less than 65,000 Btu/h became 9.7 SEER. At that time 16 electric companies were offering incentives for varying levels of equipment performance. Through the Consortium for Energy Efficiency (CEE), these utilities developed national consensus specifications that would enable them to pool their market influence to send a clear signal of performance valued by utilities. In 1994, CEE finalized consensus specifications within its High Efficiency Commercial Air Conditioner Initiative. Eleven-SEER equipment was specified as the minimum for promotion (Tier 1) and 13 SEER was considered super efficient (Tier 2). At that time only 41 air conditioning models that achieved 13 SEER existed at all capacities. In 2002, more than 1100 models achieved 13 SEER, which then became CEE’s lowest tier.

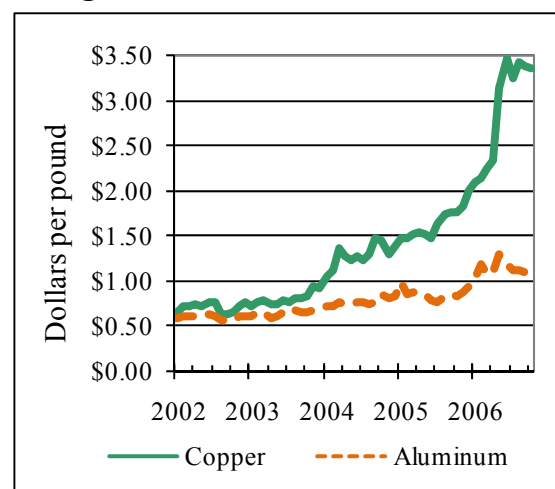
Figure 2 indicates the strong growth of the current Tier 1 rooftop products available for sale from 1998 through 2008. Until recently, 1300 units qualified for CEE’s lowest tier across a range of capacities. However, in June 2008 the minimum federal standard for this equipment became 13 SEER and CEE moved Tier 1 to 14 SEER and Tier 2 to 15 SEER. However, model availability of qualifying products at the future Tier 1 is currently limited. This situation is representative of larger rooftop equipment as well.

While it is reasonable to expect the industry to respond with new high-efficiency offerings after the new federal standard takes effect, some barriers exist. Manufacturers state that further increases in steady-state efficiency necessitate increasing the surface area of refrigerant coils. Figure 3 shows the recent dramatic increase in material prices for copper and aluminum. Larger coils also confront space and weight constraints on rooftops and increase shipping costs.

**Figure 2. CEE Tier 1 Models Available**



**Figure 3. Material Price Trends**



The most efficient unitary equipment available today achieves 16.1 SEER and 14.3 EER. While continuing incentives for the most efficient equipment is a necessary strategy for

<sup>2</sup> Increasingly, incentive programs have required both minimum SEER and EER levels for air conditioners in an effort to reduce summer peak demand.

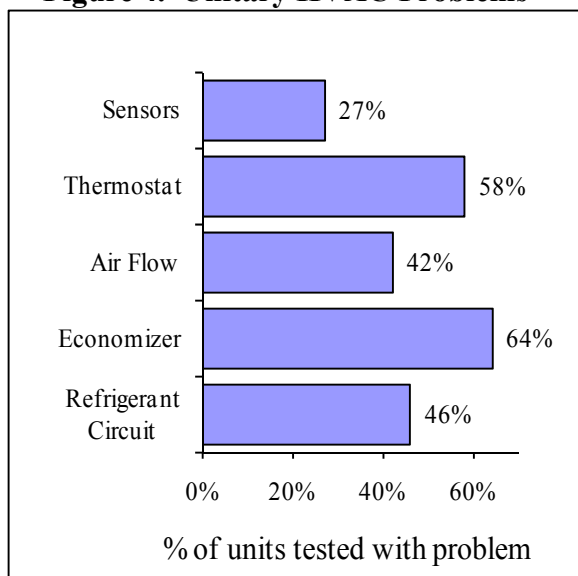
capturing kW and kWh savings, it is not sufficient to meet the increasingly ambitious savings targets facing energy efficiency organizations. Local efficiency programs—and the national organizations that support them—are evaluating other strategies to continue progress.

## Problems in Paradise

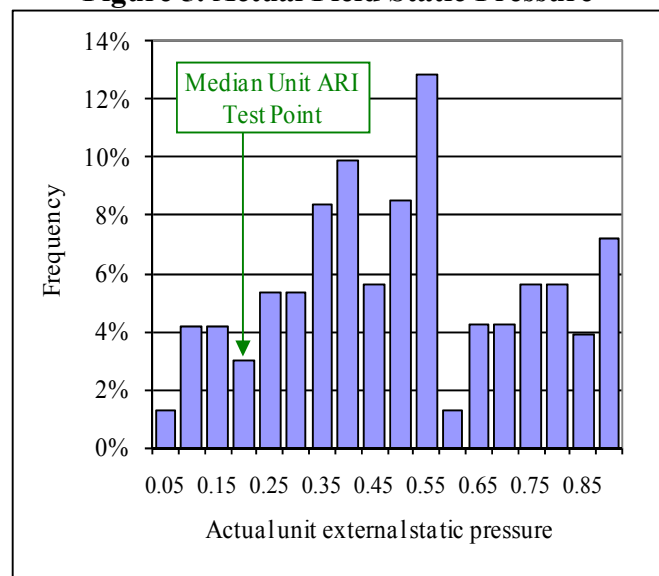
The fortunate thing about packaged units is that they run quite reliably and continue to run for many years at a time without much attention, even though maintenance of these units in the real world often is minimal. Units smaller than 15-tons (63%) typically do not receive testing, adjusting and balancing when installed and service contracts may deliver little more than filter changes. Yet the units continue to run and the owners assume they must be working properly; however, multiple field studies have found that there are many performance problems with operational packaged rooftop units.

A recent compilation of the results from four detailed rooftop field studies covering more than 500 units in the Western U.S. found a very high percentage of problems with systems as shown in Figure 4 (Cowan 2004). A brief overview of problems found follows.

**Figure 4. Unitary HVAC Problems**



**Figure 5. Actual Field Static Pressure**



Note that in Figure 4 that more than 60% of the outside air economizers on these units—many recently installed—did not work properly. The refrigerant charge tests were out of specification for more than 40% of the units. In many cases fans were either on when they needn't be or off when they should be on. The catalog of inspected deficiencies was long and varied, but it takes a deeper look to assess the roots of the problems.

Easy corrections to refrigerant charge errors could save about five percent of the cooling energy. Outside air economizer problems were more profound. Economizers are simple in principle, leading observers to conclude that a few brief observations can establish proper operation. But observing an economizer in natural operation is comparable to observing the habits of wild birds. It takes a few weeks of monitoring at the right time of the year to understand what is transpiring. Extensive monitoring of 35 packaged units was done in the Pacific

Northwest to verify results after the economizers had been tested and repaired (EMI 2004). This study showed that economizer savings was far less than expected. An interesting additional finding was that the tune-ups produced significant savings from other repairs that more than made up for the missed economizer savings. Repairs included thermostat programming, outside air minimum setpoint correction, damper linkage repair, and controls restoration. Follow-up bench tests of the economizer controls revealed inherent controller limitations that the manufacturer has expressed interest in addressing (Robison et al. 2008).

Another general category of the observed deficiencies revolved around supply fan operation and system airflow. While fan operation problems can often be fixed with a simple thermostat adjustment, the more profound problems involved air flows that were below manufacturer's minimum recommendations for the direct-expansion cooling coil. These air flows required more fan power on average than the nominal fan power assumed in the California Title 24 energy code. The combination of high fan power and low air-flow rate was due largely to excessive pressure drop in the duct systems. The frequency distribution of unit external static pressure is shown in Figure 5. At 0.48 inches WC, the average system external pressure drop was more than double the ARI Standard 210/240 test point of 0.20 inches WC for median-sized units. While this discrepancy indicates duct design could be improved, it also shows that the test procedure specifications do not reflect the required equipment capability. Certified testing at a lower static pressure than typical field application understates the importance of fan efficiency in total system efficiency and contributes to underpowered fans in standard units, with the result of deficient field airflow. The tested SEER is also typically higher than the actual efficiency of the unit as installed (Kavanaugh 2002).

The common theme here is that it takes understanding and care in design, installation, operation, and maintenance to elicit the desired energy performance from today's genre of packaged rooftop units, and even more care will be required to realize the benefits of tomorrow's more efficient units. This has profound effects on how efficiency programs are designed and implemented.

## **Hope on the Horizon**

There are multiple technologies that function outside the realm of steady-state efficiency measured by current test standards, yet have the potential to save much more energy than improvements in SEER or EER. Outside air economizers and other ventilation strategies have been available for decades. Lower-cost demand ventilation controls and variable speed drives are becoming available. Fault diagnostics are being perfected. An advanced rooftop unit (ARTU) has been developed with efficiency improvements in areas other than steady-state efficiency. Many of the advanced efficiency and diagnostic features have been incorporated into units specified by major retailers, but these are generally not offered by manufacturers all on the same model.

### **The Advanced Rooftop Unit**

The current strain on the energy system has prompted several efforts to design an advanced rooftop unit. Theoretically, credible groups could build demand for these systems that would prompt industry to respond without changes to the test procedure; however, simply adopting a prescriptive specification can lock out manufacturers who do not have access to the

prescribed technologies (due to patents) or discourage new technological innovation. When conventional performance metrics for energy consumption fail to recognize the savings potential of advanced technologies, manufacturers have little incentive to incorporate these features into systems and efficiency organizations have difficulty promoting them in a performance-based, technology-neutral manner. A test procedure that recognizes total system performance will allow excellent performing equipment to be recognized and promoted.

Over the past few years, a group of experts in the rooftop industry including manufacturers, consultants, energy efficiency organizations, and utility representatives conceived of an advanced rooftop unit (AEC 2005). The idea was to demonstrate significant improvements in four main areas: improved outdoor air control, improved economizer reliability, self-diagnostic capability, and fault-tolerant design. The target was a unit that operates according to prevailing ventilation standards while reducing energy use and maintenance requirements through improved reliability and control.

The California Energy Commission Public Interest Energy Research (PIER) Program provided funding to develop and test a prototype ARTU for hot dry climates, including improvements to the economizer, supply air fan, unit efficiency, refrigeration cycle, fan controls, refrigerant control, thermostat capability, sensors, self check-out capability, advanced monitoring, and advanced diagnostics. Based on a combination of lab tests, energy simulations, and estimates of reduced maintenance, the total benefits were estimated in the range of \$600 to \$830 annually. The estimated cost for incorporating the 36 ARTU features into a basic 5-ton rooftop unit is \$4,100 resulting in an estimated simple payback time of between 4.9 and 6.9 years (AEC 2007).

Major retailers have realized the importance of improved efficiency, reliability, comfort, indoor air quality, and maintenance for the rooftop HVAC units serving their stores. Recently Wal-Mart partnered with a manufacturer to commission a unit with many of the ARTU features. Other manufacturers are bringing similar technologies to market.

The advanced rooftop unit is an example of a more efficient and cost-effective rooftop unit that has no standardized testing procedures available to advance it in the market place. Many of the features demonstrated in the ARTU can be applied today to new units and as retrofits to existing units, even outside of a hot and dry climate. These high-end units and technologies typically have small market penetration due to the added feature cost. A testing metric that demonstrated their superior energy performance would assist buyers in comparing units and allow utilities to set appropriate rebates. It would also provide manufacturers with a marketing tool to differentiate their product offerings.

### **Unrecognized Technologies Old & New**

There are multiple strategies available for small rooftop technologies that go beyond straight efficiency (SEER/EER/HSPF). Many of these have been commercially available for decades but have not had a testing procedure available to allow them to be reliably compared. Table 1 summarizes the technologies that are candidates for an efficiency test procedure, why they save energy, and their status in the smaller packaged unit commercial marketplace. Features that provide maintenance benefits or are difficult to test in a standard procedure are not listed, as it would be difficult to include them in a lab test. Developing reliability testing or field evaluation of these features is desirable as a separate effort.

**Table 1. Technologies Considered**

<b>Technology</b>	<b>Savings Rationale</b>	<b>Status</b>
Optimum Start	Reduces energy use during building startup with moderated space temperatures	Established - in most thermostats
Resistance (strip) heat lockout for heat pumps based on outside air temperature	Reduces electric energy used for heat pump units by restricting use of resistance heating to colder ambient temperatures	Established as an option – often not installed
Ventilation warm-up lockout during startup with improved damper seals	Reduces energy use during building startup with less heating (sometimes less cooling) of ventilation air	Established option – rarely installed
Economizer Control with integration and comparative changeover control (Hart, Morehouse & Price 2006)	Reduces mechanical cooling by using outside air when appropriate to reduce mixed air temperatures	Established option – full application is rare
Demand Controlled Ventilation (DCV)	Reduces energy use during weather extremes with less heating or cooling of ventilation air, as ventilation is reduced to match actual occupancy requirements	Established as an option – rarely installed
VSD fan control – reduce fan speed and airflow during idle or floating temperature mode	Reduces supply fan energy use and impacts from duct air leakage by reducing airflow when the unit is not actively heating or cooling; requires DCV for ventilation standard compliance	Rarely installed in commercial; two known manufacturers
Evaporative assist condenser pre-cooling	Improves cooling efficiency by pre-cooling air entering the condenser; effectively reduces the ambient temperature from the dry bulb to near the wet bulb temperature	Rarely installed; several known manufacturers

### Potential Savings

A literature search revealed that with the exception of outside air economizers, little evaluation work has been done for most of these measures. A simulation of these measures was completed to determine if there was a potential for savings and justification for a new test standard. Measure savings were analyzed using DOE 2.2 for eight cities in the United States covering a range of climate zones.<sup>3</sup> Potential HVAC energy savings for these non-steady-state efficiency improvements ranged regionally from 30% to 48%, comparing favorably with a 1.5% to 6.7% savings from upgrading 13- to 15-SEER. Heat pump systems on a typical small office building were analyzed so all results would be electric for easy comparison. Gas furnace systems were also analyzed. The allocated interactive<sup>4</sup> measure saving results from the DOE2 analyses are shown in Figure 6 along with remaining HVAC energy use after all measures are completed.

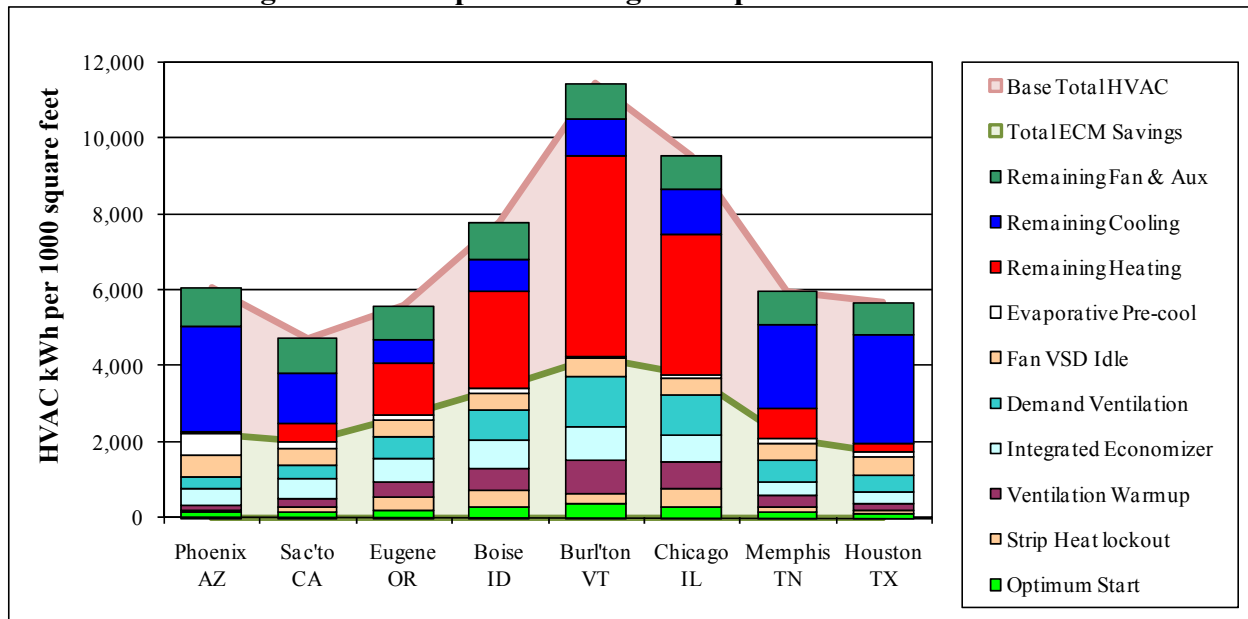
To provide a good indication of overall savings, the baseline assumed typical as-found conditions for smaller rooftop units. For example, baseline economizers were only expected to work partially, and based on actual field observation, the minimum outside air was simulated at 13% rather than code required 7% (Davis et al. 2002).<sup>3</sup> The purpose of this analysis is to demonstrate a potential for savings by measures not included in current test standards. There may be issues with some measures that need to be resolved in field testing, such as managing

<sup>3</sup> The baseline building for savings analysis is a 20,000 square foot two-story office building using primarily the Title 24 eQuest defaults with an increase in unoccupied lighting and equipment loads to reflect reality and higher than required ventilation (31 cfm/person or 13%) to partially reflect field observation of typical ventilation minimums at 20%. Packaged single-zone units with a SEER rating of 13.0 were simulated.

<sup>4</sup> For individual saving results in Figure 6 the interactive package savings are allocated using the share of savings for each measure's independent results. This method eliminates order of consideration issues inherent in a rolling baseline calculation.

proper ventilation with a high level of product VOC generation in the retail environment or resolving condenser scaling issues with evaporative pre-cooling.

**Figure 6. Rooftop Unit Savings in Representative Climates**



Overall interactive results for the comprehensive package of measures are shown in Table 2 along with a conversion of savings from heat pump heating to natural gas furnace heating. This package of measures results in a range of regional savings that is 5 to 25 times the savings of an upgrade from SEER 13 to 15.

**Table 2. Overall Package Measure Results & Climate Zone Information**

Savings for package of all measures:	Phoenix AZ	Sac'to CA	Eugene OR	Boise ID	Burl'tn VT	Chicago IL	Memphis TN	Houston TX
Percent Total Savings	36.0%	42.3%	47.9%	43.9%	37.0%	39.5%	34.9%	29.9%
<b>KWh/SqFt ECM Savings</b>	<b>2.2</b>	<b>2.0</b>	<b>2.7</b>	<b>3.4</b>	<b>4.3</b>	<b>3.8</b>	<b>2.1</b>	<b>1.7</b>
vs. SEER 13 to 15 savings	0.42	0.22	0.15	0.17	0.17	0.19	0.29	0.37
SqFt/Ton Cooling Installed	249	340	427	355	355	321	256	260
KWh/Ton ECM Savings	552.5	685.9	1,151.3	1,219.9	1,507.3	1,213.3	539.2	450.4
Annual Savings for recast of heat pump heating to gas heating at 78% AFUE:								
KWh/SqFt, all measures	2.0	1.2	0.9	0.9	0.7	0.7	1.1	1.3
Therm/SqFt, all measures	0.012	0.047	0.102	0.139	0.200	0.171	0.057	0.024
ASHRAE Climate Zone	2	3	4	6	6	5	4	2
ASHRAE Moisture Area	Dry West	Dry West	Marine West	Dry West	Moist East	Moist East	Moist East	Humid East
East vs. West								

### Cost Effectiveness and Premium Ventilation Package

The cost effectiveness of measures varies by climate zone and building characteristics. The intent of this analysis is to demonstrate that a potential for savings exists. Simple paybacks for individual measures are shown in Table 3 by climate zone, along with an expected cost,



including commissioning on one-third of installations to promote quality installations. The basis is 2000 square feet per unit, as these measure costs are per rooftop unit and not per ton of cooling. The differing paybacks indicate that measure packages should be developed for different climates. While individual measure paybacks can be long, an integrated package of all measures has reduced cost due to more efficient labor and commissioning. The overall package results in reasonable paybacks for most regions. There are significant advantages to incorporating the control measures into a “Premium Ventilation Package.” This package includes all measures except the evaporative condenser pre-cooler. Measure synergies include:

- Demand controlled ventilation is required for idle fan speed control and eliminates the need for a separate warm-up ventilation lockout control while retaining the savings.
- Economizer savings potential has been attractive, but unreliable unless commissioned. The payback on a small unit may not be attractive when the cost of commissioning was included. When multiple measures are combined—all of which require commissioning—the cost of commissioning is not much more than for one measure, so the overall cost for a combined package with commissioning is much more attractive.

**Table 3. Preliminary Regional Measure Simple Payback**

Regional Simple Payback	Retrofit Cost	Phoenix AZ	Sac'to CA	Eugene OR	Boise ID	Bur'l'tn VT	Chicago IL	Memphis TN	Houston TX
Optimum Start	\$378	<i>20.5</i>	<b>13.3</b>	18.6	<i>20.4</i>	<b>6.9</b>	<b>4.9</b>	<i>28.2</i>	<b>14.9</b>
Strip Heat Lockout	\$282	<i>171.5</i>	16.7	<b>8.9</b>	<b>9.9</b>	<b>6.9</b>	<b>2.4</b>	<i>30.8</i>	<i>28.3</i>
Ventilation Warm-up	\$528	<i>40.9</i>	<b>14.9</b>	<b>13.6</b>	<b>13.4</b>	<b>4.0</b>	<b>2.9</b>	<i>21.4</i>	<b>14.6</b>
Integrated Economizer	\$995	19.8	<b>10.7</b>	16.7	19.6	<b>7.6</b>	<b>5.6</b>	<i>34.6</i>	16.8
Demand Ventilation	\$611	19.6	<b>11.0</b>	<b>11.3</b>	<b>11.5</b>	<b>3.1</b>	<b>2.3</b>	<b>14.2</b>	<b>6.8</b>
Fan VSD Idle Control	\$636	<b>10.4</b>	<b>8.5</b>	<b>14.8</b>	<i>21.7</i>	<b>8.8</b>	<b>5.6</b>	17.3	<b>6.7</b>
Condenser Pre-cool	\$539	<b>8.8</b>	17.3	52.5	<i>58.6</i>	<i>61.1</i>	<i>25.8</i>	<i>55.0</i>	<i>21.2</i>
<b>Interactive Package</b>	\$2,600	<b>11.0</b>	<b>7.8</b>	<b>10.1</b>	<b>11.4</b>	<b>4.1</b>	<b>2.7</b>	15.7	<b>7.6</b>
<b>Premium Ventilation Package</b>	\$2,100	<b>12.0</b>	<b>6.9</b>	<b>8.5</b>	<b>9.6</b>	<b>3.3</b>	<b>2.3</b>	<b>13.5</b>	<b>6.7</b>

Note: Based on preliminary opinion of cost and interactive electric savings with regional rates. Simple paybacks less than 15 years shown bold; longer than 20 years shown italic.

## Recognizing Total System Efficiency

There is a need to enhance current test procedures for commercial facilities to recognize total system efficiency, including cycling issues, warm-up issues, and ventilation issues, including damper seal and economizer effectiveness.

Current ARI testing protocols target SEER (Seasonal Energy Efficiency Ratio) for units less than 65,000 Btu's per hour cooling output with Standard 210/240-2006 and target EER (Energy Efficiency Ratio) for larger units through Standard 340/360-2007. There exists a need for a new ARI/USDOE test protocol that considers total energy use in commercial applications, not just steady-state efficiencies. Including a method to predict regional results in the new standard is important, as Figure 6 shows a dramatic difference between regions. There have been previous calls for a new testing protocol (Jacobs et al. 2003), for multiple reasons:

- The SEER rating is targeted at residential energy use and does not reflect higher commercial cooling loads or commercial technologies such as economizers.

- EER and SEER use a steady-state efficiency rating or weighted combination of multiple steady-state ratings and do not deal with economizer effectiveness, ventilation damper losses, control issues, cycling losses, ventilation operation during warm-up, the use of condenser pre-cooling, or the impact of resistance heat on heat pump effectiveness.
- There is no current standard test for economizer effectiveness. There are multiple issues related to effective economizer operation: type of controls, damper effectiveness, location of outside air intake relative to exhaust air intake, and integration with cooling controls.
- Different implementations of optimum start and other controls are likely to have different efficiency impacts without any standard by which to measure them.
- The target static pressures in the current test procedures are far lower than most commercial situations (even if ductwork design were improved) and required fan operation when heating or cooling is off is not accounted for (Jacobs et al. 2003). As a result, the impact of fan efficiency and control on total energy use is under-represented.

### **Proposed Testing Protocol**

A total energy efficiency ratio (TEER) is suggested that would apply to commercial unitary equipment up to 25 tons. Such a test would provide a commercial seasonal energy use indicator. While there is a high variability in commercial buildings, a standardized set of parameters would allow utility efficiency program managers and commercial customers to compare different units in relation to how they operate under standardized regional conditions. Units incorporating the measures discussed earlier in this paper could have their effectiveness tested. The protocol would need to be developed through an industry-wide consensus process. It would likely be similar to the current protocols, with the following suggested modifications:

- The testing apparatus would be similar to the ones specified in ASHRAE Standard 116-1995, except that it would allow for operation of a pre-cooler on the condenser and it would allow interior air to be exchanged with the outdoor side test room to simulate an economizer and ventilation and relief damper effectiveness.
- Simulation of warm-up issues would require a warm-up period be simulated in real time with a schedule of heat load at various temperature bins. It may be possible to reduce the number of warm-up bins simulated and extrapolate for full seasonal information.
- The external fan static pressures would be changed to more typical commercial values. It is likely that reasonable values developed after review of field data would be at least double the current test specification (Jacobs et al. 2003; Kavanaugh 2002).
- Typical schedules would need to be developed for cycling patterns, thermostat staging, and carbon dioxide loading at various bin temperatures to allow capture of variable speed fan, resistance heat lockout, and DCV control operation with continuous ventilation.
- Making available single-condition results and compiling regional TEER results will be important to making the new standard flexible (Kavanaugh 2002).
- Gas furnace efficiency standards could be upgraded to incorporate unit cycling effects.

## **Installation, Design, and Maintenance Issues**

Efficient in-field performance requires high-efficiency equipment, a quality installation, and on-going maintenance. Several activities, for which a detailed explanation is outside the scope of this paper, are underway by efficiency organizations and the HVAC industry to promote improved installation and maintenance practices. These include developing consensus definitions of “quality installation” and “proper maintenance” among key stakeholders, identifying cost-effective verification protocols to determine when those definitions are met, and building demand for those services.

It is recognized that there are multiple issues that affect efficiency beyond actual testable system efficiency. Contractor installation, unit selection, and ductwork design are all critical. Air Conditioning Contractors of America is developing light-commercial equipment installation specifications and quality assurance standards. They recommend technician certification by North American Technician Excellence. At this point, the standards and training materials do a good job of addressing common residential and light-commercial issues such as proper airflow, refrigerant charge and basic controls. The authors see value in developing a commercial certification track that covers more complex control issues such as demand controlled ventilation and proper economizer installation.

Issues related to ventilation effectiveness and control integration and commissioning will have to be addressed so that recommended controls actually deliver savings. It should be acknowledged that relying on control measures for savings means that those measures will need proper maintenance. Actual performance will have to be tested with well-designed evaluation; preferably with a long-term verification component.

## **Conclusion**

While there have been dramatic gains in unitary HVAC efficiency over the last 30 years, the ability to continue improvement of steady-state efficiency is constrained by theoretical limitations in the refrigeration cycle and increasing material costs. Significant potential savings exist in the area of controls—an order of magnitude greater than moving up to the next SEER/EER increment. Unfortunately savings have been unreliable in these areas and no nationally certified lab testing protocols have been developed to provide a consistent measure of the potential efficiency impact of the technologies and practices described in this paper. Moving into the next phase of rooftop unit efficiency improvement will require increased cooperation between manufacturers, utilities, efficiency organizations, and contractor associations.

Combining multiple control measures will provide the opportunity to more effectively commission the units and improve reliability. A comprehensive lab test that includes ventilation and other control improvements can benefit manufacturers, building owners, and energy program administrators by providing a touchstone for measurement of packaged HVAC unit efficiency.

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