New Buildings Institute, Inc.
P.O. Box 653
White Salmon, Washington 98672
Phone: (509) 493-4468
Fax: (509) 493-4078
E-mail: info@newbuildings.org
Website: www.newbuildings.org

Phase 1: Commercial Rooftop HVAC Unit Retrofit Programs

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Prepared by:
Mark Cherniack, Howard Reichmuth and
David Hewitt, New Buildings Institute, Inc.

Prepared for:
Northeast Energy Efficiency Partnerships
Jon Linn, Program Manager
5 Militia Drive
Lexington, Massachusetts 02421
(781)860-9177

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1. Executive Summary

This report is sponsored by the Northeast Energy Efficiency Partnership (NEEP), to summarize regional and national experience with retrofit improvements to unitary HVAC equipment on commercial building stock. This report supports the collaborative effort among stakeholders in the NEEP service area to achieve better understanding of issues relating to establishing and maintaining energy efficient performance of rooftop package HVAC units. The report also assesses the elements that guide the design of utility programs aimed at accelerating the realization of energy and demand savings from operation of this technology.

The energy and demand savings available from rooftop HVAC systems are second only to lighting savings in the commercial buildings sector. Utility-sponsored rooftop unit service programs in the Northeast, California and Northwest have shown this resource to be a viable utility program target.

Pilot efforts have shown possible energy savings on the order of 1,800 kWh/unit treated in comprehensive rooftop unit service programs, but that overall demand savings of greater than 150W/unit are unlikely. A trial cost-effectiveness review showed that these savings have a levelized resource cost of 3.6 cents per kilowatt hour. This resource is principally an energy resource, not a substantial demand resource.

The programs include a variety of unit service measures aimed at refrigeration charge, air flow, thermostats/controls and economizers in an assortment of configurations. Most programs seek partnerships with the existing HVAC trade, emphasizing enhanced diagnostics, training, and quality control methods. The scale of both the program and the approach is driven by the new resource requirements of an individual utility and a region.

This resource is broad enough and cost effective enough to be the basis for utility demand-side program development. It is recommended that impact evaluation efforts be undertaken on a multi-utility basis to underpin the savings estimates for the principal portions of the resource in the Northeast.

Also included herein are discussions of:

- The several rooftop unit programs reviewed
- The rooftop unit equipment stock
- Estimated energy savings and cost-effectiveness
- Standard utility rooftop program service measures
- Key factors that guide the nature and scale of a rooftop program
- Marketing and training/certification and evaluation issues
- Potential for new technologies to impact the rooftop services market.

It is hoped that this report will support the design and implementation of a practical plan for the bringing energy and demand savings potential in the rooftop HVAC unit market to a level of certainty suitable for consideration as a resource for the region's power system and as a greenhouse gas mitigation strategy for the entire region.

2. Introduction

This report is a secondary research project examining current data available on pilot and operating rooftop unit (RTU) retrofit programs around the country and summarizes a variety of current information on the topic. Included are discussions of technical issues, program operational strategies, market penetration to date and evaluation findings. This material will assist ongoing review of the design and performance of existing HVAC program activities and help inform the development of an expanded RTU program effort to be launched in the Northeast.

Rooftop unit program designs are shaped by several requirements related to the nature of technically possible energy efficiency improvements. There is a critical need regionally to establish a higher level of confidence in the assumed cost and savings attributed to a number of rooftop unit operation and maintenance test and repair techniques. This information is needed to support efforts to pursue a more integrated regional power sector and related environmental resource planning and cost-effectiveness regulatory review.

Several of the initiative sponsors are contemplating the launch of programs this year to save energy through improved performance of existing packaged HVAC systems. These program administrators have either conducted pilot programs or observed others in this area. Sponsors are aware that some of the pilots now have available information that could help in development of a new program. Looking to learn from the experience of their peers, they are hoping to ascertain what works, and what doesn't, to determine savings measures and improvement costs. Though the explicit focus of this effort is on refining performance of existing units, carryover of advanced retrofit diagnostic practices and improved installation practices to the benefit of new unit installations is expected.

Size of the Market

There is no current formal estimate of the total population of RTUs in the NEEP service area. Extrapolation from data out of the Northwest points to a population estimate of ~500,000 units, with a potential 20-25 percent error factor. The most recent estimate of the size of the annual RTU market in the New England and New Jersey service areas is ~39,000 new units annually (KEMA 2005). It is assumed that approximately two-thirds are replacement and one-third are in the new construction market. This is a reasonably homogenous niche market consisting of rooftop units predominantly of 5-7 ton capacity. Most of these units are in the small retail, small office and grocery sectors. There is no "Northeast Commercial Building Stock" database that includes information on building age, size, type and characteristics of RTU stock. The physical description of the Northeast market has been derived from a review of detailed commercial building stock data for a similarly sized region in the Northwest. The installation and maintenance characteristics of new and existing units are quite similar, and the HVAC service providers are the same.

Data Sources

New Buildings Institute (NBI) staff conducted an extensive investigation of existing program experience and related operating and evaluation data through literature review and conversations with a variety of program-related personnel. Interviewees included utility staff, RTU program managers, energy service companies, engineering firms and equipment vendors, all of whom have direct experience in one or more aspects of rooftop unit service programs operating in the Northeast, Northwest and California.

All programs reviewed had extensive rooftop site detail in various stages of analysis. To date, only three of the programs had completed an evaluation or published a useful review: New York State Energy Research and Development Authority (NYSERDA), California Energy Commission's Public Interest

Energy Research (PIER) Program and National Grid. However, these three evaluated programs only address a minority of rooftop units treated. Most of the rich site detail lies in programs with pending evaluations or those with uncertain evaluation status.

This initial review of program experience is not intended to substitute for the program specific cost and measure specific savings estimates that will ultimately be developed. This review will proceed pragmatically, using evaluation results where available, and interview data abstracted from work in progress with the permission of program management. Naturally, the use of data from work in progress is sensitive, because it has not been fully vetted. Preliminary information of this type is included here in anticipation that it can be used constructively.

3. Rooftop Unit Services Program Experience

The current experience nationally includes upwards of 20,000 commercial units treated in some form in the last four years of pilot and operating program history, with about 4,100 units of this total completed in the Northwest and Northeast. The remainder are located in California. Table 1 summarizes this activity.

Table 1 – Current Programs

Sponsor	Cumulative Activity Level to Date	Program Model	Evaluation Status
EWEB	~250 with emphasis on economizers	Operated as a utility program with measure rebates, utility inspection and contractor training	Internal evaluation
NYSERDA	1100	Contractor training and incentives in exchange for site data. Program ended.	Process and causality eval by Summit Blue and Global Energy Partners
NSTAR	~150 startup phase	Current program is contractor directed at large customers "fleet management," utility supports measure rebates for broad list of measures inc economizers and thermostats	
National Grid	100	Pilot of "Check Me"	RLW 2004 includes some unit level metering
Air Care Plus-SCE	1880	Utility outreach via participating trained contractors with specific measure incentives using franchised methods	Process and Impact by Quantec, Summit Blue, due early 2007
Air Care Plus-Avista	550	Ibid.	
Puget Sound Energy- Premium Service	>1000	Utility outreach via trained contractors with specific measure incentives	Internal PSE evaluation, extensive site specific information including unit airflow
Oregon Energy Trust	~100	Part of broader commercial custom efficiency retrofit available through a broad range of trade allies and dealing with the whole building	
PIER field test	215	Field test that was advisory to the design of an Advanced Rooftop Unit, currently awaiting lab testing	NBI summary of field conditions, 2004
California Programs	thousands	Differs by utility: Verification Service Providers channel work through retail HVAC contractors; companies set up to conduct RCA*/duct work; third party program providers	Some evaluation results due 2006 low budgets suggest no metering or billing analysis

*Refrigeration Charge & Airflow

These efforts have only begun to scratch the surface of the identified technical potential. There are three primary locations of program activity: Northeast, Northwest and California. Programs are evolving in each region. All programs have a traceable intellectual lineage, with many of the same parties refining programs or designing successor ones.

The current larger-scale California programs, which differ to an extent by major investor-owned utility, emphasize refrigerant charge, airflow (RCA) and duct leakage/sealing, primarily for residential systems and driven by state building code. Pacific Gas & Electric (PG&E) is considering the addition of thermostats (adjustment/replacement) and economizers to its RCA program. The California programs are responding to a need for reduced electrical demand (kilowatts-kW). The Northwest programs place more emphasis on economizer use and thermostats valued for reducing energy (kilowatthours-kWh). The Northeast programs pursued a wide range of measures including a new emphasis on demand control ventilation. Outside of California, most of the programs are converging on a similar broad list of measures.

All the programs use fundamentally similar diagnostic approaches for refrigerant charge analysis but differ in the way they detect the reasons for charge problems. The California programs are structured to hook up gauges on all sites, while other programs opt to hook up gauges only on systems that have failed a less invasive temperature-based charge check screen.

The impetus behind the advanced diagnostics in all programs is the availability of a range of measurement tools: a variety of hand-held automated, diagnostic digital analyzer tools, including the Honeywell Service Assistant, and models such as Digi-Cool, the Stargate SG3000 and TestoKool 503, the true flow airflow meter, and other tools. Real-time feedback to the technician about the condition of the unit, regardless of the communication method, is central to service efficiency and impacts utility cost-effectiveness based on the level of financial incentive to be provided to the contractor.

Technicians involved with the use of the digital analyzer portable diagnostic tools require initial intensive support to provide them a level of comfort with and trust in using these digital tools. In some cases, such as with the Honeywell Service Assistance, the tool's developer (Field Diagnostic Services, Inc.) has been called upon to customize the software and hardware (*e.g.,* adding thermocouples) for their portable tool. It is important to note that not all active programs are using digital diagnostic tools. The Puget Sound Energy Premium Service program uses industry standard lookup tables that the technicians are familiar with and generally understand.

Program Business Models

Common to all business models is the question "who's buying and who's selling?" Utilities are the predominant cash source for most programs. They are purchasing a cost-effective demand-side resource and offering a service to their customers. The secondary cash source is the HVAC system owners themselves, through purchase of system operation and maintenance (O&M) services, which is in their own best interest. The models differ principally in the urgency and therefore the size of utility funding.

The visibility of the funding utility in the program offering varies significantly. In PG&E's RCA program, the utility is at a formal distance from field implementation. The relationship is more focused on the participating contractors and their customers, while in the NSTAR effort, the utility is an active co-marketer of the program.

All three business models may include market transformation as a sought-after result. The characteristics of the RTU retail contractor market dictate the pace and success of transformative program objectives. Within each HVAC business, there are separate constituencies with mostly congruent but different interests that must be integrated into the RTU service program to make it succeed. Business owner, sales manager, dispatcher and the technicians all must be included in the participation approach.

From our discussions with diverse interests in the RTU program design/delivery framework, one theme that emerges is longevity. This is no surprise to those who have been operating energy efficiency programs of all kinds. The stop-and-start nature of utility programs tends to hobble the market stakeholders.

Utility Contractor Model

The classic business model for RTU service programs offers training and diagnostic tools to the HVAC contracting industry, initiating a diffusion of better service practices. Participating contractors are more competitive; the industry evolves and improves as a result. The NYSERDA program took this pragmatic path, providing training and diagnostic tools to 700-plus contractors. There were no specific measure level incentives, but there was a modest ($70/unit treated) payment for site results.

This infusion of advanced diagnostic techniques and tools will eventually transform the industry as a whole and influence residential and new equipment markets as well. The process has modest cost, and it will not divert excessive resources into unproved measures. However, transformation of the contractor's business model to readily embrace the advanced diagnostics has progressed slowly all markets outside of California.

Franchise Contractor Model

As utility resource acquisition programs have become larger and more urgent, standardized advanced operations and maintenance protocols with specific trade names have emerged. In the Franchise Contractor Model, existing HVAC contractors are given training and associated advanced diagnostic tools with which to wring savings from the rooftops. The diagnostic protocols are essentially branded, such as "Check Me," RCA, AirCare plus and others. Associated with a branded protocol is limited experimental assurance that savings can be methodically determined and that predicted savings are accurate. The branded protocols involve a specified and uniform level of diligence and usually result in a mark or label affixed to a treated unit signifying that it has been "verified" or passed. This standardized diligence is treated as a prerequisite for continued utility funding.

In the franchise contractor model, most program activity goes through existing HVAC contractors, and the branded protocol of advanced diagnostics are treated as an enhancement of an existing HVAC contracting business. The underlying rationale is to minimize outreach/marketing/basic training activity by aligning the program with existing or ongoing contractor activity. It is potentially a win/win for the contractor because it enhances the contractor's service offerings. An advantage of this model is that the advanced diagnostic and installation standards carry over to benefit new system practices. Most programs rely predominantly on contractor-driven outreach mechanisms with varying degrees of marketing help from the sponsoring utility.

Franchised diagnostics were initially intended to be marketed to rooftop system operators in their own right, with the resulting savings purchased at a bargain. This pure market notion has been eclipsed by the increased need of more utilities to purchase larger blocks of resources.

In frenzied energy efficiency markets such as California, franchised diagnostics are linked to the deemed savings that underpin the financing of large programs pursued as resource acquisition. California programs have focused narrowly on two verifiable measures related primarily to peak demand savings; charge correction and airflow. Also in California, an intermediate entity has emerged: the Verification Service Provider (VSP). This entity is formally a "third-party quality program." The VSP is positioned between the funding utility and the contractors. The role of the VSP is much broader than quality control alone and includes aggregation of units, program management with training, quality control and verification services, distribution of incentives, assistance in marketing and management of program financial flows. In California, VSPs bid on verifying blocks of thousands of residential and commercial units. Bids are based on fixed incentives per unit based on deemed savings. In PG&E's service area, four

VSPs have been selected to offer RCA program services. Generally, VSPs recruit existing retail HVAC contractors to do the rooftop service work and share the utility financial incentive.

Anecdotal experience suggests training, and continuous retraining, of technicians should be viewed as a long-term, large-scale market transformation activity. Attempts to motivate existing HVAC contractor management to integrate their service activities with the utility-sponsored rooftop programs have become major centers of effort in the AirCare plus, California, National Grid, NSTAR and PSE programs.

There are some contradictions from the contractor's point of view. The relatively time-intensive advanced diagnostics do not fit well with the harried summer repair season. Program participation rates drop to near zero during the cooling season when contractors are responding continuously to customer complaint calls. Program managers are working to sequence program operations with seasonal ups and downs.

It takes persistent effort to keep programs growing. Getting the seed planted and viable appears to take some time (at least three years of sustained program activity), with cost of electricity being the most important factor driving the process. The hoped-for synergy of program objectives with existing contractor business objectives has not quickly manifested and not led to a leap of activity by the contractors, especially outside of California.

Specialty Contractor Model

There has been some activity in these programs by specialty performance contractors (as opposed to retail HVAC contractors). These contractors are essentially energy service companies (ESCO) bidding directly with the utility and training and running their own crews. Usually these contractors will use a branded advanced diagnostic protocol or will devise their own. These are not full HVAC contractors selling and installing new HVAC equipment, although they are licensed for the work. They do not need the same kind of motivation to pursue the program measures because that is their primary business activity; their business model is to pursue programs of this sort, including self-promotion.

While most specialty contractors pursue the utility objectives, others position themselves as customer advocates. One California company, ADM Associates, has reached traditionally underserved, multiethnic small commercial customers in southern California with some success. The program consisted of ADM's own service crews, with multilingual, multicultural technicians, providing each customer with a full menu of efficiency services including HVAC, lighting and hot water related. Each customer received service appropriate to their needs for both electricity and gas end-uses. The program is ongoing, with over 4,000 customers reached. Financial incentives were established for individual measures based on deemed savings estimates used statewide.

This business model is a creature of large-scale utility programs. It exists because the existing steady-state market could not meet the needs for a utility ramp-up. It is an efficient way to respond to a solicitation for large numbers of narrowly focused retrofits, but it may not carry over significantly into new equipment installation and practices.

Program Descriptions

What follows is a brief summary of each of the major rooftop programs that were contacted for review.

AirCare plus

The program was developed by Portland Energy Conservation, Inc. (PECI) and is being operated in the Avista Utility service area (northeastern Washington and northern Idaho) and at Southern California Edison (SCE). AirCare plus was piloted as a market transformation program in the Northwest. The lessons learned have been incorporated by PECI into the current AirCare plus offering.

This is a franchise program offering extensive training and digital, automated diagnostic tools to execute an expedited rooftop analysis. This program has a wealth of detailed site data, and site-specific engineering estimates of measure savings are made. An evaluation is scheduled through a Quantec Consulting, Inc./Summit Blue team. The evaluation will involve survey, interview and other process indicators and is expected to use engineering estimates for energy savings impact analysis. Some detailed metering is being considered as part of a pending evaluation. An earlier evaluation (*Small Commercial Pilot Program, Market Progress Evaluation Report No.1, Energy Market Innovations, Inc./NEEA, 2004)* involved detailed equipment monitoring on 37 units and whole building modeling and billing analysis. This work found the pilot version of this program had reasonably accurate engineering estimates, but the site inspection had missed some large unexpected (opportunistic) savings opportunities. The current site inspection protocol probably would capture such savings.

Eugene Water and Electric Board (EWEB)

The EWEB Western Economizer Program is directed principally at improving economizer performance. The important distinction to make is that the EWEB program goes deeper into economizer savings. The program proposes to improve performance of all economizers, even new and functional ones, while the other programs rely more on repairing nonfunctional economizers. EWEB and Ecotope have done extensive DOE2 modeling of economizer operation on various commercial building prototypes at several western locations. This work (*Western Premium Economizer Specifications, EWEB, 2004)* provides a good background for economizer theory and *Energy Savings Estimation for Enhanced Service to Packaged HVAC Rooftop Units, Ecotope, 2004* provides useful estimates of economizer savings potential at western sites. Economizers have significant benefits in the Northwest as well as in the Northeast, by reducing the need for compressor cooling. The generally higher humidity conditions in the Northeast would reduce economizer benefits relative to the benefits in the drier west where economizer cooling can reduce the need for compressor cooling almost entirely under certain climate and building use conditions. However, there is no question about economizer benefits in the Northeast with significant kWh savings available.

National Grid (NH, MA, NY, RI)

This program was a pilot of the Proctor Engineering Group's "Check Me" procedure applied to 100 rooftop units in the Northeast. National Grid also has a circuit-rider program in the context of its new "Cool Choice" high efficiency unit program. This circuit rider strengthens relationships with HVAC contractors and provides a listening mechanism. Some of the feedback indicates the need for a maintenance program, training and more CO_2 sensors and demand control ventilation.

An evaluation conducted on the "Check Me" pilot showed almost no savings (*Impact Evaluation of Unitary HVAC Tune-Up Program, RLW Analytics/National Grid USA, 2004)*. The evaluation is noteworthy because it has pre- and post-metering data from 20 sites with 47 units. This was an ambitious evaluation/monitoring and verification (EM&V) objective. The published results suggest extensive trouble with the outdoor temperature measurements, and the detailed tabular data is unclear. However, this is one of the few recent unit-level metering exercises available. Further useful metering information could likely be gleaned from a closer review of the data.

New York State Energy Research and Development Authority (NYSERDA)

NYSERDA has been operating the "New York Energy Smart" family of HVAC programs since 1999. Two programs in this group were directed at improving performance of rooftop units: Advanced Diagnostics (AD) and Demand Control Ventilation (DCV). In four years of activity, the program trained 700-plus HVAC contractors and technicians. Evaluation of this program included extensive work characterizing the current market and attitudes. There were no field measurements, and energy savings impact estimates were based on assuming 70 percent of the deemed savings estimates established by the California Energy Commission's Database for Energy Efficiency Resources for California and then applied to the AD program's diagnostic measures. This program showed only modest numbers of rooftop units treated, and site data is sparse. This activity showed strong results for demand control ventilation, although primarily applied to larger HVAC systems. Both Advanced Diagnostics and Demand Control Ventilation programs have ended. NYSERDA is considering an RFP for rooftop unit-related services in the 2007-08 timeframe.

NSTAR (Eastern MA)

Entering its second year, this is a pilot program for multi-facility commercial accounts and larger HVAC contractors. The program offers the customer or contractor rebates for the purchase of new units and specific retrofit measures. The range of rebated measures in the 2006 program has broadened to include thermostats, refrigeration charge and airflow check, economizer repair/replacement and DCV. There is no explicit contractor training and only occasional inspections. No operating data is yet available for this program. However, the program was designed by KEMA-Xenergy and detailed results are likely.

Significant program issues include streamlining of the current triplicate paperwork and multiple program-related websites that are confusing to participants and better integration of the existing rooftop service program with the Cool Choice high efficiency unit rebate program. NSTAR is becoming more active by providing fact sheets to customers, direct marketing support on behalf of the retail HVAC contractors and providing customer leads to contractors. Though not currently planned, evaluation will be considered at a later time. Program management will continue to emphasize building initial relationships with contractors in the coming year. The program's first-year goal was 900 units visited with all units being tested with the expectation that 50 percent of the units would require repairs of some nature. Approximately 150 jobs were completed the first year; the same overall 900-unit goal is being maintained for the second year. There were/are no energy or demand savings goals established.

Energy Trust of Oregon (ETO)

ETO runs programs to address the energy savings potential in Oregon publicly regulated utilities. In the commercial sector, the programs pay an incentive based on calculated or engineered savings. Participants in this program so far have been whole building custom savings efforts; rooftop measures have not been explicitly broken out. There is no specific ETO rooftop program at this time. However, the current ETO model of addressing RTUs within a more comprehensive, whole building framework, has important implications for program design that are discussed in the section **Elements of a Program Design**.

Puget Sound Energy (PSE) Premium Service

A broad-based retrofit program, this is the largest of the rooftop programs operating in the Northwest. This program includes training in advanced diagnostics and ongoing motivation to encourage HVAC contractor participation.

This program benefits from extensive research and modeling done in the context of EWEB's program. In comparison with the AirCare plus program, the Premium Service pilot program explicitly measures the airflow of each treated unit, rather than using nominal airflow. The airflow measurements allow for a precise setting of minimum airflow to code standards and for refrigerant system diagnostics. This program has a wealth of carefully collected site data that includes actual airflow data, but this data has not been extensively analyzed. This program is formally a pilot effort, and an evaluation may be done internally.

California

As usual, things follow this state's unique requirements. Estimates of peak load reduction from a variety of rooftop service measures, including forced retirement of poorly operating units, could result in commercial peak load savings of 700MW over five years. This statistic assumes the implementation of all rooftop service protocols and an early retirement component.

California utilities are embarking on a second generation of rooftop unit retrofit programs. The Check Me program (offered by the Proctor Engineering Group) and its progeny originated in California, and a large-scale program evaluation (1200 commercial rooftop units) is due in May 2006. Based on budget availability for 2006, there are potentially up to 200,000 residential and commercial units targeted for testing and/or repair in PG&E's Refrigeration Charge and Airflow program. The emphasis in the California programs is refrigerant charge, airflow and duct leakage, and to a limited extent, economizer repair or installation.

The program model underlying these large undertakings is the use of Verification Service Providers for program implementation. The range of measures in the California rooftop programs consists predominantly of refrigerant charge, airflow check and duct sealing, compared to the broader range of measures used in the Northwest and Northeast programs. The PSE, AirCare plus and NSTAR approaches that include thermostats, controls adjustments and economizer improvements, offer a more holistic approach to the buildings.

The California programs are focused on resource acquisition measures primarily for kW. The cost effectiveness of the resource is derived by using individual site records for the measures installed and referencing the Database for Energy Efficiency Resources (DEER) database for savings per measure. Significantly, California regulators and utilities have agreed to a three-year energy efficiency program funding cycle with annual review to smooth out the annual stop-and-start cycles that seriously disrupt program implementation and disturb contractors and customers.

Integrated Design of Small Commercial HVAC Systems, Summary of Problems Observed in Field Studies of Small HVAC Units, Architectural Energy Corporation, October 2003.

This is not a program *per se*, but a research project to assess rooftop field conditions with important results. A total of 215 units on 75 buildings were inspected for problems with equipment and controls. These inspections were limited to relatively new units (one to four years old) with 10 tons of cooling or less. It is noteworthy that the prevalence of equipment and controls problems observed in this study was similar to the problems noted for the much older units in other programs. This study is also noteworthy for finding the distribution of refrigerant charge errors that showed that only about 10 percent of systems had a significant undercharge. There is an open question about what constitutes significant over/undercharge that is beyond the scope of this review. In California, undercharge as low as 5 percent is being corrected in the PG&E refrigerant charge and airflow program.

Equipment Stock Characteristics

It is important to recognize that although this discussion pertains to existing rooftop units, new rooftop units are almost the same physically, and there is essentially a continuum between existing and new units. As a practical matter, the age distribution of the treated units plays a role in assessing programs because it bears on the issue of cost effectiveness through the remaining useful equipment life. The age distribution also underlies the central rooftop decision: repair or replace?

Essentially, a new efficient unit is an extreme retrofit measure invoked when units are beyond repair. The retrofit program should be a sub-unit of a broader integrated small commercial HVAC program that includes efficient new units. It is important to note that new high EER units will have 1.5-2.0 kW lower operating demand than older units..

Age of Units

The age of the treated units naturally varies with location and the nature of the stock as illustrated in Figures 1a and 1b. Figure 1a is drawn from unpublished field results from the AirCare plus program, 2005. Note that about two-thirds of the units treated in one program are at least 10 to 15 years old (Avista), while at another location two-thirds of the units are less than 10 years old (SCE).

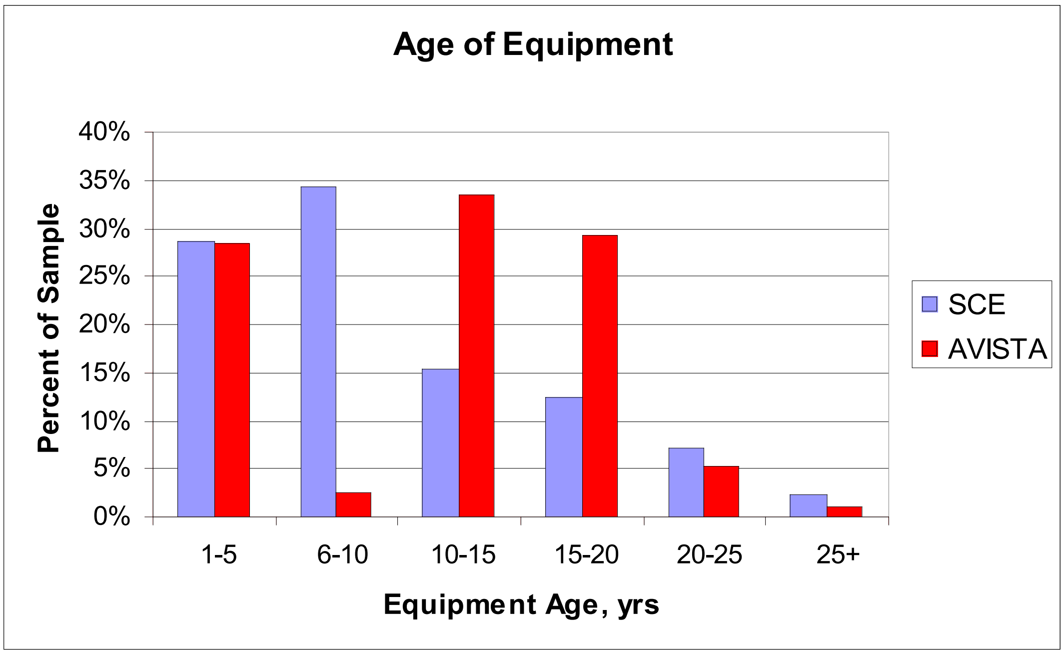

Figure 1a - Equipment Age Distribution AirCare plus Programs-Avista and Southern California Edison

Table A1-HS6

HVAC SYSTEM SUMMARY: Average (weight sqft) Packaged HVAC System Vintage

PERCENT OF REGIONAL CONDITIONED FLOOR AREA SERVED BY A PACKAGED SYSTEM

AVERAGE (WEIGHT SQFT) PACKAGED HVAC SYSTEM VINTAGE	Total	BUILDING TYPE								
		Dry Goods Retail	Grocery	Office	Restau-rant	Ware-house	Hotel/ Motel	Other Health	Other	School
4 years or less	24%	22%	28%	34%	4%	26%	27%	20%	22%	15%
5 to 9 years	30%	45%	26%	13%	46%	33%	27%	22%	30%	50%
10 to 14 years	26%	18%	14%	25%	26%	16%	10%	47%	37%	29%
15 to 19 years	9%	6%	29%	11%	<1%	9%	37%	<1%	3%	<1%
20 or more years	10%	8%	2%	17%	25%	17%	<1%	11%	8%	6%
--Total--	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
# Observations	519	82	38	136	34	57	19	22	91	36

Figure 1b - PNW Commercial Packaged System Vintage, 2002

The most favorable cost-effectiveness situation is repair to units with a long remaining useful life. The PIER field conditions project showed a high incidence of repair opportunities in units one to four years old. Clearly the feedstock of rooftop programs consists of units of all ages, but treating stock older than 15 years may have limited cost effectiveness and may better be blended into a replacement/new rooftop program, especially where demand savings are important.

About 60-plus percent of the units treated by Avista AirCare plus program had no economizer. Eighty-plus percent of treated units in southern California had no economizer. PSE's program will probably show a higher percentage of economizers because an economizer is required for entry to the program. Likewise, EWEB's program focuses on economizers. The presence of economizers is strongly age dependent. Some studies have shown that the older stock (15-plus years) has about 65 percent without economizers, intermediate stock (5 to 10 years) about 40 percent and new stock about 30 percent. Commercial Building Stock Assessment data indicated about 60 percent of distribution systems had economizers in the PNW building stock as of 2001. Economizer use is climate dependent and economizers have significant benefits for the Northeast climate.

Refrigerant Charge

Several studies have shown refrigerant charge out of manufacturers' temperature specification for superheat or sub-cooling in majority of units (60 to 70-plus percent). However, these studies significantly involve residential split systems where the refrigerant was added in the field. In the more restricted population of commercial rooftop units, the charge was added under factory conditions. Two California field studies, the AEC study of units 1-4 years old and the study of units of mixed age (average 8 years with some more than 20 years old) showed refrigerant charge errors distributed as in Figure 2. Both distributions show considerably more undercharge situations than overcharge.

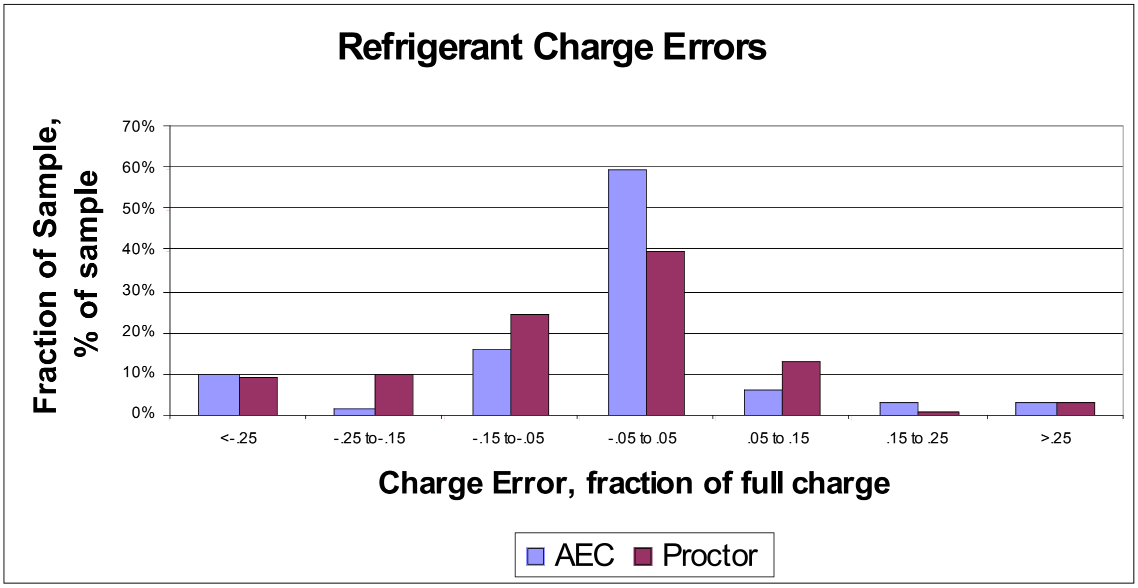

Figure 2 - Distribution of Refrigerant Charge Errors

Theoretical considerations suggest that efficiency degradation will not be significant until the over- or undercharge exceeds about 10 percent. In Figure 2, it is apparent that fewer than 15 percent of the rooftop units examined suffered from a significant under charge. The Proctor sample showed 19 percent of the sample with a significant undercharge. The AEC sample of newer units showed 12 percent of the sample with significant undercharge. Other researchers have found a much wider distribution in inspection samples that included predominantly residential split systems.

In a technical note, most of the charge errors are undercharges. In undercharged systems, the correction of charge often leads to an increase in compressor power and hence demand. The charge correction in these cases usually results in more efficient operation and it is argued that this more efficient operation results in a more diversified demand reduction.

In practice, there are two levels of refrigerant charge error detection. The first level is to find major problems using simple temperature diagnostics. These distributions reported in the referenced studies show that approximately 12-20 percent of participant roof top units are far enough off charge to be evident in an abbreviated charge test based on temperature measurements only. Correction of these major charge failures will result in efficiency increases of 20-30 percent.

The second level of detection involves the full charge test with refrigerant temperature and pressure measurements. There appear to be another 20-30 percent of the reported samples with correctible charge errors that could be detected by the full test. In the sample populations, the simple charge screen will lead to about 60 percent of the refrigeration savings potential that could be found through the full test.

Measure Distribution

The best-known element of rooftop service program experience is the distribution of field conditions and of measures implemented. Different programs had different objectives and used different categories for measure treatments. A common list of measures has been selected that is broad enough to include all categories used for the various programs. Table 2 summarizes the prevalence of the various measures from the field experience of most of the programs noted in Table 1 above. Most of the programs applicable to rooftop units address the same range of measures as illustrated below.

Table 2 - Typical Rooftop Measure Prevalence as a Percent of Inspected Units

Measure Category	PSE	AirCare plus SCE	AirCare plus Avista	NYSERDA	PIER field Inspection	Assumed for Trial Cost Effectiveness Review
Economizer repair and OSA adjustment	75% need repair. economizer is Prereq.	19% with econ; 85% need repair	6% with econ; 20% need repair		60% with econ; 37% need repair	35%
Air flow/ heat transfer	50%	5%	7%	~20%	39% low airflow	30%
Thermostat reset/controls	30%	41%	16%		40% (includes fan control)	25%
Thermostat replace	9%	20%	22%		Not assessed	10%
Refrigerant charge	0%	8% triggered by air meas. only	2% triggered by air meas. only	~35%	12% more than 15% off-PIER; 19% more than 15% off-Proctor	20%
Morning pre-condition	4%				Not assessed	20%
Demand control ventilation	0%			265 units, separate program	Not assessed	5%
Opportunistic	10%	10%	10%	10%	10%	0%, cost effectiveness based on specific measures
Total units	1000	1883	551	1086	215 recent installs	
Mean capacity, tons	7	6.8	5.6		5, (>85% 5 tons or less)	
Units/site		3.1	5.1		2.86	

Note in Table 2 the category for opportunistic savings. This is a deliberate placeholder to account for the fact that the fundamental nature of rooftop energy savings opportunities can be quite diverse depending on the unique and often unexpected circumstances on the roof and in the building.

It should be noted that the NYSERDA Advanced Diagnostics program principally trained contractors and as such was one layer removed from specific fieldwork. Direct Control Ventilation (DCV) was addressed in a separate NYSERDA program and was only applied to larger HVAC systems. It is included because it may be a significant measure for consideration in the programs where it has little or no presence. DCV is represented with an incentive in the PSE program, but there has been almost no customer interest in this measure.

The specifics and details of the measures in Table 2 generally conform to rooftop unit “best practices” that are discussed in several publications including among others: the *Small HVAC System Design Guide*, CEC #P500-03-082-A12, October 2003 and the *Good HVAC Practices for Residential and Commercial Buildings, A Guide for Thermal, Moisture and Contaminant Control to Enhance System Performance and Customer Satisfaction,* Air Conditioning Contractors Association, 2003.

The measure prevalence refers to the percentage of deficiencies in the measure category relative to the full number of units (not sites) inspected. Most programs have observed that faulty units have more than one fault; it is common for the total number of faults found to exceed the number of inspected units. Table 2 attempts to describe the measure prevalence data from several programs into a comparable format.

These measure categories have been defined broadly to capture a variety of field conditions reported under various specific field categories, but the edges are blurred in some categories. For example, the PIER inspections found a large percentage of cases (30 percent) where the fan was running during unoccupied periods and 5 percent cases with simultaneous heating and cooling; these were reclassified into the category thermostat reset/controls. The economizer category includes a full range of specific measures including sensor failures, sensor placement, damper articulation, damper controls and adjustment of minimum or maximum outside air flow. Some of the new thermostats reported were needed for temperature control and others were needed for economizer control. Refer to Table 3 for more economizer repair details.

Table 3 - Economizer Measures as Percent of Economizers Inspected

Measure	PSE	EWEB	AirCare plus SCE	AirCare plus Avista	AirCare plus Pilot	PIER
No failure	<50%	<50%	43%	80%	<40%	<36%
Outside air temp sensors	20%	23%	34%	13%		19%
Changeover	33%	~35%	60%	47%		
Controller	14%					
2 stage stats installed	9%	25%	18%	28%		
Mechanical						15%
Min air high		avg 20%				
Max air low		noted avg 65%				

The AirCare plus program reported that of units with economizers in the Avista program, 17 percent of the economizers did not work at all compared with 38 percent failed economizers in the AirCare plus SCE program.

Table 4 - Thermostat/Controls Adjustments as Percent of Units Inspected

Measure	PSE	AirCare plus Pilot	PIER
Positive adjust, will reduce energy use	22%	32%	30%
Occupied vent adjust			38%
Airflow<300cfm/ton	27%	~33%	39%

Measure Costs

In principle, measure costs are reasonably well known and measurable. However, these costs can vary significantly from contractor to contractor depending on how jobs are bundled and bid. Measure incentive levels in these early programs were usually set to at least cover the incremental cost of the measure. Therefore, the measure incentives will be assumed initially as the effective incremental time and material measure costs.

Table 5 gives these assumed effective incremental measure costs for several recent programs. The rightmost column labeled Estimated Time and Materials cost is the estimated measure cost that will be assumed in a subsequent cost effectiveness trial review.

In a full program context, there are costs above and beyond the incremental measure costs. For the purposes of this analysis, two levels of overhead costs will be applied below in a trial analysis of total program cost effectiveness. The first level of overhead is the "unit overhead" associated with that particular unit including all of the administrative costs of managing and operating the program. The second level of overhead is the "site overhead" that includes the marketing, training and site access cost applied in common to all treated units at a site.

Table 5 - Typical Rooftop Measure Incentives and Estimated Time and Materials Cost

Measure Category	Program Incentive Payments, assumed effective incremental costs				Estimated Time and Materials Cost
	NSTAR	AirCare plus SCE & Avista	EWEB	PSE	
Site inspection	NA	$60		$300	
Economizer repair and OSA adjustment	$250	$67	$375 as upgrade to $750 add on	~$150	$500
Air flow	$40	$100		Included	$50
Thermostat reset	$40	$30		Included	$50
Thermostat replace	NA	$150	$150	$300	$300
Refrigerant charge	$40	$160	NA	Included	$125
Morning Warm-up	NA	NA	NA	$125	$125

On average there have been about 4.3 units/site and unit overhead is about $70/unit, $300/site.

RTU Measure Energy Savings

All measure energy savings in the current and pending evaluations for the programs studied here were based on "engineering estimates." These estimates proceed from often-detailed site inputs but fundamentally rely on idealized buildings and equipment. None of the programs currently estimates measure or building impact using either a billing analysis or a direct monitoring approach. The RLW Analytics work done for National Grid and the Stellar Processes work completed for the Northwest Energy Efficiency Alliance (NEEA) did unit-level impact measurements, but this is a heavy cost burden for a typical impact evaluation and an insufficient sample size was obtained. Most program managers and evaluators that were interviewed acknowledged that good impact measurements were both necessary and missing.

ASHRAE has funded a project on the field performance of package equipment (1274-TRP) to quantify the energy performance benefits of "proper" service. Half the units will be 10 tons or less and half up to 15 tons. The project will monitor 375 units in a variety of climate zones, not including the Northwest. The project will also screen units by age with under and over 10 years as the baselines. One in five units will be monitored for post-servicing impacts. Site selection has included units with and without service contracts. The project is also considering fault detection and diagnostic procedures. The project is a year late due to the inherent complexity of the task and approach. Preliminary results may be available in the last quarter of 2006. It is not yet clear that this effort includes the effects of economizer work or thermostat/controls.

It is tempting to rely on "engineering estimates" because the site data usually involves several measurements taken from good instruments. However, the jump from these site measurements to normalized annual savings estimates involves many assumptions about the building and occupancy, and it is perilous to bypass rigorous impact measurements. Good impact measurements even for conceptually simple things like thermostat reset or economizers are potentially very complex.

At this stage, it is somewhat reasonable that current program impact analyses do not include direct measurement. Direct measurement via billing analysis requires a much larger sample than is currently available, and direct measurement via monitoring (with parallel engineering modeling) is an expensive and tedious addition to any particular program evaluation.

In lieu of measurement-based savings estimates, the engineering-based estimates will be used to establish savings ranges for the purposes of our initial discussions. Overall energy savings at any particular site will often be due to the interaction of several measures and physical conditions. Most engineering estimates are for measure bundles that include to some degree the effects of interaction. The consideration of measures acting individually is somewhat simplistic, but it is useful enough at this level of discussion.

Table 6 gives the estimated savings for each of the measure categories. These savings estimates will be used in the trial cost effectiveness review.

Table 6 - Measure Energy Savings per Unit

Measure Category	Mean Savings kWh/yr, kW Proctor/CA	Mean Savings kWh/yr, kW Mowris/CA, new comm	Mean Savings kWh/yr, kW NBI pending estimate	Mean Savings kWh/yr, for Trial Cost effectiveness estimate in this analysis	Measure life, yrs	Mean Gas Savings Therms/yr
Economizer repair and OSA adjustment	1,457, 0.82		3,831	2,000	8	~possibly large>5%
Air flow	w/refrigeration	w/refrigeration	3* filter only	200	8	
Thermostat reset/ controls			3,792	1,000	2	~possibly large>5%
Thermostat replace			4,722	2,000	8	~possibly large>5%
Refrigerant charge	680/avg unit 0.56	793/avg unit 0.51	NA	1500/treated unit	8	
Morning Warm-up			NA	1,000	8	~possibly large> 5%
Demand Control Ventilation			NA	4,000, arbitrary estimate for small units based on NYSERDA large jobs	8	~possibly large>5%

Note that savings estimates for large projects in California have been included for comparison. Although these California estimates are for a different climate than the Northeast and a potentially different composition of participants, they have been made by well-known practitioners and serve as indicative benchmarks.

The mean savings estimates column is drawn from a incomplete data and continuing NBI review of work in progress. The more conservative savings to be used in the trial cost-effectiveness analysis are also noted. Also note the gas savings of >5% for some measures. Gas savings estimates have not been made, but common experience suggests that there are often significant savings. There are some demand savings noted for California programs for which the derivation is taken on faith. There are no demand savings assumed in the trial cost effectiveness exercise. Most program managers were reluctant to assume demand savings except in cases where the unit power is decreased as in refrigerant charge correction.

The mean savings estimates may appear high at first glance. But these savings are denoted as per individual unit treated with that particular measure. A detailed unit level metering exercise (on a small sample in the pilot version of the AirCare plus program) did in fact show savings of that magnitude. However, in the current program, metering-based estimates of measure savings have not been made.

There is some uncertainty on the savings attributable to refrigeration corrections. The National Grid study and a NEEA study showed minimal savings, while the deemed energy savings for California programs for the melded average of residential and commercial units is reasonably high, about 700 kWh/yr and about 0.5kW for demand savings.

Achieving a sound estimate of measure-level savings is difficult because unit-level savings may be lost in whole-building-level billing information, (especially difficult when only a few of many units may have been treated). However, given a large inventory of participants, usable cases may be found. A persuasive billing analysis will either require a very large sample or a very carefully selected one, and even then it is unlikely that the analysis could distinguish savings at the measure level. A viable near-term alternative is unit-level impact measurements.

Any rigorous monitoring and modeling approach would finally need to true up to a 12-month real world base case. Such a complex monitoring and modeling exercise was executed on 37 units in the context of a NEEA/AirCare plus pilot in 2003. This rigorous approach was intended as a verification of the engineering estimates used at that time. The rigorous model showed greater savings than were estimated and claimed in the program engineering estimates. Also noteworthy in this effort were the opportunistic site observations that revealed savings about three times those in the engineering estimate. This earlier monitoring experience showed the engineering estimates were in the right ballpark (possibly even conservative), but the site protocol missed some big opportunities.

These big opportunities would not have been noticed had the sites not been revisited in the context of the monitoring. The largest savings elements are attributed to the thermostat savings and the opportunistic savings. These savings may be currently captured in updated versions of the AirCare plus site inspection protocol. It is entirely possible that with opportunistic savings included, average site savings would increase significantly.

The concern with impact measurements is that they will show diminished savings. Given the possibility of sizable opportunistic-driven savings, there appears to be a need for additional on-site, measurement-based energy and demand use impact data collection to underpin more detailed and broader savings estimates over larger participant populations.

In the early stages of rooftop diagnostics and tune-up program evolution, these measurements cannot easily be based on billing analysis because sufficiently large participant samples do not yet exist. After the programs have matured to a point large enough to support analysis samples of the order of 1,000 participants and non-participants, billing analysis could then be used as an ultimate check on savings estimates. In the meantime program evolution will benefit significantly from the detailed level of observation and inspection associated with projects that are designed to monitor individual units.

4. Elements of a Rooftop Unit Program Design

There is reason to believe that the utilities would likely harvest more energy savings at lower long run cost by achieving high penetration rates for new/replacement units than could be gained from operating RTU program for existing units. However, there are energy efficiency benefits from working with existing rooftop units as well as customer service and equity gains that are important.

The rationale for the scope and scale of a given RTU retrofit program is tied to the urgency of resource acquisition requirements by an individual utility and/or a region. Fundamental to program design is the type of resource required: demand, energy, or both.

Capacity limits are foreseen in the NEEP region for the 2008 period, squarely within the planning horizon for these programs. The forecast capacity limits suggest a need and opportunity to test program delivery models and to validate program savings impacts and cost-effectiveness.

A program design for these conditions would include:

Measure Selection

At the outset of program design, a fundamental decision needs to be made regarding the scope of measures to be included in the program. The full spectrum of measures to be considered in a program falls into three classes, differentiated by an increasing level of involvement with the operation of the building as a whole. Table 7 shows the measures classified in this fashion.

The *"tune up"* is the least intrusive category of measures. The measures can be carried out without even entering a building. This category consists of the refrigerant charge and airflow measures including filter cleaning. This complex of measures is the core of the California programs because these are the only measures with strong peak demand savings ranging from 0.5-1.0 kW/unit, and this limited measure scope is relatively easy to manage where participation is in the tens or hundreds of thousands of residential and commercial units. The energy savings from these measures are not large, 500-800 kWh/unit. Among RTUs that are predominantly pre-charged, about 20% of the stock will benefit significantly from a refrigeration correction. The RTU program may not be a significant reservoir of demand savings. With such a low "hit rate," site access costs significantly reduce cost effectiveness. The value of the energy savings from a program consisting of tune up measures alone would probably barely justify the site access costs. The programs in California have better economics. They have a higher "hit rate" because they treat a far larger stock, composed predominantly of residential split systems that are prone to over-charge from installation practices.

The next class of measures are the *"intelligent repair"* measures. These measures are more broadly involved with building control. They include assessing the building controls vis-à-vis the needs of the occupants. They include repair and enhancement of economizer operation, and assessing and setting the proper building minimum ventilation. For an old unit with low EER and lots of problems, the intelligent repair may be to replace the unit. These measures have relatively high energy savings that can justify site access costs. Replacement has the highest demand reduction benefit. However, these higher energy savings come at the price of becoming familiar with the building operation more broadly, and of having the people skills necessary to understand the needs of the occupants. In regions generally cooler than California, economizer savings increase as the cooling season decreases. In the NEEP region, it appears that the "intelligent repair" complex of measures would be the workhorse of the program. It is most probable that a program using "intelligent repair" measures would also include the "tune up " set of measures. The NSTAR program has most of the elements of the intelligent repair approach.

The deepest level of savings proceeds from *"whole building commissioning."* This complex of measures usually starts with a review of the utility billing records in the context of a simple building analysis model (EzSim-Stellar Processes, Honeywell energy management service and others). The billing analysis process may explicitly include the tune up and intelligent repair measures, but it is broader. The deeper savings here come from examining other building processes and instituting new control features, such as demand control ventilation. Often commissioning is an ongoing event, comparing ongoing utility bills to expectations. This broad and sustained approach is the way to be considered when the building operator, the utility or both, have the greatest need to save energy and/or demand.

Table 7 - Measure Classification

Measure Package	Tune-Up	Intelligent Repair	Whole Building Commissioning
Economizer repair/OSA air adjust		X	X
Air flow/heat transfer adjustment	X		X
Thermostat/controls reset		X	X
Thermostat replacement		X	X
Refrigerant charge	X		X
Demand control ventilation			X
Whole building commissioning			X
Early retirement		X	X

The specifics and details of the measures themselves generally conform to rooftop unit "best practices" that are discussed in several publications including the *Small HVAC System Design Guide*, *CEC #P500-03-082-A12,* October 2003 and the *Good HVAC Practices for Residential and Commercial Buildings, A Guide for Thermal, Moisture and Contaminant Control to Enhance System Performance and Customer Satisfaction,* Air Conditioning Contractors Association, 2003.

Beyond the description of the measures, there are specific technical issues including:

Cooling Screen – Most electricity saving RTU measures pertain to cooling. There are many specific occupancies where there is little or no cooling load and RTU measures applied in these cases will provide little or no savings. These "dry hole" situations can usually be identified in advance by analysis of the most recent 12 months of utility bills.

Energy Savings Impact Measurements for Economizers and Thermostats - The energy saving from economizers and thermostats are predominantly based on engineering estimates. Onsite monitoring experience and data at the level necessary to confirm engineering estimates is sparse nationally. The limited monitoring that has taken place showed these estimates were generally reasonable and that important control savings opportunities were being overlooked. Energy savings estimates for such measures involve coordinated unit level monitoring and whole building modeling. This specialized work costs more than is typically allocated to program level impact evaluations. Yet this information on what appears to be the strongest program measures is vital to program planning and cost effectiveness screening. A description of minimal approaches to M&V for RTU is given below in the evaluation section. The confidence with which a program can be pursued is dependent on clear and persuasive impact measurements.

The distribution of refrigerant charge errors in older stock – The use of RTU programs to access demand savings is ultimately bounded by the population of correctable units. It is well known that factory-charged unitary RTUs will have a different distribution of charge errors than field-charged residential split systems. Most published charge distribution statistics are for a stock that predominantly includes the split systems. Charge distributions for RTUs-only are much more limited and they show very limited charge correction opportunities in stock that is 1-4 years old. The big unresolved question is: what is the charge error distribution in older unitary RTUs in the Northeast commercial building stock? On this distribution rests the potential that a rooftop retrofit program can secure significant demand reductions from tune-up and/or repair services. The outcome of such a unit age study will also guide consideration of an early retirement program option.

Early Replacement – Replacement of an older RTU by a high efficiency one will have strong peak demand savings of the order of 1.5-2 kW. The replacement will also have significant energy savings, with the incremental benefits likely to be quite cost effective. Depending on the urgency of the resource need, a pre-emptive replacement may even be cost effective with a significant utility cost share, 50-plus percent. The cost effectiveness of pre-emptive replacement needs to be studied under a variety of resource acquisition scenarios. There is no specific program experience thus far, nationally with RTU early retirement

Economizer Dead Band - Earlier monitoring had showed unusual economizer operation where the economizer operated as expected one day and not another. Or economizers worked better in Idaho than in Portland. It was thought that this behavior was due to a 10 degree F dead band in the economizer controller. Apparently this issue is associated with a particular Honeywell economizer controller (W7459) coupled with a (C7650) dry bulb sensor. Honeywell has been contacted and project manager assigned. There appears little likelihood that Honeywell will respond. At least one workaround (an additional sensor) has been suggested by engineers and being reviewed in the PNW rooftop working group.

Energy Savings from Demand Control Ventilation - Demand control ventilation is widely regarded as a significant savings measure in cases where it is applicable in certain occupancy types such as auditoriums, movie theatres and generally larger, built-up HVAC systems. However, there is very little or no monitoring experience with this measure. There are clearly some practical issues such as placement and number of CO_2 sensors, the typical variation of CO_2 levels in spaces, and the interaction in practice of demand control with economizer control.

Single- or Double-Stage Thermostats with Economizer - Most economizer controllers can be used with a single-stage thermostat. However, best practice urges the use of a two-stage thermostat in this application. Two-stage commercial thermostats are available at low prices (about $100). The benefits of a double-stage thermostat should be documented.

Economizer Full Flow Limitations - Monitoring work done in 2003 showed that in most cases even when an economizer was fully "open" it did not deliver 100 percent outside air as is often assumed in modeling. This effect is due to incomplete damper movement or other throttling of the outside air intake and thermal gains. The effect can be a large portion of the economizer savings. The true percentage of outside air can be estimated from calorimetric measurements of mixing airstreams or from direct measurements of air entering the economizer hood.

Expedited Refrigerant Charge Check Screening - There is some resistance from technicians toward doing a refrigerant charge check because of the time it takes and because of technician insecurity with the procedure. With RTUs, the charge errors are expected to be rare, 1 in 10, and the full effort of a charge on every unit may not be warranted. The expedited rooftop retrofit protocols do a reasonably un-intrusive temperature split on the cooling coil to decide if the charge check is necessary, and only execute a full charge check after indications from the preliminary screen.

These measure-specific issues have been drawn from the pending proceedings of a newly formed regional working group in the Northwest, described in the **Evaluation** section on page 29.

Codes and Standards - Although not explored within this overall assessment, codes and standards play a major role in addressing market failures that cannot seem to be overcome through utility-based program efforts. The results of utility energy efficiency programs can point the need for formal standards to fully transform a given market. Codes and standards can also be considered as an exit strategy for utility programs. Codes and standards represent by several orders of magnitude, the most cost-effective approach for achieving energy efficiency resources even with consideration of utility financial support of code adoption. As reported in California, demand savings through traditional demand side management programs including incentives and rebates cost $800-1800/kW. Costs for codes and standards activities were estimated to be $2-25/kW.

Cost-Effectiveness Screening

Measure Screening

The full range of individual measures associated with RTU retrofits is examined for cost effectiveness based on time and materials costs. Then, a full program consisting of the cost effective measures is examined by assuming a further site overhead costs. The results of both the cost effectiveness perspectives are shown in Table 8, which posits a hypothetical program with middle-of-the-road assumed costs and savings.

Table 8 - Program Cost Effectiveness Example

Measure Category	Life in Years	Cost	Yield kWh/year	Measure mills/kWh level cost	Program Population Fraction	Melded Yield First Year, kWh
Economizer	8	$500	2000	42	0.35	700
Airflow	8	$50	200	42	0.3	60
Thermostat reset/controls	2	$50	1500	18	0.25	375
Thermostat replace	8	$300	2000	25	0.1	200
Refrigerant	8	$125	1500	42	0.2	300
Morning warm-up	8	$125	1000	21	0.2	200
DCV	8	$500	4000	21	0	0
Site overhead	$300	$70	per unit		1	
Melded unit cost with overhead		$365	per unit	36		1835

In this case, the discount rate is assumed to be 7 percent, and the energy cost escalation is assumed to be 5 percent. It should be noted that this assumed program targets a per unit yield of 1,835 kWh/yr, which is about double the per unit yield expected in the large California programs. This is because the hypothetical program includes a wider range of measures than the current California programs. The wider range consists of economizer repairs or upgrades, thermostat upgrades, and special controls such as demand control ventilation. (DCV). The estimates regarding measure cost yield and prevalence are drawn from previous tables. This broader slate of measures yields greater savings, but generally requires a more practiced understanding by technicians of the unit interacting with the building controls.

The principal reason for examining the hypothetical program is to understand how the various strands of information play into the overall program cost effectiveness. This brief *trial* cost effectiveness perspective is developed for an assumed program with a broad range of measures, characteristic of the programs run by NSTAR, PSE and AirCare plus. This trial cost effectiveness perspective assumes that the program eligibility is tailored to lead to the program population fractions noted.

Some measures in Table 8 have strong savings, but very short lifetimes (*i.e.,* thermostat reset/controls), while most other measures have longer lifetimes. Melding the various measure costs, benefits and lifetimes shows that a rooftop unit program including site overhead can reasonably fall within a levelized cost-effective range. In the hypothetical case illustrated in Table 7, the melded program has a levelized cost of 36 mills/kWh.

Also note that in terms of first-year yield, the highest yielding measures are economizers, thermostat reset, morning warm-up and DCV. These measures pertain to an understanding the operation of the building as a whole. It appears in this example that these specific whole building measures lead to more than 80% of the melded savings, while the refrigerant charge and airflow lead to less than 20% of the melded savings. This dramatic perspective needs to be tempered by the recognition that the dominant measures, economizers and controls, have not been extensively monitored for savings. The assumed savings estimates are based on very limited impact evaluation data.

Benefit Cost Tests - The relatively low levelized cost of 36 mills/kWh leads to very strong benefit cost results when the avoided cost of resource is $.09/ kWh. Three of the key cost benefit tests are shown in Table 9.

Table 9 - RTU Program Benefit/Cost Ratios

Cost Effectiveness Test	**Benefit/Cost Ratio**
Total Resource Cost (TRC)	2.75
Administrators Test- utility pays all	2.75
Administrator Test - participant pays all time & materials costs	14.37
Participant test	4.53

It is apparent that a program where the utility pays for all incremental time and materials and site access costs has a strong benefit cost ratio of 2.75 from a TRC perspective. This total resource cost perspective does not include the monetized value of externalities such as carbon dioxide offset, health benefits or security benefits. Had these benefits been included the benefit cost ratio would have been even stronger.

The participant test assumes that the participant paid all the incremental time and materials costs. Yet even having paid all costs, the RTU retrofit is very cost effective for the participant. If the participant were not to pay any costs, as it is in most programs, then the benefit is strongly favorable to the participant.

The administrator is the party that runs the program. This test assumes that the administrator is a utility in growth mode and benefits from the savings at the avoided cost of new generating resources. If the utility pays all costs, the benefit cost ratio of 2.75 is still strongly favorable because the utility is replacing high avoided cost energy with much lower cost conservation. If the administrator/utility were to pay no time and materials cost (letting the participant shoulder it all), the benefit cost ratio is an overwhelmingly favorable 14-plus because the conservation resource now costs almost nothing to the administrator. It is probable that an actual program design would allocate a certain cost share to the participant and the administrators benefit cost ratio could be designed to fall somewhere between 2.75 and 14. In either case, RTU retrofit is a valuable resource to a growing utility.

A cost-effectiveness estimate was made on a case where a new high efficiency replacement unit with an economizer replaces an older EER of 8.0 unit with no economizer. Such a replacement leads to a levelized cost of 2.4 cents/kWh. This is a strongly cost effective action that could be the basis for a preemptive replacement program that could have immediate and strong demand savings (estimated at up to 2kW/unit), as well as energy savings.

Overall this measure package is quite cost effective for application in the NEEP region. The program offering could even be extended to include preemptive replacement.

Assembling a Program

There are two key drivers for determining the type of RTU measure package that can be offered through a utility program: 1) the scale and pace of a utility or regional need for new resources and 2) the retail price of electricity. High prices alone are enough to create political pressure from the customer base and potential regulatory pressure to establish and/or ramp up energy savings programs. The presentation here may be viewed most usefully in the context of the ISO-New England 2005 New England Resource plan that states that high demand conditions would lead to shortages in Connecticut in 2006, that the system is already stretched to the limits in Boston, and the forecasts is for spot and region-wide capacity shortages in the 2008-2010 timeframe.

Capability Building - The absence of a utility or regional requirement to obtain larger amounts of energy and demand savings presents a significant opportunity to establish a minimal, prudent level of energy efficiency activity. This opportunity includes:

- establishment of pilot programs to test approaches to various market segments,
- support of existing programs at reduced budget levels to continue to test, refine and understand the requirements of the target market in preparation for larger-scale efforts in the future
- use of financial resources to conduct essential research and field testing (fully integrated with the operating programs) to establish consistent and reliable evaluation, monitoring and verification metrics, based on in field conditions, with less reliance on laboratory-based testing approaches.
- supports critical relationship building with key market segments.

During this phase, NEEP utilities have the time to develop the infrastructure needed to blend lower cost efficiency resources into the eventual increased need for new resources. RTU tune-ups and light repairs are central features of the capability building period. The NSTAR RTU program could be described as being appropriately matched in size (budget-wise) and scope to the capability building phase.

Medium Acquisition - A higher level of resource acquisition requires the readiness that can be developed in the Capability Building stage. Existing program operations are enhanced to match a more active need for energy efficiency resources. The tune-up and light repairs are included. Marketing elements include more intensive utility involvement with customers. Utility accelerates the overall program with additional funding as well as potential changes in incentive levels.

Urgent Acquisition - When there is a formal determination that new resource acquisition is required, and energy efficiency is a resource of choice, budgets are ramped up and the focus shifts to whole building systems approach for all rooftops existing and new. Program elements may now include:

- A whole building billing analysis
- Required review of RTU system sizing for new construction applications (it appears that 20-30 percent of systems are oversized)

- Early or pre-emptive retirement program via a financial buyout for a older (12-15 years) RTUs with a low Energy Efficiency Rating (>7-8.0)

There are other consequences of an approaching resource shortage that are linked to the results of the capacity building work. A key factor is the availability of experienced utility personnel as well as the availability of private sector contractors and technicians to be able to provide sufficient numbers of capable personnel to work in a ramped up situation.

Table 10 shows the different approaches for RTU program elements based on different stages of utility resource acquisition requirements.

Table 10 - RTU Program Elements Related to Utility Resource Acquisition Needs

Utility Resource Requirement	Capability Building	Medium Acquisition	Urgent Acquisition
Program Focus	Awareness/QC training/pilot/low operating level/EM&V	Ramp-up programs	Large-scale bid blocks
Measure Package	Tune-up measures, intelligent repair plus Cool Choice	Tune-up, repair measures plus Cool Choice	Repair, Whole Building, plus early retirement
Incentive package	Customer-cost sharing	Full incremental cost	Full incremental cost plus financing
Training	Program circuit rider plus industry training standards	Ongoing training support plus promotion of certification	technician certification requirement
Quality Control	Circuit rider plus Cool Choice quality standards plus industry standards as applicable; measurement projects for EM&V	Cool Choice quality standards plus verification sampling	Cool Choice plus industry quality standards plus verification requirements plus technician certification requirement
Marketing	Outreach to HVAC trades	Targeted marketing	Active marketing with utility and trade allies
Evaluation	Establish consistent EM&V protocols plus test in pilot & low operating programs	Concurrent process and impact evaluation	Concurrent process and impact evaluation

The New England capacity limits that are foreseen for the 2008 and post period, fit squarely within the planning horizon for RTU programs in the Northeast. The period of anticipated capacity shortfalls suggests an immediate need to test and validate existing program savings impacts and cost-effectiveness, as well as test new approaches.

Program Marketing

Most program experience points to the challenge of keeping participating contractors motivated to sell the service. This may be because the bulk of program marketing falls to the contractor although there are varying degrees of cooperation between the contractors and the sponsoring utilities. These range from the utility being a nearly invisible partner in the program, to websites and program materials branded with the utility logo to actively coordinated marketing. In one example, the utility representative called known large rooftop accounts to pass on to their HVAC contractor the particulars of an advanced diagnostics program. The HVAC contractor was enrolled through the customer's interest generated by the utility contact.

Anecdotally, some program operators (primarily outside of California) believe more attention should be paid to the relationship between the contractor and their customers, with an increase in administrative efficiency between the utility and the retail HVAC contractors or other suppliers. One utility still uses triplicate forms for participating contractors, while PG&E operates its upstream financial incentives programs for dealers and distributors without any paper changing hands, including direct deposit of rebate payments into vendor's bank accounts.

Customer marketing approaches are similar across programs with more or less direct utility involvement. It is reasonable to assume that the contractors will eventually integrate the RTU measures in their business and service model. However, anecdotal experience is indicating that program budget levels must be sustained for at 3-5 years at least, in order to build contractor interest and to keep the message in front of all customers, especially those who have not acted. When there is an urgent need for resources, customer marketing takes on a broader 'social marketing' approach. This approach widely broadcasts the need for broad public involvement in voluntary and programmatic energy efficiency activities at all levels for demand management and reductions, both immediate and for the longer term.

Program Integration

Generally, there appears to be a growing awareness of the need to more formally integrate existing rooftop service programs with new, high-efficiency unit programs. The NSTAR program provides a report to the customer comparing the cost of repairing an existing unit to replacement with a new unit including the available incentive. No other program reviewed provided that kind of formal reporting to the customer. As noted earlier, there is a fundamental choice between repair and replace. The idea of early retirement of older, poorly performing units with low EER's and no economizer, has been floated in California, at least conceptually, as analogous to the impact of refrigerator buyback programs that have operated there. This is a vital area for program design and pilot testing on a small scale given the ISO New England forecast of capacity constraints in 2008.

Quality Control/Best Practices

There is an acknowledged need industry-wide to raise the bar in terms of improving the core competencies of contractors to ensure quality HVAC installations. While quality installation and service work remain high on everyone's agenda, consistent application of quality principles remains elusive. Rarely do building owners link problems such as uncomfortable humidity, high utility bills, high dust levels and/or poor indoor air quality to substandard design, improper equipment selection, sub-par installation or incomplete commissioning. Consumers seldom demand – although most assume they are receiving - a high-performance operating and service standard from their HVAC contractor.

Nationally, there is no uniform definition of quality. To address this situation, several initiatives are underway regarding retail HVAC contractors and service quality: ACCA has embarked on initiative to define a Quality Contractor and Quality Installation (QC/QI). An industry consensus on the "vision" of QC/QI approach has been developed. A draft specification defining attributes, metrics, metric ranges, verification approach and acceptable proof of a quality installation has been drafted and will be released for public comment in April 2006.

US EPA issued a draft document "Options for a New Energy Star Specification for Residential Air Source Heat Pumps and Central Air Conditioners" in 2004. The document was prepared to solicit public comment for the Energy Star equipment specification revision in 2006. The paper included a discussion of quality and inspection issues for potential inclusion in the revised specification that would also include small commercial package units. The equipment specification revision was adopted in October 2005, but without any of the non-equipment related items. EPA is continuing discussion of the quality and inspection issues for consideration in a future revision of its Energy Star HVAC specification.

In addition, ASHRAE has ongoing work (183P) defining the maintenance needs and frequencies of commercial HVAC equipment. The result may lead to an ANSI standard.

A variety of materials have been developed that address best practices. The most comprehensive and detailed summary of best practices for nonresidential HVAC programs was published through the *Best Practices Benchmarking for Energy Efficiency Programs Project*, 2004. This report provides a very useful recitation of effective program attributes.

In California, several mechanisms are in place that promote quality, the primary one being requirements in the Title 24 Residential Standards for third-party inspection and verification for central air conditioning systems in new residential construction in selected climate zones. The standards are being revised for 2008 to require inspection in all zones for new construction and replacement units. In fact, utility service programs are designed to meet requirements set forth in the Standards. In addition, a statewide program for verification of RCA services for residential and commercial systems has been initiated with a single contractor providing inspection services statewide.

In the Northwest, the Washington State Energy Extension Program has been funded by the National Center for Energy Management and Building Technologies to create and implement a pilot O&M rating program for building owners and operators. This project will develop, test, and evaluate an O&M rating system for small and large commercial and institutional buildings, to achieve the following objectives:

- Provide a consistent industry-accepted metric for building owners and operators to use to evaluate O&M levels of service offered by trained HVAC contractors.
- Allow HVAC contractors to effectively market the "value-added" benefits of building science-based O&M services to commercial and government building owners and operators.
- Document energy and indoor environment "value-added" benefits from a rating system that provides a broader range of O&M-related services.
- Help to gain cost-share support and program participation from utilities and other stakeholders to promote adoption of an effective rating system.

It is not entirely clear where RTU programs go with all of these approaches and how they will affect the trades as the proposed quality standards are adopted. RTU programs should certainly reference industry initiatives and standards in the quality control/best practices area.

Training/Certification

Technician training and certification are associated with quality and best practice issues. Nationally, 15 organizations offer training and certification, via classes or home study, for HVAC technicians. The North American Technical Excellence (NATE) certification program has become the leading HVAC certification program nationally, with over 22,000 technicians attending training in 2004. However, most utility sponsored rooftop unit programs do not require or even take into account the certification qualifications of technicians participating in the programs. No program managers or evaluators we spoke with had yet included survey questions regarding technician certification. The single outstanding certification requirement is actually an EPA requirement for refrigeration technicians who conduct full system charges and handle quantities of coolant gas. Two of the active program managers estimate that it takes about $1,500 to train each technician.

Anecdotal evidence appears to support the presence of a somewhat higher level of knowledge and understanding among technicians with NATE or other formal certification approaches. One California program operator provides a small bonus to participating technicians who possess NATE certification. Future utility-sponsored programs are advised to consider certification qualifications for participating technicians. One double-blind study of NATE-certified and non-certified technicians showed relatively small differences in skill performance. While the certification is not an automatic guarantee of higher-level skills, one may assume that baseline HVAC principles have been covered.

Evaluation

As noted, there are only handful of evaluation studies on the variety of program approaches and energy impacts. While there are some evaluation studies in the pipeline nationally, much of the summary work presented here is based on conversations with program operators and evaluators. The need to establish utility cost-effectiveness (outside of California) is barely being addressed. There is little question that there is an urgent need for energy (kWh/kW) and cost-effectiveness evaluations. It is important to distinguish between energy and peak demand impacts of RTU service programs. Peak demand impacts can confidently be inferred from power measurements made during the retrofit service activity. As such they are relatively simple. The energy savings impacts however, are much more complicated and are the focus of the remaining discussion here. The cost and complexity of the necessary monitoring and measurement requirements for evaluating energy savings has slowed evaluation initiatives in this key area.

The need to establish the energy and demand savings for energy efficiency as a resource for the power system drives the need to design and implement monitoring and measurement projects, sooner rather than later, given the forecast of potential capacity shortages in 2008. The design of these research projects is complex and can be costly. However, there may be opportunities to collaborate on specific measurement projects that allow cost-sharing between regional and statewide entities.

A recent NEEP report, *The Need for and Approaches to Developing Common Protocols to Measure, Verify, and Report Energy Efficiency Savings in the Northeast, Final Report, January 2006*, noted a series of issues related RTU savings measurement and evaluation. The technical discussion presented by NBI is relevant to a technical framework that would emerge form the higher order policy recommendations in the NEEP report. The report determined among other things:

- Current M&V protocols in the region are not always consistent
- Savings calculations are done differently
- Savings estimates whether deemed or standard assumptions can vary significantly
- Similar algorithms are used to calculate gross savings, but the calculation of net savings differs
- Savings reporting is not consistent, and although the methods used to verify initial savings estimates are similar, the level of rigor varies
- The states have different schedules for reporting program savings as well as different levels of regulatory review and approval

The report concludes:

> "*As the region prepares to increase investments in energy efficiency along with other clean energy resources, it is in the states' interests to establish common protocols for*

measuring, verifying, and reporting energy and capacity savings in a consistent and transparent manner that meets minimum requirements for rigor."

The report draws a vision of a common and rational protocol from the International Performance Measurement and Verification Protocol (IPMVP) and the *California Evaluation Framework-Project*, February 2004. Both of these evaluation frameworks provide consistent, systematic approaches for planning and conducting evaluations of energy efficiency resource acquisition measures and programs. The level of detail is sufficient to provide a baseline from which to design and conduct high-level program cost effectiveness and impact evaluations.

However, this well developed IPMVP specification is still quite general, appropriately leaving discretion with regard to specific engineering approaches. In this context, M&V applied to RTUs is in a category of its own. Unit savings are difficult to resolve from whole building billing information because only a fraction of the several rooftop units at a particular site may have been improved, and site usage may have changed from one year to the next. Alternatively, savings established from short term pre/post monitoring of individual units involves a complex monitoring effort and the results still need to be normalized to normal annual savings using some sort of whole building model. Two recent attempts to apply this type of high level M&V specification to RTU in particular illustrate some of the practical details of the matter.

An M&V effort on RTU savings by the NEEA involved both detailed short term pre/post site monitoring and whole building billing analysis. This effort provided very useful program feedback, but the sample size was not large enough (N=37) to be statistically definitive. It would have been quite expensive to do this type of analysis on a statistically persuasive sample of 100 or more buildings.

An RLW Analytics, Inc. study for National Grid involved pre/post monitoring of about 100 rooftop units treated with the Check Me refrigerant charge adjustment. In this case, the charge adjustment was not properly executed according John Proctor, the originator of the Check Me protocol. The M&V work and analysis had a disturbingly high amount of statistical noise. This study is not enough to hang your hat on but it goes in the right direction toward appropriate unit level monitoring

Both of these prior M&V attempts leave one grasping for more confidence in the results. There is not wide experience nor consensus as to the approach for M&V on RTUs, even among approaches that conform in rigor to the IPMPV.

Collaborative Approaches

An initiative is underway in the Pacific Northwest, Regional Rooftop Unit Work Plan Working Group (RTUG), with sponsorship of the Northwest Power and Conservation Council and the Regional Technical Forum, to establish priorities for research work that will provide analytical results (kWh/kW impact) with a sufficient level of confidence to provide the basis for a PNW regionwide model rooftop unit program. Essentially, the features of a deemed program offering will be specified that will provide eligibility for the customer utilities of the Bonneville Power Administration for rate credits and discounts on their power purchases from Bonneville.

Most if not all of the research that is being scoped out in the PNW is of direct relevance to the Northeast and to the need for consistent standards for establishing energy efficiency as a resource for any power system. Both Northeast and Northwest regions need to design and implement savings impact measurement projects on several RTU related components including, but not limited to thermostats/controls, economizers as well as investigating new embedded diagnostic tools. In addition, PG&E in California is considering the addition of thermostats and economizers to its rooftop RCA program. There is every reason to believe that a possible solution to everyone's convergent and clear interest is to at least try to formally collaborate on the design, implementation and funding (of particular interest to all involved) of the research work. There is also the potential to at least by reference, influence field-level measurement standards nationally.

The working group has discussed the research collaborative potential. There has been a favorable response thus far and initial contacts are being made with NYSERDA, PG&E and Southern California Edison to determine their interest in participation. The work in progress of the RTUG will be shared with NEEP for review, consideration and joint discussion.

Confidence and Usefulness of Results

The savings observed at any particular site can depend significantly on the installation quality. Industry product ratings (*e.g.* SEER), do not provide a sufficient useful estimate of actual energy use. *In situ* measurements are more realistic. The most authoritative estimate of program savings proceeds from analysis of actual billing data because that is "where the rubber hits the road". But such an estimate in this context could easily take a sample size of several hundred sites impacted with a consistent treatment protocol. It would also require a non-participant control group similarly sized. This is the brute force approach. It is a big undertaking and it would result in a statistically defensible general conclusion, but very little useful feedback on specific program measures. While the results would be statistically conclusive to the requisite confidence level, they would be indirect as regards specific measures. One would not see a particular change in response to a particular action, and in that sense confidence would be limited. The brute force approach employs statistical methods that can be applied to anything, without necessarily the requisite minimal engineering understanding of the technology.

In practice, a deeper engineering understanding is usually required to select a proper sample and to interpret the results. When the engineering perspective is employed then confidence in the results can be significantly increased and the sample sizes and costs can be reduced. When the measurement results can be expressed in engineering terms so that for example, a particular action displaces a performance curve in a known way, then a limited number of measurements or case studies can confidently link an action with a result. Some of the most persuasive measurement data underpinning the extensive California RTU efforts is engineering graphs showing RTU power decreasing (by the order of several hundred watts to 1kW) during and after a refrigerant charge correction.

In the case of M&V applied to RTUs, the large participant samples with a homogenous treatment protocol do not yet exist. In addition, the measure treatments and methods are still maturing. Therefore, statistically significant billing based measurements on whole buildings are not yet possible, though they will be necessary after several years of program activity. In the early stages of program activity, impact measurements at the unit level will lead to a more confident and useful understanding of the program results and the individual measures.

The need for energy impact measurements is urgent enough that a brief discussion of the M&V applied specifically to RTUs and a recommended M&V approach is presented here as a starting point for work on this issue.

Preliminary discussion of an M&V approach to RTUs

The measure screening analysis showed that the most significant program savings are likely to be due to economizers (test/adjust/repair) and thermostat/controls restoration/replacement. These measures sound simple enough, but a competent estimate of the normalized annual savings from such measures is quite complex. The following discussion will start with a description of the full research approach and proceed to the recommendation of an equivalently useful, but simpler method.

Energy savings measures such as economizers or thermostat reset ultimately save energy by reducing the rooftop unit run time. But it is important to recognize that more than half the run time of a unit may be due to the specific internal heat gain in the building removed by the unit. In addition, the unit run time is also significantly dependent on the temperature control program. It is a potentially complicated situation.

Finally, further complicating the issue, are thermal transients with a duration of a few hours associated with the beginning and ending of occupancy, and with thermostat setback and recovery.

The Baseline Approach: Research Level Monitoring

In the face of these complications, the path usually chosen is research level monitoring. In research level performance monitoring, a certain level of monitoring/measurement is required in order to produce an analytically complete set of data. The object of monitoring is usually to develop a unit performance model that can be used with annual building models to predict normalized annual energy use or savings. The practical minimum objective should be to establish the energy input, thermal output, and duty cycle of each operating cycle along with a few auxiliary variables such as outdoor and indoor temperature. This approach results in impressive quantities of data and a great deal of associated analysis work, which can easily be costly.

Currently the more adept data logging systems can simplify this effort. They can identify and classify each operating cycle (economizer, cooling, heating, fan only,) as to the type of cycle. Sophisticated loggers can calculate for each type of cycle and for each hour the energy input, thermal energy output, duty cycle and type of cycle. In addition to the cycle level energy flow, each cycle will have auxiliary descriptive information such as outside air temperature (dry bulb) and, optionally, the percentage of outside air induced through the unit.

These five or six items are the minimum required for a complete description of the operating cycles of RTU operation along with specific one time site measurements particularly air flow. To monitor less than this will be analytically incomplete, though it may be sufficient to establish when the unit is operating. It is important to recognize that incomplete monitoring will have drastically reduced analytical power, and conversely, sufficiently complete monitoring will give deep analytical insight into unit operation.

With a complete enough data set, it is possible to devise a general performance map such as in Figure 3. This figure is only one version for many possibilities of a performance map. A commonly used alternate presentation uses COP by temperature bins. The intention in this figure is to provide a comprehensive reference image that includes the performance of all measures applied to rooftop units specifically including both the refrigerant loop and the economizer operation.

Figure 3 is for a hypothetical rooftop unit. If the unit were working perfectly, the points would be on or near the performance reference line. The intention in this figure is to provide a comprehensive reference image that includes the performance of both the refrigerant loop and the economizer operation. The specific input in this figure is the net of the cooling supplied by the coil less the cooling required to treat the fresh outside air, analytically derived from the supply air temperature – return air temperature

The temperature driver in Figure 3 is the thermal effort facing the unit, here expresses as the difference of the outdoor temperature relative to the return, indoor temperature.

This hypothetical example shows a case where the refrigerant loop is operating below par, and the dampers open inexplicably at high temperatures, but not at low temperatures as intended by the economizer. It takes a bit of practice to read a performance map, but it is a precise way to examine and characterize the complete range of operation of a unit. It is reasonably possible to map and identify the circumstances of all control irregularities.

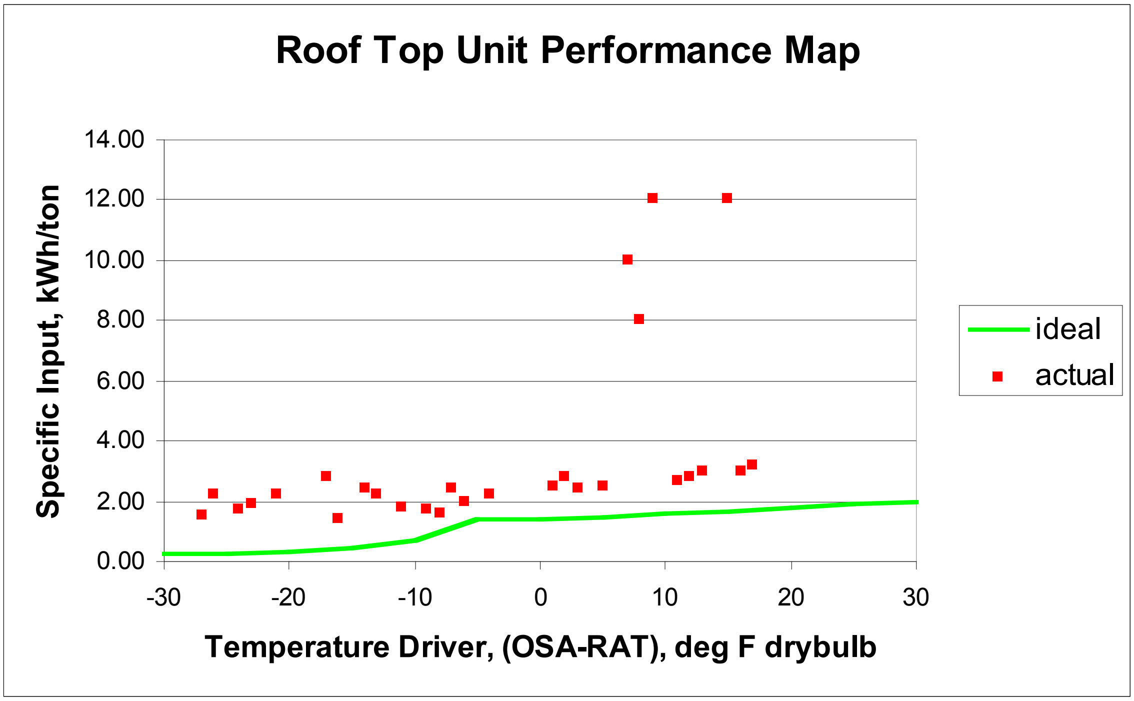

Figure 3 - Example Performance Map (outside air-OSA, return air temperature-RAT)

Regardless of the level of detail on unit efficiency afforded by the performance map, the larger energy question usually involves the actions of the thermostat in response to building internal gain. In practice, the unit operations are strongly linked to operations inside the building. From a research perspective it then becomes necessary to monitor and model the whole building in order to capture the effect of a thermostat change. This is an expensive proposition especially if a large sample size is required.

However, there is a special case where the general research problem can be simplified: i*n cases where the internal gain is highly repeatable from day to day and week to week, it can be removed from consideration as an influential variable.* In these specific cases and during a cooling season, the energy use change due to a broad package of rooftop measures operating together will be most evident. The measurements also can be done with simplified equipment.

Expedited Measurements

The special cases suitable for expedited monitoring are situations where the internal gain is repeatable from one occupied day to the next. Fortunately, this is common in many commercial buildings, especially in the retail and office sectors. In these favorable cases, the internal gain from occupants, and from lighting and plug loads. The hourly internal gain profile will be quite repeatable from one occupied day to the next. The unoccupied days will probably have a different but repeatable gain profile. In these favorable cases, changes in the daily unit energy use will be related to weather changes and to changes in the control measures.

However, even with well-behaved internal gain, the thermal transients can significantly complicate any analysis undertaken at short data logging intervals such as 15 minutes or up to hours.

Fortunately, in the cases of interest, the occupancy and weather drivers have repeatable daily periods. Analysis based on 24 hour intervals of the same day type (weekday, weekend) will usually net out the thermal transients, and will form a coherent linear or slightly quadratic plot with respect to the daily average outdoor temperature as shown in Figure 4. The graph portrays the results of a multifaceted, RTU service program in the PNW on a fast food restaurant. Note that the post retrofit period has been characterized with only seven days of data.

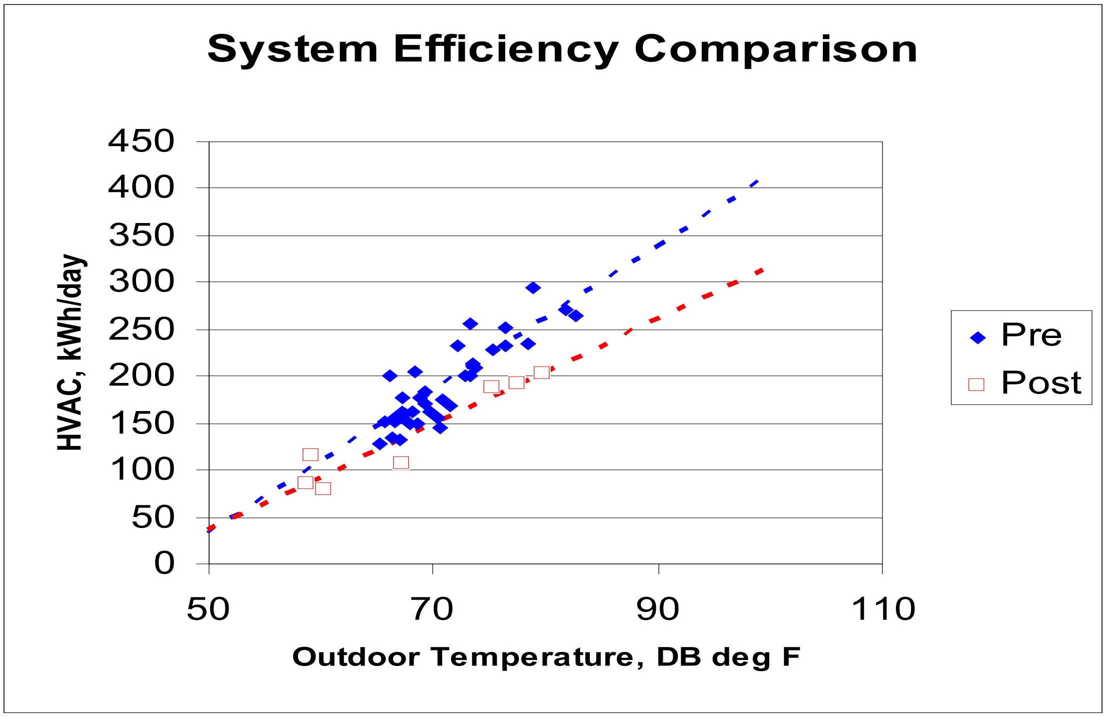

Figure 4 - Daily RTU Energy vs. Mean Daily Temperature

The pre- and post functions shown in Figure 4 can then be used with daily temperature bin data for the normal year cooling season to estimate pre- and post-annual energy use as well as annual savings.

Note that the temperature driver is simply the average daily temperature. The common driver in this situation would be cooling degree hours with the addition of an interior temperature sensor. The points would plot quite well with cooling degree-hours as the driver. But a driver defined as cooling-degree hours would include and absorb most of the effect of a thermostat reset, and therefore would not show thermostat savings.

The expedited approach involves 1) a carefully selected sample 2) pre/post monitoring during cooling season, 3) a simple performance comparison function. Specifically the data to be collected could be as follows:

For each day, pre- and post test period for a minimum of 2 weeks pre- and post retrofit:

1. Daily Average Temperature driver from outdoor air sensor or local weather station.
2. Daily unit energy (kWh) from a 3-phase power logger ('Elite' or equivalent) installed on the unit disconnect. If the energy effects of refrigerant charge or airflow are not important, then the power logger could be replaced by the simpler and lower cost runtime event logger.
3. Optional interior temperature logger. A higher quality M&V effort could include comparisons of hourly interior and exterior temperatures to provide some insight into changes seen in the daily energy, but they would play no role in the savings estimate.

4. Optional event logger. On key interior loads such as lighting to show that the internal gain was constant during the monitoring period or to be used editing non uniform daily points.

New Technology

In part, as a response to the unsuccessful attempt in 2003 by the Consortium for Energy Efficiency (CEE) to develop an advanced rooftop unit (ARTU) specification for the HVAC industry, the California Energy Commission has funded an ARTU specification development project. A technical advisory group including industry representatives and engineers, developed a list of features that will be tested for consideration by the industry, CEE and the Energy Star program for adoption in all new rooftop units. Embedded fault detection and diagnostic capabilities being developed by Field Diagnostic Services, Inc. described below, will be included in the test unit. A 5-ton/SEER 14 Carrier Centurian package unit will be reengineered and laboratory tested in April-May 2006. A cost-benefit analysis will be completed and a draft specification for the ARTU will be published and widely promoted to the industry, energy-efficiency organizations, Energy Star and codes/standards organizations at state and national levels. This activity is responsive to the NEEP business plan objective to coordinate sponsor input to the CEE High Efficiency Commercial HVAC Committee to develop a Tier 3 specification, including automated fault detection or other elements that assure improved energy performance, to create opportunities to increase energy and demand savings.

The features included in the test unit will address:

- Economizer improvements
- Fan improvements
- Unit efficiency
- Refrigeration cycle improvements
- Fan controls
- Refrigerant control
- Thermostat capability
- Sensors
- Installation & check-out capability
- Advanced monitoring
- Advanced, embedded diagnostics

The complete ARTU definitions report is included as an electronic attachment to this report due to the significant implications for new unit manufacturing specifications that should alleviate some of the inherent RTU problems encountered by installers and service technicians.

Fault Detection and Diagnostics

The use of fault detection and diagnostic (FDD) capabilities along with proper control strategies, are cited as the keys to maintaining reliability of operating performance efficiency in HVAC systems, small and large. At least two fault detection and diagnostic systems are in various stages of development and testing that provide an embedded, automated, comprehensive capability to monitor, detect and diagnose fault conditions in existing and new package rooftop units. This is continuous commissioning for rooftop units. Although several major HVAC manufactures are offering limited FDD capabilities in new, high-end equipment, the industry does not offer an FDD retrofit product for existing systems. Field Diagnostic Services, Inc. (FDSI) has been developing and field testing a retrofit FDD product for 5- to 50-ton rooftop units that operates wirelessly among multiple units and communicates operating data wirelessly to a website accessible by authorized personnel. When the product is fully commercialized, the monitoring of system performance will be based entirely on temperature measurements without the need for flow sensors. Pacific Northwest National Laboratory has also developed a wireless-based FDD product for existing units that will soon be field tested in 350 units in California. Table 11 summarizes the fault situations that are detected in the FDSI product. A more comprehensive list of faults and alarms is included as an attachment to the Draft Report.

Table 11 - Summary of Embedded Diagnostics Target Faults-FDSI

Refrigeration Cycles	**Air Handler**	**Controls**
Poor condenser (high side) heat transfer	No economizer cooling at low outdoor air temperature	Continuous call for cooling or heating
Poor evaporator (low side) heat transfer	High outdoor air fraction when high outdoor air temperature	Simultaneous heating and cooling
Refrigerant flow restriction	Low outdoor air fraction during occupied period	Fan cycling during occupied period when should be continuous
Low refrigerant charge	DCV signal and low outdoor air fraction	Fan running continuously during unoccupied period
High refrigerant charge	Low mixed air temperature	Mechanical cooling at low outdoor air temperature when should be only economizer
Low compressor pumping efficiency	Low airside temperature difference during heating or cooling	Thermostat cooling demand but no cooling
Non-condensable gas in system	High airside temperature difference during heating or cooling	Thermostat heating demand but no heating
Sensor problem	Sensor problem	Unit short cycling; short off-time or runtime for compressor
		Extended runtime (long cycles)
		Sensor problem

The expected commercial availability of these embedded automated diagnostic systems for the retrofit market and in new units should have a powerful impact on the rooftop HVAC service industry. Building operators and service contractors will have access to nearly real-time unit operating performance data. This will support eventual transformation of the current O&M service paradigm that emphasizes "repair" maintenance ("if it ain't broke, don't fix it") with a new capability that provides "performance reliability" maintenance. The significant benefit for the power system is the ability to track the persistence of savings through having the ability to review the same operating information available to the owner and service contractor.

Both the FDSI and PNNL approaches have the potential to address two fundamental issues that affect the RTU service market:

1. Web-based User Interface (UI): With access to the internet and World Wide Web reaching most areas, and in ubiquitous use by many people, the UI is as accessible to the building owner as it is to the service contractor. The business owner will be able to directly monitor the conditions and by reference, the costs of their rooftop HVAC systems. For the first time, there is no distance between the building owner, the operating performance of their HVAC units, and the service contractor.
2. The HVAC contractor will have to make adjustments in their service offering and costs to reflect the likelihood that at least initially, the embedded diagnostics are likely to immediately reveal the quality of previous service work as well as the competency of the servicing technician.

In response to the transformative potential of this information the City of Palo Alto utility program is working with FDSI to install embedded monitoring and diagnostic technology at the local school district and specifically study how it affects service personnel behavior leading to sustained efficiency improvements.

Figure 5 is a screen shot from the FDSI embedded diagnostic tool. The alarms are shown in relation to the likely impact of the fault condition that is detected on the occupants, safety or energy use/cost. In addition, details on the various operating conditions are presented in graphic format so that the system manager can easily view the history of the alarm and what specific diagnosis may be relevant.

Figure 5 - FDSI Embedded Diagnostic User Interface

Unit	Comfort Alarm	Equipment Safety Alarm	Energy Savings Opportunity	Monitoring System Alarm	Efficiency Index	Potential Annual Savings	Expected Cost	Return on Investment
RTU-1	OK	2 alarms	1 alarms	OK	83	**$940**	N/A	N/A
RTU-2	OK	2 alarms	1 alarms	OK	88	**$535**	N/A	N/A
RTU-3	OK	1 alarms	1 alarms	OK	94	**$97**	N/A	N/A
RTU-4	OK	OK	1 alarms	OK	N/A	N/A	N/A	N/A
RTU-5	OK	2 alarms	1 alarms	OK	79	**$301**	N/A	N/A

The potential power of these user interfaces to impact building owner interest/attention and HVAC contractor service is so great that we recommend NEEP consider the development and implementation of the FDSI embedded diagnostic products in one of the currently operating RTU programs in the region at a site with a minimum of two RTUs in the 5-ton size range. FDSI is considering its commercialization paths that include selling the FDD sensor and web site setup package for the retrofit market to having the FDD package embedded by original HVAC equipment manufacturers.

As these technologies become commercially available and establish their usefulness, it will be time to consider requirements for the use of embedded fault detection and diagnostic capability in future utility rooftop-related programs for both existing and new rooftop units.

It is recommended that a NEEP project be established to purchase at a minimum two FDSI embedded diagnostic units with web-based user interface for field testing (one site, two RTUs) in the NSTAR rooftop services program. Testing in an operating RTU service program provides a significant and cost-effective opportunity to evaluate the impact of new technology that has the potential to drive important structural changes in the building owner and HVAC service contractor markets. Integrating the FDD product into an existing rooftop program provides the platform of contractor and customer relationships that is necessary to introduce the technology to the market through a familiar channel.

5. CONCLUSION

There are ongoing cost-effective energy and demand savings from the range of technical service measures offered in operating utility-sponsored rooftop unit service programs in the Northeast and elsewhere nationally. The following conclusions are drawn from this review of experience:

1. Retrofit repair of commercial unitary rooftop air conditioners provides a viable resource for utility energy savings programs. The energy savings magnitude of this resource is second only to lighting among commercial demand-side resources. This resource, consisting of ~500,000 commercial rooftop units in the NEEP region, comes from three principal technical treatments: restoration of refrigerant charge/airflow, restoration of economizers and refinement of controls.

2. This efficiency resource has been approached by few utilities. The largest program activity (tens of thousands of units) has been in California, where currently most programs narrowly focus on restoring refrigerant charge, airflow and ducts in residential stock. Programs in the Northwest, Northeast and at one major California utility focus more broadly by including economizers and thermostat/controls adjustments. These programs and the conservation measures individually show favorable levelized costs of about 36 mills/kWh. In both regions, access to this resource is just beginning, with few programs beyond pilot or early operating stages.

3. The largest portions of this resource appear to be associated with restoration of economizers and thermostat- and controls-related adjustments, which together provide ~80 percent of the energy benefits, while refrigeration and airflow adjustments account for ~20. The reason for the low contribution from refrigeration is that a relatively small portion of the units need repair. Commercial rooftop units >4 tons capacity are a special population that came pre-charged from the factory; about 15-25 percent need repair depending in part on the age of the individual unit.

4. The savings potential from RTUs appears to be primarily an energy (kWh) resource. Only the refrigeration measures are capable of direct peak demand reductions, and these measures occur less frequently in this population.

5. The general RTU population in the Northeast is relatively older, with lower operating efficiency reflecting past lower efficiency standards and reduced operating performance. It is arguably necessary for utilities to prepare for an aggressive RTU early replacement program. While the efficient replacement unit is often "the repair of last resort," an early replacement program would produce the highest demand savings beyond any other program option. The offer of replacement equipment in an RTU program is a strong incentive to participating contractors and for program marketing.

6. There remains a strong need to develop clear and convincing measurements of the energy savings due to the most prominent of the program measures: economizer repairs, and thermostat correction/replacement in the context of a program operated in the Northeastern US climate. Energy savings impact measurements for these measures are difficult to make and generally more costly than is warranted in a typical program evaluations. For this reason such measurements to date are very limited. There is a clear need for these measurements for program planning, resource acquisition planning and utility and regional evaluation efforts. Collaborative measurement efforts possibly including the Northeast, Northwest and some California utilities are being explored.

Appendix A: Interview Participants

Name	Affiliation
Taghi Alereza	ADM Associates
Dave Bebrin	Connecticut Light & Power
Roseann Brusco	NSTAR
Catherine Bryan	Avista Utilities
Bruce Butler	Field Diagnostic Services, Inc.
Sue Coakley	Northeast Energy Efficiency Partnerships
Chris Clark	KEMA
Bob Davis	Ecotope
Charlie Grist	Northwest Power and Conservation Planning Council
Reid Hart	Eugene (OR) Water & Electric Board
Paul Kuraitis	Connecticut Light & Power
Jeff Harris	Northwest Energy Efficiency Alliance
Dale Hoffmeyer	US Environmental Protection Agency
Fred Gordon	Energy Trust of Oregon
Diane Levin	Portland Energy Conservation, Inc.
Kim Lenihan	New York State Energy Research and Development Authority
Jon Linn	Northeast Energy Efficiency Partnerships
Mike Lubliner	Washington State Energy Extension Service
Paul Lustig	Austin (TX) Utilities
Dave Mangouerra	Pacific Gas & Electric
Ed McGlynn	KEMA
Julie Michaels	Northeast Energy Efficiency Partnerships
Craig Muccio	Florida Power & Light
Curt Nichols	Idaho Power
Elmar Niewerth	Portland Energy Conservation, Inc.
Danny Parker	Florida Solar Energy Center
Roger Petherbridge	Portland Energy Conservation, Inc.
Stan Price	Putnam Price Group, Inc.
John Proctor	Proctor Engineering Group
Dave Robison	Stellar Processes
Todd Rossi	Field Diagnostic Services, Inc.
Buck Taylor	Roltay
Eric Taylor	Enalasys
Keith Temple	Field Diagnostic Services, Inc.
Elizabeth Titus	Northeast Energy Efficiency Partnerships
Phil Welker	Portland Energy Conservation, Inc.
Randy Vagnini	Connecticut Light & Power
Phil Welker	Portland Energy Conservation, Inc.

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