Deep Savings Interventions as an Energy Resource: Connecting the Dots

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ABSTRACT

What is the electric impact of retrofitting an over-ventilating system of gas-fired rooftop units (RTUs) by installing a dedicated outdoor air system with heat recovery and demand-control operation? What if the retrofit also replaces the gas RTUs with electric heat pump RTUs? What if it occurs in a jurisdiction that exerts strong pressure towards electrification? This type of retrofit would typically have energy impacts from improved controls (reduced outside air volume) and improved mechanical efficiency (fan efficacy and heat recovery), plus fuel switching in the heat pump case. These factors make it difficult to resolve the savings baseline.

When energy efficiency is viewed as a resource to meet future demand, the baseline resolution depends not only on system characteristics prior to the intervention, but also on system lifecycle assumptions embedded in the power planning demand forecast. This paper presents one framework for sorting through these complications.

Introduction

This paper presents one potential framework for defining the baseline and evaluating impacts of deep-saving interventions informed by whole-facility energy data in commercial building applications. The framework covers both new construction and retrofit applications and is designed to be consistent with the objectives and policies of the Northwest Power and Conservation Council (Council) and its technical advisory committee, the Regional Technical Forum (RTF). To clarify how these perspectives inform the candidate framework, our discussion includes context and background on each key element of the baseline definition.

The Northwest Power Act provides the foundation for the Council's approach to incorporating energy efficiency as a power planning resource. As directed by the Act, the Council prioritizes conservation measures in power planning insofar as they are cost-competitive alternatives to generating resources. Power planners are therefore interested in reliable electricity savings opportunities that meet the definition of conservation under the Act (*reduction in electric power consumption as a result of increases in the efficiency of energy use, production, or distribution* [Northwest Power Act, §3(3), 94 Stat. 2698]) and are incremental to the Council's baseline demand forecast.[1]

The RTF provides technical support to the Council and to efficiency programs seeking savings estimates that are compatible with Council perspectives. The RTF Guidelines (RTF 2020) describe methodologies for developing energy savings estimates that meet this requirement and can be applied consistently across very different measures.

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[1] The baseline demand forecast is designed to reflect all energy changes that would be expected to naturally occur in the absence of further program influence beyond the beginning of the planning period. Population growth is one example of a driver of naturally occurring energy changes. For a less obvious example, end-of-life equipment replacements that occur within the planning time horizon would be expected to naturally reflect federal efficiency standards and/or market-average efficiency rather than pre-existing efficiency.

Background

Commercial energy use intensities (EUIs) remain stubbornly high, even after decades of drastic improvements in building shell components, lighting power, and HVAC equipment specifications. Part of the reason is that efficient engineering, system commissioning, programming, and controls are critical performance determinants that are difficult to specify in an energy efficiency (EE) measure. Even far-reaching building code initiatives such as those undertaken in recent years in Washington State typically only specify control *capabilities*. Actual efficient operation over the course of a building's lifespan must be promoted through other channels. These concerns have led to great interest in wholistic building-level performance initiatives.

EUIs, typically calculated as total annual energy usage per square foot, with all applicable fuel consumption converted to kBtu and added together, play a critical role in many "beyond the widget" deep-savings initiatives. However, changes in all-fuel EUIs do not generally reflect conservation in the sense needed by the Council, which is responsible for resource planning in the electrical system. For example, consider an intervention that converts a natural gas system to an electric system with reduced total kBtu but increased electric usage. It is not immediately clear how such an intervention should relate to conservation as a resource for the electrical grid. This paper's main objective is to show how observable site-level energy impacts can connect with a power planning interest in using deep-savings building interventions as an energy resource on equal footing with other grid resources.

To integrate deep savings interventions into efficiency-as-a-resource power planning, planners and program evaluators need analysis methods that can address beyond-the-widget challenges such as operational efficiency, fuel choice, and state energy policies. Existing Council policy and RTF methodology developed under the Northwest Power Act (1980) provide guidance for sorting through many of these issues, but further guidance may be needed for a complete solution. Also, some policy elements may evolve as new approaches are formulated to meet new challenges. This paper presents one potential approach to resolving major complications in this space, but *it does not represent settled policy from the Council or from the RTF.* We often use the term *candidate* framework or *candidate* approach to emphasize this point.

What Do We Mean by Deep-Savings Interventions?

This section describes common elements of deep-savings interventions in commercial buildings. Table 1 compares stock EUI estimates in Washington State to performance targets set out in ASHRAE Guideline 100-18 (ASHRAE 2018) for three commercial building types.

Table 1. Example EUIs (kBtu/sf) for existing buildings: Stock means and ASHRAE 100 targets

	Zone 4C (western WA)		Zone 5B (eastern WA)	
	WA mean[1]	ASHRAE 100[2]	WA mean[1]	ASHRAE 100[2]
Office (admin/prof.)	74	40	78	42
Retail (retail store)	80	30	88	33
Education (K-8)	57	36	59	37

[1] Based on analysis of CBSA I-III and CBECs data, used to inform WA rulemaking (SBW 2020).

[2] Shown here are 25th percentile values; 40th percentile EUIs are 20-30% higher.

ASHRAE targets in the table represent 40-60% energy reductions relative to the stock averages. The efficiency interventions that enable EUI reductions of this magnitude usually entail multiple individual measures tailored to building-specific needs. Common features include:

- Design emphasis on equipment sizing and operational simplicity
- Efficient building shells
- Dedicated outdoor air system (DOAS) with heat recovery ventilation (HRV)[2]
- Heat pump heating
- LED lighting
- Occupancy-based controls
- Sustained attention to performance monitoring and fault detection to support continuous commissioning, programming, and controls

We use the term *measure package* or *intervention* for any combination of design elements, equipment specifications, commissioning, programming, controls, and performance monitoring that may be used to achieve significant energy savings at the whole-building level, in a new or existing building.

Also, we use the word *operation* as shorthand for the combination of commissioning, programming, controls, and occupant behaviors that affect the actual energy consumption of a given system. Because of the large role that these characteristics play in determining energy performance, we find it helpful to clearly distinguish operational characteristics from equipment characteristics.

Most items listed above could be described through technical characteristics of equipment, materials, or assemblies, and their delivery could be supported (and often is supported) through traditional "widget-oriented" efficiency programs. However, the first item (design emphasis) and the last item (sustained monitoring) are not amenable to technical specification in the same way. Both of these features are widely viewed as critical to consistently achieving and maintaining deep reductions in energy consumption in real buildings, and this paper takes as given that they are integral parts of the interventions we consider.

Role of Whole Building Energy Data

Whole building energy data plays a central role in the deep-savings interventions we consider because (a) it is easy to obtain using utility billing data, (b) it provides an empirical basis for estimating realized savings in a way that automatically reflects operational characteristics and unanticipated interactions, and (c) it is easy to update to for ongoing performance monitoring.[3] One of the reasons we focus on *deep savings* interventions is that their energy impacts are typically apparent from whole-building EUI data.

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[2] Energy Recovery Ventilation (ERV) is a related technology which exchanges latent heat as well as sensible heat. Sensible heat recovery is sufficient for most applications in the Pacific Northwest climate, but ERV units are sometimes selected when very high efficiency is desired and product options among high-end HRVs are limited.

[3] Strategic Energy Management (SEM) and Pay for Performance programs routinely use whole building energy data for evaluating participant savings for similar reasons. Furthermore, several elements of what we call "deep-savings" measure packages are also common elements in these programs (e.g., sustained attention to performance well after initial measure delivery). Between the overlap in program offerings and the common usage of whole building energy

Whole building EUIs are also the central metric used for energy benchmarking in prominent resources such as ASHRAE Guideline 100, and ENERGY STAR® Portfolio Manager, which is used to implement performance standards in some jurisdictions. Since whole-building EUIs reflect actual energy performance and can be monitored over extended periods of time, EUI benchmarking and monitoring offers a way to ensure that anticipated performance is actually realized and is persistent.

Key Elements of the Baseline Definition

This section describes the main elements of the candidate framework and the perspectives and objectives behind each element. The first subsection describes two baseline types that are used throughout Council and RTF work products and the basic principles that guide the baseline definition. Later subsections discuss complications that arise with fuel choice, legally mandated building performance standards, and operational efficiency.

When these complications are all resolved, and the baseline has been clearly defined, energy impacts and incremental costs can be calculated by comparing efficient-case energy usage and costs to baseline usage and costs. These comparisons must reflect full lifecycle effects, and care must be taken to ensure that all equipment, commissioning, and maintenance costs are accounted for, but the first and most important step in all of these calculations is the formulation of a well-defined baseline.

Baseline Type

Power planners and the RTF recognize two distinct types of baselines for energy efficiency measures based on how measures relate to equipment or building lifecycles.

- **Current practice.** This baseline is characterized by the efficiency characteristics of market choices and practices that are common at the time of the efficiency intervention; applicable codes and standards usually set a minimum for efficiency levels considered in a current practice baseline.
  - Applies when an actor is forced to make *some* decision on the efficiency of the design, operation, or equipment of the system affected by the measure.
  - Common examples are new construction projects, major renovations, and when existing equipment is at the end of its useful life.
- **Existing conditions.** This baseline is characterized by the energy characteristics that existed prior to measure implementation. Also called “pre-conditions” or “pre-existing conditions.”
  - Applies when the decision-maker is not imminently required to make an efficiency selection at the time of the intervention.
  - Common examples are operational improvements and retrofits where existing equipment had remaining useful life at the time of the intervention, as with weatherization in existing building or early replacement of HVAC equipment.

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data, our discussion naturally touches on issues of concern to these programs. However, our emphasis is specifically on *deep-savings* interventions, viewed from the *Council and RTF perspective*, so our discussion differs from what covered in many existing references.

When an early-replacement measure affects pre-existing equipment or systems that have remaining useful life, it often makes sense to use an existing-conditions baseline for the remaining useful life period and to assume a current-practice selection would have occurred at the end of that equipment's remaining useful life. RTF work-products for early-replacement measures therefore often separate measure life into two time periods:[4]

- **First-period baseline.** An existing-conditions baseline applies for the initial portion of measure life, lasting through the *remaining useful life* of the pre-existing equipment.
- **Second-period baseline.** A current-practice baseline applies for the portion of measure life that remains after the existing equipment's useful life would have expired (i.e., for the *balance of measure life*).[5]

This dual baseline is most relevant to early-replacement measures that affect equipment or systems with moderate natural lifespans such as HVAC or lighting. In these cases, second-period savings are of greater interest to power planners because equipment with moderate lifespans is subject to natural turnover in the near term, and planners are most interested in savings that are expected to persist through the planning time horizon. This complication does not apply to retrofit measures that affect long-lived systems (such as weatherization of building shell components). In these cases, the baseline is typically defined as existing conditions for the entire measure life. Dual baselines also do not arise in replace-on-burnout measures or new construction measures, which use current-practice baselines for their full measure lives.

Example. Consider a retail space whose existing HVAC system consists of multiple unitary rooftop heat-pumps (HP-RTUs). The RTUs are still functioning when the site is retrofitted with a variable refrigerant flow (VRF) system and a dedicated outdoor air system (DOAS) with heat recovery and demand-controlled ventilation (HRV and DCV).

The RTF Guidelines require a determination of the measure life (median time to failure of the efficient-case system), and of the remaining useful life of the pre-existing equipment. For concreteness, assume the measure life has been determined to be 20 years, and the HP-RTU's remaining useful life has been set at 7 years. Then the RTF Guidelines specify that the baseline for this measure is existing conditions for savings years 1-7 and current practice for years 8-20. *[End of example]*

Fuel Choice

Deep-savings interventions often involve major decisions about building systems that could potentially use natural gas or electricity (or for that matter, propane, heating oil, coal, or wood) as the primary fuel. A simple fuel change, as when an electric-resistance heating unit is replaced by a gas unit, clearly does not meet the definition of conservation under the Northwest Power Act because the change in electric energy consumption is not caused by increased efficiency. However, this observation does not fully resolve how fuel choice should be treated in

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[4] For further details on RTF baseline definition, see Section 3.1.6 of the RTF Guidelines.

[5] There is usually little basis for dividing a measure's expected lifetime into the remaining useful life of existing equipment and the balance of measure life. In lieu of context-specific insight, RTF measure analyses often assume the baseline system is replaced when 1/3 of its total expected life remains.

evaluating measure savings. The Council has provided the following guidance for sorting through measures that involve fuel choice (NWPCC 2017):

When the RTF analyzes a measure for which consumers have a fuel choice, the RTF should assume efficiency programs have no impact on decision makers with respect to fuel choice and assume, as a starting point, that none of the electric-source units are conversions from other fuels.

In practical terms, this means that analysts should define the baseline fuel type to be whatever fuel is used in the actual efficient-case equipment. This is essentially taking the view that the decision maker selected the fuel type prior to engagement with the efficiency program. In cases where the new equipment uses a different fuel from the pre-existing equipment, this implies that at the time of program intervention the customer was already in a position where some equipment selection must be made. We summarize the practical effect as this:

In all new-construction applications, and in retrofit applications where efficient-case fuel differs from pre-case fuel, the equipment baseline is defined as the current-practice mix of equipment options that use the same fuel as the efficient-case selection and which make sense for the site of interest.

For example, for a retail space that converts from a gas-RTU system to HP-RTU+DOAS, the baseline would be defined in terms of the market-weighted average of electric HVAC options for retrofitting a gas RTU (this average would likely include significant weight on conventional heat pump RTUs without DOAS).

Retrofit Code Trigger for Current Practice Baseline

The RTF Guidelines indicate that retrofit projects subject to local building codes generally use a current practice baseline. However, in most jurisdictions nearly any change to a commercial HVAC system, lighting system, or building envelope will technically be subject to code. The candidate framework adopts the following principle for these cases:

For retrofit projects, the current-practice baseline applies to all savings years if the facility is undergoing a major renovation that is required to meet building energy codes and is not primarily motivated by energy efficiency.

The principle indicates that the current practice baseline applies to projects that are subject to code, but it makes an exception for projects that are primarily motivated by energy efficiency. At the time of this writing, that exception is not noted in the RTF Guidelines (RTF 2020, p. 12), but it is consistent with the logic used in the RTF Nonresidential Lighting Code Compliant Protocol (RTF 2023, p. 3), which indicates that the code-compliant protocol (with current-practice baseline), and not the retrofit protocol (existing conditions), should be used if "the facility is undergoing a major renovation that is required to meet building energy codes for reasons other than the lighting efficiency project itself."

Retrofit Mixed Baseline: Equipment versus Operation

Deep-savings interventions in existing buildings often involve major renovations, fuel switching, or replacement of equipment that may be near the end of its useful life. These are all typical indicators of a current practice baseline. On the other hand, deep-savings interventions also often include design elements that are specifically intended to improve operation by facilitating zonalization and simplifying commissioning, programming, and controls.[6] Savings from improved operations are typically counted from an existing conditions baseline. Deep retrofit applications can therefore have significant savings components with different natural baselines. (The issue does not arise in new construction applications because they do not have pre-existing operational practices and use a purely current-practice baseline.)

The candidate framework uses the following principles for navigating this baseline tension when it arises. For controlled systems affected by deep retrofits in existing buildings:

- *For first-period measure analysis (when applicable), the existing conditions baseline applies as usual (for both equipment characteristics and for operational efficiency). This principle is not relevant to applications that involve fuel-switching.*
- *For second-period measure analysis in cases without fuel switching, and for the entire measure life for cases with fuel-switching, the current-practice baseline applies to equipment, but the operational baseline is as follows:*
    - *For portions of the current practice mix that are very similar to pre-existing equipment, the baseline should use pre-existing operational characteristics insofar as those operational characteristics are realistic for new equipment of that type.*
    - *For portions of the current practice equipment mix that are not similar to pre-existing equipment, the baseline should assume market-average operational characteristics for new equipment of that type.*

These principles require explanation. We first provide two examples to clarify what these principles mean in practice, and then we outline the reasoning behind this choice.

Example. Consider again the retail space whose existing HVAC system consists of multiple unitary rooftop heat-pumps (HP RTUs) that are retrofitted with VRF+DOAS+HRV. We assume the new system has a 20-year measure life, and the pre-existing system had 7 years of useful life remaining at the time of the retrofit.

The first principle indicates that the baseline for measure years 1-7 is simple pre-conditions, quantified by pre-period energy consumption data. The second principle indicates that the baseline for measure years 8-20 assumes current practice equipment but with a mix of operational assumptions. For concreteness, assume the current practice equipment mix for electric heating systems going into retail spaces with pre-existing RTUs is 90% like-for-like HP-RTU replacement and 10% VRF+DOAS+HRV. The second-period baseline energy can be estimated with this weighted sum:

- (90% weight) pre-period energy consumption with adjustments to account for things like HSPF improvements in current standard HP-RTUs relative to existing equipment
- (10% weight) energy estimated from available EUI data for similar buildings with VRF+DOAS+HRV systems.

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[6] A prominent example is when DOAS is used to decouple ventilation from space heating and cooling.

[End of example]

The second-period baseline is somewhat abstract, but some complication is unavoidable if we are to formulate a realistic baseline over a time period that spans natural replacement events. Although first-period existing-conditions savings is more directly connected to observable energy data, second period current-practice savings is at least as important for estimating lifetime savings relative to the natural equipment life-cycle.

The fuel-switching case looks slightly different.

Example. Same as before, but now assume the pre-existing system is an array of gas-fired rooftop units (gas-RTUs). Again, the retrofit is to a VRF+DOAS+HRV system with a 20-year measure life. The remaining useful life of the pre-existing equipment is not relevant because the fuel-switching guidance assumes the customer was already in the market for an electric system prior to selecting the efficient-case system.

The second principle indicates that the baseline for the entire measure life uses current practice equipment with a mix of operational assumptions. For concreteness, we again assume the current practice equipment mix for electric heating systems going into retail spaces with pre-existing RTUs is 90% HP-RTU and 10% VRF+DOAS+HRV. Our baseline approach requires an additional fuel conversion step in this case:

- (90% weight) pre-period energy consumption, but with gas heating energy converted to electric energy needed to produce the same thermal output with HP-RTUs.
- (10% weight) energy estimated from available EUI data for similar buildings with VRF+DOAS+HRV systems.

[End of example]

In practice, significant judgment (or else ideal data) is typically needed to perform the energy conversion step in the approach followed in the example. A later section walks through detailed real-world examples and discusses some practical challenges and potential solutions.

This baseline logic provides a way to account for the large role that operational efficiency often plays in the performance of deep-savings interventions with explicit assumptions about baseline operation. There is no single “correct” set of assumptions for this, but counter-factual reasoning can provide some insight into the reasonableness of different potential approaches.

Consider what operational characteristics might have prevailed in different baseline equipment scenarios. When a new system is installed at a site, how much do we expect the pre-existing operational characteristics to carry over to the new system? For example, if the existing system substantially over-ventilates or performs excessive simultaneous heating and cooling, should we expect the problems to be corrected when a new system is put in place? The truest answer is probably *somewhat, depending on the new system design*. System controls may be reset at the time of equipment replacement, but there is little reason to expect changes in occupant preferences or the level of operational diligence at a site, so some degree of regression to prior operational efficiency seems likely unless the new system includes design elements that promote better operation.

The proposed logic assumes complete continuity with prior operational efficiency when the new system is very similar to the old system, and it assumes complete disconnect with prior operating patterns when the new system is dissimilar to the old system. In terms of reasonableness, this assumption probably makes errors in both directions.

The main practical alternatives we considered were (a) complete reversion to prior operation regardless of retrofit system type, and (b) complete conversion to market-average operation regardless of prior dysfunction and regardless of system type. Each of these options makes entirely one-sided errors. Option (a) would often require analysts to assert operational characteristics for systems where those characteristics would be unnatural (e.g., asserting that a demand-controlled DOAS system wildly over-ventilates). Option (b) would assume that a history of prior dysfunction has no bearing whatsoever on future operation.

Performance Mandates

The Clean Buildings Initiative (CBI) mandates building performance standards for new and existing commercial buildings in Washington State.[7] These take the form of whole-building EUI limits that buildings must not exceed as of dates specified in a defined phase-in schedule. Since these are legally mandated standards, and applicable codes and standards usually set a minimum for current practice baseline efficiency, the default RTF and power planning approach would be to use the CBI performance standards as minimum performance levels in the baseline.

However, the CBI differs from typical codes and standards improvements in an important way. Whereas code improvements usually seek to lock in efficiency levels after program initiatives, incentives, and prior code options have built up the necessary trade capacity, the CBI targets are well beyond what existing design and trade capacity can meet at the scale needed for statewide compliance. The Washington State Department of Commerce intends that utility programs will play a pivotal role in building up capacity to meet the targets. Because of this, the CBI targets were not used as minimum performance standards in the baseline for the 2021 Power Plan, which means that efficiency gains from existing performance levels to CBI-compliant levels may be counted as program savings.

Following the 2021 Power Plan assumptions, the candidate framework assumes that CBI performance thresholds do not define performance levels in the baseline for deep-savings interventions.

Summary of Baseline Principles

This section summarizes all of the principles that make up the candidate approach to defining the baseline. We begin with general principles that apply to all deep-savings interventions, then present additional elements for new construction and retrofit projects.

For all projects:

- CBI performance thresholds are treated as program tools for recruiting program participants, so these thresholds do not define baseline efficiency levels for any deep-savings intervention.
- Baseline equipment is always assumed to use the same fuel types as the actual efficient-case equipment.

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[7] At the time of this writing, the State of Oregon is considering its own set of standards but those have not been signed into law. We are not aware of major policy shifts towards mandatory state-wide performance standards in Idaho or Montana.

For new construction projects:

- New construction applications use a current practice baseline that reflects the market-average energy consumption among all options that use the same fuel mix as the actual equipment selection, and which make sense for the given application context.

For existing-building projects:

- Improvements to long-lived physical elements (especially shell components) typically use an existing conditions baseline for the entire measure life.
  - For projects that include both shell upgrades and HVAC fuel switching, measure analysis should assume fuel choice is made first, so that shell improvements save energy in the efficient-case fuel type.
- Early replacement improvements to systems with moderate lifespans typically use a dual baseline with two savings periods, provided there is no fuel switching.
- First period analysis in applications without fuel switching uses an existing-conditions baseline.
- Second period analysis in same-fuel retrofits, and the entire measure life in fuel switching applications, use a current practice equipment baseline and a mixed operational baseline.
  - The current practice equipment baseline reflects the market mix of equipment options that use the same fuel as the actual efficient-case selection, and which make sense for the given application context.
  - Baseline operational assumptions vary by equipment type in the current practice mix:
    - Pre-case operational characteristics are assumed for portions of the current practice equipment mix that are similar to pre-existing equipment.
    - Market-average operational characteristics are assumed for portions of the current practice equipment mix that are not similar to pre-existing equipment.

In all cases, savings and costs are calculated as incremental to the defined baseline, and costs are net of federal incentives or grants.

Existing Building Retrofit Examples

This section demonstrates how the principles of the previous section can be applied to evaluate energy impacts from actual deep-saving retrofits in existing buildings. We do not include new construction examples because those use purely current-practice baselines and therefore avoid the complicated parts of the baseline logic.

The examples use data from a high-efficiency DOAS pilot project sponsored by the Northwest Energy Efficiency Alliance (NEEA, 2020), whose projects include a mix of upgrades to HVAC systems, lighting, and shell components. The NEEA report describes project characteristics and pre/post energy data for retrofits of eight commercial spaces, including two restaurants with conditioned areas of just over 1,000 square feet each and six other spaces with conditioned square footage in the 5,000 to 25,000 range. This section walks through two of these cases to illustrate a potential evaluation approach. The examples are both organized as follows:

- Project description
- Narrative description of defined baseline based on principles from the previous section
- Project energy data and estimated energy impacts relative to defined baseline
- Incremental costs relative to defined baseline

We will see that even with ideal data, a mix of empirical estimates and engineering judgment is needed to estimate savings relative to the defined baseline when the intervention affects multiple building components. In practice, further simplifying assumptions would likely be needed to apply the framework to a large number of buildings in a utility program. We discuss some likely examples in the conclusion section.

Portland Law Office

Project description. This project was a renovation of an 11,615 ft^2 law office in Portland, Oregon. The report mentions that retrofit included multiple upgrades (NEEA 2020, p. 46):

- Shell: Window upgrades and ceiling insulation
- Lighting: Upgrades to LED lighting
- HVAC: Conversion from gas RTUs to a VRF system with DOAS and HRV

Table 2 summarizes HVAC equipment before and after conversion.

Table 2. Law Office HVAC Conversion Equipment Characteristics

	HVAC type	Total capacity		Zones
Existing system	9: Gas RTUs	35 tons cooling	43 tons heating	9
Retrofit system	1: VRF	16 tons cooling	18 tons heating	8
	4: DOAS + HRV	4 × 1,025 cfm max.		4

One striking feature in Table 2 is that retrofit heating and cooling capacities are less than half of pre-existing capacities. This is enabled by three factors: reduced thermal loads from shell improvements, reduced thermal load through ventilation improvement and heat recovery, and increased design focus on equipment sizing. These are not uncommon features in deep-savings retrofits, and they can have important implications for incremental costs relative to the baseline. We will discuss incremental costs after estimating energy impacts relative to baseline.

Defined baseline. The candidate framework has several implications for this project's baseline definition. We list those implications here, with the understanding that shortcuts will be needed to estimate energy characteristics of the defined baseline in a practical analysis:

- Lighting: First-period savings use existing conditions baseline. Second-period savings use a current practice baseline.
    - Current practice lighting is dominated by LEDs, similar to the retrofit system.
    - Main lighting energy savings take place in the first period.
    - Second period energy impacts are very small relative to LED-dominated baseline.[8]
    - Main incremental lighting costs amounts to shifting retrofit expenditures from natural replacement time to the retrofit's early replacement time.

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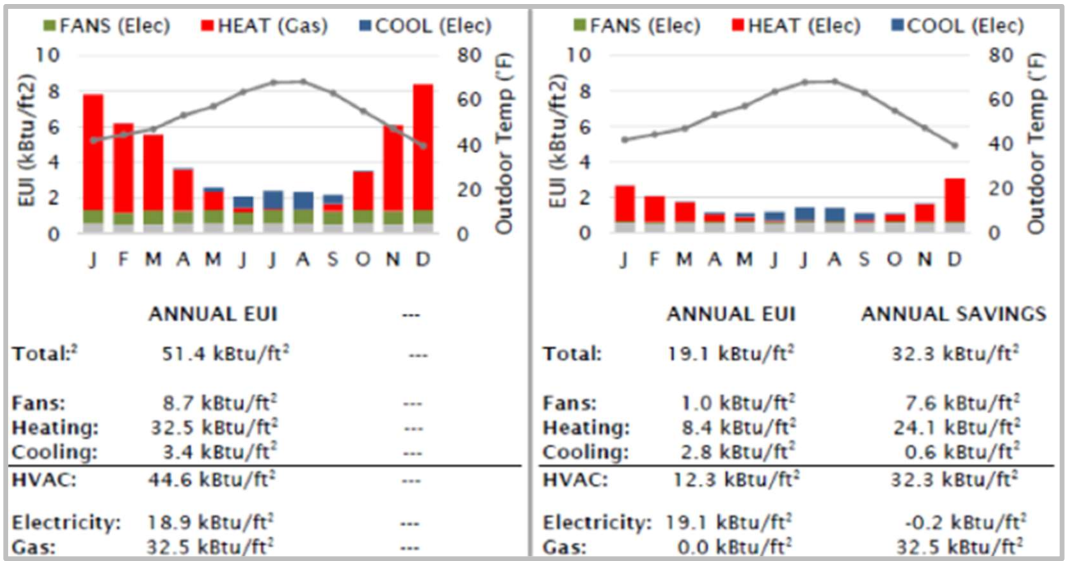
[8] For additional detail, see RTF Standard Protocol for Code-Compliant Non-Residential Lighting, https://rtf.nwcouncil.org/standard-protocol/non-residential-lighting-code-compliant/

- Shell: Existing conditions baseline
    - Energy impacts are incremental to a baseline defined by the pre-existing shell and the defined (electric) HVAC baseline.
    - Incremental cost is full direct cost of the shell improvement (because baseline is existing conditions).
- HVAC: Efficient-case fuel differs from pre-existing fuel, so HVAC equipment baseline is current practice, defined as the market mix of options that would make sense for the given application, and which use the same fuel as the efficient-case selection.
    - Conventional HP RTUs (without DOAS) likely dominate the current market for electric options in RTU retrofits. (For simplicity, the calculations that follow assume 100% HP RTUs in the current practice equipment baseline.)
    - Since HP-RTUs are operationally similar to gas-RTUs, the baseline assumes operational characteristics similar to the pre-case.
    - Incremental costs and savings are counted relative to expected costs of new standard-efficiency HP RTUs.

Energy data and estimated impacts. Figure 1 summarizes annual energy data for this site, before and after the retrofit project. Our task is to use this data to estimate savings relative to the baseline definition just described.

Figure 1. Portland Law Office, Pre-Post Energy Data



	ANNUAL EUI	---
Total:	51.4 kBtu/ft²	---
Fans:	8.7 kBtu/ft²	---
Heating:	32.5 kBtu/ft²	---
Cooling:	3.4 kBtu/ft²	---
HVAC:	44.6 kBtu/ft²	---
Electricity:	18.9 kBtu/ft²	---
Gas:	32.5 kBtu/ft²	---

	ANNUAL EUI	ANNUAL SAVINGS
Total:	19.1 kBtu/ft²	32.3 kBtu/ft²
Fans:	1.0 kBtu/ft²	7.6 kBtu/ft²
Heating:	8.4 kBtu/ft²	24.1 kBtu/ft²
Cooling:	2.8 kBtu/ft²	0.6 kBtu/ft²
HVAC:	12.3 kBtu/ft²	32.3 kBtu/ft²
Electricity:	19.1 kBtu/ft²	-0.2 kBtu/ft²
Gas:	0.0 kBtu/ft²	32.5 kBtu/ft²

Source: (NEEA, 2020, p. 49)

Figure 1 includes a breakdown of annual energy for heating, cooling, and fans, both before and after the retrofit. The HVAC baseline is defined as a system of standard HP RTUs with similar operation to pre-existing conditions. Here, we interpret "similar operation to pre-existing conditions" in terms of the heating, cooling, and fan output during the pre-retrofit period.[9] With this understanding, the pre-retrofit energy data in the left-hand side of Figure 1 provides a clear basis for estimating energy consumption consistent with our baseline definition:

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[9] This ignores HVAC interactions with lighting. In cases where this effect is expected to be significant, it could make sense to increase the baseline heating load and decrease the baseline cooling loads to reflect the reduction in

- Heating: Actual pre-case EUI = 32.5 kBtu/sf
    - Assumption 1: Actual pre-case gas heating efficiency η = 80%
    - Assumption 2: New standard-efficiency HP RTU has effective COP = 2.5
    - Result: Baseline heating EUI = 32.5 * 0.8 / 2.5 = 10.4 kBtu/sf
- Cooling: Actual pre-case EUI = 3.4 kBtu/sf
    - Assumption: New HP RTU would improve in situ cooling efficiency by 10%
    - Result: Baseline cooling EUI = 3.4 / 1.1 = 3.1 kBtu/sf
- Fan: Actual pre-case EUI = 8.7 kBtu/sf
    - Assumption: New HP RTU would improve fan efficiency by 10%
    - Result: Baseline fan EUI = 8.7 / 1.1 = 7.9 kBtu/sf

Energy savings for each end-use is estimated as the simple difference between the calculated baseline EUIs and the actual post-case EUIs:

- Heating savings: 10.4 - 8.4 = 2.0 kBtu/sf = 0.59 kWh/sf
- Cooling savings: 3.1 - 2.8 = 0.3 kBtu/sf = 0.09 kWh/sf
- Fan savings: 7.9 - 1.0 = 6.9 kBtu/sf = 2.02 kWh/sf

These figures account for both HVAC and shell savings. Lighting savings would need additional calculations, possibly based entirely on engineering judgment, and these calculations could include HVAC savings adjustments if interactive effects are expected to be significant. Since the lighting baseline changes to efficient LEDs for second-period savings, the lighting savings are zeroed out in the second period, but calculated lighting-HVAC interactions would still apply to HVAC savings in the second period (because the baseline assumes efficient lighting for that period).

This particular site had relatively good performance prior to the retrofit. Its total EUI was 51.4 kBtu/sf, which is significantly lower than the CBSA averages for office or retail. In fact, it is more than 20% lower than the first round of WA CBI targets for either of these space types. These facts suggest that this site's HVAC system functioned relatively well prior to the retrofit. Even so, its energy savings total was 2.0 + 0.3 + 6.9 = 9.2 kBtu/sf = 2.7 kWh/sf, which is 43% of total baseline HVAC energy (10.4 + 3.1 + 7.9 = 21.4 kBtu/sf = 6.3 kWh/sf).

Additional analysis would be needed to estimate demand impacts. Possible approaches could involve project-specific energy modeling, interval-level metered data, or an existing load shape library.

Incremental costs. To calculate cost-effectiveness, the evaluator would need both actual project costs and estimated baseline costs since the baseline assumes HP-RTU installation (immediately) and LED lighting conversion (at the next natural replacement time). Insofar as typical market sizing practices imply greater HVAC capacity in the baseline than what was actually installed in the efficient case, that would need to be reflected in the baseline costs. Also, the NEEA report notes that because of the way DOAS simplifies HVAC control logic, they were able to avoid a standard control package that adds significant expense to many HVAC systems. Insofar as complex control systems would be needed in the baseline system, that expense should be

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internal gains. Such calculations would need to be informed by engineering judgment if the effect was not directly discernable from available data.

included in baseline costs. In a follow-on study, NEEA examined efficiency and cost parameters associated with the pilot projects. That study estimates typical costs to be $18.7/sf for the baseline HP-RTU system and $21.6/sf for the VRF+DOAS+HRV system, which yields an incremental HVAC cost estimate of $2.9/sf (Bulger and Kekare 2022, Fig. 8, p. 17).

Additional costs are needed for insulation and window upgrades, and for costs associated with shifting the lighting upgrade forward in time. The NEEA report does not provide details for these costs. General resources such as those provided by the Seattle Office of Sustainability and Environment (Seattle OSE, 2022) provide wide costs ranges, but project specific data is needed because actual costs can be highly dependent on context (for example, is the ceiling insulation being added as part of a scheduled re-roofing project).

Seattle Airport Terminal

Project description. This section summarizes what is obtained when the analysis steps demonstrated in the previous section are applied to building with notably inefficient pre-case operation. This example was an HVAC retrofit in a 25,200 ft^2 airport terminal in Seattle, Washington. The NEEA report mentions that a prior remodel included improvements to lighting, ceiling insulation, and windows so these were reasonably efficient before the retrofit project (NEEA 2020, p. 39) and were not further improved as part of the project.

Similar to the previous example, the retrofit involved replacing a gas RTU system with VRF and DOAS with heat recovery. As before, there was significant cost efficiency obtained from simplified control needs and reduced system capacity. (The retrofit reduced nominal heating and cooling capacities by roughly two thirds relative to the existing system.)

Defined baseline. The baseline is simplified because this project only included HVAC updates. The candidate framework indicates that the equipment baseline is defined as the current practice mix of electric equipment options that would make sense for a similar building with a pre-existing RTU system. For simplicity, this example assumes that the current practice mix is 100% standard-efficiency HP RTUs without DOAS. Since HP RTUs are operationally similar to gas RTUs, the candidate framework indicates that the baseline HP RTUs should have operational characteristics similar to pre-existing operation.

Energy data and estimated impacts. As before, we calculate baseline HVAC energy and compare to efficient-case energy by end-use:

- Heating: Actual pre-case: 44.6 kBtu/sf (gas) + 0.9 kBtu/sf (electric resistance)
  - Baseline heating: 44.6 * 0.8 / 2.5 + 0.9 = 14.1 + 0.9 = 15.0 kBtu/sf
  - Efficient-case heating: 8.1 kBtu/sf
- Cooling: Actual pre-case: 7.9 kBtu/sf
  - Baseline cooling: 7.9 / 1.1 = 7.2 kBtu/sf
  - Efficient-case heating: 2.4 kBtu/sf
- Fan: Actual pre-case: 33.9 kBtu/sf
  - Baseline fan: 33.9 / 1.1 = 30.8 kBtu/sf
  - Efficient-case heating: 2.8 kBtu/sf

Energy savings for each end-use is estimated as the simple difference between the calculated baseline EUIs and the actual post-case EUIs:

- Heating savings: 15.0 - 8.1 = 6.9 kBtu/sf = 2.0 kWh/sf
- Cooling savings: 7.2 - 2.4 = 4.8 kBtu/sf = 1.4 kWh/sf
- Fan savings: 30.8 - 2.8 = 28.0 kBtu/sf = 8.2 kWh/sf

This site performed poorly prior to the retrofit. Its actual pre-case HVAC EUI was 87.3 kBtu/sf, which is significantly higher than the CBSA averages for office or retail. The baseline energy calculated under the candidate framework is 53 kBtu/sf (15.5 kWh/sf), which tells us that the operational dysfunction observed at this site would be highly energy intensive even if the heating load were being met with a standard-efficiency heat pump. The site's energy savings total was 6.9 + 4.8 + 28.0 = 39.7 kBtu/sf = 11.6 kWh/sf, which is only 75% of the total baseline HVAC energy (15.0 + 7.2 + 30.8 = 53.0 kBtu/sf = 15.5 kWh/sf).

Incremental costs. Similar to the law office example, the incremental HVAC costs (relative to the baseline of a HP-RTU retrofit) are estimated to be $2.9/sf. This project did not include other retrofits, so $2.9/sf represents the total incremental cost.

Conclusions

This paper shows that it is possible to define a baseline framework that navigates the major complications commonly encountered in deep-saving interventions and which satisfies these essential requirements:

- Consistency with principles and objectives of efficiency-as-a-resource power planning
- Practically applicable to yield reasonable results in real-world impact evaluations

The examples of the previous section involve a level of data quality that would not typically be available to an evaluator. The data granularity was helpful for illustrating how the defined baseline could be implemented in an ideal case. In more typical cases, evaluators might only have access to month-level energy consumption data, by fuel type, and (possibly) spot-meter values for pre-post fan power or other critical parameters (assuming forethought and early communication with implementers). Additional engineering judgment and analytical short-cuts would likely be needed to approximate the baseline with less-ideal data.

Energy impacts relative to the defined baseline are less dramatic than what is obtained from simple pre-post calculations with unit conversions and adjustments for combustion efficiency. This is largely due to the fact that for gas to electric conversions, the framework assumes heat pump equipment in the baseline, and heat pump heating is much more efficient than gas combustion heating. However, this assumption also adds significant heat pump conversion costs to the baseline, which reduces the incremental costs of the intervention. As the examples of the previous section illustrate, the net effect on cost-effectiveness is difficult to predict without completing the full exercise.

It is tempting to ask whether the less dramatic energy savings values calculated with the defined baseline are more "correct" than the pre-post unit conversion estimates. Our answer, of course, is that the defined baseline provides a better basis for counting impacts relative to our assumptions for what would occur naturally, which is the key question for integrating conservation as a power planning resource.

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