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Executive Summary

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This report presents the results of secondary research and analysis of several emerging technologies and new efficiency program approaches performed as the initial phase of a project for the Evaluation, Monitoring and Verification (EM&V) Forum managed by the Northeast Energy Efficiency Partnerships (NEEP). ERS and its team members Dunsky Energy Consulting, Livingston Energy Innovations, and Opinion Dynamics investigated seven emerging technologies and four innovative program approaches with the overall objective of providing performance and savings guidelines allowing the Forum members to develop measures and programs that realize associated savings. A second phase of this project will conduct primary research into a selected subset of these investigated technologies and program approaches.

The Forum member organizations have long offered residential and commercial sector energy efficiency programs. Many of these programs are recognized as “best practice” programs that are transforming markets and significantly reducing energy demand and consumption. However, the program administrators are fully aware that efficiency efforts cannot be stagnant. As markets are transformed, best practice becomes standard practice and new technology and programmatic developments offer new opportunities. This current research effort seeks to provide solid strategies that support the introduction of innovative measures and programs while establishing defensible savings methodologies that will be supported by future process and impact evaluation results.

For each new program approach, we present:

- A description of the program approach, including the markets addressed and the general delivery strategy
- The potential to harvest previously unrealized savings
- A sample of related programs that are currently being offered
- Summary results of available studies and data
- Knowledge gaps and strategies to close those gaps
- Proposed delivery mechanisms
- Proposed savings algorithms and methodologies as appropriate

For each emerging technology we present:

- The current state of development of the technology
- Near future expectations of further technology development
- Concerns related to technical performance and/or market persistence
- Regional climate related issues where appropriate
- Current and recent program experience
- Knowledge and data gaps
- Proposed study areas to close gaps
- Proposed deemed savings with supporting algorithms
- Or, algorithms and methodologies that support the development of programmatic savings

Section 12 of this report presents an overview of EM&V issues related to the introduction of emerging program approaches and technologies. This section, prepared by experienced process and impact evaluation managers, focuses on methodologies to be utilized to assure confirmable savings associated with new opportunities.

Our summary of conclusions and recommendations catalogues the knowledge gaps and recommended deemed savings and algorithms. In addition it presents the team's recommendations regarding the technologies most appropriate for primary research during the second phase of this project.

The four program areas investigated are:

- **Commercial lighting design** – Program approaches that support the design and redesign of lighting systems on a lighting system performance basis, rather than a technology displacement approach
- **Commercial commissioning** – Programs that focus on obtaining and maintaining peak performance from installed equipment
- **Whole house retrofit** – Approaches that improve upon the overall energy performance of existing homes through comprehensive retrofits and/or renovations
- **Multi-family whole building retrofit** – Programs that address both tenant and common spaces with a whole building performance focus

The six emerging technologies addressed include:

LED lighting – Solid state LED technologies for residential and commercial applications.

Heat pump water heaters – Residential and light commercial domestic/service water heaters that utilize electric heat pump technology

Ductless mini-split systems – Air conditioning and heat pump systems for residential and light commercial applications that utilize an outdoor compressor/condenser, and an indoor air-handling unit with ductless conditioned air delivery

Biomass pellet heating systems – Wood pellet stoves, furnaces, and boilers for residential and light commercial applications

Advanced power strips – Power strips for plug-load devices that reduce or eliminate device power consumption during non-active modes

Set-top boxes – Residential electronic entertainment devices that deliver subscription-based content to televisions and digital recording devices

Establishing Savings Values for Emerging Technologies

We understand the desirability of establishing consistent deemed savings values for measures offered through efficiency programs. We also recognize that there are particular challenges to establishing such values. Our priorities for savings recommendations are as follows:

1. Propose deemed values or a range of deemed savings values.
2. Provide the assumptions, algorithms, and methodologies that support the deemed values and/or can be utilized to calculate savings.
3. Provide algorithms to be used to calculate savings for programs not utilizing deemed savings values, such as New York State C&I programs, and to calculate custom projects.
4. Propose additional research to close knowledge gaps that are barriers to the above approaches.

The very nature of emerging technologies dictates that there are factors that have yet to be discovered. Implementing programs and measures, especially on a pilot basis, should be an integral part of gathering the knowledge to fully support emerging technologies and innovative program approaches. The project team urges the Forum members to utilize the available data to introduce pilot efforts that, when properly tracked and evaluated, will provide the data needed to expand programmatic efforts.

Commercial Lighting Design

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2.1 Introduction

Efficiency programs have long relied on lighting measures for a substantial portion of their overall savings. In large part, lighting efficiency programs have focused on the adoption of advancing technologies as replacements for existing equipment or as substitutes for baseline, standard-practice equipment. Recently the gap between existing/baseline technologies and program promoted technologies has grown increasingly narrow, limiting the ability to harvest savings on this basis.

This issue is especially problematic for new construction and lighting redesign projects as baseline equipment for these projects has reached reasonably high efficiency levels, with only small reductions in power consumption available on a one-for-one substitution basis. As a result, program administrators are faced with incremental project costs and savings that do not provide favorable cost-effectiveness ratios.

As a result, program administrators are looking for new models for promoting lighting efficiency through lighting design mechanisms, rather than simple technology substitution. Because energy codes and standards, such as the International Energy Conservation Code (IECC) and ASHRAE Standard 90.1 utilize lighting design (rather than technology) metrics for commercial lighting efficiency, the adoption of lighting efficiency programs that utilize the same basic assumptions will provide consistency with other efficiency efforts and will be immediately familiar to design professionals.

In this document, we provide a short description of the lighting power density standard and describe programs around the country that are using it. Then, based on our close analysis of these current programs, we provide our recommendations for how to structure a similar program, including information on lighting controls, savings algorithms, and standard practice. Finally, we provide recommended evaluation procedures for a third-party evaluator as well as a summary.

2.2 The Lighting Power Density Standard

Lighting Power Density (LPD) has become the standard methodology by which lighting efficiency for commercial, industrial, and institutional buildings are measured for new construction and renovation projects. This standard is nearly universal with one important exception: energy efficiency programs where a fixture-to-fixture comparison is more the norm. LPD is the standard methodology for all versions of ASHRAE 90.1, the IECC, LEED protocols, Collaborative for High Performance Schools (CHPS) protocols, New Buildings Institute's (NBI) Advanced Buildings Core

Performance, Massachusetts Stretch Code, and all federal, state, and local public building construction protocols of which this team is aware.

LPD involves a simple concept and simple calculations: the total power (rated wattage) dedicated to lighting in a space divided by the area (ft^2) of the space, i.e., watts/ft^2. Codes and standards establish lighting power allowances (LPA) for a variety of building and space types. The LPA is the highest LPD that complies with code for that particular space type. The LPA values are published in a table that is displayed in the code.

LPD-based lighting efficiency programs simply require that LPDs lower than the current code LPAs be achieved. Program administrators that adopt LPD-based methodologies for promoting efficient lighting design for commercial spaces will be demonstrating guaranteed savings against code-based baselines and will be presenting concepts and methodologies that are already familiar to the design community.

Recommended LPD-based savings methodologies are presented in Section 2.4, following a discussion of lighting design program approaches.

The following are three important lighting design/code terms used throughout this report section:

1. **Lighting power density** – Installed lighting power (rated wattage)/area (ft^2). The lower the number, the less power consumed.
2. **Lighting power** – The total power associated with installed lighting in a space (LPD x ft^2)
3. **Lighting power allowance** – The maximum lighting power density or lighting power allowed by code or a code-based program for either an entire building or building spaces.

2.3 Current Commercial Lighting Design Program Models

Although most efficiency programs rely on technology-based lighting programs, there are lighting program models in place, or proposed, that focus on the design and overall performance of the lighting system. The following summarizes several such approaches:

2.3.1 California Multi-Utilities – "Savings by Design"

Several California utilities (Pacific Gas & Electric, Sacramento Municipal Utility District, San Diego Gas & Electric, Southern California Edison (SCE), Southern California Gas Company) participate in this program, which promotes efficient new construction design for lighting as well as other building systems. There are two program tracks: the "whole buildings approach" and the "systems approach." Both provide design assistance as well as financial incentives to the project owner. The whole buildings approach also provides incentives to the design team in some circumstances.

Whole Buildings Approach

This approach promotes integrated design methodologies and requires a building simulation model for the project. Efficient lighting design is rewarded only as a component of an overall design that outperforms the baseline. The overall building performance is the goal, so no particular lighting criteria is established.

Systems Approach

This approach allows for design assistance and financial incentives for the design of individual systems, including lighting systems. To qualify for incentives, lighting projects must be designed and installed at LPD's at least 10% lower than those mandated by code (California Title 24). The system must provide adequate light levels as recommended by the Illuminating Engineering Society (IES). Incentives for lighting systems are calculated at $0.05 per annualized kWh savings and $100 per peak kW savings. The program publishes a table with the Title 24 LPAs as well as the program LPAs at 10% below the Title 24 levels.

2.3.2 Northeast Utilities, National Grid, NSTAR, and Efficiency Vermont – "Performance Lighting"

Northeast Utilities, National Grid, NSTAR, and Efficiency Vermont all offer a version of Performance Lighting as an option for new construction, albeit with a few individual features and different program names. Efficiency Vermont handles all lighting design projects for buildings over 10,000 ft^2 with this program model. Northeast Utilities/Connecticut Light & Power offered the region's first performance lighting option. It offered to pay incentives for lighting designs with LPDs lower than the current code LPAs. Shortly afterward, NSTAR also adopted this approach.

This early program indeed rewarded designs with lower LPDs, but there were few restrictions on the lighting technologies utilized to obtain the lower LPDs, and the administrators found that they were often paying for designs that featured fewer numbers of fixtures that represented standard practice, resulting in higher than desired free ridership. Additionally, spaces were often under-illuminated leading to customer dissatisfaction and the possibility of customers adding lighting fixtures after occupying the building.

Performance Lighting II

In 2004, at the request of NGRID, ERS developed a revised version of the original Performance Lighting to include the following features:

- Two incentive tiers – Higher incentives are paid when advanced lighting technologies (fixtures and controls) are incorporated.
- Lighting levels – Applicants are required to supply point-by-point lighting calculations to demonstrate that delivered lighting levels were in line with IES recommendations.

Lessons Learned

This second version of Performance Lighting solved most of the free-ridership problems of the initial program, but staff found it difficult to market for the following reasons:

- Program administrators continued to offer prescriptive and custom lighting incentives for new construction projects. Given a choice, participants and staff tended to work with the familiar program structures rather than learn a new approach.
- Participants had difficulty identifying lighting fixtures meeting the second-tier requirements, often seeking the higher tier incentives when the fixture requirements were not incorporated in the design.
- Many design teams failed to provide point-by-point lighting calculations modeling the lighting levels in the project, and/or sufficient design documentation, adding burden to program staff and technical assistants.

Performance Lighting III

During program year 2009, the following changes were made to the Performance Lighting model used in Massachusetts:

- The two incentives tiers were adjusted to pay the higher incentive when lower LPDs were achieved, rather than rewarding the incorporation of advanced lighting technologies in designs.
- Certain space types (retail, warehouse, and industrial) were restricted to the lower first tier incentives due to relatively high efficiency levels achieved by standard practice in the service territories.

Savings Calculations

For both versions of Performance Lighting, savings are calculated by subtracting the installed lighting power for the space from the code mandated maximum lighting power allowed for the space type and then multiplying this number by the annual operating hours.

$$[Code\ LPA\ \times\ Area\ (ft^2) - Installed\ LPD\ \times\ Area\ (ft^2)]\ = kW\ savings$$

$$kW\ savings\ \times\ Operating\ hours\ =\ Annual\ kWh\ savings$$

2.3.3 Efficiency Maine – Simplified Performance Lighting for New Construction, Renovations, and High Performance Fixture Redesigns

With limited budgets resulting from declining System Benefit Charge funds, ERS worked with the Efficiency Maine Trust to modify Performance Lighting in order to provide a simplified program that assured savings compared with a code baseline, but required only limited technical assistance to implement.

This version of Performance Lighting is currently being introduced as a part of the Maine Advanced Buildings Program (MAB). MAB utilizes the New Building Institute's Advanced Buildings Core Performance protocol to provide a "reach code" program for new construction and major renovations. Core Performance includes lighting requirements that establish LPAs that are on average 15% lower than Maine's model code (IECC 2009). In order to maintain consistency across programs, Performance Lighting has adopted the Core Performance LPAs.

Applicants are required to design/install lighting systems at or below Core Performance LPA levels. In addition, the lighting fixtures installed must meet/exceed the efficiency levels of Efficiency Maine's prescriptive lighting program. This assures that standard practice fixtures are not installed. Although there is no point-by-point calculation required, applicants are required to demonstrate that proper lighting levels will be maintained. Because many successful projects are completed at lower lighting levels, IES lighting levels are not mandated but are recommended as guidelines.

Savings Calculations

Maine does not yet have a mandated statewide energy code. In jurisdictions where an energy code has been implemented it is used as the referenced LPA. For other jurisdictions the baseline may be adjusted for local standard practice. As with the other versions of Performance Lighting, savings are calculated by subtracting the installed lighting power for the space from the code or standard practice maximum lighting power allowed for the space type and then multiplying this number by the annual operating hours.

$$\frac{kW\ savings\ =\ [Standard\ Practice\ LPA\ \times Area\ (ft^2) - Installed\ LPD^{*}\ \times\ Area(ft^2)]}{1000}$$

$$Annual\ kWh\ savings\ =\ kW\ savings\ \times\ Annual\ operating\ hours$$

*Installed LPD must be at, or below Core Performance maximum allowance to qualify

Performance Lighting for Existing Fixture Replacement

Performance lighting is often utilized for major renovations. It is also a logical choice when replacing lighting fixtures with fixtures with different performance characteristics. For example, if replacing parabolic troffers with pendant mounted fixtures, the project is not likely to represent a one-for-one fixture replacement. Such a project lends itself to a performance lighting approach utilizing the existing fixtures as a baseline. Section 2.5.1 discusses savings methodologies for LPD based projects for existing buildings. Efficiency Vermont and Efficiency Maine both offer this as an option for existing buildings.

2.3.4 "Custom" Lighting for New Construction

Whether offering a version of Performance Lighting or not, most programs offer a custom lighting option that may be applied to new construction and renovation projects. Although this program model is applied in a variety of ways, it can be seen as a lighting design program depending on how it is delivered.

Instead of basing savings on LPD calculations, this custom model relies on reductions in lighting-fixture rated power (wattage) regardless of building or space area. The process can be summarized in the following five steps:

1. Identify the standard practice baseline fixtures and the associated rated wattages and installed costs.
2. Assign the proper rated wattage to the proposed fixtures and obtain the contracted installed costs.
3. Calculate the kW and kWh savings and the associated incremental cost of the project.
4. Assign an incentive level based on the incremental cost. This is typically set at 75% of the incremental cost.
5. Run the project through the program cost-effectiveness test.

Savings Calculation

The savings are calculated by subtracting the proposed lighting system wattage from the baseline system and then multiplying that number by the operating hours.

A significant issue with this program approach is that savings compared with code assigned baselines are not ensured. Incentives can be, and are, paid for projects that consume the same or more energy than code mandates. Also, program staff and designers have difficulty identifying appropriate baseline measures and assigning incremental costs.

2.3.5 Software Tool Approach

Program administrators have long discussed the possibility of a software tool that would assist participants in creating lighting designs that would automatically produce results that consume less energy than code mandates. Several years ago, the US DOE through Pacific Northwest Laboratory began developing such a tool. Work was periodically postponed due to funding and priority issues, but the tool is now available as Commercial Lighting Solutions (CLS), a web-based tool that is part of the Commercial Building Initiative. The tool currently covers office and retail spaces and with simple user inputs generates recommended designs for the space with fixture specifications and spacing criteria.

Earlier this year, several program administrators investigated the idea of providing incentives, or bonus incentives, for projects that incorporate CLS-generated designs. At the request of a non-utility partner (NUP), ERS ran several sample projects using the tool and found that although it incorporated an impressive user interface and was indeed easy to use, many of the lighting layouts produced offered no savings compared to code mandates or resulted in designs with higher LPDs than current codes allow. Significant savings could be obtained by selecting automatic lighting controls within the tool, but most of the control strategies incorporated were mandated by current codes.

CLS or a similar tool that generates viable energy saving lighting designs would be an excellent addition to program offerings, allowing users to quickly generate program eligible designs utilizing a variety of fixture types. Especially valuable would be the ability to influence designs that have not been put through a full creative process by a lighting design practitioner. Unfortunately, work has again been suspended on the CLS tool, and it is uncertain whether an effort to complete the tool will be funded.

2.3.6 Office of the Future Initiative

Several sponsors of the Forum also sponsor NBI's Office of the Future (OTF) initiative. This initiative seeks to bundle efficient lighting designs for offices with other efficiency measures including daylighting, plug load control, and HVAC. Lighting designs focus on premium efficiency fixtures and low LPDs. The program is now being piloted in several jurisdictions.

The approach for lighting is very similar to that used for Performance Lighting. Savings are calculated using the same methodology, although they will likely be bundled with savings from the other measures.

2.3.7 Other Program Models

The following programs offer variations on the above themes:

New York Energy Smart Commercial Lighting - This is a lighting design program offered through NYSERDA's Business Partners. It mandates LPDs of at least 10% below NY code, while promoting quality lighting through such metrics as color rendering index (CRI) and glare control. Savings for this program are calculated using the Performance Lighting methodology.

BC Hydro Energy Efficient Lighting Design – BC Hydro pays a $1,000 incentive for designs that achieve LPDs that are at least 10% below those mandated by the Canadian Model Building Code. Savings are calculated using the Performance Lighting methodology

Eugene Electric Energy Smart Design Lighting – This program pays prescriptive incentives for certain components of an efficient lighting design, such as automatic controls and task lights. There are no LPD targets or other lighting design goals. Most other program administrators would not identify this as a lighting design program, and the savings assumptions would be deemed as they are for most prescriptive programs.

In addition, Eugene Electric supports and participates in NEEA's BetterBricks program and an associated regional network of design assistance labs[1] where Northwest architects and engineers have access to technical resources of credible and unbiased information that help them incorporate high performance building practices into their commercial building designs. Each lab provides access to information, tools, and resources on integrated design and other high performance building practices as well as a variety of advisory services including lighting and daylighting system modeling.

2.4 Recommendations for Harvesting and Assessing Savings Associated with Commercial Lighting Design Programs

After investigating the various program models associated with commercial lighting design, it is clear that the savings associated with such programs should be based on LPD and the control of installed lighting systems. Design teams have long expressed concern that efficiency programs focus too much on lamp, ballast, and fixture performance and not enough on overall design performance. LPD-based programs allow designers flexibility and encourage thoughtful planning not only for new construction, but also for renovation projects where one-for-one replacement may not be the best approach. LPD methodology provides the following additional benefits for market actors and program administrators:

- **The concepts are familiar to market actors.**
    - The methodology is identical to the Energy Code methodologies that market actors already follow.
    - "Reach" codes, LEED, and nearly all high performance building protocols utilize the LPD methodology.
    - For new construction and renovations, the standard design documents developed by design teams are all that is needed for project documentation.
- **It is easy to implement.**
    - Savings calculations are simple, replacing custom lighting calculations based on incremental cost formulas.
    - Assuming that custom lighting programs are replaced, no additional staff burden is anticipated following initial training.
- **It establishes a defensible and known baseline.**
    - The solid, defensible baseline established is backed by legal mandates.
    - The baseline replaces measure/technology baselines that do not reference energy codes.

[1] http://www.betterbricks.com/design-construction/integrated-design-lab-network

- The methodology uses that baseline to define project savings, which decreases the risk of a third-party evaluator reducing estimated savings through use of a different baseline.

2.4.1 A Recommended Program Model for LPD-Based Savings Calculations

This program model is a simplified version of Performance Lighting that is described in Section 2.3.2. The base program is fully expandable and several options are presented below.

The basic program assumptions include the following:

- **Program offerings**
  - Offer incentives for lighting designs/systems that outperform the lighting power density (LPD) allowances of the Energy Code currently mandated. IECC 2009 LPAs are displayed in Table 2.1 Set incentives at a rate per building, per kW, and/or per kWh saved.
  - Allow the use of ASHRAE 90.1 standard space-by-space or the IECC building area methods, but do not allow customers to mix methods within a project.
  - Provide limited design guidance such as IES standards (glare control, color rendering, visual comfort, etc.) to promote lighting quality.
- **Documents to create**
  - A simple program application that is designed to initiate the process.
  - A table of target lighting power density (LPD) allowances. Publish this to ease participant burdens. Table 2.2 provides a sample of guidelines from the California Savings by Design program.
  - A document that describes when the existing LPD may be used as the baseline for a non-code impacted retrofit project and when the code LPA must be used. See Section 2.5.1 "Exception – Program Motivated Lighting Redesign/Replacement Projects" for guidance on selecting the existing LPD as the baseline.
- **Implementation details**
  - Align target LPDs with "reach/stretch" codes being implemented in the program territory.
  - Promote emerging lighting technologies that offer efficiency levels at least as high as those promoted through other program offerings. However, as a design program, there should be enough flexibility to allow quality projects that do not fit the rule structures of other programs.
  - Program administrators should reserve the right to negotiate the final project incentive to avoid free ridership and eliminate the incentive to under-illuminate spaces.
  - Establish incentives at levels that encourage design teams to strive for lower LPDs than are typically achieved through prescriptive program offerings.
  - Require the same project documentation that is needed for code compliance (plans, specifications, lighting schedule, LPD calculations).

- Reserve the right to require design modifications or reject projects if lighting LPD or quality targets are not met.
- If the current overall program structure involves negotiating the final incentive, extend that process to the lighting design program.

Table 2.1. IECC TABLE 505.5.2; Interior Lighting Power Allowances

Building Area Type[a]	LPA
Automotive Facility	0.9
Convention Center	1.2
Court House	1.2
Dining: Bar Lounge/Leisure	1.3
Dining: Cafeteria/Fast Food	1.4
Dining: Family	1.6
Dormitory	1
Exercise Center	1
Gymnasium	1.1
Healthcare-Clinic	1
Hospital	1.2
Hotel	1
Library	1.3
Manufacturing Facility	1.3
Motel	1
Motion Picture Theater	1.2
Multi-Family	0.7
Museum	1.1
Office	1
Parking Garage	0.3
Penitentiary	1
Performing Arts Theater	1.6
Police/Fire Station	1
Post Office	1.1
Religious Building	1.3
Retail[b]	1.5
School/University	1.2
Sports Arena	1.1
Town Hall	1.1
Transportation	1
Warehouse	0.8
Workshop	1.4

a. In cases where both a general building area type and a more specific building area type are listed, the more specific building area type shall apply.

b. Where lighting equipment is specified to be installed to highlight specific merchandise in addition to lighting equipment specified for general lighting and is switched or dimmed on circuits different from the circuits for general lighting, the smaller of the actual wattage of the lighting
equipment installed specifically for merchandise, or additional lighting power as determined below shall be added to the interior lighting power determined in accordance with this line item.

Calculate the additional lighting power as follows:
Additional interior Lighting Power Allowance = 1000 watts + (Retail Area 1x 0.6 W/ft^2) + (Retail Area 2x 0.6W/ft^2) + (Retail Area 3x 1.4W/ft^2) + (Retail Area 4x
2.5W/ft^2). Where:

Retail Area 1 = The floor area for all products not listed in Retail Area 2, 3, or 4.
Retail Area 2 = The floor area used for the sale of vehicles, sporting goods and small electronics. Retail Area 3 = The floor area used for the sale of furniture, clothing, cosmetics and artwork. Retail Area 4 = The floor area used for the sale of jewelry, crystal and china.

Exception: Other merchandise categories are permitted to be included in Retail Areas 2 through 4 above, provided that justification documenting the need for additional lighting power based on visual inspection, contrast, or other critical display is approved by the authority having jurisdiction.

Notes

- ❑ Retail spaces should be adjusted for standard practice for the specific type of retail. Big box retail is often designed with LPDs lower than code values as standard practice.
- ❑ Warehouse, parking garages, and bars/lounges are best considered on a custom basis as the standard practice lighting LPD varies greatly.

Table 2.2. Sample Guidelines from California Savings by Design

LIGHTING GUIDELINES

Type of Use	2008 T24 Allowance	Savings By Design Maximum W/sf
COMPLETE BUILDING METHOD		
Auditoriums	1.50	1.35
Classroom Building	1.10	0.99
Convention Centers	1.20	1.08
Financial Institutions	1.10	0.99
General Commercial/Industrial: High Bay	1.00	0.90
General Commercial/Industrial: Low Bay	1.00	0.90
Grocery Stores	1.50	1.35
Industrial/Commercial Storage Buildings	0.60	0.54
Library	1.30	1.17
Medical Buildings and Clinics	1.10	0.99
Office Buildings	0.85	0.77
Parking Garages	0.30	0.27
Religious Facilities	1.60	1.44
Restaurants	1.20	1.08
Schools	1.00	0.90
Theatres	1.30	1.17
All Others	0.60	0.54
AREA CATEGORY METHOD		
Auditoriums	1.50	1.35
Auto Repair	0.90	0.81
Beauty Salon	1.70	1.53
Civic Meeting Place	1.30	1.17
Classroom/Lecture/Training/Vocational Rooms	1.20	1.08
Commercial/Industrial Storage (Cond and Uncond)	0.60	0.54
Commercial/Industrial Storage (Refrigerated)	0.70	0.63
Convention/Conference/Multipurpose/ Meeting Centers	1.40	1.26
Corridors/Restrooms/Stairs and Support Areas	0.60	0.54
Dining	1.10	0.99
Electrical/Mechanical Rooms	0.70	0.63
Exercise Center/Gymnasium	1.00	0.90
Exhibit/Museum Areas	2.00	1.80
AREA CATEGORY METHOD CONT'D.		
Financial Transactions	1.20	1.08
General Commercial/Industrial: High Bay	1.00	0.90
General Commercial/Industrial: Low Bay	0.90	0.81
General Commercial/Industrial: Precision	1.20	1.08
Grocery Sales	1.60	1.44
Hotel Function Area	1.50	1.35
Housing: Senior Housing Public & Common Areas	1.50	1.35
Housing: Multifamily / Dormitory Public & Common Areas	1.00	0.90
Kitchen/Food Preparation	1.60	1.44
Laboratory, Scientific	1.40	1.26
Laundry	0.90	0.81
Library Reading Areas	1.20	1.08
Library Stacks	1.50	1.35
Lobby: Hotel	1.10	0.99
Lobby: Main Entry	1.50	1.35
Locker/Dressing Room	0.80	0.72
Lounge/Recreation	1.10	0.99
Malls and Atria	1.20	1.08
Medical/Clinical Care	1.20	1.08
Office (>250 square feet)	0.90	0.81
Office (≤250 square feet)	1.10	0.99
Parking Garages: Parking Area	0.20	0.18
Parking Garages: Ramps and Entries	0.60	0.54
Religious Worship	1.50	1.35
Retail Merchandise Sales/Wholesale Showrooms	1.60	1.44
Tenant Lease Space	1.00	0.90
Theaters: Motion Picture	0.90	0.81
Teaters: Performance	1.40	1.26
Transportation Function	1.20	1.08
Waiting Areas	1.10	0.99
All Others	0.60	0.54

Program Options

The following are possible options for the base program described above that could obtain additional savings while promoting high quality lighting:

- ❑ Offer bonuses for the use of emerging/advanced technologies such as LEDs; daylighting; indirect, volumetric, and bi-level fixtures; etc.
- ❑ Offer bonus incentives for designs submitted by lighting designers certified through the IES, NCQLP, or other recognized organization.
- ❑ Develop design templates for common space types that will provide participant guidance.

- Require and or offer to perform point-by-point lighting calculations to assure adequate lighting levels.

2.4.2 Incentives for Lighting Controls

Where appropriate, efficient lighting designs should include automatic lighting controls. Program administrators need to be cautious as nearly all states throughout the region have adopted IECC 2009 as the base energy code. IECC 2009 requires automatic lighting controls in many spaces/buildings:

- All enclosed office and educational spaces must incorporate bi-level switching, occupancy control, daylight control or timer control.
- All buildings over 5,000 ft^2 must have timer or occupancy control of nearly all lighting circuits.
- Electric lighting for daylit spaces must be on separate circuits with their own switch or automatic control.

Lighting design programs should offer incentives for automatic lighting controls that provide additional savings beyond the above code mandates.

2.4.3 Special Considerations for LPD-Based Programs

As with all program models, there are some potential issues to be avoided, primarily in the area of supporting standard practice that can lead to higher rates of free ridership. Retail and warehouse spaces have both been assigned relatively high LPAs by codes and standards. For retail, especially big-box stores, designers are routinely installing systems well below code LPAs as standard practice. Warehouse spaces are difficult to assess on an LPD basis as the visual demands vary greatly depending on the items stored and whether or not the reading of product tags is necessary. For these reasons, program administrators should carefully consider projects for these spaces, exercising the right to adjust incentives as needed or simply apply prescriptive incentives.

In addition, it is important to understand and communicate that mezzanines, crawlspaces, inactive storage areas, and basement areas are not to be included in LPD calculations. Our experience tells us that area measurements should be checked by program staff or technical assistants as participants are often unsure as to what spaces to include, producing inaccurate LPD calculations.

2.5 Recommended Savings Methodologies and Algorithms

Calculating the potential savings for LPD-based lighting design programs is straight forward. Incentives are to be provided for lighting projects that obtain lighting power density (LPD) levels at or below the lighting power allowance (LPA) levels established by the program administrators. In general, it is recommended that these levels be set at least 10% lower than current code mandates. The steps involved in calculating the savings are as follows:

1. Identify the building area or space types for the project.
2. Measure and calculate the building or space area.
3. Assign each fixture type a rated wattage value. In most cases this is the rated wattage of the ballast when used with the selected lamps. Many programs utilized a rated wattage chart for ballast and lamp combinations, which will also provide accurate data. Nominal lamp wattage is not accurate for the calculation of LPD.
4. Calculate the code allowed lighting power (connected lighting load) for the space: $Code\ LPA \times ft^2$.
5. Calculate the designed LPD for the space ($Total\ rated\ wattage/ft^2$) and compare against qualifying LPD chart to determine eligibility.
6. Calculate the designed lighting power (connected lighting load) for the space: $Designed\ LPD\ x\ ft^2$.
7. Calculate the demand savings: $(Code\ allowed\ connected\ lighting\ load - Designed\ connected\ lighting\ load)/1000 = kW\ savings$.
8. Calculate energy savings: $kW\ savings \times Operating\ hours = kWh\ savings$

Savings Algorithm

New Construction, Major Renovations, Space Usage Change

$$kW\ savings = \frac{(Code\ Baseline\ LPA \times ft^2) - (Design\ LPD \times ft^2)}{1000}$$

$$kWh\ savings = kW\ savings \times Average\ operating\ hours \times WHFe$$

where,

$WHFe$ = Waste heat factor. The waste heat factor is used to adjust the savings for the interactive effects with HVAC systems. Lighting design programs are a subset of program lighting efficiency programs. The waste heat factor should be consistent across the sponsor's commercial lighting programs. For example, programs utilizing the Mid Atlantic TRM should adopt the factor of 1.13 established for fluorescent lighting measures.

2.5.1 Exception – Program Motivated Lighting Redesign/Replacement Projects

Current energy codes now impact nearly all renovation projects. Although permits are often not pulled, and energy code provisions are often ignored on renovation projects, code provisions are is in force when replacing 50% or more of the lighting fixtures in a space. As a result the same methodology for calculating savings for new construction is appropriate for building renovation projects. However, when the primary motivation for the project is energy savings, it can be argued that the baseline is the existing lighting and not the current code provisions.

We recommend the following guidelines for choosing the baseline for replacing fixtures in existing building projects:

- Baseline = Current code LPD allowance:
  - A change in the use of a space
  - A remodeling project that includes new lighting
  - Replacing lighting for reasons other than energy reduction (aesthetics, reliability, increased illumination, etc.)
- Baseline = Existing LPD for the space:
  - A lighting redesign motivated by energy savings
  - A one-for-one lighting fixture replacement motivated by energy savings

Non-Code Impacted Renovation Projects (IECC 2009 impacts nearly all retrofit projects, although local jurisdictions interpret this differently.)

$$\frac{kW\ savings\ =\ (Existing\ LPD\ \times\ ft^2) - (Design\ LPD\ \times ft^2)}{1000}$$

$$kWh\ savings\ =\ kW\ savings\ \times\ Average\ operating\ hours$$

2.5.2 Savings Methodologies for Automatic Controls Associated with Lighting Design Programs

As stated in Section 2.4.2, current codes require automatic lighting controls for most commercial spaces. The exceptions are related to areas where safety is a significant concern. However, code does leave room for advanced lighting controls beyond the required controls. For example, if office spaces are designed to meet code with bi-level switching, and occupancy, vacancy, or daylight control could also be installed increasing overall savings. Likewise if a timer system is utilized to meet a code requirement, an occupancy control could be substituted or added to allow for additional savings.

Savings for the enhanced automatic controls may be small as a result, yet program administrators will likely wish to promote additional controls where feasible.

Forum members' programs already include automatic lighting controls as a measure, with either deemed savings or a savings algorithm being applied. In order to maintain consistency, program administrators should adopt those same methodologies (and/or deemed values) for an LPD-based lighting design program. The only caution is to avoid recording and reporting savings that are associated with code mandated controls. Therefor the generic savings algorithm could be stated as:

$$Program\ savings = Watts_{ctrl} \times Hr \times \%S2 - Watts_{ctrl} \times Hr \times \%S1$$

where,

$Watts_{ctrl}$ = Lighting wattage controlled

Hr = Total lighting operating hours

$\%S1$ = Percentage savings from code required control

$\%S2$ = Percentage savings from enhanced automatic control

2.5.3 Lighting Design Program Coincidence Factors

Coincidence factor for lighting programs is defined as the fraction of demand savings associated with lighting that occur during identified peak demand periods. The assumptions and results will vary with the particular program and its peak demand periods, which are greatly affected by seasonal and geographical weather patterns. The calculated coincidence factors will also vary by building type with occupancy patterns. Lighting is especially sensitive to occupancy patterns.

However, the coincidence factor calculations for the lighting design programs discussed here will be no different than they are for any other lighting programs, with three exceptions:

- **Daylight design strategies that incorporate daylight switching or dimming controls** - Depending on compass orientation, shading coefficients, daylight apertures, and control schemes, daylight savings will affect the coincidence factor of the lighting project. For properly designed daylight systems, automatic controls and/or occupants will turn off or dim lighting fixtures during some part of the workday. For north or south orientations the daylight contributions will be most significant between the hours of 10 a.m. and 2 p.m. east and west orientations will obviously favor morning and afternoon savings respectively. Although no hard data exists, the New Buildings Institute will soon be releasing a Daylight Pattern Guide, which purports to be useful for determining daylight coincidence.
- **Lighting designs with significant utilization of occupancy or vacancy controls** – Automatic occupancy-based controls produce additional system savings, but those savings vary with operating hours. A percentage of the lighting fixtures will be off at any particular time in offices and schools that have many individual spaces. In most cases this will produce some additional savings during peak periods. Programs that promote occupancy-based controls and utilize coincidence factors will have established coincidence factors for each control measure. These control coincidence factors should also be applied to LPD-based programs, which incorporate automatic controls.

- **Layered lighting designs** – So-called "layered" lighting designs provide an overall low ambient light level, utilizing a second level of lighting at work areas. This is sometimes done with dual-level switching, but is also accomplished with a second set of task-based lighting. Assuming an effective control strategy, layered lighting will increase savings during the normal workday, affecting the coincidence factor.

The Forum's Commercial and Industrial Lighting Load Shape study conducted by KEMA/RLW Analytics includes extensive data on lighting coincidence factors and builds upon an earlier RLW study on lighting coincidence factors and load shapes for the New England State Program Working Group (SPWG). The study, which is being used to report peak demand savings to the New England ISO, concludes, in part, that the heating season coincidence factor for commercial lighting programs averages approximately 70%, while the cooling season factor averages approximately 50%. There are many details and variations that contribute to these averages. The full report may be downloaded at: [http://neep.org/emv-forum/forum-products-and-guidelines.](http://neep.org/emv-forum/forum-products-and-guidelines)

2.6 STANDARD PRACTICE AND CODE MANDATES

Although many programs have adopted the current code requirements as the baseline for new construction and renovation projects, there are arguments to be made for adjusting the baselines for various projects and project categories. In Massachusetts there is an effort underway to determine the relationship between code mandates and actual baseline practices for new construction. In addition, many states have recently completed code compliance studies associated with ARRA funding for energy efficiency projects. ERS recently completed such a study for the State of Maine and is currently on the team conducting the Massachusetts study.

The relationship of actual baseline practices to code mandates will vary by state, region, and building type. How aggressively the code is enforced is a major factor, but the extent of code compliance training and the success of new construction efficiency programs are also determining factors. Although by no means a definitive list, some general areas where this team has found that standard practice deviates from code mandates, include:

- **Better-than-code practices**
  - Big-box retail is often constructed with LPDs significantly below code mandates, as retails chains have adopted nationwide standards for efficient lighting systems.
  - Warehouse spaces are by default often built with LPDs lower than code levels, and the design LPDs vary greatly with the type of goods stored, the frequency of rotation/access, and the packaged goods labeling protocols.
- **Worse-than-code practices**
  - Small and specialty retail often incorporate LPDs above code mandates as incandescent lighting is often used to display merchandise, and the methodology for calculating LPD for track lighting is often misunderstood and/or not included in calculations.

- Renovation projects are required to comply with energy codes, and this mandate was strengthened with the introduction of IECC 2009. However, the energy code is often ignored by both designers and code officials for renovation projects.
- Lighting control commissioning – Codes require that lighting controls be commissioned following installation. The process is often neglected, resulting in poorly operating controls, minimizing savings and/or leading to the disabling of controls after building occupancy.

We believe that strong, empirical evidence from baseline studies is required for a program to adjust baseline and obtain additional savings by accounting for the practices that lead to worse-than-code projects. If allowed by regulatory agencies, program administrators should consider adjusting baselines from code to be better aligned with standard practice. Additionally, the program should realize that there are some practices that are better than code and adjust the program baseline to account for this practice. By doing so, the risk of a third-party evaluation team reducing savings for these types of projects is lowered.

2.7 Evaluation Procedures for Lighting Design Programs

This section presents recommended evaluation procedures for commercial lighting design programs.

2.7.1 Evaluation Method

Evaluation of gross impacts for projects through a lighting design program cannot use a deemed value approach. The evaluation must perform the following tasks to accurately assess the gross savings associated with projects:

1. Determine if the calculated savings are correct for a sample of projects and adjust back to the entire database as needed.
   a. Review the calculations to be sure that the appropriate algorithm is used.
   b. Review the inputs to be sure that they match the expected inputs from the project files.
2. Determine if the data as entered in the program tracking database is accurate.
   a. Sample from the entire set of projects and compare the hard copy information to the electronic information to be sure it matches. Adjust the program tracking database as needed based on these results.
3. Determine if the site information matches the application information.
   a. Perform on-site data collection to verify installations of measures (i.e., in-place-and-operating type of verification).
   b. Re-estimate LPD based on information found on-site to be sure that the LPD as specified in the application matches.
   c. Closely assess if the controls found require additional M&V through metering to more accurately capture savings at the site.
   d. Adjust the entire database as needed based on the on-site effort.

Not all evaluations have sufficient budget to perform the third task as it requires on-site data collection of sufficient number of projects to enable adjusting the entire database of savings. The program may want to judiciously use on-site realization rates found in one year across several years. Additionally, the program may choose to closely assess newer trade allies until they are comfortable that the paperwork is closely aligned with reality.

All components of the evaluation may be subject to sampling as the population of projects may be too large to cost-effectively perform evaluation of all projects. When this is the case, the evaluation team must use sample designs that optimize the number of sample points chosen to fulfill meeting the desired precision level. This sample design must be based on the expected energy (or demand[2]) impacts, not simply the number of projects.

This type of program does not lend itself well to gross impact evaluation using telephone survey data. While often done for prescriptive programs, the specificity of a LPD cannot be accurately captured over the phone.

We do not discuss net impact evaluation in this document.

2.7.2 Data Collection

Several critical gross impact evaluation data collection needs are associated with lighting design programs. The data typically collected for prescriptive and custom lighting program evaluations will not provide the information needed to assess the gross impact realization rates of lighting design programs. Assuring that the specified ballasts and lamps were installed and that operating hours were accurately predicted will only provide part of the needed data. Below is a list of additional data that should be collected by evaluators.

In data requests from program administrators, make sure that the following are provided:

- ❑ Lighting layouts either from the electrical plans set or as submitted with the application
- ❑ Lighting fixture and controls schedule, including rated wattage
- ❑ LPD calculations performed for savings calculations in electronic form
- ❑ Savings calculations for kW and kWh in electronic form

When on-site data collection is part of the evaluation, it should include the following for each of the sample of sites chosen:

- ❑ Information to allow for a calculation of current lighting power density
    - ➢ Ballast catalog number for each fluorescent fixture type
    - ➢ Lamp data

[2] Sampling on demand impacts is rare, but it does lead to different sample point choices than using energy.

- Fixture counts for a representative area or entire building depending on project size
- Building area measurements for the above areas

- Automatic controls inventory and the associated fixtures controlled
- Operating-hours information from project owners
- Power metering and data-logging of lighting circuits as needed

2.8 Summary Recommendations

Influencing the energy efficiency of lighting designs represents an excellent opportunity for efficiency programs. However, the opportunity cannot be fully realized through lighting technology recommendations. Program administrators should embrace the same methodologies utilized by lighting designers, electrical engineers, and code officials: lower LPDs and control of the lighting connected load. Advanced technologies such as LEDs, low power ballasts, high efficiency fixtures, bi-level switching, dimming, etc. are a means to those ends.

Evaluators of new construction lighting programs should familiarize themselves with how energy codes assess lighting energy usage and how the evaluated program calculates savings before conducting field work. Simply recording the technologies installed and checking the results against program documents will not result in accurate realization rates. Collecting the needed data is not difficult by any means, but evaluation staff not trained in basic energy code procedures are likely to collect incomplete data.

Adopting an LPD-based lighting design program and savings methodology will allow the accurate harvesting and reporting of savings for new construction and renovation projects. Lighting designers will appreciate the flexibility of not being directed to specific lighting measures, and evaluators may calculate and report improved realization rates.

Like all program designs, additional research will lead to improved implementation. Based on our analysis, we suggest that the following areas be considered:

- Perform empirical research, such as lighting baseline studies, to help gather the evidence needed to support the use of a baseline that differs from current code.
- Review the deemed inputs for control savings measures to determine if they are defendable and based on empirical data. If not, perform research to obtain this information.
- Review the current measure cost information planned to be used for the program and be sure that it accurately captures the true incremental measure costs associated with the fixtures in a LPD project. If not, perform research to obtain values that can be applied across all projects in the program.

Commissioning Program Approaches

3

3.1 INTRODUCTION

Commissioning (Cx) is the systematic process of evaluating, testing, and documenting the equipment and systems within a facility to ensure that they meet the defined performance objectives and criteria and operate in an integrated and optimized manner. In its most rigorous form, commissioning is an all-inclusive process encompassing planning, verification, documentation, and training of facility personnel. Proper commissioning of facility equipment and systems not only leads to energy efficiency and savings, but can also improve indoor air quality and occupant health and comfort and reduce equipment downtime and maintenance costs.

The importance of commissioning is widely recognized and accepted, but relatively few new buildings undergo a formalized commissioning process with documented results. Even those buildings that are successfully commissioned slowly lose their optimization over time to changing equipment, changing occupancy, and modification of system settings. Recommissioning of these facilities represents an important opportunity to achieve cost-effective savings and return existing facilities to optimum performance levels. Retrocommissioning (RCx) is the process of commissioning existing facilities that were not properly commissioned during construction. RCx differs from recommissioning primarily in the level of effort required to understand the performance objectives of the facility and identify and document the capabilities of the existing equipment and systems to meet these objectives. Continuous commissioning is the practice of continuously monitoring output from building automation systems and performing specific functional testing procedures at periodic intervals to ensure facilities sustain optimized levels of performance.

Commissioning is important for all systems within facilities, including but not limited to mechanical, electrical, structural, building envelope, and fire protection. The focus of this section of our report will be on commissioning, recommissioning, and retrocommissioning of HVAC and automated lighting control systems in commercial and industrial facilities. We will include a review of programs that are presently being offered, a discussion of the components that comprise various types of programs, the level of savings that can be anticipated, and suggestions for measurement and verification (M&V) strategies and practices that should be employed for these types of programs.

Throughout this section the term "commissioning" will be used generically to refer to the commissioning of either new or existing facilities. If the context is intended only to apply to one or the other, it will be clearly articulated in the text.

3.2 PROGRAM MODEL OVERVIEW

While the benefits of commissioning have been acknowledged for decades, the prevalence and utilization of programs that promote and help fund commissioning efforts are relatively low.

A 2004 ESource focus report on building commissioning indicates that only about a dozen programs for promoting and/or supporting commissioning efforts were in place at that time. Descriptions of a few of the more established and successful programs and a pilot program that ERS is presently implementing for Efficiency Maine will be described in Section 3.4.

Typically, commissioning programs for existing buildings (RCx) provide one level of incentive to support the investigation or discovery phase (generally ranging between 50% and 100% of this investigative cost) and a second round of funding to help support implementation of measures *resulting* from the discovery phase. The implementation phase is typically limited to 50% of total costs and/or is aligned with other technical assistance efforts.

For new construction, the support for commissioning is typically provided by subsidizing the commissioning agent's fees. As with RCx, the subsidy usually ranges from 50% to 100% of the fees. Deficiencies uncovered by the commissioning process during construction are typically corrected as part of the construction process. Simple adjustments to the sequence of operations of systems are often performed under the initial commissioning contract. Major redesign or reconfiguration of newly installed systems is not directly funded through the commissioning program, but is handled either as corrective action by the design/construction team or is considered an upgrade to the construction project.

Most programs require participants to utilize commissioning agents with demonstrated experience or proficiency in the appropriate technologies. Some programs pre-screen commissioning agents and provide lists of approved providers that are eligible for a cost-shared service.

3.2.1 Screening Projects

Not all projects offer cost-effective commissioning opportunities. A screening process is utilized to define eligible participant projects. Common criteria are the area of conditioned space, the facility end use, the complexity of systems, and the energy utilization index. For retrocommissioning projects, the age of the facility or systems and knowledge of increased energy usage are important factors.

For recommissioning and RCx programs, the process typically involves an initial site assessment by a qualified commissioning agent who submits a proposal for costs associated with the investigation phase and assists the participant in preparing an application. Funding for the commissioning effort usually involves a negotiation rather than the prescriptive assignment of incentives.

The deliverable for this investigation phase represents an "interim report of findings" that provides the results of functional tests, summarizes the existing conditions, and provides budgetary costs and projected levels of savings for proposed remedies. Commissioning agents work closely with program staff or their technical contractors to make determinations related to the eligibility and cost-effectiveness of the proposed measures for implementation-phase funding.

Ideally, the commissioning agent follows the project through implementation, oversees follow-up testing to confirm that the intended results are attained, and revises the interim report to reflect final conditions.

A final critical step that is integral to proper commissioning is the preparation or updating of O&M manuals, the training of facility personnel with regard to changes that have been implemented, the importance of ongoing maintenance, and the impact of setpoint modifications. Unfortunately this step is frequently under-implemented or omitted altogether. Failing to properly complete this final step in the process has a significant negative impact on the persistence of savings.

3.2.2 Typical Commissioning Measures

Measures that result from a commissioning process vary widely from site to site depending upon the facility, the existing infrastructure, the level of automated control, and the intended function. The following is a list of the more commonly proposed measures.

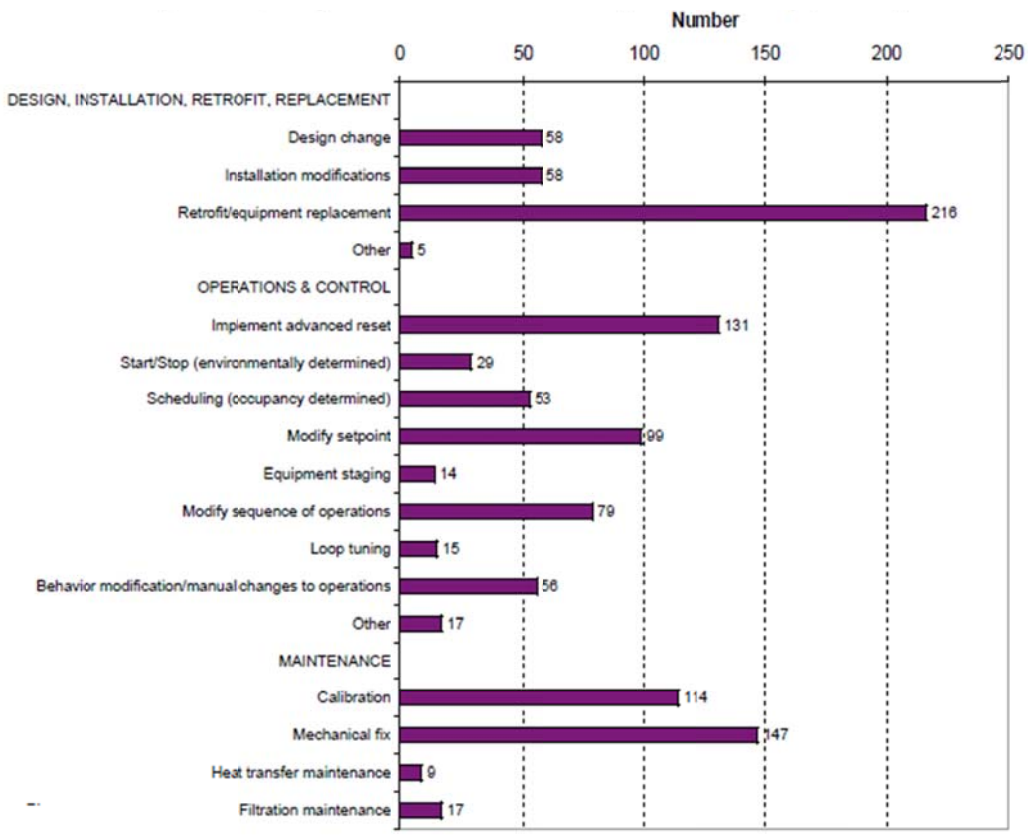
- **Calibrate or replace sensors** – Building automation systems rely upon signals from a large number of sensors that provide information related to temperatures, humidity, flow, pressure, CO_2 levels, light levels, occupancy, and a variety of other parameters. Commissioning includes tests to ensure sensors are functional and calibrated. Calibration and/or replacement of sensors is one of the most common commissioning measures.
- **Adjust/repair economizers, dampers, valves** – Poorly tuned or malfunctioning equipment such as dampers, valves, seals, actuators, linkages, and economizers can result in increased supply fan energy requirements, increased heating and cooling loads, improper ventilation rates, and premature equipment degradation from improper operation.
- **Adjust automatic temperature settings** – Unoccupied period setbacks and reset schedules are frequently modified by building operators in an attempt to resolve comfort or performance issues in the facility. Frequently the root cause of these performance issues is a malfunctioning sensor, damper, actuator, or other control device. Optimization of these schedules after sensors and control devices are repaired is an essential part of the commissioning process.
- **Modify staging or sequencing** – Part-load performance characteristics of boilers, chillers, and air-handling units should be evaluated, and operation should be coordinated in a manner that maximize system efficiency as loading on the systems varies.
- **Develop control strategies based on hours of operation** – Motors, fans, pumps, and air handlers should be scheduled to run based on the needs of building tenants and operating hours rather than a 24/7 schedule.
- **Optimize static pressure control setpoints** – Fan and pump speed and the resulting flow are frequently controlled with VFDs. Generally the speed is modulated based on a static pressure setpoint. These setpoints are frequently set conservatively high in order to ensure 100% system performance at “design” or worst possible conditions. Setpoints are often so conservative that VFDs continuously operate at full speed, negating the savings they were

intended to produce. Commissioning involves optimizing static pressure setpoints to achieve maximum savings while maintaining acceptable performance at all conditions.

- **Eliminate simultaneous heating and cooling; minimize reheat requirements** – Improper sequencing or setpoints can result in heating and cooling systems simultaneously operating in the same spaces. Commissioning identifies and eliminates these occurrences.
- **Balance and adjust distribution systems** – In order to maintain optimum performance, periodic rebalancing of air and water distribution systems is often required due to changing building or tenant needs and natural drift over time.
- **Set/reset local lighting controls** –Local occupancy, vacancy, timer, and daylight sensors also require commissioning. Significant savings are lost when occupants disable lighting controls due to frustration over non-commissioned equipment.

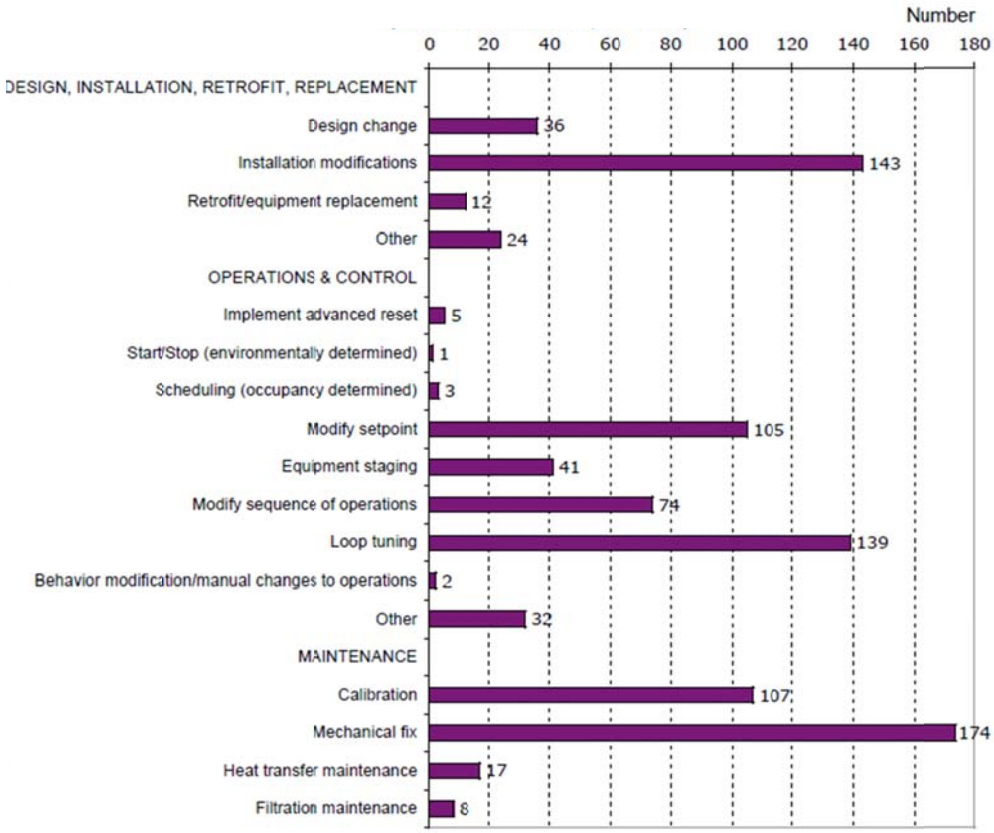
Figures 3-1 and 3-2 are taken from the Lawrence Berkley National Laboratory (LBNL) meta-analysis on commissioning[1] and illustrate how often various measures are recommended.

Figure 3-1. Frequency of Recommended Measures (Existing Buildings, N=1606)



[1] Evan Mills, et al., "The Cost-Effectiveness of Commercial Buildings Commissioning," (Berkeley: LBNL, 2004) (revised 2009), 37, 48.

Figure 3-2. Frequency of Recommended Measures (New Construction, N=1284)



3.3 POTENTIAL OF COMMISSIONING PROGRAM APPROACHES FOR EFFICIENCY PROGRAMS

Several national studies have analyzed the potential of commissioning to produce energy savings. A 2003 study completed by the American Council for an Energy Efficiency Economy (ACEEE)[2] concluded that retrocommissioning could produce 865 trillion Btus of savings by 2020, and concluded that it represented the 2nd largest potential of 38 energy savings technologies evaluated.

The 2009 update of the 2004 Lawrence Berkley National Labs meta-analysis of commissioning predicted $30 Billion in energy savings by the year 2030. While it is difficult to accurately estimate overall potential, it is obvious that the numbers are significant.

There is widespread agreement that market transformation through the education process is an important component of the overall commissioning effort and is a key to tapping this market. There are ongoing efforts to educate building operators through a commissioning module in Building Operator Certification (BOC) courses offered in many areas of the country, including the Mid-

[2] Thorne, J. and S. Nadel, *Retrocommissioning: Program Strategies to Capture Energy Savings in Existing Buildings.* Washington, DC.: ACEEE, 2003.

Atlantic and the Northeast. More rigorous training and professional certification programs are offered by agencies like the Building Commissioning Association (BCA) and the Association of Energy Engineers (AEE), with funding and support from many efficiency programs around the country.

Over the past decade, several programs (NSTAR, NYSERDA, and Efficiency Maine in the Northeast) have operated pilot commissioning programs in an attempt to evaluate the potential for savings, identify hurdles to overcome, and determine where they fit in the portfolio of offerings. To date, few of these pilots have evolved into ongoing successful programs, but there is evidence that this is changing.

One widely accepted view, especially with new construction programs, is that commissioning is not a separate program with specific savings attached, but rather it is a means to increase realization rates and the sustainability of savings associated with measures that fund equipment installations. Some programs (including NYSERDA) extend this philosophy to existing building programs by requiring commissioning - and contributing to its cost - for the equipment involved in any project that receives incentives larger than a prescribed level.

3.4 SAMPLE OF CURRENTLY OFFERED COMMISSIONING PROGRAMS

The following represent the range of commissioning programs now being offered throughout the U.S.

3.4.1 Xcel Energy – Colorado & Minnesota

Xcel Energy's recommissioning program for customers in Colorado and Minnesota covers both recommissioning and RCx for electric and natural gas use. The program consists of two steps: diagnosis and implementation. Diagnosis involves a commissioning study conducted by a provider of the customer's choice. The resulting report presents a business case for efficiency project approval based on project economics, and detailed methodologies for operating the mechanical systems at peak efficiency, and it provides savings projections and implementation cost estimates for recommended measures. Xcel Energy will pay for 75% of the study cost, up to $25,000. The program is limited to facilities that are 50,000 square feet and larger and/or facilities with high-energy usage.

The following implementation phase focuses on low-cost system tune-ups and system upgrade measures identified in the diagnostic phase. Xcel Energy will provide incentives of up to 60% of the total measure cost. Preapproval is required for all phases of the project.

Also offered is a Fast Track study option. This option is available for customers that choose to perform a recommissioning study utilizing their own facility staff. The track is intended to focus on specific measures rather than involve a comprehensive commissioning study. Upon identifying measures, customers are eligible to receive implementation incentives for qualifying measures.

Typical improvements supported by the Fast Track program include:

- Optimization of HVAC equipment
- Adjustment of EMS time-of-day schedules
- Recommissioning and upgrading of lighting controls
- Updating and optimization of process system controls
- Restoration and/or upgrading of economizer operation
- Measures targeted at reducing maintenance costs and improving equipment longevity
- Optimization of refrigeration equipment and controls – supermarkets are specifically targeted by a "refrigeration recommissioning studies" program track

Xcel Energy markets the program as "more than just energy savings," as non-energy benefits (NEBS) are an integral part of the program. Promoted benefits include: the earning of credits for LEED EB and ENERGY STAR scoring, reduced maintenance costs, increased comfort, and longer equipment life through reduced wear and tear.

3.4.2 CenterPoint Energy – RCx Market Transformation Program

CenterPoint Energy, an electric and gas utility serving the Houston Texas area, offers an RCx program targeting major energy consuming systems of existing commercial and industrial facilities. To qualify for the full range of program services, facilities must exceed 400,000 square feet of air-conditioned space. Facilities of 150,000 to 400,000 square feet are eligible for a Fast Track option. For either program track, the utility targets buildings that have higher than average energy consumption as determined by their energy utilization index (EUI).

Typical RCx measures targeted by the program include HVAC temperature reset, outside air reduction, and optimization of HVAC startup. However, measures not typically considered by RCx are also eligible, such as de-lamping of lighting systems, adding daylighting features, and installing VFDs. The program, then, could be viewed as a hybrid of conventional retrofit and RCx programs.

The program maintains a list of qualified RCx firms and will pay 100% of the cost for a technical energy analysis performed by the qualified engineering consulting firm. Upon completion of the study, the customer is responsible for investing a minimum of $10,000 for the implementation of low-cost measures identified by the study that result in a payback of less than 3 years. A matching maximum incentive of $10,000 is available from CenterPoint upon verification of post-RCx energy savings.

In addition, those customers participating in the fully funded RCx Technical Energy Analysis process must commit to implementing a minimum of $100,000 in capital expenditure energy efficiency projects targeted to obtain a minimum of 15% energy savings.

3.4.3 NYSERDA – FlexTech and New Construction Program Elements

NYSERDA offers separate Cx and RCx programs. Through the FlexTech program, NYSERDA provides 50% match funding for RCx efforts that focus specifically on energy efficiency opportunities in existing buildings. The commercial new construction program offers a Cx program that focuses on optimizing the startup of building systems and the establishment of proper operation and maintenance procedures.

Equipment that has been in use for at least one year is eligible for analysis through RCx. However, the program does not include replacement of significant HVAC or other building components, but instead focuses on the verification and identification of proper operations sequences, control strategies, operations and maintenance plans, and other building or system optimization strategies. The commissioning effort must be led by an approved NYSERDA FlexTech service provider pre-qualified for commissioning services.

For new construction, NYSERDA provides funding for commissioning services through its design and construction incentive programs. Commissioning is required for any new construction project receiving equipment incentives in excess of $100,000 and for all automated lighting control installations regardless of the incentive amount. The NYSERDA contribution for commissioning typically adds a 10% bonus to the equipment incentive amount.

3.4.4 Efficiency Maine Pilot RCx Program

In the spring of 2010 Efficiency Maine with the assistance of ERS launched a pilot RCx program supported by ARRA funding. The program targets HVAC and lighting systems in small- to medium-sized commercial and institutional facilities. Efficiency Maine matching project funding levels are set at 50%, with the match capped at $10,000 for the investigation phase and $10,000 for the implementation phase.

The program goal is to complete twenty to thirty projects with solid baselines that could be used as a basis for future savings verification and measure persistence. A list of approved commissioning agents with demonstrated experience was developed through the program and provided to potential participants. Completion of a Portfolio Manager profile was also a prerequisite for participation.

Initial response to the pilot was less than anticipated, and at the start of 2011, a direct implementation path was added, enabling participants to obtain funding for the implementation of mechanical system repairs and optimization targeted at operational issues identified by mechanical contractors. The Portfolio Manager profile was retained and validated energy savings projections were required for funding.

Measures funded under the program to date have covered a wide range including:

- Calibration and or repair/replacement of non-functioning sensors, valves, actuators, and dampers
- Optimization of set-back and reset schedules
- Balancing of air and hydronic delivery systems
- Implementation of demand control ventilation with CO_2 sensing
- Repairs to mechanical system insulation

The program did not include funding for equipment replacement or retrofits. However, it has served as a vehicle for identifying efficiency opportunities including lighting retrofits and variable-speed pumping that were subsequently funded through the Efficiency Maine Business Program.

The initial program goals include follow-up M&V at a sample of sites to determine realization rates and persistence values for selected measures. The program is currently completing an initial round of RCx projects so M&V results have yet to be established. However, the Table 3-1summarizes program results in terms of participation, overall projected energy savings, and simple paybacks through October 1, 2011.

Table 3-1. Efficiency Maine Pilot RCx Program Results

	Full RCx	Direct	Total
Projects	20	9	29
Completed	17	9	26
Cost	$ 582,292	$ 132,564	$ 714,856
Incentives	$ 269,431	$ 49,908	$ 319,339
Savings	$ 247,620	$ 32,657	$ 280,277
Payback pre-incentive (years)	2.4	4.1	2.6
Payback post incentive (years)	1.3	2.5	1.4

3.5 Commissioning Program Data Gaps and Challenges Faced

Program-sponsored commissioning and RCx initiatives are gaining momentum around the country. But these efforts are in the early stages and there are significant data gaps that limit the understanding of the savings that can be anticipated from such programs.

3.5.1 Knowledge Gap - Reporting of Savings

"Commissioning" can be defined as "the systematic process of ensuring that equipment is operating at its intended optimal efficiency (as described in the design intent) and to the owner's operational needs and that specified system documentation and training are provided to the facility staff." If this definition is accepted at face value, it presents difficult questions regarding how and when energy savings resulting from efficiency measures should be accounted for.

Certainly, for new construction projects where incentives are being provided for the installation of efficient equipment, the savings reported for the new high efficiency infrastructure are based on the assumption that the equipment will operate at the optimized design conditions.

Claiming additional savings related to the correction of installation errors, poorly calibrated sensors, improperly established setpoints, or inadequate balancing is seen by the commissioning agent as legitimate. However, while some of this energy savings might result from optimization that goes beyond the initial design, much of it represents the same savings that was originally predicted by that design. Such savings would rightly be viewed as “double dipping” by evaluation teams or individuals tasked with overseeing forward capacity markets.

The particular program claiming these savings may seem unimportant to the overall goals of improved efficiency, but without the ability to differentiate benefits, justification for funding commissioning efforts becomes difficult for program implementers and regulators. Promoters of commissioning programs are certainly justified in the desire to claim the savings associated with optimization, but methodologies must be in place to effectively assign savings without double counting.

Possible methods for addressing this issue are to:

- Discount savings for new construction measures that are not commissioned, with the understanding that noncommissioned control systems do not realize the full potential savings. How large the discount should be is a factor yet to be vetted.
- Require commissioning for all systems that involve the calibration of controls and/or the training of operators, assigning savings once to the joint installation/commissioning program.
- For RCx:
  - Claim full savings for building systems that were installed without the assistance of a program incentive.
  - Claim full savings for systems that have received an incentive, but have been in service long enough to have satisfied cost-effectiveness criteria. This is likely to be 5 years or more and is supported by the precedent of programs replacing program-supported lighting measures that have been in service for 5 years.
  - Require periodic RCx for complex control systems, assigning savings on a scheduled basis.

3.5.2 Knowledge Gap – Persistence of Savings

Persistence of savings represents one of the key knowledge gaps and biggest challenges to the more widespread implementation of commissioning programs. RCx is often performed because proper initial commissioning was not. Just as often however, it is performed because operational parameters have changed, equipment has failed, or controls setpoints have been modified by staff or have drifted out of specification.

The average elapsed time period for any of the above scenarios is extremely difficult to predict with any certainty and therefore remains a knowledge gap despite the recent growth of commissioning services. The topic of savings persistence is discussed at length in Section 3.6.3 of this report.

3.5.3 Challenge – Barriers to Widespread Adoption

Despite the potential for energy savings and relativity short payback periods, studies including the LBNL meta-analysis mentioned earlier in this report section conclude that a very low percentage of new buildings, and even fewer existing buildings, are properly commissioned. A variety of hurdles must be overcome in order to facilitate the widespread adoption and success of commissioning programs. These barriers include:

- Lack of awareness of benefits, both energy and non-energy, by building owners and operators
- Perception that commissioning occurs as an integral part of the construction process
- Lack of confidence in the anticipated results; belief that savings estimates are "too good to be true"
- Relatively low perceived persistence of savings
- Common misunderstanding that commissioning is equipment related only, rather than being integrated with operator training and the adoption of proper maintenance practices

Continued focus on understanding the savings potential of commissioning and RCx programs is essential not only to assigning and measuring savings, but also to the overall market acceptance of such programs.

3.6 Savings Assumptions, Algorithms, and Deemed Values

The above discussions illustrate the difficulty of assigning savings for commissioning and RCx projects and programs. Regardless, the ability to predict and record savings is crucial to maintaining funding for and interest in any efficiency program. The following sections present paths for establishing savings methodologies.

3.6.1 Deemed Values and Algorithms

Although it is relatively easy to provide evidence that commissioning activities result in systems that operate more efficiently and produce measurable savings, it is difficult to predict repeatable performance results. Our involvement in commissioning projects has led to a belief that robust savings methodologies should be applied to commissioning projects and programs, but deemed values and algorithms should not be applied until a monitored program experience supports consistent savings patterns.

Deemed Values

Because the nature of commissioning is to optimize a building's systems to correspond to its unique design and uses, typical commissioning measures do not lend themselves to deemed savings values. In addition, the wide variety of measures that fall under the commissioning umbrella, the great diversity in applicable measures from building to building, and the vast differential in savings derived from the same measure applied in different settings all make it difficult to establish deemed savings values and diminish the likelihood they would prove to be accurate predictors of performance.

Given this reality, the assignment of deemed savings values is likely to produce confusing and wide ranging impact evaluation results. Perhaps if averaged over a large population of projects, deemed values would return reasonable results, but evaluation budgets do not allow for such large project populations. If applied to deemed savings values for wildly divergent commissioning projects, the results from typical evaluation samples would be meaningless.

Perhaps over time, with program experience that targets specific commissioning efforts such as lighting controls or economizer repair, deemed values could be established for repeatable focused efforts. With that possible exception, we recommend that savings assumptions and methodologies be applied to the menu of systems to be commissioned for given projects.

Savings Algorithms

Individual savings algorithms intended for the calculation of savings related to each individual commissioning measure would be too numerous to be practical and too general in nature to produce a reasonable level of accuracy.

It is important to recognize that many commissioning measures deal with separate components of the same overall systems. One major goal of commissioning is to coordinate operation of the equipment in order to optimize energy consumption of the entire system(s). This leads to a great deal of overlapping influence between measures with interactive impacts on the overall reported savings. It is imperative that these interactions be recognized and accounted for. Savings should be reported as system savings and not as simply the summation of the pre- and post-commissioning performance of each individual component in the system.

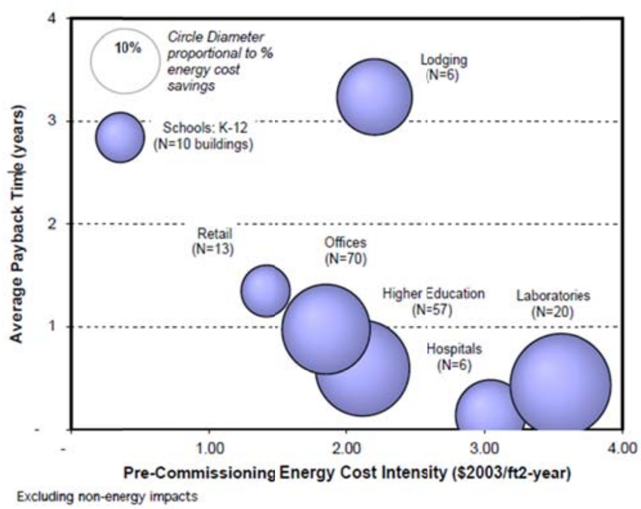
For example, one measure could involve repair of an outside air damper, resulting in the elimination of excessive ventilation on a continuous basis, with a second measure that resets unoccupied period supply temperatures for the same system. Unless the interactive impact of these measures is considered, a portion of the energy savings associated with conditioning the excess ventilation during the unoccupied periods would be counted twice.

3.6.2 Developing Savings Assumptions

Projecting a probable range of program impacts to justify the introduction of commissioning and RCx programs is difficult because there is limited data that can be utilized to establish the bounds on a range of typical savings for various measures or building categories. Typical savings ranges may have value when developing programmatic savings goals, but only when averaged over a wide variety of projects.

We identified a small number of studies that project the level of energy savings that can be anticipated from full facility commissioning to a range of 5%-20% of whole building energy use. The best documented study is the often-referenced LBNL meta-analysis, which evaluated data provided for 643 commissioned buildings. The study concluded that the median energy savings was 16% of baseline consumption for existing buildings and 13% for new construction. The same analysis derived a median cost of $0.30 per square foot for the commissioning of existing buildings, resulting in a median simple payback of 1.1 years. For new construction the median cost was $1.16 per square foot with a simple payback of 4.2 years. Figure 3-3 depicts similar values from this study differentiated by building type.

Figure 3-3. Key Results by Building Type (Existing Buildings) [3]



While the LBNL study is accepted as the largest and most comprehensive analysis of commissioning results, the chart provided above illustrates the need to use caution when attempting to extrapolate overall median results, regardless of the sample size, to a specific program. Both the commissioning expense and the associated energy savings vary greatly depending upon the end use and the relative complexity of building infrastructure. The fact that laboratories and hospitals produce the fastest simple paybacks in spite of having the highest cost per square foot suggests that the opportunity for savings increases faster in relation to the complexity of infrastructure than does the commission cost.

Other studies including Gregerson 1997[4] and Texas A&M[5] in 2002 have also found that medical and research facilities offer some of the most lucrative returns from commissioning efforts.

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[3] Mills, "The Cost-Effectiveness of Commercial Buildings Commissioning," 30.

Benchmarking

One possible approach for estimating the savings potential for a commissioning project is to establish target energy consumption benchmark values. These benchmarks could be presented as either system or whole-building values. For example, an optimized HVAC system for an office building could be determined to use X kWh per heating degree day per square foot. The whole-building benchmark energy usage could be presented as Y kWh per square foot per year differentiated by building end use. Candidate sites for commissioning could have their energy use compared to these accepted "benchmark" values to determine the rough magnitude of potential savings available at those sites. A post project monitoring process could verify the savings for that project and could be used to further calibrate benchmarking procedures.

Simulation Modeling

A potential means of predicting savings is through the use of building simulation tools to model the overall facility performance under pre- and post-commissioning conditions. This method is frequently used for new construction projects or for very large and comprehensive existing-building projects. Drawbacks to this method include the lack of transparency for the assumptions, the difficulty of calibrating the model for new construction projects, and the additional expense involved, which could easily move the project out of a cost-effective status.

An alternative to full simulation modeling is the prediction of savings using customized spreadsheet tools that can be adapted to account for the interactive impacts of overlapping measures discussed above. Many commissioning measures are weather dependent and thus lend themselves well to weather-related regression analysis, with annual savings then projected using TMY3, or bin weather data for the specific region.

3.6.3 Determining and Improving Persistence of Savings

A major hurdle in evaluating the cost-effectiveness of a commissioning program is the determination of savings persistence or, the extent to which the initial savings can be sustained over time. Commissioning is the process of fine tuning and optimizing a system's startup performance or correcting performance that has degraded over time. Commissioning, much like compressed air leak repair or steam trap maintenance, is an ongoing process that will not result in permanent savings without continuous attention. The perception of relatively low persistence levels associated with

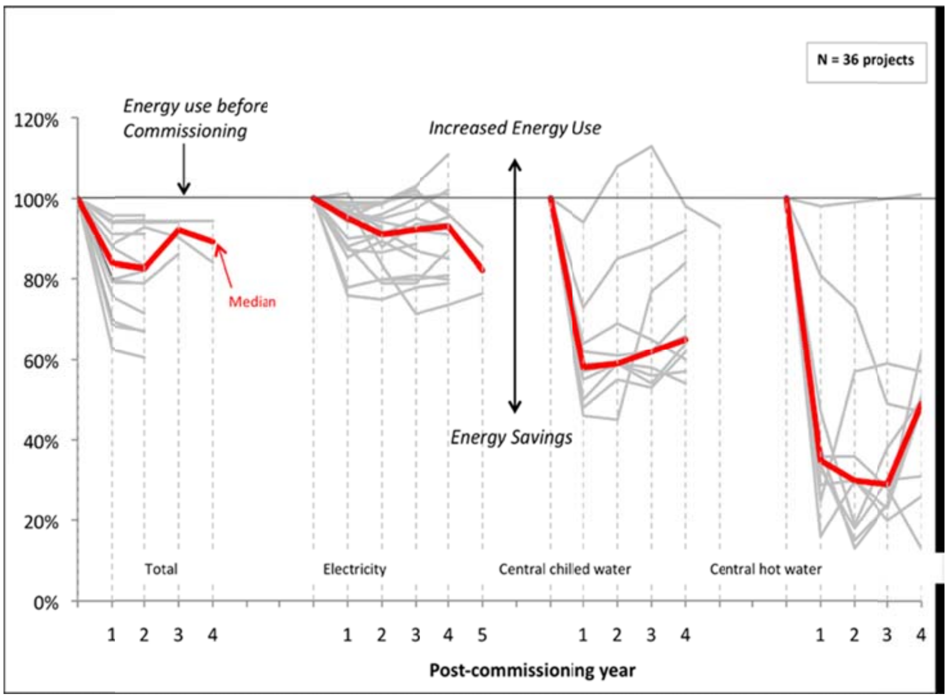
[4] J. Gregerson, "Cost-Effectiveness of Commissioning 44 Existing Buildings," in *Proceedings of the 5th National Conference on Building Commissioning* (Huntington Beach, Calif., April 28–30, 1997).

[5] M. Liu, D.E. Claridge, and W.D. Turner. 2002. *Continuous Commissioning Guidebook for Federal Energy Managers.* Prepared by the Energy Systems Laboratory, Texas A&M University System and the Energy Systems Laboratory, University of Nebraska, for the Federal Energy Management Program (FEMP), U.S. Department of Energy.

conventional (one time) commissioning efforts are recognized as a major impediment to more widespread adoption of these programs.

A 2008 study conducted by ASHRAE reached the unremarkable conclusion that hardware-based commissioning measures, which could be described as system repairs, had improved persistence more than had the optimization of system controls. Figure 3-4 is from the 2009 LBNL meta-analysis and presents relative persistence based on a sample of thirty six building evaluated for a period of 4 years.

Figure 3-4. Persistence of Commissioning Savings (Consumption as% of base year) [6]



This data tends to indicate that while persistence of some types of measures such as central chilled water and central hot water is quite poor, overall measure persistence is reasonable, with the total median degradation over 4 years at less than 15%. Most of the buildings included in the study sample were commissioned by a relatively small group of highly experienced commissioning agents. As such, the results may prove to be somewhat optimistic for new initiatives.

A recommended approach to maximizing persistence is to ensure that commissioning efforts complete the final phase of commissioning, which includes updating O&M manuals and educating facility personnel with regard to changes that have been implemented and the importance of ongoing continuous maintenance. In addition, facility personnel should understand the negative impacts that will result from altering setpoints and schedules that have been established for optimal operation.

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[6] Evan Mills, "Building Commissioning," (Berkeley: LBNL, 2009), 47.

Continuous Commissioning

The above discussion leads to another major persistence factor: the need for continuous commissioning. Complex building management systems require continuous attention to keep control systems from falling out of specification and operators from changing settings. This ongoing process attempts to alert building managers to problems as they develop, allowing them to diagnose and resolve them sooner. Data is continuously aggregated from the building automation system (BAS), utility metering data, or data loggers. A building manager or qualified partner regularly analyzes the data to identify areas for improvement, which leads to a more stable building performance than that achieved by other commissioning methods. The significant drawback to continuous commissioning is the high level of data monitoring and collection required. The accuracy and frequency of measurements must be high enough for the required diagnostics. Thus, buildings lacking direct digital control are often not promising candidates for ongoing commissioning. The fixed start-up costs of setting up such a rigorous monitoring procedure can be prohibitively expensive for all but large facilities with complex systems.

The Omaha Public Power District (OPPD) in conjunction with the University of Nebraska at Lincoln currently operates a continuous commissioning program. The program features permanently installed data logging and reporting equipment with proprietary algorithms that optimize building controls based on historical trends. The program was established in 2001 and as of 2008 had commissioned twenty-five buildings delivering a reported 30 gigawatt-hours of energy savings and 5.5 megawatts of demand reduction. OPPD claims that since the program inception only one of the twenty-five buildings has experienced a significant decline in the level of savings achieved.

The concept of continuous commissioning is also gaining momentum in the private sector. Siemens is reporting success with its trademarked “demand flow” chiller plant optimization program. This approach monitors inputs from all components of the chiller plant and utilizes proprietary algorithms to optimize overall operations. Compressor energy services reports sustained savings from compressed air systems at several large industrial facilities with an approach that includes web-based continuous monitoring of air compressor input power and flow rates to quickly identify out-of-specification operation.

3.7 EVALUATION ISSUES & CLOSING KNOWLEDGE GAPS

Fully understanding baseline performance levels and the persistence of savings obtained through commissioning are key elements of implementing programs with the expectation of measurable cost-effective savings.

Baseline performance levels are especially problematic for commissioning programs because they intersect with the baseline determinations for core programs addressing commissionable systems. For new construction, the baseline is certainly the performance of the systems proposed for commissioning services with only standard practice installation performed. Yet there are many unknowns involved:

- What is the local standard practice for installation of target systems?
  - Do design engineers specify a start-up procedure?
  - Is functional testing and system balancing typically performed by the installation contractors?
  - Do owners typically receive O&M manuals? Training?
  - Are automatic lighting controls adjusted for sensitivity and time-based deadbands by installers?
  - Is proper operation of BAS/EMS verified, including proper setpoints, by the design/installation team?
- Given a determined level of standard practice system startup, how does the performance level of various systems compare to the performance level if all systems are operating at optimum levels?

Local standard practice is remarkably inconsistent in the HVAC field. In any given geographic region, installers may or may not consider it their responsibility to provide any of the services listed above. Process evaluations or studies utilizing process evaluation techniques should be used to determine the local standard practice.

In order to determine the performance of systems at the local standard practice level as well as the commissioned performance level, there is no substitution for the analysis of metered/logged data. Pilot commissioning programs should include provisions and budgets for logging pre- and post-project energy consumption of the commissioned system(s). Such logging can be done though the owners BAS/EMS when available or can readily be performed by engineering firms that provide M&V services for impact evaluations. Collection of this data along with the annual energy consumption at a site can build knowledge around expected savings as a percent of annual energy consumption for the myriad of adjustments that occur during a commissioning activity.

Persistence of savings, as discussed in Section 3.6.3, is likely to be highly variable and difficult to predict. However, long-term M&V data logging could be used to predict savings persistence for a variety of system types. Given the low-cost of simple field installable data loggers, it should be economically feasible to log a small sample of project over a multi-year period.

Because many of the individual measures are interactive, evaluation efforts must pay special attention to the impact of cumulative energy impacts, and ensure these are adequately addressed in savings calculations.

3.8 Summary Conclusions & Recommendations

In recent years commissioning has gained more general acceptance and recognition as a necessary and valuable component of efficiency programs. Advocates of the building commissioning process have been working for decades to fill the data gaps and overcome obstacles hindering the widespread adoption of the practice. Much has been accomplished, and recent trends indicate the practice has gained more general acceptance.

Still, program administrators find it difficult to predict savings for commissioning services and even more difficult to segregate such savings from those claimed through other program activities.

3.8.1 Recommendations

- ❑ **Determine local standard practice** - Utilizing the procedures discussed in Section 3.7, standard practice related to system startup, functional testing, O&M training, and system balancing needs to be understood in order to establish the baseline.
- ❑ **Integrate the savings** – For new construction and the installation of new systems, the commissioning process ensures the predicted savings more than it creates additional savings. The recommended option is to integrate commissioning savings with the project implementation savings, making commissioning mandatory for major systems receiving incentives.
- ❑ **Or, clearly segregate the commissioning savings** – If not adopting an integrated savings approach, the savings from commissioning should be segregated from core equipment upgrade savings. The commissioning program savings are simply the difference in demand and usage between a system installed to local standard practice and the same system commissioned to program protocols.
- ❑ **Determine NET savings for RCx** – When commissioning existing systems, net savings should be determined as follows.
  - ➢ Determine measure life/persistence of the particular RCx procedure.
  - ➢ Log pre- and post-commissioning system usage.
  - ➢ If existing system was installed without program assistance, claim all measurable savings. In some circumstances, impact evaluators may discount these savings if it is determined that some of the RCx activities would have been performed without incentives due to normal maintenance procedures.
  - ➢ If existing system was installed with program assistance:
    - Determine claimed savings to date
    - Claim savings for any performance gain above installed program practice
    - Claim additional savings for extended measure life beyond program-specified “in service” limit. The service term is typically 5 years before previously program-supported measures can be replaced and receive incentives and harvest savings. The RCx service would reset the term.
- ❑ **Initiate pilots and build a database** – There are so many variables for commissioning services that the only truly viable way to close data gaps is to commission systems and log, store, and analyze the performance data. By tracking a number of similar-system commissioning results, it will be possible to better predict savings on a percentage basis for common system types. Because tenant turnover and changes in usage in large facilities will

greatly affect energy consumption, information about how the building is used at a point in time is also needed to better understand any percentage value.

- ❑ **Determine customer hurdles and adjust program design as needed** - Because there are known customer hurdles to participation, a survey can inform Forum members about the specific challenges faced in this region.

As the level of automation and the complexity of building systems continues to grow, the importance of rigorous and ongoing commissioning of these systems increases in importance. The existence of real savings associated with commissioning is not in question. However, the ability to predict and fairly assign those savings certainly is. Program administrators need to decide how commissioning fits into their portfolios and how to assign the savings in an equitable and accurate manner.

Whole House Retrofit Program Approaches

4

4.1 Introduction

Whole-house retrofits are characterized by a major energy-performance upgrade of an existing house, as well as a review of health and safety issues, using a whole-house approach. Whole-house, or "house as a system" approach, recognizes the fact that all the different components of a house, including insulation, ventilation, draft proofing, windows, doors, and control systems are interconnected. A change to one part of the system will affect other parts. For example, draft proofing will reduce the amount of heat that escapes from a house by air leakage, but can also trap moisture within the home. Therefore, an improved ventilation system may now be required to remove excess moisture from the home in a controlled manner.

Conventional energy retrofits focus on isolated upgrades (for example, attic insulation or HVAC equipment). These retrofits can be simple and fast, but they often miss cost-effective opportunities for saving additional energy. Whole-house retrofits, on the other hand, typically involve a comprehensive home audit that may be followed by an array of efficiency improvements on building envelope (insulation, air sealing, windows, and doors) and systems (HVAC, plumbing, and electrical system). A second audit can be used to confirm retrofits and associated savings.

This report begins by discussing program models, the potential benefits whole-house retrofits offer efficiency programs, a sample of programs from the U.S. and Canada, and currently used savings methodologies. We then present current available data as well as data and knowledge gaps, followed by recommendations for closing those gaps and developing program methodologies that will allow accurate modeling and monitoring of savings.

4.2 Program Model Overview

Whole house retrofits cover a wide range of approaches from a menu of measures that can be accomplished without structural concerns and resident disruption to deep retrofits that involve home remodeling that can result in savings of 30% or more. In addition to HVAC systems and building envelope upgrades, programs can address a large number of residential measures including lighting, appliances, behavioral measures, pool filter motors, equipment maintenance, etc. These can be promoted through incentives or direct installation approaches (e.g., installing CFLs during the first audit) either within a home retrofit program or as standalone measures.

It is thus useful to better define what constitutes a "home retrofit" measure, as opposed to residential measures in general. One approach would be to consider measures that will typically persist beyond one year and with any change of occupancy. Thus excluded are behavioral measures, maintenance, and plug load appliances. But even with this definition, the list is still quite large and would include, for example, the following:

- **Building shell** - Attic, wall, floor, and basement insulation, efficient windows and doors, air sealing
- **Ventilation -** Air sealing, heat-recovery ventilation, warm air solar walls
- **Space heating/cooling** - Efficient boilers and furnaces; heat pumps (air, water, or ground source); efficient air conditioner, distribution system insulation, and leakage reduction; green roofs; and shading
- **Domestic hot water -** Gray water heat recovery, efficient water heaters (including heat pump, instantaneous, solar), pipe insulation

Programs aimed at comprehensive, whole-house, single-family retrofits thus create a significant challenge from a deemed savings perspective. Indeed, these retrofits address a vast array of measures and, most importantly, an equally vast array of baselines. Furthermore, the specific elements of a retrofit will vary according to region, building vintage and characteristics, and homeowner's preferences. Program design, in addressing market barriers and promoting specific measures, also has an important influence on the actual set of measures that will be implemented by program participants.

Interactive effects also make it very difficult to determine savings for individual measures. By their very nature, these programs aim to implement "packages" of measures that interact with each other and modify individual savings. For example, HVAC upgrade will provide less savings if the house is weatherized beforehand. Actual savings of individual measures can be determined by energy modeling but even then a method of measure ranking is needed, as the order of implementation will change individual (but not overall) savings.

4.3 Potential of Whole building Retrofit Approaches

While whole-house retrofit programs have been implemented for quite some time, there is still room for improvement and expansion, mainly by increasing uptake and conversion rates, moving toward fuel-neutral programs, promoting higher levels of retrofit savings, and addressing hard-to-reach and hard-to-treat buildings.

4.3.1 Uptake and Conversion

Programs traditionally reach a small portion of the market, leaving a large potential untapped. Effective marketing strategies, including community-based approaches, marketing blitzes, awareness campaigns and partnership with supply-side market actors, can provide leads for energy efficiency retrofits and substantially increase uptake.

But generating leads is not enough; they must be converted into retrofit projects. The conversion rate can be quite low in some programs, and approaches to increase conversion include rapid follow-up and bids after an audit, lists of approved contractors, technical support to homeowners, turnkey offerings, and financing.

4.3.2 All Fuels

Whole-house programs have been historically centered on electric savings, though it is sometimes combined with natural gas. This is due to high avoided costs and the SBC revenues associated with regulated energy sources. However, there is a growing trend toward expanding to other energy sources. This will increase the potential market and savings, but in turn can add complexity to estimating savings.

4.3.3 Higher Levels of Savings

Home retrofit programs achieve typical savings of 20% of total home energy consumption, while the best programs achieve 30% or more[1]. Some strategies to increase levels of savings include tiered bonus incentives to contractors and homeowners and direct (and free of charge) installation of low-cost measures by auditors.

Higher standards, like the net zero and passive house concepts, have been developed to achieve still higher savings. While these standards apply more easily to the new construction market, retrofit projects aiming at net zero energy use have been undertaken. Higher levels of savings are often limited not by technical barriers but by cost-effectiveness considerations. For example, the Massachusetts Deep Energy Retrofit (DER) pilot targets a minimum of 50% reduction in overall energy consumption. ERS and the Cadmus Group recently completed a process evaluation of that program. The report noted that "high project costs were a major concern to all stakeholders, customers, and contractors. As currently structured, the pilot is not tenable for full deployment due to these high costs."[2]

4.3.4 Hard to Reach and Hard to Treat

Some markets and buildings are hard to reach, facing significant market barriers (low income customers, renters) or hard to treat, requiring special and costly retrofit techniques (solid walls, single cavity flat roofs, historic housing). Special care in program design and delivery is required to effectively tap the potential savings. Common approaches include low-cost or no-cost retrofit

[1] Based on work conducted for a confidential client in 2011 by Dunsky Energy Consulting.

[2] The Cadmus Group, *Massachusets 2010 Residential Retrofit and Low Income Evaluation - Deep Energy Retrofit.* (Watertown,MA: The Cadmus Group, Inc. / Energy Services, 2011).

offerings, increased outreach, and piggybacking on non-energy related work (for example, insulating a flat roof during a re-roofing job).

4.4 Efficiency Programs Currently Offering Innovative Single-Family Programs

A report from the National Home Performance Council recently looked at all programs that support whole-house energy efficiency retrofits[3]. The report restricted the survey to programs that conducted an audit and also supported whole-house retrofits through low-cost audits, education, rebates, financing, or other incentives. The report identified 126 programs that promoted a whole-home approach to energy conservation. Of these, thirty-eight had been approved by the DOE and the EPA as meeting the requirements of the Home Performance with ENERGY STAR (HPwES) program, which are as follows:

- As assessment of the home by a certified energy specialist trained in building science principles using visual and diagnostic methods
- A set of recommendations for improving the home based on the assessment
- Assistance for homeowners in identifying contractors who can implement the recommendations provided through the assessment
- Verification that work was installed and that health and safety issues were addressed by a certified energy specialist
- Quality assurance measures

In the eleven Northeast states[4], thirty programs, or 24% of the total, promoted whole-house retrofits, including at least one program in each state. Of these, programs in Massachusetts, New Hampshire, Maryland, Vermont, Rhode Island, New York, and New Jersey are qualified as HPwES programs. Finally, one PACE[5] program existed at the time of the report in the Northeast region (City of Babylon, New York state), although PACE is now available in a number of towns throughout the state of Maine.

Almost half of the programs across the U.S. require Building Performance Institute (BPI) or Home Energy Survey Professionals (HERS) certification for auditors. Several other programs are considering moving toward these requirements.

[3] Robin LeBaron and Kara Saul Rinaldi, *Residential Energy Efficiency Retrofit Programs in the U.S.* (Washington, DC: The National Home Performance Council, 2010).

[4] The Northeast region is defined in the report as including the six New England states, New York, Pennsylvania, New Jersey, Maryland, and Delaware.

[5] PACE stands for “Property Assessed Clean Energy” and allows homeowners to finance their energy efficiency and/or renewable energy systems on a long-term basis through their property tax bill.

In Canada, the ecoENERGY program, administered by the federal government, maintains a national database and a unique modeling tool for the program, in addition to providing training and certification of energy auditors. The federal government also currently offers measure-level incentives, which are commonly supplemented by utility or provincial agency incentives. Pre- and post-energy audits, involving blower door tests, are mandatory for homeowners that wish to participate to the program.

4.5 EXISTING DATA REVIEW

The following section will present a summary of relevant technical reference manuals (TRMs), including algorithms, deemed savings, and the use of energy simulation software, which is common practice for home energy retrofits.

While software modeling can provide whole-house retrofit savings, it has been noted that software inaccuracies and biases, inconsistent modeling protocols, and input errors can all affect accuracy of calculated savings. Methods aiming at improving accuracy of calculated savings include, among others, consistent modeling protocols, software improvement and uniformity, and quality assurance on energy modeling. In this section, we will discuss software accuracy, present a standard for improving modeling accuracy, and address software uniformity. We will end this section with energy usage monitoring.

4.5.1 Review of Existing TRMs

In the following subsection, we focus on building shell measures, more specifically insulation upgrade, air sealing, and efficient windows, which are most characteristic of retrofit programs. Many other measures covered by whole-house retrofits, including HVAC system upgrades, duct sealing, and water heater upgrades are also presented in the TRMs. As we will see, some TRMs address house retrofits as a whole rather than as separate measures.

New-York Standard Approach[6]

Insulation, Windows, and Air Leakage

The New York TRM provides algorithms for opaque shell insulation, high performance windows, and air leakage sealing based on savings (kWh, kW or therms) per square foot. These savings, obtained in tables, are multiplied by square footage and adjusted to account for HVAC efficiency as well as the distribution system. The tables themselves are built using the DOE-2.2 software and building prototype simulation models.

The following is a sample algorithm (kWh of savings from cooling with opaque shell insulation):

[6] Pete Jacobs, et al., *New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs.* (Oregon, WI: TecMarket Works, 2010).

$$\Delta kWh = SF \times \left(\frac{\Delta kWh}{SF}\right) \times \frac{SEER_{base}}{SEER_{part}} \times \left[\frac{\eta_{dist,base}}{\eta_{dist,part}}\right]_{cool}$$

where,

ΔkWh	= Savings in kWh
SF	= Square footage
$\frac{\Delta kWh}{SF}$	= Savings per square foot (obtained through simulation)
$SEER_{base}$	= SEER used in the simulations
$SEER_{part}$	= SEER of cooling system within participant population
$\eta_{dist,base}$	= Distribution system seasonal efficiency used in simulations
$\eta_{dist,part}$	= Distribution system seasonal efficiency within participant population

To use these formulas, measure savings tables have to be provided for each combination of energy efficiency measure, building type, geographical location, and HVAC system. Effective base and upgraded R values are displayed as rows and columns, and savings per thousand square foot are provided for electricity (kWh), peak savings (kW), and fuel (therms). Savings for R values not displayed in the tables can be interpolated.

Whole-House Retrofits

The whole-building approach is applied to the Home Performance with ENERGY STAR program, using a building energy simulation model to calculate energy savings for a combination of measures. These simulation models are informed by detailed building audits that may include "building diagnostic testing."

This section insists on the importance of quality assurance/quality control (QA/QC) functions and processes to review and verify savings estimates, as well as qualification of contractors, with general overview from the New York State Department of Public Service (DSP):

- Many of the program administrators (PAs) in the state of New York have developed internal processes for reviewing and verifying savings estimates under the whole building analysis approach.
- PAs must submit their QC and QA processes to the DSP for review.
- Any issues resulting from DSP reviews will be reported to the PAs along with a list of requirements and a schedule for resolving these issues.

- The QC and QA functions can be staffed internally or provided by external contractors. Contractors must possess appropriate certification and demonstrate expertise in whole building performance analysis.
- The DSP will review the processes used to establish project baselines and energy savings estimates, including requirements for calibrating models to measured data or benchmarking results to established energy metrics. This effort will include a review of analysis tools and simulation software including the administrator's expertise in their application.
- As part of the evaluation plan, PAs must conduct impact evaluation on at least a sample of custom projects to verify the savings claims.

Efficiency Vermont Technical Reference User Manual[7]

Air Leakage

Btu savings for air sealing are calculated using an algorithm[8] and the difference in pre- and post-air-sealing CFM_{50} blower door results. More specifically:

$$Btu\ savings = 0{,}018\ \times \frac{\Delta CFM_{50}}{n\ factor} \times 60\ \times 24\ \times HDD\ \times \frac{Adjustment\ factor}{Efficiency\ factor}$$

where:

ΔCFM_{50}	= Difference in CFM_{50} results pre and post air sealing
$n\ factor$	= 15 (conversion factor for a two-story, normal exposure building in Zone 2)
HDD	= Heating degree days (7,500 average for Vermont)
$Adjustment\ factor$	= 65% (adjustment to HDD according to typical versus default internal gains)
$Efficiency\ factor$	= Efficiency factor of the heating equipment

Specific values used in the algorithm are to account for the specific heat of air (0.018) and to convert from minutes to days($60\ \times 24$).

Electric savings are derived from Btu savings using specific algorithms.

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[7] Efficiency Vermont. *Technical Reference User Manual (TRM): Measure Savings Algorithms and Cost Assumptions* (Burlington, VT: Efficiency Vermont, 2011). Information was taken from the "Residential Emerging Markets Program" section. The "Low-Income Single-Family Program" in the same TRM uses a different set of assumptions.

[8] Note that this formula and others in this section have been slightly reorganized for easier reading but are strictly equivalent from a mathematical standpoint to the ones presented in the TRMs.

Insulation

Insulation upgrade uses effective R-values directly in an algorithm to calculate savings. These R-values, both pre and post retrofit, are to be provided by the contractors. Btu savings are calculated using the following algorithm:

$$Btu\ savings = \left(\frac{Area \times HDD \times 24 \times 65\%}{R_{base}}\right) - \left(\frac{Area \times HDD \times 24 \times 65\%}{R_{upgrade}}\right)$$

where,

$Area$	= Area in square feet receiving insulation upgrade
R_{base}	= Effective R-value of base case, as provided by contractor
$R_{upgrade}$	= Effective R-value of upgrade case, as provided by contractor

The constants in the algorithm are to account for the number of hours in a day (24) and to adjust for internal gains (65%)[9]. The efficiency factor of the heating equipment is missing in the algorithm and seems to be unaccounted for.

Electric savings are derived from Btu savings using specific algorithms.

Windows

No savings are provided for efficient windows in this TRM.

Massachusetts Technical Reference Manual[10]

Whole-House Retrofits

Retrofit measures installed through the MassSave Residential program include building envelope insulation and air sealing, duct insulation and sealing, thermostats, heating system replacement, windows, and domestic hot-water measures.

Savings values are calculated using vendor software where the user inputs a minimum set of technical data about the house to obtain heating and cooling loads as well as other key parameters. The initial estimate of energy use can then be compared with actual billing data to adjust as needed. Internal software algorithms are used to generate savings estimates for implemented energy efficiency measures. The software takes into account interactivity between building envelope and the HVAC system.

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[9] This is an adjustment to heating degree days to account for typical internal gains versus default value.

[10] Massachusetts Electric and Gas Energy Efficiency Program Administrators, *Massachusetts Technical Reference Manual,* 2010.

Insulation, Windows, and Air Leakage (Low Income)

For the low income programs, savings from weatherization (including air sealing and insulation) are deemed based on several impact evaluations of existing programs.

Mid-Atlantic Technical Reference Manual[11]

Air Leakage

This TRM provides an algorithm very similar to the one used by Efficiency Vermont. Air leakage, as measured by a trained auditor, contractor, or utility staff, will be the primary input. For homes with fossil fuel heating, for example, the following algorithm is provided:

$$\Delta MMBTU = \left(\left(\frac{(CFM_{50}Exist - CFM_{50}New)}{N\ factor}\right) \times 60 \times 24 \times HDD \times 0.018\right)/1{,}000{,}000/\eta Heat$$

where,

$CFM_{50}Exist$ = Pre-retrofit CFM_{50} result

$CFM_{50}New$ = Post-retrofit CFM_{50} result

$N\ factor$ = Conversion factor from CFM_{50} to $CFM_{Natural}$ (a table of specific values is provided)

HDD = Heating degree days

$\eta Heat$ = Efficiency factor of the heating equipment (including distribution efficiency)

Insulation

The algorithm used for insulation is very similar, using R-values instead of air leakage

$$\Delta MMBTU = \left(\left(\frac{1}{Rexist} - \frac{1}{Rnew}\right) \times HDD \times 24 \times Area\right)/1{,}000{,}000/\eta Heat$$

where,

$Rexist$ = Pre-retrofit effective R-value

$Rnew$ = Post-retrofit effective R-value

$Area$ = Area in square feet receiving insulation upgrade

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[11] Vermont Energy Investment Corporation, *Mid-Atlantic Technical Reference Manual* (Lexington, MA: VEIC, 2011).

Windows

The TRM addresses windows only for the natural replacement and new construction markets. Deemed savings per square foot for three different systems (electric resistance, heat pump COP 2.0, and cooling SEER 10) are estimated using REM/Rate software.

Whole-House Retrofits

The manual notes in the introduction that it uses engineering equations for most measures, but that one limitation of this approach is that interactive effects are not captured. For whole-building programs, the manual notes that modeling may be needed to estimate savings and recommends that a future version include the baseline specifications for whole-building efficiency measures.

New-Jersey Protocols[12]

ENERGY STAR Audit

No protocol was developed for measuring savings in this program. As many measures that are likely to produce significant savings are covered by other programs, it is assumed that most savings will be captured by these other programs and that it would be too difficult and expensive to isolate residual savings or impacts.

ENERGY STAR Windows

To determine resource savings, square foot savings estimates are multiplied by the window area. The per unit energy and demand savings estimates are based on building simulations, using REM/Rate on a 2,500 square foot home prototype.

Low-Income Program

Savings for the low-income program are estimated as a percentage of the pre-retrofit energy consumption for space heating and cooling, based on previous experiences with measured savings from similar programs. This is a very rough estimate, as the percentage used is not tied to specific baseline and upgraded insulation levels, insulated area, or other factors. Also note that where energy consumption is blended for different end uses, the energy use specific to space heating and cooling has to be estimated.

Summary of Findings on TRMs

Table 4-1 summarizes the methods used in technical reference manuals for insulation upgrades, air sealing, high performance windows, and whole-house retrofits.

[12] New Jersey Clean Energy Program, *Protocols to Measure Resource Savings* (Trenton: New Jersey Board of Public Utilities, 2009).

Table 4-1. Summary of Technical Reference Manuals

	Insulation	***Air Sealing***	***Windows***	***Whole-House Retrofits***
New York	Savings per square foot from DOE-2.2 simulations, adjusted for HVAC and distribution efficiencies			Building energy simulation models TRM insists on QA/QC and qualification of contractors.
Vermont	Algorithm using R-values	Algorithm using changes in CFM_{50}	N/A	N/A
Massachusetts	Deemed savings based on impact evaluations (low income program only)			Vendor software, comparison with billing data and internal software algorithms
Mid-Atlantic	Algorithm using R-values	Algorithm using changes in CFM_{50}	Savings per square foot from REM/Rate simulations	TRM notes the limitation of engineering equations for whole-building programs. Modeling may be needed and should be addressed in future version of manual.
New Jersey	Deemed savings as a percentage of pre-retrofit energy consumption for heating and cooling (low income only)		Savings per square foot from REM/Rate simulations	For ENERGY STAR audit, it is assumed that most savings will be captured by other programs.

It is important to note that calculations using R-values and areas are by no mean simple. In calculating the effective R-value of a basement wall before and after insulating the wall cavities, a contractor would have to take into account elements such as:

- Insulated area net of openings (windows)
- Thermal bridging of wood framing

- Thermal resistance of multiple layers of material (concrete, drywall, vapor barrier)
- Thermal conductivity of soil and portion of basement wall above versus below grade

These calculations also become increasingly complex and time consuming (and prone to errors) as multiple measures are implemented at once, leading to interactive effects.

Many algorithms presented in the TRMs are in fact based on software simulations with prototype building(s). Most of the consulted TRMs use such simulations for one or several measures (mostly windows, but also insulation and air sealing for New York). Two TRMs specifically mention using modeling for whole-house retrofits, and one is planning to include it in a future version.

Deemed savings are used only for low income programs.

4.5.2 Energy Modeling Software

There is a wide variety of energy modeling software designed to calculate energy savings and/or HVAC sizing. These different tools have varying levels of accuracy and require varying levels of efforts, some having been designed to provide quick feedback at an earlier phase of a project while others require more input to provide accurate estimates.

Software programs can be classified into four generic types[13]:

- **Screening tools** - Designed to evaluate project viability during the earliest stages, often including economic analysis capabilities. Usually simple to use although less accurate.
- **Architectural design tools** - Intended to evaluate design decisions such as building orientation and glazing.
- **Load calculation and HVAC sizing tools** - Used to properly size HVAC systems and select heating and cooling equipment. Many of these tools can also be used to calculate annual savings from energy efficiency measures. Tools such as DOE-2 would fall into this category.
- **Economic assessment tools** - Provide comprehensive economic analysis of proposed building capital investments.

A software tool must meet at least one of the following standards to be used in whole-house retrofit programs under the Home Performance with ENERGY STAR umbrella:

- Testing according to the National Renewable Energy Laboratory's HERS BESTEST software energy simulation testing protocol
- Approval by the US Department of Energy's Weatherization Assistance Program
- Approval by RESNET

[13] "Energy Analysis Tools," Whole Building Design Guide, Richard Paradis, October 6, 2010, accessed November 9, 2011, www.wbdg.org/resources/energyanalysis.php.

Software Accuracy

No energy modeling software can predict with perfect accuracy the energy consumption of a building. The main reason for this is the fact that most home energy audits use asset based models[14], thus eliminating the influence of operational factors such as occupancy, thermostat setpoints, and base load, which can induce significant variability in energy consumption[15]. Furthermore, various inputs are based on judgment rather than precise measurement (for example, insulation levels or efficiency of HVAC and distribution systems), which leads to imprecision in predicted energy consumption. Energy models also use normalized weather data to be able to predict long-term savings, while real consumption is correlated to real weather.

Modeling software and protocols must therefore be evaluated according to their ability to predict, on average, the energy consumption of similar buildings in general, in addition to predicting individual building consumption. Studies undertaken in the 1990s and early 2000s demonstrated software inaccuracy[16]. For old and inefficient buildings, there is strong indication that energy consumption could be overestimated, leading to lower-than-projected real savings. These inaccuracies arise from different factors, including:

- Interactivity of house components in leaky and poorly insulated houses not taken into account by software algorithms (large exfiltration through attic reduces conductive loss of poorly insulated ceiling, large infiltrations in basement pick up some heat loss from ducts, etc.)
- Different behavior and operational conditions in inefficient homes (aggressive thermostat set back, spaces like basement and empty room left unheated)
- Assumed R-values and HVAC efficiency lower that actual

Interestingly, recent studies have found strong levels of accuracy for both residential and commercial new construction, although with large variability for specific buildings:

- A 2009 impact study for the new construction market in the Metropolitan Houston area[17] examined the relationship between cooling-load projections using REM/Rate and electric-usage results for 10,258 homes. The average cooling loads estimated through weather-normalized monthly billing data were about 3% higher than the projected cooling loads using

[14] While operational savings might be of more use to current building owners or occupants, standardized savings based on standard operating conditions are typically required by program administrators to estimate long-term savings and for incentive qualification.

[15] Caroline M. Clevenger and John Haymaker, "The Impact of the Building Occupant on Energy Modeling Simulations," Joint International Conference on Computing and Decision Making in Civil and Building Engineering. Montreal, 2006.

[16] Michael Blasnik, *Energy Performance Scoring for Existing Homes & Households: Some Issues* (Roslindale, MA: M. Blasnik & Associates, 2009).

[17] Shaun Hassel, Michael Blasnik, and Benjamin Hannas, Houston Home Energy Efficiency Study (Raleigh, NC: Advanced Energy, 2009).

REM/Rate. The study concludes that "when using current modeling software with energy-efficient new homes, there is a strong and fairly consistent relationship between actual and projected performance using REM/Rate for both heating and cooling." The study also notes that "although the analysis found no systematic bias in the REM/Rate cooling projections, there was a large amount of variability in the data."

- A 2008 study by the New Buildings Institute[18] examined ninety-one LEED-certified commercial buildings to compare metered energy use with energy modeling. The study noted that the degree of variation in predictive accuracy on individual projects is substantial, although in aggregate the energy modeling accurately predicts sample-wide energy savings.

Building Performance Institute Standard (BPI-2400-S-2011)

To increase confidence in the accuracy of savings, the Building Performance Institute (BPI) published a voluntary standard (BPI-2400-S-2011)[19] that includes three key elements:

- An energy model calibration process
- Input constraints and standard operating conditions
- Quality assurance

These procedures are intended to increase confidence in energy savings projected by whole building simulations. The BPI approach relies on setting boundaries on estimated savings by using actual pre-retrofit energy consumption where available. More specifically, the pre-retrofit model is calibrated using monthly utility bills. The comparison between the modeled and actual consumption is conducted using an operational model (energy model using actual operating conditions). Once the calibration is completed and there is an acceptable match with actual consumption, the model can revert back to a standardized model (energy model using standard operating conditions) if required by adjusting relevant inputs.

A simplified step-by-step calibration process is detailed here:

1. Determine that available utility bills meet the requirements. This involves gathering metered energy sources billing data, eliminating estimated reads and atypical periods, and running a regression analysis of energy use against local weather data.
2. Conduct a pre-retrofit operational simulation.
3. Calibrate the operational model using either weather-normalized utility data or an energy model with actual (real) weather data.

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[18] Mark Frankel and Cathy Turner, *How Accurate Is Energy Modeling in the Market?,* ACEEE Summer Study on Energy Efficiency in Buildings, American Council for an Energy-Efficient Economy, 2008, 3-88 to 3-101.

[19] Building Performance Institute, Inc., *Standardized Qualification of Whole House Energy Savings Estimates* (Malta, NY: BPI, 2011).

4. Apply energy conservation measures to the calibrated pre-retrofit operational model[20] to create the post-retrofit operational model.
5. The difference in modeled energy usage between the calibrated pre-retrofit model and the post-retrofit model is the savings of the proposed energy conservation measures.

In addition to the calibration process, the BPI standard proposes input constraints to be applied to the models, including thermostat and DHW setpoints, HVAC efficiency, and insulation levels. These constraints are intended to prevent overestimation of savings by assuming unrealistic baseline efficiency levels. Table 4-2 provides the input constraints recommended in the BPI standard. Table 4-3 presents recommended standardized input values to be used for a standardized energy model.

Table 4-2. BPI Input Constraints

Constraints Value	Minimum Value	Maximum Value
Heating thermostat setpoint	58°F	76° F
Cooling thermostat setpoint	68°F	86° F
Domestic hot water setpoint	110°F	N/A
Forced-air furnace AFUE	72%	N/A
Hot water / steam boiler AFUE	60%	N/A
Heat Pump HSPF	4.5	N/A
Heat Pump SEER	6.5	N/A
Central air conditioner SEER	6.5	N/A
Room air conditioner EER	7.0	N/A
Gas-fired storage water heater EF	0.45	N/A
Oil-fired storage water heater EF	0.40	N/A
Electric storage water heater EF	0.80	N/A
Interior lighting hours/day (average for home)	N/A	5
Value (Including air films)	**Maximum U-Factor**	
Uninsulated wood-frame wall	0.222	
Uninsulated masonry wall	0.250	
Uninsulated wood-frame ceiling with attic (R-value from interior to attic space)	0.286	
Uninsulated unfinished roof	0.400	
Uninsulated wood-frame floor	0.222	
Single-pane window, wood frame	0.714	
Single-pane window, metal frame	0.833	

[20] Alternatively, the model can be based on standardized operating conditions by modifying relevant inputs before this step.

Duct Location	Minimum Ducted System Efficiency
Unconditioned basement or crawlspace (no insulation in walls or ceiling, or insulated walls)	85%
Unconditioned basement or crawlspace (insulated ceiling)	75%
Vented crawlspace	70%
Garage	60%
Attic: heating DSE	60%
Attic: cooling DSE	50%

Table 4-3. BPI Standardized Input Values

Energy Model Parameter	Standardized Input Value	Notes
Setpoint for cooling	76°F with no set-forward period	
Setpoint for heating	71°F with no setback period	
Interior shading multiplier	0.7	
Domestic hot water storage setpoint	130°F	
Service water inlet temperature (annual average)	Varies by location	Use equations 26 and 27 from source listed below*.
Number of occupants	0.59 × Number bedrooms + 0.87	Rounded to the nearest whole number
Occupancy (hours/day/person)	16.5	

*Source: National Renewable Energy Laboratory, *Building America House Simulation Protocols* (Oak Ridge, TN: U.S. Department of Energy, 2010).

Finally, the BPI document includes an informative appendix on QA, providing several levels of QA for insuring application of the standard:

- **Self-enforcement of meeting the standard** - Self-review and self-enforcement by the auditor conducting the energy audit. The auditor shall review his or her work prior to submitting it to the program administrator and submit documentation regarding the lack of compliance (for example, if there is good reason for an exception to a minimum R-value).
- **Third-party minimum model QA** - The program administrator or other entity conducting QA verifies that the submitted model and analysis meets the standard's criteria.
- **Third-party detailed model QA** - A detailed model QA shall be performed on a sample of submissions from auditors, including checking that the inputs are reasonable for the house described in the report, verifying that the parameters used for energy conservation measures

are reasonable and conservative, and performing utility analysis from raw-metered or delivered-energy data to determine whether or not the submitted results match.

Software Uniformity

KEMA notes that

> in recent evaluations of the MassSAVE Home Energy Solution program, KEMA has reported on the disparities in the savings methods and assumptions in this residential program area. The various energy-efficiency vendors that deliver MassSAVE tend to employ in-house software for developing/reporting savings. While the vendors and software methods are approved by the program, the savings methods are not necessarily unified or consistent.[21]

Administrators should require consistent savings methodologies across all vendors delivering comprehensive retrofits.

This is in sharp contrast to the Canadian counterpart ecoENERGY, where unique modeling software (HOT2000) has been developed and maintained by the federal government, as well as modeling protocols and auditor certification. KEMA noted that residential program offerings may be more standardized in other jurisdictions such as New Jersey and Vermont.

4.5.3 Monitoring and Billing Analysis

Monitoring and billing analysis are important EM&V tools. However, there are challenges in using them as the main method for estimating savings in a home-retrofit program:

- For single-family houses, monitoring and/or billing analysis on every participating building would increase program costs significantly. This barrier is more important for single-family than for multi-family and commercial buildings.
- Imprecision, due mainly to unregulated fuels (heating oil, propane, cordwood, and wood pellets), can limit the interest in using this approach and also increase costs for obtaining the required data. Billing information is often incomplete.
- Monitoring and billing analysis can usually provide savings only in an aggregated form (and only give approximate disaggregated savings in best cases), while PAs typically need savings for individual measures.
- Monitoring and billing analysis do not provide a predictive model to estimate savings before the energy conservation measures are undertaken. The estimated savings, as well as the report

[21] KEMA, *Common EM&V Methods and Savings Assumptions Project* (Burlington MA: KEMA, 2010).

provided by energy modeling software, are important to convince homeowners to undertake retrofits[22].

Thus, monitoring and billing analysis are useful for savings verification and software accuracy evaluation. They should be undertaken regularly on a sample of participants, but not on an ongoing basis for all participants as the main savings estimate.

4.6 WHOLE-HOUSE RETROFIT DATA GAPS

There are data gaps present for both customer acceptance of whole-house and, in particular, deep retrofits as well as gaps in specifics around the estimation of energy savings – both during the first year and over the lifecycle of the measures. As described earlier, conversion from audits to retrofit is often low and may be due to the high costs of the retrofits that made at least one pilot untenable for full program rollout.

In terms of estimating energy savings, decades of building science research have led to a better understanding of complex residential building systems, but modeling software algorithms need to be verified and improved on an ongoing basis. There is a need for evaluation of and feedback between measurement and modeling software. More accurate models, internal algorithms, and assumptions can be developed only with the assistance of billing analysis and monitoring in order to calibrate the former.

The overall measure life of whole-house retrofits is fairly speculative at this point. The recent process evaluation of the Massachusetts Residential Deep Energy Retrofit Program, performed by Cadmus and ERS, revealed that measure life has been hotly debated and that extended measure life values are needed to support the program under the current total resource cost (TRC) cost-effectiveness model. Measure lives of HVAC systems are well established, but most of the savings for whole-house retrofits are harvested from insulation and air sealing. The length of time that those measures can be expected to remain in place is unknown and is affected by renovation cycles and ownership turnover. Additionally, modeled performance levels assume the same measure effectiveness throughout the lifecycle of the measure. However, degradation of materials due to market freshness and/or improper installation is unknown and can affect the savings over time.

New technologies, construction techniques, and building materials that affect overall building loads also pose a significant challenge as they need to be integrated into modeling software when they are introduced in the market.

According to the Residential Energy Services Network (Resnet) and the various insulation trade associations, the installation quality of insulation and air sealing has a large effect on the resulting savings. Knowledge of the installation quality typical of the local tradespeople performing work

[22] Jennifer Thorne, *Residential Retrofits: Directions in Market Transformation* (Washington, DC: American Council for an Energy-Efficient Economy, 2003).

through a whole house retrofit program is a potential knowledge gap, especially for programs open to all contractors and do-it-yourself projects.

A detailed review of vendor's methods and assumptions would be necessary to promote methodological consistency[23].

4.7 Savings Assumptions, Algorithms, and Deemed Values

As indicated earlier, algorithms are not applicable for whole-house retrofits because they become increasingly complex and error prone as many energy conservation measures are implemented at the same time, leading to complex interactive effects. Algorithms can be useful though for a high level analysis of a single measure, e.g., at the program design stage.

Deemed values can be useful at the program design and regulatory approval stages, e.g., to provide savings for cost-effectiveness calculations. Deemed savings will typically be obtained by modeling retrofits on building prototypes using software, or from energy impact evaluations. They are, however, very high level and imprecise and need to be updated on a regular basis.

It is our opinion that pre and post audits with energy modeling, which are common practice, are also the best way to effectively estimate savings with a certain level of accuracy. While no software modeling can be perfectly accurate, uncertainty of estimated savings can be reduced to an acceptable level with appropriate modeling protocols, quality assurance, and continuous software improvement.

Monitoring and billing analysis performed on a sample of participants will further increase the confidence level of saving estimates and also help in improving software algorithms and modeling procedures and assumptions. Model calibration, as proposed by BPI, is an effective way to introduce billing analysis in the modeling process.

4.8 Whole House Retrofit Evaluation Procedures to Close Knowledge Gaps

Program administrators have several options for closing knowledge gaps associated with whole-house retrofits. Recommended procedures include:

- Process studies to determine the level of installer training, vendor procedures, and quality control procedures of the program.
- Customer interviews to determine the level of satisfaction and the perceived energy savings in relation to their expectations.

[23] NEEP, *Regional EM&V Methods and Savings Assumptions Guidelines* (Lexington, MA: Regional Evaluation, Measurement & Verification Forum, Northeast Energy Efficiency Partnerships, 2010).

- Energy savings evaluation procedures are necessary to return results that can be utilized to calibrate and refine model because it is not practical or cost-effective to perform pre- and post-project monitoring and/or billing analysis for every project.
  - Process studies to determine the level of installer training, vendor procedures, and quality control procedures of the program as this can greatly affect energy savings
  - Impact evaluation procedures that:
    - Stratify the sample to cut across as many local variables as possible, such as the age of homes, size ranges, type of construction, type of HVAC, etc.
    - Perform pre and post monitoring combined with billing analysis across the strata
    - Monitor performance results across at least three seasons to capture both heating and cooling results
- From pilot programs such as the Massachusetts DER program, prototypical homes could be calibrated with the monitored average energy usage of those homes to estimate program related savings.
- Quality control procedures should include retrofit site visits during construction for a percentage of completions for each contractor as installation quality dramatically affects savings. The number of quality control events can decrease in frequency as a specific contractor demonstrates proficiency in the quality of installation.

When significant new technologies or techniques are incorporated into a program, such as the latest cold climate ductless heat pumps or utilizing structural integrated panels (SIPs) for retrofit, they should be evaluated as a pilot phase. Pre and post monitoring of a large percentage (or 100%) of early installs should be conducted as should customer interviews to determine satisfaction levels.

Long-term studies could be helpful in determining the useful measure life of whole-house approaches. As retrofits go deeper the cost escalates dramatically and knowledge of the persistence of savings for envelope measures will be needed to retain cost-effectiveness and measure lifetime savings.

4.9 Recommendations

We recommend that energy modeling calibrated through pre and post audits/monitoring of a representative sample of projects be used as the primary way to estimate savings in whole-house single-family retrofit programs.

To increase confidence in savings estimates that are based on modeling, the following actions should be undertaken:

- Specify detailed modeling procedures that are consistent for all program's vendors.
- Constrain model inputs to prevent unrealistic modeling assumptions (if possible, build the constraints into the software).

- Perform model calibrations, as proposed by BPI, to further ensure that energy models are realistic and representative of the houses being audited.
- Perform monitoring and billing analysis on representative project samples on a regular basis to increase the confidence level of savings estimates and provide feedback for improving software algorithms, modeling procedures, and assumptions.
- Implement quality assurance protocols in order to realize persistent savings.
- Utilize a verification protocol for software that assures ongoing improvement.
- Follow established procedures for auditor training and certification.
- Utilize certified insulation and air sealing contractors and/or establish a training program.
- Create a database at the program level with modeling inputs and program results for continuous model calibration, tracking of new technologies and techniques utilized, and help in researching program enhancements.
- Move toward addressing all fuels either with a fuel-neutral strategy or by recording and taking credit for secondary fuel benefits. When moving to fuel-neutral strategies, programs should adopt a source energy methodology in order to deal with fuel switching fairly. The multi-family retrofit section of this report recommends a source-based fuel-neutral calculation methodology.

We are confident that with these actions undertaken, energy modeling will prove to be an effective way of providing savings estimates to program administrators.

4.10 Summary

As whole-house retrofits programs move into deeper levels of savings and draw more resources, special attention will be brought to outcomes. These programs will have to provide savings estimates with a high level of confidence. Software modeling, although the preferred means to calculate savings in whole-house retrofits programs, does not by itself necessarily lead to acceptable savings estimates. The modelling needs to be coupled with solid protocols and quality assurance. Uniformity of vendors' software algorithms and consistency in their methods is key.

Multi-Family Whole Building Retrofit Program Approaches

5

5.1 INTRODUCTION

Multi-family housing has long been recognized as an important, but difficult-to-reach market segment for efficiency programs. In addition, residential and commercial sector whole building approaches are also recognized as presenting implementation and evaluation challenges. Combining these two elements into one program model obviously involves a variety of difficult tasks for program developers, implementers, and evaluators. In this section we discuss multi-family whole building retrofit program approaches, particularly focusing on difficulties associated with predicting and assessing savings for projects implementing a wide variety of measures. Program models currently being implemented and data and knowledge gaps that present programmatic hurdles are presented first followed by recommended strategies for closing knowledge gaps and for developing savings methodologies for the prediction and reporting of savings.

5.1.1 Relationship to Single Family Whole Building Program Approach

Section 4 of this report presents our analysis and recommendations for single family whole building retrofit programs. Nearly all of what is presented there is applicable to multi-family programs. This section presents program issues that are of additional concern for multi-family programs. As such, we suggest that the reader consider the two sections as a whole when considering multi-family program models and savings methodologies.

5.2 PROGRAM MODEL OVERVIEW

When considering program approaches for this category, it is helpful to first define what is meant by "multi-family whole building retrofit." For this project we propose to define this program model by identifying program measures and features that when combined, significantly address the energy usage of an entire existing facility.

Our view of multi-family whole building retrofit programs is that they should:

- Focus on the entire facility energy usage, not simply multiple individual measures
- Include a whole building assessment/audit
- Allow and promote upgrades to both common spaces and tenant spaces
- Provide eligibility for measures typically categorized as residential or commercial are eligible

- Engage in an approach that will facilitate tenant cooperation
- Be fuel neutral or at a minimum promote both gas and electric measures
- Include facilities heated electrically by resistance equipment or heat pumps in programs that must address only electric and cannot take credit for non-electric benefits (NEBs), but program design does not encourage switching to electric from another fuel
- Include weatherization as a key mandatory program component when building shell is below standard practice performance levels

5.2.1 Hypothetical Program Model

A hypothetical program model might include the following measures:

- Common and tenant space measures
  - Mandatory for participation: Whole building assessment/audit
  - Mandatory for participation: Weatherization – insulate and air seal to program standards
  - Sub-metering
  - Central HVAC upgrade
    - System tune-up and balancing
    - Central boiler/furnace/air handler/RTU/chiller upgrade/replacement
    - VFD & VAV measures
    - Ductwork/piping optimization and insulation
  - Service water heating upgrade
- Common space measures
  - Exterior lighting and controls
  - Lobby, hallway, storage, etc. lighting and controls
  - Central laundry
- Tenant space measures
  - Refrigerator replacement
  - Programmable thermostats
  - CFL and LED lighting
  - Upgraded PTACs/window mount AC
  - Ductless mini-split unit replacements for tenant ACs
  - Advanced power strips
  - In-unit domestic water heating

- In-unit laundry appliance replacement
- Tenant weatherization: Weather-stripping, electric outlet seals, etc.

Projects developed under such a program would not need to address all measures, but would be required to meet a certain comprehensiveness level in order to be considered a whole building retrofit.

5.2.2 Program Delivery

One of the reasons that multi-family programs are difficult to deliver is that they offer, by design, a combination of residential and commercial measures. With most program administrations dividing their workforce efforts along residential and commercial measures, it can be difficult to develop consistent methodologies. For these reasons, the programs are sometimes delivered with incentives split between two program tracks. Alternatively, delivery is handled by a staff or contractor who is dedicated to the multi-family program and obtains advice and assistance from both the residential and commercial program implementers as needed.

Further, delivery is often focused around building weatherization as the group of anchor measures, with HVAC, lighting, and appliances added to the menu. This is appropriate because with the exception of recently constructed buildings built to modern code standards, the largest energy impacts will be associated with envelope measures. Building envelope measure savings are difficult to predict without modeling that is specific to the baseline insulation conditions, weather data, and building construction details or a history of monitored performance of local building stock pre and post retrofit.

Obtaining access to tenant spaces is another challenge affecting program delivery. As such, programs often focus on common spaces, leaving tenant spaces to be handled through residential audit programs, which may also include direct-install measures such as weather stripping, programmable thermostats, and CFL replacements for incandescent lamps. Separately operated refrigerator replacement programs are also often available for apartment/condominium dwellers. Although, such a segmented program approach may at times achieve significant overall building improvement, it lacks the advantages of a coordinated whole building effort.

Lastly, split incentives are present in this sector when tenants pay for the utilities, but the property owner/manager purchases energy efficiency upgrades.

5.3 Advantages of Multi-Family Whole Building Retrofit Program Approaches for Efficiency Programs

A coordinated whole building approach offers many advantages that are difficult to achieve through segmented efforts. Many of the advantages are associated with program marketing and public relations, which fall outside the scope of this project. However, there are also advantages directly associated with obtaining and accurately measuring savings.

5.3.1 Obtaining Deeper Savings

Obtaining deeper savings from both residential and commercial buildings is a current mission of most long-standing efficiency programs. Whole building approaches allow the opportunity to obtain deeper savings through the bundling of services/measures. The term "inoculation" is often used to describe the difficulty of obtaining deep savings. When a building owner is presented with a single measure that is extremely cost-effective, the installation of the measure may inoculate the building against future measures that are less economically attractive. Whole building approaches allow the program staff to present the building owner with an efficiency "plan of action" that is in aggregate financially attractive. Measures that would not likely have been accepted as stand-alone measures are now installed as part of the whole building solution.

5.3.2 Moving to All-Fuels Program Approaches

As efficiency programs become more sophisticated, a move toward all-fuels approaches is underway. Many programs now bundle gas and electric measures. Additionally, some programs allow credit for savings associated with non-regulated fuels that do not subsidize System Benefit Charge (SBC)-funded programs. Programs focused on greenhouse gas reductions, such as RGGI, also facilitate all-fuels approaches. Whole building approaches afford a perfect opportunity to bundle measures associated with differing fuels while assessing overall energy impacts. Section 5.9.5 provides guidance on calculating savings for all-fuels projects.

5.3.3 Improved Savings Calculations and Measurement

Although in many ways counterintuitive, whole building approaches can offer opportunities to calculate and measure potential and realized savings more accurately, and even more easily, than disaggregated measure approaches. The reasoning behind this proposition is that whole building energy consumption data is readily obtainable, and the methodologies for analyzing such data are well established. However, this can be complicated by the fact that tenant turnover can be frequent and can have a significant effect on energy consumption.

Attempting to predict or evaluate the savings from individual measures within a multi-family building can be a daunting task. Access to residential units is limited, and many end-uses and variables effect electric and fuel savings. However, we routinely deal with whole building energy consumption. Historical and current electric consumption data is available after clearing regulatory privacy issues. Metered gas data is also obtainable, as are the delivery records of fuel oil. As long as a significant percentage of the potential measures are implemented, it is relatively easy to assess project performance through the analysis of pre- and post-project energy consumption, adjusted with weather data. Similarly, the efficiency industry is well-versed in building modeling protocols. Whole building approaches can be readily modeled with DOE-2 based tools, returning reliable results assuming accurate model calibration.

Section 5.9 of this report explores methodologies for evaluating project and program savings for whole building approaches.

5.4 Efficiency Programs Currently Offering Comprehensive Multi-Family Programs

The following are examples of whole building and/or comprehensive multi-measure programs.

5.4.1 Con Edison Multi-Family Energy Efficiency Program

Con Edison offers an efficiency program for owners and/or managers of buildings containing five to seventy-five units. Eligible property types include rent-controlled, rent-stabilized, and market-rate rentals, as well as co-ops and condominiums. Program measures include:

- Tenant measures
  - Refrigerator replacement
  - Room air conditioning unit replacement
  - Advanced power strips (100% program funded)
  - Screw-in CFLs (100% program funded)
  - Programmable thermostats
- Building common area measures
  - Natural gas heating system replacement
  - Heating system tune-ups
  - Central air-conditioning
  - Energy management systems
  - Roof and wall insulation
  - Lighting, occupancy sensing, and LED exit signs
  - Premium efficiency HVAC pump and fan motors

The program offers both natural gas and electric measures, but is not fully fuel neutral. Incentives for natural gas heating systems are available for customers currently utilizing gas, electric, or oil for heat. Conversion of space heating from oil to natural gas is specifically promoted with additional incentives of $500 per dwelling unit up to a maximum of $37,500 in addition to the maximum $15,000 incentive for installing efficient gas equipment.

Although this program is fairly comprehensive in its offerings, there is no requirement for comprehensive projects. The incentives are offered as prescriptive menu items. As such, only a subset of projects would be considered whole building retrofits.

Program documents are available at:
http://www.coned.com/energyefficiency/residential_multifamily.asp

5.4.2 NYSERDA New York Energy $mart Multifamily Performance Program

Although NYSERDA also offers incentives for multi-family facilities through other initiatives, this particular program takes a more comprehensive approach. The program has both new construction and retrofit components. For existing buildings, participants are required to select a "multi-family performance partner" as a technical assistance provider. The owner works with the partner to benchmark the building's energy performance using a NYSRDA benchmarking tool. The performance is compared to a set of similar buildings, and a relative performance rank is assigned. Depending on that rank, a performance target is assigned.

Once the performance target is established the participant and the partner develop an Energy Reduction Plan. Implementation of the plan and confirmation of the achievement of the energy reduction targets make the building(s) eligible for installation/construction incentives. Partial incentive payments are offered at the completion of benchmarking and at the 50% construction levels. Because the program is a custom approach, the measurement of savings depends upon the project components, but may include performance testing and modeling/monitoring in comparison to the benchmarking results.

Program documents are available at:
http://www.getenergysmart.org/MultiFamilyHomes/ExistingBuilding/BuildingOwner.aspx

5.4.3 Massachusetts Deep Energy Retrofit Program

The electric and natural gas utilities of Massachusetts are jointly offering the residential Deep Energy Retrofit (DER) Pilot Program. The program is open to both single family and multi-family buildings. The program aims to take a fuel-neutral approach to achieving at least 50% overall energy savings for each project. With the 50% savings goal, the program targets a variety of measures, including significant improvements in building shell performance with major insulation and air sealing improvements. The program engages building scientists to recommend and critique contractor approaches in order to assure that envelope measure do not create durability or indoor air quality problems. Measures promoted include:

- Building out walls on either the interior or exterior to upgrade insulation levels
- Dramatically increasing attic insulation and/or building up the roof for cathedral ceiling insulation improvements
- Air sealing
- Blower door testing (in most utility territories)
- Window replacement

- Foundation insulation
- ENERGY STAR appliances
- HVAC upgrades
- Heat/energy recovery ventilation
- Lighting upgrades

As a pilot, the sponsors have not collectively decided on the best approach for predicting and recording savings. Three different approaches are currently being vetted:

- Assigning savings from prescriptive values that are associated with prototypical models
- Pre and post monitoring of project energy usage
- Pre and post HERs rating of the building

The Cadmus Energy Group recently completed a process evaluation that details the savings procedures being piloted. The final report is available through the NEEP Repository of State and Topical EM&V Studies. An impact evaluation of this program is scheduled to take place during 2012 and can be expected to critique the various savings methodologies piloted.

5.4.4 Wisconsin Focus on Energy: Apartment and Condominium Program

Wisconsin Focus on Energy (WFE) does not offer a whole building retrofit program; however the prescriptive and custom components of their multi-family efficiency program are comprehensive and if implemented as a package, would address overall building energy consumption. Some of the prescriptive measures include:

- Insulation and air-sealing
- Ground source heat pumps
- PTAC units
- Boiler and furnace upgrades
- Electric-to-gas heating conversions
- Building management systems
- ENERGY STAR Appliances
- HVAC VFDs
- Lighting for common and tenant areas
- Custom measures considered for any non-prescriptive measures

PA Consulting performed an impact evaluation of this program in 2008. This evaluation revealed that WFE uses deemed savings values for individual measures, totaling the savings from installed measures in order to gauge total project performance. The evaluators found that many of the deemed values were the same as those for the single-family program and concluded that they were "highly uncertain" for multi-family facilities, especially in the area of HVAC savings. The evaluation also demonstrated that the WFE does not account for the interactivity of measures, making it difficult to assign overall performance results.

5.4.5 ARRA-Funded Programs

Our research revealed that several states are implementing ARRA-funded multi-family efficiency programs. These programs are typically administered by state housing agencies, rather than through utilities and/or quasi-government efficiency agencies. One example is the Be Smart Multi-Family program being implemented by the Maryland Department of Housing and Community Development. The program offers energy audits and subsidized loans for energy improvements. We do not find the ARRA-funded programs to be accurate models for SBC-funded efficiency programs as the ARRA program has a different set of goals that focus on economic stimulus and job creation/retention. As such they are not governed by the same cost-effectiveness and reporting rules as are SBC-funded programs.

5.4.6 Maine State Housing Authority REACH Program

During 2007, the Maine State Housing Authority (MSHA) implemented a pilot program titled REACH, which was funded through a U.S. Department of Energy grant and was targeted at promoting "alternative" measures for reducing energy consumption in low income multi-family housing. The alternative measures represented several emerging technologies:

- Cold-climate heat pumps
- Heat-pump water heaters
- Solar domestic water heaters
- On-site wind power

A 2010 process and impact evaluation of the program was conducted by Joseph Associates.[1] The results of the evaluation were not encouraging and illustrate why multi-family program administrators should use caution when promoting emerging technologies. The evaluators found that the program administration did little, if any, engineering-based savings predictions, but instead assumed savings of 10%-50% per project. Using on-site monitoring and data logging, the impact evaluation concluded the following for realized gross savings:

- Widely variable performance even within a technology category.
- The most successful measure was heat-pump water heaters with a median savings of approximately 25%.

[1] Joseph Associates, *Maine REACH Project Evaluation: Testing the Energy Savings Outcomes of New Technologies* (Hallowell, ME, 2010).

- Disappointing results from cold-climate air-source heat pumps. Of the seven units that were monitored, five returned negative savings. Two additional units had been turned off by the renters as they suspected that their energy bills were increasing, and they found the units noisy.
- Only one of seven solar hot water systems installed to industry standards, and generating payback within 20 years.
- Poorly sited and installed wind machines returning only small savings.

The process evaluation concluded that the program administration was not fully prepared to implement an emerging technology program and undervalued the importance of installation quality. Evaluators also concluded that more attention should be paid to project and vendor management, quality control, and partner and client education and training.

5.5 EXISTING DATA REVIEW

In addition to the impact and process evaluations referred to in the previous section, we reviewed available studies and protocols on multi-family whole building retrofits. Unfortunately, just as there are few true whole building programs, there are few data points.

5.5.1 National Energy Efficiency Best Practices Study: Residential Multi-Family Comprehensive Best Practices Report

Quantum Consulting conducted this study in 2004. It offers the best review of program strategies to date. The programs studied are presented in Table 5-1:

Table 5-1. Multi-Family Programs Studied for Best Practice

Program Name	Implementers
2002 Multi-Family Incentive Program	Austin Energy
2002 California Statewide Multi-Family Program	California Joint Utilities
2002-2003 Apartment & Condo Program	Focus on Energy - Wisconsin Energy Conservation Corp.
2002 EnergyWise - Multi-Family	National Grid
2000 Multi-Family Conservation Program	Seattle City Light

Key findings of the study include the following:

- Utilize whole building approaches. "Approaching the building as a system allows auditors, project managers and contractors to consider the complex interactions of HVAC and air flow, windows and mechanical systems, and shell issues with air change per hour (ACH) requirements. However, this approach may require more time and hands-on project management. Programs managers interested in pursuing this approach will need to budget for the additional time and expertise required to integrate building systems, model the impact of upgrades and install the measures."[2]

- Conduct quality assurance and verification inspections to improve the overall understanding of how multi-family buildings function. Given the relative complexity of multi-family building systems, "assuring that measures are installed and operating as expected is particularly important . . . [as is the] need for information about what works and doesn't work in different climates, in various building types and with different measure mixes."[3]
- Evaluations often catch problems too late to enable corrections. Obtaining real-time feedback from inspections can uncover problems that can then be corrected in the same program year.

Although the study states that evaluation of multi-family programs is rare, even amongst these best practice programs, it does outline the evaluation approaches for each program:

- Austin Energy no longer conducts evaluations and has not recently contracted an evaluation. DOE2 modeling is utilized by the staff to estimate impacts.
- California conducts comprehensive process and impact evaluations for their multi-family programs. The evaluations include interviews and surveys with market actors, on-site verification, and an HTR assessment.
- The Energy Trust of Oregon conducted a thorough process evaluation of its Home Energy Savings Program, which has a multi-family component. The process evaluation included a description of the program's history and implementation structure, the program theory, and estimates of program performance.
- Wisconsin Focus on Energy Apartment & Condo program was evaluated in 2003 and 2008 (see section 5.4.4). The program relies on estimated deemed savings, and no modeled or monitored results are available.
- National Grid conducted an impact evaluation of the EnergyWise Multi-Family program, which focused on estimating energy and demand savings. The program year 2002 evaluation describes the extensive statistical methods and modeling strategies employed to determine energy and demand impacts. The evaluation relied on statistical analysis of billing data using estimates of energy savings and weather conditions as inputs to assess results.
- Seattle City Light Multi-Family program relies upon energy consumption data, weather data, engineering projections, gross and net savings equations, and regression analysis to estimate energy savings.

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[2] Quantum Consulting Group, *National Energy Efficiency Best Practices Study: Residential Multi-Family Comprehensive Best Practices Report*, R5-9.

[3] Ibid, R5-31.

5.5.2 New York Department of State Best Practices: Ontario Home Energy Retrofit Program (Single/Multi-Family)

This Ontario program is recognized for best practices by the New York Energy Efficiency Portfolio Standard Working Group (WG) as it, "provides homeowners with clear cost/benefit analysis and a direct plan of action with minimum paperwork."[4] The program covers electric, gas, and biomass measures, including:

- Insulation and air sealing
- HVAC upgrades
- Wood burning appliances
- Heat recovery ventilation

Savings for this program are established through a combination of auditing, testing, and modeling. The program interfaces with the national ecoENERGY program, which maintains a database and a unique modeling tool for the program. Pre- and post-energy audits involving blower door tests are mandatory protocols for program participation.

5.6 KNOWLEDGE AND DATA GAPS

There is much information available concerning multi-family housing efficiency program models and the collection of measures promoted through said programs. However, there is a significant knowledge gap in an area central to this project: predicting and measuring the energy performance of multi-family efficiency programs and projects when the goal is a whole building retrofit.

The gaps are related to several specific issues:

- **Program experience** - Very few true whole building programs are being implemented. Until recently, most efficiency programs have focused on one fuel with electric being the predominant energy source addressed. Given the nature of multi-family housing it is difficult to address whole building efficiency without including multiple fuels.
- **Comprehensiveness** - Prescriptive programs offering multiple measures have a difficult task in promoting whole building approaches as owners tend to seek the most cost-effective measures.
- **Modeling** - Very little modeling has been done for multi-family whole building retrofits. In addition to the fact that there are few programs being implemented, modeling is difficult when internal gains are variable and hard to predict as they are for multi-family housing.
- **Monitoring** - In addition, there has been little monitoring of pre- and post-retrofit conditions for whole building approaches. Impact evaluations tend to focus on individual measures and not whole building usage, and evaluation timetables rarely allow monitoring to span multiple

[4] NYDS Energy Efficiency Portfolio Standard, Energy Efficiency Best Practices Case Studies, Working Group 2, 2008

seasons. Program administrators and regulators now rely on impact evaluations to assign realized savings, eliminating the incentive for programmatic monitoring.

- **Interactivity of measures** – Most of the current TRMs we reviewed and searches of program documentation outside our region reveal that the factors for the interactivity of measures with HVAC measures are based on dated information. They rely on a study performed in 1993. Since 1993, heating efficiency has improved modestly, while cooling efficiency has improved dramatically especially chiller efficiency.

Our understanding is that the Forum members seek to identify program approaches that will allow for relatively easy assignment of either deemed savings, savings algorithms, savings methodologies, and any combination of these. The significant knowledge gaps do not allow for whole building deemed values or whole building algorithms. However there is enough knowledge of whole building approaches to support recommended program implementation and savings methodologies.

5.7 Closing the Knowledge Gaps

By and large, what is needed to close the knowledge gaps associated with multi-family whole building approaches is programmatic experience concurrent with solid EM&V procedures. No amount of predicting project and program performance can replace the knowledge gained from retrofitting numerous projects and monitoring the results. The specific actions recommended for closing these gaps are presented in the following subsections.

5.7.1 Fund and Implement Pilot Programs

Program administrators should actively seek to implement pilot programs that truly take a comprehensive whole building approach. Pilots should include several mandatory measures such as whole building assessments, weatherization, sub-metering, common area lighting, and HVAC upgrades. In addition, participants should be required to implement a minimum number of optional measures. Process evaluations are key components to implementing valuable pilot programs.

5.7.2 Model and/or Monitor Building Performance

From the outset, one of the main goals of the pilot programs should be to model and/or monitor building performance pre and post retrofit in order to catalog and analyze results. By combining recorded building parameters and assumptions with building performance data, a case could be built for supporting program implementation with deemed values and algorithms.

5.7.3 Allow for Comprehensive Impact Evaluation Procedures

All too often, the planning process for impact evaluations is so time consuming that insufficient time is available for significant monitoring of projects. Whole building performance is weather related. In order to accurately gauge savings, performance must be recorded across seasons. At a minimum, one winter month, one summer month, and one shoulder-season month should be recorded. Timetables for impact evaluation monitoring should not be set by calendar date. In order to preserve enough time for proper monitoring, an elapsed monitoring time that begins upon approval of the site evaluation plans should be established.

5.8 Establishing Program Baselines

As retrofit programs, it would seem simple to assign baselines as the pre-existing conditions. However, with new energy code provisions it is not necessarily so simple. All currently adopted energy codes define multi-family buildings three stories and under as residential buildings and buildings four stories and up as commercial structures. Although energy codes include many more provisions for commercial buildings, both codes are enforceable for renovation work. Earlier versions of energy codes allowed renovations that involved less than 50% of a system or a subsystem to be noncompliant. Current codes (ASHRAE 90.1 2007 & IECC 2009 and newer) have eliminated the 50% provision and require compliance for virtually all renovation work.

However, opportunities are in the details. Code language provides for many practical exceptions for major renovation projects. For multi-family projects, major exceptions include an exclusion for envelope insulation if the wall/roof/ceiling/floor cavity is not exposed. In addition, if the cavity is exposed, but is filled with properly installed insulation, there is no requirement to increase insulation to code level R-values.

What remains unclear, and subject to local interpretation and regulation, is whether or not efficiency programs are required to adopt code baselines for renovation projects that are primarily motivated by program participation. Our research identified no instances of rulings requiring efficiency programs to assign code baselines for renovation projects motivated by program participation, and we support the concept that the baseline for such projects is the pre-existing condition.

5.8.1 Proposed Baselines

- **Renovation/retro-fit projects motivated by program participation** – The baseline should be established as the pre-project conditions.
- **Efficiency projects implemented as an enhancement to an otherwise planned renovation project** – The baseline should be established as code compliant practice that also represents local standard practice. Many program regulations specify that baselines for major renovation projects be set at current energy code compliance levels. Due to the complicated and rapidly advancing code provisions, code level does not always match local standard practice. As such, program administrators may wish to argue for baselines that are lower than code level for some measures.

5.9 Savings Methodologies

There are several savings methodologies that can be utilized for assessing potential and realized savings for programs of this type. The methodology recommended for an individual program will depend on the comprehensiveness of the program approach, the regulatory accepted practice, and the relative effort and budget that can be applied.

5.9.1 Aggregated Measure Savings Approach

For programs utilizing a collection of prescriptive measures from established residential and commercial efficiency programs, an obvious simple approach is to assign the established deemed values and/or savings algorithms from each of the measures. There are interactive effects associated with heating and cooling system measures and other measures affecting building conditioning loads. However the interactivity factors and methodologies are little different than those established for the selected measures.

5.9.2 Building Simulation Model Approach

Building simulation is a well-established methodology for predicting the performance of residential and commercial building types. The standard accepted simulation methodology, DOE-2, was developed over 20 years ago and serves as the engine for eQUEST and Visual DOE, which have user interfaces that include menus and wizards designed to ease the modeler's burden. DOE-2-based tools are used to perform building energy analyses in order to predict the energy consumption of buildings. The modeler inputs building layout, construction details, occupancy/usage, conditioning systems, lighting, plug loads, etc. in addition to local energy costs/rates and weather data. With those assumption inputs, the tool performs an hourly simulation of the building to predict energy loads and to estimate utility bills.

In order to predict the energy impacts/savings of a whole building retrofit approach, the simulation model is built and run twice; once with the existing building configuration and a second time with the assumptions adjusted to match the intended collection of retrofit measures. Although time and budget consuming, the model can be run multiple times, changing the assumptions in order to predict the impact of measure/project variations. The methodology for performing these comparative models is well-known by simulation modelers, as it is the accepted methodology for verifying energy code compliance using the ASHRAE 90.1 Energy Cost Budget and the IECC Total Building Performance approaches.

5.9.3 Building Monitoring Approach

An advantage for program administrators when dealing with building retrofit programs is that there is an existing "bricks and mortar" building with real available data. Through the collection and analysis of pre- and post-project energy usage data, accurate actual impacts of whole building retrofits can be measured. Given that scenario, it might seem logical that performance monitoring be the predominant methodology for assigning savings. The fact that it is not is due to several factors:

- **Data gathering** – The very nature of multi-family housing creates difficulties in obtaining energy usage data. Such data is typically regarded as confidential and most suppliers enforce policies that do not allow the release of energy consumption data without subscriber permission. With multiple tenants in addition to building ownership, the process of obtaining valuable data can become onerous.

- **Predicting energy impacts** – Program administrators seek, and/or are required to predict energy savings impacts prior to approving retrofit projects. In addition, successful marketing of the project may be dependent on savings predictions. This can be done with reasonable accuracy through simulation modeling. Utilizing a monitoring approach, the project impacts are known only after the completion of the project and post-project monitoring that spans heating and cooling seasons.
- **Program costs** – Monitoring can be expensive. Although sub-metering equipment cost has been coming down, and electronic web-based uploading of information has eased data collection efforts, the cost of monitoring building systems is still viewed as being too expensive to be universally applied. However, the complexity of running comparative building simulation models also consumes large portions of program budgets affecting overall program cost-effectiveness.

5.9.4 Prototype Calibrated Modeling Approach

Combining features of several of the approaches discussed, this method establishes prototype buildings based on the local stock of multi-family facilities. A set of baseline and proposed measures is established for each prototype and the prototypes are modeled using a DOE-2 simulation tool. A sample of projects is pre and post monitored to further calibrate the models. This approach is being utilized by New Buildings Institute for the Advanced Buildings Core Performance Program. The program currently does not address multi-family facilities, but could be expanded to do so. Further details on this approach are included in the recommendations section.

5.9.5 Site/Source Fuel-Neutral Approach

For the great majority of multi-family buildings, a whole building retrofit will involve multiple fuels. For areas with natural gas delivery networks, the fuels will largely be natural gas and electricity. For areas lacking natural gas infrastructure the predominant fuels will be electricity and #2 fuel oil. Biomass and propane will also be included in the fuel mix to a limited degree.

Many program implementers now offer gas and electric measures to the same customer base. This is primarily done by offering a separate prescriptive menu for each fuel and/or a separate custom project calculation. The two fuel-related paths are often promoted and managed by two separate program staffs. This is a difficult way to promote and implement whole building projects for a variety of reasons: customers respond better to a single point of contact, most measures are interactive across fuels, gas and electric program staff each have their own goals to meet, etc.

A preferable methodology for whole building new construction and retrofits is to approach programs and projects from a fuel-neutral perspective. Although current and historical program structures present challenges to this approach, recent initiatives targeting overall building performance and reductions in greenhouse gas emissions have been moving programs in a direction that facilitates full fuel-neutral approaches. Adopting such a methodology allows for an equitable means of providing incentives for projects that promote efficient use of resources regardless of the existing and proposed fuel sources.

A Fuel-Neutral Source Btu Method

In recognition of the varying environmental impacts associated with the consumption of "primary fuels" such as natural gas and "secondary fuels" such as electricity, the U.S Environmental Protection Agency and the Department of Energy endorse a methodology that utilizes regional source-site ratios that reflect the losses associated with the production, transmission, and delivery of various fuel types. With this methodology, multiple fuel energy streams are converted into what is defined as "source energy."

During 2010, ERS worked with NYSERDA to develop a fuel-neutral strategy based on the source energy model. The fuel source ratios for New York are presented Table 5-2. Source ratios are available for states and regions and vary with the generation mix and other factors.

Table 5-2. New York Source-Site Ratios for All Portfolio Manager Fuels

Fuel Type	Source-Site Ratio
Electricity (grid purchase)[1]	3.2931
Electricity (on-site solar or wind installation)	1.0000
Natural gas[2]	1.0089
Fuel oil (1,2,4,5,6,diesel,kerosene)	1.0100
Propane & liquid propane	1.0100
Steam	1.4500
Hot water	1.3500
Chilled water	1.0500
Wood	1.0000
Coal/coke	1.0000
Other	1.0000

[1] Reflects NY-specific grid and loss information obtained from http://www.nyserda.org/publications/Patterns%20&%20Trends%20Final%20-%20web.pdf

[2] Reflects NY-specific distribution information obtained from http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/natural_gas_annual/current/pdf/nga07.pdf

All values based on the Energy Star Performance Rating Methodology from http://www.energystar.gov/ia/business/evaluate_performance/site_source.pdf

The source energy consumption is determined by multiplying the energy consumed on-site by the factor provided in the table.

More details relating to site and source energy and the determination of source-site ratios can be found in the ENERGY STAR publication *Understanding Site and Source Energy* and in the ENERGY STAR *Performance Ratings Methodology for Incorporating Source Energy* available online at:

www.energystar.gov/index.cfm?c=evaluate_performance.bus_benchmark_comm_bldgs

Steps in determining project savings using this process are as follows:

1. Determine the project site energy existing and post-retrofit usage for each fuel as would be done for any other savings methodology.
2. Where appropriate, calculate the electric demand savings on a site usage basis.
3. Convert the site energy consumption results to source values by applying the appropriate source-site ratios to the existing and projected consumption of each fuel.
4. Convert the resulting source energy savings consumption to equivalent Btus.
5. Deduct the total post-retrofit usage in Btus from the existing energy usage in Btus.

The results generated are the electrical demand reduction and the net energy reduction on an equitable fuel-neutral basis. A spreadsheet tool can be readily developed that will perform all site-to-source energy calculations.

5.10 Deemed Savings Values and Algorithms

5.10.1 Deemed Values

At this time, we do not believe that it is possible to assign deemed values for savings associated with multi-family whole building retrofits. There are far too many variables and too many unknowns associated with the performance of various building types for deemed values to represent an acceptable level of accuracy. This is not to imply that we reject the concept of deemed values; the gap analysis and recommendation sections address possible deemed value paths.

5.10.2 Algorithms & Methodologies

Whole building simulation modeling and monitoring approaches include the variables and assumptions associated with savings algorithms embedded in their methodologies. However, if relying on the bundling of individual prescriptive measures, a combination of deemed savings values and algorithms will likely be utilized.

For the same reasons presented for deemed savings values, we are unable to provide algorithms for an overall whole building approach. Of course, algorithms accepted for measures or groups of measures imported to a whole building program can be used, in sum, to develop overall project savings.

Interactive Effects of Multiple Measures

When developing whole building projects, it is important to recognize the significance of the interactive nature of implemented efficiency measures with HVAC loads. In many, but not all cases, this interactivity will be included in the algorithms adopted by programs for the implemented measures.

We make this point because mishandling of the interactive effect of measures in whole building approaches could lead to dramatically inaccurate savings predictions. It is important to ensure that savings are not double counted or neglected. For example, if the whole building retrofit includes insulating/sealing the envelope as well as replacing the HVAC system, the savings associated with the improved efficiency of the HVAC system needs to be calculated on the post-weatherization building loads. Calculating savings for improved HVAC efficiency on the pre-weatherization loads would ensure that portions of the savings are accounted for twice.

Although there may be exceptions, it can be assumed that the great majority of multi-family buildings will be both mechanically heated and cooled throughout the Forum member territories. Interactive HVAC factors are most commonly utilized for lighting measures although many measures will have some impact on HVAC loads. For example, replacing in-unit refrigerators with more efficient models will reduce the amount of waste heat generated in the building. As with lighting, reductions in heat gains due to power reductions decrease the need for space cooling and increase the need for space heating. HVAC interaction factors vary by climate, HVAC system type, and building type, as well as by measure usage patterns.

Below is the algorithm for calculating savings for hard-wired compact fluorescent lighting for residential sectors published in the *Mid-Atlantic Technical Reference Manual, Version 2.0* produced by VEIC for the Forum. The algorithm is used to calculate the savings associated with the installation of CFLs, including a waste heat factor for cooling savings due to reduced lighting loads. Other program TRMs within the region include similar algorithms.

Annual Energy Savings Algorithm:

$$\Delta kWh = ((\Delta Watts)\ /1000) \times ISR \times Hours \times WHFe$$

where,

$\Delta Watts$ = Compact fluorescent watts (if known) × 2.95
If compact fluorescent watts is unknown use = 48.7 23

ISR = In-service rate or percentage of units rebated that get installed =*0.95*

$Hours$ = Average hours of use per year = 1088 (2.98 hours per day)

$WHFe$ = Waste heat factor for energy to account for cooling savings from efficient lighting = 1.14 (based on the ASHRAE lighting waste heat cooling factor for Washington DC)

The recently adopted *New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs* commonly referred to as the New York Technical Manual also includes values for HVAC interaction factors for lighting, refrigerator, and freezer measures. Factors for electric consumption, electric peak demand, and gas consumption are included. Table 5.3 provides interaction factors to be utilized for New York multi-family projects. It can be noted from the table, that depending upon the region, the fuel, and the HVAC system type, the effect of improving the efficiency of lighting or refrigeration can have a negative or positive effect on HVAC loads.

Table 5-3. HVAC Interactive Effects Multipliers for Multifamily Low-Rise

	AC with Gas Heat			Heat Pump			AC with Electric Heat			Electric Heat Only			Gas Heat Only		
City	HVACc	HVACd	HVACg	HVACc	HVACd	HVACg	HVACc	HVACd	HVACg	HVACc	HVACd	HVACg	HVACc	HVACd	HVACg
Albany	0.02	0.128	-0.017	-0.14	0.15	0	-0.329	0.128	0	-0.363	0	0	-0.014	0	-0.017
Binghamton	0.003	0.137	-0.018	-0.178	0.151	0	-0.384	0.137	0	-0.407	0	0	-0.02	0	-0.018
Buffalo	0.014	0.142	-0.017	-0.143	0.157	0	-0.332	0.142	0	-0.359	0	0	-0.014	0	-0.017
Massena	0.015	0.158	-0.018	-0.161	0.181	0	-0.349	0.158	0	-0.377	0	0	-0.013	0	-0.018
NYC	0.055	0.136	-0.016	-0.064	0.163	0	-0.26	0.136	0	-0.32	0	0	-0.005	0	-0.016
Poughkeepsie	0.038	0.132	-0.017	-0.102	0.157	0	-0.295	0.132	0	-0.342	0	0	-0.01	0	-0.017
Syracuse	0.017	0.14	-0.018	-0.16	0.15	0	-0.361	0.14	0	-0.391	0	0	-0.013	0	-0.018

HVACc = HVAC system interaction factor for annual energy consumption
HVACd = HVAC system interaction factor at utility peak hour
HVACg = HVAC system interaction factor for annual gas consumption

5.11 Conclusions and Recommendations

The following conclusions and recommendations focus on implementing multi-family whole building approaches that comprehensively address facility energy loads, engage owners and tenants, and include methodologies for accurately predicting and measuring energy impacts.

5.11.1 Close the Data Gaps

As detailed in sections 5.6 and 5.7 there are significant data gaps that need to be closed in order for program administrators to make informed assumptions and develop deemed values and/or algorithms in order to simplify program delivery. As discussed in Section 4 of this report, progress is being made on whole building approaches for residential retrofit, and the knowledge gained is transferrable in many ways.

Execute Pilot Programs and Monitor Results

In order to close knowledge gaps, pilot programs will need to quantify program and project results. Regulators reluctant to fund full implementation programs based on predicted whole building performance will be more willing to approve pilot programs that inform a proposed program approach.

5.11.2 Communicate Across Departments

Multi-family housing programs involve a mix of residential and commercial efficiency measures and approaches. Program administration typically has internal expertise in both sectors and also contracts with qualified technical assistants and implementers. However, each sector program is typically implemented by a separate department. In providing implementation assistance and in performing process evaluations, it is remarkable how often the residential and commercial program departments have very little cross-program knowledge. As a result, multi-family program approaches tend to focus either on residential or commercial measures or receive limited effort due to fragmented approaches. In order to implement multi-family whole building approaches, residential and commercial expertise must come to bear. Therefore, we recommend that a multi-family program not be considered part of two portfolios, but that the staff involved be experts in one or the other and work together as a single team.

5.11.3 Adopt Fuel-Neutral Policies

Except for the few buildings that are both heated and cooled electrically, programs cannot be considered whole building approaches if addressing electric or gas consumption only. At a minimum, gas and electric program administrators must establish a methodology for collaborating on projects. However, integrated program approaches offer clear advantages for marketing as well as monitoring savings, compared to simply cooperating across programs. The recommended models are:

- Develop a shared set of gas and electric measures that can be implemented by either gas or electric program staff. This approach clearly involves coordination challenges.
- Establish a jointly funded gas and electric program that is implemented by an independent staff that shares technical expertise across fuels and sectors.
- Establish an independent program that adopts a fuel-neutral approach. An approach to evaluating measures on a fuel-neutral basis is presented in Section 5.9.5. Obtaining funding for fuel oil measures can be a challenge, but once that hurdle is cleared, marketing and evaluating projects on a fuel-neutral basis is a key step in establishing truly whole building program approaches.

5.11.4 Consider a Simulation Supported Prescriptive Program Approach

Many programs in the Northeast are currently utilizing a series of tools and protocols that facilitate a prescriptive approach for whole building commercial new construction that is backed by simulation models. The national program, Advanced Buildings - Core Performance (AB-CP), was developed and is maintained by the New Buildings Institute (NBI). Many of the Forum member organizations are sponsors of AB-CP and/or other NBI efforts. The program approach is briefly described as follows:

- Specification of a menu of prescriptive provisions that are appropriate for most commercial buildings and represent efficiency levels higher than current codes
- Simulation modeling of prototypical buildings in support of savings assurance for the prescriptive measures

- A guidebook and online support for program implementation
- Technical assistance support, including a sponsor technical committee
- Program marketing materials and support
- Regional customization for weather conditions and local construction practice
- Development and support of a "multi-measure tool" that utilizes eQUEST modeling to measure the comparative effects of altering the measure menu for projects
- A protocol for monitoring project performance

Utilizing NBI supplied data, program administrators have predicted energy savings against code based baselines and are utilizing post-project monitoring to verify savings. Project monitoring results are being provided to NBI for further model calibration leading to continuous accuracy improvement.

A program based on the above model, developed by NBI or others, would be fully appropriate for multi-family whole building approaches. The menu of measures would be clearly understood by building owners, and once regulators have approved the savings methodology, the burden of modeling or otherwise calculating savings is greatly reduced.

5.11.5 Monitor the Projects - Leverage "Smart Metering"

With the increased reliance on impact evaluation, the monitoring of projects as an implementation task is no longer common. During a recent meeting of NBI program sponsors from Massachusetts, Vermont, Maine, New York, Wisconsin, and Washington, the question was asked as to why program administrators resisted monitoring projects. The answers were varied, but included "monitoring is too costly," "monitoring is the evaluation group's task with its own budget," and "we are afraid of what we might find."

The lack of monitored data, however, makes it difficult to initiate whole building approaches. Regulators want to be assured that cost-effective savings will be achieved. Without monitored or at least modeled results, program administrators are most likely to fall back on programs that simply apply a menu of existing prescriptive measures. The cost of monitoring is coming down and should be compared to modeling. Done properly, hourly simulation modeling is expensive, with the cost typically ranging from $10,000 to $30,000 depending on the complexity of the project. Monitoring of electric and gas consumption can readily be performed in that price range. Fuel oil consumption can be measured through delivery/billing data. Monitoring provides actual performance data, not predictions based on modelers' assumptions.

Smart Metering

Advanced "smart" metering programs are being implemented throughout the region. Although "smart metering" has been adopted as a common term, "advanced metering infrastructure" (AMI) is the technical term for the protocols that will allow for easier, more accurate, and less expensive collection and analysis of consumption data. AMI is defined as "electricity meters that measure and record usage data at a minimum, in hourly intervals, and provide usage data to both consumers and energy companies at least once daily."[5] According to the Smart Grid Clearing House, AMI projects are underway or funded by the following Mid-Atlantic and Northeast states: Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, and Vermont.[6] Figure 5-1 illustrates a map of current AMI projects.

Figure 5-1.Current AMI Projects[7]

AMI represents Advanced Metering Infrastructure (AMI)
IS represents Integrated Systems (IS)
CS represents Customer Systems (CS)
TS represents Transmission Systems (TS)
DS represents AMI Distribution Systems (DS)
RD represents Regional Demonstration (RD)
EM represents AMI Equipment Manufacturing (EM)
SD represents Storage Demonstration (SD)

There is some concern amongst consumer advocates that smart metering will primarily be used for automatic billing procedures and the elimination of meter reading positions. Efficiency program administrators should engage the implementers of AMI projects and ensure that the energy efficiency promise is met. One of the first AMI projects to be implemented is underway in Maine with the customers of Central Maine Power. For no additional fees, customers will have access over the web, to their consumption data. From the CMP Smart Meter website: "In the Fall of 2011, customers with smart meters will be able to view their individual electricity usage on line. You will be able to view all the data that has been measured by the smart meter since it was installed."[8] Such

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[5] www.smartgrid.gov, U.S. Dept. of Energy.

[6] www.sgiclearinghouse.org, Virginia Tech Advanced Research Institute and U.S. Dept. of Energy.

[7] Ibid.

[8] www.cmpco.com/smartmeter/.

consumption data combined with fuel oil delivery records (Maine has very little natural gas infrastructure) will be used by Efficiency Maine to monitor whole building performance.

As with other programs approaches that assess overall consumption, issues surrounding access to customer data will need to be resolved. In some states, regulations may require customer authorization allowing program implementers access to consumption/billing data.

5.11.6 Ensure That Process Evaluations Provide Program Feedback

Past evaluations have found that the structure and implementation process of multi-family programs are very important and can support or hinder ultimate goals. Quality control of the implementation of measures plays a big part in obtaining energy savings. Managing vendors and helping to ensure partner skills are important to running a smooth program than can obtain the desired savings. Results from process evaluations are keys to helping this type of program perform optimally. Additionally, evaluators should help the program implementers determine ways to improve uptake of multiple measures so that there truly is a whole building approach.

5.11.7 Facilitate Appropriate Impact Evaluation Procedures

As discussed, schedules for impact evaluations have become problematic. As evaluation planning procedures seek to include more stakeholders, and programs are increasingly shared by multiple utilities and governmental entities, the planning phases are being continuously extended. Rather than move the completion dates forward, the typical result is that the time period available for M&V is abbreviated. Impact M&V is now too often conducted with very short data logging deployment. Impact evaluations for whole building approaches should be planned for long-term data logging that spans a minimum of three seasons.

5.12 SUMMARY

Multi-family whole building retrofits offer an opportunity for programs to reach deeper savings and avoid inoculating projects through the harvesting of low-hanging fruit. Although implementing a variety of measures can complicate the recording of savings, if programs are able to move toward fuel-neutral strategies, measuring and modeling whole building performance will be less of a burden than will approaches that simply aggregate commercial and residential building measures. Regardless of the path taken, it is clear that quality control of staff and vendor procedures are critical to realizing persistent savings.

Light Emitting Diodes

6

6.1 INTRODUCTION

Lighting systems based on light emitting diode (LED) technology offer the prospect of transforming the commercial and residential electric lighting market in a way unprecedented since the introduction of the ballasted fluorescent lamp in 1938. While most other types of lamps are approaching their maximum theoretical efficacy, the best performing white-light LED products are only half way to their maximum potential. At the same time, production costs and market pricing for LED lighting systems are dropping and are expected to continue to decrease in cost per lumen and cost per lamp. However, despite ongoing performance and cost improvements, LEDs are unlikely to completely displace the array of conventional fluorescent, halogen, and high intensity discharge (HID) products that dominate the high-efficiency lighting market today.

The range of application for LEDs has expanded rapidly since the introduction of LED products for commercial refrigerated-case lighting and exterior lighting in the mid-2000s. Researchers and industry experts have been surprised by the speed with which LEDs have entered a variety of niche markets. As legislation such as the Energy Independence and Security Act of 2007 (EISA) drives minimum performance requirements for general service lighting upward, LED performance and pricing for a variety of interior and exterior lighting applications are becoming increasingly attractive to consumers and institutional purchasers.

Nevertheless, LED products and associated market actors face a number of challenges. Chief among these is the natural tendency for some vendors to market low-cost LED lamps with poor performance characteristics. Initiatives such as the U.S. DOE Solid State Lighting Program and the U.S. EPA ENERGY STAR LED lighting program, as well as industry initiatives like the NEEP DesignLights Consortium have so far been successful in guiding consumers of replacement lamps and new luminaires (commonly termed lighting fixtures) toward products that meet or exceed consensus standards for efficiency, color rendering index (CRI), and service life, among other criteria.

LED lighting is used in a wide range of applications including interior and exterior illumination, backlighting for TVs, PCs, and mobile devices, decorative lighting and signage, exit sign and emergency lighting, traffic signal lights, and automotive lighting. This document addresses illumination only. Under the general category of illumination, the following classes of LED lighting have been identified as meeting Forum member priorities:

Residential Products

- Replacement lamps for general indoor lighting
  - A19 screw-in lamps (omni-directional general service lamps)
  - PAR20, PAR30, PAR38 screw-in lamps
  - MR16/PAR16 pin-base lamps
- Hardwire fixtures for indoor lighting
  - Recessed downlight luminaires
  - Under-cabinet luminaires
  - Cove luminaires
  - Track light / spot luminaires for indoor lighting

Commercial/Industrial Products

- Replacement lamps for general interior lighting
  - PAR30, PAR38 screw-in lamps
  - MR16/PAR16 pin-based lamps
- Hardwire fixtures for interior lighting
  - Recessed downlight luminaires
  - Integral troffers (2x4, 2x2, 1x4)
  - Under-cabinet task lighting luminaires
  - Track light luminaires
- Exterior area and security light fixtures
  - Parking garage luminaires
  - Street/parking lot luminaires
  - Low-bay/canopy luminaires
  - Wall-mounted security luminaires (wallpacks)
  - Decorative (e.g., post-top) luminaires
- Refrigerated case lighting

The next section of this document provides a brief overview of LED technology and identifies the classes of LED lighting best suited for utility programs - although these options continue to expand. The sections that follow provide overviews of some representative utility LED programs and make recommendations for structuring a robust program, including methodologies and algorithms for predicting the demand and energy savings associated with LED lamps and light fixtures. Finally, this document recommends third-party evaluation procedures for LED lighting programs and concludes with a summary of recommendations with this technology.

6.2 TECHNOLOGY OVERVIEW

LEDs are compact, solid state, light sources usually combined into modules to produce enough light for general illumination. To operate, LEDs also need a driver (power supply/controller) and a heat sink for thermal management (heat dissipation). LED lights can be configured as replacements for a variety of standard lamp types or in specially designed luminaires replacing conventional incandescent and fluorescent light fixtures.

The fundamental building block for LED lighting is a chip fabricated from electroluminescent semiconductor materials that produce light when electricity is applied, but without the glowing filament of an incandescent light bulb or the electric arc of a fluorescent or HID lamp. The light from an LED is directional, which can provide benefits over other types of lamps that emit light in all directions. Optics to further direct and focus or diffuse the light may be configured as part of the LED module or provided as a separate component.

Although LEDs emit heat and are subject to early failure if not cooled properly, their relatively low operating temperature compared to other light sources allows for potentially high efficacy and long service life. A common configuration involves an LED chip or module producing blue light. The blue light is converted into white light by phosphors similar to those in fluorescent lamps. It is also possible to produce white light by combining output from red, green, and blue LEDs, but that configuration is more expensive and less mature than phosphor-based LEDs.

LEDs lose brightness instead of burning out as they reach the end of their useful lifetime, making maintenance and replacement less urgent and potentially less expensive than they are for other light sources. LED life expectancy for most applications is expressed as L_{70}, the number of operating hours until light output is projected to drop to 70% of its original level. According to DOE, good quality white LEDs in well-designed fixtures are expected to have a rated useful life on the order of 30,000 to 50,000 hours.[1]

6.2.1 Potential of LED General Purpose Lighting for Efficiency Programs

Residential and commercial/industrial (C&I) lighting energy efficiency programs are faced with rising efficiency baselines that gradually diminish opportunities for harvesting savings from replacement of older systems with fluorescent and high intensity discharge (HID) lighting.

In the residential sector, advancing federal lighting standards defined in EISA legislation call for the phasing out of standard incandescent lamps beginning with 100 watt bulbs in 2012. EISA-compliant halogen lamps then become the de facto baseline for general service A-19 lamps. These

[1] U.S. Department of Energy, *LED Frequently Asked Questions*, May 2011.

new halogen lamps consume 25% fewer watts per delivered lumen than incandescent lamps and last about as long (≈ 1000 hours). However, they are currently priced at the same level as CFLs, which consume about 75% fewer watts per lumen than an incandescent with comparable lumen output.

Lighting industry analysts predict that consumers will initially replace burned-out 100-watt standard incandescent lamps with still available 75-watt standard incandescents, for which the first cost will likely remain well below that of the alternatives. Other experts see the phaseout as a market opportunity for compliant halogen lamps or CFLs.

The second wave of EISA incandescent lamp phaseouts in 2013 will address 75-watt A-lamps, followed by 60-watt and 40-watt A-lamps in 2014. When no inexpensive incandescent lamp alternatives remain, consumers will have to choose between relatively short-lived compliant halogen lamps and longer-lived CFLs at comparable prices. Alternately, consumers may be willing to try LED A-lamp replacements at a price that is currently hovering around ten times the alternatives and is only partly offset by the LED's longer service life.

Because CFLs have never achieved parity with incandescent lamps with regard to CRI, dimming capability, and color stability while dimmed, program administrators have an opportunity to harness EISA-driven changes in the market to support introduction of high-performance LED products that do well in regard to these criteria in addition to offering high efficacy.

EISA is also having an impact in the C&I sectors with the recent phaseout of magnetic ballasts commonly used for T12 lamps in July 2010 and the forthcoming phaseout of most T12 fluorescent lamps in July 2012. More significantly, standard practice has advanced for both indoor and outdoor lighting to a point where the demand for rapid response, multi-level lighting control is outpacing the ability of fluorescent and HID technology innovations to deliver it. A parallel, growing recognition that HID and CFL lighting is unsuited to deliver naturalistic color rendering, at a time when many HID lighting systems are reaching the end of their service life, creates a significant opportunity for LED lighting systems as flexible alternatives in the C&I sectors.

6.3 Efficiency Programs Currently Promoting LED General Purpose Lighting

As with any new and rapidly advancing energy efficient technology, program administrators in the Northeast and outside the region have begun cautiously incorporating LED lighting in their program initiatives. Most offerings are in the market introduction / pilot stage, but there is a strong desire to harness the growing interest in LEDs and validate their potential as a successor technology to HID lighting in exterior applications and to incandescent and fluorescent lighting in interior applications.

A sample of representative residential and C&I-sector LED program initiatives follows.

6.3.1 Residential Lighting Programs

- Efficiency Vermont - Offering discount pricing or instant coupons: $15 per ENERGY STAR replacement lamp, $20 per ENERGY STAR fixture (must be on Efficiency Vermont Eligible Products List).
- Sacramento Municipal Utility District – Currently providing incentives for LED downlights. The program will expand in 2012 to include ENERGY STAR-qualified downlights, under-cabinet lights, and replacement lamps.
- Silicon Valley Power (CA) - $15 or retail cost, whichever is less, per ENERGY STAR replacement lamp, rebate application with product details required.
- Rochester (MN) Public Utilities Conserve and Save – Offers $10 rebates per ENERGY STAR screw-in lamps of 10W or less, $15 per ENERGY STAR screw-in lamp over 10W, $20 per ENERGY STAR LED fixture. A rebate application with product details is required.
- Long Island Power Authority LED Markdown program – Offers point-of-purchase markdowns for ENERGY STAR qualifying screw-in replacement lamps and fixtures.

6.3.2 Commercial/Industrial Lighting Programs

The following programs represent pilot or established LED incentive programs from around the United States.

- Efficiency Maine Pilot Program – Beginning in 2010 the Efficiency Maine Business Program began offering prescriptive incentives for LED lighting as a pilot effort. Custom incentives were available for product types not covered by the prescriptive offering. Incentive offerings include:
    - Prescriptive incentives for ENERGY STAR qualified downlights, screw-in lamps, and pin-based lamps
    - Prescriptive incentives for DLC-qualified street and parking lot fixtures, decorative area fixtures, wallpacks, parking garage fixtures, and refrigerated case fixtures
    - Custom incentives for products on either the ENERGY STAR or DLC lists, which aren't covered by the prescriptive categories, on a case-by-case basis
- Efficiency Vermont – Efficiency Vermont has introduced a comprehensive package of program offerings including rebates ranging from $16 - $300 for a variety of screw-in and hard-wire LED applications. In addition, pilot projects, upstream incentives, sales incentives, trade ally education, and a municipal LED streetlighting program are offered. In an effort to "prime the pump" for LEDs in the marketplace, the program administrators offered enhanced incentives which resulted in a significant increase in the lighting program savings associated with LEDs.

- Massachusetts Joint Utilities – Led by National Grid, the Massachusetts electric utility programs are currently in the process of introducing and upstream incentive program for LED products for commercial applications. The program will offer discounted product through electrical and lighting distribution channels. Initially the focus is on lamps that will typically be used in retail display applications, such as track heads. The savings baseline is initially established as a combination of incandescent, halogen, and ceramic metal halide lamps.
- California Statewide Programs that are offered jointly by Pacific Gas & Electric Company (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E):
  - Prescriptive ENERGY STAR LED Downlights - $30 per fixture if replacing incandescent or halogen 40W or more with LED 15W or less
  - Customized Commercial Retrofit Incentives for ENERGY STAR-qualified lamps (excluding linear fluorescent and HID replacement lamps)
  - Customized Commercial Retrofit Incentives for ENERGY STAR-qualified or DesignLights Consortium (DLC)-approved fixtures (includes recessed, surface, and pendant-mounted downlights, under-cabinet shelf-mounted task lighting, portable desk task lights, wall-wash luminaires, bollards, outdoor pole/arm-mounted area and roadway luminaires, outdoor pole/arm-mounted decorative luminaires, outdoor wall-mounted area luminaires, parking garage luminaires, and track or mono-point directional lighting fixtures) - $0.05 per kWh annual savings plus $100 per peak kW
  - Custom Commercial New Construction – See description of Savings By Design Program in "Commercial Lighting Design" section of this report
- PG&E and SCE LED Accelerator Program – For large commercial, multi-site customers, particularly retailers and grocers. Tiered, demand-based incentives ranging from $400 per kW reduction (for off-peak applications) to $1400 per peak kW reduction with top performing products.
  - Interior lighting: 85 to 100 lumens per watt, 90 CRI, 0.9 PF, 7-year warrantee
  - Exterior lighting: 90 to 115 lumens per watt, 85 CRI, 0.9 PF, 7-year warrantee
  - Rebates for peak kW reductions are tier-based on efficacy, CRI, and warranty length; fixture efficacy requirements for each tier increase annually over the 3-year program cycle through 2012
  - LED low-voltage spot lights
  - LED reflector lights
  - LED refrigerated case lights – limited
  - LED exterior lights – limited
  - Services that may include lighting energy audits, economic analysis, product demonstration, technical product selection, and specification assistance

- PG&E Efficient Refrigerated Case Options (ERCO) Program.
  - Premium LED case light replacing 6 ft fluorescent $100 per door
  - Standard LED case light replacing 6 ft fluorescent $75 per door
  - Premium LED case light replacing 5 ft fluorescent $65 per door
  - Standard LED case light replacing 5 ft fluorescent $45 per door
  - All products must be listed on the DesignLights Consortium QPL.
- Sacramento Municipal Utility District (SMUD).
  - Custom Incentives for ENERGY STAR Interior LED Fixtures (recessed, surface, and pendant-mounted downlights; under cabinet, shelf-mounted task lighting; portable desk task lights; wall-wash fixtures) - $0.15 per kWh if project exceeds Title 24 (see "Commercial Lighting Design" section of this report) plus $200 per kW if lighting operation is coincident with summer peak period; $0.10 per kWh for projects that do not exceed Title 24.
  - Custom Incentive Program for ENERGY STAR Integral LED Lamp Replacements for interior applications (A, PAR, MR, etc.) - $0.15 per kWh if project exceeds Title 24 (see "Commercial Lighting Design" section of this report); $0.10 per kWh for projects that do not exceed Title 24.
  - Custom Incentive Program for Design Lights Consortium-Listed Exterior Fixtures (pole-mounted area lights, roadway fixtures, wall-mounted area fixtures (a.k.a. wall-packs), canopy fixtures (e.g., those typically found in gas stations), parking garage fixtures) - $0.10 per kWh, with existing fixtures as baseline.
  - DesignLights Consortium-listed parking garage fixtures may be considered for Custom Incentives for ENERGY STAR Interior LED Fixtures if operated during the day).
  - Prescriptive Incentives for Refrigerated and Frozen Food Cases - $55 per door for LED lights, $85 per door for LED lights with motion sensors. All fixtures and controls must be on SMUD's qualified products list.
- Other states where commercial / industrial LED programs are being offered include Arizona, Colorado, Connecticut, Delaware, Florida, Georgia, Hawaii, Illinois, Maryland, North Carolina, New Hampshire, New Jersey, New York, Ohio, Oregon, Rhode Island, South Carolina, Utah, Virginia, Washington, and British Columbia.

6.3.3 DesignLights Consortium Solid State Lighting Initiative

The DesignLights Consortium (DLC) is an organization composed of energy utility companies and regional energy efficiency organizations committed to raising awareness of the benefits of efficient lighting in commercial buildings. Its mission is to help builders, architects, designers, and commercial property owners implement improved lighting design practices.

DLC maintains a Qualified Products List (QPL) of LED light fixtures for C&I applications. The QPL provides information on tested and verified LED fixtures for C&I sector applications that are not included in the EPA ENERGY STAR product list but that meet a similar set of criteria. Energy efficiency program administrators use the QPL specifications and the listing information provided by manufacturers to determine whether customers who install LED fixtures may qualify for possible incentives.

6.4 EXISTING DATA REVIEW

Even when assessing emerging technologies, the products advance slowly enough that published data remains relevant for a reasonable length of time. This is certainly true of mechanical systems. However, over the last 2 decades it has not been true for electronics. Most available published studies assessing cell phones, digital cameras, or personal electronic tablets are now dated in at least one or two areas. LEDs as an electronic technology fit in this category. For that reason, the best sources of information are, out of necessity, those that are the most current, but they must be tempered with the knowledge that the "test of time" has not been applied. The ERS team reviewed the following documents in order to inform our assessment of LED savings approaches.

6.4.1 Mid-Atlantic Technical Reference Manual Version 2.0 – Residential Measures

Effective date - July 2011

This TRM establishes the baseline and savings values for screw-in LED recessed downlights as replacements for incandescent lamps in residential applications. The following algorithms and assumptions are presented:

Proposed measure – ENERGY STAR 12-watt LED screw-in reflector lamp

Baseline measure – 65-watt incandescent bulged reflector (BR lamp)

Annual savings algorithm:

$$\Delta kWh = ((BaseWatts - EffWatts)\ /1{,}000) \times ISR \times HOURS \times WHFe$$

where,

ΔkWh = Annual energy savings

$BaseWatts$ = 65w (65 watt BR incandescent lamp)

$EffWatts$ = 12w (12 watt LED reflector lamp)

ISR = Service factor – .95 (% of rebated products actually installed – 95%)

$WHFe$ = Waste heat factor 1.14 (cooling savings from reduced heat 14% of watts saved)

Annual deemed savings = 71 kWh:

$$((65 - 12)\ /\ 1{,}000)\ \times\ 0.95\ \times 1241\ \times\ 1.14\ =\ 71\ kWh$$

Summer peak demand savings = 0.0077 kW

$$\Delta kW\ =\ ((BaseWatts\ -\ EffWatts)\ /1000)\ \times\ ISR\ \times\ WHFd\ \times\ CF$$

where,

$WHFd$ = Waste heat factor for demand to account for cooling savings from efficient lighting = 1.39

Additional Assumptions

- Baseline lamp is not subject to EISA regulations
- In service factor and annual operating hours assumptions are increased due to the relative high cost of the LED lamp. Assumption is based on a KEMA 1999 study of CFL usage
- Measure life – 20 Years

Key Issues

The longer hours of usage due to the high measure cost is a reasonable assumption. However, as the TRM rightly states, the cost of the measure is coming down and must be monitored. The average cost is listed as $65. A random shelf survey conducted by ERS in November of 2011 revealed that this lamp is commonly available at a retail price of $20 to $30. Given that the price has dropped 50% in the last 4 months, it will not be long before price is no longer a significant determiner of operating hours.

The baseline lamp is listed as a BR-65, which is a common incandescent reflector lamp. Given the existing knowledge gap associated with what consumers are replacing with LEDs, it is reasonable to assume that this represents a median wattage. However, 45- and 50-watt halogens and 15- and 20-watt compact fluorescent reflector lamps are also very common for this fixture type. Our recommendations for deemed savings also assume that replaced lamps are incandescent. However, as we learn more about residential LED applications, average baselines may need to be adjusted downward. It can be argued that some percentage of customers who are "energy aware" and/or are "early adopters" will replace reflector CFLs with LEDs. See Section 6.5 for a discussion of data gaps.

The assumed measure life of 20 years is based on an ENERGY STAR specification of maintaining 70% of lumen output. Although there is a lack of real data on LED measure life, it would seem appropriate to adjust the measure life for persistence factors such as owner/tenant turnover, renovation schedules, next generation products, etc. especially when promoting a screw-in product that is easily replaced.

6.4.2 Mid-Atlantic Technical Reference Manual Version 2.0 – Commercial Measures

Effective Date - July 2011

This TRM also includes a commercial LED measure or recessed downlights. The approach is similar, and key assumption differences are listed below.

Proposed Measure – ENERGY STAR v1.3 qualified commercial LED recessed downlight with an average wattage of 17.8 watts

Baseline for Retrofit Measure – The existing lighting fixture connected load

Baseline for Lost Opportunity Measure - Baseline wattage is calculated with a multiplier (proposed wattage × 3.08 = baseline wattage). A typical baseline wattage from Efficiency Vermont historical installation data is given as 54.8 watts.

Measure life – 10 years

Operating hours – Actual or from default table if not known

Deemed savings – No deemed savings value

Key Issues

We agree with the approach of using typical installed fixtures to establish a multiplier for the baseline wattage for lost opportunity measures, when LPD is not used as the savings methodology.

Although some might seek a deemed savings value for this measure, until more tracking of LED usage in commercial applications is performed, the use of algorithms and project conditions is appropriate. Outdoor security lighting might be an appropriate place to initiate deemed savings, as operating hours can be reasonably established as dusk-dawn, and baseline technologies are fairly consistent.

6.4.3 New York Technical Manual – Oct 2010

The *New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs* commonly referred to as the NY Technical Manual includes a savings methodology for LED refrigerated case lighting. Unfortunately no guidance for LED area lighting is included for either residential or commercial applications. NYSERDA intends to introduce LED measures in the coming program year and will submit savings methodologies to the Public Service Commission.

The following summarizes the NY Technical Manual approach for refrigerated case LED lighting.

Measure Description

The installation of LED bulbs in commercial display refrigerators, coolers or freezers. The display lighting in a typical cooler or freezer add to the load on that unit by increasing power consumption of the unit when the light is on, and by adding heat to the inside of the unit that must be overcome through additional cooling. Replacing fluorescent lighting with low heat generating LEDs reduces the energy consumption associated with the lighting components and reduces the amount of waste heat generated from the lighting that must be overcome by the unit's compressor cycles.[2]

Savings Estimation Approach

The savings approach is based on the estimated difference in refrigerator / cooler / freezer consumption before the change-out compared to the unit consumption after the change- out for the period of time the unit is turned on during a typical year of operation.[3]

The savings estimation approach[4] is quite complicated but is summarized as:

$$Savings\ in\ kWh\ per\ year\ =\ (Annual\ lighting\ kWh\ B - Annual\ lighting\ kWh\ A)\ +\ ComEffSav$$

where,

$Annual\ lighting\ kWh\ B$ = The total annual kWh usage of the unit per year with conventional baseline lighting

$Annual\ lighting\ kWh\ A$ = The total annual kWh usage of the units with the LEDs installed

$ComEffSav$ = The kWh savings of the refrigeration unit by not needing to cool the heat generated by the inefficient lighting.

The ComEFFSav factor = 0.51 for coolers and 0.65 for freezers × 0.8 for the portion of the saved energy that would have needed to be eliminated via the compressor. Thus, ComEffFac for refrigerators and coolers = (0.51 × .8) = 0.41 and ComEffFac for freezers = (0.65 × .8) = 0.52.

The estimated savings published for typical refrigerated cases are displayed in Table 6-1 and a summary of variables and data sources are shown in Table 6-2.

Table 6-1. Estimated Savings for Typical Refrigerated Cases[5]

Measure Description	*Baseline*	*Measure Watts*	*Baseline Watts*	*Fixture Savings*
5-foot LED case light	*5-foot T8 normal*	*38*	*76*	*38*
6-foot LED case light	*6-foot T12HO*	*46*	*112*	*66*

[2] New York Evaluation Advisory Contractor Team and TecMarket Works, *New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs* (October, 2010), 120.

[3] Ibid.

[4] Ibid.

[5] Ibid, 121.

Table 6-2. Summary of Variables and Data Sources

Variable	*Value*	*Notes*
Baseline watts		*Application. Use 2x LED watts as default*
LED watts		*Application*
Run hours		*Application; default to 8760 if not known*

Key Issues

The manual presents an overly complicated series of algorithms and assumptions that fill two full pages of the document for determining savings for this measure. Yet it arrives at an alternative default for baselines that seems overly simplistic: "Use 2x the LED watts as default" for the baseline wattage and "default to 8760" run hours. We have interviewed program implementers in NY that have been unable to determine how to use the algorithms presented and intend to propose a simplified methodology to regulators.

6.4.4 U.S. DOE Lighting Facts: Product Snapshot - LED Replacement Lamps

In May of 2011, the DOE published this Lighting Facts document as part of a series on lighting technologies. The publication is based on a study performed by D&R International, which is also the firm contracted to perform the technical work for the NEEP Solid State Lighting Initiative.

The document presents a summary of the LED replacement lamp market, focusing on A-lamps, PAR reflectors, and linear fluorescent replacements. The report is designed to help market actors plan for near future progress of the technology and the market potential. Although establishing savings is not a primary goal, there are many components that relate to the calculation of savings.

The conclusions are as follows:

- Replacements for 40- and 60-watt A-lamps are currently being marketed.
- Replacements for 75- and 100-watt A-lamps are not yet market ready, but should be widely available by January 2013.
- About 50% of the A-lamp LED replacements on the market meet generally accepted color performance standards.
- PAR LED lamps are widely available for the replacement of lower wattage (below 75 watts) halogen PAR lamps. Only two products produce lumens equivalent to higher wattage halogen lamps.
- LED replacements for 4-foot linear fluorescent lamps are less efficient than the fluorescent lamps they would replace, and most produce about 50% of the total lumen output of the fluorescents.

- Many LED replacements for 4-foot linear fluorescent lamps do not meet the DOE efficacy standards for 2012.

Key Issues

The study reinforces the fact that program administrators must be cautious when using predicted savings to promote LED replacement lamp measures. Higher wattage A and PAR lamps are commonplace in the residential market. Replacing these lamps with the currently available LED lamps is likely to result in consumer dissatisfaction and loss of program savings.

6.4.5 Lighting Research Center: Streetlights for Local Roads

Published in 2011, this study by the National Lighting Product Information Program (NLPIP) at Rensselaer Polytechnic Institute's Lighting Research Center focuses on the performance of LED streetlights in comparison to 100-watt high-pressure sodium (HPS) streetlights. The study focused on six streetlights recommended by various manufacturers as 100-watt HPS equivalents: two HPS models and four LEDs.

Project results included the following:

- The tested LED streetlights required 3% to 92% (average 40%) more poles per mile than the HPS base case to meet standard roadway lighting criteria (IES RP-8).
- The tested LED streetlights required 41% less to 15% more power per mile than the base case (average 6% less per mile for a staggered layout and 24% less per mile for a single-sided layout) to meet the RP-8 criteria.
- The average tested LED streetlight life-cycle cost per mile was 1.9 times that of the base case. However this cost was driven by the installation costs due to closer pole spacing required by most of the LED products.
- Incentives of $250 to $1,550 per streetlight are required to match the life-cycle cost per mile of HPS street lighting.
- Increasing the wattage of the LED product does not improve the analysis as the lighting uniformity is negatively affected by the wider pole spacing.

Key Issues

This study is interesting in that it does not rely on a lumen-for-lumen analysis, but instead looks at the prospect of spacing poles to effectively illuminate roadways. It is somewhat alarming that the performance of the LED fixtures varies to such a degree. This serves as further evidence that predicting LED performance and savings is not simply a matter of choosing the LED wattage. Program administrators need to be cautious when delivering upstream incentives without technical assistance.

6.4.6 DOE GATEWAY Demonstration Project Case Studies

The GATEWAY program, sponsored by the U.S. Department of Energy, supports the installation and analysis of various high-performance SSL products at sites around the country. These products, whose eligibility is determined based on site-specific conditions, cover both residential and commercial applications, as well as interior and exterior installations. The studies include an evaluation of energy and cost savings, product performance, and customer satisfaction using product test data, measurements gathered on-site, and qualitative end-user surveys.

The following GATEWAY case studies are particularly relevant to this report:

LED Retrofit Lamps: Bonneville Power Administration (Portland, Oregon)

In late 2010, the Bonneville Power Administration retrofitted the track lights illuminating artwork in the lobby of their headquarters in Portland, Oregon from CFL to LED. Previous lamps, including 15-watt R30 and 23-watt PAR38 CFL lamps, were replaced with 12-watt LED PAR38 lamps. Because of the low wattage of the existing lamps and the high cost of the LED lamps compared to the CFLs, this was not a cost-effective energy project (which was anticipated before installation). However, the improved directionality and color rendering (especially of red tones) of the LED lamps compared to the CFLs led to a large improvement in the light quality in this space.

ERS Team Note: The success of this project suggests that LEDs will not be installed only when justified by the savings, but will at times replace CFLs that are underperforming.

LED Parking Lot Lights: T.J. Maxx (Manchester, New Hampshire)

In 2010, T.J. Maxx replaced twenty-two 400-watt HPS fixtures and six 400-watt MH fixtures with twenty-five LED fixtures for parking lot illumination. The LED fixtures were equipped with occupancy sensors, which allowed them to operate at 235 watts in high-output mode, and 78 watts in standby mode. The previous HID fixtures did not have this capability and operated at full power (±450 watts) 12 hours per day. After installation, the LED fixtures were determined to operate 5 hours per day at 235 watts, and 7 hours per day at 78 watts. This large reduction in power consumption, in addition to the added maintenance cost reduction and the relatively high utility rate of $.14/kWh, led to a project payback of 3 years. In addition to the economic benefits, thirty out of thirty-two store employees said they would recommend this installation elsewhere and considered the lighting quality an improvement.

LED Freezer Case Lights: Albertsons Grocery (Eugene, Oregon)

This project included the installation of LED strips as replacements for 5-foot specialty T8 lamps in twenty-six freezer-case doors. The T8 lamps were rated at 40 watts, and the LED strips were rated at 12.5 watts and 25 watts with the 25-watt LED replacing two T8 lamps. While fluorescent lamp performance degrades in low-temperature conditions, LED performance improves, which made this an ideal application for an LED fixture. Existing fixtures operated continuously, which produced substantial energy savings. In addition to the wattage reduction achieved, occupancy sensors were installed that reduced the LED power to 20% during unoccupied periods. The decrease in fixture wattage translated to less heat added to the freezer case, which resulted in additional kWh savings associated with the reduction of work required by the mechanical cooling equipment. Total payback for this project was about 5 years before incentives and tax credits.

6.5 LED Lighting Data & Knowledge Gaps

Although the studies discussed above include valuable data, as previously mentioned, the published data cannot remain current with the advancing technology.

6.5.1 Measure Life and Measure Persistence

For some residential LED applications, engineering life may approach 30 years or more, but experience with CFLs has shown that new products and building renovation rarely allow effective useful lives over 10 to 15 years. Data is needed to clarify these issues for LEDs.

6.5.2 Annual Operating Hours

Recent CFL annual operating hour studies, particularly the KEMA study in California, have led to the conclusion that actual residential operating hours are fewer than previously assumed. The KEMA study asserts that this is not a result of declining prices for subsidized CFLs leading to installations in locations where operating hours are short, but is instead due to reduced homeowner concerns about cost-effectiveness.

For LEDs there is no data or track record on operating hours in various types of residential and commercial occupancies. At a minimum, pilot studies are needed to determine if occupant behavior with regard to LED operating hours is any different from what has been observed and documented for CFLs.

6.5.3 Baseline Products

Our research revealed that many differing assumptions for baseline products are being adopted. In some cases, especially for residential lighting, incandescent lamps are the assumed baseline despite the fact that retail sales figures and residential socket surveys have shown that there is good market penetration of CFL products. Little data is available regarding the following baseline issues:

- Customer satisfaction is still less than ideal for some CFL products, such as reflector lamps. Does this lead to significant replacement of CFL applications with LEDs, especially as prices come down?
- Are the lamps typically displaced by LEDs scheduled to be eliminated by EISA regulation?

- Are the customers motivated by potential savings from LEDs the same customers who previously installed CFLs due to the same motivation, or do LEDs reach a new customer base that is replacing incandescent lamps?
- There is no market research on motivates LED purchases for residential applications. “Early adopters” of new technologies may be replacing CFLs that they previously adopted, rather than replacing incandescent lamps.
- For commercial LEDs, what is the weighted mix of technologies and wattage ratings being displaced? The Mid-Atlantic TRM demonstrates a good approach for this, but only for downlights.
- Are franchise operations beginning to specify LEDs for exterior area lighting and canopy lighting? If so, do the baselines remain the same?
- For new construction, should baselines be technology/wattage based? Energy codes utilize installed power per building area/type, expressed as lighting power density (LPD), and are technology blind. There are no studies comparing typical LPD values obtained with LEDs in comparison with conventional technologies.

6.6 Savings Assumptions, Algorithms, and Deemed Values

6.6.1 Measure Life and Measure Persistence

For the purpose of this document, equipment life is assumed to be equal to LED lamp or luminaire technical lifetime (L_{70}). As discussed above L_{70} is a lumen depreciation based lifetime, rather than an equipment failure based measure life. The C&I lighting industry standard is 50,000 hours for many types of light fixtures, and the DesignLights Consortium equipment lifetime requirement for all listed luminaires is 50,000 hours, except for LED linear panels designed to replace 2x4, 1x4, and 2x2 troffers, for which the DesignLights Consortium requirement is 35,000 hours.

ENERGY STAR-listed LED replacement lights and residential indoor light fixtures have an equipment lifetime requirement of 25,000 hours. ENERGY STAR-listed LED residential outdoor light fixtures and commercial fixtures (interior and exterior) have an equipment lifetime requirement of 35,000 hours.

Measure persistence issues may reduce LED measure life to below equipment life, especially for residential indoor applications, but little data exists to establish meaningful projections. For high-quality C&I LED lighting products, the combination of good performance along with their high initial cost is likely to reduce the likelihood of early retirement or removal. Also, as mentioned previously, future upgrades of C&I LED products may be possible with replacement LED components having superior efficacy. It is unclear whether this would constitute a measure persistence issue or could be classified as an incremental benefit in addition to the original program energy savings projections.

Measure Persistence Recommendations

Residential LED Lighting Products

- Screw-in replacement lamps – 10 years (measure life limited by measure persistence issues)
- Hard-wire fixtures – 15 years
- Track light / spot luminaires – 15 years
- Outdoor security lighting – 8 years w/o controls (assuming 12 hours per night operation)
- Outdoor decorative and landscape lighting – 15 years (assuming 6 hours per night operation)

Commercial/ Industrial LED Lighting Products

- Interior lighting – 15 years w/o controls (assuming 13 hours per day, 5 days per week operation)
- Exterior area, security, and canopy lighting – 11 years w/o controls (assuming 12 hours per night operation)
- Parking garage lighting– 5.5 years w/o controls (assuming 24/7 operation)
- Refrigerated case lighting – 5.5 years w/o controls (assuming 24/7 operation)

Assumptions are provided in Table 6-3.

Table 6-3. Assumptions

	Measure	Measure Life* (Years) (Section 3.4.1)	Yearly FLH** (Section 3.4.3)
Residential	A19 screw-in lamp	10	694-1010
	PAR20, PAR30, PAR38 screw-in lamps	10	694-1010
	MR16/PAR16 pin-base lamps	10	694-1010
	Recessed downlight luminaires	15	694-1010
	Under-cabinet luminaires	15	694-1010
	Cove luminaires	15	694-1010
	Track lights	15	694-1010
	Outdoor security light fixtures	8	4380
	Outdoor walkway/step/landscape lights	15	2190
Commercial/ Industrial	PAR 30, PAR38 screw-in lamps	15	3380
	MR16/PAR16 pin-base lamps	15	3380
	Recessed downlight luminaires	15	3380
	Integral troffers (2X2, 2X4, 1X4)	15	3380
	Task lights	15	3380
	Track lights	15	3380
	Parking garage luminaires	5.5	8760
	Street/parking lot luminaires	11	4380
	Decorative area luminaires	11	4380
	Low-bay/canopy luminaires	11	4380
	Wall-mounted security lights (wallpacks)	11	4380
	Refrigerated case luminaires	5.5	8760

* Measure lives from ERS/GDS Study

** Full load hours from multiple studies; see text

6.6.2 Annual Operating Hours

The most recent data for residential indoor energy efficient lighting operating hours come from the KEMA Upstream Lighting Program evaluation report (2010)[6], which summarizes findings from CFL data logged in 500 homes in California. Another applicable study that supports the concept of regional differences is the Nexus Market Research / RLW *Residential Lighting Markdown Impact Evaluation* (2009)[7], which summarizes findings from CFL data logged at 150 homes in Connecticut, Rhode Island, Massachusetts, and Vermont.

For residential outdoor LED applications, we assume 12-hour-per-night use of security lighting. We exclude security lighting activated by motion sensors, for which the operating hours and energy use are too low to make conversion to LEDs cost-effective. We assume an average of 6 hours per night for outdoor decorative and landscape lighting, switched on and off manually by the occupants.

C&I lighting operating hours are well-documented in a number of references. In the absence of occupancy and daylighting controls, we assume 13 hours per day, 5 days per week operation for general interior lighting other than stairwells. We assume 12 hours per night average operation for all types of C&I exterior lighting, and we assume continuous operation for fully enclosed parking garages.

For uncontrolled refrigerated-case lighting, we assume continuous operation. Staff may switch lights off manually but lights are required for restocking at night, and it is likely that lights are left on to avoid having any "dark" cases when customers arrive in the morning.

Controls generally provide cost-effective savings opportunities for lighting, and particularly for LEDs, which perform better with on-off, multi-step, and continuous dimming controls than do fluorescent or HID lights. However, programmatic consideration of lighting controls is outside the scope of this document.

Annual Operating Hours Recommendations

Residential LED Lighting Products

- ❑ Screw-in replacement lamps – 1010 hours per year (NMR – New England-specific data); 694 hours per year (KEMA – California data)
- ❑ Hard-wire fixtures – 1010 hours per year (NMR); 694 hours per year (KEMA)
- ❑ Track light / spot luminaires – 1010 hours per year (NMR); 694 hours per year (KEMA)
- ❑ Outdoor security lighting – 4380 hours per year
- ❑ Outdoor decorative and landscape lighting – 2190 hours per year

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[6] KEMA, Inc., *Final Evaluation Report: Upstream Lighting Program* (February 2010).

[7] Nexus Market Research, Inc., *Residential Lighting Markdown Impact Evaluation* (January 2009).

Commercial/Industrial LED Lighting Products

- Interior lighting – 3380 hours per year
- Exterior area, security, and canopy lighting – 4380 hours per year
- Parking garage lighting – 8760 hours per year
- Refrigerated case lighting – 8760 hours per year w/o controls

We recommend applying standard lighting savings methodologies to compute deemed or calculated savings values for LED technologies. The main difference between lighting classes and end-use categories relates to accounting for HVAC and compressor load impacts, where applicable, in C&I and residential retrofit applications. For commercial new construction applications, we recommend an LPD-based methodology as described in the "Commercial Lighting Design" section of this document.

Tables 6-4 and 6-5 on the following pages summarize key assumptions, deemed values, and algorithms for estimating LED energy savings in typical applications. Sources for assumptions and deemed values are shown in footnotes.

Table 6-4. Assumptions

	Measure	Baseline Technology	Baseline Watts	Baseline Lumens	LED Watts[1]	LED Lumens[1]	In-Service Factor[2]	Notes
Residential	A19 screw-in lamp	Incandescent	40-60	460-1010	8-13	471 -817	0.95	Baseline = 40W, 60W incandescent, see CALiPER Benchmark Study: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/a-type_benchmark_11-08.pdf
	PAR20, PAR30, PAR38 screw-in lamps	Incandescent	35-100	360-1500	7-20	320-1167	0.95	LED ranges derived from ENERGY STAR-approved products
	MR16/PAR16 pin-base lamps	Incandescent	20-50	320-600	3-8	151-380	0.95	LED ranges derived from ENERGY STAR-approved products
	Recessed downlight luminaires	Incandescent	40-100	460-1750	8-35	346-1544	1.00	Baseline = 40W-100W incandescent, LED ranges derived from ENERGY STAR-approved products. Additional info: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/recessed_downlight.pdf
	Under-cabinet luminaires	Incandescent	N/A	N/A	4-22	120-989	1.00	LED ranges derived from ENERGY STAR-approved products. Baseline data not available.
	Cove luminaires	Incandescent	N/A	N/A	12-42	544-1907	1.00	LED ranges derived from ENERGY STAR-approved products, quantity of which is limited
	Track lights	Incandescent	20-50	320-550	6-16	270-717	1.00	Baseline = MR16/Par20, LED ranges derived from ENERGY STAR-approved products. Higher output ES-approved LED fixtures not included in order to more accurately reflect baseline.
	Outdoor security light fixtures	Incandescent	N/A	N/A	6-38	222-1325	1.00	LED ranges derived from ENERGY STAR-approved products. Baseline data not available.
	Outdoor walkway/step/landscape lights	Incandescent	N/A	N/A	N/A	N/A	1.00	No ENERGY STAR-approved prpducts. Baseline data not available.
Commercial/ Industrial	PAR 30, PAR38 screw-in lamps	Incandescent	50-100	550-1500	9-20	480-1167	0.95	LED ranges derived from ENERGY STAR-approved products
	MR16/PAR16 pin-base lamps	Incandescent	20-50	320-600	3-8	151-380	0.95	LED ranges derived from ENERGY STAR-approved products
	Recessed downlight luminaires	Incandescent	40-100	460-1750	8-40	346-1692	1.00	LED ranges derived from ENERGY STAR-approved products
	Integral Troffers (2X2, 2X4, 1X4)	T12 or T8	26-160	1784-6291	24-75	2411-7468	1.00	Baseline ranges from (2X2) two-lamp F017 LBF @ 80% fixture eff to (2X4) four-lamp F40 mag ballast @ 75% fixture eff. LED ranges derived from DLC-approved products.
	Task lights	Incandescent	N/A	N/A	N/A	N/A	1.00	No data available
	Track lights	Incandescent	20-50	320-550	8-14	294-601	1.00	Baseline = MR16/PAR20, LED ranges derived from DLC-approved products
	Parking garage luminaires[3]	HPS, MH	190-205	9800-11200	30-128	2641-9935	1.00	Baseline = 150W HPS/175W MH @ 70% fixture eff, LED ranges derived from DLC-approved products (outliers eliminated in order to more accurately reflect baseline)
	Street/parking lot luminaires[3]	HPS or MH	N/A	N/A	N/A	N/A	1.00	Wide range of baseline/LED wattages and lumen outputs for this category
	Decorative area luminaires[3]	HPS or MH	190-205	9800-11200	39-138	1961-7971	1.00	Baseline = 150W HPS/175W MH @ 70% fixture eff, LED ranges derived from DLC-approved products (outliers eliminated in order to more accurately reflect baseline)
	Low-bay/canopy luminaires[3]	HPS or MH	190-205	9800-11200	35-156	2781-10904	1.00	Baseline = 150W HPS/175W MH @ 70% fixture eff, LED ranges derived from DLC-approved products (outliers eliminated in order to more accurately reflect baseline)
	Security wallpacks[3]	HPS or MH	90-205	4480-9800	15-94	1064-7634	1.00	Baseline = 70W HPS-175W MH @ 70% fixture eff, LED ranges derived from DLC-approved products (outliers eliminated in order to more accurately reflect baseline)
	Refrigerated case luminaires	T12 or T8	120-155	N/A	12-37	724-2810	1.00	Wattages reflect per-door values, assuming 5-foot doors

[1] LED data (wattages and lumen output) based on current ENERGY STAR and DLC-listed products

[2] In-service factor adjusted for screw-ins only, as a small percentage of these products may be purchased but not yet installed.

[3] Equivalent LED fixture allows for lower lumen output to achieve similar footcandle measurements due to improved distribution over baseline

Table 6-5. Deemed Savings and Algorithms

	Measure	Recommended Deemed Savings Value*	Algorithm	Knowledge Gaps	Notes
Residential	A19 screw-in lamp	22-48 kWh	#1	See Section 3.5.3	Based on ES-qualified products
	PAR20, PAR30, PAR38 screw-in lamps	19-81 kWh	#1	See Section 3.5.3	Based on ES-qualified products
	MR16/PAR16 pin-base lamps	12-42 kWh	#1	See Section 3.5.3	Based on ES-qualified products
	Recessed downlight luminaires	22-66 kWh	#1	See Section 3.5.3	Based on ES-qualified products
	Under-cabinet luminaires	N/A	#1	See Section 3.5.3	Data not available
	Cove luminaires	N/A	#1	See Section 3.5.3	Data not available
	Track lights	10-34 kWh	#1	See Section 3.5.3	Based on ES-qualified products
	Outdoor security light fixtures	N/A	#1	See Section 3.5.3	Data not available
	Outdoor walkway/step/landscape lights	N/A	#1	See Section 3.5.3	Data not available
Commercial/Industrial	PAR 30, PAR38 screw-in lamps	105-276 kWh	#1	See Section 3.5.2	Based on ES-qualified products
	MR16/PAR16 pin-base lamps	76-110 kWh	#1	See Section 3.5.2	Based on ES-qualified products
	Recessed downlight luminaires	142-440 kWh	#1	See Section 3.5.2	Based on ES-qualified products
	Integral troffers (2X2, 2X4, 1X4)	0-237 kWh	#1	See Section 3.5.2	Can potentially install LED that draws same wattage as baseline (0 kWh svgs)
	Task lights	N/A	#1	See Section 3.5.2	Data not available
	Track lights	40-122 kWh	#1	See Section 3.5.2	Based on DLC-qualified products
	Parking garage luminaires	674-1401 kWh	#1	See Section 3.5.2	Based on DLC-qualified products
	Street/parking lot luminaires	N/A	#1	See Section 3.5.2	Wide range of baseline/LED wattages for this category
	Decorative area luminaires	293-727 kWh	#1	See Section 3.5.2	Based on DLC-qualified products
	Low-bay/canopy luminaires	215-679 kWh	#1	See Section 3.5.2	Based on DLC-qualified products
	Wall-mounted security lights (wallpacks)	329-486 kWh	#1	See Section 3.5.2	Based on DLC-qualified products
	Refrigerated case luminaires	400-688 kWh	#2	See Section 3.5.2	Based on DLC-qualified products. Case study in report = 467 kWh/yr per door.

Algorithm #1

$$\Delta kW_s = \left[\frac{(\text{watts x units})_{base} - (\text{watts x units})_{ee}}{1000}\right] \times CF \times \left(1 + HVAC_{d,s}\right)$$

$$\Delta kWh = \left[\frac{(\text{watts x units})_{base} - (\text{watts x units})_{ee}}{1000}\right] \times FLH \times (1 + HVAC_c)$$

$$\Delta therm = \Delta kWh \times HVAC_g$$

ΔkW_s = Gross summer coincident demand savings

ΔkWh = Gross annual energy savings

$\Delta therm$ = Gas impacts from heating interactions

units = Number of units installed under the program

$watts_{ee}$ = Connected load of the energy-efficient unit

$watts_{base}$ = Connected load of the baseline unit displaced

FLH = Full-load operating hours

CF = Coincidence factor

$HVAC_{d,s}$ = HVAC system interaction factor at utility peak hour

$HVAC_c$ = HVAC system interaction factor for annual energy consumption

$HVAC_g$ = HVAC system interaction factor for gas

Algorithm #2

$$\Delta kW_s = \left[\frac{(\text{watts x units})_{base} - (\text{watts x units})_{ee}}{1000}\right] \times CF \times (1 + CSF)$$

$$\Delta kWh_g = \Delta kWh_l + \Delta kWh_r$$

where,

$$\Delta kWh_l = \left[\frac{(\text{watts x units})_{base} - (\text{watts x units})_{ee}}{1000}\right] \times FLH$$

$\Delta kWh_r = \Delta kWh_l \times CSF$

ΔkW_s = Gross summer coincident demand savings

ΔkWh_g = Gross annual energy savings

ΔkWh_l = Annual lighting energy savings

units = Number of units installed under the program

$watts_{ee}$ = Connected load of the energy-efficient unit

$watts_{base}$ = Connected load of the baseline unit displaced

FLH = Full-load operating hours

ΔkWh_r = Energy savings associated with the reduced cooling load on the refrigeration system, resulting from the installation of energy-efficient lighting

CSF = Compressor savings factor = .24
Compressor savings factor is based on the assumption that the typical COP of the installed compressor is 1.4[1].

6.7 Recommendations

Recommendations for closing knowledge gaps and strengthening LED energy savings calculation methodologies are summarized in the following subsections.

6.7.1 Closing Data/Knowledge Gaps & Related EM&V Approaches

We cannot overemphasize how unique LED lighting is in the context of energy efficiency measures. To our recollection, no other technology has advanced so quickly that the data and knowledge conveyed in published studies is unable to keep pace. However, it is inevitable that the pace of advancement will level out as producers focus on marketing their developed products and recoup some of their original investment in LEDs.

[1] *Demonstration Assessment of Light-Emitting Diode (LED) Freezer Case Lighting in Albertsons Grocery in Eugene, OR*, US DOE SSL Lighting GATEWAY Technology Demonstration Program, 2009.

Study can be found here: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_freezer-case.pdf

The following are recommended steps for closing some of the recognized gaps:

- **Conduct measure persistence studies** – The Forum recently conducted a lighting persistence study. The same approaches used for that study could be applied to LED lighting after enough program delivery experience is gained. Although technical measure life is determined through accelerated testing procedures, other persistence factors such as customer satisfaction, remodeling schedules, next generation replacement, etc. can be estimated by field persistence studies.
- **Conduct operating-hours studies** – There is currently a large discrepancy in lighting operating hours across studies and program assumptions. A review of various TRMs around the country, including those used in California, New York, Connecticut, Massachusetts, Maine and Vermont, reveals that some data for commercial lighting is based on total business operating hours. This data needs to be adjusted for accuracy. For example, the New York Technical Manual uses business operating hours for grocery stores taken from a Connecticut study. The lighting operating hours dedicated to restocking the shelves while closed for business are not included. Lighting loggers are now common and inexpensive and should be used to monitor actual lighting hours for typical potential LED applications.
- **Refine baseline assumptions** – Even with declining prices, it can be difficult for LED measures to pass TRC tests. Utilizing incandescent lighting as a baseline provides the largest cost and savings deltas. However, this does not mean that the assumption is accurate. Programs have been very successful at penetrating residential and retail markets with CFLs. The same customers who purchase CFLs for energy savings are the likely to purchase LEDs. Without a doubt, LED lamps are replacing or displacing some CFLs. Research is needed to estimate the mix of baseline products, especially for residential applications.
- **LEDs and Lighting Power Density** – For commercial new construction programs, lighting baselines should reference code. Energy codes do not identify lighting technology requirements, but are based on LPD values for various space types. With IECC 2009 being recently adopted by the Forum member states, LPD is also calculated for outdoor area lighting. We know of no studies that have calculated typical achieved LPD for various spaces using LED products. Such a study would be the best way to establish baselines and potential savings for commercial programs.

6.7.2 Adopting Deemed Savings Values

We see deemed savings as a desirable mechanism, especially for simple lamp replacement. However, as detailed below, we do not feel that there is enough market knowledge for deemed savings to be universally adopted. We are presenting savings algorithms for the various LED applications covered. These algorithms can be used to calculate savings on a project-specific basis. In addition, they can be used to develop average deemed savings values for specific products when there is enough market information available to assign likely incumbent wattage ratings or when the replacement is closely controlled by the program implementers.

Developing deemed savings relies on the ability to define a standard replacement lighting product at a standard wattage rating as a replacement for a specific incumbent lighting product/wattage. For example, a 15-watt CFL replacing a 60-watt incandescent A-lamp. However, determining the appropriate replacement LED wattage is not straightforward. As discussed earlier, the wide variability in LED lighting products and the importance of application efficacy makes it very difficult to define standard replacements.

In some applications, consistency is developing around LED products, and deemed incentives can be used in these instances. For example, LED downlights are trending toward products that are intended to provide equivalent lighting for particular incumbent sources, such as 65-watt PAR 38 halogen lamps. The variability in the wattage of these LED replacement products is relatively small. A deemed replacement wattage could be developed based on a market survey of available products. A similar trend is taking place with replacement lamps.

Deemed incentives could also be developed that specify a maximum wattage of the LED replacement and a minimum wattage of the incumbent source. For instance, an incentive of X dollars can be offered for an LED under-cabinet light of 10 watts maximum when replacing an incumbent light source of 30 watts minimum. Selection of the appropriate LED replacement product to deliver the desired lighting is the responsibility of the customer. Using this methodology assures that estimated savings are delivered.

6.7.3 Utilizing Savings Algorithms

We believe that the savings algorithms presented in Section 6.6.2 and Table 6-5 above provide a sufficient level of detail for estimating LED performance in a variety of applications when combined with regionally specific assumptions and deemed values. Once data is developed to fill the gaps we have identified, EM&V Forum members can apply these algorithms with confidence in designing and implementing efficiency programs.

6.8 Summary

The lighting industry has seen remarkable advances in LED lighting over the past few years. Not long ago, LEDs were considered a specialty light source used for exit signs, traffic lights, automobile tail lights, sports scoreboards, flashlights, and more recently, electronic displays. Now LEDs are showing up in virtually every residential and C&I lighting market application.

If program administrators have not yet introduced LED lighting pilot programs, they are likely under pressure to get started. Many jurisdictions that have introduced LED pilots have seen program activity reinvigorated, engaging new customers and vendors. In some cases, this has led to efficiency projects expanding beyond their initial scope in response to interest by a wide range of stakeholders.

However, as with all fast-moving emerging technologies, application of LED lighting for energy efficiency must proceed with caution. Although there are many quality LED luminaires and lamps available, a few vendors are rushing inferior products to the market to exploit the charged atmosphere.

Program administrators should participate in and support LED-lighting quality-assurance initiatives such as the ENERGY STAR, DLC, and U.S. DOE Solid State Lighting programs described throughout this document. In addition, there is much opportunity to collaborate regionally, nationally, and even internationally to build collective expertise in energy efficient application of LED lighting.

LEDs are transforming markets as their performance trends upward and price decreases – and this trend is gaining momentum. Some residential and C&I applications have reached cost-effectiveness levels that pass TRC-based tests. For other applications, market transformation success will require exceptions in the early years to program portfolio cost-effectiveness considerations. This is a worthwhile short-term accommodation to build market capacity and customer trust in high quality LED lighting products that deliver persistent savings.

Heat Pump Water Heaters

7

7.1 INTRODUCTION

Heat pump water heaters (HPWHs) were first introduced in the U.S. during the 1970s in response to the energy crisis associated with the first OPEC oil embargo. Within a few years, most major air conditioning and water heater manufacturers had introduced HPWH products and within a few more years, most had been withdrawn from the market. This was due to a combination of technical, marketing, and business-concept failures. Successive generations of HPWHs have been brought to market since that initial introduction, but each time adoption has been cut short by technical and market shortcomings.

This document focuses on mass-produced ENERGY STAR-compliant air source HPWHs for residential applications and commercial HPWHs with comparable performance characteristics. The current state of the market, the potential for efficiency programs, available data, and recommended savings methodologies are all covered.

7.1.1 The Current Market

ENERGY STAR Eligibility Criteria Version 1.1 became effective in January 2009. Within a year, GE, Rheem, A.O. Smith, and Airgenerate launched new, ENERGY STAR-compliant HPWH product lines. Rheem and A.O. Smith are major water heater manufacturers that collectively produce over 80% of residential water heaters sold in the U.S. Each produces HPWHs in two different size (water storage capacity) ranges. Although Rheem manufactures the General Electric (GE) line of standard water heaters, GE manufactures its own line of HPWHs. A fourth U.S. manufacturer, Airgenerate, also makes HPWHs in two different gallon capacities.

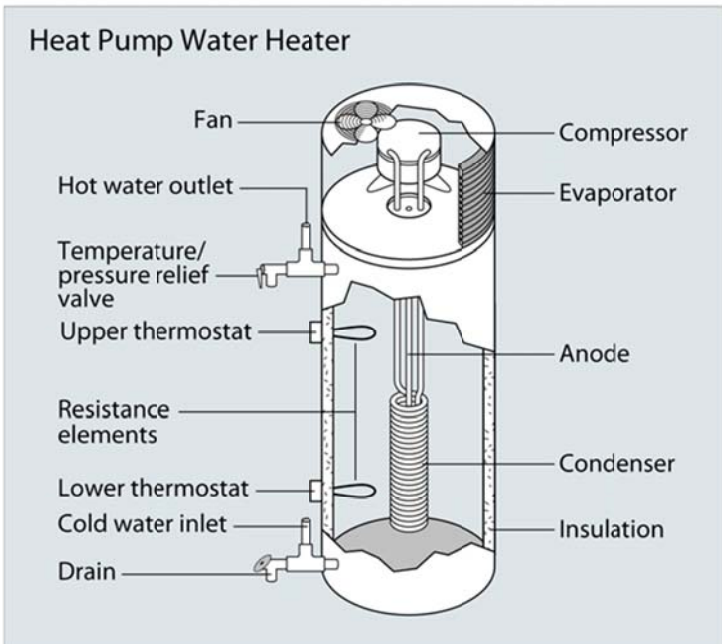
Outside of the U.S., Denso Corporation (Japan) produces the EcoCute HPWH, a very high efficiency unit intended for domestic hot water and hydronic space heating applications. The EcoCute is currently available in Asia and the European Union but not in the U.S. Oak Ridge National Laboratory is exploring commercialization of a version of the EcoCute for U.S. markets. Because its availability in the U.S. is at least several years off, this document does not address the EcoCute HPWH in detail.

Water heating accounts for 15% to 20% of electric energy use in homes with electric water heaters. New HPWHs can potentially reduce electricity use for water heating by 50% or more. Current generation U.S. HPWHs have an incremental cost of about $800–$1,700 over the installed cost of a conventional 50 to 75 gallon electric water heater. The nominal simple payback of a HPWH typically ranges from 5 to 16 years.

7.2 Technology Overview

Heat pump water heaters (HPWH) extract thermal energy from ambient air[1] using a vapor compression system similar to those in space conditioning devices such as heat pumps and air conditioners. Figure 7-1 shows the most common HPWH configuration in which the heat pump system is fully integrated into a conventional electric resistance water heater.

Figure 7-1. A Typical Integrated HPWH Configuration



The compressor is small and is sized to run 3 to 4 hours per day, keeping electric demand low while it is running. The condenser transfers heat from the heat pump to water in the storage tank and may be immersed in the tank, wrapped around the tank wall, placed inside the insulation blanket, or cooled with water pumped from the tank. The fan exhausts air cooled by the evaporator to the area around HPWH. Most units are constructed with a switch that allows users to override the compressor, at which point the unit switches over to conventional electric resistance heating.

HPWHs must be installed in locations with at least 1,000 cubic feet of air space around the water heater and where the temperature remains between 40°F and 90°F at all times. Condensate must be piped to a drain. Due to these requirements and HPWH noise level, residential units are typically installed in unconditioned basements and attached garages.

[1] Alternate heat pump water heater configurations extract heat from waste hot water or from the earth via buried coils (geothermal heat pumps). These configurations are relatively rare and are not addressed in this document.

HPWHs release cool exhaust air into the surrounding area. Alternately, the cool air can be ducted outdoors, which requires fan energy and measures to prevent heat at the building envelope penetration. Even if the HPWH is located in an unconditioned space, the release of cooler air in the winter can be an issue.

Energy factor (EF) serves as the standard measure of water heater performance in the U.S. and is defined as the number of units of useful energy output (hot water) produced for every unit of energy input at 67.5°F ambient temperature conditions. HPWH EF must equal or exceed 2.0 to receive ENERGY STAR certification. Most U.S.-based integrated HPWH products meet or exceed ENERGY STAR requirements at test conditions.

EF was developed for rating conventional water heaters and has two limitations when it comes to HPWHs. First, EF does not fully account for the effect of inefficient “backup” resistance heating that is present in HPWHs. Resistance elements may turn on at ambient temperatures as high as 75°F and become the principal source of HPWH water heating at 45°F ambient temperature and below. In other words, the effective HPWH EF starts dropping at 75°F, and energy savings goes to zero at 45°F ambient and below, which would occur for a significant portion of the year for installations in unconditioned spaces such as garages or basements. Cool air exhausted from the HPWH can further reduce the ambient temperature and water heater efficiency in unventilated spaces such as well-sealed garages or basements.

Second, EF does not account for heat extracted from conditioned air around the water heater, which is the main source of heating energy for HPWHs. If the HPWH is located in an unconditioned space, its operation will put no significant parasitic load on the building space heating system, and this issue doesn’t come into play. However, unless ducted to a location where cooling is needed, the air exhausted from the HPWH is dissipated, and the potential for extra savings due to the free cooling effect is lost.

7.3 Heat Pump Water Heater Potential for Efficiency Programs

Recent advances in lighting, HVAC, and plug load efficiencies, as well as energy codes and standards, are reducing the relative contributions of those end uses to building energy consumption. As a result, water heating is now responsible for an increasing percentage of a buildings’ residual energy loads.

Residential and commercial/industrial (C&I) energy efficiency programs have historically offered a limited number of cost-effective measures to reduce water heating energy consumption. These include tank insulation blankets, which fractionally increase EF and offer little benefit for most well-insulated replacement water heaters sold since the 1990s. Other hot water system add-on measures such as retrofit heat recovery products have not achieved widespread adoption in mass markets. Another option, tankless electric water heaters, require high amperage service and can lead to increased energy consumption due to their “limitless” hot water output.

Given this background, the 2009 release of an ENERGY STAR label for HPWHs has stimulated considerable excitement and activity in the market as evidenced by the launch of a new generation of compliant products by GE and leading U.S. water heater manufacturers, among other players. Although the ENERGY STAR criteria are based on parameters developed for other types of water heaters and have some limitations when applied to HPWHs, the current surge of consumer interest provides an opportunity for program administrators to explore expanding their portfolios to include HPWHs for residential and C&I applications.

The Electric Power Research Institute is accelerating utility industry exposure to the new HPWH products by launching a nation-wide 200-home HPWH pilot that includes the full range of available products. Bonneville Power Administration (BPA) in collaboration with Northwest Energy Efficiency Alliance (NEEA) is hosting forty of the pilot sites in their service area and is performing field assessments to validate HPWH performance and document customer acceptance. The current level of interest in HPWHs is providing both an opportunity to transform the electric water heating market and also a necessity to promptly identify and resolve issues such as those associated with the application of EF.

An important initiative that addresses a range of HPWH performance and customer acceptance issues is the Northern Climate Specification for Residential Heat Pump Water Heaters. Originally developed by NEEA and its partners in 2009 shortly after the release of the ENERGY STAR 1.1 specification, the Northern Climate Specification incorporates the ENERGY STAR criteria and addresses both EF issues described in the Technology Overview above as well as others included in the following list:

- Comfort – Managing cold exhaust air and occupant comfort during the heating season
- Hot water delivery – Ensuring that the HPWH can deliver at least the same level of hot water delivered by a comparable conventional electric resistance water heater
- Energy efficiency – Ensuring that the heat pump can operate over a wide enough range of conditions to allow for adequate energy savings to justify the cost of the HPWH
- Condensate management – Ensuring positive condensate removal and heat pump shut-off in the event of condensate removal system failure
- Freeze protection – Operating a failsafe system in the event of exposure to below-freezing temperatures for extended time periods
- Noise – Limiting noise to levels acceptable to consumers in the same space
- Reliability and service – Providing assurance to consumers that a level of reliability comparable to a conventional electric resistance water heater is provided and that routine maintenance is simple and will not cause catastrophic failure if not completed regularly

NEEA released an updated version (4.0) of the Northern Climate Specification in November 2011 that defines three tiers of HPWH performance and includes a revised definition of EF that is applicable to cold climates throughout North America[2]. NEEA is working actively with NEEP, MEEA, ACEEE, and other energy efficiency industry organizations to build support for the Northern Climate Specification and encourage manufacturers to produce HPWHs that fully comply with the specification.

Program administrators can expect HPWH manufacturers to resolve any product performance and customer acceptance issues in anticipation of new U.S. federal energy standards for electric and gas water heaters over a 55 gallon capacity that become effective in April 2015. This size threshold is very near the median size for both gas and electric water heaters, which was approximately 50 gallons in 2006, although market research reveals that the average storage size is growing due to the increasing demands of multiple bathrooms in new homes and other added hot water usage.[3]

According to ENERGY STAR, the sales volumes of gas and electric water heaters are about equal. HPWHs are the only commercially available products that meet the new standards, which aim to phase out the use of large-capacity electric resistance and non-condensing gas water heaters.

7.4 Efficiency Programs Currently Promoting Heat Pump Water Heaters

The ENERGY STAR specification provides the basis for all major U.S. residential efficiency program HPWH measures. In addition, ENERGY STAR compliant HPWHs are eligible for a $300 federal energy tax credit set to expire at the end of 2011. Combined with the deemed incentives described below, federal and state energy efficiency tax credits considerably reduce the incremental cost for customers wishing to upgrade to a HPWH.

Several NEEP EM&V Forum members including Connecticut Light & Power and United Illuminating (through the intermediary of the Connecticut Energy Efficiency Fund), as well as Con Ed and Central Hudson Gas and Electric offer $400 rebates for ENERGY STAR-compliant residential HPWHs. The Energize Delaware program (Delaware SEU) offers a deemed incentive of $200 for ENERGY STAR-compliant residential HPWHs.

Rebates in other parts of the U.S. vary widely, with Puget Sound Energy providing a $500 incentive, Seattle City Light offering $250, and Southern California Edison providing $30, all for ENERGY STAR-compliant residential HPWHs.

Some utilities provide custom C&I rebates for HPWHs, and most programs would provide custom incentives for HPWHs, providing general program rules and cost-effectiveness thresholds are met.

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[2] NEEA, *A Specification for Residential Heat Pump Water Heaters Installed in Northern Climates Version 4.0 Final* (November 7, 2011). Available at https://conduitnw.org/pages/file.aspx?rid=289.

[3] NEEA, KEMA Residential Water Heater Market, 2006.

The volume of activity through custom programs is understandably low compared to mass market prescriptive programs.

7.5 EXISTING DATA REVIEW

Several technical resource manuals (TRMs) and related publications providing data and methodologies for estimating HPWH energy savings have appeared since 2009. These include the following, in order of publication:

- New York Standard Approach[4]
- Mid-Atlantic TRM Version 2.0[5]
- ACEEE Emerging Hot Water Technologies & Practices[6]
- BPA Provisional UES Proposal[7].

Subsections 7.5.1 through 7.5.4 provide a brief overview of each report or study.

7.5.1 New York Standard Approach

This report provides deemed values and a basic algorithm for computing residential HPWH kWh and kW savings. The text refers to HPWH installations discharging cool air into a conditioned space or vented to the outside, but does not include a methodology for calculating parasitic heat losses and air conditioning benefits when cool air is discharged into a conditioned space. The report contains some useful information for assessing water heater energy requirements and hints at the need for climate-specific EF data, but provides only partial documentation of the sources for deemed values cited.

7.5.2 Mid-Atlantic TRM Version 2.0

This TRM contains two chapters on HPWHs, one providing deemed values and algorithms for residential applications and one containing deemed values and algorithms for non-residential applications. Sources for deemed values are well documented, with the residential chapter relying extensively on three rigorous and relatively recent publications: the U.S. DOE Technical Support

[4] New York Evaluation Advisory Contractor Team and TecMarket Works, *New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs* (October, 2010).

[5] Vermont Energy Investment Corporation, *Mid-Atlantic Technical Reference Manual Version 2.0* (July 2011).

[6] American Council for an Energy Efficient Economy, *Emerging Hot Water Technologies and Practices for Energy Efficiency as of 2011* (October 2011).

[7] Ecotope, *Heat Pump Water Heaters - Provisional UES Proposal* (October 2011).

Document[8], the FEMP study "Field Testing of Pre-Production Prototype Residential Heat Pump Water Heaters[9]," and the *ENERGY STAR Residential Water Heaters, Final Criteria Analysis*[10].

The residential energy savings algorithm includes a methodology for estimating parasitic losses and air conditioning benefits of HPWHs in conditioned spaces for three typical heating system types. Degree day data for Baltimore, MD is used in a sample calculation. Equivalent data can easily be obtained and substituted to apply the methodology to other locations. The only significant gap in the residential chapter is the omission of any reference to COP and EF variation with ambient temperature. This gap is likely an oversight, given the extensive coverage that COP variation receives in the FEMP study used as a primary source for deemed values.

The non-residential HPWH chapter is also useful, but takes a more generic approach, providing an algorithm that does not include parasitic losses and air conditioning benefits of HPWHs in conditioned spaces. The algorithms in this chapter can be applied to a range of non-residential water heating applications, substituting appropriate data to replace the sample deemed values for school and office applications.

7.5.3 ACEEE Emerging Hot Water Technologies & Practices

This study includes chapters on ENERGY STAR compliant (moderate climate) HPWHs, northern climate HPWHs, and add-on HPWHs that will not be discussed in this report. This report provides a good overview of residential HPWH technology and issues and provides estimates of energy and demand savings based on average test conditions per the previously cited ENERGY STAR Final Criteria Analysis document.

As with the other references, ACEEE does not address the impact of ambient temperature variations on EF. The chapter on moderate climate HPWHs makes no mention of parasitic losses and air conditioning benefits from HPWHs in conditioned spaces, perhaps assuming installations in unconditioned spaces.

The chapter on northern climate HPWHs summarizes the Northern Climate Specification described in Section 3.3 above. The energy savings analysis assumes that the installation is in a conditioned space and reduces the energy savings by 25% accordingly. This approach significantly reduces the cost-effectiveness of the northern climate HPWH relative to minimally ENERGY STAR-compliant units.

The underlying logic for deducting parasitic losses in this case and not for "moderate climate" HPWHs is unclear. Two key aspects of the Northern Climate Specification are its requirement that

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[8] U.S. DOE / Lawrence Berkeley Laboratory, *Technical Support Document: Energy Efficiency Standards for Consumer Products, Residential Water Heaters* (December 2001)

[9] FEMP Technology Focus, "Field Testing of Pre-Production Prototype Residential Heat Pump Water Heaters" (May 2007)

[10] U.S. DOE, *ENERGY STAR Residential Water Heaters, Final Criteria Analysis* (April 2008)

cool air from the evaporator be ducted to the outside, thus eliminating the primary source of parasitic heat loss, and that the HPWH air flows be configured to replace other ventilation requirements, significantly reducing the remaining parasitic heat loss or gain due to otherwise induced infiltration. The additional fan power required to move cool exhaust air from the evaporator through ducting to the outside will reduce the net energy savings by the HPWH system, but not by 25%.

7.5.4 BPA Provisional UES Proposal

The Bonneville Power Administration (BPA) commissioned this study to assess impacts of ambient air and inlet water temperature variations on residential HPWH performance. Field data was collected at the Electric Power Research Institute (EPRI) pilot installation sites and integrated with laboratory test results for several HPWHs. The project consultant performed extensive analysis and modeling and supplied additional data from rigorous secondary research as required to satisfy Northwest Power and Conservation Council – Regional Technical Forum requirements for new unitary energy savings measures.

The BPA study established that annual average HPWH COP (and potential energy savings) for installations in unconditioned garages and basements declines about 40% relative to the rated COP. EF parallels COP, so potential energy savings for installations in unconditioned spaces is much lower than estimated in other references. Further analysis revealed that a combination of lower daily hot water consumption than previous studies assumed and larger than expected impacts of chilled air exhausted into conditioned zones contribute to even lower net energy savings for HPWHs located in conditioned spaces.

The BPA study is ongoing and will examine the benefits of ducting chilled air to the outside and using HPWH air intake requirements to replace otherwise mandated ventilation, as proposed in the Northern Climate Specification. Although the climate in the Pacific Northwest is different from that in the North Atlantic, this report uses deemed values from the BPA study as appropriate.

7.6 Heat Pump Water Heater Data and Knowledge Gaps

Section 12 of this report discusses overarching evaluation issues associated with emerging technology assessments. This section presents evaluation needs for heat pump water heaters. There are both technical and customer knowledge gaps that will affect the savings from this measure. Additionally, no recent, robust sources on non-residential HPWH performance and analysis have come to light during this secondary research study.

7.6.1 Market Knowledge Gaps

Closing the following gaps in knowledge related to market factors will ease the burden of introducing HPWH programs or measures:

- **Customer reaction to operational noise levels** – Unlike conventional water heaters, these units emit compressor noise. Many customers may not realize that the newly installed HPWH will introduce this compressor noise. With override switches installed on most units, it is possible that customers will switch over to electric resistance heating in order to return to silent water heating. This of course will negate all of the predicted savings for the installation. The percentage of customers who switch back to resistance heating is currently unknown. Also unknown is the market acceptance of units without the manual override.
- **Customer satisfaction related to installation location** - The placement of the unit may be a determining factor in the persistence of savings. For example installation in conditioned spaces with homes may lead to noise complaints, while units installed in unconditioned basements and garages may be have wider acceptance. This factor could limit the market success for the multi-family housing markets.

During 2011 BPA performed a small-scale web-based survey of customers participating in the EPRI-sponsored residential HPWH pilot. Thirty-two out of a potential maximum of forty customers who had HPWHs installed approximately 6 months earlier responded. Of the customers surveyed, 72% were highly satisfied or satisfied, 13% neither satisfied nor dissatisfied, and 16% dissatisfied. However, only 39% of those surveyed said that they would purchase a HPWH again.

The findings from this small but highly relevant study point out the need to closely monitor customer acceptance issues as HPWHs are brought into energy efficiency portfolios and to perform follow-up studies to determine why customers are less than fully satisfied.

Annual hot water consumption is a key component of the potential savings from this measure. We provided energy savings using baseline information from the Pacific NW region. It is likely that people on one coast do not use hot water any differently than they do on the other coast, but it would be useful to have region-specific information.

7.6.2 Technical Knowledge Gaps

Although the studies referenced provide a wealth of data on HPWH predicted and measured performance, significant gaps remain in what is known about factors that drive the energy savings potential for this technology. Systematic data collection in the following three areas will significantly advance the potential for the Measurement and Verification Forum to achieve sustainable regional adoption of HPWHs as a cost-effective efficiency measure.

- Space conditioning interactions for North Atlantic climate zones
- In-field COP and EF for North Atlantic climate zones
- Household and business hot water consumption.

Space Conditioning Interaction for North Atlantic Climate Zones

HPWHs operate by extracting energy from the ambient air for water heating. Accordingly, the impacts that HPWHs located in conditioned areas have on the associated space conditioning loads deserve investigation. Also, the impacts that HPWHs located in unconditioned spaces have on the surrounding air temperature should be determined.

A combination of field testing and simulation will provide important insights into HPWH interactions with HVAC loads, infiltration rates, and ventilation requirements. In addition to providing data to support more robust deemed values for HPWH interactive effects, these investigations will validate or disprove key assumptions in the Northern Climate Specification. Given the level of current and anticipated manufacturer and consumer investment in HPWHs together with mounting pressure from the 2015 U.S. federal requirements for water heaters over 55 gallons in capacity, it is clear that determining space conditioning interactions will play a vital role in future product development and design.

In-field COP for North Atlantic Climate Zones

BPA has undertaken important lab testing and field monitoring studies to assess HPWH COP variation due to ambient air and inlet water temperatures. As does any new area of research, the BPA findings will require corroboration and validation though independent investigations.

EM&V Forum members share common interests across the North Atlantic and shared objectives with BPA, NEEA, and northwestern retail and municipal utilities. By working together on a national level to characterize HPWH COP variations, Forum members can accelerate development of useful and robust data to create simplified-deemed or deemed calculation methods for HPWH program delivery. This work will also inform the next round of HPWH product development and performance, placing program administrators in a strong position to drive successful water heater market transformation.

Hot Water Consumption

HPWH energy savings and cost-effective installations in residential and non-residential applications depend on reliable estimates of hot water consumption. Currently available data shows significant variation in daily and annual consumption values and estimation techniques. This is an important parameter for which acquisition of reliable data projections will contribute to more cost-effective and robust hot water efficiency programs. Restaurant, kitchen, and other food service end uses use large amounts of hot water and can benefit from cool air exhausted by HPWHs. Where practical, using HPWH ducting to provide bathroom ventilation or supplementary cooling for server rooms and “data closets” can be assessed as complementary functions to providing hot water in commercial occupancies.

The following points are particularly critical for EM&V Forum members to develop an accurate picture of HPWH energy saving performance under conditions unique to the North Atlantic.

- With a few exceptions, data and analysis from the BPA / Ecotope studies serve as the source for assumptions and deemed values presented in Table 7-1. The decision to use representative values from BPA / Ecotope is a response to the lack of agreement among earlier HPWH sources and the incomplete documentation of assumptions and methodologies in sources prior to the Mid-Atlantic TRM.
- As indicated in Table 7-1's footnotes, much of the data presented in the table is specific to the Pacific Northwest and is included here to encourage further investigation pertinent to the needs of EM&V Forum members, not because it is expected to accurately predict HPWH performance in the North Atlantic.
- No source prior to the BPA / Ecotope studies has examined HPWH space conditioning interactions and in-field COP and EF in depth. Additional field monitoring and laboratory testing of HPWHs is needed to confirm and expand the findings of the BPA / Ecotope studies in the Pacific Northwest.
- For Forum members in the Northeast, the placing of HPWHs in unconditioned spaces is certain to be problematic. If the space temperature drops much below 40°F the performance of the heat pump will suffer and a switchover to electric resistance is likely, negating savings for those periods.

7.7 SAVINGS ASSUMPTIONS, ALGORITHMS, AND DEEMED VALUES

The following tables summarize key assumptions (Table 7-1) and deemed values and algorithms (Table 7-2) for estimating HPWH energy savings in typical applications. Sources for assumptions and deemed values are shown in footnotes. The term "unconditioned buffer" refers to the HPWH being installed in an unconditioned space, eliminating the interactivity factor with space heating.

Table 7-1. HPWH Assumptions

	Measure	Baseline Technology	Baseline Annual kWh	Baseline EF	HPWH EF[4]	Cooling Savings Annual kWh[5]	Heating Savings Annual kWh[6]	Baseline kW[9]	HPWH Peak kW[10]	Coincidence Factor	Measure Life (Years)[12]
Residential	HPWH < 75 gallons, Resistance space heat	Resistance WH	3200 [1]	0.9 [3]	1.69	0 - 91	(915 - 1100)	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH < 75 gallons, heat pump space heat	Resistance WH	3200 [1]	0.9 [3]	1.69	0 - 91	(1234 - 1480)	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH < 75 gallons, fossil fuel space heat	Resistance WH	3200 [1]	0.9 [3]	1.69	0 - 91	(38 - 42 therms)[8]	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH < 75 gallons, unconditioned buffer	Resistance WH	3250 - 3450 [1]	0.87 - 0.88 [3]	1.08 - 1.36	0 - 91	(96 - 250)	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH ³ 75 gallons, Resistance space heat	Resistance WH	3300 [1]	0.89 [3]	2.09	0 - 121	(1234 - 1480)	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH ≥ 75 gallons, heat pump space heat	Resistance WH	3300 [1]	0.89 [3]	2.09	0 - 121	(486 - 742)	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH ≥ 75 gallons, fossil fuel space heat	Resistance WH	3300 [1]	0.89 [3]	2.09	0 - 121	(51 - 57 thems)[8]	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH ≥ 75 gallons, unconditioned buffer	Resistance WH	3400-3500 [1]	0.86 - 0.87 [3]	1.44 - 2.02	0 - 36	(96 - 250)	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	Northern Climate HPWH, unconditioned buffer	Resistance WH	3400-3500 [1]	0.86 - 0.87 [3]	1.64 - 2.05	0	See footnote 7	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
Commercial/ Industrial	HPWH < 75 gallons, Resistance space heat	Resistance WH	variable[2]	0.9 [3]	1.69	See footnote 7	See footnote 7	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH < 75 gallons, heat pump space heat	Resistance WH	variable[2]	0.9 [3]	1.69	See footnote 7	See footnote 7	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH < 75 gallons, fossil fuel space heat	Resistance WH	variable[2]	0.9 [3]	1.69	See footnote 7	See footnote 7	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH < 75 gallons, unconditioned buffer	Resistance WH	variable[2]	0.87 - 0.88 [3]	1.08 - 1.36	See footnote 7	See footnote 7	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH ³ 75 gallons, Resistance space heat	Resistance WH	variable[2]	0.89 [3]	2.09	See footnote 7	See footnote 7	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH ≥ 75 gallons, heat pump space heat	Resistance WH	variable[2]	0.89 [3]	2.09	See footnote 7	See footnote 7	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH ≥ 75 gallons, fossil fuel space heat	Resistance WH	variable[2]	0.89 [3]	2.09	See footnote 7	See footnote 7	4.5 - 5.0	0.425 - 0.990	See footnote 11	13
	HPWH ≥ 75 gallons, unconditioned buffer	Resistance WH	variable[2]	0.86 - 0.87 [3]	1.44 - 2.02	See footnote 7	See footnote 7	4.5 - 5.0	0.425 - 0.990	See footnote 11	13

[1] Representative values from BPA / Ecotope HPHW study, specific to Pacific NW region

[2] Use ASHRAE Handbook or comparable reference to compute based on annual water consumption per occupant and standby losses

[3] Representative values from BPA / Ecotope HPHW lab tests

[4] Representative values from BPA / Ecotope HPHW study, specific to Pacific NW region

[5] Representative values from BPA / Ecotope HPHW study, specific to Pacific NW region

[6] Representative values from BPA / Ecotope HPHW study, specific to Pacific NW region

[7] Compute for local climate and typical building characteristics for individual utility

[8] Plus furnace fan electric energy

[9] Average from on-line equipment catalogs

[10] Representative values from BPA / Ecotope HPHW lab tests

[11] Dependent on individual utility system load profile and customer coincidence definitions

[12] Adjusted upwards from 10 years (value from 2004 HPWH study) to match standard and high-performance Resistance water heater lives cited in FEMP "How to Buy an Electric Water Heater" (September 2004)

Table 7-2. HPWH Deemed Savings and Algorithms

	Measure	Recommended Deemed Savings Value	Recommended Algorithm	Knowledge Gaps	Notes
Residential	HPWH < 75 gallons, resistance space heat	560 - 650 kwh[13]	Yes - Supports deemed value	See Section 3.6	
	HPWH < 75 gallons, heat pump space heat	1190 kWh[13]	Yes - Supports deemed value	See Section 3.6	
	HPWH < 75 gallons, fossil fuel space heat	1550 kWh[13]	Yes - Supports deemed value	See Section 3.6	
	HPWH < 75 gallons, unconditioned buffer	880 kWh[13]	Yes - Supports deemed value	See Section 3.6	
	HPWH ≥ 75 gallons, resistance space heat	830 - 960 kWh[13]	Yes - Supports deemed value	See Section 3.6	
	HPWH ≥ 75 gallons, heat pump space heat	1690 kWh[13]	Yes - Supports deemed value	See Section 3.6	
	HPWH ≥ 75 gallons, fossil fuel space heat	2170 kWh[13]	Yes - Supports deemed value	See Section 3.6	
	HPWH ≥ 75 gallons, unconditioned buffer	1800 kWh[13]	Yes - Supports deemed value	See Section 3.6	
	Northern Climate HPWH, unconditioned buffer	See footnote 14	Yes	See Section 3.6	Will update as available
Commercial/Industrial	HPWH < 75 gallons, resistance space heat	See footnote 15	Yes	See Section 3.6	Water usage varies greatly
	HPWH < 75 gallons, heat pump space heat	See footnote 15	Yes	See Section 3.6	"
	HPWH < 75 gallons, fossil fuel space heat	See footnote 15	Yes	See Section 3.6	"
	HPWH < 75 gallons, unconditioned buffer	See footnote 15	Yes	See Section 3.6	"
	HPWH ≥ 75 gallons, resistance space heat	See footnote 15	Yes	See Section 3.6	"
	HPWH ≥ 75 gallons, heat pump space heat	See footnote 15	Yes	See Section 3.6	"
	HPWH ≥ 75 gallons, fossil fuel space heat	See footnote 15	Yes	See Section 3.6	"
	HPWH ≥ 75 gallons, unconditioned buffer	See footnote 15	Yes	See Section 3.6	"

[13] Representative values from BPA / Ecotope HPHW study, specific to Pacific NW region

[14] BPA analysis in progress

[15] Compute for local climate and typical building characteristics for individual utility

Savings Algorithms		
$\Delta kWh = kWhbase * ((EFhp - EFbase)/EFhp) + kWhcooling - kWhheating$	$\Delta kW = [(kWbase - kWhp) + kWexhaust\_fan] * CF$	Primary factors that affect deemed savings include variations in HPWH EF; interactions between HPWH air intake, cool air exhaust, and space conditioning system; annual hot water consumption.
where… kWhbase = Average electric DHW consumption EFhp = Energy factor of heat pump water heater EFbase = Energy factor of standard electric water heater kWhcooling = Cooling savings due to extraction of heat from conditioned space for water heating kWhheating = Heating required due to extraction of heat from conditioned space for water heating	where… kWbase = Power demand of standard electric water heater kWhp = Peak power demand of heat pump water heater, including auxiliary exhaust fan if present CF = Peak demand coincidence factor for water heating	

7.8 RECOMMENDATIONS

The key elements for establishing defensible savings methodologies and deemed values are summarized in the following paragraphs. We contend that there is currently sufficient data to support pilot programs that will close remaining knowledge gaps, strengthening HPWH energy savings data and allowing for the adoption of the measure by both residential and commercial efficiency programs.

7.8.1 Closing Data Gaps

The most robust way to determine how the identified market and technical issues affect savings is through a pilot with sufficient end use metering that follows best engineering practices in terms of what is metered and for what length of time.

Regardless of the baseline and acceptance component of this measure, the market-level potential savings is unclear and should be explored prior to undertaking too much primary research. Knowing the total market possible for installations and where current water heaters are located - in single family, multi-family, conditioned or unconditioned space - will all play a part in the ability of the measure to be deployed and the amount of energy it could save.

Because the current knowledge level of tradespeople regarding HPWH installation issues is unclear, a survey of current plumbers and HVAC installers would highlight the knowledge level of contractors in terms of their ability to optimally configure and install this measure. If contractors are found to lack knowledge, a training initiative could be explored.

Further data is needed to document space conditioning interactions and to correlate in-situ COP / EF performance with ambient temperature and HPWH water inlet temperature under North Atlantic climate conditions. Therefore, NEEP should perform a limited study to determine the technical potential for this measure using secondary sources. This will help NEEP members to decide the level of effort they should give to bringing this measure into the portfolio. For any ongoing pilot efforts, NEEP should perform customer surveys to determine satisfaction with the measure in terms of comfort, noise, etc.

For all other HPWH data requirements, we suggest that the Forum commission follow-up field and lab assessment studies to gather pertinent data that will enable validation of or challenge the BPA / Ecotope findings.

7.8.2 Utilizing Savings Algorithms

We believe that the savings algorithms presented Table 7.2 above provide a sufficient level of detail for estimating HPWH performance in a variety of applications when combined with regionally specific assumptions and deemed values. Once data is developed to fill the gaps we have identified, EM&V Forum members can apply these algorithms with confidence, incorporating HPWH measures in their residential and commercial efficiency programs.

7.8.3 Adopting Deemed Savings Values

It is reasonable to expect that robust, evidence-based HPWH performance data will not only support program implementation using the algorithms supplied, but will also lead to the possibility of developing simple, deemed savings values for mass-market HPWH measures. We recommend that program administrators be cautious in moving to deemed savings approaches until pertinent regional data has been gathered, applied successfully in programs, and vetted as part of program EM&V studies.

7.9 SUMMARY

Despite decades of development, heat pump water heaters seemed stuck in the category of emerging-but-not-yet-emerged technology until recently. The convergence of the ENERGY STAR specification for residential HPWHs with the involvement of prominent manufacturers and the upcoming federal energy standard for units over 55 gallons promises to give HPWHs a real place in the market if they are promoted, installed, and supported wisely. The availability of new generation products coupled with a voluntary standard and an upcoming mandatory one, provides several opportunities for program administrators.

For those seeking to add HPWHs to their residential measure portfolios immediately, we recommend doing so with eyes wide open. Many units come with a switch that allows users to override the compressor, instantly turning their HPWH into a conventional resistance heater. Successful program implementation will require reliable HPWH performance so that the owner never touches that switch. And some program models may not support HPWHs with override switches, just as manual overrides are not allowed for lighting occupancy sensors. Getting the application of HPWHs right the first time is complicated by the fact that optimal configuration and installation may require additional steps – such as ducting and venting to exhaust cool air from the evaporator to the exterior – that are still being clarified by the industry.

For other program administrators, HPWHs may be best approached through a pilot program, allowing installers and homeowners to experience the technology with a safety net. NEEP's HPWH collaboration and information exchanges with MEEA and NEEA are already playing important roles as part of the safety net. As indicated throughout this section, ongoing, robust regional and national collaboration will help all stakeholders better understand the technology and its optimal application as a low-energy alternative to conventional resistance water heaters.

A third opportunity for program administrators willing to follow a longer, more strategic path is supporting the Northern Climate Specification. If it gains sufficient momentum, the Northern Climate Specification will attract new products into the market that lead to higher levels of customer satisfaction, comfort, and energy savings.

Ductless Mini-Split Air Conditioners and Heat Pumps

8

8.1 INTRODUCTION

The ductless heat pump (DHP) market is well established in other parts of the world, but far less mature in North America. However, recent advances in the technology have made DHPs an attractive option for certain North American markets such as new construction and retrofit for homes with heating systems that don't use ducting.

Several North American manufacturers are now providing DHPs with performance characteristics that make them suitable for use in our colder climate. DHPs have the potential to significantly reduce home heating and cooling costs by reducing the amount of energy needed to condition the space. DHPs for residential and small commercial buildings are often referred to as "mini-split" systems because the compressor and evaporator are in two separate units, with the evaporator unit installed inside the structure.

Due to the high levels of insulation and air tightness required by current building codes, properly sized and configured DHP systems can be used as the sole HVAC solution (heating and cooling) for residential new construction. In the retrofit market the goal is often to displace as much of the heat coming from electric resistance equipment as possible. Ductless air conditioners[1] can also be installed for cooling only.

While DHPs can be an effective HVAC solution, numerous market barriers exist that reduce the uptake we might otherwise see. Chief among them is the North American public's general lack of awareness surrounding DHPs, which can often make locating qualified contractors for installation and maintenance difficult. Another issue is the relatively high upfront costs of equipment purchase and installation.

The following sections of this document will provide a brief overview of DHP technology followed by a discussion on the potential market for DHPs in residential efficiency programs. We then present a selective highlighting of programs currently offered by utilities across the continent. A review of relevant TRMs and reports is included along with sections on issues to account for when developing savings estimates for DHPs and recommendations for savings methodologies and

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[1] There is no fundamental difference between ductless air conditioners and ductless heat pumps in general, except for the obvious fact that air conditioners can be used for cooling only. This section will address both these types of ductless systems.

algorithms. Finally, we address program recommendations and evaluation procedures and provide a summary of our recommendations.

8.2 TECHNOLOGY OVERVIEW

DHPs do not directly generate heat but instead extract it from outside air (or inside air when cooling). DHPs can have a single outdoor unit paired with a single indoor unit or a single outdoor unit paired with multiple indoor units. Multiple DHPs can be used for a single building. The indoor unit is connected to the outdoor unit via refrigerant lines and contains a fan to distribute the conditioned air. The outdoor unit houses the motor and compressor.

Unlike traditional resistance heating (electrical baseboard or electric furnace), DHPs can, in addition to providing cooling, deliver more heat output than the amount of electrical input supplied. This can be anywhere from 100% to 400% heat output from the electric input. The exact amount of heat delivered depends on the outside temperature. The lower the outside temperature, the less heat it contains and the less efficient the heat transfer process will be.

Features and general design of DHPs that can enhance performance (higher efficiency, less noise, increased reliability, etc.) are as follows:

- ❑ **Inverter-fed motor** - Allows for variable speed use, avoiding constant on/off cycles of the unit, increasing efficiency and durability.
- ❑ **Scroll compressor** - Operates more smoothly than a regular piston compressor, reducing noise and electric consumption and enhancing the compressor's expected life.
- ❑ **Electronic (precise) expansion device** - Better refrigerant flow control provides a superior level of room temperature control and uses less energy.

The outdoor unit can have a variety of motor and compressor arrangements. The trend in split heat pumps is toward using inverter-fed motors with scroll compressors. There are a number of advantages to this technology as described above.

Older designs incorporated a motor that had one or two speeds of operation. This meant that the temperature of the house varied in time by a few degrees to avoid constantly triggering the compressor motor to turn on or off. Even so, the on/off cycles caused wear and tear on the motor and reduced its lifespan.

With an inverter-fed motor the unit can vary its speed rather than shut off. Consequently it can maintain the conditioned space at a more even temperature by lowering its speed to match the required load. By avoiding many of the on/off cycles, these motors can have a significantly longer lifespan. Another benefit of the inverter-fed motor is that it will use up to 30% less energy during operation than a comparable one- or two-speed unit.

Scroll compressors are a type of rotary compressor. They are becoming more widespread in recent DHPs models because they have fewer moving parts and operate more smoothly and reliably than other design types.

8.3 POTENTIAL OF HEAT PUMPS FOR EFFICIENCY PROGRAMS

DHPs are a good solution for a sizable segment of the market for residential HVAC. They can be used to provide the primary heat source for a home or heat for secondary zones. If a DHP is to be used as the primary heat source then the measure works best in homes/apartments that have a large open space as the primary living space due to the lack of ducted delivery.

The ideal size, configuration, and number of DHPs to install are dependent on the details of the home. This is ultimately determined by the contractor, based on the size of the zone to be conditioned, the layout of the house, and other factors such as the level of insulation and the climate zone.

For new construction, building code updates have resulted in new homes having a lower heat loss than the vintage stock. Many new homes are built to a standard that allows a DHP system to supply the entire space conditioning requirements. For colder regions, DHPs are normally sized upwards to meet the heating loads even though the cooling power of the larger units is not required.

In retrofits it is usually not cost-effective to size the DHP to cover 100% of the heating needs as the peak heating demand only occurs a few days (the coldest) of the year. Displacement theory is the idea that significant savings can be achieved by displacing as much of the heat provided by other installed heating systems as feasible. Under this model a DHP is installed as a retrofit measure and the original heating system is left intact. Modern DHPs can provide adequate heat to displace a substantial amount of heating requirement over the duration of the heating season even in older, less air-tight buildings. On the coldest days that the DHP might not be able to provide the full load, the original equipment is used as a supplemental heat source. At these colder temperatures, the heat pump reaches a balance point where it no longer produces more heat than the electricity it consumes. This is typically somewhere between 0 and 300°F. This limits the achievable heating savings in cold climate zones.

The above retrofit discussion is most cost-effective from an electric utility standpoint when the original primary space heating equipment is electric resistance. While some utilities provide DHP incentives for non-electrically heated homes[2], this is an electric load building exercise and, from an overall efficiency standpoint, may or may not lead to net energy savings depending on the marginal power generation assumptions i.e., what power source, with what efficiency if non-renewable based, is assumed meet the additional load generated by the DHP?.

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[2] Research into Action, Northwest Ductless Heat Pump Pilot Project, July 2011

8.4 EFFICIENCY PROGRAMS CURRENTLY PROMOTING HEAT PUMPS

As noted earlier, DHPs with good cold climate performance have only recently been introduced in the North American market. Even so, program administrators in the Northeast and elsewhere have initiated programs to encourage DHP adoption.

The following is a sample of DHP programs across the United States.

- **Connecticut Energy Efficiency Fund** – A rebate from $250 to $1,000 is available from the Connecticut Energy Efficiency Fund and qualified units may be eligible for a $300 federal tax credit.
- **Long Island Power Authority Residential Energy Efficiency Rebate Program** – Offers $250 to $400 for DHPs, depending on efficiency rating
- **Bangor Hydro Residential Efficient Heat Pump Rebate Program** – Offers a $100-per-ton rebate for DHPs
- **New Jersey's Clean Energy Program, COOLAdvantage** – Offers $500 for qualified DHPs
- **Western Massachusetts Electric** – Offers $500 rebate for an ENERGY STAR-qualified DHP
- **Clallam County PUD, Washington** – Offers $1,500 for existing site-built homes with electric zonal heating.
- **Columbia River PUD, Oregon** – Offers a $1,500 rebate for approved installations in single family homes, and a $1,000 rebate for installations in multi-family housing units, such as apartment complexes.

8.5 EXISTING DATA REVIEW

A review of a selection of Technical Reference Manuals (TRMs) allows us to compare the algorithms used to calculate annual energy savings as well as peak demand savings. The annual energy savings algorithms are presented in Table 8-1 and the peak demand savings algorithms are presented in Table 8-3.

The sample set contains five different TRMs referenced from across the Northeast region. While there is variation in the algorithms, the differences are small. The main differences are the input values but there are some algorithms that contain terms that the others do not. These issues are discussed below.

Table 8-1[3]
Annual Energy Savings Algorithms

TRM	Annual Energy Savings Algorithm
NY, 2011[4]	$\Delta kWh = units \times \frac{tons}{unit} \times \left(\left[\frac{12}{SEER_{base}} - \frac{12}{SEER_{ee}}\right] \times EFLH_c + \left[\frac{12}{HSPF_{base}} - \frac{12}{HSPF_{ee}}\right] \times EFLH_h\right)$
UI/CL&P C&LM, 2008[5]	$\Delta kWh = kBtu/hr \times \left(\left[\frac{1}{SEER_{base}} - \frac{1}{SEER_{ee}}\right] \times EFLH_c + \left[\frac{1}{HSPF_{base}} - \frac{1}{HSPF_{ee}}\right] \times EFLH_h\right)$
MA, 2010[6]	$\Delta kWh = tons \times \frac{12\ kBtu/hr}{ton} \times \left(\left[\frac{1}{SEER_{base}} - \frac{1}{SEER_{ee}}\right] \times EFLH_c + \left[\frac{1}{HSPF_{base}} - \frac{1}{HSPF_{ee}}\right] \times EFLH_h\right) + \Delta kWh_{seal}$
PA, 2011[7]	$\Delta kWh = kBtu/hr \times \left(\left[\frac{1}{SEER_{base}} - \frac{1}{SEER_{ee}}\right] \times EFLH_c \times LF + \left[\frac{1}{HSPF_{base}} - \frac{1}{HSPF_{ee}}\right] \times EFLH_h \times LF\right)$
VT, 2011[8]	$\Delta kWh = kBtu/hr \times \left(\left[\frac{1}{SEER_{base}} - \frac{1}{SEER_{ee}}\right] \times EFLH_c + \left[\frac{1}{HSPF_{base}} - \frac{1}{HSPF_{ee}}\right] \times EFLH_h\right)$

where:

ΔkWh	= Gross annual energy savings
ΔkWh_{seal}	= Gross annual energy savings from duct sealing
Units	= Number of units installed
kBtu/hr	= Nominal capacity of DHP
$SEER_{base}$	= Seasonal energy efficiency ratio of baseline unit
$SEER_{ee}$	= Seasonal energy efficiency ratio of energy-efficient unit
$HSPF_{base}$	= Heating season performance actor of baseline unit
$HSPF_{ee}$	= Heating season performance factor of energy-efficient unit
$EFLH_h$	= Equivalent full-load hours for heating
$EFLH_c$	= Equivalent full-load hours for cooling
LF	= Load factor

3 Naming conventions for the terms in the algorithms has been changed to use consistent terminology for the various parameters.

4 ERS, *Deemed Savings Estimates for Seven Residential Measures*, May 2011

5 The Connecticut Light and Power Company and The United Illuminating Company, *CL&P and UI Program Savings Documentation for 2008 Program Year*, 2008

6 Steve Bower et al, *Massachusetts Technical Reference Manual*, October 2010

7 Pennsylvania Public Utility Commission, *Technical Reference Manual*, June 2011

8 Efficiency Vermont, *Technical Reference User Manual*, July 2011

8.5.1 Nomenclature and Typesetting

Some of the TRMs, when displaying the algorithms, choose to place the default baseline values directly in the equation rather than provide the values in a table. For example, UI/CL&P uses 1500 full-load hours for heating everywhere within their jurisdiction. In their algorithm they use this value directly rather than specifying it as $EFLH_h$.

8.5.2 Primary or Secondary Heating

As mentioned above, DHPs can be used as the primary heat source for the main living spaces of a building or as a secondary heat source for zones within the house. Only the Pennsylvania TRM provides recommended EFLH for the two different cases.

The zones as defined by Pennsylvania are:

- **Primary heating zones**:- Living room, dining room, house hallway, family room, recreation room
- **Secondary heating zones** - Bedroom, bathroom, basement, storage room, office/study, laundry, mudroom, sunroom/seasonal room

8.5.3 Extra Terms

There are two states that each include a term to account for an effect that the other jurisdictions do not. Massachusetts includes a fixed value term related to savings achieved from duct sealing, and Pennsylvania includes a term that ostensibly addresses issues related to the variable output inherent with inverter technology as well as differences in load hours. Both cases are discussed below.

The Massachusetts algorithm includes a fixed value for duct savings: 212 kWh for annual energy savings and 0.3 kW for annual kW reductions, based on DOE-2 modeling. However the TRM posits that the *baseline* equipment for this measure is a non-ENERGY STAR-rated ductless mini-split heat pump. Therefore it does not seem appropriate to include a savings term for duct savings if the baseline is assumed to be a ductless system as well. The addition of this term makes sense logically when the baseline equipment for the measure is a system that utilizes ducts for conditioned air delivery.

A possible explanation is found by looking at the algorithm for ductless air conditioners found in the same TRM. There the baseline equipment is a central AC and the algorithm for that measure rightly includes a term for duct savings.

The algorithm found in the Pennsylvania TRM includes a load factor (LF) function, the purpose of which is to account for two different issues. It attempts to correct for the fact that inverter-based DHP units will operate at partial loads some of the time as well as accounting for EFLH that are based on central HVAC systems and might be overestimating actual usage for the systems the DHP is replacing. The value of 0.25 for the LF was used to ". . . align savings with what is seen in other jurisdictions." This will be discussed further in the section covering the Connecticut pilot.

8.5.4 Full-Load Hours

The TRMs in the sample set use multiple naming conventions for full-load hours . Some TRMs use EFLH (equivalent full-load hours), others AFLH (annual full-load hours) or FLH (full-load hours). It appears that they all intend to use the same concept, but different terminology.

8.5.5 Measure Life

The measure life for DHPs in the sample of TRMs has a value range of 15 to 18 years. This is consistent with other residential HVAC systems.

8.5.6 Baseline Performance Ratings and Inputs

DHPs are interesting in that they provide both heating and cooling. Therefore there is a range of baseline equipment and ratings in the sample set of TRMs. The EFLH values also differ between sample TRMs due to their states' geographic spread. Some states include default EFLH values that cover their entire jurisdiction while others provide tables of appropriate values based on different climates found within their region. Table 8-2summarizes the values used within the sample TRM set.

Table 8-2. Baseline Performance Ratings and Inputs

TRM	$SEER_b$	$HSPF_b$	EER_b	Life	$EFLH_c$	$EFLH_h$
NY, 2011	RAC 10.7 CAC 13	RAC 7.7 CAC 8.0	RAC 9.7 CAC 11.3	15	Multiple	Multiple
UI/CL&P C&LK, 2008[1]	RAC 7.5 CAC 10	ERH 3.41 HP 5.0	RAC 7.5	N/A	500	1500
MA, 2010	Nameplate	Nameplate	Nameplate	18	360	1200
PA, 2011	DHP 13 ASHP 13 CAC 13 RAC 11 NEC_p 13 NEC_s 11	DHP 7.7 ER 3.413 ASHP 7.7 EF 3.242 NEH 7.7	RAC 9.8, DHP, CAC[2]	15	Multiple	Multiple
VT, 2011	Multiple	Multiple		15	800	2200

[1] The TRM states "For retrofits actual baseline of the equipment should be used. If the baseline is unknown use the following defaults."
[2] For this use (11.3/13) x $SEER_{bS}$

where:

ASHP	= Air source heat pump
CAC	= Central air conditioner
DHP	= Ductless heat pump
EF	= Electric furnace
ER, ERH	= Electric resistance
HP	= Heat pump
NEC_p	= No existing cooling in primary space
NEC_s	= No existing cooling in secondary space
NEH	= No existing heating or non-electric heating
RAC	= Room air conditioner

8.5.7 Peak Demand Savings

The peak demand savings algorithms are displayed in Table 8-3**Table** . We see the same pattern of minor variations in the inputs and naming conventions.

Table 8-3. Peak Demand Algorithm[9]

TRM	Peak Demand Algorithm
NY, 2010	$\Delta kW = units \times \frac{tons}{unit} \times \left(\left[\frac{12}{EER_{base}} - \frac{12}{EER_{ee}}\right] \times CF\right)$
UI/CL&P C&LM, 2008	N/A
MA, 2010	$\Delta kW = max\left(tons \times \frac{12\ kBtu/hr}{ton} \times \left(\left[\frac{1}{EER_{base}} - \frac{1}{EER_{ee}}\right]\right), tons \times \frac{12\ kBtu/hr}{ton} \times \left(\left[\frac{1}{HSPF_{base}} - \frac{1}{HSPF_{ee}}\right]\right)\right.$ $\left. + \Delta kW_{seal}\right)$
PA, 2011	$\Delta kW = kBtu/hr \times \left(\left[\frac{1}{EER_{base}} - \frac{1}{EER_{ee}}\right] \times CF\right)$
VT, 2011	$\Delta kW_h = kBtu/hr \times \left(\left[\frac{1}{EER_{base}} - \frac{1}{EER_{ee}}\right] \times CF\right), \Delta kW_h = kBtu/hr \times \left(\left[\frac{1}{HSPF_{base}} - \frac{1}{HSFP_{ee}}\right] \times CF\right)$

where:

ΔkW	= Gross annual peak savings
ΔkW_{duct}	= Gross annual peak savings from duct sealing
Units	= Number of units installed

[9] Naming conventions for the terms in the algorithms has been changed to use consistent terminology for the various parameters.

kBtu/hr	= Nominal rating of DHP
EER_{base}	= Energy efficiency ratio of baseline unit
EER_{ee}	= Energy efficiency ratio of energy-efficiency unit
$HSPF_{base}$	= Heating season performance factor of baseline unit
$HSPF_{ee}$	= Heating season performance factor of energy-efficiency unit
CF	= Coincidence Factor

Coincidence Factor

The Massachusetts TRM again distinguishes itself in that the peak demand reduction calculation takes two steps. The TRM algorithm as stated above is for primary energy impact and does not include a CF term. CFs for both summer and winter are listed under "Impact Factors for Calculating Adjusted Gross Savings" and are applied after the demand reduction due to the equipment change is calculated.

Winter/Summer Peak

Both Vermont and Massachusetts cover a winter peak demand algorithm for DHPs while the other TRMs focus on summer peak calculations only.

8.5.8 Connecticut DHP Pilot

In 2007 CL&P and UI et al. ran a pilot to test the feasibility of DHPs. The pilot involved the installation of ninety DHPs in residential homes in Connecticut and an additional forty-eight in Massachusetts. The pilot took place between October and December of 2007.

The target market for the pilot was electric heated homes with electric strip or radiant heat and air conditioning. In order to qualify for the program, participants had to be full-time residents in the winter and currently use electric resistance heating for the primary source of heat. Participants were selected based on a number of criteria including electricity consumption, presence of window air conditioner, size of home, and willingness to allow a contractor to install the DHP.

CL&P and UI paid the full cost of installation and equipment for a standard one- or two-zone system. The systems installed in Connecticut were all twenty-four kBtu/hr systems and did not typically meet the full heating and cooling load of the house. The units installed in Massachusetts were larger multi-zone units that were designed to meet the heating and cooling load of the house. The original heating equipment was left in place in all cases.

A paper[10] prepared by CL&P and UI on just the portion of installs within their jurisdiction noted that ". . . the installed DHPs demonstrated savings of over 2000 kilowatt-hours (kWh) . . . during the heating season and significantly reduced summer air conditioning electrical consumption." Also important to note is that the authors felt that ". . . newer more advanced DHPs have superior cold weather ratings; thus the result of the pilot may be somewhat conservative when considering the

[10] Joseph R. Swift et al., *Ductless Heat Pumps for Residential Customers in Connecticut,* 2010.

newest generation of DHPs." The authors state that the majority of ". . . heat pumps installed were Mitsubishi Mr Slims, which maintained approximately 60% of their heating capacity at 17°F. Newer units maintain 100% of their heating capacity at 5°F and 87% at -4°F according to Mitsubishi."

An impact evaluation of the pilot was carried out by KEMA. They used interval meter data collected at the forty on-site locations as well as interval billing data for all the pilot participants. No non-participant control was group used for the analysis.

The study used three separate methodologies to calculate the heating savings: total heat regression, whole premise regression, and billing analysis. The results from that the energy savings were significant, averaging 35%. However this is lower than what was predicted based on the theoretical performance of the DHPs.

Various issues arose with many of the data forty -metered sites that reduced the number of sites with usable data to thirty-one. Of these sites, some used supplemental non-electric heat. Therefore the sample size of houses that were electric heat only was twenty-two for the whole premise regression and twenty for the total heat regression.

The KEMA study used the data collected from the homes to construct regression models in order to predict savings. These savings were compared against the Massachusetts TRM energy savings algorithm to determine how close the predictions are from the different approaches. At the time of the report, Massachusetts did not have a DHP heating algorithm so the savings were compared for cooling only.

The baseline equipment selected for use in the TRM calculation was a central A/C. The algorithm predicts 311 kWh in energy savings (99 kWh from the improvement in the SEER values and 212 kWh from studies done on energy lost due to ducting). This estimate was then screened against three levels of savings as predicted from the regression models: initial savings, adjusted savings, and fully adjusted savings. These are average-per-house values.

The differences between the three levels of savings are related to data specific to the pilot. The initial savings estimate assumes that all the DHP cooling load was met by the equipment already in place. The adjusted savings takes into account that 22.5% of the participant homes did not have cooling to begin with. This plays out by reducing the average savings for each home. The fully adjusted case accounts for the 22.5% with no initial cooling as well as the incremental increase in cooling for the homes that had a system in place but where the capacity of the DHP was higher than the original system.

The regression models considered a variety of baseline equipment performance for both central AC and room A/C. The baseline equipment used to compare against the TRM savings estimate in the above scenarios was a room air conditioner with an EER of 9.0. Note this is not in agreement with the baseline equipment of the TRM algorithm to which it is being compared. The TRM algorithm assumes the baseline equipment is a central AC with an EER of 11. By not using the same equipment baseline with the same performance ratings when comparing the predictions, the strength of the conclusions that can be reached are reduced. More effort is required to understand how this impacts the savings comparison.

The results of the comparison show that the initial savings estimate is closest to the TRM algorithm savings for each of the separate locations (between 57% and 88%) whereas the fully adjusted savings, which include added AC load for homes that previously were not cooled, are lower (between 24% and 37%). These results illustrate that for homes with electric heat with no cooling before the installation of a DHP, the increase in load due to summer cooling is more than offset by the savings from winter heating.

Related to the baseline differences discussed above, the adjusted and fully adjusted savings estimates are dependent on the equipment that was present in the participant houses. This is a useful adjustment that reflects the baseline equipment present in the pilot. The TRM algorithm used in the comparison was not able to capture the differences in capacities between the baseline equipment and the energy-efficient equipment. This issue will be addressed in the recommended algorithm presented in Section 8.7.3.

The Pennsylvania TRM algorithm for DHPs cites this study to justify the inclusion of a LF to reduce the expected savings by 75%. It appears that they have taken the lowest value from the fully adjusted savings and used that to determine their LF. For the reasons stated above this does not seem appropriate given that the information it is based on is dependent on the equipment found within the pilot.

A general LF term in the savings algorithm is not recommended as baselines will differ according to region and program design (e.g., limiting participation to homes with existing central A/C).

Explanations for the lower savings can be attributed to the fact that some of the participant homes did not have AC and so the DHP actually builds load in this case. If window units were in place beforehand, the DHP will still represent a larger capacity of cooling ,which again would build load. Since both Connecticut and Massachusetts have cold winters the load building should be more than offset by savings in the winter when compared with electric resistance heating. However if the system peak is in the summer this might be an area of concern.

KEMA listed a few possible reasons for the lower than expected heating savings:

- ❑ Typically baseboards each have their own thermostat and are controlled individually. Some participants, in particular those with multi-zone systems, may have increased the size of the zone(s) they were heating. Electric heat participants will often only heat the primary living spaces and reduce or turn off the heat in the secondary spaces. The DHP may have been producing more heat than the baseboards because it was conditioning a larger area.

- Almost half of the pilot participants had single-zone systems. This means that electric resistance continued to be used in other areas of the house. In the worst case, heat produced by the resistance heaters spilled over into the zone heated by the DHP and caused it to operate less.
- The fact that DHPs provide even temperatures by constantly circulating the air could effectively increase heat loss and could increase the amount of energy a DHP is using compared to baseboards.

Based on the results of the pilot CL&P believes that " . . . a realistic savings estimate for electric heat homes retrofitted with a DHP is 40 percent."[11]

Overall satisfaction with the DHP system was high with " . . . 38 of 40 participants surveyed rating their satisfaction with a four or five on a one to five scale."[12]

8.5.9 Northwest Ductless Heat Pump Pilot

The Northwest Energy Alliance (NEEA) is a non-profit corporation that operates in Idaho, Montana, Oregon, and Washington. It is supported by electric utilities, public benefits administrators, state governments, public interest groups and energy efficiency industry representatives.

NEEA ran a DHP pilot program from October 2008 to December 2009. The program had a number of goals, one of which was to demonstrate the effectiveness of " . . . inverter-driven ductless heat pumps to displace electric heat in existing Northwest homes."[13.]

The target audience for the pilot was single-family, site-built homes that used electric resistance zonal heating systems as the primary source of heat. Secondary targets included single-family, site-built homes that used central forced-air electric furnaces and manufactured homes using central forced-air systems.

The program promoted DHPs as "an appropriate space conditioning technology for homes where residents spend most of their time in a single zone." However many found the DHP conditioned nearly their entire home.

The pilot exceeded its target goal by 55% and by November 15, 2010 had installed 7,116 DHPs. Since completing the pilot project NEEA has initiated a region-wide market transformation program.

Market Evaluation

Research Into Action wrote a market progress evaluation report for the pilot. Program stakeholders were interviewed in the first year and then again in the second year of the program. The results

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[11] Swift, *Ductless Heat Pumps for Residential Customers in Connecticut*, 2-301.

[12] Ibid, 2-297.

[13] Research Into Action, Northwest Ductless Heat Pump Pilot Project, July 2011.

found that 96% of respondents used the DHP on the coldest days of the year. Slightly over three quarters (77%) indicated that the DHP was able to keep their space at a comfortable temperature despite the cold and just over a quarter of the respondents said that the DHP was their only form of heating equipment used during the prior season.

In nearly all reports the DHP met or exceeded the participant's expectation regarding the amount of space conditioned.

Lab Testing Report

In order to evaluate the effectiveness of DHPs, Ecotope carried out laboratory analysis as well as in field monitoring of DHPs. Two models were selected (a Mitsubishi FE12NA and a Fujitsu 12RLS) as indicative of the models available in the market (at the high end), and tests were carried out to determine performance. High end models were selected so that the results would be valid farther into the future.

The testing showed that both models performed well overall including at low temperature. Interestingly, "the testing showed that the DHP technologies often perform better that the ratings suggest by optimizing the outputs and inputs to the current environmental conditions."[14] The efficiency of the systems stems from their ability to change thermal outputs and fan flow in response to control signals from the occupant or ambient conditions. The graphs below, taken from the report[15], compare the two units' rated, lab-tested, and real-world measured heating efficiencies across a spectrum of outdoor temperatures.

Figure 8. FE12NA COP Plot.
(Field data given as box plots. Steady state lab data plotted as points.)

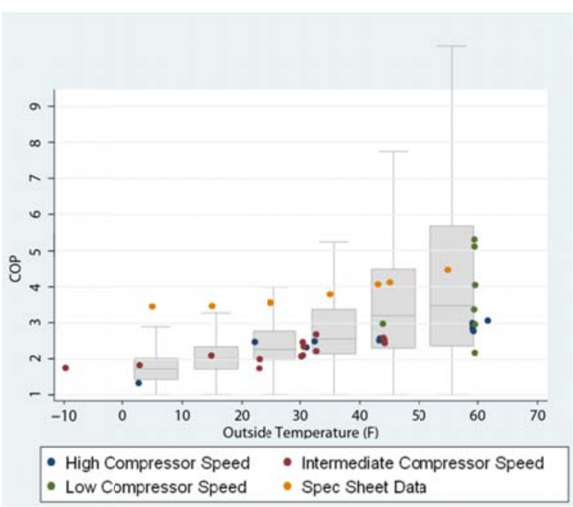
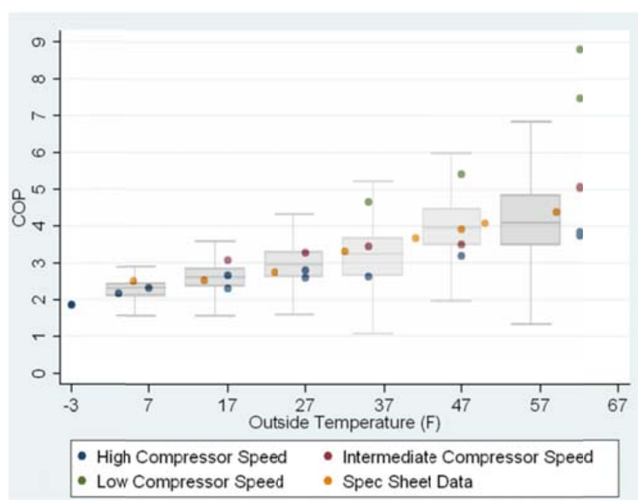


Figure 7. 12RLS COP Plot.
(Field data given as box plots. Steady state lab data plotted as points.)



[14] Ecotope, *Ductless Heat Pump Impact & Process Evaluation: Lab-Testing Report* (July 2011), 1.

[15] Ibid, 16-17.

The authors note that the current rating system of using HSPF and SEER ratings are not well suited to DHPs. The standard test and calculation procedures did not always produce ratings that characterize the performance of the equipment well.

Neither of the measured SEER values for the two DHP models tested agreed with the catalog data; both were lower. However, due to challenges encountered in the testing, these results do not definitively demonstrate higher or lower performance than the manufacturers supplied data. One of the major reasons for disagreement of the values is due to the intermediate speed operating points, which were difficult to replicate.

In addition to the lab testing, Ecotope conducted measurements and collected data from over thirty participant houses. The report detailing their findings has yet to be released.

8.5.10 Heat Pump Characterization Study

A background paper on the appropriateness of heat pump technology for HVAC in Yukon, Canada was prepared by Caneta Research for Energy Solutions Centre. One of the heat pump technologies highlighted was DHPs.

The study found that a heat pump could supply the heating requirements for a house or building for a significant portion of the heating season. The study found that a reasonable sizing approach was to select a heat pump with a heating capacity at 0°F of 25% – 35% of the house design heating load. A heat pump of this size would supply 60% to 75% of the annual heating load and could be economical.

8.6 HEAT PUMP DATA GAPS

The above-discussed studies provide a sound basis for determining the feasibility of DHPs energy savings. However there remain areas with insufficient data. These areas are outlined below.

- Space conditioning interactions with other heating systems
- Impact of sizing and the number of zones on savings
- Impact of summer AC load building in cold climates
- Savings attributable to the elimination of duct losses
- Reliability of EER, SEER and HSPF ratings for DHPs due to the use of inverter-fed motors
- Long-term data on measure life for DHPs

Space Conditioning Interaction with Other Heating Systems

How the DHP interacts with existing heating equipment requires further study. If a DHP is used as primary space heat but is not sized to supply the whole load, secondary heat is provided in other parts of the house. If heat produced in the secondary zones spills into the primary zone it will cause the DHP to lower its output. This also can cause cycling of the DHP (having it turn on and off), which negatively affects efficiency and potentially equipment life.

Impact of Sizing and Number of Zones

How total energy savings are affected by having a multi-zone system requires more study. The interaction between the various zones might have an effect on the operation of the DHP. Also, depending on the role they play (primary space or secondary space), different zones have different heating requirements. This affects the value of the EFLH used in the savings algorithm. Currently the Pennsylvania TRM provides values for EFLHc and EFLHh for various locations within its jurisdiction.

Impact of Summer AC Load Building in Cold Climate Zones

Although both central and zone AC are becoming more common in cold climates, there are still many existing homes that have no mechanical cooling systems. There are also newly constructed homes in New England with no cooling systems, although this is becoming less common. Program administrators need to consider summer load building when supporting DHP installations. Virtually all installed systems will be used to supply cooling even if there is no pre-existing cooling system. In fact, the addition of cooling is a strong vendor selling point for retrofit DHP projects. With the concerns related to summer loads on the power grid, and participation in the forward capacity market the impacts on summer loads that DHP programs produce need to be understood.

Savings Attributable to Elimination of Duct Losses

A paper by RLW Analytics published in 2002 suggested that 212 kWh of annual savings could be achieved by reducing duct losses from 15% to 5%. This estimate is used by the Massachusetts TRM as a proxy for the elimination of losses due to ducting when moving from baseline equipment that has ducts to a DHP. Incorporating a term that attempts to address this factor is warranted. However, there are many factors to consider such as the level of duct insulation and leakage, the percentage of duct system outside the thermal envelope, and the HVAC systems using the ducts (heating in the winter, cooling in the summer). Given the different baseline combinations possible and the different heating and cooling requirements found in the various geographic areas, jurisdictions will need to develop local estimates of energy savings based on the local building stock and climate.

Reliability of EER, SEER and HSPF

The NEEA lab testing conducted the full suite of tests necessary to calculate the SEER and HSPF ratings. Further tests were made in order to create a detailed performance map of the DHPs studied in order to get sufficient data to be able to model DHPs in energy simulation software.

It was found that the current HSPF and SEER ratings are not well suited to DHPs. More data is needed to assess both the relative performance between models and the likely energy use of a single model. Performance curves (including capacity and input power over a range of compressor loadings) and a description of operational strategies would be very useful.

For larger heat pump equipment (>65 kBtu) a new testing procedure and rating came into effect on January 1, 2010. The new testing procedure produces an integrated energy efficiency ratio (IEER) rating. To obtain IEER ratings, the systems are tested at four different capacity levels and outdoor temperature conditions to provide a very accurate part-load measure. This new rating better reflects the operation of equipment using inverter-fed motors. Although this rating does not apply to the equipment discussed in this paper it is worth noting possible future directions for updating performance values for inverter-fed DHPs.

Long-Term Data on Measure Life

There are two data points in the TRMs for measure life, 15 years and 18 years. A review of the citations for the values shows that the data used is from various sources including DEER, and other measure life reports, such as GDS Associates' *Measure Life Report*, 2007. None of these sources mention DHPs in particular, and they are based on values used for other heat pump technologies. Thus, more data is needed in order to better understand measure life for DHP.

8.7 Savings Assumptions, Algorithms, and Deemed Values

For this technology we recommend using an algorithm that builds upon the prevailing saving methodology in use by TRMs across the Northeast for DHPs.

8.7.1 Assumptions

The values used for input in the algorithm need the flexibility to adapt to local conditions. The estimate for EFLH for heating and cooling loads should be location specific as should the CF for the peak demand. Local program administrators should tailor these to reflect the conditions in their areas.

Two assumptions that apply to the algorithm presented below are the following:

- If the capacity of the indoor units is larger than the capacity of the outdoor unit, the DHP system capacity is determined by the outdoor unit.
- The capacity of the DHP system is less than 65 kBtu/hr.

Multiple Indoor Units

A DHP with one outdoor unit and two indoor units might not be matched in capacity. For example the indoor units might each have a capacity of 9,000 Btu (combined capacity of 18,000 Btu) and be matched to an outdoor unit with a capacity of 15,000 Btu. This leaves a 3,000 Btu deficit between the indoor units and the outdoor unit. Contractors will sometimes do this under the assumption that both heads will not need full capacity at the same time. The capacity of the system in this case is that of the outdoor unit (15,000) and not the combined capacity of the two indoor units.

The results of research for this paper found only cases where the indoor units were oversized in comparison to the outdoor unit and never the other way round. This makes perfect sense.

8.7.2 Recommended Deemed Values

The recommended deemed values presented in this section all relate to the default baseline ratings that should be used in the savings algorithms. Three different upgrade scenarios are discussed: new construction, natural (end-of-life) replacement, and retrofit.

Baseline Performance Values

The baseline unit values for new construction and for natural replacement should use the current minimum federal standards for HSPF and SEER for DHPs or market baseline if higher.

For the retrofit market the values of the baseline equipment in place should be used. If the performance values of a unit are unknown but the make and model numbers are known, PAs can refer to the AHRI directory[16]. If the baseline in not a DHP (likely, as most programs will focus on installing DHPs to displace electric resistance heat), the same algorithm can be used with the baseline values for the specific technology as detailed in Table 8-4.

Table 8-4. Recommended Baseline Performance Values

Technology	$SEER_{base}$	$HSPF_{base}$	EER_{base}[17]
ASHP	13	7.7	11.2
CAC	13	N/A	11.2
DHP	13	7.7	11.2
EF	N/A	3.413	3.413
ER	N/A	3.413	3.413
HP	13	7.7	11.2

where,

ASHP = Air source heat pump
CAC = Central air conditioner
DHP = Ductless heat pump
EF = Electric furnace

[16] http://www.ahridirectory.org

[17] For ASHP, CAC, DHP and HP, this value is calculated using $EER = -0.02 \times SEER^2 + 1.12 \times SEER$. Equation taken from *U.S. DOE Building America House Simulation Protocols*, 2010

ER = Electric resistance
HP = Heat pump
NEC_p = No existing cooling in primary space
NEC_s = No existing cooling in secondary space

8.7.3 Recommended Algorithm(s)

There is a large number of possible combinations of heating and cooling equipment that a DHP might replace. Though there are many baseline cases, we will focus on the baselines most likely to be of interest to program sponsors, namely, the DHP replacing electric resistance heating (furnace and baseboard) and RAC or CAC cooling system.

For heating it is very often the case that the upgrade equipment provides the same capacity of output as the baseline equipment. However, for the cooling loads, cooling capacity can be different. Often the cooling capacity increases with the installation of the DHP. This is especially true in colder climates where the system is sized for a larger heating load. The savings algorithm should take this possibility into account.

Annual Energy Savings Algorithm

The recommended algorithm for computing savings per DHP is:

$$\Delta kWh = \left(\frac{kBtu/hr_{base,c}}{SEER_{base}} - \frac{kBtu/hr_{ee,c}}{SEER_{ee}}\right) \times EFLH_c + \left(\frac{kBtu/hr_{base,h}}{HSPF_{base}} - \frac{kBtu/hr_{ee,h}}{HSPF_{ee}}\right) \times EFLH_h + \Delta kWh_{duct}$$

where,

ΔkWh = Gross annual energy savings
ΔkWh_{duct} = Gross annual energy savings from elimination of duct losses
$kBtu/hr_{base,c}$ = Nominal capacity of baseline unit for cooling
$kBtu/hr_{base,h}$ = Nominal capacity of baseline unit for heating
$kBtu/hr_{ee,c}$ = Nominal capacity of energy-efficient unit for unit for cooling
$kBtu/hr_{ee,h}$ = Nominal capacity of energy-efficient unit for heating
$SEER_{base}$ = Seasonal energy efficiency ratio of baseline unit
$SEER_{ee}$ = Seasonal energy efficiency ratio of energy-efficient unit
$HSPF_{base}$ = Heating season performance factor of baseline unit
$HSPF_{ee}$ = Heating season performance factor of energy-efficient unit
$EFLH_h$ = Equivalent full-load hours for heating
$EFLH_c$ = Equivalent full-load hours for cooling

The above algorithm fits the most general case. If the heating capacity of the baseline equipment and the energy-efficient equipment are the same, then equation can be simplified to:

$$\Delta kWh = \left(\frac{kBtu/hr_{base,c}}{SEER_{base}} - \frac{kBtu/hr_{ee,c}}{SEER_{ee}}\right) \times EFLH_c + kBtu/hr_h \times \left[\frac{1}{HSPF_{base}} - \frac{1}{HSPF_{ee}}\right] \times EFLH_h + \Delta kWh_{duct}$$

A similar simplification can be made if there is no change in cooling capacity between the baseline equipment and the energy-efficient equipment.

The algorithm should use kBtu/hr as its input. This is a more accurate value than using the stated tons rating from the equipment. A unit with an advertised ton rating has a range of possible kBtu/hr (i.e., 35,600 Btu or 37,600 Btu systems are both considered 3 tons). If the unit only has a ton rating then the conversion factor of 12 kBtu/hr per ton can be used.

As discussed above, if the baseline equipment uses ducts then a term related to savings that come about from not using the ducts (ΔkWh_{duct}) must be included. If the baseline equipment did not use ducts (electric baseboard, DHP) then the value for ΔkWh_{duct} is zero.

When calculating the savings from a multi-zone DHP system, the above algorithm should be used for each of the outdoor units using appropriate EFLH values for the type of zone (whether primary or secondary) and appropriate capacity values for the units. The zoning of the DHP system will play a large part in the correct EFLH for this algorithm and is currently one of the larger unknowns. While the maximum capacity is limited to the outdoor unit, if multiple indoor units are included in the system, there is uncertainty related to how the customer uses settings within each zone. Customer systems and preferences will affect how much cooling or heating is actually called for within the residence.

Annual Peak Demand Savings

The recommended reduction in peak demand equation is

$$\Delta kW_c = \left(\frac{kBtu/hr_{base,c}}{EER_{base}} - \frac{kBtu/hr_{ee,c}}{EER_{ee}} + \Delta kW_{duct}\right) \times CF, \quad \Delta kW_h = \left(\frac{kBtu/hr_{base,h}}{HSPF_{base}} - \frac{kBtu/hr_{ee,h}}{HSPF_{ee}} + \Delta kW_{duct}\right) \times CF$$

where,

ΔkW_c = Gross annual peak savings for cooling
ΔkW_h = Gross annual peak savings for cooling
ΔkW_{duct} = Gross annual peak savings from elimination of duct losses
$kBtu/hr_{base,c}$ = Nominal rating of baseline unit for cooling
$kBtu/hr_{base,h}$ = Nominal rating of baseline unit for heating
$kBtu/hr_{ee,c}$ = Nominal rating of energy-efficient unit for cooling
$kBtu/hr_{ee,h}$ = Nominal rating of energy-efficient unit for heating
EER_{base} = Energy efficiency ratio of baseline unit
EER_{ee} = Energy efficiency ratio of energy-efficiency unit
$HSPF_{base}$ = Heating season performance factor for baseline unit
$HSPF_{ee}$ = Heating season performance factor for energy-efficient unit
CF = Coincidence factor

The recommended baseline EER and HSPF are found in Table 8-4 above. The CF is dependent on the makeup of the local network and jurisdictions should use the value that is relevant to their circumstances.

The choice of which equation to use will depend on whether there is a summer or winter peak. For a winter peak the demand savings will be calculated using ΔkW_h. For a summer peak the demand savings will be calculated using ΔkW_c.

To calculate the winter peak demand reduction, HSPF values are used. HSPF is a seasonal efficiency measure that is computed by taking the total heat output of a heat pump over the entire heating season (in Btu) divided by the total energy it uses during that time.[18] As noted previously, the lower the outdoor temperature the less efficient the DHP operates. If the winter peak of the system is of critical importance, and it occurs at very cold temperatures, the HSPF rating of a unit might not reflect well the performance characteristics of the DHP.

8.8 Technology Specific Evaluation Issues

It is important for Forum members to investigate the following points in order to develop an accurate understanding of how DHPs will behave within their jurisdictions.

- Lab testing of models prevalent within the Northeast should be performed in order to determine the models' performance across the entire range of their operation. Detailed lab testing results can then be used to create models to predicate energy savings. Particular attention should be taken to see if lab testing can help reduce uncertainty around the specific EER/SEER/HSPF values for the DHP as there is partial evidence that the efficiency may be lower than stated. Use of the manufacturer data in an algorithm may overestimate actual savings.
- In situ monitoring of installations should be carried out in order to gather all the relevant data needed to determine the level of savings, both energy and power, that DHPs provide. Because DHP systems are promoted for both partial heat displacement and as a sole HVAC system for homes, both types of installations should be monitored across a variety of climatic conditions.
  - During any in situ monitoring, Forum members should consider an approach that allows for engineering modeling to create calibrated building prototypes based on the metered sites. This approach would provide for less expensive modeling after the original in situ effort to help assess incremental savings through multiple scenarios that will be found in member territories.
  - Additionally, if Forum members deploy sufficient units though a pilot program, a survey of customers would reveal how they are using the new system in relation to the system it replaced. If the new DHP only displaces partial heat load, it would be very useful to know how customers utilize the additional heating and cooling. For example, do they condition only some spaces with the DHP, and/or do they only use the DHP during moderate winter conditions relying on another fuel for colder winter conditions? This process would also point to any quality or satisfaction issues that have arisen. This information can be used to adjust assumptions around the overall savings values.

[18] http://oee.nrcan.gc.ca/residential/personal/heat-pump-terms.cfm

- The secondary reports found indicate a high level of customer satisfaction with the technology. It is less clear, and would be important to ascertain, if there were contractor-training opportunities associated with the pilot phases of DHP programs.

8.9 Recommendations

8.9.1 Closing Data Gaps

The NEEA work done in the Pacific Northwest provides laboratory testing of two specific DHP models. The above sections reviewing existing research have highlighted the areas that require further research.

How savings are affected by multi-zone DHP systems as well as interaction with other space conditioning equipment is not well understood. More studies that gather data from in situ installations that monitor the necessary variables are needed to produce a better understanding.

Programs serving cold climate regions with DHP retrofit programs should model the summer load building effects of adding AC to homes that are currently not mechanically cooled. Program administrators in the Northeast should engage staff who are involved with the forward capacity market to determine the effect on overall load reduction efforts. Program administrators will also want to carefully consider their assumptions about the share of a program's target market that would likely already have – or intend to move to having – air conditioning.

To better estimate the peak demand savings during the winter, appropriate values are needed for DHP performance at the conditions pertaining to the peak. DHP models with similar HSPF values can have different performance curves as operating conditions change and so specific models might need to be tested to be certain of outputs.

The measure life of DHPs is currently associated with previous studies based on other types of heat pumps. These values may or may not be appropriate for DHPs. Long-term studies should try to identify what an appropriate measure life is for DHPs. As the measure life is a population value used in calculation of benefits from a program, Forum members would need to put in place monitoring of installed systems, operating across many years. This would "tag" a sufficient number of specific units (using sampling design to determine the best number, but most likely this would be around 100 units) and follow up on their presence/absence in 6-, 9-, and 12-year intervals. Statistical analysis of those units still in place and operating (using appropriate analyses such as survival functions) would indicate if the current EUL of 15-18 years should be changed. Obviously, this is a long-term undertaking.

As with any fast advancing technology, it must be considered whether or not the measure life should be discounted for replacement of next generation products. Many of the programs researched for this report were established to replace electric heat. A fairly large percentage (typically around 40%) of the replaced heating equipment has been earlier models of heat pumps, rather than electric baseboard. One can assume that this trend might continue with subsequent generations of DHPs, especially for cold climate applications. Any long range customer surveys should include a focus on early replacement and whether or not the replacement was due to continuing advancements in HP technology.

8.10 Summary

DHPs are an interesting HVAC system because they provide both cooling and heating with the same equipment. DHPs are popular in both Europe and Asia and show great promise here in North America. Customer awareness is low regarding the technology but a review of market assessment studies performed on both the West and East Coasts show that customer satisfaction with the technology is high once installed.

DHPs are a rapidly evolving technology. For the Northeast region, the technology is attractive primarily as a replacement for electric resistance heating, providing the summer load building issues are carefully considered. The value proposition for DHPs replacing non-electric heating is not so straightforward and will depend largely on the assumed marginal power generation mix.

Biomass Wood Pellet Heating Systems

9

9.1 INTRODUCTION

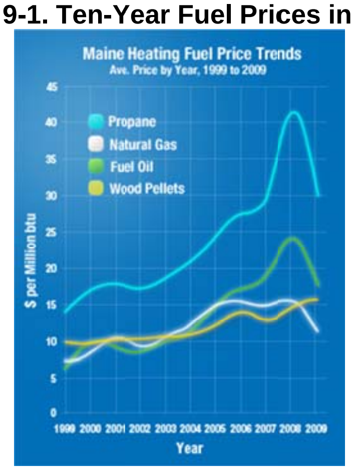
The focus of this section is on wood pellet fuelled furnaces, boilers, and combination systems (providing space heating and domestic hot water). It does not encompass partial-load pellet stoves.

In the U.S., biomass energy accounts for 45% of renewable energy used[1]. Most biomass is burned in old furnaces and boilers, leading to hazardous particulate emissions (PM2.5) as well as Volatile Organic Compounds, VOCs, from incomplete combustion and unsuitable fuels.[2]

The creation of wood pellets as a suitable biomass fuel was prompted by the oil crises of 1973 and 1979. While subsequently low oil prices led to a decline in interest, pellets have since been revived alongside interest in climate change, renewable energy, resource sustainability and energy efficiency. The benefits of wood pellets are summarized below:

- Wood pellets can be made from waste products from the wood industry and from specifically harvested wood supplies, contributing to their price stability in a volatile fuel market as shown in Figure 9-1.

Figure 9-1. Ten-Year Fuel Prices in Maine[3]



[1] Biomass Power Association, *US Biomass: Growing a Greener Economy*.

[2] C. Torres-Duque, *Biomass Fuels and Respiratory Diseases* (The American Thoracic Society 5, 2008), 577-590.

[3] Pinnacle Renewable Energy Group, *Why Wood Pellets*?, 2010-2011, cited 10/13/11, http://www.pinnaclepellet.com/environmental-commitment.php.

- Wood pellet technology is typically classified as "carbon neutral" because the CO_2 released in the combustion is, in theory at least, equivalent to that absorbed in the biomass growth cycle. While outside the scope of this report, we note that this assumption of carbon neutrality is sometimes challenged in the scientific community.
- The manufacturing of wood pellets promotes the local wood industry and therefore stimulates local economy development and employment opportunities.
- Recent advances in combustion of wood pellets now allow for full, controlled combustion, reducing harmful particulate emissions and increasing thermal efficiency.

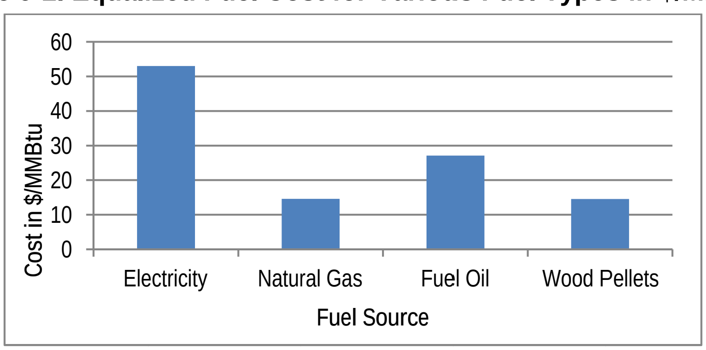
The gross heating value per unit of fuel is shown in Table 9-1. The gross heating value accounts for water in the exhaust leaving as vapor and includes liquid water in the fuel prior to combustion; this is termed the lower heating value (LHV) where vapor is allowed to escape i.e., a non-condensing unit. In the case of a higher heating value (HHV), the vapor is allowed to condense, thereby releasing the heat imparted in the process of vaporization and increasing the thermal efficiency of the unit i.e., a condensing unit.

Table 9-1. Gross Heating Value for Various Fuel Types[4]

Wood pellets (premium)[b]	Natural gas	Electricity	Firewood (seasoned) (20% MC)[a]	Switchgrass (ovendried)	Bituminous coal	Shelled corn (15% MC)	Fuel oil		Propane
							#2	#6	
16,400,000 (Btu/ton)	1,025,000 (Btu/1000 ft³)	3,412 (Btu/kWh)	20,000,000 (Btu/cord)	15,500,000 (Btu/ton)	30,600,000 (Btu/ton)	392,000 (Btu/bu)	138,800 (Btu/gal)	150,000 (Btu/gal)	91,300 (Btu/gal)

Figure 9-2 provides the equalized fuel cost for various types of Fuel.

Figure 9-2. Equalized Fuel Cost for Various Fuel Types in \$/MMBtu[5]



Since the 1990s, Europe has been the major proving ground for biomass technology, with users on the North American continent importing boilers and furnaces. However, with the rise of interest

[4] Forest Products Laboratory, TechLine: Fuel Value Calculator, 07/2004, cited 10/12/11, http://www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf.

[5] Group, *Why Wood Pellets*?, http://www.pinnaclepellet.com/environmental-commitment.php.

and use in the U.S. and Canada, North American manufacturers have begun to emerge. Ironically, the U.S. and Canada have long been major pellet suppliers for European demand, with pellet exports reaching 1.6 million tons in 2010. Other research suggests that states such as Maine could replace 49% of its liquid fossil fuel dependence in the home-heating sector with wood pellets.[6]

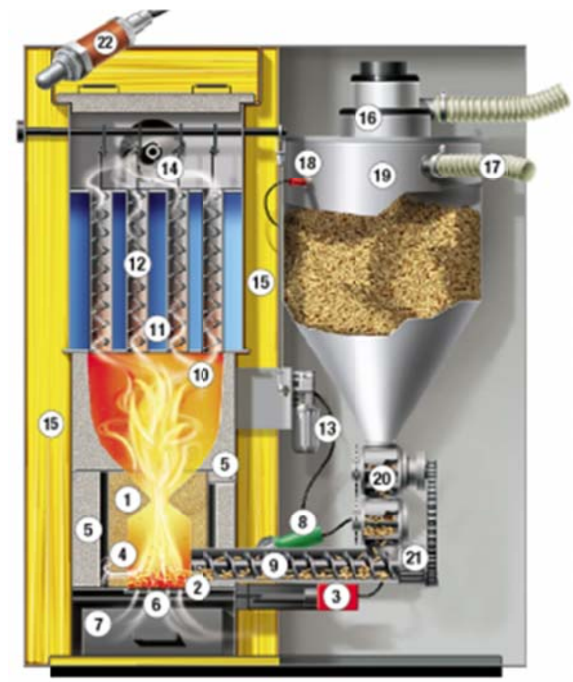
9.2 TECHNOLOGY OVERVIEW

9.2.1 Biomass Boilers and Furnaces

The common biomass boiler, as supplied in the U.S. by companies such as MESys, TARM Biomass, and Biomass Commodities Corporation, involves the basic set-up, shown in Figure 9-3.

Current pellet boilers have combustion efficiencies ranging from 80% – 94%[7], with outputs from less than 0.1 to over 15 MMBtu/hr. It is the circulation zone that allows for the secondary combustion of finer particles, leading to higher efficiencies and less hazardous particulate emissions.

Figure 9-3. Pellet Boiler Layout[8]



1. Fully refractory-lined combustion chamber
2. Sliding grate
3. Drive motor for sliding grate
4. Secondary air flow
5. High temperature resistant insulation plates
6. Primary air
7. Ash box
8. Automatic ignition
9. Stoker auger
10. Circulation zone
11. Boiler heat exchanger
12. Turbulators
13. Automatic boiler cleaning system
14. Induced draught fan
15. Cover insulation
16. Pellets vacuum turbine
17. Closed vacuum system, maintenance-free, no filter
18. Level detector
19. Cyclone hopper
20. Double rotary valve
21. Motor drive unit
22. Lambda sensor

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[6] Richard A Kessler, "Northeast US Biomass Could Replace Some Fossil Fuels," ReCharge: The global source for renewable energy news, 2/ 24/11, cited 10/04/11, http://www.rechargenews.com/energy/biofuels/article245982.ece.

[7] TARM Biomass, *Multi Heat Technical Datasheet*, 07/2010, cited 10/12/11, http://www.woodboilers.com/admin/uploads/public/MultiHeatDataSheettb.pdf.

[8] Hargassner, Pellet Boilers, Hargassner, cited 10/04,/11, http://hargassner.websline-cms113.com/wcms/binary/Server.dll?Article?ID=449&Session=1-znWQBaPn-1-130124201131101604&Via=Nav.

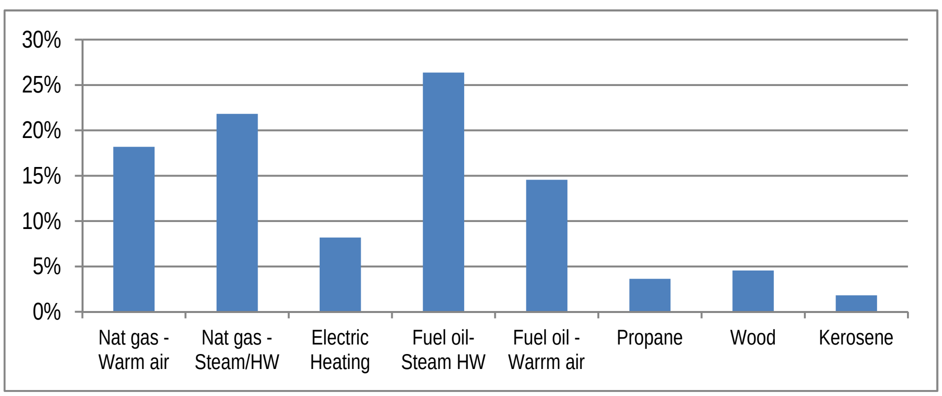
Biomass furnaces, such as those produced by Pinnacle and Harman, have typical efficiencies closer to 80%. The furnaces operate in a similar manner to the boiler shown in Figure 9-3**Error! Reference source not found.**; however clean air is contained within the heat exchange tubes.

9.2.2 Integrated Systems (Heat/DHW)

Integrated systems that provide both space heat and domestic hot water (DHW) are not as abundant as stand-alone systems and exist mainly in Europe. An example of this is the Extraflame Ecologica Idro, which operates with a 22 kW (75,067 Btu/hr) furnace and 17.5 kW (59,712 Btu/hr) back boiler, at an efficiency of 90%. The USEIA 2009 Residential Energy Consumption Survey shows that 33% of houses in the Northeast census region[9] use a forced air central heating system, and 48% of houses use a hot water one. The forced air central heating systems could be satisfied by a pellet furnace, while the hot water heating systems could be satisfied with a pellet boiler. All houses would require domestic hot water and could therefore benefit from an integrated system.[10]

Figure 9-4 provides the space heating market share in New England.

Figure 9-4. Graph Showing the Space Heating Market Share in the Census Region of New England: MA, CT, ME, NH, RI, VT [11]



9.3 POTENTIAL OF BIOMASS FOR EFFICIENCY PROGRAMS

Biomass furnaces and boilers are mature technologies, with significant market penetration in Europe but as yet little penetration in the U.S.

[9] The census regions used for this data includes MA, CT, ME, NH, RI and VT

[10] USEIA, *Space Heating by Census Region*, 2009.

[11] Ibid.

9.3.1 Market Size

Parts of the European market are more mature than others; pellet burners are widespread but not commonplace. Table 9-2 shows wood pellet use in some European countries and respective market shares.

Table 9-2. Comparison of Countries in the EU and Their Wood Pellet Market Share [12]

Country	Pellets Consumed (tons/year)	MMBtu Installed	MMBtu/Capita	Kg Pellets/Capita	Market Share%
Austria	500,000	8,000,000	0.96	59.97	8.45
Baltic Countries	76,000	1,216,000	0.18	11.14	1.57
Belgium	920,000	14,720,000	1.37	85.90	12.11
Bulgaria	11,880	190,080	0.03	1.58	0.22
Czech Republic	3,000	48,000	0.00	0.29	0.04
Denmark	1,100,000	17,600,000	3.20	200.22	28.22
Finland	150,000	2,400,000	0.45	28.23	3.98
France	140,000	2,240,000	0.04	2.28	0.32
Germany	900,000	14,400,000	0.18	10.96	1.54
Greece	Negligible				0.00
Hungary	1,000	16,000	0.00	0.10	0.01
Ireland	30,000	480,000	0.11	6.78	0.96
Italy	850,000	13,600,000	0.23	14.21	2.00
Netherlands	913,500	14,616,000	0.89	55.55	7.83
Norway	40,000	640,000	0.13	8.39	1.18
Poland	120,000	1,920,000	0.05	3.15	0.44
Portugal	10,000	160,000	0.02	0.94	0.13
Romania	25,000	400,000	0.02	1.16	0.16
Slovakia	17,000	272,000	0.05	3.14	0.44
Spain	10,000	160,000	0.00	0.22	0.03
Sweden	1,850,000	29,600,000	3.21	200.65	28.28
Switzerland	90,000	1,440,000	0.19	11.77	1.66
UK	176,000	2,816,000	0.05	2.98	0.42
Total	7,933,380	126,934,080	11.35	709.62	

The market in the northeast U.S. is small in comparison, yet holds significant potential. Indeed, the region includes 55 million acres of forestland[13] and strong winter heating loads.

[12] Pellet Atlas, Pellet Atlas Country Reports, cited 10/04/11, http://www.pelletsatlas.info.

[13] Chuck Wooster, *The Burning Question: Is Biomass Right for the Northeast?* 08/10/10, cited 10/04/11, http://northernwoodlands.org/articles/article/the-burning-question-is-biomass-right-for-the-northeast.

9.3.2 Supply Issues

While oil and gas distribution is a long-established industry, distribution of pellets in bulk is relatively new, which may raise concerns about supply risk. These risks relate to two scenarios: one in which the pellet supplier sources its wood from mill waste, in which case it is vulnerable to changes in mill operations including plant closures, and the other in which the pellet supplier has a secure source of wood, but may choose to export pellets rather than sell domestically if conditions elsewhere are more advantageous.

For the end user, two options can address this supply concern: co-firing burners and redundant heating systems. Co-firing burner technology is neither widely available nor, for large numbers, practical. One available system is the HS Tarm Excel 2000, which has an AFUE of 80% and requires two combustion chambers for the different fuel sources. It is also recommended that the heat given off from this boiler be stored in a thermal storage tank to minimize heat loss.[14] Redundancy is another option: if the users already own an operable fossil fuel boiler and are considering biomass as the primary energy source, they may install the pellet burner in series with the gas or oil burner. In this configuration the biomass boiler remains the primary heat source but the fossil fuel burner is also on hand to supply any extra heating required.

While these options are available to the end user, program administrators may also want to work upstream to address supply risk concerns. For example, programs can promote suppliers who offer supply guarantees. Note that security of supply concerns, already relatively small, should further diminish as domestic markets grow.

9.4 Current Programs and Standards

9.4.1 Existing Programs

Wood pellet technology has been around in its current state for some time. However incentive programs have only recently been put in place and therefore evaluations and studies of these programs have yet to occur.

Table 9-3 provides brief descriptions of ongoing programs that involve wood pellet burners and their promotion in and outside of the area under consideration in this report.

[14] HS Tarm, Excel 2000. cited 10 24, 2011, http://www.woodboilers.com/admin/uploads/public/TA_SpecSht_Excel_2000%20rev.pdf.

Table 9-3. Summary of Programs for Wood Pellet Installations

Program	What Is Offered	Running Dates	Stipulations
Maine Energy Systems Northeast Affordable Heat Program[15]	Guarantee that customers will pay no more than $239 per ton for bulk-delivered pellets up till June 30, 2014	01/2011 through 30/06/2014 or until 1000 wood-pellet boilers are sold	• Valid in Maine, New Hampshire and Vermont • Pellets for use with only new MESys systems • Minimum residential delivery of 3 tons, commercial of 6 tons
New Hampshire Public Utilities[16]	30% of system and installation cost up to $6000	04/2010 - 02/2012	• Efficiency >80% • Particulate emission <0.32lb/MMBtu heat output • Installation must be used as a central heating facility • Must provide at least 75% of the home heating load needs
Efficiency Vermont[17]	$1000 per system	≥07/2011	• Efficiency >80% (HHV) • Small systems only (< 300 MBH) • Automated fuel feeder and min. 1-ton storage capacity • Must provide at least 70% of the home heating load needs
Efficiency Nova Scotia[18]	Rebate of $2,500 - $16,000 depending on system	Ongoing	• Meet the CSA-B415.1-10 or the US EPA 40CFR Part 60 AAA standard • Have a PM emissions rating of <4.5g/hr • Be an indoor system • Replace electric space heat (may also include hot water) • Be installed by a certified professional
Newfoundland & Labrador[19]	Rebate of $1,500 or 25%	2008 - 03/2011	• Must have Wood Energy Technology Transfer Inc Certification • The dealer must be registered with the provincial government
Canadian ecoEnergy Program[20]	$375 for replacement of wood burning system	Ongoing	• Must be an indoor wood-burning appliance certified to either CSA-B415.1-10 or the US EPA 40 CFR Part 60 AAA wood-burning appliance standard. OR • An indoor pellet-burning appliance (includes stoves, furnaces and boilers that burn wood, corn, grain or cherry pits).

[15] Maine Energy Systems, cited 11/01/11, http://www.maineenergysystems.com/CoverageRestrictions.htm.

[16] NH Public Utilities Commission, Renewable Energy Rebates: Step 1 Pellet Rebate Application, 06/15/11, cited 10 04, 2011, http://www.puc.nh.gov/Sustainable%20Energy/RenewableEnergyRebates-WP.html.

[17] Efficiency Vermont, Wood Pellet Heating Systems, 2011 Rebate Form, 2011, http://www.efficiencyvermont.com/docs/for_my_business/rebate_forms/2011WoodPellet_Form_Final.pdf.

[18] Efficiency Nova Scotia, Wood & Pellet Furnaces or Boilers, cited 10/04/11, http://www.efficiencyns.ca/for_homes/energy_savings_programs/fuel_substitution_pilot_program/wood_pellet_furnace_or_boiler_rebates_and_eligibility/.

[19] Canadian Biomass, NL Extends Pellet Heating Rebate, 04/23/10, cited 10/05/11, http://www.canadianbiomassmagazine.ca/index.php?option=com_content&task=view&Itemid=132&id=1678.

[20] Natural Resources Canada, ecoEnergy Retrofit, 06/06/11, cited 10/12/11, http://oee.nrcan.gc.ca/residential/personal/retrofit-homes/retrofit-qualify-grant.cfm.

9.4.2 Current Standards

Current manufacturers of wood pellet appliances must adhere to the CSA-B415.1-10 or the U.S. EPA 40CFR Part 60 AAA. However, for residential-scale systems (<200,000Btu/hr), the American standard was devised for cordwood, such that wood pellet technologies far surpass the minimum requirements. For example, the EPA standard was adopted in 1988, and while clauses 60.530, h-2 and h-3 specifically exempt boilers and furnaces, it has become the EPA's reference.

Canadian Standards Association

Published in March 2010, the Canadian Standards Association's CSA-B415.1-10 is more directly applicable to pellet appliances, and states are beginning to use it as an equivalent for in-state regulation of wood pellet appliances. The standard lays out the requirements for the performance testing and evaluation of solid-fuel burning heating appliances including maximum emissions rates. The code is applicable to stoves, fireplace inserts, furnaces, and boilers, and provides methods for determining the following:

- Heat outputs
- Appliance efficiencies
- Emission levels and composition
- Flue gas flow rates

For wood pellet appliances, the regulation uses test fuel with moisture content less than 8%. In the tests for wood pellet appliances, the fuel must be analyzed for the higher heating value, ash composition, moisture content, and carbon, hydrogen, and oxygen analysis. The standard also requires that each central heating appliance be labeled with the following information:

- Average particulate emissions in g/MJ
- Average efficiency of the appliance based on amount of delivered heat (AFUE)
- Minimum delivered heat output rate from a test used in determining the average emission rate
- Average efficiency, as a percentage, based on the overall heat output rate (equation to be used is presented in the standard)
- Minimum overall heat output
- Maximum overall heat output
- Average electrical power consumption in kW[21]

[21] Canadian Standards Association, *Performance Testing of Solid Fuel-Burning Heating Appliances.* s.l. : CSA, 2010, B415.1-10.

Environmental Protection Agency

As of September 2011, the EPA has released an updated list of pellet appliances that have achieved its voluntary Phase 2 certification. These appliances have been independently tested and shown to have emissions below 4.1g/hr[22] or 0.32lb/MMBtu.

The Vermont Department of Environmental Conservation is in the process of finalizing a state certification, with the Maine Department of Environmental Protection following suit (Gibson 2011). Pressure is being applied by Northeast States for Coordinated Air Use Management (NESCAUM) for federal level regulations for wood pellet appliances.[23]

9.5 Wood Pellet Fuel Characteristics

Wood pellet fuel can vary in energy content. Currently there are four standard pellet categories to which the EPA and the Pellet Fuels Institute (PFI) have agreed, including moisture contents ranging between 6%-10% [24] (see Figure 9-5).

Figure 9-5. Wood Pellet Categories as Defined by the Pellet Fuels Institute[25]

Property	Super Premium	Premium	Standard	Utility
Bulk density (lb/ft^3)	40-46	40-46	38-46	38-46
Diameter (inches)	0.250-0.285	0.250-0.285	0.250-0.285	0.250-0.285
Inorganic ash (%)	≤0.50	≤1.00	≤1.00	≤1.00
Moisture (%)	**≤6.00**	**≤8.00**	**≤8.00**	**≤10.00**

22 USEPA, List of Certified EPA Woodstoves, 09/22/11, cited 10/12/11. http://www.epa.gov/oecaerth/resources/publications/monitoring/caa/woodstoves/certifiedwood.pdf.

23 WESTAR, EPA, Residential Wood Heaters, New Source Performance Standards (NSPS). 03/01/11, cited 10/24/11, http://www.epa.gov/burnwise/workshop2011/NSPS-DraftRevisions-Wood.pdf.

24 The Pellet Fuels Institute (PFI) and EPA have agreed on the four grades of wood pellets. The PFI currently comprises of *"120 members, including fuel manufacturers and equipment suppliers, as well as organizations representing non-profit, university and government sectors."* (P. F. Institute, Who is PFI 2011)

25 Pellet Fuels Institute, Wood Pellet Fuel Standards, cited 10/05/11, http://www.pelletinfo.com/wood-pellets/wood-pellet-fuel-standards.

An approximation of the energy content of wood pellets is 16,500,000 Btu/ton at 8% moisture content[26]. Energy content varies with moisture based on the following equation:

$$Btu/ton = 947{,}813 \times (19.2 - (0.2164 \times Moisture\ content))^{27}.$$

Table 9-4 provides energy content for various moisture contents.

Table 9-4. Energy Content of Wood Pellets According to Moisture Content

Moisture Content %	Energy Density Btu/Ton	
4	17,377,590	Wood Pellets
5	17,172,483	
6	16,967,376	
7	16,762,269	
8	16,557,163	
9	16,352,056	
10	16,146,949	
15	15,121,415	Dry Wood
20	14,095,881	

9.6 Existing Data Review

This report could not find any evidence of savings algorithms for wood pellet appliances in the range of TRMs consulted. This section will instead review the algorithms used to calculate savings from high efficiency fossil-fired heaters and boilers. These are examined because the algorithms developed for wood pellet appliances will be similar to those of fossil fuels. While we are addressing a fuel switch, the end use remains the same.

An overview of relevant non-pellet TRM algorithms has been conducted by KEMA[28] with the prevailing savings algorithm for space heating presented.

$$ThermsSaved = (Size\ in\ Btu/hr) \times \left(\frac{1}{AFUE_{baseline}} - \frac{1}{AFUE_{installed}}\right) \times (Full\ load\ heating\ hours)/100000$$

It also suggests an alternative algorithm that is increasingly being used:

$$ThermsSaved = (Size\ in\ Btu/hr\ INPUT) \times \left(EFLH_{eff}\right) \times \left(\frac{AFUE_{eff}}{AFUE_{base}} - 1\right)/100000$$

[26] Sustainable Authority of Ireland, SEAI - Wood Pellets, cited 10/06/11, http://www.seai.ie/Renewables/Bioenergy/Wood_Energy/Fuels/Wood_Pellets/.

[27] Wood Energy, Ireland's Natural and Renewable Energy Source, 2006 cited 10 14, 2011, http://www.woodenergy.ie/frequentlyaskedquestions/.

[28] KEMA, *Common EM&V Methods and Savings Assumptions Project*, 2010.

where,

$AFUE$ = The average seasonal thermal efficiency of a furnace or boiler, taking into account the unit's response to changes in load due to weather and occupant controls. Simply put, it is useful heat out/total energy in.

$EFLH$ = Equivalent full-load hours is "an estimate of the full load hours of operation of the heating equipment for a particular climate that, when multiplied by the rated energy input, gives the total heating energy consumption."[29] This is a rough estimate of energy use and is based on average conditions and therefore varies widely by region. It can also be defined as the use in hours per year, if all the consumption occurred at maximum load.

Figure 9-6 shows Appendix A from the KEMA report, which provides the varying assumptions made by states when presenting their algorithms.

Figure 9-6. KEMA Residential Gas Heating Equipment Savings Assumptions

State	Utility	Application	Type	Savings Estimation Method	Baseline Efficiency	Minimum Installed Efficiency	Eligible Capacity Range	Operating Hours	Summer Coinc.	Winter Coinc.
CT	CL&P and UI	Low Income Early Replacement	Boilers & Furnaces	Stipulated	Existing equipment	Sufficiently > baseline to pass benefit cost test	Not specified	1500	N/A	N/A
CT	CL&P and UI	New Construction	Boilers & Furnaces	REMrate software	Average "baseline" home in CT	Energy Star	Not specified	Not specified	N/A	N/A
MA	NGRID	Time of Replacement	Boilers (FHW)	Stipulated	80% AFUE	>85% non-condensing >90% condensing	Not specified	Not specified	N/A	N/A
MA	NGRID	Time of Replacement	Boilers (Steam)	Stipulated	75% AFUE	>82% with electronic ignition	Not specified	Not specified	N/A	N/A
MA	NGRID	Time of Replacement	Furnaces	Stipulated	78% AFUE	>92% AFUE	Not specified	Not specified	N/A	N/A
NJ	All	Time of Replacement	Boilers	Calculated	83% AFUE	Not specified	Not specified	965	N/A	N/A
NJ	All	Time of Replacement	Furnaces	Calculated	80% AFUE	Not specified	Not specified	965	N/A	N/A
NY	All	Single Family	Furnaces	Calculated	78% AFUE	>90% AFUE condensing	Not specified	1076-1982	N/A	N/A
NY	All	Single Family	Boilers (Hot Water)	Calculated	80% AFUE	>85% non-condensing >90% condensing	<300,000 Btu/hr	1076-1982	N/A	N/A
NY	All	Single Family	Boilers (Steam)	Calculated	75% AFUE	>82% with electronic ignition	<300,000 Btu/hr	1076-1982	N/A	N/A
VT	All	Low Income Multi-family	Boilers	Calculated	Mid-efficiency boiler (not specified)	High-efficiency boiler w/smart controls (not specified)	Not specified	N/A	N/A	N/A
VT	All	Existing Homes	Boilers	Stipulated lookups	Oil boiler ≤65% LP boiler ≤70%	85% AFUE (all fuels)	Not specified	Not specified	0%	45%
VT	All	Existing Homes	Furnaces	Stipulated lookups	Nat gas ≤75% Oil furnace ≤75%	Nat gas 92% AFUE (ENERGY STAR) + efficient fan motor	≤200,000 Btu/hr	Not specified	0%	45%

[29] Bruce D. Hunn, "Equivalent Full-Load Hours," *Fundamentals of Building Energy Dynamics*. s.l. (MIT Press, 1996).

9.6.1 Heating Review

- The idea of heating load / square foot, as used in the Vermont TRM (again for fossil-fired heating systems)[30], is one that allows for a better comparison between the baseline and new installation and therefore more accurate savings calculations.
- kWh/therm[31] is an important value to incorporate as it accounts for the electrical demand from the ignition, exhaust fan, and automated pellet supply. It can also account for the circulation system if incorporated into the unit (pump for water, fan for forced air).
- The Annual fuel utilization efficiency (AFUE) is useful and is used by many TRMs as the primary efficiency variable (Mid-Atlantic, Massachusetts, New York, KEMA deemed savings). It is a measure of how fuel efficient the appliance is.
- Algorithms studied have separate baselines: one for replacing an electric heater and one for replacing a gas heater. This is prudent, as one will result in electric savings, and the other in fossil fuel savings.
- Heating degree days is important for the algorithms as it accounts for the external temperatures and therefore provides an accurate value for yearly operational hours.

9.6.2 Domestic Hot Water Review

- The New York TRM[32] goes into in depth analysis of heat loss during stand-by, heat loss coefficients, and recovery efficiency; however, this is dealing with the storage tank. In this case the tank is assumed to be a separate system and the energy required to maintain the water at the required temperature is supplied by the burner *in* the tank.

9.6.3 Integrated Review

- None of the integrated systems found in the TRMs had algorithms to predict the savings. Measurements were taken before and after installation, and the savings were calculated from these values.

9.7 DATA GAPS

In order for the algorithms to be accurate, there are a handful of data gaps that must be addressed. These are:

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[30] Efficiency Vermont, *Technical Reference User Manual (TRM) Measure Savings Algorithms and Cost Assumption,* 2011.

[31] KEMA, *Deemed Savings Manual,* 2010.

[32] New York Evaluation Advisory Contractor Team, *New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs* . s.l. : TecMarket Works, 2010.

- Frequency of the ignition - How often and for how long the ignition is used in a heating season.
- The efficiency vs. load curve for the unit is necessary to validate the assumption that the efficiency is constant for the range of outputs of the appliance. The acquisition of this data could be made necessary for a unit to be included on the program-approved list of wood pellet appliances.
- Data is needed on how much the units are oversized. This will have an influence on the savings calculated through the program.
- The amount of time that the ignition, distribution fan, feeder and exhaust fan operate, as well as their electrical consumption should be taken from either the manufacturer or an on-site test.
- Research into the kW/therm produced by different wood pellet units is recommended. If this value is constant, then the electrical consumption of any unit is predictable, regardless of climate or region.

9.8 Manufacturers' Performance Data

This section presents some examples of pellet burners readily available in the Northeast U.S. The information provided below is directly from the manufacturers.

9.8.1 Boilers

In Table 9-5, the electrical consumption covers the feeder motor, ignition, and combustion motor.

Table 9-5. Available Boiler Model Specifications

Make	Output (Btu/hr)	Efficiency %	Electrical Consumption (W)
Maine Energy Systems	11,500 – 191,000	87.7	5
TARM Biomass (Multi-heat)	51,000 – 146,000	91	460
TARM Biomass (Froling)	35,800 – 197,900	85	96 - 120
Biomass Commodities Corporation	68,260 – 204,780	80	300
Harman	0 – 113,900	85	635 ignition mode 200 normal operation
Hargassner	85,000 – 200,000	93.8	0.2% of output
Pinnacle (PB150)	85,000 or 130,000	80	300
Wood Master (flex-fuel)	200,000	90	116

The reader will note that the electrical consumption given by Maine Energy Systems is much lower than the others; it should be treated as an unrepresentative outlier.

9.8.2 Furnaces

The electrical consumption in the Table 9-6 covers the burner, feeder, ignition, and blower. Electrical consumption is much higher for furnaces than boilers because the distribution blower is included in the unit.

Table 9-6. Available Furnace Model Specifications

Make	Output (Btu/hr)	Efficiency%	Electrical Consumption (W)
Wood Master (Force 20)	68,242	93	828 - Blower 400 - Igniter 100 - Burner
Harman	112,000	89	900
Enviro	70,000	86	432

9.8.3 Integrated

The electrical consumption given in Table 9-7 below covers the feeder motor, combustion motor and ignition.

Table 9-7. Available Integrated Appliance Model Specifications

Make	Output (Btu/hr)	Efficiency%	Electrical Consumption (W)
Extraflam Ecological Idro	49,476 furnace 29,000 boiler	86	80-100 + 280 for ignition
Extraflam Lucrezia	75,000 furnace 59,700 boiler	95	150-180 + 280
Pinnacle (PB150)	85,000 – 130,000	80	300
Pinnacle (PB130)	85,000 – 130,000	80	n/a

9.9 Savings Assumptions, Algorithms, and Deemed Values

9.9.1 Viability of Adopting Deemed Savings Values

The adoption of deemed savings for this technology would not be viable, as heating loads can vary widely depending on home size, insulation levels, air tightness, climate and other factors.

9.9.2 Assumptions

The following assumptions apply to the algorithms and are separated into applicable categories.

Overall Assumptions

- The distribution system is assumed the same for the baseline and the new unit, and any improvements made to the distribution system are part of a separate measure. It is assumed that any losses are taken into account when the sizing of the new unit is conducted.
- The wood pellet appliance electrical consumption for all units covers the exhaust fan, ignition, feeder motor and the combustion motor.
- The thermal efficiency of the heat exchanger in the appliance is included in the AFUE.
- If a range of Btu/hr outputs is given, the appropriate value for the installation will be used.
- It is assumed that the wood pellet equipment operates at the stated efficiency at all loads within the operating range. This is a data gap that has been flagged and must be addressed.

Boilers

- The circulating pump is held external to the unit and its electric consumption is not considered here. This is because it is assumed that there is no pump replacement and the power needs for the pump are the same for the baseline and replacement units.

Furnaces

- The furnace has an additional electrical consumption of the ECM fan used for distribution and is contained within the unit. The baseline comparison for ECM and older PSC fans will be accounted for.

Integrated System

- The system is running with an internal ECM fan for forced air and an external circulation pump for hydronic systems. Only the electricity for the forced air system will be accounted for as the fan is held within the unit.
- The entire system is assumed to be boiler fed if using hot water central heating as this can supply the domestic hot water load as well. It is also assumed that the domestic hot water is held within an external storage tank. If the system is a furnace with a back boiler for domestic hot water, the algorithm will account for this; however the savings will not differ much as the load output will be the same in both cases.
- The average cold inlet and hot outlet temperatures will be used to estimate the energy needed and therefore the savings applicable. The hot outlet can be estimated to be 140°F as in the OPA TRM.[33]

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[33] Ontario Power Authority, *2011 Prescrptive Measures and Assumptions,* 2011.

9.9.3 Measure Life

The measure life for savings from wood pellet central heat appliances is assumed to be 20 years for new construction and natural replacement-focused programs. However if the replacement is an early retirement, then there are two stages to the measure life. The first is from installation up to the point where the old appliance would have naturally been replaced; here the savings could be high because the old appliance may have had a low efficiency. The second is similar to that of new construction, where the baseline is the new code standard appliance available; however in this case the measure life is the new appliance life minus the duration of the first stage. For example, if an old inefficient gas boiler is replaced 5 years before it naturally needs to be replaced, then the first stage is 5 years and the second is 15 years (assuming an overall 20 year lifetime of the new installation).

9.9.4 Algorithms

Introductory Notes

Before looking at savings algorithms, it is important to note that the implementation of wood pellet equipment constitutes a fuel switch. It is possible that installing a wood pellet appliance will cause a drop in efficiency; however we assume that the primary purpose of this measure is not to increase theoretical end-use efficiency, but rather to reduce consumption of electricity and non-renewable fuels. This is the same logic that would apply to promotion of other renewable resources such as solar PV, wherein efficiencies can be far lower than those for fossil fuel equipment, but the focus is on reduction of the fossil fuel consumption.

Table 9-8 shows the calorific values of the different fuels as well as cost per million Btu as a comparison method.

Table 9-8. Comparison of fuel types[34]

Fuel Type	Unit	Btu/unit	Cost per 1 MMBtu ($)
Electricity	kWh	3,413	53.03
Natural gas	Cubic ft	100,010	14.60
Fuel oil	Gallon	14.8	27.12
Wood pellets	Pound	8,000	14.57

Early replacements are only a realistic option for old fossil fuel appliances with low efficiency. In order for this report to withstand the test of time, we address this option in a distinct subsection in order to account for a changing baseline as technology evolves.

[34] Pinnacle Renewable Energy Group, *Why Wood Pellets?,* 2010-2011, cited 10/13/11, http://www.pinnaclepellet.com/environmental-commitment.php.

In the algorithms, consistency of values is key. If the lower heating value (LHV) of the fuel is chosen, then the AFUE as calculated using the LHV must also be used. If the higher heating value (HHV) of the fuel is chosen then the AFUE as calculated using the HHV must be used.

Fossil Fuel Btu Savings

Use of wood pellet technology, as mentioned previously, is a fuel switch and not an energy efficiency measure. The baselines for calculations are as follows:

- Space heating: Fossil fuel furnace (for forced air heating) or boiler (for hot water heating)
- Integrated systems: Fossil fuel boiler that satisfies the space heating and hot water loads

For this technology, the fossil fuel savings are assumed to be 100% of the full load and can be calculated using the following algorithm. Note that the second part of this algorithm is for DHW savings and is to be used only in the case of an integrated system.

$$BtuSavings = \left(\frac{HDD \times 24 \times BtuReq\ /\ hr}{DTD \times \eta_{FF\_SPACE}}\right) + \left(\frac{\Delta T \times GPD \times 8.35 \times 365}{\eta_{FF\_HW}}\right)$$

Units are defined below.

If a program assumes that users keep fossil fuel equipment as a secondary source to use for a share of heating needs, then the following savings algorithm applies. As the baseline changes with evolving, more efficient fossil-fuel technology, the algorithm will still be valid.

$$BtuSavings = Btutotal - \left(\frac{BtuReq/hr \times 24 \times HDD \times \%use_{space}}{DTD \times \eta_{FF\_SPACE}}\right) - \left(\frac{\Delta T \times GPD \times \%use_{hot\ water} \times 8.35 \times 365}{\eta_{FF\_HW}}\right)$$

where,

$Btutotal$ = The total amount of Btu consumed by the baseline unit.

$BtuReq/hr$ = The energy output of the new pellet appliance. When addressing this output, it might be prudent to use a reduction factor to compensate for potential over-sizing of the unit. In this situation the BtuReq/hr would be the output capacity of the unit divided by, for example, 1.2 (for a 20% oversizing). Real values would need to be taken from a study as touched on in the section on data gaps.

DTD = The design temperature difference, normally around 80°F for the region under study. It is defined as the difference between the desired internal temperature and the coldest outdoor temperature of the region.

HDD = The heating degree days in the region. It is calculated by taking the difference in outdoor temperature and an internal reference temperature (normally 60 or 65°F), which is then multiplied by the amount of days this outdoor temperature is realised. For example if the reference temperature is 60°F and the external average is 35°F,

and this outdoor temperature lasts for 2 weeks, then the HDD for these 2 weeks are calculated as follows:
$HDD = (60 - 35) \times 14 = 350$. Raw data for this can be found at www.degreedays.net however this will need to be normalized over many years. It would be much better to find normalized weather data for the previous 15-30 years. This allows for comparison between different periods and, more importantly, different places. New York State has 30-year normals for seasonal HDD on the NYSERDA website.[35] Thirty-year normals have recently been released by the National Climatic Data Centre, and the information is contained at their website given here: http://www.ncdc.noaa.gov/oa/climate/normals/usnormals.html. We have also compiled an Excel file with the HDD for the area covered by NEEP members from this website (HDD fromNOAAforNEEP.xlsx).

$\%use_{space}$ = The % of space heating that the baseline boiler is providing

$\%use_{hot\ water}$ = The % of hot water that the baseline boiler is providing.

GPD = Gallons per day of domestic hot water used (DHW).

ΔT = The temperature of hot water required (we recommend using 140°F) minus the temperature of mains supply water entering the boiler system (normally around 50°F, use region-specific value when available). Therefore ΔT is 90° F.

8.35 = A conversion factor from gallons to Btu/°F

η_{FF_SPACE} = the annual fuel utilization efficiency (AFUE) of the fossil fuel appliance being used for space heating. The minimum AFUE given by the BPI Standard for Retrofit Modelling is 72% (0.72) for forced-air furnace and 60% (0.6) for hot water boiler[36]. These values are for early retirement situations. Also note that these are *minimal* recommended values and are therefore not representative of average efficiencies of existing units.

η_{FF_HW} = the AFUE of the fossil fuel appliance being used to provide domestic hot water. The minimum energy factor for a gas water heater is 0.45, for an oil-fired heater is 0.4, and for an electric heater is 0.8[37]. These values are for an early retirement. Also note that these are *minimal* recommended values and are therefore not representative of average efficiencies of existing units.

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[35] NYSERDA, Heating Degree Day Information, 10/04/11, cited 11/01/11, http://www.nyserda.org/energy_information/nyepk.asp.

[36] Building Performance Institute, *Standardized Qualification of Whole House Energy Savings Estimate.* s.l. : BPI Standards, 2011.

[37] Ibid.

Table 9-9 details the recommended baseline conditions for new construction and natural replacement situations for space heating and DHW supply.

Table 9-9. Baseline Efficiencies to be Used for New Construction, Natural Replacement, and Phase 2 of Early Retirement

Measure	Gas or Oil fired Warm air furnace	Gas fired boiler, Hot water system	Gas fired boiler, steam system	Oil fired boiler	Electric Furnace	Electric Baseboard
New Construction or Natural Replacement Space Heating Baseline	85%	80%	75%	80%	94%	100%
New Construction or Natural Replacement DHW Baseline	Electric Resistance	Gas - Storage	Oil Fire Boiler			
	100%	80%	78%			

Wood Pellet Consumption

The information from the section "Wood Pellet Fuel Characteristics can now be used to put forward an algorithm determining the consumption of wood pellets per year.

Space Heating

$$Consumption(ton) = \frac{24 \times HDD \times (BtuReq/hr)}{\eta_{wp} \times EC_{pellet} \times DTD}$$

$BtuReq/hr$ = The Energy output required per hour of heating.

DTD = The Design Temperature Difference and is normally around 80°F for the region under study.

EC_{pellet} = The energy content of the pellets used in Btu/Ton based on the moisture content. These values are given in Table 9-1.

HDD = The Heating Degree Days in the region given in the excel file or by the NOAA.

η_{wp} = The AFUE of the wood pellet boiler and can be found in Table 9-2.

Integrated Use

For this situation, wood pellets must be provided for both space heating and hot water requirements. Therefore the consumption algorithm is a combination of the preceding two. If it is not possible to acquire two different efficiencies, then a combined value can be used; however this will result in a small loss of precision.

$$Consumption(ton)$$

$$= \frac{1}{EC_{pellet}} \times \left(\frac{(GPD \times \Delta T \times 8.35 \times 365 \times \%use_{hot\ water})}{\eta_{HW}} + \frac{(HDD \times BtuReq/hr \times 24 \times \%use_{space})}{DTD \times \eta_{SPACE}} \right)$$

All of the variables have the same definitions as above; however in this situation the following definitions apply.

$\%use$ = Refers to the percentage of load requirement met by the pellet appliance.

η_{HW} = The efficiency of the integrated appliance for domestic hot water

η_{SPACE} = The efficiency of the integrated appliance for space heating

The efficiencies can also be found from Tables 9-5 and 9-6. The above algorithm incorporates the situation of a combined system, where fossil-fuels are used to supplement the wood pellet appliance use for a portion of the operating time.

9.9.5 Early Replacement

This section gives an algorithm for the savings for an early replacement situation discussed in "Measure Life" above.

In order to calculate the savings over the life of the new installation, the savings for the two stages must be summed. To calculate the savings from the first stage, the proposed *Btusavings* algorithm in Section 9.9.4 is used; however the efficiency refers to the appliance that was retired early. These savings last for the amount of time for which the original appliance could have remained active.

To calculate the savings from the second stage, the proposed Btusavings algorithm is used again; however the efficiencies now refer to the minimum efficiencies required by the regulations (as given in Table 9-6) or actual average efficiencies of new units where markets are ahead of regulation standards. These savings last for the measure life of the pellet appliance minus the lifetime of stage one.

Electrical Savings

The baseline for electrical impacts, both increases or decreases, varies for the different wood pellet uses. In all cases, the wood pellet appliance will consume electricity for the automated pellet supply, ignition, and draft fan. The baselines for these impacts are as follows:

- Space heating: Fossil fuel furnace (for forced air heating) and a fossil fuel boiler (for hot water central heating).
- Integrated systems: Fossil fuel boiler that satisfies the space heating and domestic hot water loads.

The following assumptions need to be made before the electrical impacts can be calculated:

- The exhaust fan runs continuously for the heating season only
- The distribution fan included in the furnace runs continuously for the heating season only
- The pellet feeder motor runs continuously for the heating season only

- It is assumed the ignition runs for 2 minutes once every 50 hours of use during the heating season. Actual frequency of ignition is difficult to assess as it is dependent upon the household use and load required from the appliance. As the system is fully automated, it is difficult to measure this value as well. The assumption of ignition once every 50 hours has been chosen to be a reasonable estimate of the ignition frequency. [38]
- The operating time of the appliance is assumed to be 400 hours, following the OPA figures. This value is weather dependent and should be adjusted if possible using local values.[39]

Using these assumptions the electrical savings algorithm is:

$$k〚Wh〛\_savings = [OpHours \times (kW_{Fan} + kW_{Consump})] - \{[(OpHours/50) \times 2/60 \times Ign] + [OpHours \times (Dist + Burn + Feed + Exh)]\}$$

$OpHours$ = The amount of hours that the appliance is being used for in one year. OPA gives this value as 400 hours.

kW_{Fan} = The electrical consumption of the baseline distribution fan and can be taken from the OPA TRM or from nameplate values. We recommend using the Table 9-10 below to calculate electric savings.

Table 9-10. Fan Consumption, Values Taken from OPA[40]

Situation	Fan Type	kW Fan
New construction or natural replacement	ECM	1.1
Early retirement	PSC	5.0

$kW_{Consump}$ = The electrical fuel consumption of the baseline unit. This is, in the case of an electric baseline unit, $\frac{output}{efficiency}$. In the case of a fossil fuel baseline, the electric consumption is assumed to be 0 for ignition.

Table 9-11 gives values for this variable in the algorithm.

[38] Grant Gagner, 10 25, 2011.

[39] Sustainable Authority of Ireland, SEAI, Wood Pellets, cited 10 06, 2011, http://www.seai.ie/Renewables/Bioenergy/Wood_Energy/Fuels/Wood_Pellets/.

[40] Ibid.

Table 9-11. Electric Furnace Consumption, Values Taken from OPA[41]

Situation	kW Furnace Consumption
New construction or Natural replacement	49
Early retirement	45

Ign = The electrical consumption of the ignition

2/60 = The time, in hours, that the ignition operates for

Dist, Burn, Feed and *Exh* are the electrical consumption of the distribution fan, burner motor, feeder motor and exhaust fan, respectively, for the wood pellet unit. These values, as well as the ignition values can be obtained from the tables presented earlier or from a manufacturer.

1/50 is the assumption that the ignition occurs once every 50 hours of operation

Peak Savings

In this section, peak electric savings are examined.

<u>**Space Heating**</u>

When using a wood pellet appliance in place of an electrical space heater, the electrical consumption of the former is very low, as shown above. If a peak grid load occurs in winter then there will be very high peak savings, and if the peak grid load occurs only in summer then there will be no peak savings.

With the replacement of a fossil fuel space heating system with a wood pellet appliance, there might be an increase or decrease in electrical consumption. A peak use increase/decrease will only occur if the grid peak occurs in winter, but even then the effect is small. If the grid peak occurs only in summer, then there is no peak use increase/decrease; therefore the following algorithm is for use in the winter.

Both baseline situations use the following algorithm to determine the peak savings

$$PeakSavingsSpace\ kW = CF_{space} \times \left\{ \left(kW_{fan} + kW_{Consump} \right) - \left[\frac{1}{50} \times \frac{2}{60} \times Ign \right] - \left(Dist + Burn + Feed + Exh \right) \right\}$$

In order to calculate peak savings, a space heating coincidence factor (CF_{space}) needs to be used. This factor is a percentage value, representative of how often the appliance is used at peak load when the grid is also experiencing peak load. As the coincidence factor varies depending on region, the program administrator should obtain values specific for the region(s) where the program is implemented.

[41] Ibid.

Integrated

For domestic hot water use there will also be peak savings only if the grid experiences a peak load during winter because even if the demand for domestic hot water is continuous throughout the year, the integrated system will not be used for water heating only as this would not be efficient. Thus, outside of the heating season, the storage tank will also heat up inlet cold water. In the case of an integrated system supplying both hot water and space heating, the peak savings are given in the algorithm below.

$$PeakSavingsInt\ kW = PeakSavingsSpacekW + \langle CF_{HW} \times (\ kW_{Consump\_HW}) \rangle$$

$kW_{Consump\_HW}$ = The electrical consumption of the baseline domestic water heating appliance

CF_{HW} = The coincidence factor for hot water

9.10 Appropriate EM&V Approaches to Fill Knowledge Gaps

The evaluation procedures discussed in this section are aimed at understanding specifics about the equipment and typical usage within a site, related to the calculations of energy savings. A discussion of measure knowledge gaps is followed by our research recommendations.

9.10.1 Equipment Specifics

Technical measurements of the equipment are needed to help ensure savings. An understanding of the typical on/off cycle of the furnace/boiler and the electric energy used by the ignition/fan/motor system is necessary. To better determine if there are positive or negative electric energy impacts, in-situ measurements of the end-use-specific electric consumption across multiple homes is needed. Sampling designs for any metering should be based on the knowledge of the wood pellet categories available to customers.

We assume that homes installing this technology through a program and using our described approach must be moving from, or supplementing, either electric or natural gas heating. We understand that there are programs that do include various fuels such as fuel oil, but these programs are funded differently and are not addressed herein. As such, once included in a program, the appropriate approaches to assess savings for wood pellet appliances follows on from those for residential fossil fuel boilers and furnaces provided in the current NEEP EM&V Guidelines[42]. This approach uses billing analysis for fossil fuel savings, supported by on-site inspections for verification and phone surveys, to provide savings when the fuel switch is used in a furnace/boiler early or natural (end-of-life) replacement situation, but will not provide information if the customer was

[42] NEEP, *Regional EM&V Methods and Savings Assumptions Guidelines,* 2010.

going to move to an energy code level piece of equipment and chose instead to install a wood pellet appliance.

Verification of the installation of wood pellet appliances can be accomplished with telephone calls. However, to obtain more detailed information about the specific equipment installed and displaced, verification of installation is best conducted through contractor invoices and/or site visits.

Another knowledge gap that affects energy savings is the possible oversizing of equipment for both the baseline and wood pellet equipment. The fossil fuel savings would be overestimated with an oversized baseline, and the pellet consumption would be overestimated with an oversized pellet appliance. Unfortunately, conservative rules of thumb are often used for the sizing of heating and cooling equipment. Even the marketers of the most modern ductless mini-split heat pump systems often rely on standardized rules of thumb that calculate system sizing on room size only. Whether it is biomass, gas heat, or heat pumps, sizing based on such limited data will produce oversized systems in the majority of cases in order to avoid the occasional undersized system that results in a call-back.

All electric and gas consumption readings should be taken as close to the installation date as possible and then tracked for verification and accuracy. This allows the consumer time to adjust to using a new fuel and acts to smooth out any anomalous results taken initially. These readings should be taken on a representative sample of participants, as would be done with an impact evaluation, as it is unrealistic to take these measurements for everyone who participates in the program.

9.10.2 Summary of Research Needs

Below are the most urgent knowledge gaps that need research.

- ❑ Pilot projects with in-situ measurements of system performance and displacement of electric and gas are needed and should be associated with local climatic conditions.
- ❑ The electric consumption of pellet systems over a typical heating season is not well-known and should be specifically measured in order to obtain net energy effects.
- ❑ Research the wood pellet supply distribution to assess the probability of future substantial supply difficulties that might be faced as residents move to this technology. Naturally, long-term savings of displaced fuels will degrade if supply issues adversely affect the availability and price of pellet fuel.
- ❑ Research electric and gas residential energy usage for space heating and determine the magnitude of biomass pellet potential for a given service territory.
- ❑ Assess the efficiency impact of system sizing.

9.11 Summary of Recommendations

This report has presented algorithms to calculate the fossil-fuel Btu savings, wood pellet consumption, electrical savings, and peak savings. It has presented values that can be used for new construction, natural replacement, and early retirement. There are, however, some data gaps that must be researched for increased accuracy of these algorithms.

With these data gaps filled, the savings for all scenarios can be calculated and a reasonable, thought-out decision can be made about the viability of wood pellets.

Advanced Power Strips

10

10.1 Introduction

During the past two decades, efficiency programs have contributed significantly to efficiency improvements for residential and commercial buildings. At the same time that HVAC and lighting efficiency measures have been reducing energy demands, plug loads have been increasing. Much of the equipment contributing to this increasing load not only uses electrical energy when it is active, but also when it is inactive in a sleep, or stand-by mode. Advanced power strips (APS) are intended to reduce these loads both by turning equipment fully off when not in use and by reducing total full-power usage when users neglect to turn equipment off.

NEEP coordinates an effort to establish the potential market, program viability, and savings potential for APS in the residential sector. The APS Data Working Group (APS Group) has been reviewing studies and developing strategies that the sponsor programs plan to use to establish incentive programs for the residential sector. The intention of this EM&V Forum project is to review their efforts, coordinating with them to identify and close knowledge gaps. It is important to note that the APS Group is a volunteer effort with no contractual arrangement with a service provider.

In addition to reviewing the efforts of the APS Group, we are expanding the assessment of the savings potential of APS to the commercial sector, identifying controllable equipment, implementation opportunities, and the associated savings.

APS, also known as "smart strips," resemble standard power strips but have additional outlets with different functionalities. There are two main types:

1. The first type of power strip has one "control" outlet, a typical configuration of four to six controlled outlets, and two outlets that are always on. The control outlet operates as a master outlet that is connected to an electronic device, such as a television or computer, which is used in conjunction with one or more peripheral devices. When a control (master) device is turned off or enters sleep mode, the smart strip cuts power to the controlled peripherals: items such as printers, speakers, and DVD players. Peripherals that need to be on at all times, such as fax machines, telephones, and DVRs, are plugged into the outlets that are always on, so their power status will be unaffected by the state of the control device.
2. The second type is a power strip with an occupancy sensor that has a typical configuration of six occupancy controlled outlets and two outlets that are always on. The operation differs in that that the occupancy sensor, rather than the status of a master device, controls the power to the controlled outlets. The occupancy sensor is designed to be installed in such a manner as to

only respond to occupancy/vacancy in the immediate area of the device. A user-adjustable time delay prevents short cycling of equipment during brief periods of vacancy. When vacancy is detected after the time delay, the strip disconnects power to the controlled devices. Power is re-established when the occupant returns.

Neither type of APS is intended to have any impact on the usability of electronic devices; they achieve savings only by reducing the hours when loads are inactive, but fully powered or in a standby mode.

A number of savings opportunities have been identified for APS. Vampire loads (i.e., the power consumed by electronic devices while in standby or off mode) account for a significant portion of energy consumption. These plug loads can be eliminated by physically unplugging electronic devices or by manually turning off power strips. APS eliminates the need for manual intervention by interrupting power to devices automatically. When the smart strip detects a drop in electric current to the controlling device or when the occupancy sensor detects no motion in its vicinity, it shuts off the power supplied to the controlled peripherals. Power is automatically restored to the controlled outlets when the controlling device is turned on again or when the sensor senses motion.

Table 10-1 provides a list of several APS manufacturers and products that are currently available on the market. A growing number of manufacturers are making improving these products. Please note that this list is not exhaustive; it does not make up the entire industry or cover every APS product line.

Table 10-1. APS Manufacturers

Product Type	Manufacturer
Control Outlet Strips	Belkin
	APC
	Bits Ltd
	NTE/ECG
	Coleman Cable/Woods
Occupancy Control Strips	WattStopper
	VendingMiser (designed for vending machines and commercial equipment)

A review of on-line suppliers reveals that the products range roughly from \$30 - \$60 with the exception of the specialty application VendingMiser, products which are priced around \$150.

Power mode and APS terms used throughout this report section include:

Standby – A devise is inactive but is drawing reduced power in a "ready" mode for the next usage. For the purposes of our analysis we are incorporating the term "sleep" mode with this definition.

Soft off/off – A device is connected to a main power source but is turned off and drawing minimal power. This is typified by an electronic device that is associated with a remote control, incorporates a clock, or maintains memory.

Active – A device is connected to a main power source and is in full use and drawing the full rated power.

Control outlet – A master outlet that controls additional outlets. When a device is connected to the control outlet and the device is turned off or enters sleep mode, the advanced power strip cuts power to the controlled outlets.

Controlled outlets – Outlets that operate in response to the control outlet.

Uncontrolled outlets – APS outlets used for devices that are always powered. The power status of these outlets will not be affected by the state of the control outlet or sensor.

10.2 APS Data Committee Progress and Results

The APS Group compiled approximately twenty studies and/or reports related to APS, which they narrowed down to four that provided the most valuable data. The results from the twenty studies varied greatly with annual savings ranging from less than 30 kWh up to 500 kWh. The studies are focused on residential applications.

As recognized by the APS Group, the four studies selected for supporting data vary in their relative merit for this project. The first three studies were conducted in Denmark (2007), Minnesota (2010), and California (2006), and may not all relate well to consumer practices in the Northeast and/or Mid-Atlantic regions. However, the fourth study (2009-2010 Experian Simmons study) relied on a survey of 26,000 homes across the United States from 2009 to 2010. To date we have not been granted access to the study, but according to the APS Group, it accurately reflects the current technology found in households today on a state-by-state level.

Each study reviewed had a slightly different focus, whether it was measuring the energy savings potential under a specific power mode or identifying which plug-in devices were used most often under various power modes. The APS Group and/or these studies have not clearly defined the different power mode terms (standby, sleep, idle, hibernate, etc.), making it somewhat difficult to aggregate study data.

Across the studies, there was significant uniformity in the types of plug-in devices, with home-office computer systems and peripherals as well as home entertainment equipment covered by all the studies. Additional devices such as HVAC equipment and kitchen appliances were also occasionally included. Where metering was performed, power consumption was measured for 1 to 4 weeks. The 2010 Minnesota study in particular conducted metering and surveys during each of the four seasons to capture the differences in plug load type and use. This same study recognized computer power management savings opportunities. The study found that roughly 80% of the time the desktop power management systems were not enabled.[1]

The studies used similar methodologies for calculating the energy savings, utilizing average wattage by device type for each power usage mode, and assigning uncontrolled and APS-controlled

[1] Based on on-site data-physically checking more than half of the sites that were metered.

operating hours. As previously mentioned, the studies do not assign standardized terms, which complicates the process of assessing the findings.

Considering the volunteer nature of the effort, the APS Group has been reasonably responsive to questions regarding their research, and we find the supporting material to be helpful as we draw conclusions in identifying gaps and making recommendations. Yet, without receiving the detailed calculations it is hard to assess exactly how energy savings predictions were derived. To the extent of our understanding of their methodology, we have not identified any reasons to argue with the savings conclusions. Nevertheless, in order to review the APS Group's results, we would need full access to the additional information requested.

ERS has received raw data and the selected studies (with the exception of 2009-2010 Experian Simmons study) from the APS Group that include the following supporting data:

- Power consumption by device type during active, off, and standby usage periods
- Average hours of usage by mode and device type
- Types of products appropriate for APS control and the average number per household

To date, ERS has not received the calculation methodologies adopted by the APS Group or the 2009-2010 Experian Simmons study, which reportedly forms the basis for most of the group's conclusions. Therefore the ERS Team had to make several assumptions based on the data given, including:

- The communicated Experian study data accurately reflects the types of devices found in households.
- The hourly usage data used in the study is consistent with similar data available from ENERGY STAR and/or other studies.
- The demand and consumption associated with the various modes of equipment operation.

It is reasonable to assume that the APS Group properly applied the Experian study data in reaching their conclusions, but without the ability to review the details of the study and the calculations, the ERS Team cannot fully evaluate or verify the results.

The APS Group only focused on advanced power strips that have one controlled outlet and multiple uncontrolled plug outlets. To our understanding, the APS Group decided to select the plug-in devices shown in Table 10-2 based on the national average of products per household[2] and their power usage (Simmons study[3]). These devices are separated into two categories within residential homes: IT Area and TV Area/Home Entertainment.

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[2] The APS Group included any plug-in devices that appeared in at least 50% of the surveyed households.

[3] This study defines what the usage patterns are in the average home by state.

Table 10-2. Plug-in Devices Based on National Average per Household

IT Area	Computer (control)
	Monitor (controlled)
	Printer (controlled)
TV Area/Home Entertainment	TV (control)
	DVD/VCR (controlled)
	Video game console-Play Station (controlled)

The APS Group compiled data from the Denmark (2007), Minnesota (2010), and California (2006) studies that contained the hours (through survey or metered data) of each device type by power mode and then extrapolated the results in order to generate the annual operating hours. They compiled a list of average power consumption (wattage) by active-, standby-, and off-power modes for the studied devices. They assumed computers and/or televisions to be plugged into the control outlet of an APS and, excluding the use of both the computer and TV, they took the sum of the average standby kWh savings to compile the overall savings for the TV Area and IT Area. Our assumed breakdown of the calculation is presented below.

Energy Savings

$$If\ (Hours_{Controlled-Off}) + (Hours_{Controlled-Standby}) < (Hours_{Control-Off})$$

$$then, \Delta kWh = (kW_{Controlled-Standby}) \times (Hours_{Controlled-Standby}) + (kW_{Controlled-Off}) \times (Hours_{Controlled-Off})$$

$$If\ (Hours_{Controlled-Off}) + (Hours_{Controlled-Standby}) \geq (Hours_{Control-Off})$$

$$then, \Delta kWh = (kW_{Controlled-Standby} + kW_{Controlled-Off}) \times (Hours_{Control-Off})$$

where,

ΔkWh = Yearly kWh savings associated with the use of an APS

$kW_{Controlled-Off}$ = kW of the controlled unit(s) when turned off

$kW_{Controlled-Standby}$ = kW of the controlled unit(s) when in standby mode

$Hours_{Control-Off}$ = Hours per year the controlled unit(s) is turned off

$Hours_{Controlled-Standby}$ = Hours per year the controlled unit(s) is in standby mode

$Hours_{Control-Off})$ = Hours per year the control unit is turned off

To date, the working group has provided kWh savings estimates for the IT Area and the TV Area/Home Entertainment categories. The predicted average annual savings are:

- **Home IT Area:** 33.6 kWh per year
- **Home Entertainment Area:** 86 kWh per year

10.2.1 Gap Analysis

An important aspect of the APS portion of this project is to identify knowledge and study gaps. Our intention is to identify significant gaps that would prevent program administrators from supporting the technology through their efficiency programs and/or identifying gaps that represent unrealized savings opportunities.

In summary the gaps we have identified include:

- The APS Group focused on residential applications. Commercial measures including staff workstations and business machines offer potential opportunities.
- Within the residential arena, the focus was narrowed to limited control of two equipment categories. Expanding the potential of APS to a larger mix of equipment may prove beneficial.
- Obtaining full data from the APS Group may reveal additional gaps and opportunities in the residential market.
- ENERGY STAR data on plug loads, power management, and device lifecycles has yet to be incorporated in the APS Group efforts.
- The APS Group apparently limited their focus to the control of one component from a control outlet. Controlling a wider array of equipment from the control outlet may be practical and should generate additional savings.
- Savings persistence needs to be addressed in order for program administrators to properly assess cost-effectiveness. Currently annual savings are presumed to remain constant after initial deployment. The following are persistence factors that could be explored:
  - Manufacturers of TVs, set-top boxes, gaming devices, computers, etc. are beginning to incorporate smart technology within the devices themselves. As a result, when new replacement equipment is purchased, some savings will double counted.
  - As discussed for commercial applications, computer operating systems incorporate power management for the CPU, hard drive, and monitor. The settings are user adjustable, including an ability to disable the power management features. A discounting of the savings associated with computers should be considered.
  - Although APS should have a long technical lifetime, the controlled equipment will experience turnover. When turnover of devices such as televisions occurs, can it be assumed that the APS will be retained? It may be possible to apply reasonable discount factors to apply to savings due to turnover.
  - As we all learned with CFLs and lighting occupancy sensors, consumer satisfaction plays a major role in persistence factors. Consumer satisfaction with APS will depend on the

reliability of the products and convenience factors. For example, an issue with gaming consoles is that many will not retain memory of a player's position in a game if power to the unit is interrupted. For serious gamers, losing the position mid-game would be a deal breaker for controlling the console with APS.

10.3 Commercial APS Applications

Without a doubt there is the potential to harvest savings utilizing APS technology in the office environment. It is important to note the distinctive characteristics of the commercial sector as compared to the residential sector:

- Several of the same plug-load devices, such as computers/laptops, monitors, and printers can be found in both residential and commercial spaces. However, office environments typically have a more diverse mix of equipment, including some larger sized machines.
- Company-wide IT procedures may have an effect on overall savings potential and may make savings more predictable.
- The potential for hardwiring APS into workstations should result in higher persistence levels.
- It is more difficult to predict when these plug-in devices are used in residential settings than in an office environment, which is has more predictable hours of operation.

In 2009, ERS conducted a limited study (2009 Massachusetts Building Study) on the potential savings associated with controlling commercial office workstation equipment, as part of ongoing support of Massachusetts program efforts. Table 10-3 illustrates an example of the typical rated wattages of common devices found in the assessed commercial workstations. The study primarily focused on commercial work stations because they were viewed as better candidates for APS technology than the common areas where various business machines are located. Although we recognize a savings opportunity for other business machines, plug-load occupancy sensors will turn off all peripherals regardless of whether or not the occupant shuts down their CPU. In most offices large business machines serving multiple staff members tend to be used frequently throughout the day and lengthy boot-up periods make them poor candidates for APS.

Table 10-3. Typical Rated Wattages of Common Devices

Workstation	Device	Quantity	Rated Power (W)
1	Monitor	2	324
	Computer	1	235
	Laptop	1	130
	Speaker set	1	25
2	Printer	1	396
	Laptop	1	130
	Monitor	1	162

	Task light	1	22
3	Printer	1	756
	Laptop	1	130
	Monitor	1	162

In addition to this ERS study, we conducted research to search for existing studies, reports, and evaluations relating to the use of advanced power strips in commercial workstations. Other than a 2008 BC Hydro study, we found little additional data related to the potential savings associated with APS in the commercial sector. These two studies involved on-site metering for a small selective sample of commercial workstations.

The ERS study and the BC Hydro study both involved monitoring the power usage before and after installing the APS. Metering was conducted for a duration of 2-4 weeks. The studies produced similar results:

- On average, the commercial workstation savings claimed by both studies was roughly 100 kWh annually. However, the savings vary widely from workstation to workstation. The work patterns at a particular workstation had a greater impact on the savings than the amount of plug loads present in the workstation. This is significant, as an intuitive assumption might be that the cubicle with more plug-in loads has a greater potential for savings. Although certainly a factor, the number of plug-load devices at a workstation cannot be considered a definitive savings metric.
- Both studies roughly estimated the average measure life for APS to be around 4-5 years.
- Both studies assumed 3 watts per power strip in demand savings. They used the average of the standby/sleep/idling mode wattage for the controlled equipment.
- The 2009 MA office building study determined that approximately 21% of the APS workstation savings occurred during peak demand periods. Savings of 1.5 hours were associated with the normal 8 a.m. to 5 p.m. business operating hours, with the remaining savings associated with turning equipment off at the end of the workday.

10.3.1 Energy Savings Assumptions

Based on our analysis, the BC Hydro Study included two outliers that dramatically affected the overall sample. Therefore we disregarded the data from the two workstations that showed the lowest and highest plug loads in order to identify a representative average.

The results are presented in Table 10-4[4], calculating an average annual savings of 75 kWh. Since the 2009 MA office building study used a smaller sample we decided to utilize those results as a sanity check on the BC Hydro results rather than blend the data. This study calculated the average savings using an arithmetic average for the monitored workstations due to the high differences between them. The study's results are shown in Table 10-5[5]. Due to the variable nature of workstation equipment and activity, a range of savings between 75-100 kWh is more defensible than providing a definitive savings metric.

Table 10-4. Results of the BC Hydro Study

Workstation	Plug Load (W)	Stand-by Load (W)	Baseline		Post-Installation		Energy Savings (kWh/year)
			kWh	Energy Use (kWh/year)	kWh	Energy Use (kWh/year)	
1	107	4	11	141	9	65	76.5
2	123	4	30	401	38	273	127.8
3	64	4	11	146	3	90	55.8
4	194	1	22	286	20	143	143.1
5	57	1	10	128	15	106	21.6
6	143	2	26	343	43	322	20.9
7	116	3	29	229	5	150	79.0
Average	**115**	**3**	**19.9**	**238.9**	**19.19**	**164.0**	**74.9**

Table 10-5. Results of the 2009 MA Office Building Study

Workstation	Plug Load (W)	Sleeping/ Idling Load (W)	Baseline		Post-Installation		Energy Savings (kWh/year)
			kWh	Energy Use (kWh/year)	kWh	Energy Use (kWh/year)	
1062	368	8	19.9	1,035	15.7	818	216.8
2133	206	48	2.7	142	2.4	125	17.2
2032	187	16	5.8	302	4.4	229	72.8
Average	**254**	**24**	**9.5**	**493.3**	**7.5**	**391.0**	**102.3**

The *Massachusetts Technical Reference Manual* (TRM) states that smart strips used in the workplace save an average of 75 kWh annually.[6] In contrast, the *Ohio Technical Reference Manual* states an average annual savings of only 23.6 kWh.[7] Based on the logged data from the Massachusetts and BC Hydro studies, the Ohio deemed savings number appears to be unrealistically low.

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[4] Power Smart Engineering, Smart Strip Electrical Savings and Usability, BC Hydro Study, 2008.

[5] ERS, MA Office Building Study, 2009.

[6] *MA Technical Reference Manual*, p. 47.

[7] *Ohio Technical Reference Manual*, p. 280.

10.4 Recommended Deemed Savings, Methodologies, and Algorithms

The following recommendations represent approaches to identifying savings for APS installations at workstations in commercial environments:

- **Deemed Savings** – It is recommended that deemed annual savings of 75 – 100 kWh be assigned. Unless logged data specific to the program territory is available, a more conservative figure of 75 kWh is advised.
- **Measure Life** – We recommend that the life of the APS measures in commercial environments be established at 5 years. Certainly the strips themselves have the potential to remain in service longer before failing. But other factors, such as the replacement of office equipment, office renovations, employee turnover, IT policy changes, etc. are widely accepted as factors in determining the net measure life of equipment. There are some prefabricated workstations available with integral hardwired APS, although market penetration is very limited. An extended measure life would be appropriate for these products.
- **Savings Persistence** – Although no data is available, newly introduced equipment is becoming more efficient and is incorporating smart power features. Even within a 5-year measure life window, program administrators may wish to consider discounting the savings after the initial year. The discount would be small and perhaps could only be established through program impact evaluation.

10.4.1 Savings Algorithm

Although we are proposing that deemed savings be adopted for APS measures, the following represents the algorithm that supports a savings value for APS in commercial applications. This algorithm can be used to assign savings for specific projects or programs.

Energy Savings

$$If\ (Hours_{Controlled-Off}) + (Hours_{Controlled-Standby}) < (Hours_{Control-Off})$$
$$then,\ \Delta kWh = (kW_{Controlled-Standby}) \times (Hours_{Controlled-Standby}) + (kW_{Controlled-Off}) \times (Hours_{Controlled-Off})$$

$$If\ (Hours_{Controlled-Off}) + (Hours_{Controlled-Standby}) \geq (Hours_{Control-Off})$$
$$then,\ \Delta kWh = (kW_{Controlled-Standby} + kW_{Controlled-Off}) \times (Hours_{Control-Off})$$

where,

ΔkWh	= Yearly kWh savings associated with the use of an APS
$kW_{Controlled-Off}$	= kW of the controlled unit(s) when turned off
$kW_{Controlled-Standby}$	= kW of the controlled unit(s) when in standby mode

$Hours_{Control-Off}$ = Hours per year the controlled unit(s) is turned off

$Hours_{Controlled-Standby}$ = Hours per year the controlled unit(s) is in standby mode

$Hours_{Control-Off})$ = Hours per year the control unit is turned off

10.5 GAP ANALYSIS ASSOCIATED WITH COMMERCIAL APS DATA

There is currently enough data to defend the assignment of programmatic savings to commercial APS applications. However, the data is weakened by a lack of variety in equipment and work environments. Obvious gaps include:

- **Controlled Devices** - Our research suggests there is very limited market data available that accurately describes the specific devices (and their power needs) typically found at a commercial workstations. For example, it's difficult to predict the types and numbers of monitors at workstations because often technical staff work with more than one monitor. Additional data on laptop vs. desktop computers, external speakers, types of printers, etc. would also be helpful.
- **IT Practices** – At one time, nearly all IT departments directed employees to leave PCs powered 24/7 and disabled all power management functions. IT departments are not typically concerned with energy efficiency and to this day will often disable power management at the first sign of system problems. Understanding current practices will help determine the full potential of savings.
- **Demand and Peak Demand Savings** – APS represents a very diverse demand savings profile. Understanding what percentage of workstations are potentially inactive during particular timeframes would allow demand savings to be accurately associated.

10.6 EVALUATION CONSIDERATIONS RELATED TO APS

The ERS Team will be covering evaluation procedures associated with emerging technologies in a broader fashion as this project progresses. However some observations associated with the above discussions regarding residential and commercial APS applications are presented here:

- **Data Logging** – The ERS Team recommends using on-site metered data for plug-in devices whenever possible in order to determine the operating hours under different power modes and the site-specific energy savings. When in the field, it is extremely difficult to determine the actual power consumption of equipment. Even if the power rating is accessible, the rating methodologies are not consistent and will not always represent the actual power draw of the equipment. Additionally, APS savings are critically associated with the power draw in specific equipment modes. For example, the amount of power consumed by a modern PC changes with different modes. The current Windows 7 operating system offers fifty-two different power management settings that have direct effect on AC power consumption. Metering/logging is the only possible way to obtain reasonably accurate results.

- **Proper Installation** – Unlike most plug-in/screw-in measures, it is not sufficient to simply determine if the specified strip is in place. As detailed earlier in this report, the configuration of APS products requires that devices to be controlled are plugged in to the appropriate outlet on the strip. Since strips include uncontrolled outlets, plugging into the wrong outlet can negate savings.
- **Upstream Market Process** – It is assumed that efficiency program efforts with APS will focus on upstream initiatives. Selling APS with computer and entertainment equipment is an excellent implementation approach. Process evaluations will need to assess the procedures followed by the market actors in terms of their abilities and thoroughness in explaining the benefits and the deployment of the strips.

10.7 Summary Conclusions and Recommendations

The ERS Team has no reservations in supporting the concept of efficiency programs claiming savings for APS applications. However our conclusions are split between residential and commercial applications.

As requested we have engaged the APS Data Working Group, assessing their progress and conclusions regarding APS savings. The group has focused thus far on residential applications. To date, a report of their findings has not been delivered. Preliminary findings have been presented to the sponsor group and have been discussed with this project team. A substantial portion of their findings are based on a study that they thus far have been unable to provide. At this point it is unclear how and/or when the group's work will be completed as they are currently having funding support issues. Our findings do not disagree with the preliminary conclusions of the APS Group, but more complete data is needed to make a final determination regarding deemed savings.

The APS Group has not considered commercial applications. As a result we assessed the limited data that is available on the topic and have applied our own professional judgment, also applying the preliminary conclusions of the APS Group's residential efforts as appropriate. We conclude that there is substantial evidence to support deemed savings for commercial workstation control with APS technologies. In addition, a recommended algorithm can be utilized to calculate savings for APS technologies for non-standard workstation commercial applications. The deemed savings values and algorithm are presented in Section 10.4.

Set-Top Boxes

11

11.1 INTRODUCTION

Set-top boxes (STBs) are electronic devices that enable entertainment and other content delivery from a service provider to televisions and other electronic entertainment systems. The U.S. cable TV business was initiated in 1948 to serve areas where terrestrial (broadcast) reception was poor, and since then pay TV has become pervasive, bringing more and more content and with it, the ubiquitous STBs, to more than 80% of homes. Current STB penetration in the U.S. is about 160 million units, an average of 1.6 STBs per household.

The average STB consumes about 170 kWh per year, and the energy use per home is climbing as service providers add new features in response to competition and technology advances. Today U.S. STB energy consumption is about 27 million GWh per year, and although individual component energy use has declined over the past few years, the national total for STB energy use remains steady[1].

Given the energy reductions that efficiency programs have achieved for nearly all other residential systems and devices, STBs represent a promising target for systematic energy efficiency initiatives. However, achieving sustainable reductions in overall STB energy use may require new approaches. Program administrators face a number of challenges, including the following[2]:

- Influencing service providers
- Shifting baselines & tiers with the introduction of new products
- Validating test results
- Attribution with mid-stream incentives
- Retiring old units / e-waste management

The first of these issues – influencing service providers – reflects the crucial role that this group plays in all decisions regarding STB design and performance. The business model for pay TV revolves around bundling STBs with content offered to subscribers, and that business model is managed by pay TV service providers that control the features and set the design parameters for nearly all STBs.

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[1] National Resource Defense Council, "Better Viewing, Lower Energy Bills, and Less Pollution: Improving the Efficiency of Television Set-Top Boxes" (June 2011)

[2] Jonathan Livingston, "More Fun for Less – the World of High Efficiency Home Entertainment" (October 2008)

Cable, satellite, and Internet protocol TV (IPTV) service providers own the majority of STBs and lease them to subscribers at a base monthly rate of $10 or less. Some service providers sell their proprietary STBs to subscribers at a discounted rate relative to the estimated wholesale cost of $400 to $500[3].

Table 11-1 lists the leading service providers in the U.S. market, including some that are well-known ones and others that have only regional brand recognition.

Table 11-1. Leading U.S. Service Providers Major U.S. Cable Service Providers

Major U.S. cable service providers	Comcast
	Time Warner
	Cox Communications
	Charter Communications
	Cablevision Systems Corp
	Bright House Networks
	Mediacom Communications
	Suddenlink Communications
	Insight Communications
	CableOne
Major U.S. satellite service providers	DirecTV
	Dish Network
Major U.S. IPTV service providers	Verizon
	AT&T
	SureWest Communications

A relatively small number of companies produce the majority of STBs. Below is a list of the leading manufacturers for the U.S. market.

- Cisco / Scientific Atlanta
- EchoStar
- LG

[3] American Cable Association, "ACA Applauds FCC for Issuing Set-Top Box Waivers" (June 2009)

- Motorola
- Pace Micro
- Pioneer Electronics
- Sanmina-SCI Corp.
- Thomson
- Sony
- Panasonic

A number of STB manufacturers are ENERGY STAR partners and consider energy efficiency to be an important characteristic of the products they manufacture. However, it is the service providers that specify and select STB products, and it has been found that service providers view energy efficiency as a lower priority than other STB design and operating characteristics.

Of course it is the service subscriber that pays the bill for STB energy consumption regardless of the ownership of the box itself. As the end-use consumer, the subscriber has very little control and likely very little knowledge of the energy consumption associated with STB performance, and energy issues play a very small, if any, role in the selection of equipment and service providers.

11.2 Technology Overview

An STB is a compact information appliance device, generally incorporating a tuner and connected to a television or other display device. The STB receives a signal from an external source and converts the signal into content for display.

STBs differ depending on whether the incoming signal comes from a cable, satellite, or Internet source. STBs can enable decoding of standard or high definition (HD) signals. In recent years, service providers have responded to competition and technology innovation by adding new features such as an integral digital video recorder (DVR) to enable "time shifting" so that subscribers can access a program at any time regardless of when it was originally made available. DVRs usually incorporate a hard drive to record and play back content, and the associated energy consumption has contributed significantly to the overall consumption of STB systems.

Another recent STB advance has been the development of configurations allowing multi-room, multi-program content delivery with local terminal devices such as "thin clients"[4] that can potentially reduce total household STB energy use compared to providing a full-featured STB with integral DVR for each TV in the home. The cost savings the service provider realizes by minimizing

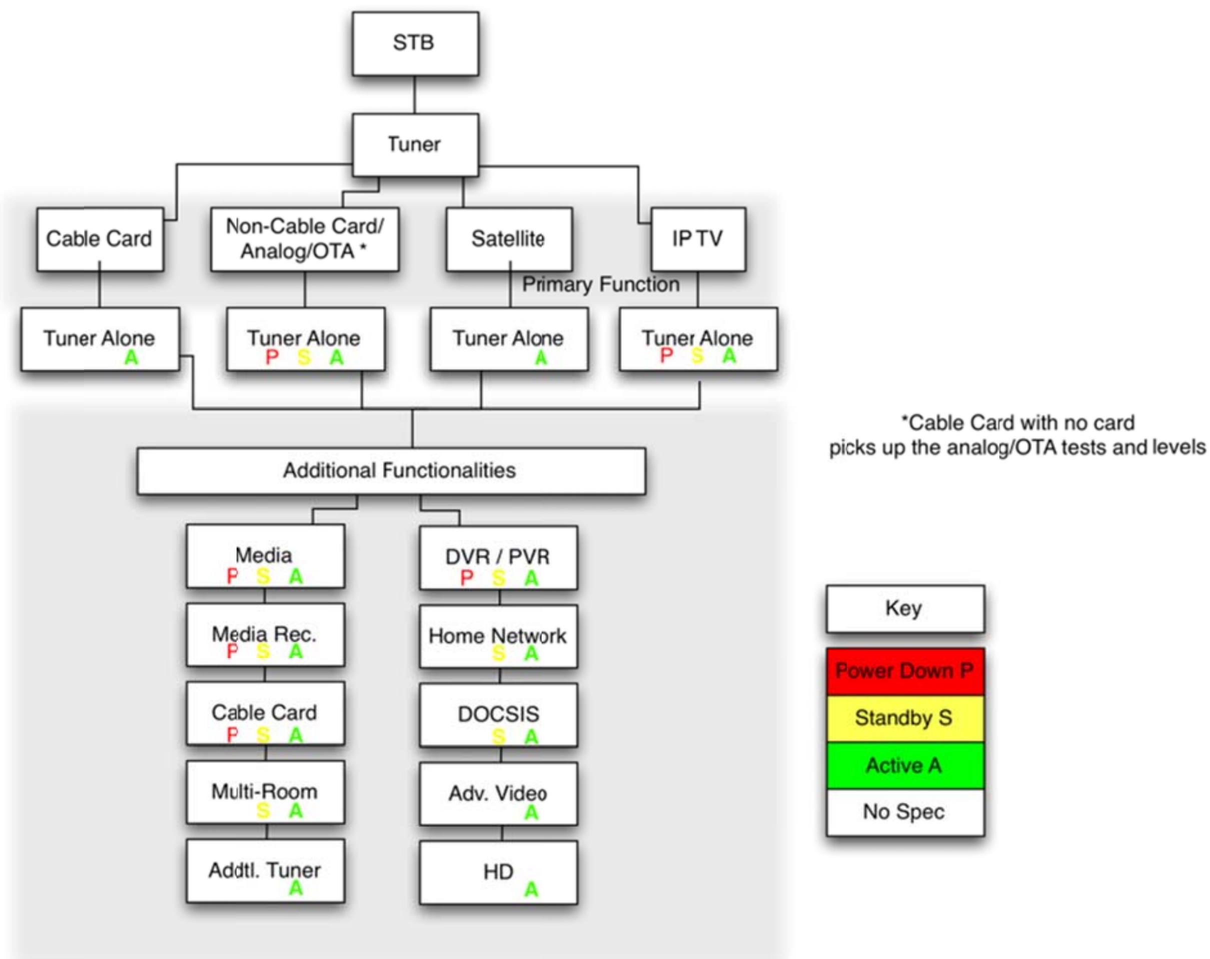
[4] A thin client is an inexpensive, barebones computer setup that serves as a user interface device. It does not have any processor or data storage device but it does have enough RAM to run a leaner version of an operating system.

the number of STB/DVR devices is substantial and enables competitive pricing and better profitability than the more hardware-intensive option of multiple DVRs per home.

This concept may evolve further with the RVU (which is pronounced *r-view* and is not an acronym) networking protocol, launched several years ago to support thin-client approaches but may also enable TVs with internal decoders that can display content from a central STB/DVR without the need for any external hardware.

To help visualize and hopefully clarify the potentially confusing range of STB options, ENERGY STAR produced the diagram in Figure 11-1.

Figure 11-1. ENERGY STAR Technical Requirements for STBs[5]



ENERGY STAR

[5] Katharine Kaplan, US EPA, "ENERGY STAR for Set-top Boxes" (National Workshop on ENERGY STAR Set-top Boxes, Toronto, Canada. June 2009)

A potentially significant, emerging STB technology development comes as "over-the-top" (OTT) devices become widely available. OTT devices allow users to access streaming media from the Internet via computers, game consoles, and other IP-connected systems including dedicated streaming devices such as the Apple TV. Growth of streaming media as alternatives to traditional multichannel video programming distribution could be a disruptive trend, particularly for cable providers who are already seeing their market flatten due to competition in recent years.

The standard metric for STB energy use is typical electricity consumption (TEC) for each device measured in annual kWh. Device wattage is also important, particularly because some energy-saving measures reduce STB energy consumption without altering peak demand.

Strategies for STB energy and demand reduction include the following:

- Reducing component power requirements
- Reducing the number of components with high power requirements
- Enabling sleep or deep sleep mode operation when a component is not in use

11.2.1 Reducing Component Power Requirements

STB component energy use has trended down since the first published measurements made in 2006. In some cases, component power decreased by as much as 20% to 40% from 2006 to 2010[6]. This trend probably reflects STB design changes to reduce the heat generated inside the box in order to extend its life.

The processors, other microchips, and disk drives found inside an STB are more prone to fail at elevated temperatures. Controlling STB internal temperature is complicated because most units are sealed and do not permit end-user maintenance. The heat-dissipation problem is compounded as the form factors of STBs shrink, in part due to competitive pressures to maintain the cachet of an STB as a compact, high-tech device as well as to reduce production costs. Given the long-term investments that service providers make in their STB fleet, they welcome design enhancements that may extend STB effective useful life.

11.2.2 Reducing the Number of Components with High Power Requirements

This option can be accomplished with DVR/thin client local content delivery systems, advanced RVU protocol-based TVs, or OTT devices as mentioned previously. Enabling sleep or deep sleep mode is potentially the easiest energy savings option for STBs, but realizing meaningful savings has proven elusive. Many STBs have installed software that can enable a partial or full powering down when not in use, such as late at night. It is up to the service provider to enable these functions, but in practice, this is rare.

[6] Gregg Hardy, Set-top Box (STB): Framing the Discussion about Utility Program Design (ENERGY STAR Partner Meeting, October 2010)

11.2.3 Enabling Sleep/Deep Sleep Mode Operation When Component Is Not in Use

The ENERGY STAR specification for STBs, now in Version 3.0, provides clear opportunities for sleep or deep sleep energy savings. Surprisingly, despite the existence of on-board software functionality, most systems – even those listed as ENERGY STAR-qualified products at the time this report went to press – show little or no difference in energy use between on mode and so called "sleep" mode. A rare exception is the previously mentioned Apple TV OTT device, which reports a tested on-mode power rating of 2.1 watts and a sleep mode rating of 0.19 watts[7].

A more representative STB system with deep sleep capability, unfortunately not available in the U.S., is the Sky Broadcasting HD-DVR described as follows in a recent brochure from National Resource Defense Council:

> Their highly featured HD-DVR draws 23 watts in On mode and 13 watts when the user puts the box into light sleep state by pressing the power button on the remote. In light sleep, the box does not output or record video, but remains connected to the network and able to resume full functionality almost instantly.
>
> In addition, Sky set-top boxes default to a less than 1 watt deep sleep state each evening at 11:00 pm. In this mode, Sky's boxes wake for a brief period every half hour to check for new program recording requests entered by subscribers using smart phones. If there is no scheduled activity, the box will automatically return to deep sleep state. Sky's customers experience a 90-second wake time when they press the power button to wake from deep sleep state, and they may disable this deep sleep feature if they choose.[8]

Unfortunately, U.S. service providers have resisted production or implementation of these types of STB capabilities. Service provider concerns include the risk of subscriber complaints if at any time content is not instantly available, which would be the case for a few minutes if the STB is transitioning from sleep mode to on mode. Another service provider concern is about their ability to remotely manage sleep-enabling software.

11.3 Potential of Set-Top Boxes for Efficiency Programs

STBs have received increasing attention by program administrators as initiatives addressing other miscellaneous electric loads and consumer electronic devices begin to gain traction. However, as mentioned in the introduction, a programmatic approach to STB efficiency faces several challenges. These include the following:

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[7] ENERGY STAR, "Set-top Box Qualified Products List" (November 2011).

[8] National Resource Defense Council, "Better Viewing, Lower Energy Bills, and Less Pollution: Improving the Efficiency of Television Set-Top Boxes" (June 2011).

- Influencing service providers
- Attribution with mid-stream incentives
- Shifting baselines & tiers with the introduction of new products
- Validating test results
- Retiring old units / e-waste management

The ENERGY STAR specifications for STBs provide a framework for addressing the product related baseline and test result issues. E-waste management is an overriding issue for all electronics products as newer versions reach market acceptance. This report will focus on (1) influencing service providers and (2) mid-stream incentive approaches as the areas that can be influenced by program administrators.

Influencing service providers and attribution and proving causality when savings occur, turn out to be significant challenges in addressing STB efficiency. These items are also connected. Understanding service provider needs and working with service providers are particularly important steps for achieving energy savings with this technology and for attribution of the savings.

It is worth noting that the role of service provider does not exist with most other energy-using systems. In addition to controlling STB features and design parameters and owning the device outright (in most cases), service providers are literally in control of STBs via the signals transmitted with content to the subscriber's home. Since STBs may not function properly if the subscriber intervenes by connecting the STB to a smart plug strip or timer, the program administrator has little leverage to effect energy savings without involving the service provider. This represents an important interaction with efforts to promote advanced power strips for home entertainment.

This one-sided situation can benefit program administrators, if they can influence the service provider to make sustained STB energy performance improvements. Once completed, interventions by service providers can be verified more easily than for other programs requiring contact with the end-user. In addition, service provider interventions are difficult for any other party to reverse. These characteristics, together with the large size of the potential efficiency resource, make STBs a compelling opportunity.

Unfortunately, it is unclear that conventional incentive/rebate programs can succeed in affecting service provider decisions in a way that meets regulatory and EM&V standards for attribution. While informed and engaged end-use customers care about their energy costs, service providers have yet to make efficiency an integral part of their branding. Arguably, many service providers would resist efficiency if it meant reducing the STB feature set in order to lower subscribers' energy bills. Although it may be possible to save energy with a full or even enhanced feature set as indicated above, many service providers doubt that this is true or are consumed with other business priorities.

In this context, any service provider decision that reduces STB energy use is unlikely to be motivated by efficiency objectives. EM&V studies can be expected to reveal this attribution deficiency, leading to unfavorably low net-to-gross ratios.

Consequently, conventional programmatic approaches to STB efficiency may not achieve the desired results. It is too soon to gauge the impact of current initiatives including the previously mentioned voluntary standards (ENERGY STAR Specifications 3.0 and 4.0), mid-stream rebate programs directed at service providers (BC Hydro Power Smart and New Jersey Clean Energy, described in the following subsection), and energy code requirements (under consideration in California and several other states, as well as nationwide in Canada).

Although one or more of these initiatives may achieve success, an alternative programmatic approach is worth consideration. This would involve applying a market transformation (MT) approach in addressing service providers and the STB opportunity.

Although detailed consideration of the MT option is beyond the scope of this report, it appears that a regional- or national-scale, multi-year effort based on study and understanding of service provider business needs and business culture could accelerate the process of bringing STBs to a favorable energy efficiency tipping point.

11.4 Efficiency Programs Currently Promoting Set-Top Boxes

The ENERGY STAR 3.0 and 4.0 specifications were finalized in January 2011, and version 3.0 went into effect in September 2011. These two specifications are identical except that the TEC thresholds for ENERGY STAR compliance become more aggressive in July 2013.

These ENERGY STAR specifications provide a standardized basis for testing STBs and calculating TEC for comparison with ENERGY STAR TEC requirements, as well as standard definitions for STB component types and add-on capabilities. In addition, they define STB purchase and fleet requirements for a service provider to qualify for ENERGY STAR certification – by either certifying that 50% of all new STB purchases in a calendar year are ENERGY STAR qualified., or by certifying that at least 25% of all set-top boxes deployed to subscribers at the end of a calendar year are ENERGY STAR qualified.

There are few utility rebate programs addressing STBs in North America.

Since 2009, the New Jersey Clean Energy Program administered by Honeywell has offered incentives for energy efficient STB under their Creative Initiatives & Consumer Electronics Program. To participate, service providers must compete in an annual request-for-proposal (RFP) process with a proposal that offers aggressive STB efficiency savings. In a typical year, about one third of the bidders are admitted to the program.[9] Regulatory documents show that NJCE

[9] Chris Badger, personal communication, November 11, 2011.

budgeted for 100,000 STBs incentives in 2011 and is slated to offer 65,000 incentives energy efficient STBs in 2012.[10]

BC Hydro offers the only other STB program in North America. Their program is the product of a STB collaboration with other Canadian utilities that ended in 2009. The Canadian government announced that a national standard for STB energy performance would go into effect later that year, possibly eliminating the need for a utility program from most other utilities. The government later deferrer implementation of the standard to 2012, but by that time most utilities had dropped out of the working group. BC Hydro decided to pursue a programmatic approach, in part because of their success with a consumer electronics efficient TV program.

Few details about the BC Hydro program have been made available publically, but an announcement in November 2011 disclosed that BC Hydro was entering into an agreement with service provider TELUS to provide an STB/DVR product that uses about 30% less energy than ENERGY STAR 3.0 specification, approximately 120 kWh per year. The underlying technology is an auto power-down feature that operates after 4 hours of inactivity[11].

This coincides with an announcement by TELUS that it intends to double its market share in BC, and an announcement by Shaw Communications, the large incumbent service provider in BC, that it will begin offering its subscribers a new multi-function STB that provides streaming media access and other features.

11.5 Existing Data Review

One TRM and several relevant studies providing data and methodologies for estimating STB energy savings have appeared since 2007. These include the following, in order of publication:

- Residential Miscellaneous Electric Loads[12]
- Energy Consumption by Consumer Electronics in U.S. Residences[13]
    - Electronics and Energy Efficiency[14]
    - Set-Top Box Market Assessment[15]

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[10] New Jersey's Clean Energy Program /Honeywell, "Residential Energy Efficiency and Renewable Energy Program Plan Filing for 2012 – Draft" (October 2012).

[11] http://www.bchydro.com/news/unplug_this_blog/2011/efficient_pvr.html

[12] TIAX, *Residential Miscellaneous Electric Loads: Energy Consumption Characteristics and Savings Potential* (July 2007).

[13] TIAX, *Energy Consumption by Consumer Electronics in U.S. Residences – Final Report to the Consumer Electronics Association* (December 2007).

[14] Research Into Action, Inc., *Final Report – Electronics and Energy Efficiency: A Plug Load Characterization Study* (January 2010).

[15] Lawrence Berkeley National Laboratory, *EEDN: Set Top Box Market Assessment Report* (February 2010).

- Protocols to Measure Resource Savings[16]
- Consumer Electronics Energy Savings Opportunities[17]
- Proposal Information Template for Set-Top Boxes and Small Network Equipment[18]

11.5.1 Residential Miscellaneous Electric Loads

The U.S. DOE Buildings Technology Program commissioned this study with the ambitious goal of characterizing national energy use in 2006 for each significant type of miscellaneous residential electric load. The STB section builds on the work TIAX did for the Energy Consumption by Consumer Electronics in U.S. Residences report (see explanation below) as well as other earlier publications and provides a comparison of average STB and best-in-class energy performance for cable and satellite STBs with and without DVR capability.

11.5.2 Energy Consumption by Consumer Electronics in U.S. Residences

The Consumer Electronics Association (CEA) commissioned this report and originally released it in January 2007. The findings rely heavily on a phone survey of consumer usage patterns designed by CEA with input from TIAX and outside reviewers and on STB power consumption data provided by CEA and its membership. This report also includes a useful summary of STB energy and demand data published in previous studies. CEA released a revised version in December 2007 after TIAX completed the Residential Miscellaneous Loads Study.

11.5.3 Electronics and Energy Efficiency

Southern California Edison commissioned this comprehensive study of plug load energy efficiency opportunities. Unlike the other publications listed here, this study does not address energy use at a component level. However, it provides a wealth of data on STB markets, industry players and their attitudes toward energy efficiency, and program opportunities and challenges.

11.5.4 Set Top Box Market Assessment

The California Energy Commission - Public Interest Energy Research Program commissioned this study as part of the Energy Efficient Digital Network research project. It provides a survey of STB technical components, an overview of U.S. and global STB markets by service provider type, and data on annual energy consumption and savings potential for cable, satellite, and IP systems with and without DVR capability. This is one of the first studies to characterize IP STB energy consumption.

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[16] New Jersey Board of Public Utilities / New Jersey Clean Energy Program, *Protocols to Measure Resource Savings* (December 2009).

[17] Research Into Action and Ecos Consulting, *Energy Savings Opportunities and Market Descriptions for Four Residential Consumer Electronics Products* (August 2011).

[18] Ecos Consulting, *Proposal Information Template for Set Top Boxes and Small Network Equipment* (September 2011).

11.5.5 Protocols to Measure Resource Savings

This document is the December revised version of the 2009 TRM for the New Jersey Board of Public Utilities / New Jersey Clean Energy Program. It is included here for completeness. It provides the following estimates of savings by converting from a standard STB to one that meets the ENERGY STAR specification: 94 kWh per year, 10.7 W.

The TRM cites as the source for this data Marbek / Ecos for BC Hydro, Feasibility Assessment of Canadian ENERGY STAR Set-Top Box Promotion Program (2009). The Marbek / Ecos report is available upon request from Navigant Consulting, which recently acquired Marbek, or from BC Hydro.

11.5.6 Consumer Electronics Energy Savings Opportunities

This report by Research Into Action and Ecos Consulting describes the program opportunity in the Pacific Northwest for replacing multi-room DVR STBs with a single master DVR and a number of thin-client STBs. It also describes the streaming media industry and its point of overlap and competition with the incumbent pay TV industry, including the potential for streaming media to eliminate the need for STBs.

11.5.7 Proposal Information Template for Set-Top Boxes and Small Network Equipment

This report commissioned by the California Investor-Owned Utilities (PG&E, SCE, SoCal Gas, and SDG&E) provides the rigorous data and supporting documentation for California Energy Commission Rulemaking in support of a new appliance energy code requirement (Title 20). The report takes two tracks: one for reducing energy use by requiring that all new STBs deployed in California be ENERGY STAR compliant and the other by requiring that all new STBs meet a maximum power consumption level of 1 to 5 watts when not in use. Each of these options is well-documented and no recommendation is made to pursue one over the other.

11.6 Set-Top Box Data Gaps

The primary factors that affect potential deemed savings include types and energy performance levels of currently installed (standard) STBs and the characteristics and energy performance levels of the enhanced or best practices models proposed to replace them. These statistics will vary among service providers and for cable providers, among franchise territories, depending on the equipment they select for their fleet and their customers and based on the percentages of customers choosing various service level options.

Consequently, the primary data needed for STB programs involves collecting STB fleet statistics that only the service provider can provide. This can be done with a simple survey, provided that service providers choose to disclose this information.

There is also a need for STB component testing, both for bench-top energy consumption and demand data in various operating modes for a variety of models and configurations and for field testing at subscriber homes to document typical usage and performance patterns. It is possible that the field testing could be replaced with data from service providers if their STB remote monitoring capabilities permit and they are willing to disclose the data.

11.7 Savings Assumptions, Algorithms, and Deemed Values

Tables 11-2 and 11-3 on the following pages summarize key assumptions, deemed values, and algorithms for estimating STB energy savings in typical applications. Sources for assumptions and deemed values are shown in footnotes.

Table 11-2. Assumptions

Measure	Baseline Technology	Baseline Annual kWh[1]	Enhanced Technology	Enhanced Technology Annual kWh[1]	Baseline W[5]	Enhanced Technology W[5]	Coincidence Factor[7]	Measure Life (Years)[8]
Cable set-top box (STB)	Standard STB	180	ENERGY STAR 3.0 compliant STB	145	20	15	See footnote 7	5
Cable STB w/digital video recorder (DVR)	Standard STB w/DVR	270	ENERGY STAR 3.0 compliant STB w/DVR	205	30	22	See footnote 7	5
Satellite STB	Standard STB	150	ENERGY STAR 3.0 compliant STB	125	17	14	See footnote 7	5
Satellite STB w/DVR	Standard STB w/DVR	335	ENERGY STAR 3.0 compliant STB w/DVR	290	38	25	See footnote 7	5
Internet protocol (IP) STB	Standard STB	60	ENERGY STAR 3.0 compliant STB	45	10	8 [6]	See footnote 7	5
IP STB w/DVR	Standard STB w/DVR	135	ENERGY STAR 3.0 compliant STB w/DVR	110	19	15 [6]	See footnote 7	5

Measure	Baseline Technology	Baseline Annual kWh[1]	Best Practice Technology[2]	Best Practice Technology Annual kWh[4]	Baseline W[5]	Best Practice Technology W[5]	Coincidence Factor[7]	Measure Life (Years)[8]
Cable set-top box (STB)	Standard STB	180	5 W max power in standby mode[3]	85 - 140	20	15	See footnote 7	5
Cable STB w/digital video recorder (DVR)	Standard STB w/DVR	270	5 W max power in standby mode[3]	110 - 205	30	22	See footnote 7	5
Satellite STB	Standard STB	145	5 W max power in standby mode[3]	75 - 125	17	14	See footnote 7	5
Satellite STB w/DVR	Standard STB w/DVR	335	5 W max power in standby mode[3]	135 - 270	38	25	See footnote 7	5
Internet protocol (IP) STB	Standard STB	60	5 W max power in standby mode[3]	40	10	8 [6]	See footnote 7	5
IP STB w/DVR	Standard STB w/DVR	135	5 W max power in standby mode[3]	75 - 105	19	15 [6]	See footnote 7	5

[1] From PG&E, SCE, SDG&E and SoCal Gas, Proposal Information Template for Set Top Boxes and Small Network Equipment (September 2011)

[2] Best practice technology is also fully compliant with ENERGY STAR 3.0 requirements

[3] Standby corresponds to "sleep" or "deep sleep" mode

[4] From PG&E, SCE, SDG&E and SoCal Gas, Proposal Information Template for Set Top Boxes and Small Network Equipment (September 2011) - ranges explained in Section x-7

[5] From NRDC / Ecos Consulting on-mode power results presented at ENERGY STAR Partner meeting (October 2010) except for IP data - see Note 6

[6] Based on ENERGY STAR Set-Top Box Qualified Product List (November 2011)

[7] Dependent on individual utility system load profile and customer coincidence definitions

[8] Based on satellite and cable service provider standard practice of refreshing / refurbishing 20 percent of STBs every year

Table 11-3. Deemed Savings and Algorithms

Measure	Enhanced Technology - Representative Deemed Savings Value (kWh)[1]	Best Practice Technology - Representative Deemed Savings Value[1] (kWh)	Enhanced Technology - Representative Deemed Savings Value (kW)	Best Practice Technology - Representative Deemed Savings Value[2] (kW)	Knowledge Gaps	Notes
Cable set-top box (STB)	35	40 - 95	5	5	See Section 11.6	Use algorithms
Cable STB w/digital video recorder (DVR)	65	65 - 160	8	8	See Section 11.6	Use algorithms
Satellite STB	25	20 - 70	3	3	See Section 11.6	Use algorithms
Satellite STB w/DVR	45	65 - 200	13	13	See Section 11.6	Use algorithms
Internet protocol (IP) STB	15	20	2	2	See Section 11.6	Use algorithms
IP STB w/DVR	25	30 - 60	4	4	See Section 11.6	Use algorithms

[1] From PG&E, SCE, SDG&E and SoCal Gas, Proposal Information Template for Set Top Boxes and Small Network Equipment (September 2011) - values rounded to reflect uncertainty

[2] Current best practice technology involves standby power reduction, which reduces annual kWh but does not directly affect peak kW demand

Savings Algorithms		
$\Delta kWh = kWh_{base} - kWh_{enh}$ or $\Delta kWh = kWh_{base} - kWh_{bestpr}$	$\Delta kW = (kW_{base} - kW_{enh}) \times CF$ or $\Delta kW = (kW_{base} - kW_{bestpr}) \times CF$	Primary factors that affect deemed savings include types and energy performance levels of installed (standard) STBs, and the characteristics and energy performance levels of the enhanced or best practices models proposed to replace them. These values will vary by service provider and for cable providers, by franchise territory.
where… kWh_{base} = annual kWh of standard STB configuration kWh_{enh} = annual kWh of enhanced STB configuration kWh_{bestp} = annual kWh of "best practice" STB	where… kWh_{base} = annual kWh of standard STB configuration kWh_{enh} = annual kWh of enhanced STB configuration kWh_{bestp} = annual kWh of "best practice" STB configuration CF = Peak demand coincidence factor for STBs	

11.8 STB Evaluation Issues

Section 12 of this report discusses overarching evaluation issues associated with emerging technology assessments. This section addresses technology specific evaluation needs and concerns associated with STBs.

The primary evaluation need relates to influencing service provider business decision-making in maintaining and refurbishing the existing STB fleet as well as replacing units with more energy efficient ones. A secondary evaluation need is to expand and validate the knowledge base on specific STB models and on usage and energy performance patterns at subscribers' homes.

It is noteworthy that if program administrators are able to gain the trust of service providers who are prepared to deploy energy efficient STBs, the level of effort and investment to obtain relevant model, performance, and usage patterns is dramatically reduced. This is because the service provider can provide specific fleet and future model purchasing information, and testing can be focused on those specific STB models.

Conversely, if relations with service providers are not optimal, it will be possible to infer the makeup of the fleet by surveying a statistical sample of households that subscribe to each service. However, service provider purchasing decisions and future energy performance by STBs acquired for the fleet will remain the subject of conjecture.

It is possible that STB usage patterns in the North Atlantic are different from those in other parts of North America, but this hypothesis would need further support before we could make a case for region-specific studies of STB usage. Assuming that usage patterns are not regional, the EM&V Forum members can combine forces with other entities to gather this data, obtaining it from service providers if possible.

11.9 Recommendations

Our conclusions and recommendations for strengthening STB energy savings calculation methodologies in order to support program implementation are summarized in the following paragraphs.

11.9.1 Closing Data Gaps

As discussed in section 11.6, data is needed to document types and energy performance levels of currently installed (standard) STBs, and the characteristics and energy performance levels of the enhanced or best practices models proposed to replace them. There is also a need for STB component testing, both for bench-top energy consumption and demand data in various operating modes for a variety of models and configurations and for field testing at subscriber homes to document typical usage and performance patterns.

We recommend that the EM&V Forum members begin by exploring its network of relationships to build cooperative relationships with key service providers who deploy STB to subscribers.

Discussions should focus on the deployment of energy efficient STBs to their subscribers. Even if the local service providers are not interested in efficiency, they may be able to provide access to other industry decision-makers. Strong business relationships with key service providers will greatly reduce the level of effort and investment to obtain relevant model, performance, and usage pattern data.

As outlined in Section 11.8, traditional bench-top testing, field measurements, and statistical sampling of subscriber households can yield equivalent data, but at a considerably greater level of effort and cost. Arguably, without the relationships, program administrators will find it difficult to obtain robust service provider participation in programs, and the data gathering exercise may be fruitless in terms of resource acquisition and market transformation.

11.9.2 Adopting Deemed Savings Values

As illustrated in Section 11.7 above, the algorithms for STB energy savings and demand reduction are straightforward. Robust deemed savings values can be produced if robust data is available to characterize the fleets and products specific to the service providers who participate in the STB program.

Conversely, deemed savings estimates have limited to no value in the absence of a specific service provider and data on currently deployed and proposed STB components. We recommend that program administrators exercise caution in applying deemed savings approaches until pertinent STB and fleet data has been gathered and vetted.

11.9.3 Utilizing Savings Algorithms

We believe that the savings algorithms presented in Table 11-3 in Section 11.7 above provide a sufficient level of detail for estimating STB performance in a variety of applications when combined with service provider-specific assumptions and data from component measurements. Once data is developed to fill the gaps we have identified, EM&V Forum members can apply these algorithms with confidence in designing and implementing efficiency programs.

11.10 Summary

Set–top boxes represent a significant and largely untapped opportunity for energy efficiency. Third and fourth generation ENERGY STAR specifications as well as the studies discussed previously provide a solid foundation for developing and deploying STB programs. The use of typical energy consumption (TEC) as the standard program metric for baseline and high-efficiency STBs is well established.

Unlike most other emerging energy efficiency technologies, measuring performance and defining the needed data does not present any real challenges. What can be challenging are the unique characteristics of the multichannel video programming distribution business and of the service providers that exercise nearly complete control over large, aging STB fleets into which they have sunk significant capital resources. This business model, not closely paralleled in other markets for which efficiency programs have been developed, is further complicated by the multi-faceted competition that incumbent service providers face.

It is possible that competition, including that coming from streaming media providers, could play an important part in defining the rules of the game for successful STB programs. The cable TV market share has been shrinking in recent years, even with the addition of so-called “triple play” offerings where customers receive telecom and Internet services by cable along with entertainment. Satellite providers, especially DirectTV, are expanding. All service providers are facing significant risk and opportunity.

Efficiency, which has not been part of media delivery branding, may offer an opportunity for competing service providers to polish their images. Utility program administrators and ratepayers may be able to benefit from a strategic moment when market forces are driving service providers toward STB options such as thin client and sleep mode that enable efficiency as well as other forms of competitive advantage.

In this context, it is useful to consider which type of program intervention is most appropriate for STBs. The options include mid-stream rebates, voluntary or mandatory STB energy performance standards, and a market transformation approach.

From the service provider’s point of view, there is a clear priority in terms of which is likely to bring about sustainable results in the shortest time. Mandatory codes and standards even if found politically viable are not likely to be well received by service providers. During 2010 the Consumer Electronics Association objected strongly to the California Energy Commission’s regulations over TV energy performance.

Given all the options, the most hopeful scenario would be for a state- or region-wide initiative that would upgrade deployed STBs. Program administrators would partner with subscription service providers to include ENERGY STAR STBs for all new installs and possibly for replacement. Because the power consumption and usage has been well documented through ENERGY STAR, the calculations and recording of savings would be straight forward. Programs could harvest previously unattainable savings and service providers could leverage the program for public relations benefits.

11.11 Breaking News Related to Set-Top Boxes

As this section of the report was being completed, the National Cable & Telecommunications Association announced that an agreement had been reached for improvements in the efficiency levels of set-top boxes. The following is quoted from the press release, “Cable TV operators that provide service to 85% of US customers have pledged to make 90% of all new cable boxes Energy Star 3.0 by the end of 2013. One of the big improvements will be that like computers, cable boxes will go to "sleep" when not in use, greatly reducing energy consumption. Currently, they consume as much power when the TV is turned off as when it is on.”

This development creates a path for program administrators to initiate efforts that would deploy efficient equipment prior to the 2013 deadline. However, it may also restrict the savings that can be claimed by such programs.

EM&V Considerations Related to Emerging Technologies

12

This section of the report discusses EM&V approaches that are targeted at accurately assessing the savings and closing the knowledge gaps associated with emerging technologies. In addition to this section, each technology-related section includes EM&V recommendations specific to the covered technology or program approach.

Emerging technologies are equipment or processes that are not yet fully embedded in the market place. Often, the purchasers of these technologies or the implementers of an innovative approach are those willing to take a chance on something new with an apparent advantage. Following the theory of Rogers' diffusion of innovation[1], these innovators and early adopters differ from the majority in their ability to cope with the high degree of uncertainty that may surround an innovation at the time they adopt it. They also tend to have greater financial resources to help cushion losses. By embracing an innovation, early adopters help trigger the critical mass by decreasing uncertainty about a new idea and then conveying a subjective evaluation of the innovation to near peers through interpersonal networks.

When manufacturers are considering putting a new technology or process on the market, they tend to place emphasis on understanding the market for an individual product and communicating in specific ways to different groups within the market. The technological aspects of products are present, but minimized.

Program developers must be aware of what will appeal to the innovator and early adopter.

This is because technology is only one source of uncertainty for companies trying to sell a new product. Other areas of uncertainty include customer needs and perception. Program developers must be aware of what will appeal to the innovator and early adopter market as well as what the possible energy savings will be.

Unlike the specific methodology for gross impacts that we have described elsewhere, evaluation of an emerging technology must take a holistic approach that is flexible and meets the needs of the program implementer for formative feedback as well as creating the ability to determine net impacts. As such, we provide a high level of evaluation recommendations.

[1] Rogers, E. 2003. *Diffusion of Innovation. 5th Edition*. New York: The Free Press. . Diffusion of innovations is a theory of how ideas and innovations move into a social system (or market).

12.1 EM&V Approaches for Closing Knowledge Gaps

Prior to introducing emerging technologies as integral program components, it is often necessary to predict programmatic savings as accurately as possible. In addition to analyzing available performance data, it is preferable to initiate pilot efforts that integrate an appropriate combination of data logging, billing analysis, and other EM&V procedures at a small sample of sites. Care should be taken to ensure that installations represent the types of customers that are anticipated for future deployment of the technology as closely as possible and do not represent highly controlled conditions or "technology friendly" environments such as the homes/offices of efficiency program personnel. The logging of performance data and the recording of customer satisfaction will provide the truest measure of anticipated persistent savings.

12.2 Formative Evaluation

This type of evaluation helps to assure the program is implemented cost-effectively and efficiently. In addition to the estimation of energy savings as described above, we recommend that formative evaluation activities be undertaken to obtain targeted knowledge of customer acceptance of the technology during the pilot phase (if present) and within the first year of program rollout. For example, this can include assessing customer's ideas about the aesthetics or illumination capability of a lighting product or the comfort obtained from a wood pellet furnace compared to that of a baseline furnace. While formative evaluation can cover many different areas, the main idea for this research is that an evaluation team creates a plan in conjunction with program implementers to help make a decision. The program can then use this quick and targeted research to adjust their incentives, offerings, or marketing. Some products, such as LEDs or efficient televisions, are in the midst of a dynamic evolution of technology, performance, and pricing. This fast-moving market needs regular check-ins to ensure that the program information is not out of date and help to keep the program nimble and responsive to the market. By doing so, the risk of later impact evaluations finding a high level of free ridership is reduced.

12.3 Impact Evaluation

The implementation team should use evaluation research not only to close knowledge gaps and understand annual impacts, but also to prepare for net impacts in the future. Once included in a program, though, evaluators do not typically assess an emerging technology any differently than other measures. However, if the implementation team plans an upstream program, a defensible baseline must be established prior to introducing the upstream component to help determine later impacts. The evaluation team must carefully plan baseline data collection and make choices based on how they will use the data in the future. While there are many methods that evaluators could use to calculate gross impacts, we do not discuss them further here as the methods for emerging technologies do not differ from those utilized for other measures.

Net impacts also involve multiple evaluation methods such as comparison group analyses. This can be problematic for emerging technologies newly included in a portfolio, as there are insufficient installations for this type of analysis. As such, gross impacts from emerging technologies may best be estimated in a pre/post billing analysis or calibrated engineering algorithms. If a technology is planned for an upstream program, the often-used customer self-report method may not always be the best way to determine attribution. However, a Delphi of market experts could be used to forecast market penetration with and without the utility intervention to calculate net savings. Evaluators have successfully used this approach in the past for areas such as codes and standards as well as residential new construction.

Conclusions & Recommendations

13

All of the program approaches and emerging technologies researched for this project show potential for generating savings for program administrators. They range greatly in scope from the simple upstream support of advanced power strips to customized retrocommissioning plans for commercial and industrial systems. All however, must be sustained by defensible savings methodologies. While the next phase of the study will include primary research on a subset of these technologies, we have been able to provide a combination of deemed values and/or savings methodologies for all of technologies. In addition we have recommended implementation and EM&V approaches for all of the program approaches. Table 13-1 presents a summary of our findings for each emerging technology area. Our investigation of new program approaches resulted in somewhat different results regarding savings methodologies, and Table 13.2 summarizes our findings.

Table 13-1. Summary of Emerging Technology Findings

Technology	Sub-Measure	Recommended Deemed Savings Value	Report Section	Recommended Savings Algorithm	Report Section	Significant Knowled Gaps	Notes
LED lighting	Residential	Yes	6.3.1	Yes	6.6	Average run hours Typical baseline measure	• Much research being conducted by others • Energy Star and DLC data very reliable
	Small commercial	Not for all measures	6.3.2	Yes	6.6	Typical baseline measures	
Heat pump water heater	Residential	Yes	7.3	Yes	7.7	Insufficient measure life data Lack of field monitoring	Possible noise issues when installed in dwelling units
	Small commercial	No	7.3	Yes	7.7		
Ductless HP & AC	AC Only	Conditional[1]	8	Yes	8.16	Baseline window units or other	Will require lengthy monitoring period to determine load shapes, especially when adding HP/AC to homes without previously installed AC
	HP & AC		8		8.16	Cold climate performance of newest models Control strategy for displacement retrofit	
Biomass pellet systems		Yes	9	Yes	9.9	Fuel switching measure, or viewed as a displacement measure by regulators	• Performance well documented and displaces well known conventional systems • Concerns are mostly environmental
Advanced power strips	Residential	Preliminary	10.2	Preliminary	10.4	Homeowner usage patterns	Anticpated NEEP working group results
	Commercial	Preliminary	10.3	Preliminary	10.4	Split savings with software approaches	
Set-top boxes	None	No	11	Yes	11.7	Methodology for deployment with subscription services	Savings easily established upon forming partnership with sucscription service

[1] Deemed value methodology is provided; final deemed value is weather dependent

Table 13-2. Summary of New Program Approach Findings

Technology	Sub-Measure	Recommended Savings Algorithm/Methodology	Report Section	Significant Knowled Gaps	Notes
Commercial lighting design programs	New construction	Yes	2.3	None	Savings methodology well established
	Renovation/replacement	Yes	2.3	None	
Commissioning programs	Newly installed systems	Custom methodology	3	• Assignment of split savings between system installation and commissioning activities • Potential savings for different system types • Persistence of Savings • Potential for incremental savings of previously incentivized measures	• Many knowledge gaps to fill • Program activity in Maine and Massachusetts will provide access to projects
	Retrocommissioning	Custom methodology	3		
Whole house retrofit programs		Prototype modeling Pilot program monitoring	4	• Whole building performance results • Persistence of measures	•Pilot program monitoring needed • Prototype model building beyond scope and budget • Current Massachustts impact evaluation will produce data for deep residential retrofits • Performance very dependent on program fuel neutrality approach, local climate, and local metering protocols
Multi-family whole building retrofit programs			5	• Whole building performance results • Effects of tennant turnover • Effects of split utility responsibility	

13.1 Conclusions & Recommendations Regarding Primary Research

From the phase 1 findings we have developed recommendations for prioritizing primary research for the next phase of this project. With a few exceptions, all of the technologies and approaches would benefit from more study. Selecting two to four technologies for primary research through this study presents some difficult decisions. We feel that the decisions should be guided by at least the following factors:

- ❑ The current status of credible savings data
- ❑ The overall potential for significant programmatic savings
- ❑ Access to savings information generated by credible third-party sources
- ❑ Successful implementation by some current program administrations
- ❑ Local climate or market factors that create knowledge gaps
- ❑ The existence of a clear research path that will produce valuable data

Table 13-3 summarizes the priority factors. The table is followed by a summary discussion on the technologies and programs approaches we are recommending for primary research, as well as factors leading to low priority rankings for some areas.

Table 13-3. Primary Research Priority Ranking

Technology or Program Area	Sub-Measure	Priority Rank for Primary Research	Notes
Ductless HP & AC	AC only	1	• Large potential savings • In situ performance data needed • Cold climate performace data needed • M&V approach is clear
	HP & AC		
Heat pump water heater	Residential	2	M&V procedures needed to determine customer satisfaction as well as performance
	Small commercial		
Commissioning programs	New installations	3	• Will need direction from Forum to select system types for study • Opportunity to work with existing pilot programs
	Retrocommissioning		
Advanced power strips	Residential	Not recommended	Anticpated NEEP working group results
	Commercial	4	• M&V results will be very dependable as office work stations have little variability • Data on shared savings with software approaches needed
LED lighting	Residential	5	• Technology moving very fast M&V results will soon be dated • Much research being conducted by others • ENERGY STAR and DLC data very reliable
	Small commercial		
Biomass pellet systems		6	• Performance is well-documented • M&V procudures for displaced conventional systems are well established • Usage patterns as supplimental heat would be of interest • Likely a low priority outside of New England

The above priority rankings are based on our understanding of what Forum member organizations are seeking in terms of new program opportunities and/or the potential for improved M&V data on new or recently implemented measures and programs. We urge the Forum to consider the possibilities involved with each of the categories and to develop their own conclusions as to primary research priorities.

13.1.1 Recommended Priorities for Primary Research

The following narrative presents the reasoning behind our priority recommendations, with the highest priority listed first:

1. **Ductless Mini-Split Systems** – These systems offer significant potential for programs after knowledge gaps are closed. Ducted ASHPs have not been a very successful replacement for electric heat in colder climates, and recent "cold climate" ASHPs have experienced substantial reliability problems. GSHPs offer high efficiency, but installation costs are high, and siting issues restrict their market potential. For air conditioning, inexpensive imported window units

are detrimental to efficiency efforts and split systems are an attractive replacement. Contributing factors favoring primary research, include the following:

- There is a rapidly growing desire to promote these systems, and manufacturer-provided performance data is promising.
- Testing/rating procedures for these systems have been controversial, and in situ performance data will be very important in backing manufacturer claims.
- The measure is climate dependent and therefore it is not feasible to rely on performance results from outside the region.
- New models with claimed improved cold climate performance need in situ research.
- The M&V paths are clear and will produce reliable and accurate results.

2. **Heat Pump Water Heaters** – Domestic water heating is typically the largest energy load in homes, following space conditioning. Additionally, for some small commercial applications, service water heating also represents a significant opportunity. Programs have had limited opportunity to address DHW with the most significant measure being a fuel switch from electric to natural gas. HPWHs have experienced development issues, but the current products show improvement. M&V will greatly help in determining the viability of this technology for implementation. Contributing factors favoring primary research include the following:
   - Data is needed to verify if noise factors are affecting the persistence of savings.
   - Installation in unconditioned spaces such as garages has been popular in moderate climates. Water heaters in most Forum member territories are located in basements, laundry rooms, and closets. Primary research will identify issues and potentially result in net energy usage data.
   - Market research combined with field data will help to assess whether or not it is practical to require the elimination of electric resistance override switches for program inclusion.
3. **Commissioning Programs** – Commissioning and retrocommissioning represent major opportunities for program administrators. However, program administrators struggle with predicting savings and assigning savings appropriately. Because of these uncertainties, commissioning opportunities are not fully pursued through most efficiency programs. Contributing factors favoring primary research include the following:
   - Large potential for programmatic savings.
   - Essentially all facilities have commissioning opportunities.
   - Past program participants provide immediate potential customers.
   - Existing data demonstrates savings, but only with a wide range of potential.
   - Pilot commissioning programs offer good M&V opportunities.
   - The Maine ARRA-funded retrocommissioning program offers an excellent opportunity for primary research.
   - The knowledge gaps can be directly addressed by primary research.

We further recommend that the Forum members refine this category by working together to select target measures with the most potential. For example, EMS, HVAC systems, and lighting control systems installed 5 or more years ago through program efforts are likely to offer predictable savings.

4. **Advanced Power Strips for Commercial Applications** – The focus of the NEEP APS working group is on residential applications. Commercial applications will differ greatly in the load savings shape. Contributing factors favoring primary research include the following:
   - Commercial applications will be very repeatable in terms of the connected equipment.
   - Existing knowledge gap related to the uptake of software based power management and the incremental opportunity for APS.
   - Existing knowledge gap as to the potential for non-workstation equipment such as printers, fax machines, copiers, etc.
5. **LED Lighting** - This is not ranked higher for primary research as there are a lot of current and recent efforts that support the prediction/reporting of savings for LED measures. The Forum members should have enough data from these efforts to initiate pilot or full programs. Also, there is little that differs in terms of EM&V techniques from conventional lighting measures. However, if LEDs are selected as a priority, we recognize the following:
   - Residential LED applications as well as all exterior applications offer solid predictable savings.
   - A knowledge gap exists for interior commercial applications. New LED troffers may provide an opportunity to log energy usage and gauge customer satisfaction.
   - Retail track and downlighting offer an immediate niche market for LEDs as demonstrated by the pilot efforts of Efficiency Vermont. Data logging and project surveys would provide significant knowledge as to displaced technologies and operating hours.
6. **Biomass Systems** – Although research in this area could provide very interesting results, we tend to believe that this technology area presently has limited appeal for the majority of Forum members for the following reasons:
   - Considered ineligible (fuel switching) in many jurisdictions.
   - Environmental concerns and controversy limit program appeal.
   - Typically installed as supplemental systems and therefore difficult to assign consistent, persistent savings.
   - In cold climate zones, market forces support these products well.

13.1.2 Factors Associated with Areas Not Recommended for Primary Research

Although all of the program approaches and technology areas would benefit from primary research, we recognize the following factors that contribute to a lower priority ranking for some of the categories.

- Whole House and Multi-Family Retrofit Programs
  - Extensive monitoring and/or modeling are required, and monitoring should be done over a 12-month period. Project timeframe and budget would not allow for a comprehensive effort.
  - Full impact evaluations are really needed to provide significant data.
  - Most Forum member programs do not have fuel-neutral status.
  - Pilot programs with the associated modeling and monitoring are recommended.
- Commercial Lighting Design Programs
  - The savings methodology is now well established and fully defensible.
  - Program administrators likely need implementation assistance rather than further M&V assistance.
  - National Grid, NSTAR, CL&P, Efficiency Vermont, and Efficiency Maine all use a version of this model. Staff of all of these programs have been fully cooperative in sharing information and developing regional strategies.
- Set-Top Boxes
  - The savings methodologies are straight forward and well established.
  - The only identified market avenues are cooperative ventures with service subscription services for cable/satellite services.
  - Once implemented a cooperative effort with such a subscription service would offer simple calculation of deemed savings.

13.2 EM&V Procedures

Section 12 of this report presents many conclusions and recommendations related to EM&V procedures associated with emerging technologies and program approaches. There are some items however, that we believe are worth reinforcing:

- **Evaluation and implementation cooperation** – With the current trend of handling all M&V through a separate evaluation department, most implementers no longer perform any M&V, as the task and budget resides elsewhere. Especially in the area of emerging technologies, evaluation efforts must recognize that their mission is not only to report realization rates to regulators, but also to assist implementers in continuous improvement of programs.

- **Process evaluations** – Harvesting savings from emerging technologies is as much about the implementation process as it is about the technical qualities of the products. Proper process evaluations should carefully critique how the programs go to market and how projects are tracked. Recently reviewed process evaluations illustrate a discouraging trend to simply catalogue processes rather than subject them to critical scrutiny.

- **Evaluation timelines** – When determining evaluation schedules, an elapsed time should be established for M&V. As the evaluation planning processes experience inevitable delays, the timeline for M&V should be scheduled out rather than compressed. This project team has worked on several evaluations where lengthy planning compressed the M&V time allotment to the extent that the quality of the M&V results suffered.