FINAL REPORT NCEMBT-090417

DEVELOPMENT OF AN OPERATION AND MAINTENANCE RATING SYSTEM FOR COMMERCIAL BUILDINGS

Rich Prill

Washington State University Extension Energy Program

Rick Kunkle

Washington State University Extension Energy Program

Davor Novosel

National Center for Energy Management and Building Technologies

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NATIONAL CENTER FOR ENERGY MANAGEMENT AND BUILDING TECHNOLOGIES TASK 06-09: DEVELOPMENT OF AN OPERATION AND MAINTENANCE RATING SYSTEM FOR COMMERCIAL BUILDINGS

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Prepared By:

Rich Prill
Washington State University Extension Energy Program

Rick Kunkle
Washington State University Extension Energy Program

Davor Novosel
National Center for Energy Management and Building Technologies

Prepared For:

U.S. Department of Energy
William Haslebacher
Project Officer / Manager

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NOTICE

WASHINGTON STATE UNIVERSITY EXTENSION ENERGY PROGRAM CONTACT

Richard Prill
Building Science and Indoor Air Quality Specialist
Washington State University Extension Energy Program
222 N. Havana Street
Spokane, WA 99202
509-477-6701
prillr@energy.wsu.edu
www.energy.wsu.edu

NATIONAL CENTER FOR ENERGY MANAGEMENT AND BUILDING TECHNOLOGIES CONTACT

Davor Novosel
Chief Technology Officer
National Center for Energy Management and Building Technologies
601 North Fairfax Street, Suite 250
Alexandria VA 22314
703-299-5633
dnovosel@ncembt.org
www.ncembt.org

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EXECUTIVE SUMMARY

The purpose of this market transformation pilot project is to create a rating system framework to score or rate the performance of commercial buildings.

The building performance factors addressed by this project are building energy usage; operation, maintenance, and functionality of the heating, ventilation and air conditioning (HVAC) systems; building occupant satisfaction; and building operation and management. Current guidance for improved building performance consists mainly of recommended practices. Implementing some or all of these applicable recommended practices may or may not result in improved building performance. This project attempts to create a practical method to rate outcomes, in terms of actual building performance, which is necessary to evaluate and refine practices and interventions.

Outsourced operation and maintenance (O&M) service contracts are currently not standardized, and are generally negotiated on a task and cost-of-service basis rather than specific building performance criteria. In a marketplace that is informed through a scoring or rating system that identifies, reports and tracks key elements of building performance, it is expected that building owners and managers – and their O&M service providers – will be better able to negotiate and obtain O&M services that deliver higher performance buildings.

Advanced O&M services that focus on practical and cost effective operation and maintenance practices and interventions will produce improved building performance as documented by higher ratings or scores. Higher scores are expected to translate into improved equipment function, reduced equipment failure, increased occupant satisfaction (and assumed productivity), higher energy efficiency, as well as increased demand for advanced O&M services in the broader marketplace.

As a building owner/manager is able to compare and evaluate scores over time they will be able to track these parameters and make adjustments in terms of budget planning as well as negotiate more effective O&M service contracts based on performance factors, not just costs.

Building owners/managers and occupants will benefit directly from improved building performance and reliability as advanced O&M services are implemented, documented and tracked. Providers of O&M and HVAC services will benefit by a marketplace that recognizes the value of advanced services that optimize building performance. Service providers will document specific deficiencies requiring interventions, and also gain useful results-driven feedback in terms of improved performance "ratings" or "scores."

Basic and routine industry-accepted O&M practices are prerequisites to the rating system. Thus the rating system builds on basic and routine services, focusing on optimizing building and systems performance through concise guidance and evaluation of critical performance factors currently overlooked or ignored in the marketplace.

A detailed rating or scoring method was created for four building performance parameters: 1) HVAC Roof Top Unit O&M and Performance; 2) Building Energy Performance; 3) Building Occupant Satisfaction; 4) Walk-Through Assessment. Using this scoring system, O&M contractors and building owners/managers are able to quickly evaluate the building performance for these parameters. A list of "Advanced Building Performance Management" options is also provided.

Guidance is provided for implementing and scoring each parameter. Guidance follows an easy three-step format. Electronic scoring tabulation is provided using computer spreadsheet tools, electronic occupant survey form, HVAC performance and functionality score card and protocols, building walk-through checklist, and advanced building performance management options.

Six pilot project buildings in Washington State were recruited and used to obtain input from the building owner/manager, occupants, and O&M service providers and to field test the proposed rating system tools. Each of the pilot building's energy usage was documented and the operation and functionality of some HVAC systems were evaluated. Occupant satisfaction surveys were conducted in conjunction with space temperature and ventilation assessments. Limited technical monitoring was performed.

1. PROJECT OBJECTIVE

The goal of this project was to develop an O&M rating system for owners and contractors that accounts for building performance and promotes energy savings and improved occupant satisfaction and indoor environmental quality. The desired results include:

- Develop an O&M rating system scoring methodology and tools for small- and medium-size office and retail buildings.
- Create detailed scoring systems and protocols for HVAC O&M service providers.
- Provide a metric for building occupant satisfaction, energy performance, and walk-through performance assessments.
- Summarize the experience from field work in six pilot buildings and feedback from building owner/managers, O&M service providers, and other advisors.

2. BACKGROUND

The motivation for this project is to encourage market transformation toward improved building performance through the development of an O&M rating or scoring system. The intent in this project is to focus on rating operations-related building performance and to develop an approach that can be applied to small- and medium-size office and retail buildings by O&M service providers and building staff.

Currently a myriad of O&M guidance exists ranging from specific and detailed to broad and general in nature. For example, individual O&M contractors create and utilize their own customized service checklists for specific mechanical equipment. Various industry organizations offer minimum requirement standards and good practice guides. Heating, ventilation, and air conditioning (HVAC) equipment manufacturers provide operation and maintenance specifications for their individual products. The U.S. Department of Energy (DOE), utility companies and others provide broad lists of energy performance tips and suggestions. More broadly, the U.S. Green Building Council promotes the Leadership in Energy and Environmental Design (LEED™) rating system for Existing Buildings (Operations & Maintenance), outlining general prescriptions and topical guidance.

A literature search and discussions with industry leaders revealed that no detailed, integrated, or multi-dimensional operations-related building performance guidance or ratings systems currently exist, although there is an increasing amount of recent interest and discussion in this area. Most O&M related guidance is prescriptive in nature, consisting mostly of recommended practices intended to result in improved building performance, but the outcomes of these practices are rarely assessed in a systematic fashion. While LEED for Existing Buildings is a rating system that does include performance elements, there are a large number of rating categories (most appropriate for larger buildings) and many of these categories deal with management practices, policies, and building characteristics.

Currently building owners/managers are seldom provided with metrics to help them identify specific areas for improving their building's performance. Small- to medium-size buildings commonly rely on out-sourced operation and maintenance services provided by technicians with responsibilities generally limited to a prescribed set of routine service tasks. Building owners/managers do not generally receive meaningful documentation or feedback about their building's energy usage trends, a useful rating of the HVAC equipment and systems functionality, or an organized feedback mechanism to assess the building occupant's satisfaction with the building's performance. Building performance is impacted by occupant behaviors, equipment degradation and failure, structural deficiencies, and building usage and design. Building owners and managers are seldom offered or receive routine walk-through assessments to assist them to identify and correct performance deficiencies through practical recommendations.

According to Chimack (Chimack 2006), to determine the success of a maintenance program, goals need to be set for the program and analyzed yearly to see if the program is meeting its goals. Additionally, every year, equipment failures from the previous year should be analyzed as to the root-cause of the failure. This analysis should analyze each specific cause of the problems. The maintenance program should then be reviewed and altered where applicable to aid in the reduction of future failures. Similarly, the energy efficiencies of major equipment should be noted annually to verify optimal operation. If efficiencies decrease significantly, a failure may be imminent. Furthermore, occupant complaints should be tracked by work order and analyzed to identify patterns. The purpose of scheduled maintenance and O&M in general is to manage expenses. This is done through decreasing equipment failures, increasing equipment life, energy efficiency, productivity and indoor air quality. If this can be done, the maintenance program will be successful and the program will become a priority. The challenge is to incorporate these ideas into routine practices that are appropriate for small to medium size buildings.

Barriers To Building Efficiencies

Herzog (Herzog. 1997) states that the barriers to efficient operation are managerial and organizational, not technical. Clients are usually not aware of savings potentials, and often assume systems are working okay due to the "routine" O&M practices and services provided. Energy waste can often be due to lack of a well organized O&M process. Another barrier is that O&M procedures (actual) are designed primarily to achieve "complaint management" and avoidance of premature or catastrophic equipment failure (reliability). Guidance or services for the efficient operation and management of facilities are not readily available to building owners/managers. Therefore, instead of ensuring efficient operations through effective management and organizational structures, the tendency has been to focus all energy conservation efforts on equipment upgrades and replacement. The O&M industry may have a vested interest in these types of projects rather than lower cost preventive O&M and optimization of equipment function.

The perceived costs and benefits of enhanced O&M services are an important factor in their market acceptance. The following statement, summarized from our discussions with multiple mechanical contractors involved in enhanced O&M programs in the Pacific Northwest, makes these points:

> *"O&M contractors have determined the service levels and related price points that work with their own business model – any additional O&M services will have a direct effect on their current offerings (e.g., levels of service and service packages) and therefore need to be carefully considered before further O&M steps are proposed to their current or prospective customers. For example, a four-year utility-sponsored 'enhanced HVAC service program' has required contractors to provide enhanced O&M activities on roof top HVAC units (RTU). Over the program's 4-year history, O&M contractors have shown various levels of participation. One reason that some have given for their low participation (or decision to leave the program) is the rebate levels. These rebates (incentives) are seen as not high enough, in some cases, to cover the extra labor time required. Any proposed set of additional maintenance practices would undergo the same scrutiny."*

O&M contractors' concerns that the rebates are not high enough to cover their costs are reinforced by the lack of attention by building owners/managers to building operations and management (and their potential for generating savings). Building owners/managers are not asking for these services.

3. METHODOLOGY

The project team used a multi-step approach to develop a pilot O&M rating system that consisted of three primary elements:

1. Collecting input
2. Developing the O&M rating system
3. Conducting testing in pilot buildings

The process of creating the O&M rating system was not linear. While collecting input was an important first step, we continued to gather information and solicit input and feedback throughout the project. We developed a number of different O&M rating concepts early in the project to inform our conversations and give us something to work with. The effort was more creative than technical in nature, which added to the complexity and effort required to develop materials. We also began working in pilot buildings in the early stages to gain experience working with owners and contractors and to identify important issues that needed to be addressed. Thus, we used an iterative process to create the O&M rating system concept. In this section of the report we describe the three elements in our approach.

3.1 Collecting Input

We formed advisory teams, conducted interviews, and performed a literature review to collect input for creating the O&M rating system. These were the first steps in the project and allowed us to better define the project scope and create the initial rating system concepts. We continued to rely on inputs from our contacts throughout the project.

To gain insights into current market fundamentals, three project advisory teams were recruited representing:

- The O&M and HVAC service delivery industry,
- HVAC and energy technical professionals, and
- Stakeholders consisting of O&M customers (building owners/managers/operators) and representatives of utility and efficiency programs.

Most of our technical advisors were sub-contractors and played specific roles in the pilot building testing and the development of the rating system concepts. We engaged most of the other members of the advisory teams through individual phone conversations and e-mail. This was an informal process. We had some challenges involving advisory team members in the project. This was partly due to their limited availability and to the conceptual nature of this project.

We conducted interviews with O&M contractors to gain insights about the O&M services they offer and their interest and suggestions about enhanced O&M services. We acquired copies of typical service agreements and contracts. We also spoke with building owners/managers/operators about the O&M services they receive, and with utility and energy efficiency program representatives involved with O&M-related activities.

Throughout the course of the project we solicited feedback from our advisory team members and others we had contacted about the O&M rating system concepts we were developing. We used this feedback to further refine the rating system and to raise issues that might need to be addressed later.

A literature review of O&M programs and energy usage by buildings and building systems was conducted. This review included research reports on O&M practices, programs aimed at improving O&M practices, and O&M guidelines, tips, and standards (see References). The literature review provided input on current practices, needs, and opportunities.

3.2 Developing the O&M Rating System

The steps in developing the O&M rating system concept included defining the scope of our project, what we were rating, the parameters to be rated, and development and refining of the beta version of the rating system.

3.2.1 Scope

During the initial scoping of this pilot project, it was proposed that small, medium and large buildings and a variety of HVAC systems would be addressed, and the pilot buildings would represent these building types and systems. As the project team researched the literature and gained input from advisory team members and industry stakeholders, it became clear that this range of building sizes and types of HVAC systems would add far too much complexity and was overly ambitious given the limited project resources.

Focus was directed to the O&M market for small- to medium-size office and retail buildings. This sector of the O&M market generally outsources O&M services, making this a prime target for a concise package of practical performance metrics. For these buildings, in-house expertise and understanding of building systems and performance issues are generally very limited to non-existent. The result is that HVAC systems operate under less-than-optimal conditions because the owner/manager and/or occupants do not perceive a problem, do not understand the alternatives, and rely completely on their O&M service contractor to maintain and control the building in an efficient manner. These buildings also tend to have packaged roof-top HVAC systems, which simplifies rating system development.

3.2.2 What Is Being Rated

One issue that came up in the initial phase of the project was whether we were rating O&M services or rating buildings. We considered the purpose of the project and market needs. It was determined to use individual scoring to represent a particular building's performance relative to distinct performance parameters. Therefore, the project focused on rating building performance, not O&M services.

3.2.3 Parameters to Be Rated

To meet the goal of improved building performance for commercial and institutional buildings, the project team – collaborating with the three advisory teams, O&M contractors, and the pilot building owners/managers – identified a set of inter-related building performance rating tools. It was determined that, beyond preventive and corrective maintenance services for HVAC equipment, there are other vitally important performance factors necessary to evaluate an individual building's performance. Clearly a number of building performance metrics would be necessary to effectively evaluate, rate and recommend the most important building performance parameters. The range of metrics suggested included:

- Building energy use and trending
- Evaluation and documentation of HVAC system performance
- Evaluation of the O&M service package and delivery
- Subjective building performance assessment by occupants

- Thoroughness of building O&M policies and procedures, and education and training
- Routine building walk-through assessment
- Energy and lighting audits, commissioning, efficiency studies
- Building O&M management factors

The rating system also needed to focus on the essentials and be provided in a user-friendly format such that an O&M contractor could conduct the rating within a reasonable timeframe, and without the need for significant additional training, instruments, or tools. Through literature review and advisory team discussions, four key parameters were ultimately identified as critical areas to be developed.

1. HVAC system condition, operation, functionality, and maintenance
2. Building energy performance based on actual energy usage
3. Occupant satisfaction and input
4. Routine building walk-through assessment

Through attention to these four elements, a contractor and owner/manager can quickly arrive at an understanding of the current building performance and discuss options for interventions and improvements. A building's performance cannot be adequately understood without a comprehensive evaluation – for example using only an energy usage value does not ensure optimum equipment performance or occupant satisfaction. A meaningful, multi-faceted rating system allows frequent evaluation and tracking of these different metrics over time, to ensure the building performance remains constant or is being improved. The Discussion section of this report (Section 5) provides more information on the selection and development process for these parameters.

3.2.4 Rating System Development

The development of the rating system was an iterative process. This included consideration of the form of the ratings (labels such as stars, scores, etc.), how they would be summarized, formatting and appearance, what building systems to include, protocols, determination of scores, existing materials/protocols/approaches that could be used, and addition/removal of elements. Initial formats were more conceptual, with detail being added to later versions. We shared our concepts with advisory team members and contractors to obtain their feedback.

3.2.5 BETA Version of the Rating System

A BETA version of the rating system was ultimately developed and formatted into a rating system notebook. The BETA system notebooks were distributed for review and critique to project advisors, industry stakeholders, and energy/HVAC technical professionals. The notebooks also included a reviewer questionnaire to guide reviewer feedback and critique and prompt suggestions for improvements. Of the 25 notebooks distributed, feedback from reviewers was very limited, and no completed survey questionnaires were returned. The BETA version was also presented, discussed, and reviewed at various venues including energy workshops, building operator trainings, national conferences, and industry meetings. Subsequent modifications were incorporated based on this wide review process.

3.3 CONDUCTING TESTING IN PILOT BUILDINGS

Six pilot buildings were recruited to gain field experience during the development and refinement process of the various rating concepts and tools through interaction with the building owner/managers, building occupants, and the individual O&M service providers (see Appendix B – Pilot Building Testing). The practicality and relative effectiveness of various approaches and tools were tested and evaluated in the context of these buildings. Real-time instrumentation was installed in pilot buildings to monitor basic operation and performance of the HVAC systems, occupied zone temperatures and relative humidity. Indoor carbon dioxide concentrations were logged as an indicator of outside air ventilation. Occupant satisfaction surveys were conducted and scored. Energy usage of the buildings was determined using the Environmental Protection Agency *Portfolio Manager* Program.

The initial scope of the project suggested creating a training curriculum and providing training, and developing some representative marketing materials. Through interaction with the pilot building contractors it was clear that developing a set of unique training and technical materials was unnecessary. Again, an important objective of the project was to create systems and tools that could be adopted and used by O&M contractors without the necessity for additional skills training. Also in keeping with this objective, the rating system we developed provides a straight-forward three-step implementation procedure for each component, and the HVAC equipment scoring includes detailed protocols. As the rating system is further developed, education and supporting materials such as case studies and marketing materials should be created.

4. RESULTS

The goals of the project were met through development of a building performance rating system that provides for a relatively low-tech method to gauge multiple facets of building performance. Advisory teams and pilot buildings were engaged in developing, testing, and refining various approaches and models. Key objectives for the system were practicality, broad applicability, meaningful scoring, and ease of use.

Our research suggested the need for a rating system that focused on building performance and conditions rather than prescriptive practices. We also saw the need for a multi-faceted approach to more comprehensively evaluate a particular building's performance. For example, we have incorporated existing performance benchmarking systems such as the Environmental Protection Agency's Energy Star *Portfolio Manager* into the rating system, but an Energy Star rating alone does not provide evidence of optimized equipment function, occupant satisfaction, or good-practice management and operation of the building and systems. The project's advisory teams provided unique insights and guidance throughout the process of creating a concise set of rating tools, which are described in this section.

4.1 Overall Description of the Rating System

Five building performance parameters were identified, and detailed scoring methodologies and implementation protocols were established where appropriate and practical.

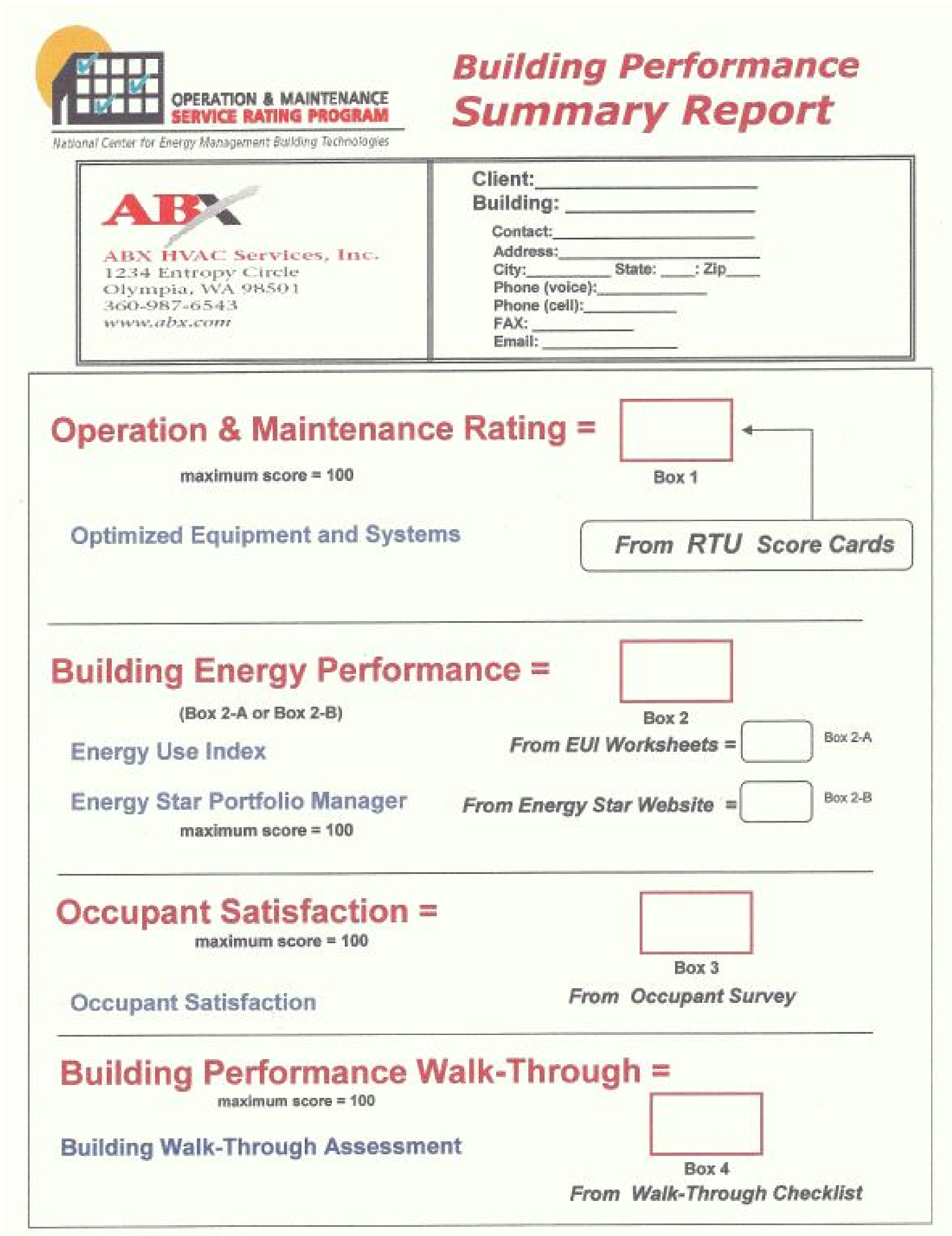
1. **Optimized Operation and Maintenance**. The condition and performance factors of roof top units (4 to 20 ton) are scored. Each roof top unit (RTU) is evaluated and a score assigned comparing "As-Found" with "As Left" conditions and performance. These scores are recorded on a one-page RTU Score Card that serves as documentation. A set of protocols guide the service provider through the equipment assessment and scoring. The protocols are aimed at creating a standardized scoring metric focusing on those measures that are not generally part of a "routine" O&M practice or service contract, yet significantly impact energy and unit/building performance.
2. **Building Energy Usage**. The energy consumption of the building is analyzed and an energy performance score is determined using the U.S. Environmental Protection Agency Energy Star *Portfolio Manager*. As an alternative, a simplified Energy Use Index (EUI) worksheet is provided. This electronic spreadsheet-based worksheet uses commercial energy use data from the U.S. Department of Energy's Energy Information Agency (EIA) Commercial Buildings Energy Consumption Survey (CBECS).
3. **Occupant Survey**. The building's occupants are surveyed through a concise two-page Occupant Survey to determine their degree of satisfaction/dissatisfaction with the building and building systems. Elements include comfort, lighting, noise, odors, and impacts on productivity. The survey also provides the building owner/manager and the O&M contractor with additional occupant feedback in terms of specific actions occupants take in response to real or perceived deficiencies (i.e., use of fans or space heaters, blocking of supply diffusers, etc. to improve comfort). This information allows more energy efficient corrective actions by the owner/manager and/or O&M contractor (reducing the need for occupants to take individual actions, which are often inefficient and even counter-productive). An electronic tally sheet and Score Card are provided.
4. **Routine Building Walk-through Performance Assessment**. The building performance "walk-through assessment" was suggested late in the project, precluding sufficient time and resources to

develop a thoroughly reviewed and fine-tuned protocol and scoring mechanism. The assessment was suggested to supplement the other elements in the rating system, which may not always be sufficient to achieve optimized building performance. Routine assessment of the building and systems through a practical checklist-driven approach (incorporating observations, basic measurements, and discussions) provides opportunities to recommend interventions or recommend further study. Basic good practice interventions can often result in low-cost/no-cost improvement of building performance – and immediate payback – in terms of energy, reliability, comfort, productivity, and durability.

5. **Recommendations for Advanced Building Performance Management.** Seven key areas of building management are provided. Managing buildings and operations for optimum performance is widely promoted and is considered an essential element for improving building performance. A scoring system for these measures was considered, but was ultimately deemed impractical by the project team and advisors because these management practices are different from the other more performance-based elements of the rating system.

Summary Score Sheet

All four scores (elements 1-4) are presented on the "Building Performance Summary Report" (Figure 1) which provides the owner/manager (decision maker) and O&M contractor a basis on which to discuss levels of O&M services, upgrades, interventions, and capital improvements. It is expected these discussions will also include cost-benefit analysis, and the possible need to secure the services of a specialist such as a commissioning agent, energy auditor, lighting specialist, etc. Over time the trending of scores provides all parties with essential feedback on which to modify service agreements (practices) and other approaches to ensure building performance is sustained and even improved.



OPERATION & MAINTENANCE SERVICE RATING PROGRAM

National Center for Energy Management Building Technologies

Building Performance Summary Report

ABX

ABX HVAC Services, Inc.
1234 Entropy Circle
Olympia, WA 98501
360-987-6543
www.abx.com

Client:__________________
Building: __________________
Contact:__________________
Address:__________________
City:_________ State: ____: Zip____
Phone (voice):____________
Phone (cell):____________
FAX: ____________
Email: ____________

Operation & Maintenance Rating = [Box 1]

maximum score = 100

Optimized Equipment and Systems

From RTU Score Cards

Building Energy Performance = [Box 2]

(Box 2-A or Box 2-B)

Energy Use Index — *From EUI Worksheets =* [Box 2-A]

Energy Star Portfolio Manager — *From Energy Star Website =* [Box 2-B]

maximum score = 100

Occupant Satisfaction = [Box 3]

maximum score = 100

Occupant Satisfaction — *From Occupant Survey*

Building Performance Walk-Through = [Box 4]

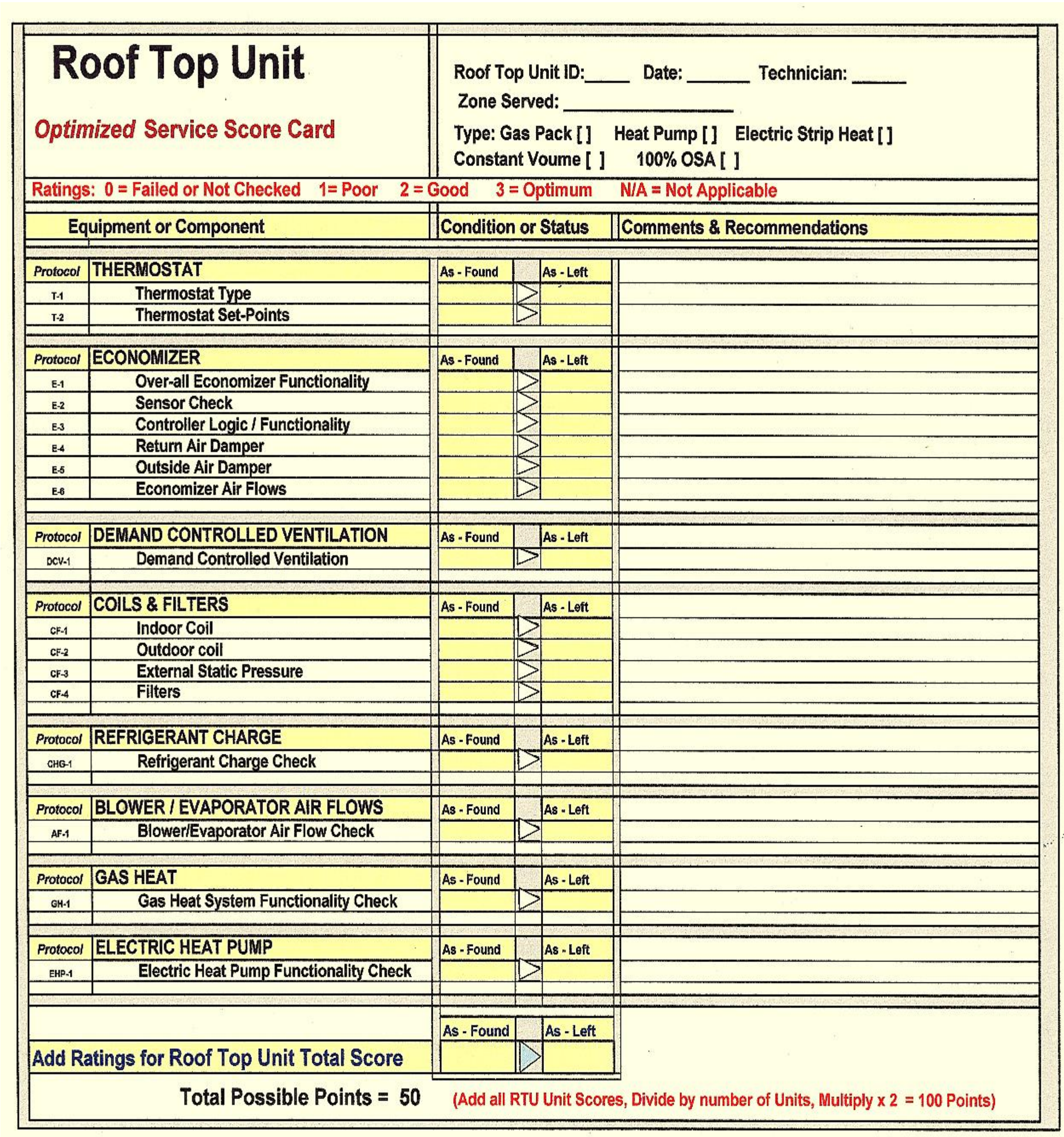
maximum score = 100

Building Walk-Through Assessment — *From Walk-Through Checklist*

Figure 1. Building Performance Summary Report

4.2 ROOF TOP UNIT SCORE CARD AND PROTOCOLS: RATING PARAMETER #1

A concise one-page "Roof Top Unit *Optimized* Service Score Card" (RTU Score Card) was created (Figure 2). In practice, each RTU HVAC system is evaluated in terms of initial ***As-Found*** condition and functionality, and these scores assigned on the RTU Score Card. Subsequent to the O&M service provider's inspection, service, adjustment, and repair, each RTU unit is again scored in terms of the ***As-Left*** condition.



Roof Top Unit

***Optimized* Service Score Card**

Roof Top Unit ID:____ Date: ______ Technician: ______
Zone Served: ________________
Type: Gas Pack [ ] Heat Pump [ ] Electric Strip Heat [ ]
Constant Voume [ ] 100% OSA [ ]

Ratings: 0 = Failed or Not Checked 1= Poor 2 = Good 3 = Optimum N/A = Not Applicable

	Equipment or Component	Condition or Status		Comments & Recommendations
Protocol	**THERMOSTAT**	As - Found	As - Left	
T-1	Thermostat Type			
T-2	Thermostat Set-Points			
Protocol	**ECONOMIZER**	As - Found	As - Left	
E-1	Over-all Economizer Functionality			
E-2	Sensor Check			
E-3	Controller Logic / Functionality			
E-4	Return Air Damper			
E-5	Outside Air Damper			
E-6	Economizer Air Flows			
Protocol	**DEMAND CONTROLLED VENTILATION**	As - Found	As - Left	
DCV-1	Demand Controlled Ventilation			
Protocol	**COILS & FILTERS**	As - Found	As - Left	
CF-1	Indoor Coil			
CF-2	Outdoor coil			
CF-3	External Static Pressure			
CF-4	Filters			
Protocol	**REFRIGERANT CHARGE**	As - Found	As - Left	
CHG-1	Refrigerant Charge Check			
Protocol	**BLOWER / EVAPORATOR AIR FLOWS**	As - Found	As - Left	
AF-1	Blower/Evaporator Air Flow Check			
Protocol	**GAS HEAT**	As - Found	As - Left	
GH-1	Gas Heat System Functionality Check			
Protocol	**ELECTRIC HEAT PUMP**	As - Found	As - Left	
EHP-1	Electric Heat Pump Functionality Check			
	Add Ratings for Roof Top Unit Total Score	As - Found	As - Left	

Total Possible Points = 50 (Add all RTU Unit Scores, Divide by number of Units, Multiply x 2 = 100 Points)

Figure 2. RTU Score Card

Three-Step Method

The rating system provides a three-step method to determine RTU scores:

Step 1: *Complete a separate RTU Score Card for each Roof Top Unit*

Step 2: *Calculate total score (add all Roof Top Unit scores, divide by total number of units, multiply by 2)*

Step 3: *Enter total score for Optimized Roof Top Unit O&M in Summary Report (Box 1)*

A maximum score of 50 represents an optimized unit. The scoring was designed to be as simple and easy as possible, resulting in a scoring range of 0 to 3 for most of the RTU elements (a number of more complex scoring systems were considered, but ultimately deemed too complicated and unnecessary). Since most small- to medium-size office buildings will often have more than one RTU unit, scores for all units are added together. The resulting total score from all units is divided by the number of RTU units, then multiplied by two to produce a final composite score for all the building's RTU systems. A maximum total score of 100 is possible and is reported in the Summary Report. A quick review of each completed Score Card identifies which units are optimized and which units need additional service, adjustment, or repair as described in the "Comments" section.

The RTU individual score cards provide a historical record of each unit's service, functionality, and condition over time. Both contractor and client can easily track individual RTU equipment conditions and performance over time allowing meaningful negotiations toward effective services to ensure optimized equipment performance and reliability. Higher scores reflect quality O&M services and functionality of equipment, while trends toward lower scores promote discussions for additional services, repairs, interventions and equipment upgrades or replacement.

The purpose of the RTU Score Card is to enable *optimized* services and document performance. Routine and basic industry "good practices" such as lubrication, belts, drains and condensate lines, cleanliness, filters, etc. are prerequisites and are assumed as being performed. Given the absence of a universally accepted set of routine "industry standard" maintenance guidelines and protocols for RTUs, the O&M contractors are encouraged to continue to use their current checklists and service protocols to meet these basic tasks. Additionally, these contractor checklists for basic and routine services are necessarily regionally and seasonally different, and thus beyond the scope of this project.

The RTU Score Card is used for each RTU, providing a quantified assessment of the condition and functionality for eight critical performance areas: These eight performance areas were chosen through a process of elimination using matrix that allowed the advisory members to rank a broad list of possible performance areas in terms of relative importance. It was agreed that these are areas that are either commonly overlooked, insufficiently checked, or not included in many "routine" O&M service agreements.

1. Thermostat
2. Economizer
3. Demand Controlled Ventilation
4. Coils and Filters
5. Refrigerant Charge
6. Blower/Evaporator Air Flows
7. Gas Heat

8. Electric Heat Pump

To standardize the scoring for the RTUs, O&M service technicians are provided with a two-page "Roof Top Unit *Optimized* O&M Protocols and Scoring" sheet (RTU Protocols, Figure 3) matched to the RTU Score Card The RTU Protocols provide servicing and scoring guidance for each specific element under the eight performance areas. For example, if an element is not inspected, or is non-functional, a score of "0" is assigned. Increasing levels of functionality are assigned higher scores — up to a score of "3". These higher scores are assigned according to the protocols and scoring guidance provided. Increased scores can be attained from adjustments, repair or replacement of components, and are reflected in the As-Left score. More extensive scoring of "0" through "10" was discussed but judged as too complicated and unnecessary. It is expected that O&M service providers will be able to quickly determine and record these scores onto the one-page RTU Score Card for each unit.

Space is provided on the RTU Score Card for comments and recommendations to document condition and functionality for each element. This documentation is a record of service details and informs the building owner/manager of functionality and recommendations for energy, reliability, and performance interventions and/or upgrades. Technical resources, specific guidance and methodology can be developed and added to complete these protocol and scoring documents.

Roof Top Unit

Page 1

Optimized O&M Protocols and Scoring

Component Protocols and Scoring Guidance

Thermostats and Set-Points

T-l	Scoring	Thermostat Type (assumes commercial stat installed; if not, must install. Heat pumps must have heat pump T-Stats)
	0	does not work
	1	Functions but only has 1 stage cooling
	2	Has 2 stages cooling and wired correclty on roof
	3	2 stages cooling and morning warmup feature available
T-2	Scoring	Thermostat Set-Points
	0	not checked
	1	checked only and noted problems; did not adjust
	2	adjusted heating/ coolign setpoints/schedules
	3	same as previous plus enabled morning warmup

Economizer

E-1	Scoring	Over-all Economizer Functionality
	0	not checked
	1	does not function; two or more components bad but repairable
	2	does not function; one or more components bad but repairable
	3	all functions operate
E-2	Scoring	Sensor Checkout
	0	not checked
	1	presence of outside, mixed, return (if installed) sensors confirmed
	2	sensor output checked vs expected values
	3	sensors agree to within 5% of expected and/or bad sensor(s) replaced
E-3	Scoring	Controller Logic / Functionality
	0	not checked
	1	minimum air or change-over works; other function does not (replace)
	2	works OK; *cannot* support DCV
	3	works OK; *can* support DCV
E-4	Scoring	Return Air Damper
	0	not checked
	1	disconnected, broken, non-fuctioning
	2	binding, not full stroke, greater than 20% leakage
	3	fixed damper; closes fully
E-5	Scoring	Outside Air Damper
	0	not checked
	1	disconnected, broken, non-fuctioning
	2	binding, not full stroke
	3	fixed binding damper
E-6	Scoring	Economizer Airflows
	0	not checked
	1	damper positions as expected (equals "visual check" of min and max airflows)
	2	measured at least one air flow using approved method
	3	measured both flows using approved method; adjusted as needed

Demand Controlled Ventilation

DCV-1	Scoring	Demand Controlled Ventilation
	N/A	DCV System Not Installed
	0	not checked
	1	pass/fail sensor check (responds when exposed to CO_2)
	2	sensor checks out; system performs as designed

Roof Top Unit

Page 2

Optimized O&M Protocols and Scoring

Coils and Filters		
CF-1	Scoring	Indoor Coil (Cleaning of evaporator coils improves capacity)
	0	not checked
	1	checked for major blockages; not cleaned
	2	major soil removed with air or water
	3	cleand with approved coil cleaner
CF-2	Scoring	Outdoor Coil
	0	not checked
	1	checked for major blockages; not cleaned
	2	major soil removed with air or water
	3	cleaned with approved coil cleaner
CF-3	Scoring	External Static Pressure
	0	not checked
	1	checked to make sure all registers open and return grilles not blocked
	2	checked ESP; found <nameplate (or 1" WC if no nameplate for standard blower)
	3	checked ESP; found <1" WC for standard blower; fixed problem(s) contrib. to high ESP
CF-4	Scoring	Filters (Replace as needed for normal PM before testing)
	0	no filter
	1	significant by-pass
	2	high static or other problem; no significant bypass
	3	correct type & tight fit. Pressure Drop OK
Refrigerant Charge		
CHG -1	Scoring	Check Refrigerant Charge
	0	not checked
	1	checked in cooling or heating modes (heat pump) using temperature split method
	2	checked using superheat / subcooling method
	3	checked using superheat / subcooling method; adjusted charge
Blower/Evaporator Air Flow		
AF-1	Scoring	Blower/Evaporator Air Flow
	0	blower / flow not checked
	1	checked amp draw and compared to expected value
	2	adjusted/replaced blower belts as indicated
	3	measured/adjusted airflow with approved method
Gas Heat		
GH -1	Scoring	Functionality (Basic safeties *MUST* be checked and replaced as needed as part of testing.)
	0	not checked
	1	checked ignition sequence of operation; unit fires and runs for at least 5 minutess
	2	as above; *and* temp rise in expected range
	3	as above; *and* combustion efficiency checked; burners cleaned and/or gas valve pressure adjusted
Electric Heat/Heat Pump		
EHP-1	Scoring	Functionality
	0	not checked
	1	Sequence of ops ok; compressor-only operation on Stage 1 heating (HP)
	2	temp rise as expected; make any needed repairs to heating side
	3	check heat pump charge (operating pressures vs targets); remove strip heat operation from stage 1 heating as needed

Figure 3. RTU Protocols

4.3 Building Energy Performance: Rating Parameter #2

The project recognized the critical importance of rating a specific building in terms of energy usage. Energy use trending and indexing provides the owner/manager and the O&M service provider with a useful benchmark of the building's energy performance relative to similar buildings. When the building's energy performance is coupled with the scores from the HVAC equipment, occupant satisfaction, and walkthrough assessment, then targeted services and upgrades can be strategically discussed and implemented.

The rating system promotes the use of the Environmental Protection Agency's (EPA) Energy Star *Portfolio Manager* to obtain a useful energy performance benchmark. The project selected *Portfolio Manager* because it is one of the most widely known and available benchmarking system for commercial buildings. For users who would prefer not to use the web-based Energy Star program, we also provide a streamlined Energy Use Index (EUI) Worksheet. The building's energy use index value can be calculated manually, or more easily calculated using the electronic worksheet provided. Either the Energy Star or simplified EUI approach is acceptable, and can be completed by the O&M contractor or owner/manager with no specialized training required.

Three-Step Method

The rating system provides a three-step method to calculate building energy performance (compared to similar buildings), which is applicable to Energy Star or EUI methods:

Step 1: *Collect basic building parameters and previous energy usage from utility records.*

Step 2: *Compare your building's energy performance to similar buildings through either the Energy Use Index worksheet or the U.S. EPA Energy Star Portfolio Manager web-based program.*

Step 3: *Enter the results from the EUI worksheet or the Energy Star Portfolio Manager on the Building Performance Summary Report (Box 2).*

Energy Star Portfolio Manager

While the rating system provides an alternative EUI method, we encourage use of the U.S. Environmental Protection Agency's (EPA) Energy Star *Portfolio Manager*. According to the EPA, the Energy Star *Portfolio Manager* is "*A user-friendly, secure, and powerful web-based program for all types of commercial and institutional buildings to track and benchmark energy use over time.*"

The program is available free at https://www.energystar.gov/istar/pmpam/. Users are required to register with a self-selected Username and Password and then provide the necessary data as requested.

Some buildings can benchmark energy usage relative to a national population of similar buildings using a scale of 0 to 100:

> A rating of 50 indicates that the building, from an energy consumption standpoint, performs better than 50% of all similar buildings nationwide, while a rating of 75 indicates that the building performs better than 75% of all similar buildings nationwide. Similar peer groups of buildings across the nation are identified by the Commercial Building Energy Consumption Survey (CBECS) conducted by the U.S. Department of Energy.

To receive an energy performance rating, users must enter data from energy meters that account for all of the building's energy use (all fuel types). This data must include at least 11 consecutive calendar months of energy data for all active meters — for multiple meters, data must be for 11 consecutive and overlapping months.

Additional key operating characteristics are also needed for each building space. These characteristics ensure your building falls into an operation pattern consistent with a peer group of buildings used for the performance comparison. Key characteristics include (some exceptions apply):

- Building must be at least 5,000 square feet gross
- Need to enter at least 11consecutive months of data for all operation characteristics
- Must be in operation at least 30 hours per week
- Must contain at least one personal computer or cash register
- Each space must contain at least one worker during main shift

Figure 4 provides a list of input values to facilitate data collection and entry into *Portfolio Manager*.

ENERGY STAR PORTFOLIO MANAGER – BASIC INPUTS

Building Name: ______________________________
    Address ___________________________ City/State/Zip ____________________
    Year Built ______
    Brief history of remodel/additions/renovations
    ____
Type of facility
    Single facility with ownership or management of 90% more of space? ____ %
    Portion of single facility with ownership or management of less than 90% of space?
    Owner % _____ Other % _____
Space Use
    Gross floor area ___ (sq ft)
    Weekly operating hours ___
    Workers on main shift ___
    # PCs ___
    % of space with air conditioning ___%
    % of space with heating ___%
Energy Usage
    What types of energy does the facility use? ________________________________
    How many meters? ____

Provide at least eleven consecutive months of energy use data

Energy Meters

1) Meter name ____________________
Serves entire facility? Yes ___ No ___
Space Identifier ___________________
Energy Type _____________________
Energy Units ____________________

2) Meter name ____________________
Serves entire facility? Yes ___ No ___
Space Identifier ___________________
Energy Type _____________________
Energy Units ____________________

3) Meter name _________________________
Serves entire facility? Yes ___ No ___
Space Identifier ___________________
Energy Type _____________________
Energy Units ____________________

4) Meter name _________________________
Serves entire facility? Yes ___ No ___
Space Identifier ___________________
Energy Type _____________________
Energy Units ____________________

Note spaces for parking lots if on main meter – open or enclosed
Note computer centers

Water Meter –

How many water meters? _____
Type: Indoor ____ Outdoor ____

Figure 4. Energy Star *Portfolio Manager* – Basic Inputs

Energy Use Index Calculator

A basic, easy-to-use spreadsheet program is provided for those who would prefer not to use the web-based Energy Star *Portfolio Manager* program. The user needs to enter only eight input values in spaces provided and the spreadsheet automatically calculates the EUI. This streamlined tool produces a basic energy usage value represented in Thousands of BTU (British Thermal Units) per square foot on an annual basis. While not as powerful as the *Portfolio Manager,* this is an easy and useful tool and is provided as an option. An example of the EUI spreadsheet worksheet calculator is provided in Figure 5.

Figure 5 EUI Worksheet

Energy Use Index Calculator - Advanced *(example)*

Values for Principal Activity Code and Building Square Footage are required. Other values are optional (enter '0' if the value is unknown)

To find numbers for Principal Activity Code and Census Region and Division, use the drop-down menus under Choices or find in lists below.
Enter these numbers in the Survey Values column

Weighted Total (EUI x SF)

Survey Categories	Survey Values		FACTOR	Choices (Use Drop Down Menus or select from lists below)	Avg:
Principal Activity Code (required)*	4		242.90	Inpatient: 5	109.5
Open Hours per week	168		1.42		
Building Square Footage (required)*	200,000		1.00		
Number of Computers	100		1.01		
Year Constructed	1950		0.94		
Census Region and Division	13		0.67	Pacific: 13	

TOTAL FACTOR	0.90	
TOTAL ENERGY USAGE	43,483	Million Btus per year
ENERGY USAGE INDEX	217.4	Thousand Btus per square foot per year

Principal Building Activity
Education: 1..
Food Sales: 2..
Food Service: 3 ....
Health Care: 4 ....
Inpatient: 5 ....
Outpatient: 6 ....
Lodging: 7 ....
Retail (Other Than Mall): 8..
Office: 9 ....
Public Assembly: 10 ....
Public Order and Safety: 11 ....
Religious Worship: 12 ....
Service: 13 ....
Warehouse and Storage: 14 ....
Other: 15 ....
Vacant: 16 ....

Census Region and Division
Northeast: 1 ....
New England: 2 ....
Middle Atlantic: 3 ....
Midwest: 4 ....
East North Central: 5 ....
West North Central: 6 ....
South: 7 ....
South Atlantic: 8 ....
East South Central: 9 ....
West South Central: 10 ....
West: 11 ....
Mountain: 12 ....
Pacific: 13 ....

Figure 5. Energy Use Index Worksheet

4.4 OCCUPANT SURVEY OF BUILDING PERFORMANCE: PARAMETER #3

A concise two-page occupant satisfaction survey was developed. The "Occupant Rating of Building Performance" (Occupant Survey, Figure 6) provides a subjective assessment of a building's performance from the occupant's perspective. Even a well maintained and operated HVAC system is not totally optimized unless it results in satisfied occupants (increased productivity is assumed). Ultimately, buildings are for the use of the people that occupy them, and user feedback is a valuable performance measure. The project recognizes the importance of both occupancy feedback and the more detailed technical (quantitative) building performance walk-through assessment (Parameter #4). The Occupant Survey can be distributed electronically or in hard copy to occupants.

OPERATION & MAINTENANCE
SERVICE RATING PROGRAM

OCCUPANT RATING OF BUILDING PERFORMANCE

BUILDING NAME: ______________________ Date: ______________

Please provide your rating of this building's performance by circling the number that best fits your experiences. Your feedback will help improve the Operation & Maintenance of the building and building systems.

Please rate the following:

COMFORT

In terms of the overall comfort of my work area, I am:

5	4	3	2	1
Very Satisfied	*Satisfied*	*Somewhat Satisfied*	*Unsatisfied*	*Very Unsatisfied*

In terms of the temperature in my work area, I am:

5	4	3	2	1
Very Satisfied	*Satisfied*	*Somewhat Satisfied*	*Unsatisfied*	*Very Unsatisfied*

If unsatisfied with the temperature in my work area, I am able to:

5	4	3	2	1
Adjust thermostat	*Adjust doors*	*Add /remove clothing*	*open /close windows*	*Block /unblock a register*

In terms of the movement of air in my work area, I am:

5	4	3	2	1
Very Satisfied	*Satisfied*	*Somewhat Satisfied*	*Unsatisfied*	*Very Unsatisfied*

In terms of the humidity in my work area I am:

5	4	3	2	1
Very Satisfied	*Satisfied*	*Somewhat Satisfied*	*Unsatisfied*	*Very Unsatisfied*

I would be more satisfied with the comfort in my work area if I were able to:

5	4	3	2	1
Adjust thermostat	*Adjust air currents*	*Open window*	*Use a personal fan*	*Use a space heater*

ODORS:

In terms of odors in my work area , I am:

5	4	3	2	1
Very Satisfied	*Satisfied*	*Somewhat Satisfied*	*Unsatisfied*	*Very Unsatisfied*

(Occupant Rating, page 1)

NOISE:

In terms of the overall level of noise in my work area, I am:

5	4	3	2	1
Very Satisfied	*Satisfied*	*Somewhat Satisfied*	*Unsatisfied*	*Very Unsatisfied*

In general, I am most satisfied when the noise level in my work area is:

5	4	3	2	1
Very quiet	*Somewhat quiet*	*Neither quiet nor loud*	*Somewhat loud*	*Very loud*

When the noise level is not acceptable, the noise that adversely affects me is:

5	4	3	2	1
Co-workers talking	*Printer/copier*	*Outdoor noise*	*Lights*	*Air System*

When unsatisfied with the noise level, I am:

5	4	3	2	1
Not distracted at all	*Mildly distracted*	*Somewhat distracted*	*Mostly distracted*	*Very distracted*

LIGHTING:

In terms of the lighting in my work area, I am:

5	4	3	2	1
Very Satisfied	*Satisfied*	*Somewhat Satisfied*	*Unsatisfied*	*Very Unsatisfied*

I believe the biggest problem with lighting in my work area is:

5	4	3	2	1
Too dim	*Too bright*	*Glare*	*Lighting "Quality"*	*Inadequate control/switches*

When unsatisfied with the lighting, I am:

5	4	3	2	1
Not distracted at all	*Mildly distracted*	*Somewhat distracted*	*Mostly distracted*	*Very distracted*

GENERAL COMMENTS:

How does the performance of the building in your area impact your job productivity:

5	4	3	2	1
Enhances productivity	*Promotes productivity*	*Somewhat promotes productivity*	*Somewhat hinders productivity*	*Hinders productivity*

Briefly describe your overall perception of how the performance of the building meets your needs:

____

In what part of the building do you work, or spend most of your time: ______________________________

____

Briefly describe how the staff responsible for the Operations & Maintenance of the building respond to your comfort or other issues: ______________________________

____

Other comments regarding how the building impacts your ability to do your work ______________________________

____

____

(Occupant Rating, page 2)

Figure 6. Occupant Survey

The survey provides useful insights to the O&M service provider, the walk-through assessment individual or team, and the building owner/manager. These insights into the performance of a building are generally not currently revealed to a building owner/manager in a standardized manner, and rarely provided to an outsourced O&M contractor. Survey elements include comfort, lighting, noise, odors, and impacts on productivity. Building occupants provide satisfaction ratings (on a scale of 1 to 5) for one or more questions within each of these elements. The overall occupant rating is based on a compilation of the scores for each element. Beyond generating a standardized 100 point score, the survey also provides the building owner/manager and the O&M contractor with occupant feedback on overall building performance and in terms of actions occupants take in response to real or perceived deficiencies. For example, when occupants become uncomfortable they may respond through the use of space heaters or fans, adjust thermostats, block diffusers, or take other actions that can often negatively impact building performance. These occupant actions (reactions) suggest deficiencies with the building's HVAC system. This information allows more energy efficient corrective actions by the owner/manager and/or O&M contractor, and reduces the need for occupants to take individual actions.

An "Occupant Survey Score Card" (Figure 7) is provided to assist in tallying and presenting the survey results and occupant comments. The score card can be completed manually or by using an electronic spreadsheet version that automatically tallies the responses and produces a total score. A brief summary of occupant responses to four open-ended questions provides the building owner/manager and the O&M contractor with insights into the building performance.

The rating system provides a three-step approach for determining an occupant satisfaction score:

Three-Step Method

> ***Step 1:*** *Distribute the Occupant Survey via email or hard copy (explain that this is a voluntary, proactive approach toward energy efficiency, sustainability, occupant satisfaction, indoor environment, and productivity).*
>
> ***Step 2:*** *Collect surveys, tally the responses and determine scores for key criteria using the Occupant Survey Score Card.*
>
> ***Step 3:*** *Enter the occupant survey score on the Building Performance Summary Report (Box 3).*

Occupant Survey Score Card

Building: ____________________

Survey Date (s) : ____________

Enter total number of responses for each rating category for each key question listed below

Note: questions not scored can also provide useful information

Category	Key Questions	Rated 5 (Very Satisfied)	Rated 4 (Satisfied)	Rated 3 (Somewhat Satisfied)	Rated 2 (Dissatisfied)	Rated 1 (Very Dissatisfied)	Average Rating
COMFORT							
C-1	*Overall Comfort*						
C-2	*Temperature*						
C-3	*Temperature Actions*	N/A	N/A	N/A	N/A	N/A	
C-4	*Air Movement*						
C-5	*Humidity*						
C-6	*Comfort Actions*	N/A	N/A	N/A	N/A	N/A	
ODOR							
O-1	*Odors*						
NOISE							
N-1	*Noise Level*						
N-2	*Noise Preference*	N/A	N/A	N/A	N/A	N/A	
N-3	*Noise Type*	N/A	N/A	N/A	N/A	N/A	
N-4	*Noise Impacts*	N/A	N/A	N/A	N/A	N/A	
LIGHTING							
L-1	*Lighting Satisfaction*						
L-2	*Lighting Problems*	N/A	N/A	N/A	N/A	N/A	
L-3	*Lighting Impacts*	N/A	N/A	N/A	N/A	N/A	
GENERAL							
GC-1	*Productivity*						

Sub-total = ______

Total Occupant Survey Score = ______

(maximum score = 100)

Enter Total in BOX 3 Summary Report

Summarize written responses in General Comments section for the following key parameters

GC-2 *Overall Perception Comments:*

GC-3 *Where do you work in building:*

GC-4 *Operations & Maintenance staff responsiveness:*

GC-5 *Building impacts on ability to do work:*

Figure 7. Occupant Survey Score Card

4.5 BUILDING PERFORMANCE WALK-THROUGH ASSESSMENT: PARAMETER #4

As has been mentioned, the performance of a particular building should be assessed on a number of levels. A building's design and construction details as well as the day-to-day operation and activities in the building can have a significant impact on energy usage, comfort, and occupant satisfaction. The project developed a "Building Performance Walk-Through Assessment" tool (Walk-Through Checklist, Figure 8). This tool is designed to be used by an O&M contractor or other technician with a fundamental knowledge of building science and energy.

The energy savings potential from walk-through assessments is often limited, and the bottom-line impacts of comfort, productivity and occupant satisfaction can be difficult to calculate. Therefore, detailed and technical audits are generally not justified on a cost-benefit basis. In spite of the relatively limited "payback," understanding the details of how a building is performing and is being operated is an important element toward optimization. Focusing and limiting this effort delivers the greatest benefit.

To fill this need, the walk-through assessment is intended to pick the "low-hanging fruit" of energy savings and equipment function, be conducted in an hour or less, and employ the technical skills of a practicing O&M technician. Unique benefits are realized through the process of the O&M technician observing first-hand the delivered performance of the HVAC equipment and the opportunity to discuss issues with the owner/manager and occupants. The Walk-Through Checklist includes ten categories and is scored on a 0 to 10 Lykert Scale. The scoring methodology is designed to provide the building owner/manager with a set of relative values that indicate areas where savings can be realized, other improvements can be made, or where more study is needed

The walk-through team or individual is encouraged to summarize observations, measurement results, and comments into a brief report with suggestions for improvements or additional study. Comments and recommendations might include specific recommendations for more efficient operation, additional checks or measurements that are needed, or additional services from a specialist that may be indicated.

Three-Step Method

The rating system provides a three-step approach to assess the building's performance based on a walk-through assessment:

> ***Step 1:*** *Review the RTU score and the Building Energy Performance score, and study the Occupant Survey results.*
>
> ***Step 2:*** *Using the Walk-Through Checklist as a guide, conduct a building performance walk-through assessment, score conditions, and note issues needing additional study.*
>
> ***Step 3:*** *Add Walk-Through Checklist scores and enter the result on the Building Performance Summary Report (Box 4).*

This parameter was assigned and developed late in the project and should be considered as a basic model toward the future development and refinement of an industry-standard assessment tool. Creating a meaningful scoring method for this parameter – as was accomplished for the other parameters – requires significant trial and error refinement.

Building Performance Walk-Through Assessment

TOTAL SCORE = [ ]

(add all scores below)

Building: ______________________ Date & Time: __________________ Technician: _______________

Zones: __________________________ Conditions: [ ] heating [ ] cooling [ ] econo

1 Building Envelope & Ducts

[ ]	Walls, Ceilings, Floors	Note air leaks, insulation, solar insolation, etc.
[ ]	Windows & Doors	Note air leaks, solar insolation, U-Value, Reflectance
[ ]	Ducts	Ducts outside thermal envelope - check sealing and insulation
		Other duct leakage and ceiling plenum returns

Not Checked			Poor		Average		Very Good			Excellent
0	1	2	3	4	5	6	7	8	9	10

Explain scoring and provide recommendations

2 Thermostats

[ ]	Thermostat location and nearby heat sources	proper sensing location and no heat/cooling influences
[ ]	Time and date OK ?	
[ ]	Set Points - check & record	verify T-stat accuracy
[ ]	2-Stage cooling with economizer	
[ ]	Outside Air Sensor	compare sensor reading to actual outside temperature

Not Checked			Poor		Average		Very Good			Excellent
0	1	2	3	4	5	6	7	8	9	10

Explain scoring and provide recommendations

3 Comfort

Use ASHRAE 55 as guidance

[ ]	Air Temperatures @ occupied zones	consider surface temperatures
[ ]	Air velocity - occupied zone - 35-75 fpm OK	measure air speed (feet per minute) at occupied zone
		> 75 fpm @cooling - check with occupants
[ ]	Relative humidity	consider surface dew-point temperatures - avoid molds

Not Checked			Poor		Average		Very Good			Excellent
0	1	2	3	4	5	6	7	8	9	10

Explain scoring and provide recommendations

4 Carbon Dioxide Breathing Zones

compare to outside air - follow ASHRAE 62-1 Guidelines

[ ]	Breathing Zone > 1,400 Poor	insufficient outside air exchange
[ ]	Breathing Zone 1,000 -1,200 inadequate	border-line outside air exchange
[ ]	Breathing Zone 800- 1,000 Fair	adequate outside air exchange
[ ]	Breathing Zone 600-800 Normal -	good outside air exchange
[ ]	Breathing Zone 400-600	over-ventilated or economizer "on"

Not Checked			Poor		Average		Very Good			Excellent
0	1	2	3	4	5	6	7	8	9	10

Explain scoring and provide recommendations

5 Supply Air Diffusers

[ ]	proper location and configuration	delivers comfort and fresh air to occupied zone
[ ]	proper velocity and "throw"	provides proper air mixing & velocities in occupied zone
[ ]	quiet	use decibel meter and compare to guidelines
[ ]	clean	
[ ]	Supply Air CO2 Concentrations	Indicator of Outside Air fraction & economizer

Not Checked			Poor		Average		Very Good			Excellent
0	1	2	3	4	5	6	7	8	9	10

Explain scoring and provide recommendations

6	**Return Air Grills**	
	location OK	check for possible short-circuiting of supply air using CO2 meter
	size OK	check zone pressure for proper supply vs. return balancing
	clean	
	Return Air Concentrations	Indicator of short-circuiting of supply air

Not Checked			Poor		Average		Very Good			Excellent
0	1	2	3	4	5	6	7	8	9	10

Explain scoring and provide recommendations

7	**Exhaust Fans & Pressures**	
	check all exhaust fans	proper flow rates (CFM) and pressure differentials in zone
		noise, vibration
	exhaust fan controls	determine desired on/off schedules
		automatic controls warranted? (occupancy, timers, etc.)
	Pressures: Indoors vs. Outdoors	positive DP inside vs outside suggests economizer operation
		Negative inside vs outside suggests supply air duct leakage
	Pressures: Zone to Zone	Zones with indoor air pollutants need to be negative pressure

Not Checked			Poor		Average		Very Good			Excellent
0	1	2	3	4	5	6	7	8	9	10

Explain scoring and provide recommendations

8	**Lighting**	Use Illuminating Engineering Society guidance
	Note excessive or insufficient lighting	use Footcandle meter - refer to guidelines
	Note lighting controls issues	unnecessary lighting, lights on after hours, excessive lighting
	Identify incandescent lamps	visual or hand-held sensor
	identify magnetic ballast lamps	hand-held sensor

Not Checked			Poor		Average		Very Good			Excellent
0	1	2	3	4	5	6	7	8	9	10

Explain scoring and provide recommendations

9	**Office Equipment & appliances**	
	Computers and Monitors	note Energy Star rated, standby settings, on/off schedules
	Photo copiers	note Energy Star rated, standby settings, on/off schedules
	Printers	note Energy Star rated, standby settings, on/off schedules
	space heaters	investigate HVAC deficiencies, surface temperature issues
	personal fans	investigate HVAC deficiencies, surface temperature issues
	air cleaners, deodorizers, candles	Investigate particulate and/or odor sources (no ozone devices)
	galley or personal refrigerators	note usage, settings, clean coils, adequate air flow
	vending machines	note usage, timers or automatic controls
	Other	

Not Checked			Poor		Average		Very Good			Excellent
0	1	2	3	4	5	6	7	8	9	10

Explain scoring and provide recommendations

10	**Building Equipment**	
	water heaters	measure water temperatures, evaluate usage patterns
		consider tankless "demand" options
		evaluate tank & pipe insulation & anti-thermosiphon control
		check adequate combustion air and zone pressures
		carbon monoxide alarm installed and functioning
	Pumps	short cycling, operating "off-cycle"?
	compressors	air leaks, short cycling

Not Checked	Poor	Average	Very Good	Excellent

Explain scoring and provide recommendations

Figure 8. Walk-Through Checklist

4.6 ADVANCED BUILDING PERFORMANCE MANAGEMENT: PARAMETER #5

Building owners/managers do not always recognize the value of investing in improved building performance for energy efficiency, occupant satisfaction, and reliability of HVAC systems. Too often, building operation and maintenance is seen simply as a cost of doing business and a line-item to be addressed at the least possible cost.

The project developed a set of “Advanced Building Performance Management Measures” that address effective building management (Figure 9). Best practices management elements were identified that provide information and documentation that support and verify improved building performance management – these were refined and compiled into seven categories:

1. Energy audit
2. O&M Service Provider Training
3. Building Operator Certification Training
4. Operating Plan, System Narrative, PM Narrative
5. Documenting Building Cost Impacts
6. Existing Building Tune-Up (retro-commissioning)
7. System Level Monitoring

Each of the proposed building management elements includes a statement of “intent” and a brief explanation of the “requirements” necessary for implementation. Most of these elements are LEED prerequisites or LEED eligible.

As the rating system was developed, we initially proposed a couple of scoring methods for this parameter. Ultimately it was determined that an effective scoring method did not fit in the rating system as these seven elements are recommendations rather than performance measures. Another difficulty with scoring is the fact that implementation of these measures generally encompasses a wide time frame, often in terms of years, making tracking and trending difficult.

A three-step process for determining and presenting the Advanced Building Performance Management scores was also proposed. This is provided below for information purposes, in spite of the fact that a score is not reported. As the rating system is further developed, a practical scoring method may ultimately be created.

> ***Step 1**: Review the rating scores from the Building Performance Summary Report and the findings from the Occupant Survey and the recommendations from the walk-through assessment.*
>
> ***Step 2:** Review “Advanced Building Performance Management Measures” options 1-7 with qualified experts to determine which options may result in the greatest potential to improve building performance.*
>
> ***Step 3:** Implement and document the selected options as they are completed.*

Advanced Building Performance Management Measures		
Category	1	Energy Audit *Intent*....Conduct a building energy audit to identify opportunities for energy savings. *Intent*....Conduct a building and site lighting audit to identify opportunities for ....Lighting quality improvements and energy savings. ....LEED EB prerequisite and credit *Requirements*....Conduct a building energy audit using ASHRAE Level 1 or 2 ....Conduct a lighting audit - [a lighting audit only can be performed for partial credit]
	2	Training: O&M Service Provider Training *Intent*.... Continuing education and skills development for O&M service providers. ....High performance building. ....LEED EB eligible *Requirements* ...O&M service providers complete the Builder Operator Certification training or ....become a LEED Accredited Professional. ....Level 2 energy survey and analysis approaches.
	3	Training: Builder Operator Certification *Intent* ...This training is design for in-house operations and maintenance staff and ....building managers. The course work is designed to address all major facets of ....building performance. LEED Accredited Professional *Intent* ...Develop the capability of facility staff to operate and maintain a ....high performance building. ....LEED EB eligible *Requirements* ...In-house O&M Staff complete the Builder Operator ....Certification training or attain a LEED Accredited Professional. ....Level 2 energy survey and analysis approaches.
	4	Operating Plan, System Narrative, PM Narrative *Intent* ...Ensure up-to-date building operation and maintenance documentation exists. ....LEED EB prerequisite. *Requirements* ...Check documentation describing system operation, system descriptions, ...preventive maintenance and update as needed.
	5	Documenting Building Cost Impacts *Intent*....Document building operation and maintenance costs to identify the ....benefits of adopting best practices. ....LEED EB eligible *Requirements* ...Track utility costs and other costs for operating and maintaining the building.
	6	Existing Building Tune-Up (Retro-commissioning) *Intent*.... Implement a process to ensure the major building energy systems are operating .... in a manner that meets occupant needs and optimizes energy performance. ....LEED EB eligible *Requirements*.... Existing building commissioning is a multi-step process that includes an ....investigation, implementation, and ongoing phase
	7	System Level Monitoring *Intent*.... Collect energy use information for major building systems to inform operation ....and maintenance practices. ....LEED EB eligible *Requirements* ...Use a building automation system (control system) or stand-alone metering to ....collect energy use information for major building systems.

Figure 9. Advanced Building Performance Management Measures

5. DISCUSSION

5.1 BACKGROUND

This project was a creative, concept approach developed to provide a practical method to rate building performance. The building performance ratings developed are essential for reporting and tracking actual building performance. Building performance metrics can be contrasted to the commonly available lists of practices, interventions, and/or upgrades. Adopting and implementing upgrades may or may not result in improved performance. Incorporating performance metrics, along with improved practices and upgrades, provides a method to evaluate the effectiveness of efficiency efforts, and continued tracking of performance.

This pilot project pursued various approaches to offer creative alternatives to current O&M practice. Markets are complex, driven by many factors and if change were obvious or easy it would likely occur with limited outside encouragement. Change often takes persistence, the application of multiple approaches, is generally non-linear, and the human element of "cultural change" is often a major barrier.

Currently, the small- to medium-size office and retail building market sector is dominated by customers looking for the lowest available cost for O&M services. When customers purchase services based solely on lowest cost, and absent of specifications, this drives competition down to a level where delivery of quality services is no longer competitive. This "race to the bottom" environment results in services often characterized as "breakdown" maintenance or "emergency" maintenance. Routine scheduled maintenance is limited to the absolute basics such as checking belts and filter changes. While this is an approach that can be provided at the lowest-cost under a simple service contract, most experts agree that energy efficiency, reliability, and occupant satisfaction are often compromised. The result is predictable: buildings are not operating at or near their potential, resulting in false economy.

The development of the rating system necessitated a lengthy and thorough trial and error process. Project advisors, industry professionals, technicians, and building owners and occupants provided useful perspectives and suggestions through multiple reviews and refinement of proposed rating systems. Narrowing the scope of the project was a challenge due to the wide variety of suggested approaches, including some very elaborate and all-inclusive schemes.

Through the literature review and discussions with the advisory teams and stakeholders some key outcomes were ultimately defined. In general a rating system should:

- Allow implementation by O&M trades persons with current skill levels
- Provide for a concise and targeted HVAC O&M evaluation
- Define protocols/methodology for each score or rating element
- Provide useful documentation of HVAC condition and functionality for building owner/managers
- Provide building energy use tracking
- Include a building occupant satisfaction component
- Include provisions for recommended building performance improvements

Through discussions with advisory teams and O&M contractors, it was clear that O&M (essentially HVAC) was a primary element and must be rated or scored. A number of O&M concepts and rating schemes were proposed and discussed. Service contracts were obtained from large, medium and small contractors in the Pacific Northwest. These ranged from one-page agreements to multi-page contracts complete with detailed checklists. A typical one-page agreement establishes payment schedule and terms, a short list of service items, frequency of visits, and hourly rates for additional services as requested. The more detailed contracts provided checklists that ranged from a one-page form to more extensive checklists that included checks and services for each type of equipment with annual and seasonal details specified.

A typical client receiving services under a basic agreement receives little more than an invoice for "routine" service, while a client with a more extensive contract may receive copies of completed checklists. The documentation received essentially indicates that the service was performed, notes repair parts, and may recommend upgrades (usually complete new systems and/or equipment).

None of these agreements included a performance metric, or provided for detailed feedback to the client in terms of the "relative" performance of equipment. None of these materials provided for tracking, trending, or comparing previous operating conditions or performance to the current conditions.

Clearly, in order for a client to easily grasp the past and present functionality and performance of their HVAC equipment, a basic performance "report card" should be completed and shared with the client.

It was determined that the rating system format should be concise and include only those equipment performance factors with the most critical impact on energy use, equipment reliability and comfort delivery (occupant satisfaction). The next challenge was to create a scoring or labeling method to characterize the relative performance of a particular building or HVAC equipment. Numbers or labels were deemed necessary to provide a building owner/manager with a ranking. Based on their building's performance score or ranking, it is assumed that many owner/managers will be motivated to upgrade a "One-Star" building to a "Two-Star" or Three-Star" rating. It was suggested that possible motivations for upgrades might include: a marketing advantage, tenant retention, employee retention, energy savings, equipment reliability, sustainability, reduced climate change impact, utility incentives, and other "Green" ideals, although cost savings is a major driver in small- to medium-size commercial buildings.

5.2 What Should Be Rated

Early discussions revolved around the issue of whether this system should rate a "building" or rate the O&M "services." It was decided that this system should rate multiple aspects of a building, and that rating only the O&M services would clearly not adequately characterize a building's performance. This decision was reached after considering options for rating O&M services.

Using existing O&M service contracts and checklists – collected from small, medium and large O&M contracting firms – the team created a comprehensive list of O&M tasks and assigned a particular value to each. The values assigned were intended to represent the relative importance in terms of energy efficiency and building performance. The O&M measures were also categorized as basic or routine, required, recommended, and advanced or optimum.

The next challenge was to assign a score or label to each task or category. Some initial proposed scoring or "labels" included the following:

- Good, Better, Best
- Basic, Recommended, Advanced, Premium
- 1-Star, 2-Star, 3-Star, 4-Star, 5-Star
- Poor, Fair, Good, Very Good, Excellent
- Bronze, Silver, Gold, Platinum (borrowing from the U.S. Green Building Council LEED ratings)

A building's total score, calculated from the assigned values for each category would make the building eligible for a rating label of One-Star, Two-Star, Three-Star or a Bronze, Silver, Gold, or Platinum, or other equivalent scale. A significant problem inherent to all of these labeling concepts was the difficulty of assigning scores to each O&M element. Assigning a 1-Star or 2-Star, or other label to a building based on the sum of points from each of the individual O&M measures within the Basic, Recommended, and Advanced categories would be complex. It was agreed that building owners/managers as well as the service providers would likely not accept this level of complexity and would be skeptical of the value of the scores and labels.

The list of elements and the complexity of scoring was clearly excessive and would generate much controversy. Development of a comprehensive list, intended to include all basic and routine elements, would likely be argued by some as incomplete and by others as too complex. Arriving at a total HVAC performance score would have been unnecessarily complex, as would the documentation and reporting to the client.

Clearly, a simpler approach was needed. The idea for a one-page "score card" emerged – creating a practical, concise tool that addresses only those elements considered by the project team as "essential" to optimizing a typical HVAC system. Scored elements would be limited to those that were deemed essential for optimum performance, and those elements that are currently most often overlooked or deemed "too expensive" or "too much trouble" and thus are not generally included in existing service agreements or in practice. The score card also needed to provide the building owner/manager with information on building performance. In contrast to trying to rate O&M services, a building performance rating gives an indication of progress that can be tracked over time.

5.3 Focus on Packaged Roof Top Units

Given the wide variety of HVAC systems and components, it was decided to focus on roof top packaged units. The majority of packaged roof top units tend to have similar components and thus were ideal systems for this pilot project.

The decision to focus the HVAC and O&M rating on packaged roof top units was also influenced by findings from recent rooftop package unit research and programs, and the fact that these units are in wide usage across the U.S. Several utilities in the Pacific Northwest region have been involved in efforts to improve the performance of small- to medium-size (4-20 cooling ton) rooftop package HVAC units (RTUs) over the last eight years. Literature from work conducted in this region and other parts of the country have suggested that up to 80% of these units are performing poorly and have either no or very little economizer cooling even though such cooling is required by both codes and current federal manufacturing standards. These observations have propelled a great deal of inquiry into the use of various auditing, diagnostic and maintenance techniques to improve the overall performance of RTUs. Creating a rating system for these units was judged to offer good value to the market. See Appendix A for specific details on RTU performance research.

By focusing our efforts on roof top units, a concise RTU Score Card was developed. The scoring or rating method compares the "as found" condition of a particular RTU to the after-servicing or "as left" condition. The *As-Found* comparison to *As-Left* approach provides a useful and necessary metric for both the service provider/technician and the owner/manager to quickly assess the system performance and trending. This performance documentation and trending will inform decisions for repairs and upgrades to systems, and necessary capital improvements (equipment replacement).

According to a study by Energy Market Innovations (Energy Market Innovations, Inc. 2004):

- Most RTUs are not adequately serviced after installation and the majority of existing RTUs have problems affecting efficiency.
- Due to a widespread neglect of small HVAC units, numerous mechanical problems are often identified.

- Service providers expressed reluctance to draw attention to what their existing service contracts do not provide – thus recommended that any " new service" be clearly identified as "advanced" or "optimization," and thus distinct from what they currently offer.
- Service providers expressed reluctance to champion a service to their customers that will inevitably identify costly repairs.
- Since actual energy savings from various measures (kWh) are not easily validated or determined, estimated benefits should come from a credible source. Some form of incentive may be initially required to motivate the marketplace.

5.4 FEEDBACK FROM PROJECT ADVISORS AND STAKEHOLDERS

- The necessity for a one-page RTU Score Card was also based on direct experience with an advanced HVAC service program, where technicians reported that they found a six-page Rooftop Unit Checkout Form to be excessively time-consuming and challenging given rooftop environments (e.g., rain, wind, etc.).
- A few advisors suggested the RTU rating should include a comprehensive list of measures. Alternatively, most advisors agreed that "routine" and "basic" measures will be performed under current practices and the rating system should stay focused on those elements that have the potential for the greatest impact on performance.
- Another concern voiced by O&M contractors was that a poor RTU performance "score" would jeopardize their relationship with existing clients – raising the question "what have I been paying you for in the past?" By limiting the scoring to "advanced" or "optimized" elements, the contractors can safely market this as an optimized level of service, and distinguish this service package compared to their "lowest-bid" competition.
- A number of HVAC technicians remarked that "the RTU Score Card is impressive and will be very useful in demonstrating to the client (and my boss!) the thorough attention to detail that I practice on the roof. My hard work and dedication to quality goes largely unappreciated because nobody else sees my work."
- One of the major O&M contractors noted that the RTU Protocols, as currently presented, do not provide a fully refined set of specific details and methodologies. He stated, for example, that a contractor should ultimately be provided with recommended equipment and methods to accurately measure air flows for specific HVAC equipment. These types of specifications and references need to be refined through experience and linked to the appropriate element. This contractor also recognized that – as the rating model is further refined and adapted to other building and HVAC systems (chillers, boilers, etc.) – easy-to-use and appropriate specifications, methodologies, and equipment can be provided.
- Overall, contractors reported that the RTU Score Card was reasonable and provided easy and useful documentation.

5.5 PILOT BUILDINGS

The project developed a set of building performance rating elements through direct experience in six pilot buildings. The intent of the monitoring in the pilot buildings was not to conduct technical research and document energy savings or performance data but to inform the development of the "concept" of a practical rating "system." The value of the buildings work was to create and refine specific rating "tools" through direct on-site interaction with the O&M service provider, owner/managers, and building occupants.

The six pilot buildings were recruited concurrent with the development of the rating system and tools. Pilot buildings were chosen based on location, climate zone, size, usage, HVAC system, and willingness of owner/manager and O&M service provider to participate in the study. Experience with each of the sites provided value to the testing and refinement of the RTU Score Card, RTU Protocols, Occupant Survey, and Walk-Through Checklist.

Discussions with the O&M service providers included review of technical details pertaining to the rating materials, and served as on-site training opportunities relative to the assessment requirements of the HVAC rating tools. The practicality and relative effectiveness of various approaches and tools were evaluated in context with the findings of the occupant survey, energy history, and the HVAC equipment in these buildings. The project also anticipated that work in the pilot buildings would provide useful insights toward creation of possible case studies and/or marketing materials.

Instrumentation was installed in the pilot buildings to monitor basic performance of the HVAC systems as well as occupied zone temperatures, relative humidity and carbon dioxide. Energy use of the buildings was determined and the Occupant Surveys were completed as appropriate.

During the early stages of this project it was unclear how valuable the basic building HVAC monitoring would be in helping define and create a rating system and tools. More detailed HVAC monitoring and limited interventions in the first two pilot buildings resulted in some useful information, but also demonstrated that HVAC equipment monitoring was not necessary to meet the goals of this project. The information gained from these efforts essentially substantiated the findings of other recent, and technically focused, studies of packaged roof top HVAC systems. These studies have identified wide-spread problems with factory installed sensors, set-point adjustment, air mixing, thermostats, and economizer failures (see Appendix A).

Experience in the pilot buildings with data logging of system performance showed that a detailed technical monitoring effort cannot generally be justified for routine performance checks in small- to medium-size building HVAC systems. Logging of system performance is a desirable activity in HVAC but the tools and expertise to actually deliver useful results – for a reasonable amount of time and money invested – represents a significant barrier. In larger buildings (over 50,000 ft^2), it is quite possible to cost-effectively amortize the expense of a building automation/monitoring system and competent operator into the overall operating budget. But in smaller buildings, monitoring is rarely attempted and generally not justified in terms of cost-benefit. In smaller buildings the building owner/operator typically accepts the energy costs month-by-month and doesn't pay much attention until the cost becomes too much of a burden. A substantial amount of monitoring work has been done in the Pacific Northwest region, which allowed the project to leverage that experience to keep monitoring effort to a minimum.

For this project, the primary monitoring emphasis was focused on adjustments to economizer settings. This type of monitoring has not been done extensively and is still in development. The effects measured are typically not dramatic. Estimates of savings in the Pacific Northwest range from about 0.5 to 1.5 kWh/ft^2–year (this research continues and savings estimates are currently under further review).

Therefore, instrumented HVAC equipment monitoring – especially non-invasive approaches – is somewhat still in the experimental stage.

5.6 Lessons Learned in the Pilot Buildings

Two of the pilot buildings were evaluated with a custom-designed system (see Appendix B for discussion of this monitoring) that included conditional logging (to reduce data file size), system control status, and remote real-time internet access to the data. This type of metering can show tendencies, but is relatively expensive to envision, install, and attend to. Detailed metering over several months produces large data files, and a highly experienced technician with thorough knowledge of the HVAC systems is required to interpret the data. During this project, limited interventions were subsequently approved and implemented by these building owners.

Due to the scope of the project and focus on practical approaches, the remaining four pilot buildings were monitored with a streamlined monitoring protocol utilizing a relatively low cost instrument set and reduced data set (see Appendix C). The streamlined RTU monitoring emphasis was on functionality and adjustments to economizer settings. Occupied zone temperatures and ventilation (estimated with carbon dioxide concentrations) were also monitored. Results of the monitoring were presented to the owners of these buildings along with recommendations for improvements.

Recent packaged roof top unit research in the Pacific Northwest has documented cost-effective results from component upgrades and optimized service protocols (see Appendix D). For example, new commercial thermostats and redesigned outdoor air sensors will increase economizing hours. Savings from these changes are currently being re-evaluated, and it is likely that overall savings estimates will be revised somewhat downward. The reduced savings estimates are due to a growing recognition that cooling loads in Pacific Northwest commercial buildings are smaller than previously believed. It is likely that more emphasis will be placed on heating savings (from limiting the amount of outside air entering the building) in future O&M programs in the Pacific Northwest. An increased emphasis on demand controlled ventilation is expected.

The building owners/managers were interested in learning more about their building's performance. When deficiencies were reported to these building owners and their O&M service contractors, the response was generally to begin a dialogue of costs and timelines. In some cases retrofits would tend to increase energy usage (i.e., correcting restricted outside air ventilation rates). The O&M contractors for the six buildings were largely very cooperative and interested in the project, and contributed to the development of the rating tools.

Circumstances precluded occupant surveys, RTU scoring, and walk-through assessments to be conducted in all buildings. In buildings #5 and #6 for example, the tenants had recently been inconvenienced by other types of survey. These employers declined to participate in the occupant survey, at the time of this project, but stated that they would normally be very receptive. It is interesting to note that only building #5 (out of all six buildings) had measured indoor temperatures significantly exceeding normally accepted comfort ranges.

5.7 Applying Rating System to Pilot Buildings

A review of the six buildings' Energy Star *Portfolio Manager* scores would indicate that most of these buildings are performing in the upper range of comparable buildings (Table 1). However, when the roof top HVAC systems were evaluated, it's clear that an Energy Star rating alone is not sufficient to characterize over-all building performance. This finding supports the need for a more comprehensive, multi-parameter rating approach in order to gain a more complete and useful building performance assessment.

The building owner of pilot buildings #5 and #6 determined the Energy Star *Portfolio Manager* scores for these buildings. The resulting scores reported likely reflect problems with the data used for these inputs into the *Portfolio Manager* program. Both buildings have data centers that may not have been properly accounted for in the energy use accounting and inputs. The building owner is an enthusiastic participant in this project and insisted on self verifying and reentry of input into *Portfolio Manager*. In spite of some difficulties, work in pilot buildings demonstrates that performance scoring can motivate building owners/managers, and confirms the need for careful data collection and reporting. It is also reported that relatively small differences in *Portfolio Manager* inputs can result in surprisingly significant and disproportionate changes in the Energy Star score.

The time necessary to conduct the As-Found checks and measurements to evaluate the RTU and determine a score on the RTU Score Card averaged less than two hours. In completing the RTU Score Card on three of the pilot buildings, it was also discovered that none of these RTU units were operating at optimum performance. At Building #1 for example, the RTU scores were improved from the “As Found” to the “As Left” condition from 60 to 74 by installing a different thermostat with morning warm up, changing the thermostat set points, and coil cleaning. The measured system airflow for this RTU was only 275 CFM, well below the recommended 400 CFM/ton, due to the incorrect size of the economizer outside air (OSA) hood.

Table 1. Pilot Buildings Score Summary

Pilot Building	Building Sq Ft	RTU Score	Energy Star Score	Occupancy Survey Score
1	125,000	74	96	53
2	9,000	64	82	72
3	80,000	46	70	64
4	25,656	- -	71	declined
5	16,893	- -	25	declined
6	6,750	- -	76	63

In buildings numbers #4, #5, #6 the RTUs were monitored with the streamlined monitoring equipment, but the RTU Score Cards were not completed due to resource constraints and the decision that the RTU scoring protocols were sufficiently developed and tested in the first three pilot buildings.

In spite of the relatively high Occupant Survey score for building #2, the measured CO_2 values measured during the same period revealed insufficient outside air exchange. The CO_2 in a representative occupied zone is shown below (Figure 10).

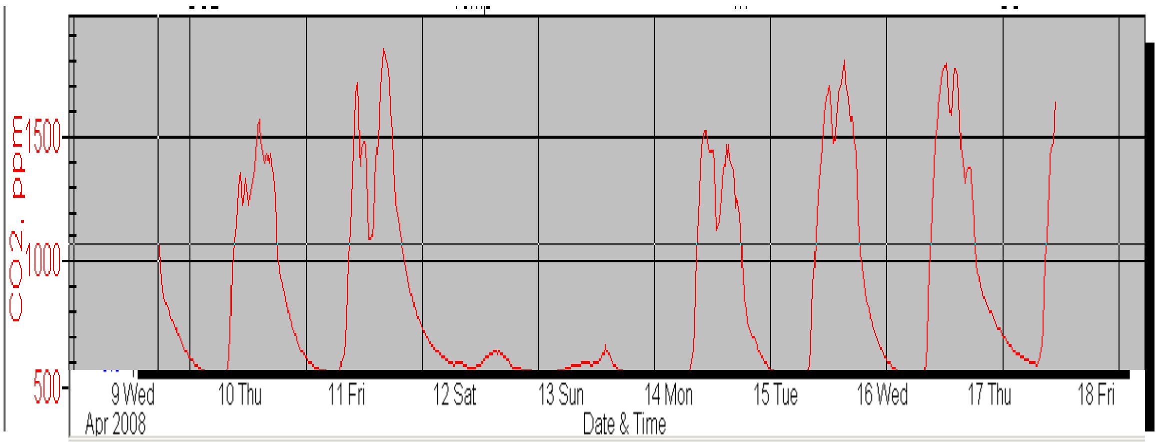


Figure 10. Pilot Building # 2 Carbon Dioxide Concentrations

Approximately 20 cubic feet per minute (CFM) *per person* outside air (OSA) ventilation rate is specified by ASHRAE 62.1 and the Washington State Ventilation and Indoor Air Quality Code (1993) for office spaces. The resulting CO_2 concentration would be expected to be in the range of ~ 800 ppm at unity, or steady-state conditions. The CO_2 monitoring results suggest the ventilation rate for this zone is approximately 8 CFM outside air per person, or less than half the recommended air exchange. Increasing the outside air fraction will likely increase energy usage during some seasons.

This example demonstrates the value of multi-faceted performance metrics to adequately help characterize a particular building. For this building the occupant survey alone did not reflect deficiencies (insufficient ventilation) that were identified through the more thorough monitoring provided by the walk-through assessment.

6. CONCLUSIONS

As a market transformation mechanism, this project developed an easy and effective rating and scoring system that allows O&M contractors and building owners/managers to discuss a building's performance on a meaningful level. Provided with detailed score cards, O&M protocols, an occupant survey tool, and a walk-through checklist, the O&M contractor and the client can discuss and negotiate various approaches toward optimizing a particular building's performance. In contrast to typical guidance that recommends general or specific measures, the rating system focuses on outcomes as represented by building performance scores. The performance metrics are essential to understanding and evaluating the effectiveness of implemented measures and interventions.

This pilot project focused on small- to medium-size office and retail buildings with unitary roof top heating, ventilation, and air conditioning units. Six buildings were recruited to allow the project to gain field experience with the various proposed rating concepts and tools in actual buildings, and obtain input through interaction with the O&M service provider, owner/managers, and building occupants. Work in the pilot buildings clearly demonstrated the value of multiple scoring elements to more fully characterize and understand the performance of buildings.

Five building performance parameters were identified and developed through this project. An easy three-step process using streamlined score cards and guidance is provided to establish a performance rating or score for four of these parameters: 1) HVAC Roof Top Unit O&M and Performance; 2) Building Energy Performance; 3) Building Occupant Satisfaction; 4) Walk-Through Assessment. "Advanced Building Performance Management" options are also presented.

Individual scores allow client and contractor to discuss current conditions as reflected by these scores and negotiate for improvements. The detailed documentation and resulting scores provide trending for client and contractor to evaluate effectiveness of O&M service and interventions.

The evaluation of HVAC equipment operation and functionality using a detailed, yet concise scoring method (RTU Score Card, completed during servicing by a technician) provides a useful and cost-effective indicator of equipment performance. The results are immediately available and are likely to be more easily understood by the client compared to technical measurement approaches. Use of an RTU Score Card also allows performance trending and documentation to be easily accomplished and understood. Providing this level of information to the client is expected to result in better decision making toward improved HVAC system services and equipment performance.

The unitary roof top HVAC operation and maintenance scoring format is suggested as a model that can be easily adapted for other energy consuming systems and equipment in most buildings. Using this model format, easy and useful scoring, documentation, and reporting can be accomplished for boilers, chillers, heat pumps, and other systems by substituting the essential elements and protocols for these systems.

Throughout the course of this pilot project HVAC and O&M industry contractors and advisors were generally reluctant to embrace the concept of a rating system. Feedback consistently suggested that the industry is hesitant to introduce additional metrics and/or evaluation tools into their business models. However, the findings in this project and other studies of building performance and HVAC equipment (especially unitary roof top units) clearly indicate that current practices are not delivering the level of performance that can be reasonably and practically achieved.

The limited work performed in the pilot buildings revealed numerous problems in all of the buildings, ranging from temperature problems and elevated CO2 levels, to failed economizers. The project identified problems with economizer control sensors found in typical HVAC units the field. The project scope did not include sufficient resources to fully characterize or demonstrate performance improvements through targeted interventions in the six pilot buildings   Research projects specifically designed to study the technical aspects of HVAC systems performance and functionality should be fully supported and integrated with rating systems and other market transformation initiatives.

The project demonstrated that collecting, summarizing, and reporting of basic building data – in order to establish performance criteria such as a packaged roof top HVAC system performance, Energy Use Index, Energy Star *Portfolio Manager score*, and occupant satisfaction scores – are relatively easy to accomplish. These reports provide useful information to building owners/managers and lead to meaningful discussions with O&M service providers and others toward building performance. Therefore, it is suggested that an expanded set of buildings be used to further refine the rating system developed under this pilot project.

Recommendations for Subsequent Projects

Future projects might follow this framework:

1. Use this system to rate approximately 25 buildings.
2. Optimize these buildings based on scores and assessments.
3. Conduct quarterly checks and monitoring of performance for a period of at least one year.
4. Evaluate impacts from interventions and compare to subsequent rating scores.
5. Refine the rating system based on findings.

A goal of subsequent rating system projects would be to validate the hypothesis that scoring tools serve as benchmarks to track building performance over time, which encourages sustained performance, improved management, and evaluation of outcomes or results from interventions.

Projects should include careful discussions with the building owners/managers and the O&M service providers. It can be expected that not all owners/managers will be motivated by scores, but it is assumed that many will respond to the scoring results and authorize a range of improvements. This hypothesis needs to be tested. Documentation of the discussion, negotiations, and subsequent interventions will help refine the rating system in terms of how recommendations are generally prescribed and valued in the marketplace. It is also recognized that not all recommendations or suggested actions will save energy or money. Indeed, some interventions may well increase energy usage to some degree, but provide other benefits such as improved occupant comfort.

Study buildings adopting significant changes and interventions should be more fully monitored to determine changes in rating scores as well as other factors such as energy savings, equipment reliability, and acceptability of changes made to occupied spaces. Many owners/managers are realizing the connection between building performance and intangible benefits (e.g., improved worker performance, tenant retention, employee retention) and avoidance of easily documented costs (e.g., escalating energy costs, premature equipment failures, and emergency repair costs).

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APPENDIX A. RTU SERVICE AND MAINTENANCE COST EFFECTIVENESS ANALYSIS

The following cost-effectiveness analysis describes the economics of a retrofit operation and maintenance (O&M) program that could be aimed at rooftop package units (RTU) in the Pacific Northwest. For the most part, the analysis was based on the field monitoring and contractor interactions in various programs and research efforts. The RTU O&M approach would be developed around five distinct measures. These measures have been evaluated together for purposes of this analysis. The measures are discussed in the subsections below and form the basis of the savings and cost effectiveness.

A1. SERVICE ECONOMIZER

Assessment and adjustment of economizer changeover temperature is included in all measure packages. The economizer changeover temperature is often set to about 55º F; at this setting the outside air can be used for cooling only when the outdoor temperature is below 55º F. This setting leaves many hours of effective economizing weather unused. Furthermore, for most commercial buildings, relatively small cooling loads would be expected when outside temperatures are below 55º F. A changeover temperature of 65º F (or higher) is recommended here.

Other components of the economizer service include airflow measured at both minimum and maximum economizer operation. This measurement informs adjustment of outside air and return air dampers. In the event that dampers are stuck or poorly adjusted, the technician must repair them (where possible).

In 2007–2008, a small research project was managed by the New Buildings Institute and conducted by Stellar Processes and Ecotope to evaluate the poorly performing dry bulb temperature sensors that are used by many economizer systems. That work showed that the most commonly used dry bulb sensor contained a design flaw that resulted in significantly reduced economizer operation. The manufacturer of the sensor, Honeywell, has come out with a new product that should perform much better. This sensor provides an additional savings opportunity for a new program, but requires that old sensors be replaced in about 60% of the units already serviced.

All measure packages also include a biannual condenser coil cleaning and evaluation of refrigerant charge. Finally, the program would include a change in filters, although this is already a part of virtually all routine maintenance visits.

A2. TWO-STAGE THERMOSTAT

In commercial buildings, especially small commercial buildings, residential thermostats are often used. This means there is no dedicated economizer stage and can also mean that the space might not be adequately cooled (depending on how the thermostat interacts with the economizer controller). Use of a commercial thermostat which has least 2 cooling stages will increase economizing hours and also ensure mechanical cooling will operate when needed. Also, most newer commercial thermostats will support a fix which shuts down the outside air damper during heating recovery time (typically very early morning), resulting in heating savings.

A3. Controller Replacement

Relatively rarely, economizer controllers become jammed, shorted, or otherwise dysfunctional and the economizer is no longer operational. In these cases, the controller is replaced by a new controller. If Demand control ventilation (DCV) is being considered, the new controller should be chosen so that it supports DCV.

A4. DCV Package

Demand control ventilation (DCV) is not only feasible but desirable in many RTUs. Simulations suggest DCV provides one of the most readily available heating savings. For this measure, the right controller is needed along with a CO_2 sensor, and the outside air dampers are reset to a very low minimum air level. The CO_2 sensor would be set to open the dampers to 40-50% outside air when the CO_2 level reaches a threshold and the economizer would proceed to operate as before when cooling is required.

A5. New Economizer

This measure is an application of a new economizer to an existing unit (or installation of a completely new RTU that includes an economizer) and commissioning of the system using the procedures described in the first package (above). Consideration of DCV and also the type of thermostat in the system should be considered when a new economizer is installed.

A6. Simulation Results

The results of the simulation evaluation have been aggregated together into 2 major measure categories:

- **Optimal Repair Package Category:** This package includes the controllers, thermostats and optimal start control in proportion to their presence in the PSE program as well as repair and maintenance on the RTU including the dampers, settings, coil cleaning, and charge review.
- **DCV Low Ventilation Rate Category:** The assumption here is that all of the repair measures are completed as part of the DCV upgrade. A new controller and CO_2 sensor setup is added to minimize outside airflow during periods of low occupancy and maximize outside air flow as ventilation requirements increase. The low ventilation case assumes that the initial set-up was consistent with the ASHRAE Standard 62 for the particular occupancy. The measure implements the Standard's requirements for DCV controller setting for minimum make-up air. It is our observation that damper settings are fairly arbitrary and the effective ventilation rate is often set without regard for the particular occupancy or the ASHRAE standard for that occupancy.
- **DCV High Ventilation Rate Category:** This category is similar to the low ventilation case, except that the high ventilation case assumes an initial condition of approximately 30% outdoor make up air with a reduction to approximately 8% minimum outside air. This measure is meant to characterize a limited number of cases, but one where the DCV option offers significant functional improvement in the RTU.

In both of these cases, a fraction of the measure is assumed to include a morning warm up. This was about 30% of "Premium Service" cases, and 100% in the cases of thermostat replacement and controller replacement. In the case of this measure, it results in gas savings or space heating savings separate and distinct from the measures that focus on adjusting the economizer, cleaning coils, and adjusting refrigerant charge.

Table A1 shows the estimated savings for these three measures and includes all the weighting and aggregation necessary to construct these measures. The DCV measure is a single measure that includes all of the economizer repair and maintenance as well as the integration of a DCV controller and CO_2 sensor. The simulations in this case used the Spokane (Zone 2) and Seattle (Zone 1) climates to estimate savings.

Table A1. Normalized Savings, RTU Packages

Measure	Climate	Savings					
		Cooling (kWh/f²)			Heating (kbtu/f²)		
		OFFICE	RETAIL #1	RETAIL #2	OFFICE	RETAIL #1	RETAIL #2
Optimal Repair	Zone 2	0.238	0.339	0.501	2.31	0.92	0.89
	Zone 1	0.282	0.395	0.632	1.64	0.79	0.65
Demand Control CO_2	Zone 2	0.029	0.092	0.047	5.35	9.93	7.25
Low Ventilation Rate	Zone 1	0.010	0.042	0.013	4.33	8.82	4.08
Demand Control CO_2	Zone 2	0.088	0.103	0.045	18.48	12.43	9.77
High Ventilation Rate	Zone 1	0.024	0.047	0.002	15.01	11.11	6.23

The savings have been divided into three major occupancies which differ from one another in occupancy and lighting power density (LPD). The "Office" use is based on ten hour occupancy and an LPD of 1.35 Watts/ft^2. "Retail 1" assumes a 12 hour occupancy and an LPD of 1.4 Watts/ft^2. The "Retail 2" runs were similar to the Retail 1 runs but used an LPD of 3.4 Watts/ft^2.

In Table A2 the results of the savings calculations are renormalized to a 7.5 ton rooftop package unit. The cost/benefit analysis is based on this unit. It was selected as it represented an average size for units observed in the regional field research as well as the work done for this effort.

Table A2. Package Savings (kWh/Therms)

Measure	Climate	Savings					
		Cooling (kWh)			Heating (Therms)		
		OFFICE	RETAIL #1	RETAIL #2	OFFICE	RETAIL #1	RETAIL #2
Optimal Repair	Zone 2	666	949	1403	65	26	25
	Zone 1	791	1106	1769	46	22	18
Demand Control CO_2	Zone 2	81	258	132	150	278	203
Low Ventilation Rate	Zone 1	28	118	36	121	247	114
Demand Control CO_2	Zone 2	246	288	126	517	348	274
High Ventilation Rate	Zone 1	67	132	6	420	311	174

In Table A3, the estimated costs of these measures are shown. These costs were derived from two sources. Costs are based on the average unit size of 7.5 cooling tons.

1. Incentive payments made by a utility "Premium Service" program (which targets RTU operational changes and maintenance) for various measures included in their program. In this case we have assumed that "Premium Service" is providing close to 100% of the labor cost to check out and clean the RTU and to replace controllers and thermostats. In some cases, the full

cost of labor and components might not be covered by these incentive amounts but generally they have proven pretty close.

2. Actual costs associated with the supply of individual components that are either not included in the above maintenance program but estimated from trade and other HVAC contractor sources. This would include the new Honeywell sensor which has only existed for the last two months, and the DCV controller and CO_2 sensor, which while it has been included in the package since the beginning, has never been used. For those reasons, we have done our best to estimate the costs of these components.

Table A3. Measure Costs per RTU

Measure	$/unit
Tune-up, repair	300
Tune-up with new sensor	350
Warm-up relay	80
Thermostat	300
Controller	150
DCV	400
New economizer	800

Table A-4 summarizes the cost-effectiveness of these three component measures when applied to a 7.5 ton unit operating to supply ventilation and space conditioning to a 2,800 ft^2 single-zone building under various occupancy types. For this purpose, however, we have normalized to the individual unit without regard to the interaction between this individual unit and other units that might be present in typical applications. The measure costs used in this analysis are in Table A-4.

The levelized cost calculations are based on a present value of the cost of the measure divided into the annual savings. The analysis uses a 4% discount rate over a 5 year measure life.

Table A4. Levelized Cost Results (based on cost/savings per RTU)

Measure	Climate	OFFICE	RETAIL #1	RETAIL #2
		$/kWh	$/kWh	$/kWh
Optimal Repair	Zone 2	0.017	0.053	0.036
	Zone 1	0.038	0.049	0.033
		$/Therm	$/Therm	$/Therm
DCV *low*	Zone 2	0.95	0.50	0.70
	Zone 1	1.18	0.57	1.25
DCV *high*	Zone 2	0.27	0.40	0.52
	Zone 1	0.34	0.45	0.82

For measures where there are both gas an electric savings, the less significant fuel is valued at the avoided cost ($1/Therm or $0.065/kWh) and included as a negative cost in the present value calculation. Thus for the Optimal Repair package, the gas savings (mostly from the morning warm up measure) are valued and deducted from the annualized cost of the O&M measure.

These measure packages are generally cost-effective in both climate zones that were examined. The first DCV measure ("DCV low") is borderline if the ventilation rates in the existing units are near the minimum required for those spaces. This problem is considerably less significant in new construction, where a new controller and sensor could be specified in the initial installation, dropping the cost by a factor of 3. Limiting the DCV measure to systems that have at least 25% minimum outside air and the ability to be set down to 7-10% minimum air is required to ensure cost effectiveness. The second DCV option assumes an initial condition of approximately 30% outdoor make up air with a reduction to approximately 8% minimum outside air. This system is cost-effective in virtually all cases against an 80 cent/therm levelized cost threshold.

The optimal start (morning warm up) measure is not cost-effective by itself, although it can be very cost-effective when integrated with the overall Optimal Repair package. This measure provides most of the heating season savings if no DCV measure is installed.

Overall, this analysis suggests that a cost-effective RTU program can be delivered. It is important to emphasize that existing RTU programs have focused on training HVAC technicians who install and maintain single-zone packaged rooftop equipment. In many cases, experienced technicians have not had much recent experience working on economizers.

Most of the deficiencies with economizers in the Northwest, in terms of the lack of enabling of the morning warm-up option, and limited use of DCV, have been a result of lost opportunity when the equipment was ordered or overly conservative economizer settings during the initial installation. While it is true that these deficiencies make a retrofit RTU program cost-effective, it is also true that it is much more cost-effective to have new units meet specification and set-up standards. By paying more attention to new units, the long term impact of this program could be much more cost-effective and the need for ongoing assessment of economizers should be more limited.

The project team thanks Bob Davis and Dave Baylon, Ecotope Inc, Seattle WA for contributing this material.

APPENDIX B. PILOT BUILDING TESTING

This discussion provides details of the technical monitoring conducted in the six project pilot buildings.

Two of the six pilot buildings (pilot buildings # 1 and # 2) were evaluated with a custom-designed system which included conditional logging (to reduce data file size), system control status, and internet access. The remaining four pilot buildings were monitored with a simplified equipment set-up due to the project's scope and limited resources.

B1. ON-SITE ONE-TIME MEASUREMENTS

For these tests, the focus is on the economizer function, system airflow, refrigerant charge, and thermostat type setting. Check-out requires from 1.5 to 3.5 hours per unit. These tests are critical to the rating system RTU Score Card procedures.

Manufacturer's instructions for checking out economizer controller and sensor are used; a multi-meter that reads in milliamps (mA) is needed. Condition of damper seals and operation is noted and repaired if needed/possible. (Damper leakage is a common problem on packaged units.) Sensor contacts are cleaned or the entire sensor is replaced if defective.

Both economizer and system (evaporator) airflow are measured with averaging velocity pressure flow meters. System external static pressure is measured in Pascals using a digital micromanometer.

Figure B1. Flow Grid Installed on Outdoor Intake Hood

The mixed air temperature is often subject to "plumes" of differing temperature, so at least three measurements of mixed air are taken. Mixed air and outside air temperature can be used as another indication of economizer operation. Mixed air sensors will be designed for removal and replacement during a treatment that involves cleaning the evaporator coil.

Special care is also needed for measurement of the outside air temperature. This sensor, which will usually be close outside the fan cabinet, needs protection from solar radiation and re-radiation from the roof surface. This sensor needs to be placed so that it accurately measures the temperature of the air entering the fan unit as well as the outside air temperature when the fan is not running.

The primary objective of this project is to describe the amount of economizer operation before and after adjustments to changeover temperature are made and the effect of the adjustment on energy used for cooling (expressed in kWh/day at a specific outdoor temperature. At the same time, return air temperature (as a surrogate for indoor temperature) is assessed to make sure the building is maintained at the same indoor temperature during cooling mode.

A typical energy signature plot for a 5 ton rooftop packaged unit is shown in Figure B-3. The kWh use per day is relatively flat to the left of the curve, reflecting only air handler usage. At some point (around the mid 50's F outside temperature), there is need for cooling that cannot be satisfied only by the economizer. That is, the compressor must operate to meet cooling set-point. The kWh/day usage increases (solid diamonds).

When an adjustment is made to the economizer changeover temperature, the kWh/day usage should decrease in some band of outdoor temperature. This is shown, if a bit coarsely, in the graphic, by the open blue diamonds for outdoor temperatures between about 55° and 65° F. The open blue diamonds reflect a warmer economizer changeover temperature (65° F vs. 55° F to start) and mean the unit can meet cooling set-point by using only outside air. Above about 65° F, the unit switches to only mechanical cooling.

B2. DETAILED DATA-LOGGING - DISCUSSION

Detailed logging occurred at two sites beginning in February 2008.

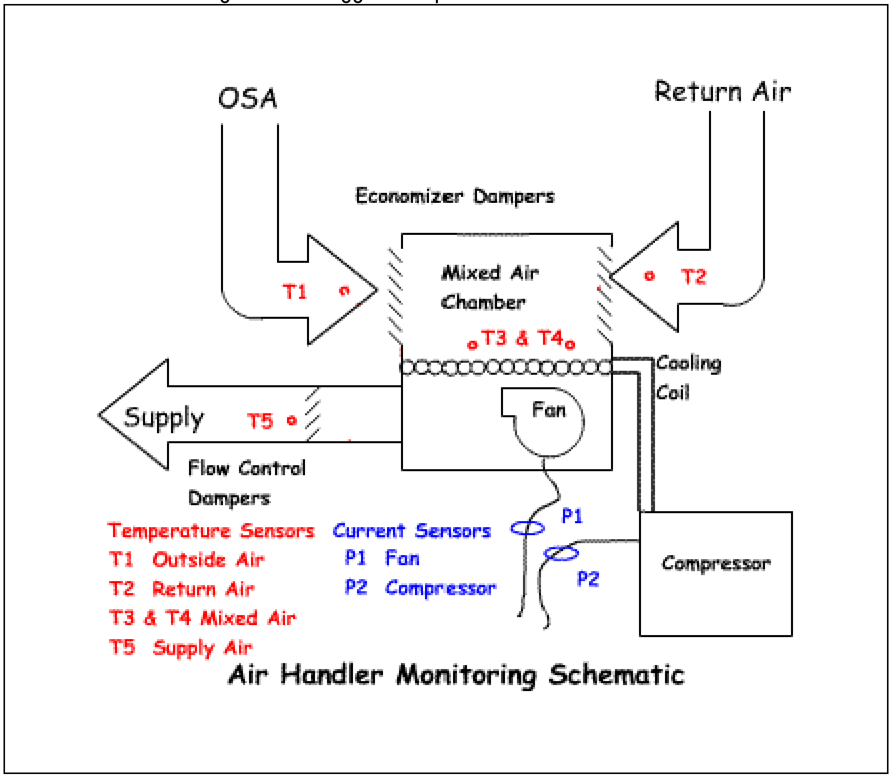
On each unit, we monitored amps/volts to the compressor + outdoor fan and indoor fan circuits at least once per cycle (Hz). Depending on one phase versus 3-phase equipment we performed manipulations to determine the actual true power.

We also measured 4 mixed air temperatures (to get an average), outdoor temperatures in 2 spots, supply air temperatures, and return air temperatures at each unit. Return air temperature is a proxy for indoor temperature (generally a reasonable assumption). We also measured outside air damper position with a string potentiometer and gas valve status with a 24v relay.

From these measurements, we calculated a number of other parameters such as scavenged heat/cooling, fan-only operation, and COP (when combined with system flow, which we also measured).

Figure B-2 shows all temperature and true power measurement locations. Not shown are sensors which indicate the position of the outside air damper (via a string potentiometer) and a 24v relay connected in series with the gas valve (to indicate its operation). Not shown are sensors which indicate the position of the outside air damper (via a string potentiometer) and a 24v relay connected in series with the gas valve (to indicate its operation).

Figure B 2. Logged Temperature and Power Points



Logged temperature and power measurements were taken on 60-minute data intervals with readings binned in real time by operation mode.

The mixed air temperature is often subject to "plumes" of differing temperature, so at least three measurements of mixed air are taken. Mixed air and outside air temperature can be used as another indication of economizer operation. Mixed air sensors will be designed for removal and replacement during a treatment that involves cleaning the evaporator coil.

Special care is also needed for measurement of the outside air temperature. This sensor, which will usually be close outside the fan cabinet, needs protection from solar radiation and re-radiation from the roof surface. This sensor needs to be placed so that it accurately measures the temperature of the air entering the fan unit as well as the outside air temperature when the fan is not running.

The primary objective of this project is to describe the amount of economizer operation before and after adjustments to changeover temperature are made and the effect of the adjustment on energy used for cooling (expressed in kWh/day at a specific outdoor temperature. At the same time, return air temperature (as a surrogate for indoor temperature) is assessed to make sure the building is maintained at the same indoor temperature during cooling mode.

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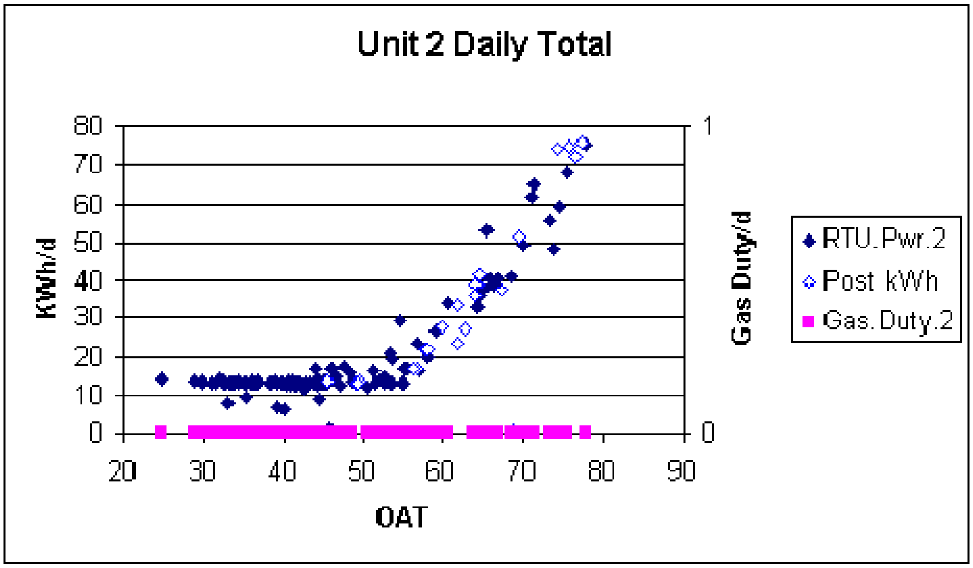
Figure B3. Energy Signature Plot



B3. Individual Pilot Building Discussion

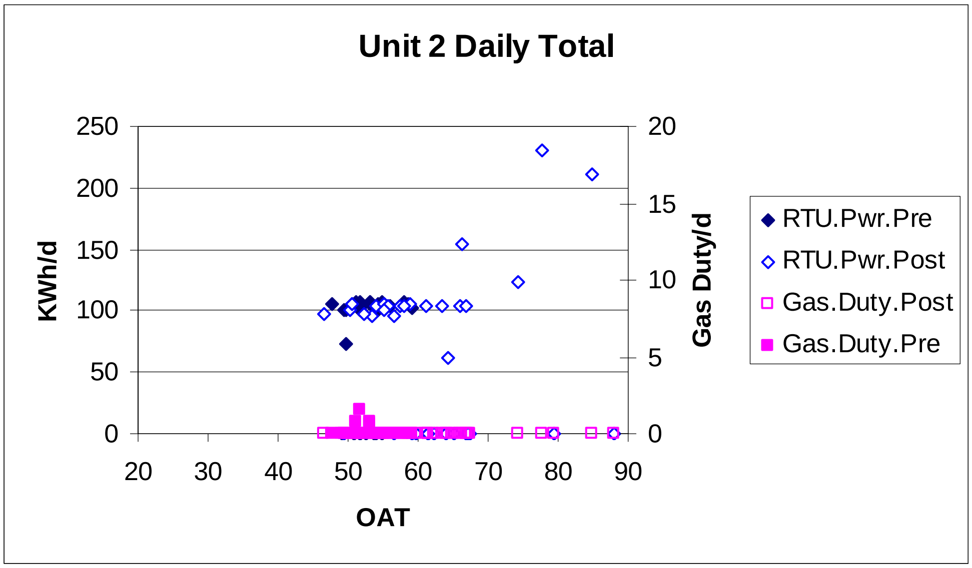
B3.1 Pilot Building #1

The building is a good example of a smaller sized (~100,000 ft^2) regional big-box retail store located in Washougal, Washington. The building has a moderate cooling load since lighting is mostly T-12 shop lights, and occupancy is generally moderate. The main objectives for metering at this site were demonstration of economizer changeover adjustment and demonstration of optimal start in heating mode (which shuts down minimum outside air to zero during morning heating recovery).

Two gas packaged units were monitored. Both used a non-HW economizer logic and components. Unit 1 is 5 ton, measured evaporator airflow is 355 CFM/ton; max OA is 55% and minimum is 12% of evaporator flow. Unit 2 is 10 ton; airflow is 273 CFM/ton; max OA is 45% and minimum air is 15% of evaporator flow. Both units were originally running with economizer dry-bulb changeover temps of 55° F. These changeovers were adjusted to about 65° F on 6/20/08. The delay in adjustment had to do with a protracted cold late spring/early summer. The negative consequence of the delay was a limited amount of post-adjustment data.

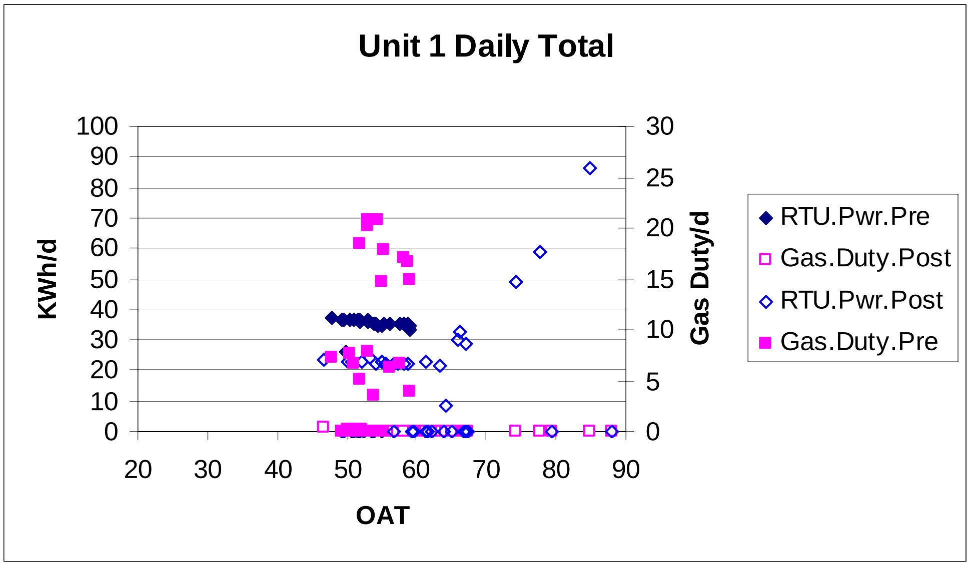
The 10-ton unit, which serves part of the main retail floor, uses very little gas for heating and also has no compressor operation until outside temperatures approach about 70° F (as shown in the post-adjustment data (open blue diamonds Figure B-4)). There were no temperatures this warm in the pre-adjustment period so it is not possible to ascribe savings to the economizer adjustment on this unit.

Figure B4. Pilot Building #1 RTU 2 Energy Signature



Unit 1 has a similar problem with cooling operation and a similar graphic (Figure B-5). There is a reduction in air handler usage at this site that corresponded with thermostat replaced in late March (see next paragraph). We have no explanation for this reduction since we did not make any changes to the air handler circuit. It is possible that the power reading on the air handler is in error, but we checked out this possibility and ruled it out. This change remains a mystery.

Figure B5. Pilot Building #1 RTU 1 Energy Signature



To test optimal start, new proprietary 5 vdc thermostats were installed on 24 March 2008. Because of delays in finding these thermostats, there was not enough post-change-out data to demonstrate the effect of the change-out over a good chunk of a heating season. A short-term review of outside air damper position was undertaken in the two nights following the change-out. The metering was switched into 2 minute mode to allow a closer look at damper position. The new thermostats performed as expected (minimum outside air dropped to zero during morning recovery), which over the course of a heating season would save a modest amount of gas usage. Also, as the existing thermostats were not programmable and the new ones were), modest setbacks/setups were added; these adjustments should also produce modest reductions in gas and electricity use.

B3.2 Pilot Building #2

This building houses a software company located in Camas, Washington. It is the second floor of an older building (with updated windows) and has approximately 5,000 ft^2 of conditioned space. Occupancy in the main space appears to be at least 15 people during normal business hours. Two packaged units serve the main part of the space (open office with cubicles), and at least some of the ancillary spaces. The business operates mostly on an 8 AM to 6 PM occupancy schedule with some after-hours operation. A computer server room is conditioned by a min-split air conditioner.

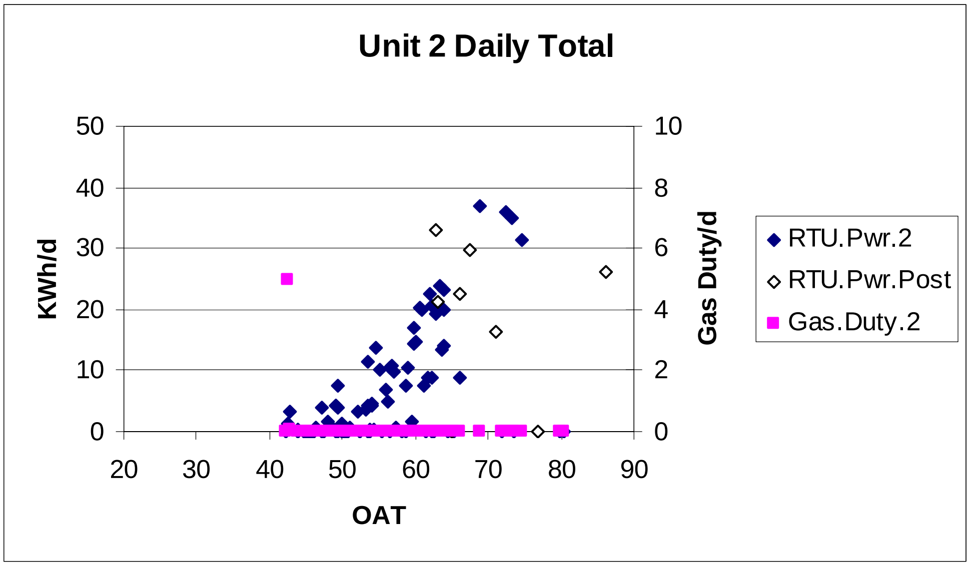
A 5 ton gas pack serves the north end of the building. It has measured system airflow of 1285 CFM, which is very low for a unit of this size. Many supply diffusers are apparently throttled down in the space, and the system is very noisy (from jets of air getting around the diffuser dampers). Outside air for ventilation was measured at 173 CFM as-found. A 4 ton gas pack serves the south end; it has much better airflow (1814 CFM for the whole system and 199 CFM for ventilation air).

The two package units are controlled by Honeywell residential touch-screen thermostats with set-points of 70º F heat/73º F cool starting at 7:30 am then changing to 67º F heat/76º F cool at 6 pm. Each has 2 stages of cooling set up/wired. The setback temperatures are applied on weekends. The system air handlers were set at CIRC when we first installed equipment (early 2008); this means air handlers should operate about 30% of the time regardless of a heating or cooling call. This scheme improves ventilation since when the air handler is on, the ventilation airflows mentioned above apply. At some point, air handler operation was changed to AUTO, meaning the system fans only run when there is a heating/cooling call.

Our preliminary assessment of operation is that the site requires very little heating energy due to the internal gains (people and computers) in the main space. There is very little artificial lighting added since most staff members are involved with programming tasks using personal computers for much of the day.

Assessing cooling operation was straightforward at this site but “seeing” the economizer adjustment proved challenging. The original installation was in mid-February but given significant internal gains, we expected to see economizing operation even in winter months. We did see some economizing at moderate outdoor temperatures (around 60 F, which conforms to the expected, given the changeover temperature was 65 F). Because the as-found changeover temperature was 65 F, we decided to make the post-adjustment setting about 60 F (which is the lowest setting available on this economizer controller) rather than a setting in the low 70s F (since that could cause comfort complaints). We had a difficult time picking out a measurable change in economizer operation given the relatively close pre/post-adjustment changeover temperatures. Figure B-6 illustrates the operation of Unit 2.

Figure B6. Pilot Building #2 RTU 2 Energy Signature



In Figure B6, the blue diamonds (open and closed) show daily kWh usage before and after the adjustment. There is almost no heating operation on this unit, so the electricity usage is either for just the air handler operation, for economizing, or for mechanical cooling. In looking at the operation by mode, it is clear that usages under10 kWh/day conform to air handler operation only. Values above this correspond to mechanical cooling. As outdoor temperature increases above about 55° F, mechanical cooling usage increases. (Note that there are some times where economizing alone cannot meet the cooling load, even at these mild outdoor temperatures.)

Figure B7. Pilot Building #2 RTU 1 Energy Signature

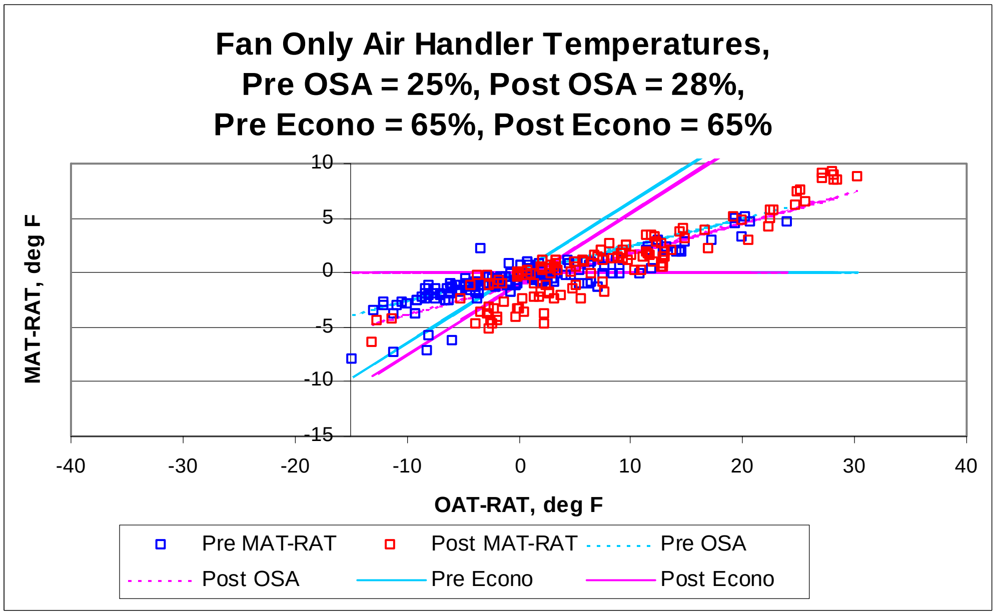
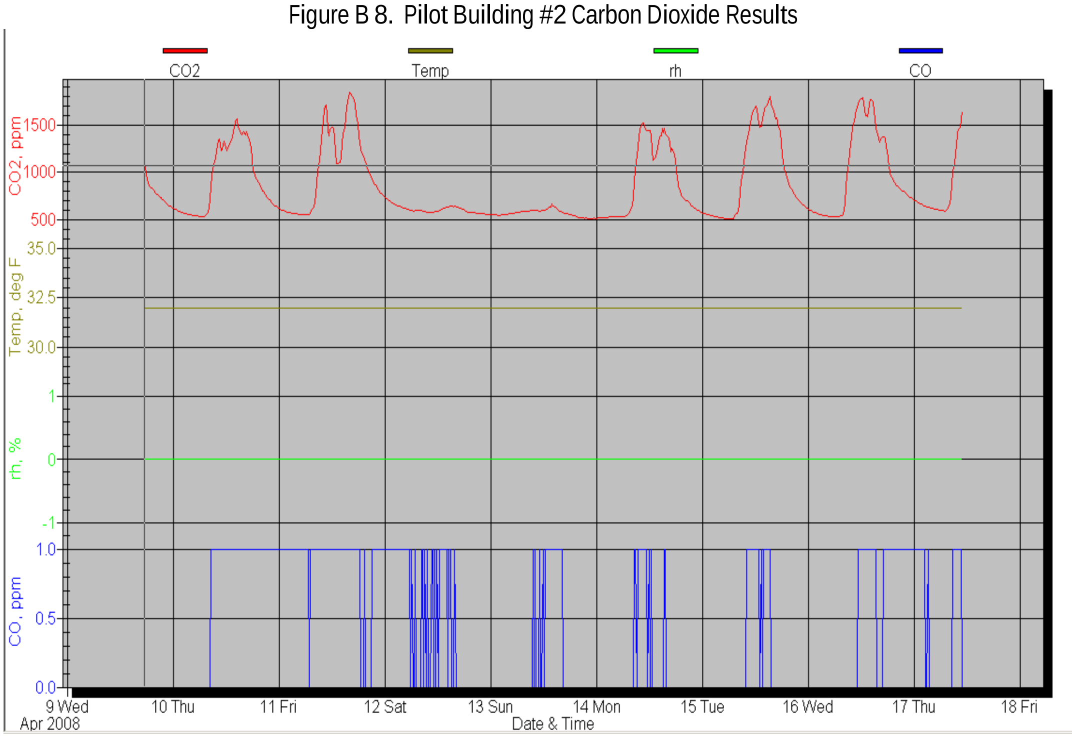


Figure B6 by itself is not instructive given there turned out to be only limited data collection after the adjustment was made (because of how work was timed in accordance with the site manager's preferences). This unfortunate situation meant there was little that could be proven about overall cooling energy usage (since there are not many days of post-adjustment data available for comparison). However, a second graphic (Figure B7) shows that the difference in economizing operation did not change a huge amount after the adjustment, which was expected given there was only about a 5 F change in economizer changeover temperature. (The blue and magenta lines have very close to the same slope, indicating very little change in economizing hours.)

Unit 1 has a similar problem with cooling operation and a similar graphic (Figure B7). There is a reduction in air handler usage at this site that corresponded with the thermostat replacement in late March (see next paragraph). We have no explanation for this reduction since we did not make any changes to the air handler circuit. It is possible that the power reading on the air handler is in error, but we checked out this possibility and ruled it out. This change remains a mystery.

Ventilation was also assessed in this building (all pilot buildings) via use of a real-time carbon dioxide (CO_2) meter (TSI Inc.) As expected, CO2 levels were elevated at many times during the monitoring period (in excess of 1,000 ppm). The building manager was shown the results (Figure B-8). Outside air amounts could have been increased during normal occupancy and the fan setting could have been set to run continuously, at least on Unit 2. (Unit 1 was very noisy to operate given constricted supply runs.) The manager apparently was not interested in making a change, so no adjustments to minimum outside air mounts or operation scheduling were made. In spite of the elevated CO_2 concentrations recorded, the Occupant Survey results for the Overall Comfort category was 3.9 out of possible 5 points, and the Odor

Figure B 8. Pilot Building #2 Carbon Dioxide Results



Category score was 4.4 out of 5. General comments on the Occupant Survey did not mention stuffy, stale, or uncomfortable conditions.

B4. Short-term Monitoring in Four Pilot Buildings

The equipment used in this streamlined monitoring is off-the-shelf temperature sensors and current transducers available from a well-know manufacturer - - see Appendix C for detailed discussion of this approach.

B4.1 Pilot Building # 3

This building houses a retail and warehouse business located in Olympia, WA. Monitoring include two 20 ton rooftops that serve the main retail areas (approximately 14,000 ft^2 total). These systems use a two-stage commercial thermostat. Monitoring began in mid-April 2008, and an adjustment of the economizer changeover setting was made in late May. Because of the cold weather, we did not see significant economizing until early May. A Johnson Controls economizer controller and sensor is employed on both of these units.

We looked at compressor run-time before and after the changeover adjustment (set up to about 65 F from the starting temperature of about 55° F, according to the Johnson Controls literature that describes changeover temperature versus potentiometer settings). The compressor run-time (vs. outdoor temperature) appeared to decrease slightly on Unit 1 (Figure B-9) but actually increased on Unit 2 (Figure B-10). There was considerable scatter in the data points (as for the first plot) but even after these outliers were screened, the trend was apparent.

Figure B9. Unit 1 Usage Before/After Economizer Adjustment

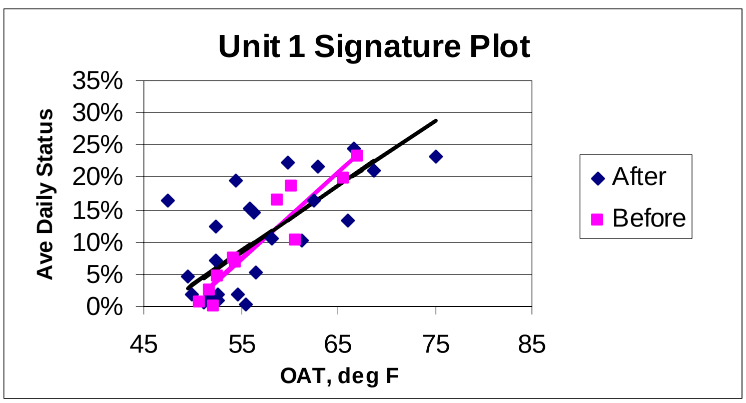
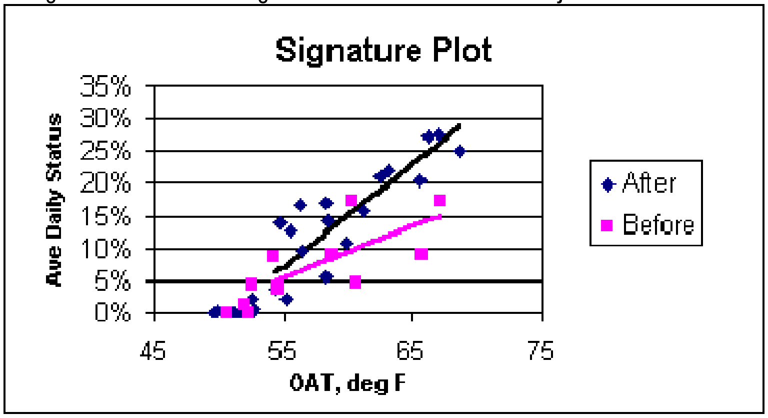


Figure B 10. Unit 2 Usage Before/After Economizer Adjustment



We consulted Airefco, Carrier's technical representative, about the issue in September 2008. They have not returned a verdict yet, but they are not sure the pairing of the Johnson Controls economizer with their equipment will result in expected operation. We did not expect this to be a problem given that Carrier typically uses others' economizer components.

B4.2 Pilot Buildings # 4 and #5

Pilot buildings #4 and #5 are multi-tenant office buildings located in Spokane, Washington. These buildings are part of a large office park built and managed by a single property management firm. The mechanical systems for these buildings are similar and receive regular O&M services under contract from a local HVAC contractor. Both sites are newer (post-2000) insulated concrete tilt-up buildings which house office workers. Carrier gas pack rooftops (mostly 5 ton cooling capacity) provide heating and air conditioning for these sites. The units are serviced quarterly by a local HVAC contractor who was described as amenable to the goals of the review and adjustment.

The owner and property manager note there have been shell pressurization problems in one building and comfort problems were identified through temperature monitoring at both buildings. The over-pressure issue (due to economizer operation) was diagnosed as a problem with the barometric relief associated with the RTU units. Powered exhaust is being considered as a solution. The inspection of selected RTU units on each building showed the economizers have outdoor air enthalpy sensors and are set on the most conservative setting ("D"). Space thermostats are Honeywell 7300 series. Two stages of cooling operation are wired on the roof and had a properly working economizer (outside air damper actuated at the expected temperature/relative humidity). We noted residential-type air filters and coil fins showed some damage (likely due to pressure-washing).

B4.3 Pilot Building # 5

At the building #5 (710) site, the same RTU units and thermostats are installed. At this site, many cubicle occupants had small circulating fans, indicating a possible comfort problem. Temperature monitoring for six weeks in a central and representative area showed excellent temperature control during the six week monitoring period. Carbon dioxide levels at this central location were also in the acceptable range during this period. About 50 occupants work in the ~10,000 ft^2 main open office area.

A thorough review of these units (full airflow measurements, refrigerant charge adjustment, etc.) was not carried out because of time constraint, but short-term monitoring equipment was deployed on one RTU for each building in mid September, 2008. The expectation was that there would be sufficient economizing operation over a two week period so that an adjustment in changeover temperature could be evaluated by looking at early October system operation (compressor run-time).

The HVAC service provider resisted suggested changes to the economizer adjustment and since the occupants were comfortable, no changes were made.

B4.4 Pilot Building # 6

A one-story owner occupied office building located in Mt. Vernon, Wash. Three older (10 to 15 years) rooftop units serve the 6,750 square foot open office areas. The units were not equipped with economizers and the outside air dampers were mechanically fixed in the open position. The owner was surprised to learn that the dampers remain open 24/7. As expected, CO_2 measurements demonstrated sufficient outside air delivery, and the Occupant Survey showed relatively satisfied occupants. Given the age of the existing units, and the lack of economizers, the owner is strongly considering replacing the units with newer efficient systems, in spite of the Energy Star *Portfolio Manager* score of 76.

B5. PILOT BUILDING CONCLUSIONS

Pilot buildings were chosen based on location, climate zone, size, usage, HVAC system, and willingness of owner/manager and O&M service provider to participate in the study. Experience with each of the sites provided value to the project. Again, the primary intent of working with these buildings was not to conduct technical research or testing, but to gain insights for all aspects of the rating system.

Recent developments in economizer technology will facilitate harvesting energy savings. (See Appendix A) New commercial thermostats and redesigned outdoor air sensors will increase economizing hours. Savings from these changes are being re-evaluated, and it is likely overall savings estimates will be revised downward (mostly because there is growing recognition that cooling loads in Pacific NW commercial buildings are smaller than previously thought.) It is likely that more emphasis will be placed on heating savings (from limiting the amount of outside air entering the building) in future O&M programs in the Pacific NW.

Overall, the impact of the monitoring results in these few installations point out the importance of a measurement base review of this type of equipment. It is typical that RTU equipment is initially installed without significant intervention from engineering design and thus the particular settings and approaches of the original installer are likely to be the continued into decades of HVAC operation. With the development of new sensors and new research on economizer and fan settings there is a clear advantage to both comfort and energy efficiency to a detailed review. The use of airflow measurement tools and careful one time review of control and temperature settings can provide savings and prevent IAQ complaints and related problems. The research in the PNW suggests that savings of about 1 kWh/sf from proper economizer set-up alone would be anticipated. This would be improved by the reduced heating demand resulting from proper outside air settings and from proper scheduling of occupancy and setback. The rating system RTU Score Card, RTU Protocols, Occupancy Survey, and Walk-Through Checklist are expected to provide O&M service providers and building owners/managers with the necessary guidance, feedback, and documentation necessary to optimize mechanical equipment and their buildings.

The project thanks Bob Davis and Dave Baylon, Ecotope Inc, Seattle WA, technical subcontractors to the project for contributing this material.

APPENDIX C. SIMPLIFIED ROOF TOP PACKAGE HVAC UNIT MONITORING

Due to the project's scope and limited resources, a streamlined monitoring set-up was used in four of the project's pilot buildings. The monitoring equipment consists of readily available, off-the-shelf temperature sensors and current transducers (CTs) from a well-known manufacturer. Taking data with one hour averages means the data loggers can operate for about two weeks before a technician must visit the site and retrieve data.

Overall cost of this type of logging is modest; about $500 is required to purchase sufficient CTs and temperature sensors to identify a change in economizer operation after an adjustment (or to notice an expected change has not occurred). It is also possible to indirectly assess changes in outside air fraction by comparing supply, return, and ambient temperatures, but this is not necessary if the outside air amount is measured directly with an averaging velocity pressure grid.

In the basic set up, the channels monitored are:

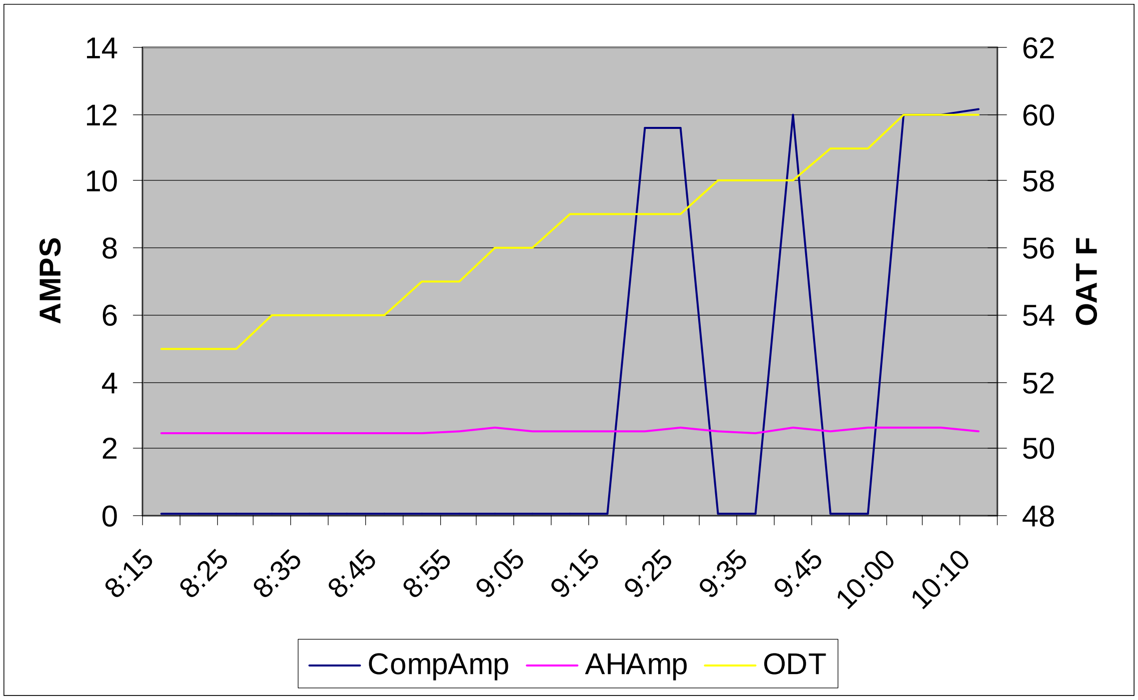
- Ambient temperature
- Supply air temperature
- Return air temperature
- Air handler status (run time)
- Compressor status (run time)
- Cooling call status (on/off; installed on 24 VAC circuit)

Note that in this configuration, actual running amps of the compressor are not measured. It is possible to do this, but there is added expense and also the type of electrical service (one phase or three phase) can make the installation more involved. If the technician is not prepared for a more detailed installation, or if budget is limited, this basic set up is advisable.

Once the pattern of outdoor temperature and cooling call status is determined, it is possible to see how much of the cooling cycle(s), defined as a continuous cooling call, is satisfied by the economizer and how much is satisfied by the compressor. The number of minutes of each cycle can be visually determined by looking at the graph of cooling call and seeing how much of the time requires only air handle operation (indicating economizer only). Visual inspection is relatively coarse; a more thorough treatment requires exporting logged data to a spreadsheet or analysis software package. If desired, cooling cycles can be binned by outdoor temperature and compared with the economizer changeover temperature to further refine the estimate of the economizer fraction.

An detailed view of about two hours of rooftop operation on one of the Spokane pilot buildings is shown in Figure C1. This rooftop unit used a non-aggressive economizer changeover (of about 55° F) so limited economizer operation would be expected. The air handler is not set to run continuously, so when it is on relatively horizontal line (magenta), we can assume either heating or cooling is occurring. Given the outdoor temperature and time of year (late September), the system is providing cooling. In the early part of the cycle, the system is economizing (air handler on but compressor off). Later in the cycle (about 9:15 am), the system has switched to full mechanical cooling (compressor amp channel shows this clearly). The system does cycle between economizer and compressor cooling later in the hour, indicating the economizer controller/sensor combination may in fact allow economizing at a temperature above 55° F (at least for short duration). Data collected later in the day, when outdoor temperatures are above 60° F, show only compressor cooling.

Figure C 1. Detailed View of Rooftop Cooling Operation



The project team thanks Bob Davis and Dave Baylon, Ecotope Inc, Seattle WA, technical subcontractors to the project for contributing this material.

APPENDIX D. RTU COMPONENT RESEARCH IN THE PACIFIC NORTHWEST

D1. SENSOR ACCURACY

Recent bench-level testing by Stellar Processes Portland, Oregon, and Ecotope, Inc. Seattle, Washington, (Ecotope was subcontractor to the rating system project) has shown a large range in packaged roof top unit (RTU) sensor accuracy. These inaccuracies are on the order of at least +/-5 F around a nominal outdoor temperature set-point that would mark the transition from air-side economizing to mechanical cooling operation. This is very significant since one well-known manufacturer provides over 75% of the sensors now in use in small packaged units.

The inaccuracy noted above applies to the dry bulb sensor; a large number of systems use enthalpy sensors, but the general directives given to installers in the Pacific Northwest by utilities sponsoring economizer programs has been to change out enthalpy sensors with dry bulb (given concerns about enthalpy sensor accuracy and also given the relatively dry outdoor air in available in this region for free cooling). This effect had been noted in earlier field research by Stellar. The sensor manufacture's literature suggests this effect, but provides no clear direction on what to do about it. The sensor's interaction with the economizer controller can further complicate the expected behavior of the economizer.

Stellar has shared the results of their tests with the sensor manufacturer. The response has been to redesign their dry bulb sensor. The new design, now in prototyping, will have a user-determined changeover temperature with +-2 F tolerance; the sensor will make the economizer circuit either open or closed, taking the controller out of the decision-making loop. If this sensor is successful, it should greatly simplify economizer set up and retrofit. The sensor should be priced similarly to the dry bulb sensor they have been selling since the early 90s (about $25 to the trade).

D2. THERMOSTATS

Commercial thermostats have also made strides. The newer Honeywell touch-screen commercial model is easy to program and works with many rooftop units. It also has a dedicated economizer output, which facilitates enabling reducing minimum outside air to zero during morning recovery (in heating mode). This means outside air will not have to be heated when non one is in the building. This feature enables reduction of natural gas use (or electricity, if the rooftop is a heat pump).

Another helpful thermostat development solves a potential wiring problem. Honeywell sells a combination thermostat/programmable logic controller (PLC) that only requires three control wires be run between the thermostat and the PLC (which sis installed inside the packaged unit). This allows enabling of a second stage of cooling AND morning warm-up in systems that have a control wire bundle of perhaps only 5 wires. In the past, this situation might have meant it would not be possible to enable second stage cooling and morning warm-up. Now, since only three wires have to go between the building space and the unit, more systems can be retrofit. The cost of the 3 wire thermostat/PLC combo is about the same as the commercial touch-screen stat.

As mentioned above, some commercial thermostats facilitate closing down the outside air damper during the heating recovery period so that outside air does not have to be conditioned. This offers a heating conservation strategy. This feature is not well known and until recently required installation of an additional relay on the most common models of commercial thermostat (Honeywell 7300 series). The new commercial touch-screen stat has a dedicated economizer output so enabling of this measure is relatively straightforward. As detailed above, if there are not enough low voltage wires from the indoor thermostat to the RTU, a 3 wire thermostat (VisionPRo IAQ) is an option.

D3. Demand Controlled Ventilation

Of potentially more benefit is demand controlled ventilation (DCV). In this scenario, a CO2 sensor controls how much/often outside air is brought in to dilute living space air. In addition to improving air quality when most needed, this approach reduces the amount of outside air that must be heated, thereby reducing heating energy usage. DCV requires a CO2 sensor, which until recently has been costly (over $300 to the installer) and an economizer controller that supports DCV.

The project team thanks Bob Davis and Dave Baylon, Ecotope Inc, Seattle WA, technical subcontractors to the project for contributing this material.

NATIONAL CENTER FOR ENERGY MANAGEMENT AND BUILDING TECHNOLOGIES

601 NORTH FAIRFAX STREET, SUITE 250

ALEXANDRIA, VA 22314

WWW.NCEMBT.ORG