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Estimating Building End-use Energy Consumption Using CBECS, RECS and CEUS Data

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ABSTRACT

Estimating energy and cost savings associated with replacing existing equipment in commercial and multifamily buildings with new high efficiency equipment can be a daunting task. While dynamic building simulation modeling may be the preferred technical approach, the expense of using this data intensive, expensive and time-consuming method to support existing equipment replacements in small- to medium-size buildings (SMBs) is often cost prohibitive. As such, for SMB retrofits with limited budgets the energy professional is confronted with the challenge of finding a more cost-effective and less resource intensive approach. This paper discusses one such approach that focuses on developing good building end-use energy consumption data from which energy savings may be reasonably estimated. The approach relies on collecting a whole building's actual energy consumption data, determining the energy consumption of the building's end-uses by adjusting energy consumption data collected via publicly available government surveys on similar buildings, and combining this with conventional energy savings algorithms. Currently in use by Property Assessed Clean Energy (PACE) and other energy efficiency programs in the U.S., this approach has proven to provide a technically sound, reasonable energy cost savings estimate in a timely and cost-effective manner for SMB retrofits.

INTRODUCTION

Energy professionals are frequently asked to estimate the energy savings associated with replacing existing energy-consuming equipment such as heating, cooling, ventilation, and lighting systems with new high efficiency equipment in commercial and multifamily buildings, the majority of which are small-to-medium size buildings (SMBs) less than 50,000 ft^2.

The challenge is that while dynamic building simulation modeling remains the preferred technical approach for new buildings, the expense of using this analysis approach to support existing SMB equipment replacements often is not economically justifiable. Moreover, it can be foolhardy to waste significant time and resources to develop a savings estimate using simulation modeling that results in an unattractive business case for the SMB owner and causes the project to be delayed or canceled. As such, the energy professional is often faced with the challenge of finding an alternative more cost-effective and less complicated approach that can quickly provide reasonable estimates and be used by the SMB owner to evaluate the economic impact of alternative energy improvements.

In support of thousands of SMB energy improvement projects throughout the U.S., algorithms have been developed [1] and used to provide a quick and cost-effective estimate of the energy savings associated with high efficiency equipment upgrades in SMBs. These algorithms typically have been able to estimate the potential energy savings for high efficiency equipment replacement within ±20% of estimates in a fraction of the labor hours and cost typically associated with more rigorous approaches such as detailed spreadsheets or dynamic building simulation methods.

The principal objective of this paper is to assist energy professionals, project developers, contractors, building owners and managers with a technically sound approach better suited to SMB retrofit projects that can quickly and cost-effectively develop baseline building end-use (space heating, cooling, water heating, ventilation, lighting, etc.) energy consumption estimates for use in energy savings evaluations. Such estimates, for example, can enable a quick assessment of potential savings when replacing minimally code-compliant (standard) equipment with higher efficiency (above-code) equipment. Code-compliant equipment will typically have a lower first cost, but the lifetime energy cost savings of the higher efficiency equipment can often justify the upfront cost premium and result in a more cost-effective solution for the building owner. However, justifying the added expense of the higher efficiency equipment necessitates being able to provide the SMB owner with comparative energy and cost savings.

Interestingly, SMB owners who need to replace equipment that is near, has reached, or exceeded its useful life, usually solicit bids from local contractors to obtain "best" pricing. For competitive reasons, contractor bids typically propose the lowest price equipment that complies with the local building energy code. Unfortunately, due to a lack of expertise in estimating lifetime energy cost savings, rarely are energy cost implications addressed in these contractor proposals. As such, making the business case to the building owner for higher efficiency equipment, which usually comes at a cost premium, is rarely attempted. The approach advocated in this paper will enable energy professionals and contractors to provide building owners quickly and cost effectively with an estimate of energy savings, supporting the business case for high efficiency equipment investment.

GENERAL METHODOLOGY

The general methodology assumes that whole building energy consumption data are available, which is likely because utility bills are typically reviewed in any energy assessment. Two key tasks must then be undertaken:

(1) Estimate the baseline energy consumption of building end-uses; and
(2) Estimate the energy savings of the end-use(s) impacted by the replacement equipment.

Building baseline end-use energy consumption data are publicly available for commercial buildings in the U.S. from three publicly available sources. For commercial buildings in California there is the 2006 California Commercial End-Use Survey (CEUS). [2] For commercial buildings located elsewhere, there is the Energy Information Agency's (EIA's) 2018 Commercial Buildings Energy Consumption Survey (CBECS). [3] For multifamily buildings, there is the Energy Information Agency's 2020 Residential Energy Consumption Survey (RECS). [4] However, using this end-use energy consumption data directly may result in significant error stemming from how these data are provided, i.e., typically representing large geographic regions that can encompass significant variation in differing weather conditions (and thus different building energy use profiles). As such, the data must be adjusted to facilitate its use accurately.

Assuming the energy efficiency metrics associated with the existing equipment being replaced and the new high efficiency replacement equipment is known (which should be the case), available industry standard algorithms can be employed to estimate the energy consumption savings (refer to Table A1). [5]

END-USE DATA ADJUSTMENT RATIONALE

CBECS end-use energy consumption data are available by property type nationwide in the U.S. but not by climate zone for each property type. This presents an issue that can introduce significant error in building energy consumption analysis. As such, CBECS national end-use energy consumption data must be adjusted for weather conditions that may exist at a specific building's location.

RECS is a national sample survey that collects information on the stock of U.S. residential buildings, including their energy-related building characteristics and energy consumption data. Residential buildings include attached and detached single family homes, apartments with less than five units and apartment complexes with five or more units and mobile homes. RECS end-use energy consumption data for multifamily apartment buildings typically considered a part of the commercial sector are available for the nine U.S. Census Regions. However, without adjustment for weather conditions that may exist at a specific building's location, direct use of the data can introduce significant error in multifamily building end-use energy consumption analysis.

CEUS provides weather-normalized building end-use energy consumption data for commercial buildings in California for the service areas of Pacific Gas & Electric (PG&E), San Diego Gas & Electric (SDG&E), Southern California Edison (SCE) and the Sacramento Municipal Utility District (SMUD). Such broad service area coverage, however, presents an issue similar to the above data sources that can introduce error in end-use energy consumption analysis. As such, CEUS end-use energy consumption data must also be adjusted for weather conditions that may exist at a specific building's location within the service area.

THE ADJUSTMENT PROCESS

End-use data adjustments can be made using heating degree day (HDD) and cooling degree day (CDD) data. HDD and CDD data are typically recorded for the airport/weather station located nearest to the building (e.g., www.degreedays.com). However, there are more sophisticated methodologies [1] using multiple weather stations combined with local climate data to obtain even more localized HDD and CDD data for a building.

For 2018 CBECS data adjustment, the following data collection would be required for the building being analyzed:

- Building type (office, retail, lodging, warehouse, etc.) and location
- Whole building energy consumption and unit cost data (which should be readily available by reviewing the building's utility invoices)
- The specific year that the whole building energy consumption data were collected (it is assumed in this analysis that a full 12-month calendar year is being evaluated; however, the analysis period can be for any 12-month period)
- 2018 CBECS national end-use energy consumption allocation (percentages) for the specific building type
- National HDD and CDD in 2018 (see Table A2)
- HDD and CDD in 2018 at the building's location
- HDD and CDD for the year the whole building energy consumption data were collected
- Typical or average HDD and CDD for the geographic area where the building is located. [5]

For the 2020 RECS data adjustment, the following is required for an apartment complex with five or more units:

- Apartment location
- Whole building energy consumption data
- The specific year that the whole building energy consumption and unit cost data were collected
- 2020 RECS Census Region (division) end-use energy consumption allocation (percentages) for apartment complexes with five or more units
- 2020 census division HDD and CDD [5]
- HDD and CDD in 2020 at the apartment's location
- HDD and CDD for the year in which the whole building energy consumption data were collected
- Typical or average HDD and CDD for the geographic area where the apartment building is located.

For the 2006 CEUS data adjustment, the following is required:

- Building type and location
- Whole building energy consumption and unit cost data
- The specific year that the whole building energy consumption data were collected
- The CEUS weather-normalized end-use energy consumption allocation (percentages) for the building type and utility service area
- HDD and CDD for the year the whole building energy consumption data were collected
- Typical or average HDD and CDD for the geographic area where the building is located.

With these data, the weather-normalized whole building energy use intensity (EUI, in units of kBtu/ft^2-yr) and the energy consumption of the building end-uses can be estimated. The CBECS and RECS data adjustment methodology assumes that the building being analyzed behaves similar to the 50th percentile (median) CBECS and RECS data for the building type, and that the heating and cooling energy consumption end-uses will represent the principal end-uses impacted by weather. The CEUS data adjustment assumes the building's weather-normalized end-use energy consumption allocation is approximately the same for the building being evaluated and that the heating and cooling energy consumption end-uses will be the principal end-uses impacted by weather.

EXAMPLE CASE STUDIES

The following three cases illustrate how the adjustment process works with the CBECS, RECS and CEUS data. The goal for each of these cases is to estimate the weather-normalized end-use energy consumption, which represents the baseline from which the energy savings can be estimated.

2018 CBECS Data Case

Office Building in Denver, CO

Baseline utility data (1 year) for 2022with whole building EUI at 75.6 kBtu/ft^2-yr.

Objective: Determine the baseline normalized energy consumption of the building end-uses relying on 2018 CBECS data.

Data Collected for Denver

	Avg. Denver	2018 Denver	2022 Denver	2018 U.S (See Table A2)
HDD	5,942	5,632	6,001	4,291
CDD	777	1,026	1,168	1,579

CBECS National Office Data for 2018

	kBtu/ft^2-yr	%
Cooling	5.1	7.8
Heating	20.1	30.6
Ventilation	12.9	19.7
Lighting	7.8	11.9
DHW*	1.0	1.5
Other	18.7	28.5
Total	65.6	100.0

* Domestic hot water (DHW)

It is now necessary to adjust CBECS national data in 2018 for the building's location in Denver. This is done by correcting the 2018 CBECS heating and cooling energy consumptions (assuming they will be the principal end-uses impacted by weather).

Heating end-use adjustment factor = 5,632/4,291 = 1.3125

Cooling end-use adjustment factor = 1,026/1,579 = 0.65

All other end-use EUIs remain the same.

The 2018 CBECS data adjusted for the building's location in Denver become the following.

	kBtu/ft^2-yr	%
Cooling	3.3	4.7
Heating	26.4	37.7
Ventilation	12.9	18.4
Lighting	7.8	11.1
DHW	1.0	1.4
Other	18.7	26.7
Total	70.1	100.0

Because the whole building energy consumption was collected for the year 2022, the 2018 end-use data must be adjusted to 2022.

Heating end-use adjustment factor = 6,001/5,632= 1.0655

Cooling end-use adjustment factor = 1,168/1,026 = 1.1384

All other end-use EUIs remain the same.

The 2018 Denver data adjusted to 2022 become the following.

	$kBtu/ft^2$-yr	%
Cooling	3.8	5.26
Heating	28.1	38.87
Ventilation	12.9	17.84
Lighting	7.8	10.79
DHW	1.0	1.38
Other	18.7	25.86
Total	72.3	100.00

Assuming the 2022 end-use allocation percentages remain approximately the same and knowing that the 2022 whole building EUI is 75.6 kBtu/ft^2-yr, the 2022 end-use energy consumptions can now be determined.

	%	$kBtu/ft^2$-yr
Cooling	5.26	3.98
Heating	38.87	29.39
Ventilation	17.84	13.49
Lighting	10.79	8.16
DHW	1.38	1.04
Other	25.86	19.55
Total	100.00	75.6

It is now possible to determine the weather-normalized end-use energy consumption and weather-normalized whole building energy consumption. This is accomplished by adjusting the 2022 end-use data to obtain weather-normalized data.

Heating end-use adjustment factor = 5,942/6,001 = 0.99.
Cooling end-use adjustment factor = 777/1,168 = 0.665.
All other 2022 end-use EUIs remain the same.

The weather-normalized baseline whole building energy consumption and weather-normalized end-use energy consumptions can now be determined for energy savings estimation and are summarized here.

	$kBtu/ft^2$-yr	%
Cooling	2.65	3.58
Heating	29.10	39.33
Ventilation	13.49	18.23
Lighting	8.16	11.03
DHW	1.04	1.41
Other	19.55	26.42
Total	73.99	100.00

Weather-normalized data are used in energy savings calculations because energy savings can only be realized in the future after new high efficiency equipment is installed. Unfortunately, the weather that will exist at that time is not known; however, long-term average weather data are generally available. As such, assuming future weather approaches long-term average weather is a reasonable assumption to evaluate future long-term energy savings using weather-normalized data.

CEUS Data Case

Large Office Building in San Francisco, CA

Baseline utility data (1 year) for 2023 with whole building EUI at 86.5 kBtu/ft^2-yr.

Objective: Determine the baseline weather-normalized energy consumption of building end-uses relying on weather-normalized CEUS data.

Data Collected for San Francisco

	Average	2023	
HDD	2,708	2,530	(2023 experienced a warmer winter)
CDD	142	40	(2023 experienced a much cooler summer)

CEUS Large Office Weather-Normalized Whole Building Data (natural gas and electricity) in PG&E's service area [5] is provided as follows.

	kBtu/ft^2-yr	%
Cooling	10.58	13.03
Heating	22.27	27.43
Ventilation	10.17	12.53
Lighting	15.56	19.17
DHW	2.98	3.67
Other	19.62	24.17
Total	81.18	100.00

The CEUS weather-normalized whole building EUI is 81.18 kBtu/ft^2-yr. The unknown is whether this whole building EUI would result in an actual whole building EUI of 86.5 kBtu/ft^2-yr in 2023. If it is approximately the same, then the CEUS weather-normalized end-use energy consumptions can be used for energy savings estimation. However, if it is different, then the CEUS weather-normalized end-use energy consumptions need to be adjusted to better reflect actual building performance.

If the actual 2023 cooling end-use energy consumption is x and space heating end-use energy consumption is y, then the normalized cooling end-use energy consumption would be 142/40 or 3.55 * x. The normalized space heating end-use energy consumption would be 2,708/2,530 or 1.0704 * y. All other end-use energy consumptions would remain the same.

To accomplish adjustment of the CEUS weather normalized end-use energy consumptions to reflect actual building performance requires a bit of mathematics (again assuming weather principally impacts the heating and cooling end-uses and that the weather-normalized end-use percentages remain approximately the same):

Let x = the actual cooling end-use energy consumption
Let y = the actual heating end-use energy consumption
Let z = the actual energy consumption of all other end-uses (not impacted by weather)
Let T = normalized whole building EUI calculated from the 2023 data

End-use	Actual 2023 EUI of End-uses	Normalized Total Bldg. EUI	Normalized CEUS End-use Percentages
Cooling	x	3.55 * x	13.03%
Heating	y	1.0704 * y	27.43%
Other	z	z	59.54%
Total	86.5	T	

The following equations can be used to calculate the unknowns (x, y, z and T):

$$x + y + z = 86.5$$
$$3.55\,x + 1.0704\,y + z = T$$
$$0.1303\,T = 3.55\,x$$
$$0.2743\,T = 1.0704\,y$$
$$0.5954\,T = z$$

Solving for the unknowns results in:

x = 3.57
y = 24.96
z = 57.98
T = 97.37

Because the weather-normalized whole building energy consumption is 97.37 kBtu/ft^2-yr for the actual building, this is greater than the CEUS whole building energy consumption of 81.18 kBtu/ft^2-yr. As such, the CEUS weather-normalized end-use energy consumption needs to be adjusted to better reflect the building's actual location.

Assuming again that the CEUS end-use energy consumption allocations (end-use percentage of normalized whole building energy consumption) are approximately the same, then the end-use energy consumption can be adjusted as follows:

Cooling	= 0.1303 * 97.37 = 12.69 kBtu/ft^2-yr
Space Heating	= 0.2743 * 97.37 = 26.71 kBtu/ft^2-yr
Other	= 0.5954 * 97.37 = 57.97 kBtu/ft^2-yr

(The Other category in the above calculations includes ventilation, lighting, DHW heating and a new "other" end-use category whose total energy consumption (z) is 57.97 kBtu/ft^2-yr. However, how the energy consumption is allocated in this Other category needs to be estimated. This can be accomplished by using the percentage allocation determined from the CEUS data, i.e., individual end-use energy consumption divided by the total energy consumption of ventilation, lighting, DHW heating and Other end-uses (48.33 kBtu/ft^2-yr).

The percentage allocation becomes: ventilation at 10.17/48.33 or 21.04%, lighting at 15.56/48.33 or 32.2%, DHW heating at 2.98/48.33 or 6.16% and other at 19.62/48.33 or 40.6%. This results in a ventilation end-use energy consumption of 0.2104 * 57.97 kBtu/ft^2-yr or 12.2kBtu/ft^2-yr, a lighting end-use of 0.322* 57.97 kBtu/ft^2-yr or 18.67 kBtu/ft^2-yr, a DHW heating end-use of 0.0616 * 57.97 kBtu/ft^2-yr or 3.57 kBtu/ft^2-yr, and a new "Other" category at 0.406 * 57.97 kBtu/ft^2-yr or 25.53 kBtu/ft^2-yr.)

This results in adjusted weather-normalized end-use energy consumptions (shown here) that can be used to estimate energy savings.

	kBtu/ft^2-yr	%
Cooling	12.69	13.03
Heating	26.71	27.43
Ventilation	12.20	12.53
Lighting	18.67	19.17
DHW	3.57	3.67
Other	23.53	24.17
Total	97.37	100.00

RECS Data Case

Apartment Building in Detroit, MI

Natural gas use for space heating

Objective: Determine the baseline normalized energy consumption of the end-uses relying on 2020 RECS data.

Data Collected

An audit of 2011 utility bills found that whole building energy consumption (electricity and natural gas) was 54.8 kBtu/ft^2-yr.

HDD and CDD data were as follows.

	Avg. Detroit	2011 Detroit	2020 Detroit	2020 East North Central Division Data for RECS [5]
HDD	6,183	6,656	5,674	5,855
CDD	775	694	988	831

2020 RECS apartment (five or more units in the Mid-West Census Division) end-use energy consumption and end-use percentage allocation (percentage of whole building energy consumption) data [4] are provided below:

	kBtu/ft^2-yr	%
Cooling	2.74	6.4
Heating	18.23	42.6
Refrigeration	1.97	4.6
DHW	10.96	25.6
Other	8.90	20.8
Total	42.80	100.0

The 2020 RECS data are by U.S. Census Region and Division. The Midwest Region (which includes the East North Central Division) covers multiple states, including IL, IN, MI, OH, WI, IA, KS, MN, MO, NE, ND and SD. As such, the 2020 RECS data need to be adjusted to Detroit, MI, where the building is actually located. This is accomplished by adjusting the cooling and space heating end-use energy consumptions:

Heating end-use adjustment factor = 5,674/5,855 = 0.969

Cooling end-use adjustment factor = 988/831 = 1.189

All other end-use EUIs remain the same.

The adjusted RECS data for an apartment building in Detroit, MI, in 2020 are then:

	$kBtu/ft^2$-yr	%
Cooling	3.26	7.63
Heating	17.66	41.31
Refrigeration	1.97	4.61
DHW	10.96	25.64
Other	8.90	20.81
Total	42.75	100.00

Assuming the end-use percentage allocations are approximately the same, the new end-use energy consumptions in 2020 can be estimated if the "actual" 2020 whole building EUI is known. The "actual" whole building EUI in 2020 can be estimated knowing the "actual" whole building EUI in 2011 (54.8 $kBtu/ft^2$-yr), assuming the building experienced no major operational or renovation changes since 2011.

If the actual 2011 cooling end-use energy consumption is x and space heating end-use energy consumption is y, then the 2020 cooling end-use energy consumption would be 988/694 or 1.4236 * x. The 2020 space heating end-use energy consumption would be 5,674/6,656 or 0.8525 * y. All other end-use energy consumptions would remain the same.

To accomplish getting the end-use energy consumptions requires a bit of mathematics (again assuming weather principally impacts the heating and cooling end-uses and that the 2020 end-use percentages of the whole building EUI remain approximately the same):

Let x = the actual cooling end-use energy consumption
Let y = the actual heating end-use energy consumption
Let z = the actual energy consumption of all other end-uses (not impacted by weather
Let T = whole building EUI calculated from the 2020 data

End-use	Actual 2011 EUI of End-uses	2020 "Actual" Total Bldg. EUI	2020 End-use Percentages*
Cooling	x	1.4236 * x	7.63%
Heating	y	0.8525 * y	41.31%
Other	z	z	51.06%
Total	54.8	T	

*2020 adjusted (for Detroit) RECS end-use allocation (percentage of whole building EUI) is assumed to be a reasonable approximation for end-use allocation (%).

The following equations can be used to calculate the unknowns (x, y, z and T):

$$x + y + z = 54.8$$
$$1.4236\,x + 0.8525\,y + z = T$$
$$0.0763\,T = 1.4236\,x$$
$$0.4131\,T = 0.8525\,y$$
$$0.5106\,T = z$$

Solving for the unknowns results in:

$$x = 2.80$$
$$y = 25.32$$
$$z = 26.68$$
$$T = 52.24$$

The 2020 "actual" whole building EUI and end-use energy consumptions would then be:

	EUI, kBtu/ft^2-yr	%
Heating	21.58	41.3
Cooling	3.98	7.6
Other	26.68	51.1
Total	52.24	100.0

The 2020 data now need to be weather-normalized for the energy savings calculations:

Heating end-use adjustment factor = 6,183/5,674 = 1.09
Cooling end-use adjustment factor = 775/988 = 0.7844
Assume all other end-use EUIs remain the same.

(The Other category in the above calculations includes the refrigeration, DHW heating and a new "other" end-uses whose total energy consumption (z) is 26.68 kBtu/ft^2-yr. However, how the energy consumption is allocated in this Other category needs to be estimated. This can be accomplished by using the percentage allocation determined from the 2020 RECS data, i.e., individual end-use energy consumption divided by the total energy consumption of all end-uses (21.83 kBtu/ft^2-yr) comprising the other category.

The percentage allocation becomes: refrigeration at 1.97/21.83 or 9.02%, DHW at 10.96/21.83 or 50.21% and other at 8.90/21.83 or

40.77%. This results in a refrigeration end-use energy consumption of 0.0902* 26.68 kBtu/ft^2-yr or 2.4 kBtu/ft^2-yr, a DHW end-use of 0.5021 * 26.68 kBtu/ft^2-yr or 13.4 kBtu/ft^2-yr, and a new "other" category at 0.4077 * 26.68 kBtu/ft^2-yr or 10.88 kBtu/ft^2-yr).

The weather-normalized end-use energy consumptions to estimate energy savings are summarized below:

	kBtu/ft^2-yr	%
Cooling	3.12	5.85
Heating	23.52	44.11
Refrigeration	2.40	4.50
DHW	13.40	25.13
Other	10.88	20.41
Total	53.32	100.00

ESTIMATING THE PERCENT OF ENERGY CONSUMPTION SAVINGS

The percentage of energy consumption savings associated with equipment replacement can be estimated knowing the energy efficiency metrics of the existing equipment (referred to as the baseline) and the energy efficiency metrics of the new high efficiency equipment to be installed (refer to Table A1). Hence, for the CBECS case above, if the office building's existing rooftop units (RTUs, with an integrated energy efficiency ratio (IEER) = 8.5) were being replaced by high efficiency RTUs (IEER = 13.5), the estimated percentage energy savings would be (1 − (8.5/13.5)) = 37%. The energy consumption savings would then be approximately 0.37 * 2.65 kBtu/ft^2 = 0.98 kBtu/ft^2. In addition to an energy consumption savings, there would also be an energy demand savings. Energy consumption and demand savings algorithms for different systems are readily available in the literature. [5]

Another consideration in establishing baseline end-use energy consumption is when multiple energy efficiency measures are installed. The sequencing of these measures can be important because of interactive effects (and to avoid double counting the savings). The suggested approach is to keep adjusting the energy consumption of the impacted end-use as each additional efficiency improvement is made. Hence, if an LED lighting upgrade is proposed along with an RTU upgrade, the LED upgrade is assumed to be installed first and the kWh cooling reduction would be subtracted from the baseline space cooling end-use energy consumption (because the cooling needed in the summer months would be reduced by the LED lighting). At the same time, there would be an increase in the baseline space heating end-use energy consumption (because the heating needed in the winter months would be greater). Additional information on interactivity and sequencing is available in the literature. [5]

The energy efficiency metrics of the new system should be known or available, for example, in the manufacturer's literature. The energy efficiency metrics of the existing system being replaced, however, may not be so readily available. Fortunately, there are a number of ways existing system energy efficiency metrics may be estimated:

1. Original contractor or building owner files containing equipment specifications, or
2. Equipment nameplate information (manufacturer and model) and contacting the manufacturer, or
3. Knowing the age of the equipment (when it was installed), referring to the building code effective at that time, or
4. Assuming the equipment followed the 90.1 ASHRAE standard (or IECC standard) effective at the time of its installation.

Regardless of the methodology used to estimate existing equipment energy efficiency metrics, these metrics do not consider performance degradation that may have taken place since the equipment was installed. Therefore, an estimate of equipment average annual performance degradation over the period from the date of installation to the date of replacement must be made. Typical average annual performance degradation factors may be available from the manufacturer or are available in the literature. [5]

CONCLUSION

Building end-use energy consumptions can be estimated in a number of ways, including dynamic building energy simulation modeling, detailed spreadsheet modeling, equivalent full load hours (EFLH) and capacity calculations, graphical analysis of monthly electricity and natural gas usage (assuming the building only relies on air conditioning in the summer months and natural gas for space heating only in the winter months). Unfortunately, dynamic modeling can be time consuming and relatively expensive. EFLH and capacity calculations are sometimes relied upon by utilities in their Technical Resource Manuals [5], but any energy savings analysis can only be viewed as very approximate because of the relatively large geographic area covered. Buildings meeting the graphical analysis conditions generally are few and far between. In the final analysis, a weather-normalized baseline energy consumption analysis approach using calibrated CBECS, RECS or CEUS data can provide a cost effective and reasonable savings estimate compared to more complex and time-consuming methods. Energy savings analysis using this methodology will help support the business case for high efficiency equipment replacement investment.

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APPENDIX

Table A1.
Typical Energy Savings Algorithms for Select Equipment Replacement

Equipment Being Replaced	**Estimated Percent Savings**
Air Conditioning	$[1 - (IEER_{Existing} / IEER_{New})]$
Chiller	$[1 - (IPLV_{New} / IPLV_{Existing})]$
Space Heating	$[1 - (\eta_{Existing} / \eta_{New})]$
DHW	$[1 - (EF_{Existing} / EF_{New})]$
Lighting	$[1 - (LPD_{New} / LPD_{Existing})]$
where: IEER = Integrated Energy Efficiency Ratio, Btu cooling output/Watt-hr of electricity input IPLV = Integrated Part Load Value, kW input/ton output η = Average Fuel Utilization Efficiency, fraction EF = Energy Factor, fraction LPD = Lighting Power Density, Watts / ft^2	

Source: Buonicore [5]

Table A2.
U.S. National HDD and CDD Data for use with CBECS Data

Year	**HDD**	**CDD**
2018	4,291	1,579
2019	4,317	1,496
2020	3,914	1,519
2021	3,934	1,492
2022	4,240	1,556
U.S. Average	4,291	1,579

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