TECHNICAL REFERENCE MANUAL

Volume 3:

Commercial & Industrial Measures

State of Pennsylvania

Act 129 Energy Efficiency and Conservation Program

&

Act 213 Alternative Energy Portfolio Standards

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PUBLIC UTILITY COMMISSION

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3. COMMERCIAL & INDUSTRIAL MEASURES

3.1. LIGHTING

3.1.1. LIGHTING RETROFITS

Target Sector	Commercial and Industrial
Measure Unit	Lighting Equipment
Measure Life	LED Lighting Equipment: 15 years[Source 1] Permanent Lamp/Fixture Removal: 11 years[Source 2]
Measure Vintage	Early Replacement or Permanent Removal

ELIGIBILITY

Lighting improvements include fixture or lamp replacement and/or permanent removal in existing commercial and industrial customers' facilities. Since the EISA "backstop" provision introduced minimum efficacy standards for general service lamps (effective August 1, 2023), screw-based integrated LED lamps are no longer an eligible measure for lighting retrofit incentives. Eligible General Service Lighting consists of all other fixture and lamp types including, but not limited to, ballasted screw-in ("corn cob") lamps in high intensity discharge applications and hardwired/pin-based recessed cans.

Permanent fixture and lamp removal savings do not include replacements. Participants are responsible for determining whether permanent fixture and/or lamp removal will maintain or exceed minimum lighting requirements. To be eligible for savings from permanent fixture and lamp removal, customers must have permanently removed unneeded, functional light fixtures, lamps, lamp holders, and/or ballasts in accordance with local regulations. The removal of non-operational equipment is not eligible for the defined savings. Permanent lamp removal includes the permanent removal of existing 8', 4', 3' and 2' T8 fluorescent lamps. The savings are defined on a per-removed-lamp basis and don't include savings from lamp replacements.

The Energy Policy Act of 2005 ("EPACT 2005") and Energy Independence and Security Act ("EISA") 2007, and subsequent federal rulemakings, introduced new efficacy standards for linear fluorescent bulbs and ballasts, effectively phasing out magnetic ballasts (effective October 1, 2010) and most T-12 bulbs (effective July 14, 2012). Despite this change, Act 129 Non-Residential Baseline Studies continue to observe T-12 linear fluorescent lighting in Pennsylvania businesses. To address and convert this remaining hard-to-reach equipment the wattage of the existing T-12 fixture removed by program participants or contractors may be used as the baseline provided the existing fixture is in working condition at the time of the retrofit.

See Appendix E for general eligibility requirements for solid state lighting products in commercial and industrial applications.

ALGORITHMS

For all lighting fixture improvements (without control improvements), the following algorithms apply:

$$\Delta kWh = DeltakW \times [HOU \times (1 - SVG_{base}) \times (1 + IF_{energy})]$$

$$\Delta kW_{summer\ peak} = DeltakW \times [CF_s \times (1 - SVG_{base}) \times (1 + IF_{demand\_s})]$$

$$\Delta kW_{winter\ peak} = DeltakW \times [CF_w \times (1 - SVG_{base}) \times (1 + IF_{demand\_w})]$$

$$DeltakW = (kW_{base} - kW_{ee})$$

DEFINITION OF TERMS

Table 3-1: Terms, Values, and References for Lighting Retrofits

Term	Unit	Values	Source
kW_{base}, Connected load of the baseline lighting as defined by project classification	*kW*	See Fixture Identities in Appendix C Default Permanent Lamp Removal: Table 3-7	Appendix C
kW_{ee}, Connected load of the post-retrofit or energy–efficient lighting system	*kW*	See Fixture Identities in Appendix C For Permanent Fixture and/or Lamp Removal, $kW_{ee} = 0$	Appendix C
SVG_{base}, Savings factor for existing lighting control (percent of time the lights are off)	*None*	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-2	Table 3-2
CF_s, Summer coincidence factor	*Decimal*	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-3	Table 3-3
CF_w, Winter coincidence factor	*Decimal*	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-3	Table 3-3
HOU, Hours of Use – the average annual operating hours of the baseline lighting equipment, which if applied to full connected load will yield annual energy use.	$\frac{Hours}{Year}$	EDC Data Gathering	EDC Data Gathering
		Default General Service: Table 3-3 Default Street Lighting: Table 3-4	Table 3-3, and Table 3-4
IF_{energy}, Interactive Energy Factor – applies to C&I interior lighting in space that has air conditioning, electric space heating, or refrigeration. This represents the secondary energy impacts which results from the decreased waste heat from efficient lighting.	*None*	Exterior or Unconditioned: 0.00 Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6
IF_{demand_s}, Summer Interactive Demand Factor – applies to C&I interior lighting in space that has air conditioning or refrigeration only. This represents the secondary demand impact on the cooling system which results from the decreased waste heat from efficient lighting.	*None*	Exterior or Unconditioned: 0.00 Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6
IF_{demand_w}, Winter Interactive Demand Factor – applies to C&I interior lighting in space that has heating or refrigeration only. This represents the secondary demand impact on the heating system which results from the decreased waste heat from efficient lighting.	*None*	Exterior or Unconditioned: 0.00 Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6

Other factors required to calculate savings are shown in Table 3-2, Table 3-3, Table 3-4, Table 3-5, and Table 3-6. Note that if HOU is stated and verified by logging lighting hours of use groupings, actual hours should be applied. In addition, the site-specific coincidence factors must be used to calculate peak demand savings if actual hours are used.

Table 3-2: Savings Control Factors Assumptions

Strategy	Definition	Technology	Savings	Source
Switch	Manual On/Off Switch	Light Switch	0%	3
Occupancy	Adjusting light levels according to the presence of occupants	Occupancy Sensors	24%	
		Time Clocks	24%	
		Energy Management System	24%	
Daylighting	Adjusting light levels automatically in response to the presence of natural light	Photosensors	28%	
		Time Clocks	28%	
Personal Tuning	Adjusting individual light levels by occupants according to their personal preferences; applies, for example, to private offices, workstation-specific lighting in open-plan offices, and classrooms	Dimmers	31%	
		Wireless on-off switches	31%	
		Bi-level switches	31%	
		Computer based controls	31%	
		Pre-set scene selection	31%	
Institutional Tuning	Adjustment of light levels through commissioning and technology to meet location specific needs or building policies; or provision of switches or controls for areas or groups of occupants; examples of the former include high-end trim dimming (also known as ballast tuning or reduction of ballast factor), task tuning and lumen maintenance	Dimmable ballasts	36%	
		On-off or dimmer switches for non-personal tuning	36%	
Multiple Types	Includes combination of any of the types described above. Occupancy and personal tuning, daylighting and occupancy are most common.	Occupancy and personal tuning/ daylighting and occupancy	38%	
Networked Lighting Control	A networked lighting control system consists of an intelligent network of individually addressable luminaires and control devices, allowing for application of multiple control strategies, programmability, building- or enterprise-level control, zoning and rezoning using software, and measuring and monitoring.	Networking of luminaries and devices, Occupancy sensors, Photosensors, High-end trimming, Zoning, Continuous dimming	49%	16

Table 3-3: Lighting HOU and CF by Building Type for Other General Service Lighting

Building Type	HOU	CF_s	CF_w	Source
Education	2,371	0.45	0.41	4
Exterior, Photocell-Controlled (All Building Types)	4,305	0.11	0.58	5, 6
Exterior (All Building Types)	3,604	0.11	0.58	6
Grocery	6,471	0.93	0.84	4
Health	2,943	0.52	0.42	4
Industrial/Manufacturing - 1 Shift	2,857	0.96	0.82	6, 7
Industrial/Manufacturing - 2 Shift	4,730	0.96	0.82	6, 7
Industrial/Manufacturing - 3 Shift	6,631	0.96	0.82	6, 7
Institutional/Public Service	1,419	0.23	0.19	4
Lodging	3,579	0.45	0.49	4
Miscellaneous/Other	2,830	0.58	0.39	4
Multifamily Common Areas	5,950	0.73	0.76	6
Office	2,294	0.48	0.35	4
Parking Garage	8,678	0.98	0.99	6
Restaurant	4,747	0.77	0.65	4
Retail	2,915	0.66	0.41	4
Street Lighting	See Table 3-4	0.00	0.50	See Table 3-4
Warehouse	2,545	0.48	0.37	4

Table 3-4: Street lighting HOU by EDC

EDC	HOU	Source
Duquesne	4,200	8
PECO	4,100	9
PPL	4,300	10
Met-Ed	4,200	11
Penelec	4,200	12
Penn Power	4,070	13
West Penn Power	4,200	14

Table 3-5: Interactive Factors for Refrigerated Spaces

Values	IF_{energy}	IF_{demand_s}	IF_{demand_w}	Source
Freezer spaces (-35 °F – 20 °F)	0.50	0.50	0.50	15
Medium-temperature refrigerated spaces (20 °F – 40 °F)	0.29	0.29	0.29	
High-temperature refrigerated spaces (40 °F – 60 °F)	0.18	0.18	0.18	

Table 3-6: Interactive Factors for Conditioned Spaces for All Building Types

HVAC Configuration	IF_{energy}	IF_{demand_s}	IF_{demand_w}	Source
AC with Fossil Fuel Heat	0.0573	0.1379	0.0000	18
AC with Electric Heat	-0.0700	0.1379	-0.2880	
Fossil Fuel Heat Only	0.0000	0.0000	0.0000	
Electric Heat Only	-0.1273	0.0000	-0.2880	
Unknown (Market Average)	0.0256	0.0813	-0.0185	

Table 3-7: Connected Load of the Baseline Lighting

Lamp Length	Wattage Removed (kW_{base}) per Lamp	Source
	T8	
8-foot	0.0386	17
4-foot	0.0194	
3-foot	0.0146	
2-foot	0.0098	

EVALUATION PROTOCOLS

Methods for Determining Baseline Conditions

The following are acceptable methods for determining baseline conditions when verification by direct inspection is not possible as may occur in a rebate program where customers submit an application and equipment receipts only after installing efficient lighting equipment, or for a retroactive project as allowed by Act 129. In order of preference:

- Examination of replaced lighting equipment that is still on site waiting to be recycled or otherwise disposed of
- Examination of replacement lamp and ballast inventories where the customer has replacement equipment for the retrofitted fixtures in stock. The inventory must be under the control of the customer or customer's agent
- Interviews with and written statements from customers, facility managers, building engineers or others with firsthand knowledge about purchasing and operating practices at the affected site(s) identifying the lamp and ballast configuration(s) of the baseline condition
- Interviews with and written statements from the project's lighting contractor or the customer's project coordinator identifying the lamp and ballast configuration(s) of the baseline equipment

Detailed Inventory Form

A detailed lighting inventory is required for all lighting improvement projects. The lighting inventory form will use the algorithms presented above to derive the total $\Delta kW_{summer\ peak}$, $\Delta kW_{winter\ peak}$, and ΔkWh savings for each installed measure. Within a single project, to the extent there are multiple combinations of control strategies (SVG), hours of use (HOU), coincidence factors (CF) or interactive factors (IF), the ΔkW will be broken out to account for these different factors. This will be accomplished using Appendix C, a Microsoft Excel inventory form that specifies the lamp and ballast configuration using the "Fixture Identities" sheet and SVG, HOU, CF and IF values for each line entry. The inventory form will also specify the location and number of fixtures for reference and validation.

Appendix C was developed to automate the calculation of energy and demand impacts for retrofit lighting projects, based on a series of entries by the user defining key characteristics of the retrofit project. The "General Information" sheet is provided for the user to identify facility-specific details of the project that have an effect on the calculation of gross savings. Facility-specific details include contact information, electric utility, building area information, and operating schedule. The "Lighting Inventory" sheet is the main worksheet that calculates energy savings and peak demand reduction for the user-specified lighting fixture and controls improvements. This form follows the algorithms presented above and facilitates the calculation of gross savings for implementation and evaluation purposes. Each line item on this tab represents a specific area with common baseline fixtures, retrofit fixtures, controls strategy, space cooling, and space usage.

Baseline and retrofit fixture wattages are determined by selecting the appropriate fixture code from the “Fixture Identities” sheet. The sheet can also be used to find the appropriate code for a particular lamp-ballast combination by using the enabled auto-filter options. Actual wattages of fixtures determined by manufacturer’s equipment specification sheets or other independent sources may not be used unless (1) the manufacturer's cut sheet indicates that the difference in delta-watts of fixture wattages (i.e. difference in delta watts of baseline and “actual” installed efficient fixture wattage and delta watts of baseline and nearest matching efficient fixture in the “Fixture Identities” of Appendix C is more than 10% or (2) the corresponding fixture code is not listed in the “Fixture Identities” list. In these cases, alternate wattages for lamp-ballast combinations can be entered using the appropriate cells within the “Fixture Identities” tab. Rows 9 through 28 provide a guided custom LED fixture generator to be used with non-self-ballasted LEDs. All other custom cut sheets should be inputted into rows 932 through 981. Documentation supporting the alternate wattages must be provided in the form of manufacturer-provided specification sheets or other industry accepted sources (e.g. Design Lights Consortium listing). Submitted specification sheets must cite test data performed under standard ANSI procedures. These exceptions will be used as the basis for periodically updating the “Fixture Identities” to better reflect market conditions and more accurately represent savings.

Some EDC Implementation CSPs may have developed in-house lighting inventory forms that are used to determine reported savings estimates for projects and calculate rebate amounts. The Appendix C form is the preferred tool for reported and verified savings calculations. However, a ICSP lighting inventory form may be used for program delivery purposes provided it (1) includes all the same functionality, formulas, and calculation steps as the Appendix C form and (2) is approved by the SWE prior to being utilized to calculate reported savings. In the case where an ICSP tool produces a different savings estimate from the Appendix C calculator, the Appendix C result is considered to be the TRM-supported savings value. Appendix C will be updated periodically to include new fixtures and technologies available as may be appropriate. Additional guidance can be found in the “Manual” sheet of Appendix C.

Custom Hours of Use and Coincidence Factors

If the project cannot be described by the building type categories listed in Table 3-3, or if the facility’s actual lighting hours deviate by more than 10% from the tables, or if the project retrofitted only a portion of a facility’s lighting system for which whole building hours of use would not be appropriate, the deemed HOU and CF assumptions can be overridden by inputting custom operating schedules into the Lighting Operation Schedule portion of the “General Information” tab of Appendix C. The custom schedule inputs must be corroborated by an acceptable source such as posted hours, customer interviews, building monitoring system (BMS), or metered data.

For all projects, annual hours are subject to adjustment by EDC evaluators or SWE.

Metering – Projects with savings below 750,000 kWh

Metering is encouraged for projects with expected savings below 750,000 kWh but have high uncertainty, i.e. where hours are unknown, variable, or difficult to verify. Exact conditions of “high uncertainty” are to be determined by the EDC evaluation contractors to appropriately manage variance. Metering completed by the implementation contractor may be leveraged by the evaluation contractor, subject to a reasonableness review. Sampling methodologies within a site are to be either discerned by the EDC evaluation contractor based on the characteristics of the facility in question or performed consistent with guidance the EDC EM&V contractor provides.

Metering – Projects with savings of 750,000 kWh or higher

For projects with expected savings of 750,000 kWh or higher, metering is required. The Commission allows the EDCs to use alternative methods for obtaining customer-specific data where customer processes do not support metering. The EDCs are required to provide supporting documentation to the SWE for review if there are any such exceptions. Installation of light loggers is the accepted method of metering, but trend data from BMS is an acceptable substitute. Metering completed by the implementation contractor may be leveraged by the evaluation contractor, subject to a reasonableness review. Sampling methodologies within a site are to be either discerned by the EDC evaluation contractor or communicated to implementation contractors based on the characteristics of the facility in question or performed consistent with guidance the EDC EM&V contractor provides.

When BMS data is used as a method of obtaining customer-specific data in lieu of metering, the following guidelines should be followed:

- Care should be taken with respect to BMS data, since the programmed schedule may not reflect regular hours of long unscheduled overrides of the lighting system, such as nightly cleaning in office buildings, and may not reflect how the lights were actually used, but only the times of day the common area lighting is commanded on and off by the BMS.
- The BMS trends should represent the actual status of the lights (not just the command sent to the lights), and the ICSP and EC are required to demonstrate that the BMS system is functioning as expected, prior to relying on the data for evaluation purposes.
- The BMS data utilized should be specific to the lighting systems and should be required to be representative of the building areas included in the lighting project.

SOURCES

1) Design Lights Consortium (2020). Solid-State Lighting Technical Requirements V5.1 requires a rated lifetime of 50,000 hours. Depending on building type, 50,000 hours divided by annual HOU returns an implied measure life ranging from 6 to 35 years with most building types falling between 10 and 20 years. The default value is set to the legislated limit of 15 years. Weblink
2) Measure life values were developed using rated life values of lamps and ballasts from Osram Sylvania's 2014 – 2015 Lamp & Ballast Catalog. The rated lives were divided by the average HOU for all building types.
3) Williams, A., Atkinson, B., Garbesi, K., Rubinstein, F., "A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings", Lawrence Berkeley National Laboratory, September 2011. Weblink
4) Pennsylvania Statewide Act 129 2014 Commercial & Residential Lighting Metering Study. Prepared for Pennsylvania Public Utilities Commission. January 13, 2015. Weblink
5) U.S. Naval Observatory. Duration of Daylight/Darkness Table for One Year. Assumes values for State College, PA. Weblink
6) Navigant Consulting, Inc. for EmPOWER Maryland Program Administrators. (2017) Commercial and Industrial Long-Term Metering Study. Weblink
7) New York TRM. (2023, version 10). Commercial and Industrial Interior and Exterior Lighting – Operating Hours table. Weblink
8) Duquesne Light Schedule of Rates, page 72, Released June 21, 2023. Weblink
9) PECO Energy Company Electric Service Tariff, page 64, Released March 20, 2024. Weblink
10) PPL Electric Utilities General Tariff, page 36A, Released June 28, 2023. Weblink
11) Metropolitan Edison Company Electric Service Tariff, page 86, Released June 20, 2023. Weblink
12) Pennsylvania Electric Company Electric Service Tariff, page 102, Released June 20, 2023. Weblink
13) Pennsylvania Power Company Schedule of Rates, Rules and Regulations for Electric Service, page 88, Released June 20, 2023. Weblink
14) West Penn Power Company Tariff, page 96, Released June 20, 2023. Weblink
15) Efficiency Vermont Technical Reference Manual. (2022) Measure CR-LTG-LEDOF, LED Other Fixtures. Weblink

16) Wen, Yao-Jung, et al. Energy Savings from Networked Lighting Control (NLC) Systems with and without LLLC. Northeast Energy Efficiency Alliance and Design Lighting Consortium. 2020. Weblink
17) Illinois Statewide Technical Reference Manual. (2022, version 11.0). "4.5.2 Fluorescent Delamping". Weblink
18) SWE Interactive Effect Calculator

3.1.2. New Construction Lighting

Target Sector	Commercial and Industrial
Measure Unit	Lighting Equipment
Measure Life	15 years Source 1
Measure Vintage	New Construction

New Construction incentives are intended to encourage decision-makers in new construction projects to incorporate greater energy efficiency into their building design and construction practices that will result in a permanent reduction in electrical (kWh) usage above baseline practices. See Appendix E for general eligibility requirements for solid state lighting products in commercial and industrial applications.

Eligibility Requirements

New construction applies to new building projects wherein no structure or site footprint presently exists, addition or expansion of an existing building or site footprint, or major tenant improvements that change the use of the space. See Appendix E for general eligibility requirements for solid state lighting products in commercial and industrial applications.

The baseline demand for calculating savings is determined using one of the two methods detailed in IECC 2021. The interior lighting baseline is calculated using either the Building Area Method as shown in Table 3-9 or the Space-by-Space Method as shown in Table 3-10. For exterior lighting, the baseline is calculated using the Baseline Exterior Lighting Power Densities as shown Table 3-11. Table 3-11 does not distinguish between tradable and non-tradable exterior spaces. When analyzing exterior spaces, all exterior spaces must be included in savings calculations so that energy penalties from any over-lit spaces are properly accounted for in the facility-level savings estimates. The post-installation demand is calculated based on the installed fixtures using the "Fixture Identities" sheet in Appendix C.

Algorithms

For all new construction projects analyzed using the IECC 2021 **Building Area Method**, the following algorithms apply Source 2:

$$\Delta kWh = (kW_{base} - kW_{ee}) \times \left[HOU \times (1 - SVG_{base}) \times \left(1 + IF_{energy}\right)\right]$$

$$\Delta kW_{summer\ peak} = (kW_{base} - kW_{ee}) \times \left[CF_s \times (1 - SVG_{base}) \times \left(1 + IF_{demand\_s}\right)\right]$$

$$\Delta kW_{winter\ peak} = (kW_{base} - kW_{ee}) \times \left[CF_w \times (1 - SVG_{base}) \times \left(1 + IF_{demand\_w}\right)\right]$$

For all new construction projects analyzed using the IECC 2021 **Space-by-Space Method**, the following algorithms apply Source 2:

$$\mathrm{D}kWh = \sum_{i=1}^{n} \Delta kWh_1 + \Delta kWh_2 + \cdots \Delta kWh_n$$

$$\Delta kW_{summer\ peak} = \sum_{i=1}^{n} \Delta kW_{summer\ peak\ 1} + \Delta kW_{summer\ peak\ 2} + \cdots \Delta kW_{summer\ peak\ n}$$

$$\Delta kW_{winter\ peak} = \sum_{i=1}^{n} \Delta kW_{winter\ peak\ 1} + \Delta kW_{winter\ peak\ 2} + \cdots \Delta kW_{winter\ peak\ n}$$

Where n is the number of spaces and:

$$\Delta kWh_1 = (kW_{base,1} - kW_{ee,1}) \times [HOU_1 \times (1 - SVG_{base1}) \times (1 + IF_{energy,1})]$$

$$\Delta kW_{summer\ peak\ 1} = (kW_{base,1} - kW_{ee,1}) \times [CF_{s,1} \times (1 - SVG_{base1}) \times (1 + IF_{demand\_s,1})]$$

$$\Delta kW_{winter\ peak\ 1} = (kW_{base,1} - kW_{ee,1}) \times [CF_{w,1} \times (1 - SVG_{base1}) \times (1 + IF_{demand\_w,1})]$$

Definition of Terms

Table 3-8: Terms, Values, and References for New Construction Lighting

Term	Unit	Values	Source
kW_{base}, The baseline space or building connected load as calculated by multiplying the space or building area by the appropriate Lighting Power Density (LPD) values specified in either Table 3-9 or Table 3-10	*kW*	Calculated based on space or building type and size.	Calculated Value
kW_{ee}, The calculated connected load of the energy efficient lighting	*kW*	Calculated based on specifications of installed equipment using Appendix C	Calculated Value
SVG_{base}, Baseline savings factor in accordance with code-required lighting controls (percent of time the lights are off)	*None*	Based on Code	EDC Data Gathering
		Default: Table 3-12	2
CF_s, Summer coincidence factor	*Decimal*	Based on Metering	EDC Data Gathering
		Default: Table 3-3	Table 3-3
CF_w, Winter coincidence factor	*Decimal*	Based on Metering	EDC Data Gathering
		Default: Table 3-3	Table 3-3
HOU, Hours of Use – the average annual operating hours of the facility	$\frac{Hours}{Year}$	Based on Metering	EDC Data Gathering
		Default: Table 3-3	Table 3-3
IF_{energy}, Interactive Energy Factor	*None*	Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6
IF_{demand_s}, Summer Interactive Demand Factor – applies to C&I interior lighting in conditioned spaces.	*None*	Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6
IF_{demand_w}, Winter Interactive Demand Factor – applies to C&I interior lighting in conditioned spaces.	*None*	Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6

Table 3-9: Lighting Power Densities from IECC 2021 Building Area Method Source 2

Building Area Type	LPD (W/ft^2)	Building Area Type	LPD (W/ft^2)
Automotive facility	0.75	Multifamily	0.45
Convention center	0.64	Museum	0.55
Courthouse	0.79	Office	0.64
Dining: bar lounge/leisure	0.80	Parking garage	0.18
Dining: cafeteria/fast food	0.76	Penitentiary	0.69

Building Area Type	LPD (W/ft^2)	Building Area Type	LPD (W/ft^2)
Dining: family	0.71	Performing arts theater	0.84
Dormitory	0.53	Police station	0.66
Exercise center	0.72	Post office	0.65
Fire station	0.56	Religious building	0.67
Gymnasium	0.76	Retail	0.84
Health care clinic	0.81	School/university	0.72
Hospital	0.96	Sports arena	0.76
Hotel/Motel	0.56	Town hall	0.69
Library	0.83	Transportation	0.50
Manufacturing facility	0.82	Warehouse	0.45
Motion picture theater	0.44	Workshop	0.91

Table 3-10: Lighting Power Densities from IECC 2021 Space-by-Space Method Source 2

Common Space Type	LPD (W/ft2)	Building Specific Space Types	LPD (W/ft2)
Atrium		**Facility for the visually impaired**	
Less than 40 feet in height	0.48	In a chapel (and not used primarily by the staff)	0.70
Greater than 40 feet in height	0.60	In a recreation room (and not used primarily by the staff)	1.77
Audience seating area		**Automotive (See Vehicle Maintenance Area)**	
In an auditorium	0.61	Convention Center—exhibit space	0.61
		Dormitory—living quarters	0.50
In a gymnasium	0.23	Fire Station—sleeping quarters	0.23
In a motion picture theater	0.27	**Gymnasium/fitness center**	
In a penitentiary	0.67	In an exercise area	0.90
In a performing arts theater	1.16	In a playing area	0.85
In a religious building	0.72	**Healthcare facility**	
In a sports arena	0.33	In an exam/treatment room	1.40
Otherwise	0.33	In an imaging room	0.94
Banking activity area	0.61	In a medical supply room	0.62
Breakroom (See Lounge/Breakroom)		In a nursery	0.92
Classroom/lecture hall/training room		In a nurse's station	1.17
In a penitentiary	0.89	In an operating room	2.26
Otherwise	0.71	In a patient room	0.68
Computer room, data center	0.94	In a physical therapy room	0.91
Conference/meeting/multipurpose room	0.97	In a recovery room	1.25
Copy/print room	0.31	**Library**	
Corridor		In a reading area	0.96
In a facility for the visually impaired (and not used primarily by the staff)	0.71	In the stacks	1.18

Common Space Type	LPD (W/ft2)	Building Specific Space Types	LPD (W/ft2)
In a hospital	0.71	**Manufacturing facility**	
Otherwise	0.41	In a detailed manufacturing area	0.80
		In an equipment room	0.76
Courtroom	1.20	In an extra high bay area (greater than 50' floor-to-ceiling height)	1.42
		In a high bay area (25-50' floor-to-ceiling height)	1.24
Dining area		In a low bay area (less than 25' floor-to-ceiling height)	0.86
In a penitentiary	0.42	**Museum**	
In a facility for the visually impaired (and not used primarily by the staff)	1.27	In a general exhibition area	0.31
In bar/lounge or leisure dining	0.86	In a restoration room	1.10
In cafeteria or fast food dining	0.40	Performing arts theater—dressing room	0.41
In family dining	0.60	Post Office—Sorting Area	0.76
Otherwise	0.43	**Religious buildings**	
Electrical/mechanical room	0.43	In a fellowship hall	0.54
Emergency vehicle garage	0.52	In a worship/pulpit/choir area	0.85
Food preparation area	1.09	**Retail facilities**	
Guest room	0.41	In a dressing/fitting room	0.51
Laboratory		In a mall concourse	0.82
In or as a classroom	1.11	**Sports arena—playing area**	
Otherwise	1.33	For a Class I facility	2.94
Laundry/washing area	0.53	For a Class II facility	2.01
Loading dock, interior	0.88	For a Class III facility	1.30
Lobby		For a Class IV facility	0.86
In a facility for the visually impaired (and not used primarily by the staff)	1.69	**Transportation facility**	
For an elevator	0.65	In a baggage/carousel area	0.39
In a hotel	0.51	In an airport concourse	0.25
In a motion picture theater	0.23	At a terminal ticket counter	0.51
In a performing arts theater	1.25	**Warehouse—storage area**	
Otherwise	0.84	For medium to bulky, palletized items	0.33
Locker room	0.52	For smaller, hand-carried items	0.69
Lounge/breakroom		**Restroom**	
In a healthcare facility	0.42	In a facility for the visually impaired (and not used primarily by the staff)	1.26
Otherwise	0.59	Otherwise	0.63
Office		Sales area	1.05
Enclosed	0.74	Seating area, general	0.23
Open plan	0.61		
Parking area, interior	0.15		
Pharmacy area	1.66		

Common Space Type	LPD (W/ft2)	Building Specific Space Types	LPD (W/ft2)
Stairway (See space containing stairway)			
Stairwell	0.49		
Storage room	0.38		
Vehicle maintenance area	0.60		
Workshop	1.26		

Table 3-11 presents baseline allowances for exterior lighting zones. Lighting Zone 1 includes developed areas of national parks, state parks, forest land, and rural areas. Zone 2 includes areas predominantly consisting of residential zoning, neighborhood business districts, light industrial with limited nighttime use and residential mixed-use areas. Zone 3 includes all other areas not classified as lighting zone 1, 2, or 4. Zone 4 includes high-activity commercial districts in major metropolitan areas as designated by the local land use planning authority.

Table 3-11: Baseline Exterior Lighting Power Densities Source 2

Space Description	Lighting Zones			
	Zone 1	Zone 2	Zone 3	Zone 4
Base Site Allowance (Base allowance is usable in tradable or non-tradable surfaces.)	350 W	400 W	500 W	900 W
Uncovered Parking Areas				
Parking areas and drives	0.03 W/ft^2	0.04 W/ft^2	0.06 W/ft^2	0.08 W/ft^2
Building Grounds				
Walkways and ramps less than 10 feet wide	0.5 W/linear foot	0.5 W/linear foot	0.6 W/linear foot	0.7 W/linear foot
Walkways and ramps 10 feet wide or greater, plaza areas, special feature areas	0.10 W/ft^2	0.10 W/ft^2	0.11 W/ft^2	0.14 W/ft^2
Dining areas	0.65 W/ft^2	0.65 W/ft^2	0.75 W/ft^2	0.95 W/ft^2
Stairways	0.6 W/ft^2	0.7 W/ft^2	0.7 W/ft^2	0.7 W/ft^2
Pedestrian tunnels	0.12 W/ft^2	0.12 W/ft^2	0.14 W/ft^2	0.21 W/ft^2
Landscaping	0.03 W/ft^2	0.04 W/ft^2	0.04 W/ft^2	0.04 W/ft^2
Building Entrances and Exits				
Pedestrian and vehicular entrances and exits	14 W/linear foot of door width	14 W/linear foot of door width	21 W/linear foot of door width	21 W/linear foot of door width
Entry canopies	0.20 W/ft^2	0.25 W/ft^2	0.4 W/ft^2	0.4 W/ft^2
Loading docks	0.35 W/ft^2	0.35 W/ft^2	0.35 W/ft^2	0.35 W/ft^2
Sales Canopies				
Free-standing and attached	0.40 W/ft^2	0.40 W/ft^2	0.6 W/ft^2	0.7 W/ft^2
Outdoor Sales				
Open areas (including vehicle sales lots)	0.20 W/ft^2	0.20 W/ft^2	0.35 W/ft^2	0.50 W/ft^2

Space Description	Lighting Zones			
	Zone 1	Zone 2	Zone 3	Zone 4
Street frontage for vehicle sales lots in addition to “open area” allowance	No allowance	7 W/linear foot	7 W/linear foot	21 W/linear foot
Building facades	No allowance	0.075 W/ft^2 of gross above-grade wall area	0.113 W/ft^2 of gross above-grade wall area	0.15 W/ft^2 of gross above-grade wall area
Automated teller machines (ATM) and night depositories	135 W per location plus 45 W per additional ATM per location			
Uncovered entrances and gatehouse inspection stations at guarded facilities	0.5 W/ft^2 of area			
Uncovered loading areas for law enforcement, fire, ambulance, and other emergency service vehicles	0.35 W/ft^2 of area			
Drive-up windows/doors	200 W per drive-through			
Parking near 24-hour retail entrances	400 W per main entry			

Various lighting control strategies are required by IECC 2021 for multiple new construction space types. The percentage of connected load found in space types with required controls varies by commercial building type. The default values for SVGbase for new construction are estimated by building type and were determined by scaling the savings factor of 24% associated with occupancy sensors from Table 3-2 by the percentage of connected load found in covered space types. The percentage of connected load is based on Source 3. For example, education facilities have 69% of the load within the space types requiring occupancy sensors. As such, the baseline SVG_{base} becomes 0.69 × 0.24, or 0.17. Table 3-12 provides the default baseline savings control factors (SVG_{base}) by building type.

Table 3-12: Default Baseline Savings Control Factors Assumptions for New Construction Only

Building Type	SVG_{base}
Education	17%
Exterior	0%
Grocery	5%
Health	8%
Industrial/Manufacturing – 1 Shift	0%
Industrial/Manufacturing – 2 Shift	0%
Industrial/Manufacturing – 3 Shift	0%
Institutional/Public Service	12%
Lodging	15%
Miscellaneous/Other	6%
Office	15%
Parking Garage	0%
Restaurant	5%
Retail	5%
Warehouse	14%
Custom	Based on Code

EVALUATION PROTOCOLS

Detailed Inventory Form

A detailed inventory of all installed fixtures contributing to general light requirements is mandatory for participation in this measure. Lighting that need not be included in the inventory is as follows:

1) Display or accent lighting in galleries, museums, and monuments
2) Lighting that is integral to:
    a. Equipment or instrumentation and installed by its manufacturer,
    b. Refrigerator and freezer cases (both open and glass-enclosed),
    c. Equipment used for food warming and food preparation,
    d. Medical equipment,
    e. Advertising or directional signage,
    f. Exit signs, or
    g. Emergency lighting
3) Lighting specifically designed only for use during medical procedures
4) Lighting used for plant growth or maintenance
5) Lighting used in spaces designed specifically for occupants with special lighting needs
6) Lighting in retail display windows that are enclosed by ceiling height partitions.

A detailed lighting inventory is required for all lighting improvement projects. The lighting inventory form will use the algorithms presented above to derive the total ΔkW_{summer}, ΔkW_{winter}, and ΔkWh savings for each installed measure. Within a single project, to the extent there are multiple combinations of control strategies (SVG), hours of use (HOU), coincidence factors (CF) or interactive factors (IF), the ΔkW will be broken out to account for these different factors. This will be accomplished using Appendix C, a Microsoft Excel inventory form that specifies the lamp and ballast configuration using the “Fixture Identities” sheet and SVG, HOU, CF and IF values for each line entry. The inventory form will also specify the location and number of fixtures for reference and validation.

Appendix C was developed to automate the calculation of energy and demand impacts for new construction lighting projects, based on a series of entries by the user defining key characteristics of the new construction project. The "General Information" sheet is provided for the user to identify facility-specific details of the project that have an effect on the calculation of gross savings. Facility-specific details include contact information, electric utility, building area information, and operating schedule. The "Lighting Inventory" sheet is the main worksheet that calculates energy savings and peak demand reduction for the user-specified lighting fixture and controls improvements. This form follows the algorithms presented above and facilitates the calculation of gross savings for implementation and evaluation purposes. Each line item on this tab represents a specific area with common baseline fixtures, retrofit fixtures, controls strategy, space cooling, and space usage.

Baseline and retrofit fixture wattages are determined by selecting the appropriate fixture code from the “Fixture Identities” sheet. The sheet can also be used to find the appropriate code for a particular lamp-ballast combination by using the enabled auto-filter options. Actual wattages of fixtures determined by manufacturer’s equipment specification sheets or other independent sources may not be used unless (1) the manufacturer's cut sheet indicates that the difference in delta-watts of fixture wattages (i.e. difference in delta watts of baseline and “actual” installed efficient fixture wattage and delta watts of baseline and nearest matching efficient fixture in the “Fixture Identities” of Appendix C is more than 10% or (2) the corresponding fixture code is not listed in the “Fixture Identities” list. In these cases, alternate wattages for lamp-ballast combinations can be entered using the appropriate cells within the “Fixture Identities” tab. Rows 9 through 28 provide a guided custom LED fixture generator to be used with non-self-ballasted LEDs. All other custom cut sheets should be inputted into rows 932 through 981. Documentation supporting the alternate wattages must be provided in the form of manufacturer-provided specification sheets or other industry accepted sources (e.g. ENERGY STAR listing, Design Lights Consortium listing, etc.). Submitted specification sheets must cite test data performed under standard ANSI procedures. These exceptions will be used as the basis for periodically updating the “Fixture Identities” to better reflect market conditions and more accurately represent savings.

Some EDC Implementation CSPs may have developed in-house lighting inventory forms that are used to determine reported savings estimates for projects and calculate rebate amounts. The Appendix C form is the preferred tool for reported and verified savings calculations. However, a ICSP lighting inventory form may be used for program delivery purposes provided it (1) includes all the same functionality, formulas, and calculation steps as the Appendix C form (2) is approved by the SWE prior to being utilized to calculate reported savings. In the case where an ICSP tool produces a different savings estimate from the Appendix C calculator, the Appendix C result is considered to be the TRM-supported savings value. Appendix C will be updated periodically to include new fixtures and technologies available as may be appropriate. Additional guidance can be found in the “Manual” sheet of Appendix C.

Custom Hours of Use and Coincidence Factors

If the project cannot be described by the building type categories listed in Table 3-3, or if the facility’s actual lighting hours deviate by more than 10% from the table, or if the project retrofitted only a portion of a facility’s lighting system for which whole building hours of use would not be appropriate, the deemed HOU and CF assumptions can be overridden by inputting custom operating schedules into the Lighting Operation Schedule portion of the “General Information” tab of Appendix C. The custom schedule inputs must be corroborated by an acceptable source such as posted hours, customer interviews, building monitoring system (BMS), or metered data.

For all projects, annual hours are subject to adjustment by EDC evaluators or SWE.

Metering – Projects with savings below 750,000 kWh

Metering is encouraged for projects with expected savings below 750,000 kWh but have high uncertainty, i.e. where hours are unknown, variable, or difficult to verify. Exact conditions of “high uncertainty” are to be determined by the EDC evaluation contractors to appropriately manage variance. Metering completed by the implementation contractor may be leveraged by the evaluation contractor, subject to a reasonableness review. Sampling methodologies within a site are to be either discerned by the EDC evaluation contractor based on the characteristics of the facility in question or performed consistent with guidance the EDC EM&V contractor provides.

Metering – Projects with savings of 750,000 kWh or higher

For projects with expected savings of 750,000 kWh or higher, metering is required. Exceptions may be made, and EDC data gathering may be substituted, if necessary, at the evaluation contractor's discretion in cases involving early occupancy. Otherwise, installation of light loggers is the accepted method of metering, but trend data from BMS is an acceptable substitute. Metering completed by the implementation contractor may be leveraged by the evaluation contractor, subject to a reasonableness review. Sampling methodologies within a site are to be either discerned by the EDC evaluation contractor or communicated to implementation contractors based on the characteristics of the facility in question or performed consistent with guidance the EDC EM&V contractor provides.

When BMS data is used as a method of obtaining customer-specific data in lieu of metering, the following guidelines should be followed:

- Care should be taken with respect to BMS data, since the programmed schedule may not reflect regular hours of long unscheduled overrides of the lighting system, such as nightly cleaning in office buildings, and may not reflect how the lights were actually used, but only the times of day the common area lighting is commanded on and off by the BMS.
- The BMS trends should represent the actual status of the lights (not just the command sent to the lights), and the ICSP and EC are required to demonstrate that the BMS system is functioning as expected, prior to relying on the data for evaluation purposes.
- The BMS data utilized should be specific to the lighting systems and should be required to be representative of the building areas included in the lighting project.

Sources

1) Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, June 2007. Weblink
2) International Energy Conservation Code 2021. International Code Council. Weblink
3) Pennsylvania Statewide Act 129 2014 Commercial & Residential Lighting Metering Study. Prepared for Pennsylvania Public Utilities Commission. January 13, 2014. Weblink

3.1.3. Lighting Controls

Target Sector	Commercial and Industrial
Measure Unit	Wattage Controlled
Measure Life	8 years Source 1
Measure Vintage	Retrofit and New Construction

Eligibility

Lighting controls turn lights on and off or dim them automatically, when activated by time, light, motion, or sound. The measurement of energy savings is based on algorithms with key variables (e.g. coincidence factor (CF), hours of use (HOU) provided through existing end-use metering of a sample of facilities or from other utility programs with experience with these measures (i.e., % of annual lighting energy saved by lighting control). These key variables are listed in Table 3-13.

If a lighting improvement consists of solely lighting controls, the lighting fixture baseline is the existing fixtures with the existing lamps and ballasts or, if retrofitted, new fixtures with new lamps and ballasts as defined in Lighting Audit and Design Tool shown in Appendix C.

Algorithms

Algorithms for annual energy savings and peak demand savings are shown below.

$$\Delta kWh = kW_{controlled} \times HOU \times (SVG_{ee} - SVG_{base}) \times (1 + IF_{energy})$$

$$\Delta kW_{summer\ peak} = kW_{controlled} \times (SVG_{ee} - SVG_{base}) \times (1 + IF_{demand\_s}) \times CF_s$$

$$\Delta kW_{winter\ peak} = kW_{controlled} \times (SVG_{ee} - SVG_{base}) \times (1 + IF_{demand\_w}) \times CF_w$$

Definition of Terms

Table 3-13: Terms, Values, and References for Lighting Controls

Term	Unit	Values	Source
$kW_{controlled}$, Total lighting load connected to the new control in kilowatts. Savings are per controlled system. The total connected load per controlled system should be collected from the customer	*kW*	Lighting Audit and Design Tool in Appendix C	EDC Data Gathering
SVG_{ee}, Savings factor for installed lighting control (percent of time the lights are turned off by controls)	*None*	Based on metering	EDC Data Gathering
		Default: Table 3-2	2, 4
SVG_{base}, Baseline savings factor (percent of time the lights are turned off by controls)	*None*	Retrofit Default: Table 3-2	2
		New Construction Default: Table 3-12	3
CF_s, Summer coincidence factor	*Decimal*	Based on Metering	EDC Data Gathering
		Default:Table 3-3	Table 3-3
CF_w, Winter coincidence factor	*Decimal*	Based on Metering	EDC Data Gathering
		Default:Table 3-3	Table 3-3
HOU, Hours of Use – the average annual operating hours of the baseline lighting equipment (before the lighting controls are in place), which if applied to full connected load will yield annual energy use.	$\frac{Hours}{Year}$	Based on metering	EDC Data Gathering
		By building type	Table 3-3
IF_{energy}, Interactive Energy Factor	*None*	Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6
IF_{demand_s}, Summer Interactive Demand Factor – applies to C&I interior lighting in conditioned spaces.	*None*	Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6
IF_{demand_w}, Winter Interactive Demand Factor – applies to C&I interior lighting in conditioned spaces.	*None*	Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables.

It is noted that if site-specific data is used to determine HOU, then the same data must be used to determine the site-specific summer and winter CFs. Similarly, if the default TRM HOU is used, then the default TRM summer and winter CFs must also be used in the savings calculations. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. Effective Useful Life and Remaining Useful Life Support Table. Effective Useful Life ID = “GlazDaylt-Dayltg”. Weblink. Accessed December 2023.
2) Williams, A., Atkinson, B., Garbesi, K., Rubinstein, F., “A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings”, Lawrence Berkeley National Laboratory, September 2011. Weblink

3) Pennsylvania Statewide Act 129 2014 Commercial & Residential Lighting Metering Study. Prepared for Pennsylvania Public Utilities Commission. January 13, 2015. Weblink
4) Wen, Yao-Jung, et al. Energy Savings from Networked Lighting Control (NLC) Systems with and without LLLC. Northeast Energy Efficiency Alliance and Design Lighting Consortium. 2020. Weblink

3.1.4. LED Exit Signs

Target Sector	Commercial and Industrial
Measure Unit	LED Exit Sign
Measure Life	15 years Source 1
Measure Vintage	Early Replacement

Eligibility

This measure includes the early replacement of existing incandescent or fluorescent exit signs with a new LED exit sign. If the exit signs match those listed in Table 3-14, the default savings value for LED exit signs installed cooled spaces can be used without completing Appendix C.

See Appendix E for general eligibility requirements for solid state lighting products in commercial and industrial applications.

Algorithms

The algorithms shown below can be used to calculate annual energy savings and peak demand savings associated with this measure.

$$\Delta kWh = DeltakW \times \left[HOU \times \left(1 + IF_{energy}\right)\right]$$

$$\Delta kW_{summer\ peak} = DeltakW \times \left[CF_s \times \left(1 + IF_{demand\_s}\right)\right]$$

$$\Delta kW_{winter\ peak} = DeltakW \times \left[CF_w \times \left(1 + IF_{demand\_w}\right)\right]$$

$$DeltakW = \left(kW_{base} - kW_{ee}\right)$$

Definition of Terms

Table 3-14: Terms, Values, and References for LED Exit Signs

Term	Unit	Values	Source
kW_{base}, Connected load of baseline lighting as defined by project classification	*kW*	Actual Wattage	EDC Data Gathering
		Single-Sided Incandescent: 0.020 Dual-Sided Incandescent: 0.040 Single-Sided Fluorescent: 0.009 Dual-Sided Fluorescent: 0.020	Appendix C
kW_{ee}, Connected load of the post-retrofit or energy-efficient lighting	*kW*	Actual Wattage	EDC Data Gathering
		Single-Sided: 0.002 Dual-Sided: 0.004	Appendix C
DeltakW, difference between connected load of baseline and post-retrofit energy efficiency lighting system	*kW*	Default Unknown Type: 0.032	2
CF_s, Summer Coincidence Factor	*Decimal*	1.0	3
CF_w, Winter Coincidence Factor	*Decimal*	1.0	3
HOU, Hours of Use – the average annual operating hours of the baseline lighting equipment.	$\frac{Hours}{Year}$	8,760	3
IF_{energy}, Interactive Energy Factor	*None*	Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6
IF_{demand_s}, Summer Interactive Demand Factor – applies to C&I interior lighting in conditioned spaces.	*None*	Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6
IF_{demand_w}, Winter Interactive Demand Factor – applies to C&I interior lighting in conditioned spaces.	*None*	Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6

Default Savings

Single-Sided LED Exit Signs replacing Incandescent Exit Signs

$$\Delta kWh = 164\ kWh$$
$$\Delta kW_{summer\ peak} = 0.020\ kW$$
$$\Delta kW_{winter\ peak} = 0.018\ kW$$

Dual-Sided LED Exit Signs replacing Incandescent Exit Signs

$$\Delta kWh = 327\ kWh$$
$$\Delta kW_{summer\ peak} = 0.040\ kW$$
$$\Delta kW_{winter\ peak} = 0.035\ kW$$

Single-Sided LED Exit Signs replacing Fluorescent Exit Signs

$$\Delta kWh = 64\ kWh$$
$$\Delta kW_{summer\ peak} = 0.008\ kW$$
$$\Delta kW_{winter\ peak} = 0.007\ kW$$

Dual-Sided LED Exit Signs replacing Fluorescent Exit Signs

$$\Delta kWh = 145\ kWh$$
$$\Delta kW_{summer\ peak} = 0.018\ kW$$
$$\Delta kW_{winter\ peak} = 0.016\ kW$$

LED Exit Signs replacing Unknown Baseline Exit Signs

$$\Delta kWh = 291\ kWh$$

$$\Delta kW_{summer\ peak} = 0.035\ kW$$
$$\Delta kW_{winter\ peak} = 0.031\ kW$$

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. Effective Useful Life and Remaining Useful Life Support Table. Effective Useful Life ID = “ILtg-Exit” Weblink. Accessed December 2023.
2) Navigant analysis of Phase III evaluation-verified lighting data across all seven Pennsylvania EDC’s.
3) This assumes operation 24 hours per day, 365 days per year. Additionally, the load shape is assumed to be flat, so the coincidence factor is assumed to be 1.

3.1.5. LED Refrigeration Display Case Lighting

Target Sector	Commercial and Industrial
Measure Unit	Refrigeration Display Case Lighting
Measure Life	8 years Source 1
Measure Vintage	Early Replacement

This protocol applies to LED lamps with and without motion sensors installed in vertical display refrigerators, coolers, and freezers replacing T8 or T12 linear fluorescent lamps. The LED lamps produce less waste heat than the fluorescent baseline lamps, decreasing the cooling load on the refrigeration system and energy needed by the refrigerator compressor. Additional savings can be achieved from the installation of motion sensors which dim the lights when the space is unoccupied.

See Appendix E for general eligibility requirements for solid state lighting products in commercial and industrial applications.

Eligibility

This measure is targeted to non-residential customers who install LED case lighting with or without motion sensors on existing refrigerators, coolers, and freezers - specifically on vertical displays. The baseline equipment is assumed to be cases with uncontrolled T8 or T12 linear fluorescent lamps.

Algorithms

Savings and assumptions are based on a per door basis.

$$\Delta kWh = \frac{(WATTS_{base} - WATTS_{ee})}{1,000} \times N_{doors} \times HOURS \times (1 + IF_{energy})$$

$$\Delta kW_{summer\ peak} = \frac{(WATTS_{base} - WATTS_{ee})}{1,000} \times N_{doors} \times (1 + IF_{demand\_s}) \times CF_s$$

$$\Delta kW_{winter\ peak} = \frac{(WATTS_{base} - WATTS_{ee})}{1,000} \times N_{doors} \times (1 + IF_{demand\_w}) \times CF_w$$

Definition of Terms

Table 3-15: Terms, Values, and References for LED Refrigeration Case Lighting

Term	Unit	Values	Source
$WATTS_{base}$, Connected wattage of baseline fixtures for each door	*W*	EDC Data Gathering	EDC Data Gathering
$WATTS_{ee}$, Connected wattage of efficient fixtures for each door	*W*	EDC Data Gathering	EDC Data Gathering
N_{doors}, Number of doors	*None*	EDC Data Gathering	EDC Data Gathering
$HOURS$, Annual operating hours	$\frac{Hours}{Year}$	EDC Data Gathering Default: 6,471	1
IF_{energy}, Interactive Energy Factor	*None*	Default: Table 3-5	Table 3-5
IF_{demand_s}, Summer Interactive Demand Factor	*None*	Default: Table 3-5	Table 3-5
IF_{demand_w}, Winter Interactive Demand Factor	*None*	Default: Table 3-5	Table 3-5
CF_s, Summer coincidence factor	*Decimal*	EDC Data Gathering Default: 0.93	1
CF_w, Winter coincidence factor	*Decimal*	EDC Data Gathering Default: 0.84	1
$1{,}000$, Conversion factor from watts to kilowatts	$\frac{W}{kW}$	1,000	Conversion Factor

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) EUL calculations assume 6,471 annual operating hours and 50,000 lifetime hours. Note that 6,471 is the assumed HOU for general service lighting in grocery settings. Pennsylvania Statewide Act 129 2014 Commercial & Residential Lighting Metering Study. Prepared for Pennsylvania Public Utilities Commission. January 13, 2015. Weblink

3.1.6. Midstream Lighting Incentives

Target Sector	Commercial and Industrial
Measure Unit	Lighting Equipment
Measure Life	LED Lighting Equipment: 15 years [Source 1]
Measure Vintage	Replace on burnout

Mid-Stream Lighting Overview

Midstream Lighting differs from the Lighting Retrofit measure (3.1.1) in both delivery mechanism and baseline assumptions. In a midstream lighting offering EDCs engage directly with commercial lighting suppliers to increase the adoption of energy efficient lighting equipment at the point-of-sale amongst commercial and industrial customers. Under this measure, the baseline is the least efficient lighting product the participant could choose to purchase with comparable characteristics and performance. This is a fundamentally different measure characterization from the Lighting Retrofit measure (3.1.1) where the baseline is the replaced equipment as documented in an Appendix C Lighting Audit & Design Tool. This protocol applies to efficient lighting delivered through a midstream channel. Code minimum and least efficient readily available (replace on burnout) product were used to determine baseline wattage.

Midstream Lighting Programs offer incentives on eligible products sold to trade allies and customers through commercial sales channels such as distributors of lighting products. This complements other delivery channels (such as downstream rebates to trade allies and customers) by providing incentives to encourage distributors to stock, promote, and sell more efficient lighting. Midstream Delivery Programs assume that purchase of qualified LED lighting products happen in place of baseline lighting equipment with equivalent lumen output, but lower efficacy.

Eligibility

Measures covered by this protocol include LED fixtures and TLED lamps with or without integrated controls, in existing commercial and industrial customers' facilities. Screw-based general service LED lamps are not eligible due to the US Department of Energy's codification of the 45 lumen per Watt "backstop" requirement for general service lamps.[Source 10] The protocol is used for programs where EDCs pay incentives to qualified midstream participants including but not limited to distributors, for eligible LED lamps and fixtures. Retrofit measures where incentives are paid to customers or trade allies are covered by the Lighting Retrofits protocol. New construction measures are covered by the New Construction Lighting protocol and excluded here. Lighting equipment included in this protocol are categorized as follows:

- Select LED lamps and fixtures
- Highbay and lowbay fixtures
- Highbay and lowbay fixtures with integrated controls
- Exterior area and wall pack fixtures
- Parking garage lighting

See Appendix E for general eligibility requirements for solid state lighting products in commercial and industrial applications.

Algorithms

For all midstream lighting measures, the following algorithms apply:

$$\Delta kWh = [kW_{base} \times (1 - SVG_{base}) - kW_{ee} \times (1 - SVG_{ee})] \times HOU \times (1 + IF_{energy}) \times ISR$$

$$\Delta kW_{summer\ peak} = [kW_{base} \times (1 - SVG_{base}) - kW_{ee} \times (1 - SVG_{ee})] \times CF_{summer} \times (1 + IF_{demand\_s}) \times ISR$$

$$\Delta kW_{winter\ peak} = [kW_{base} \times (1 - SVG_{base}) - kW_{ee} \times (1 - SVG_{ee})] \times CF_{winter} \times (1 + IF_{demand\_w}) \times ISR$$

For LED replacements of linear fluorescent and HID interior and exterior lamps and fixtures, the following algorithm is used to calculate kW_{base} for use in the above formulas:

$$kW_{base} = \frac{Lumens_{ee}}{Efficacy_{base} \times 1000}$$

Definition of Terms

Table 3-16: Terms, Values, and References for Lighting Improvements for Midstream Lighting Incentives

Term	Unit	Values	Source
kW_{base}, Wattage of baseline lighting	*kW*	Default: Table 3-17, Table 3-18, Table 3-19, and Table 3-21 or calculated using Table 3-20	Table 3-17, Table 3-18, Table 3-19, Table 3-20, and Table 3-21
kW_{ee}, Wattage of incentivized lighting	*kW*	EDC Data Gathering	EDC Data Gathering
HOU, Hours of Use – the average annual operating hours of the lighting equipment, which if applied to full connected load will yield annual energy use.	$\frac{Hours}{Year}$	Default Other General Service: Table 3-3 Default Street Lighting: Table 3-4 EDC Data Gathering If building type unknown: 2,500 hours	Table 3-3, and Table 3-4 EDC Data Gathering
CF_{summer}, Summer Coincidence Factor	*Decimal*	Default: Table 3-3 If building type is unknown: 0.62	Table 3-3
CF_{winter}, Winter Coincidence Factor	*Decimal*	Default: Table 3-3 If building type is unknown: 0.59	Table 3-3
SVG_{base}, Savings factor for existing lighting control (percent of time the lights are off)	*None*	Default: 3.47%	6
SVG_{ee}, Savings factor for integrated lighting control (percent of time the lights are off)	*None*	EDC Data Gathering Unknown or Manual Switch = 3.47% Occupancy Sensors = 24% Photosensors or Time Clocks = 28% Combination (Occupancy and personal tuning /daylighting, dimming and occupancy) = 38%	1, 2, 3, 6

Term	Unit	Values	Source
IF_{energy}, Interactive Energy Factor	*None*	Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6
IF_{demand_s}, Summer Interactive Demand Factor	*None*	Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6
IF_{demand_w}, Winter Interactive Demand Factor	*None*	Default: Table 3-5 and Table 3-6	Table 3-5 and Table 3-6
ISR, In-Service Rate, the fraction of incentivized lamps or fixtures that are installed within three years of purchase	*%*	EDC Data Gathering Default = 99.1%	13
Lumens$_{ee}$, Lumen rating of the incentivized lighting product	*Lumens*	EDC Data Gathering	EDC Data Gathering
Efficacy$_{base}$, Efficacy of the baseline fixture type for linear fluorescents and interior and exterior HID lamps	*Lumens /watt*	Default: Table 3-20	11, 12
1000, Conversion factor from watts to kW	*W/kW*	N/A	N/A

Table 3-17 through Table 3-21 are arranged by equipment type. For eligible equipment baseline wattage is the least-efficient, commercially-available, commonly-installed technology available in the market. Efficient product wattages are manufacturer or Design Lights Consortium published values as collected by EDCs and ICSPs.

HOU and CF values in Table 3-3 use building types or EDC data gathering. Building type information must be collected by EDCs and ICSPs for all projects with a change in connected load above 20 KW.

Table 3-17: Baseline Wattage, Eligible Omnidirectional Lamps

Efficient Lamp	Minimum Lumen	Maximum Lumen	$Watts_{base}$	Source
Omnidirectional, General Service Lamp, Screw-based	250	309	25	5, 8, 9
	3,301	3,999	200	
	4,000	6,000	300	

Table 3-18: Baseline Wattage, Decorative Lamps

Efficient Lamp	Minimum Lumen	Maximum Lumen	$Watts_{base}$	Source
Decorative, Non-Globe, Screw-based	70	89	10	4, 7, 8
	90	149	15	
	150	299	25	
	300	309	29	
Decorative, Globe, Screw-based	250	309	25	4, 7, 8

Table 3-19: Baseline Wattage, Directional Lamps

Efficient Lamp	Minimum Lumen	Maximum Lumen	$Watts_{base}$	Source
Reflector Lamp; R, ER, BR, with screw-based, >=2.25" diameter	3,301	4,500	200	4, 7, 8
Reflector Lamp; R, ER, BR, with screw-based, diameter <2.25"	400	449	9	4, 7, 8
	450	499	11	
	500	649	13	
	650	1,199	21	
R20 Short Lamps	400	449	9	4, 7, 8
	450	719	13	
Reflector Lamp; PAR, MR, MRX	3,301	4,500	200	4, 7, 8
All reflector lamps < 400 lumen	200	309	20	4, 7, 8
Ceiling Mount Hard Wired Fixture	3,301	4,500	200	4, 7, 8

Table 3-20: Baseline Wattage, Linear Lamps & Fixtures, HID Interior and Exterior Fixtures

Efficient Lamp or Fixture	$Efficacy_{base}$ (Lumens/watt)	Source
Linear Lamps, Fixtures, and Retrofit Kits, 2 ft	67.4	11, 12
Linear Lamps, Fixtures, and Retrofit Kits, 3 ft	72.5	11, 12
Linear Lamps, Fixtures, and Retrofit Kits, 4 ft	75.8	11, 12
Linear Lamps, Fixtures, and Retrofit Kits, 5 ft	80.4	11, 12
Linear Lamps, Fixtures, and Retrofit Kits, 8 ft	82.3	11, 12
Linear Lamps, Fixtures, and Retrofit Kits, 8 ft HO	78.2	11, 12
Highbay & Lowbay LED Fixture and Retrofit Kits	51.1	11, 12
Exterior Fixture (Wall Pack, Flood, Area, Pole, or Parking Garage)	51.4	11, 12

Table 3-21: Baseline Wattage, Pin Based Lamps

Efficient Lamp or Fixture	Minimum Lumen	Maximum Lumen	$Watts_{base}$	Source
Pin-based LEDs Bulb Base 2-Pin, 4-Pin, or GU24 Baseline Tech = CFL	500	934	13	9, 10
	935	1349	18	
	1350	1834	26	
	1835	2549	32	
	2550	3200	42	
Pin-based LEDs, Bulb Base G5.3, GU5.3, GX5.3, G8, GU10 Baseline Tech = Halogen	400	400	36	
	401	500	45	
	501		59	

Evaluation Protocols

All midstream program evaluations should follow the SWE approved method in the EDC EM&V plan. This includes baseline selection, hours of use determination, and coincident demand calculations.

The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Design Lights Consortium (2020). Solid-State Lighting Technical Requirements V5.1 requires a rated lifetime of 50,000 hours. Depending on building type, 50,000 hours divided by annual HOU returns an implied measure life ranging from 6 to 35 years with most building types falling between 10 and 20 years. The default values is set to the legislated limit of 15 years. Weblink
2) Williams, A., Atkinson, B., Garbesi, K., Rubinstein, F., "A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings", Lawrence Berkeley National Laboratory, September 2011. Weblink
3) Pennsylvania Statewide Act 129 2014 Commercial & Residential Lighting Metering Study. Prepared for Pennsylvania Public Utilities Commission. January 13, 2015. Weblink
4) Illinois Statewide Technical Reference Manual. (2024, v12.0). 4.5.4 LED Bulbs and Fixtures. Weblink
5) ENERGY STAR® Program Requirements for Lamps (Light Bulbs) V2.1. Weblink
6) DOE LED Lighting Facts. Weblink
7) The Pennsylvania Statewide Act 129 2018 Non-Residential Baseline study, Table 16. On average, 13% of statewide connected load is controlled by advanced controls (occupancy sensors, photocells, EMS, etc.), resulting in a weighted average 3.47% baseline controls factor. Weblink
8) Energy Conservation Program: Definitions for General Service Lamps. 87 FR 27461 (May 9, 2022). Weblink
9) Energy Conservation Program: Energy Conservation Standards for General Service Lamps. 87 FR 27439 (May 9, 2022). Weblink
10) US Department of Energy Appliance and Equipment Standards Rulemakings and Notices. July 25, 2022. Weblink
11) Grainger Lighting Product Web Pages: Weblink1, Weblink2
12) PA 2021 TRM Appendix C. Weblink
13) Weighted average PY14 evaluated ISR across 19 midstream lighting projects included in SWE audit activities

3.1.7. Indoor Horticultural Lighting

Target Sector	Commercial and Industrial Establishments
Measure Unit	Lighting Equipment
Measure Life	7 years [Source 1]
Measure Vintage	New Construction

This measure relates to the installation of high efficacy LED lighting used to provide energy for plant growth in indoor controlled-environment horticulture spaces.

Eligibility

LED grow lights must meet the Design Lights Consortium (DLC) Horticultural Technical Requirements V3.0 or later [Source 2]. This measure saves energy by providing more photosynthetic energy for plant growth while using less energy to do so. This reduction in lighting power also reduces cooling loads and cooling energy consumption within the space.

This measure characterization is intended for use in new construction or in existing buildings where significant lighting renovations are taking place and energy code requirements must be met. For retrofit projects in horticultural facilities, measure 3.1.1 should be utilized given the replaced fixture wattages are known and a calculation using photosynthetic photon efficacy (PPE) is not required. Controlled environment horticulture can be classified into two broad categories based on the building structure: 1) greenhouses which are typically translucent using combination of natural lighting and electric lighting, and 2) fully enclosed structures for which electric lighting is the only source of photosynthetic energy for plant growth.

Definition of Baseline Equipment

The baseline condition assumes the plants are illuminated with the same amount of light output as the installed lighting to stimulate the same amount of plant growth with an efficacy of 1.6 μmol/J (micromoles per joule). The baseline construction style for cannabis and lettuce is a fully enclosed structure, but these crops can be cultivated in greenhouses and greenhouse operations require less energy. This protocol assumes a fully enclosed baseline case for cannabis and lettuce operations even if the as-built configuration is a greenhouse. This characterization allows EDCs to encourage developers to build greenhouses instead of fully enclosed operations and quantifies the savings associated with the less energy-intense construction type.

Definition of Efficient Equipment

The efficient case is defined as LED indoor horticultural light fixtures that are used in fully enclosed structures or greenhouses with a PPE of 2.30 μmol/J and are qualified by the DLC Horticultural Technical Requirements V3.0 or later [Source 2].

Algorithms

The following algorithms apply in cases where there is no dimming:

$$\Delta kWh = \left[\left(\frac{PPF_{total}}{PPE_{base} \times 1{,}000}\right) \times HOU_{base} - kW_{ee} \times HOU_{ee}\right] \times (1 + IF_{energy})$$

$$\Delta kW_{summer\ peak} = \left[\left(\frac{PPF_{total}}{PPE_{base} \times 1{,}000}\right) \times CF_{s\_base} - kW_{ee} \times CF_{s\_ee}\right] \times (1 + IF_{demand\_s})$$

$$\Delta kW_{winter\ peak} = \left[\left(\frac{PPF_{total}}{PPE_{base} \times 1{,}000}\right) \times CF_{w\_base} - kW_{ee} \times CF_{w\_ee}\right] \times (1 + IF_{demand\_w})$$

The following algorithms apply in cases where a dimming strategy is used to lower the light output of the LED equipment during certain phases of the plant growth cycles and the EDC gathers data on dimming levels and the dimming schedule:

$$\Delta kWh = \left[\left(\frac{PPF_{total}}{PPE_{base} \times 1{,}000}\right) \times HOU_{base} \times (1 + IF_{energy})\right] - \left[kW_{ee} \times HOU_{adj} \times (1 + IF_{energy})\right]$$

$$\Delta kW_{summer\ peak} = \left[\left(\frac{PPF_{total}}{PPE_{base} \times 1{,}000}\right) \times CF_{s\_base} \times (1 + IF_{demand\_s})\right] - \left[kW_{ee} \times DF \times CF_{s\_ee} \times (1 + IF_{demand\_s})\right]$$

$$\Delta kW_{winter\ peak} = \left[\left(\frac{PPF_{total}}{PPE_{base} \times 1{,}000}\right) \times CF_{w\_base} \times (1 + IF_{demand\_w})\right] - \left[kW_{ee} \times DF \times CF_{w\_ee} \times (1 + IF_{demand\_w})\right]$$

Where:

$$HOU_{adj} = HOU_{ee} \times DF$$

$$DF = 1 - (Dim_{level\_\%} \times Dim_{time\_\%})$$

DEFINITION OF TERMS

Table 3-22: Terms, Values, and References for Indoor Horticultural Lighting

Term	Unit	Values	Source
PPF_{total}, Total Photosynthetic Photon Flux of the installed LED. PPF is the rate of flow of photons between 400 to 700 nanometers in wavelength from a radiation source as defined by ANSI/ASABE S640.	*μmol/s*	EDC Data Gathering, Calculated as the number of fixtures installed multiplied by the tested PPF per fixture. This value should be taken from the tested PPF (in accordance with ANSI/ASABE S640) from the DLC listing for installed fixtures.	3
PPE_{base}, Photosynthetic photon efficacy (PPE) is PPF divided by input electric power of the baseline fixture. PPE is used to measure the horticulture lighting efficiency. The higher the PPE the more efficient the light fixture is.	*μmol/J*	1.6	3
1,000, Watts to kilowatts conversion factor	*W/kW*	1,000	N/A
kW_{ee}, Total power of the installed/proposed fixtures (kW)	*kW*	EDC Data Gathering	EDC Data Gathering
HOU_{ee}, Scheduled hours of use of lighting of installed/proposed equipment	*Hours*	EDC Data Gathering. Default: 5,200 hours for indoor operations and 2,000 hours for greenhouses	4, EDC Data Gathering
HOU_{base}, Hours of use for lighting in the baseline system	*Hours*	EDC Data Gathering Default: 5,200 hours for indoor operations and greenhouses if the crop is lettuce or cannabis. 2,000 hours for greenhouses cultivating crops other than lettuce or cannabis	4, EDC Data Gathering

Term	Unit	Values	Source
IF_{energy}, Interactive Energy Factor – applies to indoor agriculture spaces that have air conditioning and space heating. This represents the secondary energy impacts that result from the decreased waste heat from efficient lighting.	*None*	0.141	5
IF_{demand_s}, Interactive Demand Factor for summer – applies to indoor agriculture spaces that have air conditioning and space heating. This represents the secondary demand savings in cooling required that results from the decreased waste heat from efficient lighting.	*None*	0.201	5
IF_{demand_w} Interactive Demand Factor for winter – applies to indoor agriculture spaces that have air conditioning and space heating. This represents the secondary demand savings in cooling required that results from the decreased waste heat from efficient lighting.	*None*	0	5
CF_{s_base}, Coincidence Factor for summer peak demand in the baseline configuration	*None*	EDC Data Gathering. Default: 0.594 hours for indoor operations and greenhouses if the crop is lettuce or cannabis. 0.238 hours for greenhouses cultivating crops other than lettuce or cannabis	EDC Data Gathering. 5,200 HOU / 8,760 hours per year = 0.594 2,000 HOU / 8,760 hours per year = 0.238
CF_{s_ee}, Coincidence Factor for summer peak demand in the efficient configuration	*None*	EDC Data Gathering. Default: 0.594 for indoor operations 0.238 for greenhouses	EDC Data Gathering. 5,200 HOU / 8,760 hours per year = 0.594 2,000 HOU / 8,760 hours per year = 0.238
CF_{w_base}, Coincidence Factor for winter peak demand in the baseline configuration	*None*	EDC Data Gathering. Default: 0.594 hours for indoor operations and greenhouses if the crop is lettuce or cannabis. 0.238 hours for greenhouses cultivating crops other than lettuce or cannabis	EDC Data Gathering. 5,200 HOU / 8,760 hours per year = 0.594 2,000 HOU / 8,760 hours per year = 0.238
CF_{w_ee}, Coincidence Factor for winter peak demand in the efficient configuration	*None*	EDC Data Gathering. Default: 0.594 for indoor operations 0.238 for greenhouses	EDC Data Gathering. 5,200 HOU / 8,760 hours per year = 0.594 2,000 HOU / 8,760 hours per year = 0.238
HOU_{adj}, Scheduled hours of use of lighting, adjusted for dimming	*Hours*	Calculation	Calculation
DF, Dimming factor to adjust scheduled hours of use to account for dimming level and duration	*None*	Calculation	Calculation
$Dim_{level\_\%}$, Average dimming level as a percentage of full power when dimming strategy is in place. If LEDs are dimmed to 75% of the rated output, this term is equal to 0.25 or 25%	*None*	EDC Data Gathering	EDC Data Gathering
$Dim_{time\_\%}$, Percentage of the scheduled hours of use of the lighting when lights are dimmed. If LEDs are dimmed 520 of the 5,200 annual operating hours, this term is equal to 0.1 or 10%	*None*	EDC Data Gathering	EDC Data Gathering

Evaluation Protocols

Detailed Inventory
A detailed lighting inventory is required for all lighting improvement projects. The lighting inventory form will use the algorithms presented above to derive the total ΔkW and ΔkWh savings for each installed measure.

Metering – Projects with savings below 750,000 kWh
Metering is encouraged for projects with expected savings below 750,000 kWh but have high uncertainty, i.e. where hours are unknown, variable, or difficult to verify. Exact conditions of "high uncertainty" are to be determined by the EDC evaluation contractors to appropriately manage variance. Metering completed by the implementation contractor may be leveraged by the evaluation contractor, subject to a reasonableness review. Sampling methodologies within a site are to be either discerned by the EDC evaluation contractor based on the characteristics of the facility in question or performed consistent with guidance the EDC EM&V contractor provides.

Metering – Projects with savings of 750,000 kWh or higher
For projects with expected savings of 750,000 kWh or higher, metering is required. The Commission allows the EDCs to use alternative methods for obtaining customer-specific data where customer processes do not support metering. The EDCs are required to provide supporting documentation to the SWE for review if there are any such exceptions. Installation of light loggers is the accepted method of metering, but trend data from BMS is an acceptable substitute. Metering completed by the implementation contractor may be leveraged by the evaluation contractor, subject to a reasonableness review. Sampling methodologies within a site are to be either discerned by the EDC evaluation contractor or communicated to implementation contractors based on the characteristics of the facility in question or performed consistent with guidance the EDC EM&V contractor provides.

When growing automation software data is used as a method of obtaining customer-specific data in lieu of metering, the following guidelines should be followed:

- Care should be taken with respect to growing automation software data, since the programmed schedule may not reflect regular hours of long unscheduled overrides of the lighting system, such as nightly cleaning in office buildings, and may not reflect how the lights were actually used, but only the times of day the common area lighting is commanded on and off by the growing automation software.
- The growing automation software trends should represent the actual status of the lights (not just the command sent to the lights), and the ICSP and EC are required to demonstrate that the growing automation software system is functioning as expected, prior to relying on the data for evaluation purposes.
- The growing automation software data utilized should be specific to the lighting systems and should be required to be representative of the building areas included in the lighting project.

Sources

1) The DLC requires either LED device-level or whole-fixture testing and projections in accordance with the LM-80 and TM-21, or LM-84 and TM-28, industry standards sufficient for a Q90 of at least 36,000 hours within the Φp (PPF) range (400-700 nm). The "Q" in the Q90 value is based strictly on the value shown in cell I42 of the ENERGY STAR TM-21 calculator or cell I45 of the ENERGY STAR TM-28 calculator. The EUL of 7 years is estimated based on the DLC minimum requirement of 36,000 hours and average hours of use of 5,200 hours per year.
2) Design Lights Consortium's (DLC) "Horticultural Technical Requirements V3.0" and Horticultural Qualified Product List (QPL) DLC. Effective March 31, 2023. Weblink 1, Weblink 2

3) 2021 International Energy Conservation Code (IECC), Section C405.4. Weblink
4) "Energy Savings Potential of SSL in Agriculture Applications", U.S. DOE, Table 4.1 Summary of Horticultural Lighting Analysis. June 2020. Weblink
5) SWE Interactive Effects Tool. Indoor horticulture adjustments include an Internal Gain Contribution of 80% with cooling required when outdoor air temperature exceeds 40 degrees (F). Operations are assumed to have no heating other than the waste heat from the grow lights.

3.2. HVAC

3.2.1. HVAC Systems

Target Sector	Commercial and Industrial
Measure Unit	HVAC System
Measure Life	15 years Source 1
Measure Vintage	Replace on Burnout, New Construction, or Early Replacement

Eligibility

The energy and demand savings for Commercial and Industrial HVAC systems is determined from the algorithms listed below. This protocol excludes Ground source, and Ground water source heat pump measures that are covered in measure 3.2.4. All HVAC applications other than comfort cooling and heating, such as process cooling, are defined as non-standard applications and are ineligible for this measure.

Algorithms

Air Conditioning (central AC, air-cooled DX, split systems)

For A/C units < 65,000 Btu/hr, use SEER2 to calculate ΔkWh and for units rated in both EER2 and IEER, use IEER for energy savings calculations.

$$\boldsymbol{\Delta kWh} = \left(\frac{\boldsymbol{Btu_{cool}}}{\boldsymbol{hr}} \times \frac{\boldsymbol{1\ kW}}{\boldsymbol{1,000\ W}}\right) \times \left(\frac{\boldsymbol{1}}{\boldsymbol{EER2_{base}}} - \frac{\boldsymbol{1}}{\boldsymbol{EER2_{ee}}}\right) \times \boldsymbol{EFLH_{cool}}$$

$$= \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{IEER_{base}} - \frac{1}{IEER_{ee}}\right) \times EFLH_{cool}$$

$$= \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{SEER2_{base}} - \frac{1}{SEER2_{ee}}\right) \times EFLH_{cool}$$

$$\boldsymbol{\Delta kW_{summer\ peak}} = \Delta kWh \times ETDF_{summer}$$

$$\boldsymbol{\Delta kW_{winter\ peak}} = \Delta kWh \times ETDF_{winter}$$

Air Source Heat Pump

For ASHP units < 65,000 Btu/hr, use SEER2 to calculate ΔkWh_{cool} and HSPF2 to calculate ΔkWh_{heat}. For units rated in both EER2 and IEER, use IEER for energy savings calculations.

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat}$$

$$\Delta kWh_{cool} = \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{IEER_{base}} - \frac{1}{IEER_{ee}}\right) \times EFLH_{cool}$$

$$= \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{SEER2_{base}} - \frac{1}{SEER2_{ee}}\right) \times EFLH_{cool}$$

$$\Delta kWh_{heat} = \left(\frac{Btu_{heat}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \frac{1}{3.412} \times \left(\frac{1}{COP_{base}} - \frac{1}{COP_{ee}}\right) \times EFLH_{heat}$$

$$= \left(\frac{Btu_{heat}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{HSPF2_{base}} - \frac{1}{HSPF2_{ee}}\right) \times EFLH_{heat}$$

$$\boldsymbol{\Delta kW_{summer\ peak}} = \boldsymbol{\Delta kWh \times ETDF_{summer}}$$

$$\boldsymbol{\Delta kW_{winter\ peak}} = \Delta kWh \times ETDF_{winter}$$

Packaged Terminal Air Conditioner and Packaged Terminal Heat Pump

For ASHP units < 65,000 Btu/hr, use SEER to calculate ΔkWh_{cool} and HSPF to calculate ΔkWh_{heat}. For units rated in both EER and IEER, use IEER for energy savings calculations.

ΔkWh	$= \Delta kWh_{cool} + \Delta kWh_{heat}$
ΔkWh_{cool}	$= \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{EER_{base}} - \frac{1}{EER_{ee}}\right) \times EFLH_{cool}$
ΔkWh_{heat}	$= \left(\frac{Btu_{heat}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \frac{1}{3.412} \times \left(\frac{1}{COP_{base}} - \frac{1}{COP_{ee}}\right) \times EFLH_{heat}$
$\boldsymbol{\Delta kW_{summer\ peak}}$	$= \boldsymbol{\Delta kWh \times ETDF_{summer}}$
$\boldsymbol{\Delta kW_{winter\ peak}}$	$= \Delta kWh \times ETDF_{winter}$

Definition of Terms

Table 3-23: Terms, Values, and References for HVAC Systems

Term	Unit	Values	Source
$\frac{Btu_{cool}}{hr}$, Rated cooling capacity of the energy efficient unit	$\frac{Btu}{hr}$	Nameplate data (AHRI)	EDC Data Gathering
$\frac{Btu_{heat}}{hr}$, Rated heating capacity of the energy efficient unit	$\frac{Btu}{hr}$	Nameplate data (AHRI)	EDC Data Gathering
$IEER_{base}$, Integrated energy efficiency ratio of the baseline unit.	$\frac{Btu/hr}{W}$	Early Replacement: Nameplate data	EDC Data Gathering
		New Construction or Replace on Burnout: Default values from Table 3-24	See Table 3-24
$IEER_{ee}$, Integrated energy efficiency ratio of the energy efficient unit.	$\frac{Btu/hr}{W}$	Nameplate data (AHRI)	EDC Data Gathering
$EER2_{base}$, EER_{base}, Energy efficiency ratio of the baseline unit. For air-source AC and ASHP units < 65,000 $\frac{Btu}{hr}$, SEER should be used for cooling savings	$\frac{Btu/hr}{W}$	Early Replacement: Nameplate data	EDC Data Gathering
		New Construction or Replace on Burnout: Default values from Table 3-24	See Table 3-24
$EER2_{ee}$, EER_{ee}, Energy efficiency ratio of the energy efficient unit. For air-source AC and ASHP units < 65,000 $\frac{Btu}{hr}$, SEER should be used for cooling savings.	$\frac{Btu/hr}{W}$	Nameplate data (AHRI)	EDC Data Gathering
$SEER2_{base}$, $SEER_{base}$, Seasonal energy efficiency ratio of the baseline unit. For units > 65,000 $\frac{Btu}{hr}$, EER should be used for cooling savings.	$\frac{Btu/hr}{W}$	Early Replacement: Nameplate data	EDC Data Gathering
		New Construction or Replace on Burnout: Default values from Table 3-24	See Table 3-24
$SEER2_{ee}$, $SEER_{ee}$, Seasonal energy efficiency ratio of the energy efficient unit. For units > 65,000 $\frac{Btu}{hr}$, EER should be used for cooling savings.	$\frac{Btu/hr}{W}$	Nameplate data (AHRI)	EDC Data Gathering
COP_{base}, Coefficient of performance of the baseline unit. For ASHP units < 65,000$\frac{Btu}{hr}$, HSPF should be used for heating savings.	None	Early Replacement: Nameplate data	EDC Data Gathering
		New Construction or Replace on Burnout: Default values from Table 3-24	See Table 3-24
COP_{ee}, Coefficient of performance of the energy efficient unit. For ASHP units < 65,000 $\frac{Btu}{hr}$ HSPF should be used for heating savings.	None	Nameplate data (AHRI)	EDC Data Gathering
		Early Replacement: Nameplate data	EDC Data Gathering

Term	Unit	Values	Source
$HSPF2_{base}$, $HSPF_{base}$, Heating seasonal performance factor of the baseline unit. For units > 65,000 $\frac{Btu}{hr}$, COP should be used for heating savings.	$\frac{Btu/hr}{W}$	New Construction or Replace on Burnout: Default values from Table 3-24	See Table 3-24
$HSPF2_{ee}$, $HSPF_{ee}$, Heating seasonal performance factor of the energy efficiency unit. For units > 65,000 $\frac{Btu}{hr}$, COP should be used for heating savings.	$\frac{Btu/hr}{W}$	Nameplate data (AHRI)	EDC Data Gathering
$ETDF_{summer}$, Energy to Demand Factor Summer	$\frac{kW}{kWh}$	Default: Table 3-26	2
$ETDF_{winter}$, Energy to Demand Factor Winter			
$EFLH_{cool}$, Equivalent Full Load Hours for the cooling season – The kWh during the entire operating season divided by the kW at design conditions.	$\frac{Hours}{Year}$	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-25	2
$EFLH_{heat}$, Equivalent Full Load Hours for the heating season – The kWh during the entire operating season divided by the kW at design conditions.	$\frac{Hours}{Year}$	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-28	2
1,000, conversion from watts to kilowatts	$\frac{kW}{W}$	1,000	Conversion Factor
3.412, conversion factor from kWh to kBtu	$\frac{kBtu}{kWh}$	3.412	Conversion Factor

Note: Where appropriate, nameplate data collected for usage in savings calculations (i.e., SEER, EER, HSPF) should be converted to new efficiency metrics (i.e., SEER2, EER2, HSPF2) using conversion equations laid out in Vol 1. App. A

Table 3-24: HVAC Baseline Efficiencies

Equipment Type and Capacity	Subcategory or Rating Condition	Cooling Baseline	Heating Baseline	Source
Air-Source Air Conditioners				
< 65,000 Btu/h	Split System	13.4 SEER2	N/A	3
	Single Package	13.4 SEER2		
> 65,000 Btu/h and < 135,000 Btu/h	Split System and Single Package	14.8 IEER	N/A	3, 4
≥ 135,000 Btu/h and < 240,000 Btu/h	Split System and Single Package	14.2 IEER	N/A	3, 4
≥ 240,000 Btu/h and < 760,000 Btu/h	Split System and Single Package	13.2 IEER	N/A	3, 4
≥ 760,000 Btu/h	Split System and Single Package	12.5 IEER	N/A	3

Air-Source Heat Pumps				
< 65,000 Btu/h	Split System	14.3 SEER2	7.5 HSPF2	3
	Single Package	13.4 SEER2	6.7 HSPF2	
≥ 65,000 Btu/h and < 135,000 Btu/h	Split System and Single Package	14.1 IEER	3.4 COP	3, 4
≥ 135,000 Btu/h and < 240,000 Btu/h	Split System and Single Package	13.5 IEER	3.3 COP	3, 4
≥ 240,000 Btu/h and < 760,000 Btu/h	Split System and Single Package	12.5 IEER	3.2 COP	3, 4
Packaged Terminal Systems (Nonstandard Size)				
PTAC	N/A	EER = 10.9 – (0.213 x Cap / 1,000)	N/A	4
PTHP	N/A	EER = 10.8 – (0.213 x Cap / 1,000)	COP = 2.9 – (0.026 x Cap / 1,000)	
Packaged Terminal Systems (Standard Size)				
PTAC	N/A	EER = 14.0 – (0.300 x Cap / 1,000)	N/A	4
PTHP	N/A	EER = 14.0 – (0.300 x Cap / 1,000)	COP = 3.7 – (0.052 x Cap / 1,000)	
Water-Cooled Air Conditioners				
< 65,000 Btu/h	Split System and Single Package	12.1 EER	N/A	3
		12.3 IEER		
≥ 65,000 Btu/h and < 135,000 Btu/h	Split System and Single Package	12.1 EER	N/A	
		13.9 IEER		
≥ 135,000 Btu/h and < 240,000 Btu/h	Split System and Single Package	12.5 EER	N/A	
		13.9 IEER		
≥ 240,000 Btu/h and < 760,000 Btu/h	Split System and Single Package	12.4 EER	N/A	
		13.6 IEER		
≥ 760,000 Btu/h	Split System and Single Package	12.2 EER	N/A	
		13.5 IEER		

Evaporatively-Cooled Air Conditioners				
< 65,000 Btu/h	Split System and Single Package	12.1 EER 12.3 IEER	N/A	
≥ 65,000 Btu/h and < 135,000 Btu/h	Split System and Single Package	12.1 EER 12.3 IEER	N/A	
≥ 135,000 Btu/h and < 240,000 Btu/h	Split System and Single Package	12.0 EER 12.2 IEER	N/A	3
≥ 240,000 Btu/h and < 760,000 Btu/h	Split System and Single Package	11.9 EER 12.1 IEER	N/A	
≥ 760,000 Btu/h	Split System and Single Package	11.7 EER 11.9 IEER	N/A	

Notes: (1) For non-PTAC/PTHP equipment at capacities greater than 65,000 Btu/h, subtract 0.2 from the required cooling baseline efficiency rating value if unit has heating section other than electric resistance. (2) For PTAC and PTHP equipment, "Cap" represents the rated cooling capacity of the product in Btu/h. If the unit's capacity is less than 7,000 Btu/h, 7,000 Btu/h is used in the calculation. If the unit's capacity is greater than 15,000 Btu/h, 15,000 Btu/h is used in the Calculation.

Table 3-25: Cooling EFLHs for Pennsylvania Cities

Space and/or Building Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsport	Source
Education – College/University	870	436	513	664	729	895	701	741	678	2
Education – Other	363	161	193	257	344	421	322	302	272	2
Grocery	889	537	753	884	503	654	753	603	504	2
Health – Hospital	1,401	967	1,358	1,443	990	1,292	930	1,421	1,155	2
Health – Other	649	393	487	669	599	834	603	649	543	2
Industrial Manufacturing	775	357	430	571	684	832	625	619	545	2
Institutional/Public Service	1,024	511	632	844	910	1,326	833	874	781	2
Lodging	1,885	1,193	1,507	1,935	1,691	2,113	1,744	1,874	1,578	2
Multifamily (Common Areas)	1,897	647	802	1,069	1,645	2,009	1,388	1,377	1,199	6, 7

Space and/or Building Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsport	Source
Office	623	211	449	573	627	859	851	695	531	2
Restaurant	748	425	520	713	655	965	746	726	677	2
Retail	1,000	530	645	862	824	1,111	963	838	739	2
Warehouse – Other	237	96	120	158	261	422	227	181	203	2
Warehouse – Refrigerated	4,257	3,018	4,184	4,281	3,511	3,904	3,677	4,301	3,574	2

Table 3-26: Cooling Demand CFs for Pennsylvania Cities

Space and/or Building Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsport	Source
Education – College/University	0.48	0.40	0.37	0.38	0.48	0.51	0.48	0.45	0.49	2
Education – Other	0.12	0.09	0.07	0.09	0.18	0.19	0.18	0.13	0.15	
Grocery	0.33	0.26	0.26	0.27	0.24	0.26	0.27	0.21	0.24	
Health – Hospital	0.43	0.36	0.34	0.37	0.39	0.44	0.39	0.37	0.42	
Health – Other	0.26	0.25	0.23	0.27	0.30	0.34	0.32	0.28	0.29	
Industrial Manufacturing	0.51	0.37	0.33	0.39	0.55	0.60	0.53	0.45	0.48	
Institutional/Public Service	0.53	0.38	0.34	0.45	0.60	0.72	0.56	0.48	0.52	
Lodging	0.72	0.73	0.71	0.77	0.78	0.83	0.83	0.73	0.78	
Multifamily (Common Areas)	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	5
Office	0.32	0.16	0.26	0.31	0.41	0.27	0.35	0.36	0.37	2
Restaurant	0.38	0.36	0.33	0.37	0.42	0.50	0.49	0.39	0.45	
Retail	0.52	0.45	0.42	0.46	0.53	0.57	0.56	0.47	0.49	
Warehouse – Other	0.18	0.11	0.10	0.13	0.24	0.30	0.23	0.15	0.20	
Warehouse – Refrigerated	0.50	0.47	0.45	0.48	0.52	0.53	0.51	0.48	0.51	

Table 3-27: Energy to Demand Factors (ETDFs) for Pennsylvania Cities

Space and/or Building Type	ASHP/PTHP		AC/PTAC/Electric chillers		Source
	$ETDF_{summer}$	$ETDF_{winter}$	$ETDF_{summer}$	$ETDF_{winter}$	
Data Center – No Economizer	0.000628378	0.000378617	0.000628378	0.000003966	8
Data Center – With Economizer	0.000628378	0.000378617	0.000628378	0.000003966	
Education – College/University	0.000551098	0.000399223	0.000551098	0.000007615	
Education – Primary School	0.000540157	0.000385467	0.000540157	0.000009855	
Education – Secondary School	0.000551098	0.000399223	0.000551098	0.000007615	
Grocery	0.000462546	0.000350736	0.000462546	0.000014563	
Health – Hospital	0.000302267	0.000295338	0.000302267	0.000011491	
Health – Other	0.000390448	0.000318096	0.000390448	0.000017713	
Industrial Manufacturing – 1 Shift	0.000628378	0.000378617	0.000628378	0.000003966	
Industrial Manufacturing – 2 Shift	0.000628378	0.000378617	0.000628378	0.000003966	
Industrial Manufacturing – 3 Shift	0.000628378	0.000378617	0.000628378	0.000003966	
Institutional/Public Service	0.000316384	0.000306416	0.000316384	0.000035531	
Large Office	0.000316384	0.000306416	0.000316384	0.000035531	
Lodging – Large Hotel	0.000294894	0.000375780	0.000294894	0.000047198	
Lodging – Small Hotel	0.000247397	0.000411215	0.000247397	0.000043987	
Medium Office	0.000427200	0.000359444	0.0004272	0.000020284	
Multifamily Common Areas	0.000247397	0.000411215	0.000247397	0.000043987	
Restaurant – Full Service	0.000484911	0.000302561	0.000484911	0.000023505	
Restaurant – Quick Service	0.000359006	0.000334799	0.000359006	0.000049439	
Retail – Standalone	0.000487603	0.000326039	0.000487603	0.000007464	
Retail – Strip mall	0.000462546	0.000350736	0.000462546	0.000014563	
Small Office	0.000585656	0.000404026	0.000585656	0.000004985	
Warehouse – Other	0.000628378	0.000378617	0.000628378	0.000003966	
Warehouse – Refrigerated	0.000628378	0.000378617	0.000628378	0.000003966	

Table 3-28: Heating EFLHs for Pennsylvania Cities

Space and/or Building Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsport	Source
Education – College/University	654	984	938	763	442	418	592	733	629	2
Education – Other	579	910	886	593	593	581	804	823	629	
Grocery	667	1,068	929	475	1,015	1,095	513	1,546	1,362	
Health – Hospital	134	81	62	85	289	311	380	94	148	
Health – Other	859	1,432	1,418	1,161	683	725	931	1,062	920	
Industrial Manufacturing	369	500	494	421	299	305	364	392	332	
Institutional/Public Service	1,072	1,489	1,496	1,279	878	1,009	1,058	1,247	1,023	
Lodging	2,158	3,219	3,346	2,739	1,727	1,815	2,194	2,306	2,307	
Multifamily (Common Areas)	252	320	308	287	210	233	240	250	267	6, 7
Office	292	159	458	376	264	253	313	293	326	2
Restaurant	1,047	1,865	1,835	1,501	832	894	1,219	1,336	1,191	
Retail	736	1,085	1,062	872	518	569	711	761	648	
Warehouse – Other	771	1,108	1,094	991	674	810	890	897	768	
Warehouse – Refrigerated	330	613	581	475	246	200	372	391	315	

Default Savings

There are no default savings for this measure.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Packaged Heat Pump Air Conditioner Commercial, Fuel Substitution" and "Packaged Air Conditioner Heat Recovery". Accessed October 2023. Weblink

2) EFLHs, and CFs for Pennsylvania are calculated based on Nexant's eQuest modeling analysis 2014 and updated based on the latest CDD and HDD values from NOAA's 15-year annual climate Normals (2006–2020). Weblink
3) International Energy Conservation Code 2021. Table C403.3.2(1) Weblink
4) U.S. Department of Energy. 10 CFR Part 431. Energy Efficiency Standards and their compliance dates. Weblink
5) C&I Unitary HVAC Load Shape Project Final Report, Version 1.1, KEMA, 2011. Weblink
6) Connecticut's 2018 Program Savings Document. Eversource Energy and UIL Holdings Corp. December 15, 2017. The EFLH values reported in this document were adjusted using full load hours (FLH) from Source 7 to account for differences in weather conditions. Weblink
7) ENERGY STAR Air-Source Heat Pump Calculator. US Department of Energy. Updated July 2011. Weblink
8) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.2.2. HVAC Systems for Midstream Delivery

Target Sector	Commercial and Industrial
Measure Unit	HVAC System
Measure Life	15 years Source 1
Measure Vintage	Replace on Burnout or New Construction

This measure defines the methods for determining the annual electric energy and peak demand savings from installation of non-residential high-efficiency cooling and heating equipment that is sold to trade allies and customers through commercial channels such as HVAC distributors, supply houses, and direct relationships with manufacturers. This complements other delivery channels (such as downstream rebates to trade allies and customers) by providing incentives to encourage distributors to stock, promote, and sell more-efficient HVAC equipment.

Input data to savings algorithms are based both on stipulated code minimum baselines and operating assumption in combination with actual equipment properties recorded by the participating distributors. EDCs, their implementation CSPs, and participating distributors are expected to collect premise type and AHRI reference numbers and use the AHRI rated capacity and efficiency metrics to calculate savings. The algorithms for this measure path assume a 1:1 installation of a high-efficiency unit with a code minimum piece of HVAC equipment with the same capacity. Smaller residential air conditioning and heat pump applications are dealt with in Section 2 of Volume 2: Residential and Industrial Measures of the 2026 Technical Reference Manual.

Eligibility

The energy and demand savings for Commercial and Industrial HVAC systems is determined from the algorithms listed below. This protocol excludes water source, ground source, and groundwater source heat pumps measures. All HVAC applications other than comfort cooling and heating, such as process cooling, are defined as non-standard applications and are ineligible for this measure.

This measure protocol requires the purchase of a high-efficiency air, evaporative, and water source air conditioning, Air Source Heat Pump (ASHP), Packaged Terminal Air Conditioner (PTAC) or Packaged Terminal Heat Pump (PTHP). The qualifying equipment must be purchased through a commercial channel (such as an HVAC contractor or distributor) for installation in a commercial setting. The distributor will need to collect information on the premise type and installation address for verification purposes. The minimum efficiency levels for units less than 5.4 tons under Midstream delivery are defined as follows:

- **Air Source Air Conditioning**: greater than or equal to 14.3 SEER2
- **ASHP**: Greater than or equal to 15.1 SEER2 *or* 7.6 HSPF2
- **PTAC**: EER ≥ $14.0 - (0.2 \times \frac{Btu_{cool}}{1000})$
- **PTHP**: EER ≥ $14.0 - (0.2 \times \frac{Btu_{cool}}{1000})$ *or* HSPF = $3.412 \times (3.7 - 0.04 \times CAPY_{hea}\ )$

For non-residential HVAC air source air conditioning, Air Source Heat Pump (ASHP), Packaged Terminal Air Conditioner (PTAC) or Packaged Terminal Heat Pump (PTHP) systems larger than 5.4 tons, there is no minimum efficiency level threshold.

ALGORITHMS

Air Conditioning (central AC, air-cooled DX, split systems)

For A/C units < 65,000 Btu/hr, use SEER2 to calculate ΔkWh and for units rated in both EER2 and IEER, use IEER for energy savings calculations.

$$\boldsymbol{\Delta kWh} = \left(\frac{\boldsymbol{Btu_{cool}}}{\boldsymbol{hr}} \times \frac{\boldsymbol{1\ kW}}{\boldsymbol{1,000\ W}}\right) \times \left(\frac{\boldsymbol{1}}{\boldsymbol{EER2_{base}}} - \frac{\boldsymbol{1}}{\boldsymbol{EER2_{ee}}}\right) \times \boldsymbol{EFLH_{cool}}$$

$$= \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{IEER_{base}} - \frac{1}{IEER_{ee}}\right) \times EFLH_{cool}$$

$$= \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{SEER2_{base}} - \frac{1}{SEER2_{ee}}\right) \times EFLH_{cool}$$

$$\boldsymbol{\Delta kW_{summer\ peak}} = \Delta kWh \times ETDF_{summer}$$

$$\boldsymbol{\Delta kW_{winter\ peak}} = \Delta kWh \times ETDF_{winter}$$

Air Source Heat Pump

For ASHP units < 65,000 Btu/hr, use SEER2 to calculate ΔkWh_{cool} and HSPF2 to calculate ΔkWh_{heat}. For units rated in both EER2 and IEER, use IEER for energy savings calculations.

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat}$$

$$\Delta kWh_{cool} = \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{IEER_{base}} - \frac{1}{IEER_{ee}}\right) \times EFLH_{cool}$$

$$= \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{SEER2_{base}} - \frac{1}{SEER2_{ee}}\right) \times EFLH_{cool}$$

$$\Delta kWh_{heat} = \left(\frac{Btu_{heat}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \frac{1}{3.412} \times \left(\frac{1}{COP_{base}} - \frac{1}{COP_{ee}}\right) \times EFLH_{heat}$$

$$= \left(\frac{Btu_{heat}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{HSPF2_{base}} - \frac{1}{HSPF2_{ee}}\right) \times EFLH_{heat}$$

$$\boldsymbol{\Delta kW_{summer\ peak}} = \boldsymbol{\Delta kWh \times ETDF_{summer}}$$

$$\boldsymbol{\Delta kW_{winter\ peak}} = \Delta kWh \times ETDF_{winter}$$

Packaged Terminal Air Conditioner and Packaged Terminal Heat Pump

For ASHP units < 65,000 Btu/hr, use SEER to calculate ΔkWh_{cool} and HSPF to calculate ΔkWh_{heat}. For units rated in both EER and IEER, use IEER for energy savings calculations.

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat}$$

$$\Delta kWh_{cool} = \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{EER_{base}} - \frac{1}{EER_{ee}}\right) \times EFLH_{cool}$$

$$\Delta kWh_{heat} = \left(\frac{Btu_{heat}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \frac{1}{3.412} \times \left(\frac{1}{COP_{base}} - \frac{1}{COP_{ee}}\right) \times EFLH_{heat}$$

$$\boldsymbol{\Delta kW_{summer\ peak}} = \boldsymbol{\Delta kWh \times ETDF_{summer}}$$

$$\boldsymbol{\Delta kW_{winter\ peak}} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-29: Terms, Values, and References for HVAC Systems

Term	Unit	Values	Source
$\frac{Btu_{cool}}{hr}$, Rated cooling capacity of the energy efficient unit	$\frac{Btu}{hr}$	Rated Value from AHRI Certificate • **Air Conditioning / Heat Pump**: Cooling Capacity at 95 degrees (F) • **PTAC/PTHP**: Cooling Capacity at 230V if dual voltage	EDC Data Gathering
$\frac{Btu_{heat}}{hr}$, Rated heating capacity of the energy efficient unit	$\frac{Btu}{hr}$	Rated Value from AHRI Certificate • **Heat Pump**: Heating Capacity at 47 degrees (F)	EDC Data Gathering
$IEER_{base}$, Integrated energy efficiency ratio of the baseline unit.	$\frac{Btu/hr}{W}$	Default values from Table 3-24	See Table 3-24
$IEER_{ee}$, Integrated energy efficiency ratio of the energy efficient unit.	$\frac{Btu/hr}{W}$	Rated Value from AHRI Certificate	EDC Data Gathering
$EER2_{base}$, EER_{base}, Energy efficiency ratio of the baseline unit. For air-source AC and ASHP units < 65,000 $\frac{Btu}{hr}$, SEER should be used for cooling savings	$\frac{Btu/hr}{W}$	New Construction or Replace on Burnout: Default values from Table 3-24	See Table 3-24
$EER2_{ee}$, $EER_{ee,}$ Energy efficiency ratio of the energy efficient unit. For air-source AC and ASHP units < 65,000 $\frac{Btu}{hr}$, SEER should be used for cooling savings.	$\frac{Btu/hr}{W}$	Rated Value from AHRI Certificate	EDC Data Gathering
$SEER2_{base}$, $SEER_{base}$, Seasonal energy efficiency ratio of the baseline unit. For units > 65,000 $\frac{Btu}{hr}$, EER should be used for cooling savings.	$\frac{Btu/hr}{W}$	Default values from Table 3-24	See Table 3-24
$SEER2_{ee}$, $SEER_{ee}$, Seasonal energy efficiency ratio of the energy efficient unit. For units > 65,000 $\frac{Btu}{hr}$, EER should be used for cooling savings.	$\frac{Btu/hr}{W}$	Rated Value from AHRI Certificate	EDC Data Gathering
COP_{base}, Coefficient of performance of the baseline unit. For ASHP units < 65,000$\frac{Btu}{hr}$, HSPF should be used for heating savings.	None	Default values from Table 3-24	See Table 3-24
COP_{ee}, Coefficient of performance of the energy efficient unit. For ASHP units < 65,000 $\frac{Btu}{hr}$ HSPF should be used for heating savings.	None	Rated Value from AHRI Certificate	EDC Data Gathering

Term	Unit	Values	Source
$HSPF2_{base}$, $HSPF_{base}$, Heating seasonal performance factor of the baseline unit. For units > 65,000 $\frac{Btu}{hr}$, COP should be used for heating savings.	$\frac{Btu/_{hr}}{W}$	Default values from Table 3-24	See Table 3-24
$HSPF2_{ee}$, $HSPF_{ee}$, Heating seasonal performance factor of the energy efficiency unit. For units > 65,000 $\frac{Btu}{hr}$, COP should be used for heating savings.	$\frac{Btu/_{hr}}{W}$	Rated Value from AHRI Certificate)	EDC Data Gathering
$ETDF_{summer}$, Energy to Demand Factor Summer	$\frac{kW}{kWh}$	Default: Table 3-27	2
$ETDF_{winter}$, Energy to Demand Factor Winter			
$EFLH_{cool}$, Equivalent Full Load Hours for the cooling season – The kWh during the entire operating season divided by the kW at design conditions.	$\frac{Hours}{Year}$	Default value: Table 3-25	2, 5, 6
$EFLH_{heat}$, Equivalent Full Load Hours for the heating season – The kWh during the entire operating season divided by the kW at design conditions.	$\frac{Hours}{Year}$	Default value: Table 3-28	2, 5, 6
1,000, conversion from watts to kilowatts	$\frac{kW}{W}$	1,000	Conversion Factor
3.412, conversion factor from kWh to kBtu	$\frac{kBtu}{kWh}$	3.412	Conversion Factor

Note: Where appropriate, nameplate data collected for usage in savings calculations (i.e., SEER, EER, HSPF) should be converted to new efficiency metrics (i.e., SEER2, EER2, HSPF2) using conversion equations laid out in Vol 1. App. A

Table 3-30: HVAC Baseline Efficiencies

Equipment Type and Capacity	Subcategory or Rating Condition	Cooling Baseline	Heating Baseline	Source
Air-Source Air Conditioners				
< 65,000 Btu/h	Split System	13.4 SEER2	N/A	6
	Single Package	13.4 SEER2		
> 65,000 Btu/h and < 135,000 Btu/h	Split System and Single Package	14.8 IEER	N/A	6, 7
≥ 135,000 Btu/h and < 240,000 Btu/h	Split System and Single Package	14.2 IEER	N/A	6, 7
≥ 240,000 Btu/h and < 760,000 Btu/h	Split System and Single Package	13.2 IEER	N/A	6, 7

Equipment Type and Capacity	Subcategory or Rating Condition	Cooling Baseline	Heating Baseline	Source
≥ 760,000 Btu/h	Split System and Single Package	11.2 IEER	N/A	6
Air-Source Heat Pumps				
< 65,000 Btu/h	Split System	14.3 SEER2	7.5 HSPF2	6
	Single Package	13.4 SEER2	6.7 HSPF2	
≥ 65,000 Btu/h and < 135,000 Btu/h	Split System and Single Package	14.1 IEER	3.4 COP	6, 7
≥ 135,000 Btu/h and < 240,000 Btu/h	Split System and Single Package	13.5 IEER	3.3 COP	6, 7
≥ 240,000 Btu/h	Split System and Single Package	12.5 IEER	3.2 COP	6, 7
Packaged Terminal Systems (Nonstandard Size)				
PTAC	N/A	EER = 10.9 – (0.213 x Cap / 1,000)	N/A	7
PTHP	N/A	EER = 10.8 – (0.213 x Cap / 1,000)	COP = 2.9 – (0.026 x Cap / 1,000)	
Packaged Terminal Systems (Standard Size)				
PTAC	N/A	EER = 14.0 – (0.300 x Cap / 1,000)	N/A	7
PTHP	N/A	EER = 14.0 – (0.300 x Cap / 1,000)	COP = 3.2 – (0.026 x Cap / 1,000)	
Water-Cooled Air Conditioners				
< 65,000 Btu/h	Split System and Single Package	12.1 EER	N/A	6
		12.3 IEER		
≥ 65,000 Btu/h and < 135,000 Btu/h	Split System and Single Package	12.1 EER	N/A	
		13.9 IEER		
	Split System and Single Package	12.5 EER	N/A	

Equipment Type and Capacity	Subcategory or Rating Condition	Cooling Baseline	Heating Baseline	Source
≥ 135,000 Btu/h and < 240,000 Btu/h		13.9 IEER		
≥ 240,000 Btu/h and < 760,000 Btu/h	Split System and Single Package	12.4 EER	N/A	
		13.6 IEER		
≥ 760,000 Btu/h	Split System and Single Package	12.2 EER	N/A	
		13.5 IEER		
Evaporatively-Cooled Air Conditioners				
< 65,000 Btu/h	Split System and Single Package	12.1 EER	N/A	6
		12.3 IEER		
≥ 65,000 Btu/h and < 135,000 Btu/h	Split System and Single Package	12.1 EER	N/A	
		12.3 IEER		
≥ 135,000 Btu/h and < 240,000 Btu/h	Split System and Single Package	12.0 EER	N/A	
		12.2 IEER		
≥ 240,000 Btu/h and < 760,000 Btu/h	Split System and Single Package	11.9 EER	N/A	6
		12.1 IEER		
≥ 760,000 Btu/h	Split System and Single Package	11.7 EER	N/A	
		11.9 IEER		

Notes:
1) For non-PTAC/PTHP equipment at capacities greater than 65,000 Btu/h, subtract 0.2 from the required cooling baseline efficiency rating value if unit has heating section other than electric resistance.
2) For PTAC and PTHP equipment, "Cap" represents the rated cooling capacity of the product in Btu/h. If the unit's capacity is less than 7,000 Btu/h, 7,000 Btu/h is used in the calculation. If the unit's capacity is greater than 15,000 Btu/h, 15,000 Btu/h is used in the Calculation.

The values in Table 3-31*Table 3-25*, and Table 3-32*Table 3-26* are a composite of non-residential tables Table 3-25, and Table 3-28*Table 3-25* and the climate dependent values from Appendix A of the 2026 Technical Reference Manual. Appendix A provides climate region weights for each EDC, based on the overlap of the EDC territories and climate regions. EDCs are encouraged to use the factors for the installation location's climate region, if it is possible to identify the region based on the premise address. Otherwise, the composite factors can be used as the default value for each EDC. The composite factors were developed as a weighted average of the EFLH and CF climate region values and the EDC weights for each climate region.

Table 3-31: Cooling EFLHs for Pennsylvania EDC Climate Region Weighted Composite Factors

Space and/or Building Type	EDC						
	Duquesne	First Energy				PECO	PPL
		Met-Ed	Penelec	Penn Power	West Penn Power		
Education – College/University	701	811	663	691	694	895	792
Education – Other	322	372	277	304	314	421	346
Grocery	753	618	759	790	701	654	649
Health – Hospital	930	1190	1209	1074	984	1291	1269
Health – Other	603	698	607	621	593	834	668
Industrial Manufacturing	625	747	575	610	615	832	703
Institutional/Public Service	833	1080	809	836	829	1325	1007
Lodging	1744	1889	1768	1798	1715	2112	1853
Multi-Family (Common Areas)	1388	1795	1188	1298	1369	2009	1659
Office	851	719	653	773	774	858	678
Restaurant	746	790	693	737	720	964	766
Retail	963	956	854	934	911	1111	921
Warehouse – Other	227	313	184	207	223	422	268
Warehouse – Refrigerated	3677	3814	3957	3847	3675	3903	3940

Table 3-32: Heating EFLHs for Pennsylvania EDC Climate Region Weighted Composite Factors

Space and/or Building Type	EDC						
	Duquesne	First Energy				PECO	PPL
		Met-Ed	Penelec	Penn Power	West Penn Power		
Education – College/University	592	482	707	640	595	418	578
Education - Other	804	603	722	745	763	581	645
Grocery	513	1039	702	503	673	1095	1114
Health - Hospital	380	262	196	297	330	310	196
Health - Other	931	750	1077	995	924	724	855
Industrial Manufacturing	364	317	399	380	359	305	343
Institutional/Public Service	1058	980	1198	1120	1054	1009	1060
Lodging	2194	1859	2539	2347	2206	1815	2067
Multi-Family (Common Areas)	240	227	268	253	243	233	243
Office	313	265	345	331	315	253	280
Restaurant	1219	921	1395	1299	1201	894	1065
Retail	711	584	808	756	698	569	657
Warehouse - Other	890	755	939	918	863	810	795
Warehouse - Refrigerated	372	250	430	401	362	200	299

Default Savings

There are no default savings for this measure.

Evaluation Protocols

Midstream program delivery reduces the data collection requirements of EDCs, their implementation CSPs, and program participants. However, EDC evaluation contractors should validate the make and model of a statistically representative sample of program-supported equipment. The EDC evaluation contractor should also confirm that the installation premise is (a) served by the EDC that supplied the incentive and (b) metered on a non-residential tariff using the installation address collected by the distributor. EDC evaluation contractors may also choose to recalculate the weighted average EFLH values in Table 3-25 and Table 3-28 based on actual program participation. The Pennsylvania Evaluation Framework provides additional guidelines and requirements for evaluation procedures in the context of midstream program delivery.

Sources

1) California Electronic Technical Reference Manual. “Packaged Heat Pump Air Conditioner Commercial, Fuel Substitution” and “Packaged Air Conditioner Heat Recovery”. Accessed October 2023. Weblink. AHRI Institute Directory of Certified Product Performance. Weblink
2) EFLHs and CFs for Pennsylvania are calculated based on Nexant’s eQuest modeling analysis 2014 and updated based on the latest CDD and HDD values from NOAA’s 15-year annual climate Normals (2006–2020). Weblink
3) C&I Unitary HVAC Load Shape Project Final Report, Version 1.1, KEMA, 2011. Weblink
4) ENERGY STAR Air-Source Heat Pump Calculator. US Department of Energy. Updated July 2011. Weblink

5) Connecticut's 2018 Program Savings Document. Eversource Energy and UIL Holdings Corp. December 15, 2017. The EFLH values reported in this document were adjusted using full load hours (FLH) from Source 4 to account for differences in weather conditions. Weblink
6) International Energy Conservation Code 2021. Table C403.3.2(1) Weblink
7) U.S. Department of Energy. 10 CFR Part 431. Energy Efficiency Standards and their compliance dates Weblink

3.2.3. Electric Chillers

Target Sector	Commercial and Industrial
Measure Unit	Electric Chiller
Measure Life	15 years Source 1
Measure Vintage	Replace on Burnout, New Construction, or Early Replacement

This protocol shall apply to high efficiency electric chillers in commercial applications as further described below. This measure may apply to early replacement of an existing system, replacement on burnout, or installation of a new unit in a new or existing non-residential building for HVAC applications.

Eligibility

These prescriptive algorithms and stipulated values are valid for standard comfort cooling applications, defined as unitary electric chillers serving a single load at the system or sub-system level. The savings calculated using the prescriptive algorithms need to be supported by a certification that the chiller is appropriately sized for site design load condition.

All other chiller applications, including existing multiple chiller configurations (including redundant or ‘stand-by’ chillers), existing chillers serving multiple load groups, chillers in industrial applications, chillers using glycol, and heat recovery chillers are defined as non-standard applications and must follow a site-specific custom protocol. Situations with existing non-VFD chillers upgrading to VFD chillers may use the protocol algorithm. This protocol does not apply to VFD retrofits to an existing chiller. In this scenario, the IPLV of the baseline chiller (factory tested IPLV) would be known, but the IPLV for the old chiller/new VFD would be unknown. The algorithms, assumptions, and default factors in this section may be applied to new construction applications.

Algorithms

For Equipment with Efficiency Ratings in EER (i.e., Btu/Wh) units

$$\Delta kWh = Tons_{ee} \times 12 \times \left(\frac{1}{IPLV_{base}} - \frac{1}{IPLV_{ee}}\right) \times EFLH$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

For Equipment with Efficiency Ratings in kW/ton units

$$\Delta kWh = Tons_{ee} \times (IPLV_{base} - IPLV_{ee}) \times EFLH$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-33: Terms, Values, and References for Electric Chillers

Term	Unit	Values	Source
$Tons_{ee}$, The capacity of the chiller at site design conditions accepted by the program	*ton*	Nameplate Data	EDC Data Gathering
12, conversion factor from tons cooling to kBtu/hr	$\frac{kBtu/hr}{ton}$	12	Conversion Factor
$IPLV_{base}$, Integrated Part Load Value of the baseline unit.	$\frac{Btu/hr}{W}$ or $\frac{kW}{ton}$	Early Replacement: Nameplate Data	EDC Data Gathering
		New Construction or Replace on Burnout: See Table 3-34	2
$IPLV_{ee}$, Integrated Part Load Value of the efficient unit.	$\frac{Btu/hr}{W}$ or $\frac{kW}{ton}$	Nameplate Data (AHRI Standards 550/590). At minimum, must satisfy standard listed in Table 3-34	EDC Data Gathering
$ETDF_{summer}$, Energy to Demand Factor Summer	$\frac{kW}{kWh}$	See Table 3-36	3
$ETDF_{winter}$, Energy to Demand Factor Winter			
$EFLH$, Equivalent Full Load Hours – The kWh during the entire operating season divided by the kW at design conditions. The most appropriate EFLH shall be utilized in the calculation.	$\frac{Hours}{Year}$	Based on Logging, BMS data or Modeling	EDC Data Gathering
		Default values from Table 3-35	4

When determining a site-specific EFLH, modeling is an acceptable substitute to metering and BMS data if modeling is conducted using building- and equipment-specific information at the site and the facility consumption is calibrated using 12 months of billing data (pre-retrofit).

Table 3-34: Electric Chiller Baseline Efficiencies Source 2

Chiller Type	Size	Path A (Full-Load Optimized Applications)	Path B (Part-Load Optimized Applications)
Air Cooled Chillers	< 150 tons	Full load: 10.1 EER	Full load: 9.7 EER
		IPLV: 13.7 EER	IPLV: 15.8 EER
	≥ 150 tons	Full load: 10.1 EER	Full load: 9.7 EER
		IPLV: 14.0 EER	IPLV: 16.1 EER
Air-Cooled Chiller without Condenser	All capacities	Air-cooled chillers without condensers must be rated with matching condensers and comply with the air-cooled chiller efficiency requirements.	
Water Cooled Positive Displacement Chiller	< 75 tons	Full load: 0.750 kW/ton	Full load: 0.780 kW/ton
		IPLV: 0.600 kW/ton	IPLV: 0.500 kW/ton
	≥ 75 tons and < 150 tons	Full load: 0.720 kW/ton	Full load: 0.750 kW/ton
		IPLV: 0.560 kW/ton	IPLV: 0.490 kW/ton
	≥ 150 tons and < 300 tons	Full load: 0.660 kW/ton	Full load: 0.680 kW/ton
		IPLV: 0.540 kW/ton	IPLV: 0.440 kW/ton
	≥ 300 tons and	Full load: 0.610 kW/ton	Full load: 0.625 kW/ton

Chiller Type	Size	Path A (Full-Load Optimized Applications)	Path B (Part-Load Optimized Applications)
	< 600 tons	IPLV: 0.520 kW/ton	IPLV: 0.410 kW/ton
	≥ 600 tons	Full load: 0.560 kW/ton	Full load: 0.585 kW/ton
		IPLV: 0.500 kW/ton	IPLV: 0.380 kW/ton
Water Cooled Centrifugal Chiller	< 150 tons	Full load: 0.610 kW/ton	Full load: 0.695 kW/ton
		IPLV: 0.550 kW/ton	IPLV: 0.440 kW/ton
	≥ 150 tons and < 300 tons	Full load: 0.610 kW/ton	Full load: 0.635 kW/ton
		IPLV: 0.550 kW/ton	IPLV: 0.400 kW/ton
	≥ 300 tons and < 400 tons	Full load: 0.560 kW/ton	Full load: 0.595 kW/ton
		IPLV: 0.520 kW/ton	IPLV: 0.390 kW/ton
	≥ 400 tons and < 600 tons	Full load: 0.560 kW/ton	Full load: 0.585 kW/ton
		IPLV: 0.500 kW/ton	IPLV: 0.380 kW/ton
	≥ 600 tons	Full load: 0.560 kW/ton	Full load: 0.585 kW/ton
		IPLV: 0.500 kW/ton	IPLV: 0.380 kW/ton

Chillers must satisfy efficiency requirements for both full load and IPLV efficiencies for either Path A or Path B in Table 3-34. Table 3-34 shows code-minimum efficiency ratings to be used for the baseline chiller efficiency in the savings estimation algorithm, which must be consistent with the expected operating conditions of the efficient chiller. For example, if the efficient chiller satisfies Path A and generally performs at part load, the appropriate baseline chiller efficiency is the IPLV value under Path A for energy savings. If the efficient chiller satisfies Path B and generally performs at full load, the appropriate baseline chiller efficiency is the full load value under Path B for energy savings. Generally, chillers operating above 70 percent load for a majority (50% or more) of operating hours should use Path A and chillers below 70% load for a majority of operating hours should use Path B. The “full load” efficiency from the appropriate

Table 3-35: Chiller EFLHs for Pennsylvania Cities

Space and/or Building Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsport
Data Center - No Economizer	EDC Data Gathering								
Data Center - With Economizer	EDC Data Gathering								
Education - College/University	904	412	512	681	773	939	708	728	706
Education - Other	374	180	224	297	382	475	333	339	360
Health - Hospital	1,686	926	1,147	1,529	1,512	1,898	1,398	1,576	1,377
Health - Other	624	344	425	567	577	759	557	581	527
Industrial Manufacturing	963	445	549	733	777	952	745	798	700
Lodging	1,900	1,166	1,373	1,831	1,677	2,018	1,690	1,879	1,613
Office	607	331	410	546	578	715	523	570	516
Retail	1,019	513	635	847	928	1,094	825	916	846

Table 3-36: Chiller ETDFs for Pennsylvania Cities

Space and/or Building Type	Chiller Equipment		Source
	ETDFsummer	ETDFwinter	
Data Center - No Economizer	0.000628378	0.000003966	3
Data Center - With Economizer	0.000628378	0.000003966	
Education - College/University	0.000551098	0.000007615	
Education – Primary School	0.000540157	0.000009855	
Education – Secondary School	0.000551098	0.000007615	
Grocery	0.000462546	0.000014563	
Health - Hospital	0.000302267	0.000011491	
Health - Other	0.000390448	0.000017713	
Industrial Manufacturing - 1 Shift	0.000628378	0.000003966	
Industrial Manufacturing - 2 Shift	0.000628378	0.000003966	
Industrial Manufacturing - 3 Shift	0.000628378	0.000003966	
Institutional/Public Service	0.000316384	0.000035531	
Large Office	0.000316384	0.000035531	
Lodging – Large Hotel	0.000294894	0.000047198	
Lodging – Small Hotel	0.000247397	0.000043987	
Medium Office	0.0004272	0.000020284	
Multifamily Common Areas	0.000247397	0.000043987	
Restaurant – Full Service	0.000484911	0.000023505	
Restaurant – Quick Service	0.000359006	0.000049439	
Retail - Standalone	0.000487603	0.000007464	
Retail - Strip mall	0.000462546	0.000014563	
Small Office	0.000585656	0.000004985	
Warehouse - Other	0.000628378	0.000003966	
Warehouse - Refrigerated	0.000628378	0.000003966	

Default Savings

There are no default savings for this measure.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. “Air-Cooled Chiller”. Accessed October 2023. Weblink. Capped at 15 years per Act 129.
2) International Energy Conservation Code 2021. Table C403.3.2(3) Weblink
3) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink
4) EFLHs and CFs for Pennsylvania are calculated based on Nexant’s eQuest modeling analysis conducted in 2014 and updated based on the latest CDD and HDD values from NOAA’s 15-year annual climate Normals (2006–2020). Weblink

3.2.4. Groundwater Source and Ground Source Heat Pumps

Target Sector	Commercial and Industrial
Measure Unit	Geothermal Heat Pump
Measure Life	15 years Source 1
Measure Vintage	Replace on Burnout, New Construction, or Early Replacement

This protocol shall apply to ground source and groundwater source heat pumps in commercial applications as further described below. This measure may apply to early replacement of an existing system, replacement on burnout, or installation of a new unit in a new or existing non-residential building for HVAC applications. The base case may employ a different system than the retrofit case.

Eligibility

In order for this characterization to apply, the efficient equipment is a high-efficiency groundwater source or ground source heat pump system that exceeds the energy efficiency requirements of the International Energy Conservation Code (IECC) 2021, Table 403.3.2(14). The following retrofit scenarios are considered:

- Ground source heat pumps for existing or new non-residential HVAC applications
- Groundwater source heat pumps for existing or new non-residential HVAC applications

These retrofits reduce energy consumption by the improved thermodynamic efficiency of the refrigeration cycle of new equipment, by improving the efficiency of the cooling and heating cycle, and by lowering the condensing temperature when the system is in cooling mode and raising the evaporating temperature when the equipment is in heating mode as compared to the base case heating or cooling system. It is expected that the retrofit system will use a similar conditioned-air distribution system as the base case system.

This protocol does not apply to heat pump systems coupled with non-heat pump systems such as chillers, rooftop AC units, boilers, or cooling towers. Projects that use unique, combined systems such as these should use a site-specific M&V plan (SSMVP) to describe the particulars of the project and how savings are calculated. All HVAC applications other than comfort cooling and heating, such as process cooling, are defined as non-standard applications and are ineligible for this measure.

Definition of Baseline Equipment

In order for this protocol to apply, the baseline equipment could be a standard-efficiency air source, water source, groundwater source, or ground source heat pump system, an electric chiller and boiler system, or other chilled/hot water loop system. To calculate savings, the baseline system type is assumed to be an air source heat pump of similar size except for cases where the project is replacing a ground source, groundwater source, or water source heat pump; in those cases, the baseline system type is assumed to be a similar system at code.

Table 3-37: Water Source or Geothermal Heat Pump Baseline Assumptions

Baseline Scenario		Baseline Efficiency Assumptions
New Construction		Standard efficiency air source heat pump system
Replace on Burnout	Replacing any technology besides a ground source, groundwater source, or water source heat pump	Standard efficiency air source heat pump system
Early Replacement	Replacing a ground source, groundwater source, or water source heat pump	Efficiency of the replaced geothermal system for early replacement only (if known), else code for a similar system

ALGORITHMS

There are three primary components that must be accounted for in the energy and demand calculations. The first component is the heat pump unit energy and power, the second is the circulating pump in the ground/water loop system energy and power, and the third is the well pump in the ground/water loop system energy and power. For projects where the retrofit system is similar to the baseline system, such as a standard efficiency ground source system replaced with a high efficiency ground source system, the pump energy is expected to be the same for both conditions and does not need to be calculated. The kWh savings should be calculated using the basic equations below. For baseline units rated in both EER and IEER, use IEER in place of EER where listed in the kWh savings calculations below, and use EER for the kW savings calculations.

For air-cooled base case units with cooling capacities less than 65 kBtu/h:

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat} + \Delta kWh_{pump}$$

$$\Delta kWh_{cool} = \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left\{\frac{1}{SEER_{base}} - \left(\frac{1}{EER_{ee} \times GSER}\right)\right\} \times EFLH_{cool}$$

$$\Delta kWh_{heat} = \left(\frac{Btu_{heat}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left\{\frac{1}{HSPF_{base}} - \left(\frac{1}{COP_{ee} \times 3.412 \times GSOP}\right)\right\} \times EFLH_{heat}$$

$$\Delta kWh_{pump} = 0.746 \times \left\{\left\{HP_{basemotor} \times LF_{base} \times \left(\frac{1}{\eta_{basemotor}}\right) \times HOURS_{basepump}\right\} - \left\{HP_{eemotor} \times LF_{ee} \times \left(\frac{1}{\eta_{eemotor}}\right) \times HOURS_{eepump}\right\}\right\}$$

$$\Delta kW_{summer\ peak} = \Delta kW_{peak\ cool\ summer} + \Delta kW_{peak\ pump\ summer}$$

$$\Delta kW_{peak\ cool\ summer} = \Delta kWh_{cool} \times ETDF_{summer}$$

$$\Delta kW_{peak\ pump\ summer} = \Delta kWh_{pump} \times ETDF_{pump\ summer}$$

$$\Delta kW_{winter\ peak} = \Delta kW_{peak\ heat\ winter} + \Delta kW_{peak\ pump\ winter}$$

$$\Delta kW_{peak\ pump\ winter} = \Delta kWh_{pump} \times ETDF_{pump\ winter}$$

$$\boldsymbol{\Delta kW_{peak\ heat\ winter} = \Delta kWh_{heat} \times ETDF_{winter}}$$

For air-cooled base case units with cooling capacities equal to or greater than 65 kBtu/h, and all other units:

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat} + \Delta kWh_{pump}$$

$$\Delta kWh_{cool} = \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{EER_{base}} - \frac{1}{EER_{ee}}\right) \times EFLH_{cool}$$

$$\Delta kWh_{heat} = \left(\frac{Btu_{heat}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \frac{1}{3.412} \times \left(\frac{1}{COP_{base}} - \frac{1}{COP_{ee}}\right) \times EFLH_{heat}$$

$$\Delta kWh_{pump} = 0.746 \times \left\{\left\{HP_{basemotor} \times LF_{base} \times \left(\frac{1}{\eta_{basemotor}}\right) \times HOURS_{basepump}\right\} - \left\{HP_{eemotor} \times LF_{ee} \times \left(\frac{1}{\eta_{eemotor}}\right) \times HOURS_{eepump}\right\}\right\}$$

$$\Delta kW_{peak\ summer} = \Delta kW_{peak\ cool\ summer} + \Delta kW_{peak\ pump\ summer}$$

$$\Delta kW_{peak\ cool\ summer} = \Delta kWh_{cool} \times ETDF_{summer}$$

$$\Delta kW_{peak\ pump\ summer} = \Delta kWh_{pump} \times ETDF_{pump\ summer}$$

$$\Delta kW_{peak\ winter} = \Delta kW_{peak\ heat\ winter} + \Delta kW_{peak\ pump\ winter}$$

$$\Delta kW_{peak\ pump\ winter} = \Delta kWh_{pump} \times ETDF_{pump\ winter}$$

$$\Delta \boldsymbol{kW}_{\boldsymbol{peak\ heat\ winter}} = \Delta \boldsymbol{kWh}_{\boldsymbol{heat}} \times \boldsymbol{ETDF}_{\boldsymbol{winter}}$$

Definition of Terms

Table 3-38: Terms, Values, and References for Geothermal Heat Pumps [a]

Term	Unit	Value	Source
$\frac{Btu_{cool}}{hr}$, Rated cooling capacity of the energy efficient unit	$\frac{Btu}{hr}$	Nameplate data (AHRI)	EDC Data Gathering
$\frac{Btu_{heat}}{hr}$, Rated heating capacity of the energy efficient unit	$\frac{Btu}{hr}$	Nameplate data (AHRI) Use $\frac{Btu_{cool}}{hr}$ if the heating capacity is not known	EDC Data Gathering
$SEER_{base}$, the cooling seasonal energy efficiency ratio of the baseline unit	$\frac{Btu/hr}{W}$	Early Replacement: Nameplate data	EDC Data Gathering
		New Construction or Replace on Burnout: Default values from Table 3-24 and Table 3-41	See Table 3-24 and **Error! Reference source not found.**
$IEER_{base}$, the integrated energy efficiency ratio of the baseline unit.	$\frac{Btu/hr}{W}$	Early Replacement: Nameplate data	EDC Data Gathering
		New Construction or Replace on Burnout Default values from Table 3-24	See Table 3-24
EER_{base}, the cooling energy efficiency ratio of the baseline unit	$\frac{Btu/hr}{W}$	Early Replacement: Nameplate data	EDC Data Gathering
		New Construction or Replace on Burnout: Default values from Table 3-24 and Table 3-41	See Table 3-24 and **Error! Reference source not found.**

Term	Unit	Value	Source
$HSPF_{base}$, the heating seasonal performance factor of the baseline unit	$\frac{Btu/hr}{W}$	Early Replacement: Nameplate data	EDC Data Gathering
		New Construction or Replace on Burnout: Default values from Table 3-24	See Table 3-24
COP_{base}, the coefficient of performance of the baseline unit	*None*	Early Replacement: Nameplate data	EDC Data Gathering
		New Construction or Replace on Burnout: Default values from Table 3-24 and Table 3-41	See **Error! Reference source not found.**
EER_{ee}, the cooling energy efficiency ratio of the new ground source or groundwater source heat pump being installed	$\frac{Btu/hr}{W}$	Nameplate data (AHRI)	EDC Data Gathering
COP_{ee}, the coefficient of performance of the new ground source, groundwater source, or water source heat pump being installed	*None*	Nameplate data (AHRI)	EDC Data Gathering
$EFLH_{cool}$, Cooling annual Equivalent Full Load Hours EFLH for Commercial HVAC for different occupancies	$\frac{Hours}{Year}$	Based on Logging, BMS data or Modeling [b]	EDC Data Gathering
		Default values from Table 3-25	3
$EFLH_{heat}$, Heating annual Equivalent Full Load Hours EFLH for Commercial HVAC for different occupancies	$\frac{Hours}{Year}$	Based on Logging, BMS data or Modeling [b]	EDC Data Gathering
		Default values from Table 3-28	3
$ETDF_{summer}$, Energy to Demand Factor Summer	$\frac{kW}{kWh}$	Default: Table 3-27	4
$ETDF_{winter}$, Energy to Demand Factor Winter			
$HP_{basemotor}$, Horsepower of base case ground loop pump motor	*HP*	Ground source or groundwater source heat pump baseline: Nameplate ASHP baseline: 0	EDC Data Gathering
LF_{base}, Load factor of the base case ground loop pump motor; ratio of the peak running load to the nameplate rating of the pump motor.	*None*	Based on spot metering and nameplate	EDC Data Gathering
		Default: 75%	2
$\eta_{basemotor}$, efficiency of base case ground loop pump motor	*None*	Nameplate	EDC Data Gathering
		If unknown, assume the federal minimum efficiency requirements in Table 3-39	5
$\eta_{basepump}$, efficiency of base case ground loop pump at design point	*None*	Nameplate	EDC Data Gathering
		If unknown, assume program compliance efficiency in **Error! Reference source not found.**	9
$HOURS_{basepump}$, Run hours of base case ground loop pump motor	*Hours*	Based on Logging, BMS data or Modeling [b]	EDC Data Gathering
		$EFLH_{cool} + EFLH_{heat}$ [c] Default values from Table 3-25 and Table 3-28	3
$HP_{eemotor}$, Horsepower of retrofit case ground loop pump motor	*HP*	Nameplate	EDC Data Gathering
	None	Based on spot metering and nameplate	EDC Data Gathering

Term	Unit	Value	Source
LF_{ee}, Load factor of the retrofit case ground loop pump motor; Ratio of the peak running load to the nameplate rating of the pump motor.		Default: 75%	2
$\eta_{eemotor}$, efficiency of retrofit case ground loop pump motor	*None*	Nameplate	EDC Data Gathering
η_{eepump}, efficiency of retrofit case ground loop pump at design point	*None*	Nameplate	EDC Data Gathering
$HOURS_{eepump}$, Run hours of retrofit case ground loop pump motor	*Hours*	Based on Logging, BMS data or Modeling	EDC Data Gathering
		$EFLH_{cool} + EFLH_{heat}$ [c] Default values from Table 3-25 and Table 3-28	3
3.412, conversion factor from kWh to kBtu	$\frac{kBtu}{kWh}$	3.412	Conversion Factor
0.746, conversion factor from horsepower to kW	$\frac{kW}{hp}$	0.746	Conversion Factor
GSER, Factor used to determine the SEER of a GSHP based on its EER	*None*	See Table 3-42	8
GSOP, Factor used to determine the HSPF of a GSHP based on its COP	*None*	See Table 3-42	8

[a] The cooling efficiency ratings of the baseline and efficient units should be used not including pumps where appropriate.
[b] Modeling is an acceptable substitute to metering and BMS data if modeling is conducted using building- and equipment-specific information at the site and the facility consumption is calibrated using 12 months of billing data (pre-retrofit).
[c] $EFLH_{cool}+EFLH_{heat}$ represents the addition of cooling and heating annual equivalent full load hours for commercial HVAC for different occupancies, respectively.

Table 3-39: Federal Baseline Motor Efficiencies for NEMA Design A and NEMA Design B

Motor HP	Motor Nominal Full-Load Efficiencies (percent)							
	2 Poles		4 poles		6 Poles		8 Poles	
	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1	77.0	77.0	85.5	85.5	82.5	82.5	75.5	75.5
1.5	84.0	84.0	86.5	86.5	87.5	86.5	78.5	77.0
2	85.5	85.5	86.5	86.5	88.5	87.5	84.0	86.5
3	86.5	85.5	89.5	89.5	89.5	88.5	85.5	87.5
5	88.5	86.5	89.5	89.5	89.5	89.5	86.5	88.5
7.5	89.5	88.5	91.7	91.0	91.0	90.2	86.5	89.5
10	90.2	89.5	91.7	91.7	91.0	91.7	89.5	90.2
15	91.0	90.2	92.4	93.0	91.7	91.7	89.5	90.2
20	91.0	91.0	93.0	93.0	91.7	92.4	90.2	91.0

Table 3-40: Ground/Water Loop Pump and Circulating Pump Efficiency

HP	Minimum Pump Efficiency at Design Point (η_{pump})	Source
1.5	65%	9
2	65%	
3	67%	
5	70%	
7.5	73%	
10	75%	
15	77%	
20	77%	

Table 3-41: Default Baseline Equipment Efficiencies

Equipment Type and Capacity	Cooling Baseline	Heating Baseline	Source
Water to Air: Ground Water			
$< 135{,}000 \frac{Btu}{hr}$	18.0 EER (59^0 F entering water)	3.7 COP (50^0 F entering water)	7
Brine to Air: Ground Loop			
$< 135{,}000 \frac{Btu}{hr}$	14.1 EER (77^0 F entering fluid)	3.2 COP (32^0 F entering fluid)	7
Water to Water: Ground Water			
$< 135{,}000 \frac{Btu}{hr}$	16.3 EER (59^0 F entering water)	3.1 COP (50^0 F entering water)	7
Brine to Water: Ground Loop			
$< 135{,}000 \frac{Btu}{hr}$	12.1 EER (77^0 F entering fluid)	2.5 COP (32^0 F entering fluid)	7

Table 3-42: Conversion factors to derive Air-source equivalent metrics of a Ground source heat pump

GSHP Type	GSER	GSOP
Water-to-Air: Ground water	1.04	0.81
Brine-to-Air: Ground loop	1.03	0.87
Water-to-Water: Ground water	0.93	0.84
Brine-to-Water: Ground loop	0.96	0.89

Default Savings

There are no default savings for this measure.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "High Efficiency Water Source Heat Pump" listed in the CPUC Support Table "Effective Useful Life and Remaining Useful Life". Accessed December 2023. Weblink
2) California Public Utility Commission. Database for Energy Efficiency Resources 2005.

3) EFLHs and CFs for Pennsylvania are calculated based on Nexant's eQuest modeling analysis 2014 and updated based on the latest CDD and HDD values from NOAA's 15-year annual climate Normals (2006–2020). Weblink
4) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink
5) Energy Conservation Program: Energy Conservation Standards for Electric Motors. Accessed October 2023. Weblink
6) Factors are derived from the conversion algorithms depicted in the Heat Pump – Water-to-air Ground Source (GSHP) Measure of the Version 11 of the NY TRM. Weblink. Substituting for defaults where applicable and borrowing current market data from the AHRI Database. Weblink
7) International Energy Conservation Code 2021 Table C403.3.2(14) Weblink
8) Factors are derived from the conversion algorithms depicted in the Heat Pump – Water-to-air Ground Source (GSHP) Measure of the Version 11 of the NY TRM. Weblink. Substituting for defaults where applicable and borrowing current market data from the AHRI Database. Weblink
9) Efficiencies are based on program requirements submitted during Phase IV protocol review.

3.2.5. Ductless Mini-Split Heat Pumps – Commercial < 5.4 tons

Target Sector	Commercial and Industrial
Measure Unit	Ductless Heat Pump
Measure Life	15 years Source 1
Measure Vintage	Replace on Burnout

ENERGY STAR Version 6.1 ductless "mini-split" heat pumps (DHP) utilize high efficiency SEER2/EER2 and HSPF2 energy performance factors of 15.2/11.7 and 7.8, respectively, or greater. This technology typically converts an electric resistance heated space into a space heated/cooled with a single or multi-zonal ductless heat pump system. Source 2

Eligibility

This protocol applies to air-to-air, split system, non-ducted heat pumps for single-zone and multi-zone use that are certified to the ENERGY STAR Version 6.1 specification for Cold Climate Heat pumps or otherwise meet ENERGY STAR Version 6.1 qualifying criteria, summarized in Table 3-45. The baseline heating system could be an existing electric resistance, a lower-efficiency ductless heat pump system, a ducted heat pump, packaged terminal heat pump (PTHP), electric furnace, or a non-electric fuel-based system. The baseline cooling system could be a standard efficiency heat pump system, central air conditioning system, packaged terminal air conditioner (PTAC), or room air conditioner. The DHP could be a new device in an existing space, a new device in a new space, or could replace an existing heating/cooling device. The DHP systems could be installed as a single-zone system (one indoor unit, one outdoor unit) or a multi-zone system (multiple indoor units, one outdoor unit). In addition, the old systems should be de-energized, completely uninstalled and removed to ensure that the full savings are realized. All HVAC applications other than comfort cooling and heating, such as process cooling, are defined as non-standard applications and are ineligible for this measure.

Table 3-43: ENERGY STAR Version 6.1 Minimum Qualifying Efficiency

Product Type	SEER2	EER2	HSPF2
Ductless Mini-Split Heat Pump	≥ 15.2	≥ 11.7	≥ 7.8
Cold Climate Ductless Mini-Split Heat Pump	≥ 15.2	≥ 11.7	≥ 8.5

In addition, eligible units must show performance of COP at 5°F ≥ 1.75, and the percentage of heating capacity at 5°F ≥ 70% of that at 47°F per the ENERGY STAR Version 6.1 qualifying criteria.

Algorithms

The savings depend on three main factors: baseline condition, usage, and the capacity of the indoor unit. The algorithms, shown below, are separated into two calculations: single zone and multi-zone ductless heat pumps.

Single Zone:

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat}$$

$$\Delta kWh_{heat} = \frac{CAPY_{heat}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{HSPF2_{base}} - \frac{1}{HSPF2_{ee}}\right) \times EFLH_{heat}$$

$$\Delta kWh_{cool} = \frac{CAPY_{cool}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{SEER2_{base}} - \frac{1}{SEER2_{ee}}\right) \times EFLH_{cool}$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Multi-Zone:

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat}$$

$$\Delta kWh_{heat} = \left[\frac{CAPY_{heat}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{HSPF2_{base}} - \frac{1}{HSPF2_{ee}}\right) \times EFLH_{heat}\right]_{ZONE} + \left[\frac{CAPY_{heat}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{HSPF2_{base}} - \frac{1}{HSPF2_{ee}}\right) \times EFLH_{heat}\right]_{ZONE2} \cdots + \left[\frac{CAPY_{heat}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{HSPF2_{base}} - \frac{1}{HSPF2_{ee}}\right) \times EFLH_{heat}\right]_{ZONEn}$$

$$\Delta kWh_{cool} = \left[\frac{CAPY_{cool}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{SEER2_{base}} - \frac{1}{SEER2_{ee}}\right) \times EFLH_{cool}\right]_{ZONE1} + \left[\frac{CAPY_{cool}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{SEER2_{base}} - \frac{1}{SEER2_{ee}}\right) \times EFLH_{cool}\right]_{ZONE2} \cdots + \left[\frac{CAPY_{cool}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{SEER2_{base}} - \frac{1}{SEER2_{ee}}\right) \times EFLH_{cool}\right]_{ZONEn}$$

$$\Delta kW_{summer\ peak} = [[\Delta kWh]_{ZONE1} + [\Delta kWh]_{ZONE2} + [\Delta kWh]_{ZONEn}] \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = [[\Delta kWh]_{ZONE1} + [\Delta kWh]_{ZONE2} + [\Delta kWh]_{ZONEn}] \times ETDF_{winter}$$

Definition of Terms

Table 3-44: Terms, Values, and References for DHP

Term	Unit	Values	Source
$CAPY_{cool}$, The cooling capacity of the indoor unit, given in $\frac{Btu}{hr}$ as appropriate for the calculation. This protocol is limited to units < 65,000 $\frac{Btu}{hr}$ (5.4 tons) $CAPY_{heat}$, The heating capacity of the indoor unit, given in $\frac{Btu}{hr}$ as appropriate for the calculation.	$\frac{Btu}{hr}$	Nameplate	EDC Data Gathering
$EFLH_{cool}$, Equivalent Full Load Hours for cooling $EFLH_{heat}$, Equivalent Full Load Hours for heating	$\frac{Hours}{Year}$	Based on Logging, BMS data or Modeling Default: Table 3-25 and Table 3-28	EDC Data Gathering 3
$HSPF2_{base}$, $HSPF_{base}$, Heating Seasonal Performance Factor, heating efficiency of the baseline unit	$\frac{Btu/hr}{W}$	Standard DHP: 7.5 HSPF2 Electric resistance: 2.9 HSPF2 Electric furnace: 2.7 HSPF2 ASHP: 7.5 HSPF2 PTHP (Replacements): 2.9 - (0.026 x Cap / 1,000) COP PTHP (New Construction): 3.2 - (0.026 x Cap / 1,000) COP For new space, no heat in an existing space, or non-electric heating in an existing space: use electric resistance: 2.9	4, 5, 7, 8, 9
$SEER2_{base}$, $SEER_{base}$, Seasonal Energy Efficiency Ratio cooling efficiency of baseline unit	$\frac{Btu/hr}{W}$	DHP, ASHP, or central AC: 14.3 SEER2 Room AC: 11.4 SEER PTAC (Replacements): 10.9 - (0.213 x Cap / 1,000) EER PTAC (New Construction): 14.0 - (0.300 x Cap / 1,000) EER PTHP (Replacements): 10.8 - (0.213 x Cap / 1,000) EER PTHP (New Construction): 14.0 - (0.300 x Cap / 1,000) EER For new space or no cooling in an existing space: use Room AC: 11.4 SEER	5, 6, 7, 8, 9
$HSPF2_{ee}$, $HSPF_{ee}$, Heating Seasonal Performance Factor, heating efficiency of the installed DHP	$\frac{Btu/hr}{W}$	Based on nameplate information. Should be at least ENERGY STAR.	EDC Data Gathering
$SEER2_{ee}$, $SEER_{ee}$, Seasonal Energy Efficiency Ratio cooling efficiency of the installed DHP	$\frac{Btu/hr}{W}$	Based on nameplate information. Should be at least ENERGY STAR.	EDC Data Gathering
$ETDF_{summer}$, Energy to Demand Factor Summer $ETDF_{winter}$, Energy to Demand Factor Winter	$\frac{kW}{kWh}$	Default: Table 3-27	10

Note: Cap represents the rated cooling capacity of the product in Btu/h. If the unit's capacity is less than 7,000 Btu/h, 7,000 Btu/h is used in the calculation. If the unit's capacity is greater than 15,000 Btu/h, 15,000 Btu/h is used in the Calculation. Use HSPF2 = COP x 3.412. Where appropriate, nameplate data collected for usage in savings calculations (i.e., SEER, EER, HSPF) should be converted to new efficiency metrics (i.e., SEER2, EER2, HSPF2) using conversion equations laid out in Vol 1. App. A

Default Savings

There are no default savings for this measure.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. “Ductless Heat Pump, Residential”. Accessed October 2023. Weblink
2) ENERGY STAR Program Requirements Product Specification for Central Air Conditioner and Heat Pump Equipment. Eligibility Criteria Final Specification Version 6.1. Weblink
3) EFLHs and CFs for Pennsylvania are calculated based on Nexant’s eQuest modeling analysis 2014 and updated based on the latest CDD and HDD values from NOAA’s 15-year annual climate Normals (2006–2020). Weblink
4) COP = HSPF/3.412. HSPF = 3.412 for electric resistance heating, HSPF = 8.2 for standard DHP. Electric furnace COP typically varies from 0.95 to 1.00 and thereby assumed a COP 0.95 (HSPF = 3.241). HSPF values are further converted to HSPF2 using the guidance laid out in Vol 1.
5) Air-Conditioning, Heating, and Refrigeration Institute (AHRI); the directory of the available ductless mini-split heat pumps and corresponding efficiencies (lowest efficiency currently available). Accessed 03/07/2024. Weblink
6) Engineering judgement: Code of Federal Regulations at 10 CFR 430.32(b). Assumes 10,000 Btu/hr unit with louvered sides. Note: As of 1/1/2014, room air conditioners are rated with the Combined Energy Efficiency Ratio (CEER) which incorporated the impact of standby power consumption. Because this metric is not comparable to SEER, the previous EER requirement is assumed and converted to SEER.
7) Package terminal air conditioners (PTAC) and package terminal heat pumps (PTHP) COP and EER minimum efficiency requirements is based on CAPY value. If the unit’s capacity is less than 7,000 Btu/hr, use 7,000 Btu/hr in the calculation. If the unit’s capacity is greater than 15,000 Btu/hr, use 15,000 Btu/hr in the calculation.
8) International Energy Conservation Code 2021 HVAC equipment performance requirements. Weblink
9) U.S. Department of Energy. 10 CFR Part 431. Energy Efficiency Program for Certain Commercial and Industrial Equipment: Energy efficiency standards and their compliance dates Weblink
10) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.2.6. Ductless Mini-Split Heat Pumps – Commercial < 5.4 tons for Midstream Delivery

Target Sector	Commercial and Industrial
Measure Unit	Ductless Heat Pump
Measure Life	15 years [Source 1]
Measure Vintage	Replace on Burnout, New Construction

ENERGY STAR Version 6.1 ductless "mini-split" heat pumps (DHP) utilize high efficiency SEER2/EER2 and HSPF2 energy performance factors of 15.2/11.7 and 7.8, respectively, or greater. This technology typically converts an electric resistance heated space into a space heated/cooled with a single or multi-zonal ductless heat pump system.

This measure defines the methods for savings from installation of non-residential ductless mini-split heat pumps that is sold to trade allies and customers through commercial channels such as HVAC distributors, supply houses, and direct relationships with manufacturers. This complements other delivery channels (such as downstream rebates to trade allies and customers) by providing incentives to encourage distributors to stock, promote, and sell more-efficient HVAC equipment.

Input data to savings algorithms are based both on stipulated code minimum baselines and operating assumption in combination with actual equipment properties recorded by the participating distributors. EDCs, their implementation CSPs, and participating distributors are expected to collect premise type and AHRI reference numbers and use the AHRI rated capacity and efficiency metrics to calculate savings. The algorithms for this measure path assume a 1:1 installation of a high-efficiency unit of a code DHP with the same capacity. Residential ductless heat pump applications are dealt with in the measure 2.2.3 High Efficiency Equipment: Ductless Heat Pumps with Midstream Delivery Option**.**

Eligibility

This protocol applies to air-to-air, split system, non-ducted heat pumps for single-zone and multi-zone use that are certified to the ENERGY STAR Version 6.1 specification for Cold Climate Heat pumps or otherwise meet ENERGY STAR Version 6.1 qualifying criteria, summarized in Table 3-45[Source 2] The DHP could be a new device in an existing space, a new device in a new space, or could replace an existing heating/cooling device. The DHP systems could be installed as a single-zone system (one indoor unit, one outdoor unit) or a multi-zone system (multiple indoor units, one outdoor unit). All HVAC applications other than comfort cooling and heating, such as process cooling, are defined as non-standard applications and are ineligible for this measure.

Table 3-45: Minimum Efficiency Requirements

Product Type	SEER2	EER2	HSPF2
Ductless Mini-Split Heat Pump	≥ 15.2	≥ 11.7	≥ 7.8
Cold Climate Ductless Mini-Split Heat Pump	≥ 15.2	≥ 11.7	≥ 8.5

In addition, eligible units must show performance of COP at 5°F ≥ 1.75, and the percentage of heating capacity at 5°F ≥ 70% of that at 47°F per the ENERGY STAR Version 6.1 qualifying criteria.

ALGORITHMS

Single Zone:

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat}$$

$$\Delta kWh_{heat} = \frac{CAPY_{heat}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{HSPF2_{base}} - \frac{1}{HSPF2_{ee}}\right) \times EFLH_{heat}$$

$$\Delta kWh_{cool} = \frac{CAPY_{cool}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{SEER2_{base}} - \frac{1}{SEER2_{ee}}\right) \times EFLH_{cool}$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Multi-Zone:

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat}$$

$$\Delta kWh_{hea} = \left[\frac{CAPY_{heat}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{HSPF2_{base}} - \frac{1}{HSPF2_{ee}}\right) \times EFLH_{heat}\right]_{ZONE} + \left[\frac{CAPY_{hea}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{HSPF2_{base}} - \frac{1}{HSPF2_{ee}}\right) \times EFLH_{hea}\right]_{ZONE2} \cdots + \left[\frac{CAPY_{heat}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{HSPF2_{base}} - \frac{1}{HSPF2_{ee}}\right) \times EFLH_{heat}\right]_{ZONEn}$$

$$\Delta kWh_{cool} = \left[\frac{CAPY_{cool}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{SEER2_{base}} - \frac{1}{SEER2_{ee}}\right) \times EFLH_{cool}\right]_{ZONE1} + \left[\frac{CAPY_{cool}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{SEER2_{base}} - \frac{1}{SEER2_{ee}}\right) \times EFLH_{cool}\right]_{ZONE2} \cdots + \left[\frac{CAPY_{cool}}{1{,}000\,\frac{W}{kW}} \times \left(\frac{1}{SEER2_{base}} - \frac{1}{SEER2_{ee}}\right) \times EFLH_{cool}\right]_{ZONEn}$$

$$\Delta kW_{summer\ peak} = [[\Delta kWh]_{ZONE1} + [\Delta kWh]_{ZONE2} + [\Delta kWh]_{ZONEn}] \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = [[\Delta kWh]_{ZONE1} + [\Delta kWh]_{ZONE2} + [\Delta kWh]_{ZONEn}] \times ETDF_{winter}$$

Definition of Terms

Table 3-46: Terms, Values, and References for DHP

Term	Unit	Values	Source
$CAPY_{cool}$, The cooling capacity of the indoor unit, given in $\frac{Btu}{hr}$ as appropriate for the calculation. This protocol is limited to units < 65,000 $\frac{Btu}{hr}$ (5.4 tons) $CAPY_{heat}$, The heating capacity of the indoor unit, given in $\frac{Btu}{hr}$ as appropriate for the calculation.	$\frac{Btu}{hr}$	Rated Value from AHRI Certificate • **Air Conditioning / Heat Pump**: Cooling Capacity at 95 degrees (F) • **Heat Pump**: Cooling Capacity at 230V if dual voltage • **Heat Pump**: Heating Capacity at 47 degrees (F)	3, EDC Data Gathering
$EFLH_{cool}$, Equivalent Full Load Hours for cooling $EFLH_{heat}$, Equivalent Full Load Hours for heating	$\frac{Hours}{Year}$	Default: Table 3-25 and Table 3-28	4, EDC Data Gathering
$HSPF2_{base}$, Heating Seasonal Performance Factor, heating efficiency of the baseline unit	$\frac{Btu/hr}{W}$	7.5	5
$SEER2_{base}$, Seasonal Energy Efficiency Ratio cooling efficiency of baseline unit	$\frac{Btu/hr}{W}$	14.3	5
$HSPF2_{ee}$, Heating Seasonal Performance Factor, heating efficiency of the installed DHP	$\frac{Btu/hr}{W}$	Rated Value from AHRI Certificate. Should be at least ENERGY STAR.	3, EDC Data Gathering
$SEER2_{ee}$, Seasonal Energy Efficiency Ratio cooling efficiency of the installed DHP	$\frac{Btu/hr}{W}$	Rated Value from AHRI Certificate. Should be at least ENERGY STAR.	3, EDC Data Gathering
$ETDF_{summer}$, Energy to Demand Factor Summer $ETDF_{winter}$, Energy to Demand Factor Winter	$\frac{kW}{kWh}$	Default: Table 3-27	6

Note: Cap represents the rated cooling capacity of the product in Btu/h. If the unit's capacity is less than 7,000 Btu/h, 7,000 Btu/h is used in the calculation. If the unit's capacity is greater than 15,000 Btu/h, 15,000 Btu/h is used in the Calculation. Use HSPF2 = COP x 3.412. Where appropriate, nameplate data collected for usage in savings calculations (i.e., SEER, EER, HSPF) should be converted to new efficiency metrics (i.e., SEER2, EER2, HSPF2) using conversion equations laid out in Vol 1. App. A

Default Savings

There are no default savings for this measure.

Evaluation Protocols

Midstream program delivery reduces the data collection requirements of EDCs, their implementation CSPs, and program participants. However, it creates additional verification responsibilities for the EDC evaluation contractors. EDC evaluation contractors should validate the make and model of a statistically representative sample of program-supported equipment and confirm that the installation premise is (a) served by the EDC that supplied the incentive (b) metered on a non-residential. EDC evaluation contractors may also choose to recalculate the weighted average EFLH values in Table 3-25 (cooling EFLHs for Pennsylvania cities) and Table 3-28 (heating EFLHs for Pennsylvania cities) of the Pennsylvania TRM volume 3, based on actual program participation. The Pennsylvania Evaluation Framework provides additional guidelines and requirements for evaluation procedures in the context of midstream program delivery.

Sources

1) California Electronic Technical Reference Manual. "Ductless Heat Pump, Residential". Accessed October 2023. Weblink
2) ENERGY STAR Program Requirements Product Specification for Central Air Conditioner and Heat Pump Equipment. Eligibility Criteria Final Specification Version 6.1. Weblink
3) AHRI Institute Directory of Certified Product Performance. Weblink
4) EFLHs and CFs for Pennsylvania are calculated based on Nexant's eQuest modeling analysis 2014 and updated based on the latest CDD and HDD values from NOAA's 15-year annual climate Normals (2006–2020). Weblink
5) International Energy Conservation Code 2021 HVAC equipment performance requirements. Weblink
6) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.2.7. Small C&I HVAC Refrigerant Charge Correction

Target Sector	Commercial and Industrial
Measure Unit	Tons of Refrigeration Capacity
Measure Life	3 years Source 1
Measure Vintage	Retrofit

This protocol describes the assumptions and algorithms used to quantify energy savings for refrigerant charging on packaged AC units and heat pumps operating in small commercial applications. The protocol herein describes a partially deemed energy savings and demand reduction estimation.

Eligibility

This protocol is applicable for small commercial and industrial customers and applies to documented tune-ups for package or split systems up to 20 tons. All HVAC applications other than comfort cooling and heating, such as process cooling, are defined as non-standard applications and are ineligible for this measure.

Algorithms

This section describes the process of creating energy savings and demand reduction calculations.

Note: Efficiency metrics have been labelled with old terminology for simplification of algorithms. New efficiency metrics have to be used where applicable: SEER2, EER2 and HSPF2.

Air Conditioning

For A/C units < 65,000 Btu/hr, use SEER to calculate ΔkWh. For A/C units > 65,000 Btu/hr, if rated in both EER and IEER, use IEER for energy savings calculations.

$$\Delta kWh = \left(EFLH_c \times \frac{CAPY_c}{1{,}000\,\frac{W}{kW}}\right) \times \left(\frac{1}{[EER \times RCF]} - \frac{1}{EER}\right)$$

$$\Delta kWh = \left(EFLH_c \times \frac{CAPY_c}{1{,}000\,\frac{W}{kW}}\right) \times \left(\frac{1}{[SEER \times RCF]} - \frac{1}{SEER}\right)$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = 0$$

Heat Pumps

For Heat Pump units < 65,000 Btu/hr, use SEER to calculate ΔkWh_{cool} and HSPF instead of COP to calculate ΔkWh_{hea} . For Heat Pump units > 65,000 Btu/hr, if rated in both EER and IEER, use IEER to calculate ΔkWh_{cool}.

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat}$$

$$\Delta kWh_{cool} = \left(EFLH_c \times \frac{CAPY_c}{1{,}000\,\frac{W}{kW}}\right) \times \left(\frac{1}{[IEER \times RCF]} - \frac{1}{IEER}\right)$$

$$\Delta kWh_{cool} = \left(EFLH_c \times \frac{CAPY_c}{1{,}000\,\frac{W}{kW}}\right) \times \left(\frac{1}{[SEER \times RCF]} - \frac{1}{SEER}\right)$$

$$\Delta kWh_{heat} = \left(EFLH_h \times \frac{CAPY_h}{1{,}000\,\frac{W}{kW}}\right) \times \frac{1}{3.412} \times \left(\frac{1}{[COP \times RCF]} - \frac{1}{COP}\right)$$

$$\Delta kWh_{heat} = \left(EFLH_h \times \frac{CAPY_h}{1{,}000\,\frac{W}{kW}}\right) \times \left(\frac{1}{[HSPF \times RCF]} - \frac{1}{HSPF}\right)$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-47: Terms, Values, and References for Refrigerant Charge Correction

Term	Unit	Values	Source
$CAPY_c$, Unit capacity for cooling	$\frac{Btu}{hr}$	From nameplate	EDC Data Gathering
$CAPY_h$, Unit capacity for heating	$\frac{Btu}{hr}$	From nameplate	EDC Data Gathering
EER, $EER2$, Energy Efficiency Ratio. For A/C and heat pump units < 65,000 $\frac{Btu}{hr}$, SEER2 should be used for cooling savings.	$\frac{Btu/hr}{W}$	From nameplate	EDC Data Gathering
		Default: Table 3-24	See Table 3-24
$IEER$, Integrated energy efficiency ratio of the baseline unit.	$\frac{Btu/hr}{W}$	From nameplate	EDC Data Gathering
		Default: Table 3-24	See Table 3-24
$SEER$, $SEER2$, Seasonal Energy Efficiency Ratio. For A/C and heat pump units > 65,000 $\frac{Btu}{hr}$, EER2 should be used for cooling savings.	$\frac{Btu/hr}{W}$	From nameplate	EDC Data Gathering
		Default: Table 3-24	See Table 3-24
$HSPF$, $HSPF2$, Heating Seasonal Performance Factor. For heat pump units > 65,000 $\frac{Btu}{hr}$, COP should be used for heating savings.	$\frac{Btu/hr}{W}$	From nameplate	EDC Data Gathering
		Default: Table 3-24	See Table 3-24
COP, Coefficient of Performance. For heat pump units < 65,000 $\frac{Btu}{hr}$, HSPF should be used for heating savings.	*None*	From nameplate	EDC Data Gathering
		Default: Table 3-24	See Table 3-24
$EFLH_c$, Equivalent Full-Load Hours for mechanical cooling	$\frac{Hours}{Year}$	Default: Table 3-25	2
		Based on Logging, BMS data or Modeling	EDC Data Gathering
$EFLH_h$, Equivalent Full-Load Hours for Heating	$\frac{Hours}{Year}$	See Table 3-28	2
RCF, COP Degradation Factor for Cooling	*None*	See Table 3-48	3
$ETDF_{summer}$, Energy to Demand Factor Summer	$\frac{kW}{kWh}$	Default: Table 3-27	4
$ETDF_{winter}$, Energy to Demand Factor Winter			
$1{,}000$, conversion factor from watts to kilowatts	$\frac{W}{kW}$	1,000	Conversion Factor

Note: Where appropriate, nameplate data collected for usage in savings calculations (i.e., SEER, EER, HSPF) should be converted to new efficiency metrics (i.e., SEER2, EER2, HSPF2) using conversion equations laid out in Vol 1. App. A

Table 3-48: Refrigerant charge correction COP degradation factor (RCF) for various relative charge adjustments for both TXV metered and non-TXV units

% of nameplate charge added (removed)	RCF (TXV)	RCF (Non-TXV)	% of nameplate charge added (removed)	RCF (TXV)	RCF (Non-TXV)	% of nameplate charge added (removed)	RCF (TXV)	RCF (Non-TXV)	Source
60%	68%	13%	28%	95%	83%	(4%)	100%	100%	3
59%	70%	16%	27%	96%	84%	(5%)	100%	99%	
58%	71%	19%	26%	96%	85%	(6%)	100%	99%	
57%	72%	22%	25%	97%	87%	(7%)	99%	99%	
56%	73%	25%	24%	97%	88%	(8%)	99%	99%	
55%	74%	28%	23%	97%	89%	(9%)	99%	98%	
54%	76%	31%	22%	98%	90%	(10%)	99%	98%	
53%	77%	33%	21%	98%	91%	(11%)	99%	97%	
52%	78%	36%	20%	98%	92%	(12%)	99%	97%	
51%	79%	39%	19%	98%	92%	(13%)	99%	96%	
50%	80%	41%	18%	99%	93%	(14%)	98%	96%	
49%	81%	44%	17%	99%	94%	(15%)	98%	95%	
48%	82%	46%	16%	99%	95%	(16%)	98%	95%	
47%	83%	48%	15%	99%	95%	(17%)	98%	94%	
46%	84%	51%	14%	99%	96%	(18%)	98%	93%	
45%	85%	53%	13%	100%	97%	(19%)	98%	93%	
44%	86%	55%	12%	100%	97%	(20%)	97%	92%	
43%	86%	57%	11%	100%	98%	(21%)	97%	91%	
42%	87%	60%	10%	100%	98%	(22%)	97%	90%	
41%	88%	62%	9%	100%	98%	(23%)	97%	90%	
40%	89%	64%	8%	100%	99%	(24%)	97%	89%	
39%	89%	65%	7%	100%	99%	(25%)	96%	88%	
38%	90%	67%	6%	100%	99%	(26%)	96%	87%	
37%	91%	69%	5%	100%	100%	(27%)	96%	86%	
36%	91%	71%	4%	100%	100%	(28%)	96%	85%	
35%	92%	73%	3%	100%	100%	(29%)	95%	84%	
34%	92%	74%	2%	100%	100%	(30%)	95%	83%	
33%	93%	76%	1%	100%	100%	(31%)	95%	82%	
32%	94%	77%	(0%)	100%	100%	(32%)	95%	81%	
31%	94%	79%	(1%)	100%	100%	(33%)	95%	80%	
30%	95%	80%	(2%)	100%	100%	(34%)	94%	78%	
29%	95%	82%	(3%)	100%	100%	(35%)	94%	77%	

Note: In the table above, "% of nameplate charge added (removed)" is the independent variable. Modeling is an acceptable substitute to metering and BMS data if modeling is conducted using building- and equipment-specific information at the site and the facility consumption is calibrated using 12 months of billing data (pre-retrofit).

DEFAULT SAVINGS

There are no default savings for this measure.

EVALUATION PROTOCOLS

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

SOURCES

1) California Electronic Technical Reference Manual. "Refrigerant Charge Adjustment, Commercial". Accessed February 2024. Weblink
2) EFLHs and CFs for Pennsylvania are calculated based on Nexant's eQuest modeling analysis 2014 and updated based on the latest CDD and HDD values from NOAA's 15-year annual climate Normals (2006–2020). Weblink
3) California Energy Commission. (2003). Small HVAC Problems and Potential Savings Report. Weblink
4) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.2.8. HVAC Tune Up

Target Sector	Commercial and Industrial
Measure Unit	HVAC System
Measure Life	3 years Source 1
Measure Vintage	Retrofit
Effective Date	June 1, 2021

This protocol measure defines the methods for determining the annual electric energy and peak demand savings from tune-ups on air conditioners and heat pumps operating in commercial applications. The measure requires that a certified technician performs the following items on air conditioners or heat pumps of up to 20 tons in capacity:

- Change air filter per manufacturer's specification
- Check and correct refrigerant charge as applicable and record data
- Identify and repair leaks if refrigerant charge is low
- Measure and record refrigerant pressures, and temperature drop at indoor coil
- Clean condensate drain line
- Clean outdoor coil and straighten fins
- Clean indoor and outdoor fan blades
- Clean indoor coil with spray-on cleaner and straighten fins
- Repair damaged insulation on suction line
- Measure and record blower amp draw

A copy of contractor invoices that detail work performed to identify tune-up items, as well as additional labor and parts to improve/repair air conditioner or heat pump performance must be submitted by the program.

Eligibility

This protocol is applicable for small commercial and industrial customers and applies to documented tune-ups for air-cooled packages or split air conditioners or air-source heat pumps up to 20 tons. All HVAC applications other than comfort cooling and heating, such as process cooling, are defined as non-standard applications and are ineligible for this measure. The HVAC system must not have a standing maintenance contract and must not have had a tune-up in the last three years. In cases where refrigerant charge correction is the only tune-up action performed, savings must be calculated using measure protocol Small C&I HVAC Refrigerant Charge Correction (3.2.7)

Algorithms

Note: Efficiency metrics have been identified with old terminology for simplification of algorithms. New efficiency metrics have to be used where applicable: SEER2, EER2 and HSPF2.

Air Conditioning (central AC, air-cooled DX, split systems, and packaged terminal AC)
For A/C units < 65,000 Btu/hr, use SEER to calculate ΔkWh and for units rated in both EER and IEER, use IEER for energy savings calculations and EER2 for peak demand savings calculations.

ΔkWh $= \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{EER_{base}}\right) \times EFLH_{cool} \times ESF$

$= \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{IEER_{base}}\right) \times EFLH_{cool} \times ESF$

$= \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{SEER_{base}}\right) \times EFLH_{cool} \times ESF$

$\Delta kW_{summer\ peak}$ $= \Delta kWh \times ETDF_{summer}$

$\Delta kW_{winter\ peak}$ $= \Delta kWh \times ETDF_{winter}$

Air Source and Packaged Terminal Heat Pump

For ASHP units < 65,000 Btu/hr, use SEER to calculate ΔkWh_{cool} and HSPF to calculate ΔkWh_{heat}. For units rated in both EER and IEER, use IEER for energy savings calculations and EER for peak demand savings calculations.

ΔkWh $= \Delta kWh_{cool} + \Delta kWh_{heat}$

ΔkWh_{cool} $= \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{EER_{base}}\right) \times EFLH_{cool} \times ESF$

$= \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{IEER_{base}}\right) \times EFLH_{cool} \times ESF$

$= \left(\frac{Btu_{cool}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{SEER_{base}}\right) \times EFLH_{cool} \times ESF$

ΔkWh_{heat} $= \left(\frac{Btu_{heat}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \frac{1}{3.412} \times \left(\frac{1}{COP_{base}}\right) \times EFLH_{heat} \times ESF$

$= \left(\frac{Btu_{heat}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \left(\frac{1}{HSPF_{base}}\right) \times EFLH_{heat} \times ESF$

$\Delta kW_{summer\ peak}$ $= \Delta kWh \times ETDF_{summer}$

$\boldsymbol{\Delta kW_{winter\ peak}}$ $\boldsymbol{= \Delta kWh \times ETDF_{winter}}$

Definition of Terms

Table 3-49: Terms, Values, and References for HVAC Systems

Term	Unit	Values	Source
$\frac{Btu_{cool}}{hr}$, Rated cooling capacity of the energy efficient unit	$\frac{Btu}{hr}$	Rated Value from AHRI Certificate • **Air Conditioning / Heat Pump**: Cooling Capacity at 95 degrees (F) • **PTAC/PTHP**: Cooling Capacity at 230V if dual voltage	2, EDC Data Gathering
$\frac{Btu_{heat}}{hr}$, Rated heating capacity of the energy efficient unit	$\frac{Btu}{hr}$	Rated Value from AHRI Certificate • **Heat Pump**: Heating Capacity at 47 degrees (F)	2, EDC Data Gathering
$IEER_{base}$, Integrated energy efficiency ratio of the baseline unit.	$\frac{Btu/hr}{W}$	From nameplate	EDC Data Gathering
		Default: Table 3-24	See Table 3-24
$EER2_{base}$, EER_{base} Energy efficiency ratio of the baseline unit. For air-source AC and ASHP units < 65,000 $\frac{Btu}{hr}$, SEER should be used for cooling savings	$\frac{Btu/hr}{W}$	From nameplate	EDC Data Gathering
		Default: Table 3-24	See Table 3-24
$SEER2_{base}$, $SEER_{base}$ Seasonal energy efficiency ratio of the	$\frac{Btu/hr}{W}$	From nameplate	EDC Data Gathering

Term	Unit	Values	Source
baseline unit. For units > 65,000 $\frac{Btu}{hr}$, EER should be used for cooling savings.		Default: Table 3-24	See Table 3-24
COP_{base}, Coefficient of performance of the baseline unit. For ASHP units < 65,000$\frac{Btu}{hr}$, HSPF should be used for heating savings.	None	From nameplate	EDC Data Gathering
		Default: Table 3-24	See Table 3-24
$HSPF2_{base}$, $HSPF_{base}$ Heating seasonal performance factor of the baseline unit. For units > 65,000 $\frac{Btu}{hr}$, COP should be used for heating savings.	$\frac{Btu/hr}{W}$	From nameplate	EDC Data Gathering
		Default: Table 3-24	See Table 3-24
$ETDF_{summer}$, Energy to Demand Factor Summer	$\frac{kW}{kWh}$	Default: Table 3-27	4
$ETDF_{winter}$, Energy to Demand Factor Summer			
$EFLH_{cool}$, Equivalent Full Load Hours for the cooling season – The kWh during the entire operating season divided by the kW at design conditions.	$\frac{Hours}{Year}$	Default: Table 3-25	3
$EFLH_{heat}$, Equivalent Full Load Hours for the heating season – The kWh during the entire operating season divided by the kW at design conditions.	$\frac{Hours}{Year}$	Default: Table 3-28	3
1/1,000, conversion from watts to kilowatts	$\frac{kW}{W}$	1/1,000	Conversion Factor
3.412, conversion factor from kWh to kBtu	$\frac{kBtu}{kWh}$	3.412	Conversion Factor
ESF, Energy Savings Factor	*None*	Default value: Table 3-50	See Table 3-50

Note: Where appropriate, nameplate data collected for usage in savings calculations (i.e., SEER, EER, HSPF) should be converted to new efficiency metrics (i.e., SEER2, EER2, HSPF2) using conversion equations laid out in Vol 1. App. A

Table 3-50: Energy Savings Factors

Tune-Up Component	ESF	Source
Condenser Cleaning	0.061	5
Evaporator Cleaning	0.0022	
Refrigerant Charge Correction (<=20% of refrigerant capacity)	0.0068	
Refrigerant Charge Correction (>20% of refrigerant capacity)	0.0844	
Combo: Condenser Cleaning, Evaporator Cleaning, Charge Correction (<=20%)	0.07	
Combo: Condenser Cleaning, Evaporator Cleaning, Charge Correction (>20%)	0.1476	

Default Savings

There are no default savings for this measure.

Evaluation Protocols

The appropriate evaluation protocol is to verify tune-up activities through inspection of work orders and invoices and customer interviews, and to verify and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Engineering judgement: Keeping in line with Refrigerant charge correction and Coil cleaning measure lives of 3 years of the CA eTRM. Weblink
2) AHRI Institute Directory of Certified Product Performance. Weblink
3) EFLHs and CFs for Pennsylvania are calculated based on Nexant's eQuest modeling analysis 2014 and updated based on the latest CDD and HDD values from NOAA's 15-year annual climate Normals (2006–2020). Weblink
4) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink
5) Derived from the findings of DNV-GL study for California CPUC "Impact Evaluation of 2013-2014 HVAC3 Commercial Quality Maintenance Programs", April 2016, to simulate the inefficient condition within select eQuest models and across climate zones. Weblink

3.2.9. Room Air Conditioner

Target Sector	Commercial and Industrial
Measure Unit	Room Air Conditioner
Measure Life	9 years Source 1
Measure Vintage	Replace on Burnout, Early Retirement, or New Construction

Eligibility

This measure relates to the purchase and installation of a room air conditioner having an efficiency exceeding the minimum level as required by the federal standards effective May 26, 2026. Source 2

Algorithms

Algorithms for annual energy savings and peak demand savings are shown below.

$$\Delta kWh = \left(\frac{1\text{ kW}}{1{,}000\text{ W}} \times \frac{Btu_{cool}}{hr}\right) \times \left(\frac{1}{CEER_{base}} - \frac{1}{CEER_{ee}}\right) \times EFLH_{cool} \times ELFH_{RAC:CAC}$$

$$\Delta kW_{summer\ peak} = \left(\frac{1\text{ kW}}{1{,}000\text{ W}} \times \frac{Btu_{cool}}{hr}\right) \times \left(\frac{1}{CEER_{base}} - \frac{1}{CEER_{ee}}\right) \times \text{CF}$$

$$\Delta kW_{winter\ peak} = 0$$

Definition of Terms

Table 3-51: Terms, Values, and References for ENERGY STAR Room Air Conditioners

Term	Unit	Values	Source
$\frac{Btu_{cool}}{hr}$, Rated cooling capacity of the energy efficient unit	$\frac{Btu}{hr}$	Nameplate data (AHRI)	EDC Data Gathering
$CEER_{base}$, Combined Energy Efficiency ratio of the baseline unit	$\frac{Btu}{hr}$	New Construction or Replace on Burnout: Default Federal Standard values from Table 3-52 to Table 3-54	2
$CEER_{ee}$, Combined Energy Efficiency ratio of the energy efficiency unit	$\frac{Btu}{hr}$	Nameplate data (AHRI)	EDC Data Gathering
CF, Coincidence factor	*Decimal*	Default: Table 3-26	3
$EFLH_{cool}$, Equivalent Full Load Hours for the cooling season – kWh during the entire operating season divided by kW at design conditions.	$\frac{Hours}{Year}$	Based on Logging, BMS data or Modeling	EDC Data Gathering
		Default: Table 3-25	3
$EFLH_{RAC:CAC}$, RAC ELFH to Central Air Conditioner (CAC) ELFH conversion	*Fraction*	0.31	4

Estimating $EFLH_{cool}$ using an energy model is an acceptable substitute to metering and BMS data if modeling is conducted using building- and equipment-specific information at the site and the facility consumption is calibrated using 12 months of billing data (pre-retrofit).

Error! Reference source not found. Table 3-52 to Table 3-54 lists the minimum federal efficiency standards for RAC units of various capacity ranges, with and without louvered sides. Units without louvered sides are also referred to as “through the wall” units or “built-in” units.

Table 3-52: RAC Federal Minimum Efficiency

Capacity (kBTU/h)	Federal Minimum CEER	
	With Louvered Sides	Without Louvered Sides
<6	13.1	12.8
6<8	13.7	
8<11	16.0	14.1
11<14		13.9
14<20		13.7
20<28	13.8	13.8
≥28	13.2	

Table 3-53 lists the minimum federal efficiency standards for casement-only and casement-slider RAC units. Casement-only refers to a RAC designed for mounting in a casement window with an encased assembly with a width of 14.8 inches or less and a height of 11.2 inches or less. Casement-slider refers to a RAC with an encased assembly designed for mounting in a sliding or casement window with a width of 15.5 inches or less.

Table 3-53: Casement-Only and Casement-Slider RAC Federal Minimum Efficiency

Casement	Federal Standard CEER
Casement-only	13.9
Casement-slider	15.3

Table 3-54: Reverse-Cycle RAC Federal Minimum Efficiency

Capacity (kBTU/h)	Federal Standard CEER, with louvered sides	Federal Standard CEER, without louvered sides
< 14	n/a	13.7
≥ 14		12.8
< 20	14.4	n/a
≥ 20	13.7	

Default Savings

There are no default savings for this measure.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Room Air Conditioner, Residential". Accessed August 2023. Weblink
2) 10 C.F.R. § 430.32 (b)(2). Weblink
3) EFLHs and CFs for Pennsylvania are calculated based on Nexant's eQuest modeling analysis 2014 and updated based on the latest CDD and HDD values from NOAA's 15-year annual climate Normals (2006–2020). Weblink
4) The average ratio of Room AC EFLH provided in the RLW report to central cooling EFLH for the same locations in the contemporaneous ENERGY STAR ASHP savings calculator. RLW for the Northeast Energy Efficiency Partnerships' New England Evaluation and State Program Working Group. (2008, June). Coincidence Factor Study Residential Room Air Conditioners. Section 3.7, Page 32, Table 22. Weblink
5) ENERGY STAR (2009, April). Air Source Heat Pump Savings Calculator. U.S. EPA. Weblink

3.2.10. Controls: Guest Room Occupancy Sensor

Target Sector	Commercial and Industrial
Measure Unit	Occupancy Sensor
Measure Life	11 years Source 1
Measure Vintage	Retrofit

This protocol applies to the installation of a control system in hotel guest rooms to automatically adjust the temperature setback during unoccupied periods. Savings are based on the management of the guest room's set temperatures and controlling the HVAC unit for various occupancy modes. The savings are per guestroom controlled, rather than per sensor, for multi-room suites.

Eligibility

This measure is targeted to hotel customers whose guest rooms are equipped with energy management thermostats replacing manual heating/cooling temperature set-point and fan On/Off/Auto thermostat controls. Acceptable baseline conditions are hotel guest rooms with manual heating/cooling temperature set-point and fan On/Off/Auto thermostat controls. Efficient conditions are hotel/motel guest rooms with energy management controls of the heating/cooling temperature set-points and operation state based on occupancy modes.

Algorithms

Energy savings estimates are deemed using the tables below. Estimates were derived using an EnergyPlus model of a motel2. Model outputs were normalized to the installed capacity and reported here as kWh/ton and coincident peak kW/ton. Motels and hotels show differences in shell performance, number of external walls per room and typical heating and cooling efficiencies, thus savings values are presented for hotels and motels separately. Savings also depend on the size and type of HVAC unit, and whether housekeeping staff are directed to set-back/turn-off the thermostats when rooms are unrented.

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat}$$

$$\Delta kWh_{cool} = CAPY \times ESF_{cool}$$

$$\Delta kWh_{heat} = CAPY \times ESF_{heat}$$

$$\Delta kW_{summer\ peak} = \Delta kWh_{cool} \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh_{heat} \times ETDF_{winter}$$

Definition of Terms

Table 3-55: Terms, Values, and References for Guest Room Occupancy Sensors

Term	Unit	Values	Source
$CAPY$, Cooling capacity of controlled unit in tons	ton	EDC Data Gathering	EDC Data Gathering
ESF_{cool}, Energy savings factor cooling	$\frac{kWh}{ton}$	See Table 3-56 and Table 3-57	2
ESF_{heat}, Energy savings factor heating			
$ETDF_{summer}$, Energy to Demand Factor Summer	$\frac{kW}{kWh}$	See Table 3-27	3
$ETDF_{winter}$, Energy to Demand Factor Summer			

Table 3-56: Energy Savings for Guest Room Occupancy Sensors – Motels

HVAC Type	Baseline	ESF_{cool} (kWh/ton)	ESF_{heat} (kWh/ton)
PTAC with Electric Resistance Heating	Housekeeping Setback	85	474
	No Housekeeping Setback	287	1,590
PTAC with Gas Heating	Housekeeping Setback	85	0
	No Housekeeping Setback	287	0
PTHP	Housekeeping Setback	85	175
	No Housekeeping Setback	287	736

Table 3-57: Energy Savings for Guest Room Occupancy Sensors – Hotels

HVAC Type	Baseline	ESF_{cool} (kWh/ton)	ESF_{heat} (kWh/ton)
PTAC with Electric Resistance Heating	Housekeeping Setback	259	63
	No Housekeeping Setback	876	207
PTAC with Gas Heating	Housekeeping Setback	259	0
	No Housekeeping Setback	876	0
PTHP	Housekeeping Setback	259	24
	No Housekeeping Setback	876	237
Central Hot Water Fan Coil with Electric Resistance Heating	Housekeeping Setback	182	63
	No Housekeeping Setback	615	207
Central Hot Water Fan Coil with Gas Heating	Housekeeping Setback	182	0
	No Housekeeping Setback	615	0

Default Savings

There are no default savings for this measure.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "HVAC Occupancy Sensor, Classroom". Accessed October 2023. Weblink
2) S. Keates, ADM Associates Workpaper: "Suggested Revisions to Guest Room Energy Management (PTAC & PTHP)", 11/14/2013 and spreadsheet summarizing the results: 'GREM Savings Summary IL TRM_1_22_14.xlsx.' Five cities in IL were part of this study. Values in this protocol are based on the model for the city of Belleville, IL due to the similarity in the weather heating and cooling degree days with the city of Philadelphia, PA. ESFcool and ESFheat have further been disaggregated from the IL savings values, by technology type, to better serve winter peak demand calculations.
3) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.2.11. Controls: Economizer

Target Sector	Commercial and Industrial
Measure Unit	Economizer
Measure Life	3 years[Source1]
Measure Vintage	Replace on Burnout, New Construction, or Retrofit

This protocol describes the assumptions and algorithms used to quantify energy savings for dual enthalpy economizers on HVAC equipment in commercial applications. Dual enthalpy economizers regulate the amount of outside air introduced into the ventilation system based on the relative temperature and humidity of the outside and return air. If the enthalpy (latent and sensible heat) of the outside air is less than that of the return air when space cooling is required, then outside air is allowed in to reduce or eliminate the cooling requirement of the air conditioning equipment. Since the economizers will not be saving energy during peak hours, the demand savings are zero.

Eligibility

This measure is targeted to non-residential establishments whose HVAC equipment is not equipped with a functional economizer. The baseline condition is an HVAC unit with no economizer installed or with a non-functional/disabled economizer. The efficient condition is an HVAC unit with an economizer and dual enthalpy (differential) control. New construction installations are only eligible when not already required by IECC 2021 energy code.

Algorithms

Replace on Burnout or New Construction

$$\Delta kWh = \frac{SF \times AREA \times FCH_r \times 12}{Eff}$$

$$\Delta kW_{summer\ peak} = 0$$

$$\Delta kW_{winter\ peak} = 0$$

Retrofit

$$\Delta kWh = \frac{SF \times AREA \times FCH_r \times 12}{Eff_{ret}}$$

$$\Delta kW_{summer\ peak} = 0$$

$$\Delta kW_{winter\ peak} = 0$$

Definition of Terms

Table 3-58: Terms, Values, and References for Economizers

Term	Unit	Values	Source
SF, Savings factor; Annual cooling load savings per unit area of conditioned space in the building when compared with a baseline HVAC system with no economizer.	$\frac{tons}{ft^2}$	0.002	2
$AREA$, Area of conditioned space served by controlled unit	ft^2	EDC Data Gathering	EDC Data Gathering
FCH_r, Free cooling hours with outdoor temperature between 60 F and 70 F. Typical operating hour conditions are defined below with standard climate zones for PA.	$\frac{Hours}{Year}$	See Table 3-59	3
Eff, Efficiency of existing HVAC equipment. Depending on the size and age, this will either be the SEER/SEER2, IEER, or EER/EER2 (use EER/EER2 only if SEER/SEER2 or IEER are not available)	$\frac{Btu/hr}{W}$	EDC Data Gathering Default: Table 3-24	See Table 3-24
Eff_{ret}, Efficiency of existing HVAC equipment. Depending on the size and age, this will either be the SEER/SEER2, IEER, or EER/EER2 (use EER/EER2 only if SEER/SEER2 or IEER are not available)	$\frac{Btu/hr}{W}$	EDC Data Gathering 11.0 EER	EDC Data Gathering 4

Table 3-59: FCHr for PA Climate Zones and Various Operating Conditions

Location	FCH_r by Operating Schedule			
	1 Shift, 5 days per week	2 Shift, 5 days per week	3 Shift, 5 days per week	24/7
Allentown	384	754	1,205	1,687
Binghamton	421	855	1,274	1,761
Bradford	430	856	1,166	1,604
Erie	398	790	1,260	1,744
Harrisburg	363	717	1,161	1,629
Philadelphia	374	728	1,170	1,646
Pittsburgh	384	754	1,205	1,687
Scranton	401	807	1,258	1,746
Williamsport	391	775	1,233	1,714

Default Savings

Default savings may be claimed using the algorithms above and the variable defaults along with required EDC data gathering of customer data.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. “Economizer Controls, Commercial”. Accessed October 2023. Weblink
2) Engineering judgement based on: Bell Jr., Arthur A., 2007. *HVAC Equations, Data, and Rules of Thumb*, second edition, pages 51-52. Assuming 500 CFM/ton (total heat of 300-500 cfm/ton @20F delta) and interior supply flow of 1 CFM/Sq Ft as rule of thumb for all spaces, divide 1 by 500 to get 0.002 ton/Sq Ft savings factor used. This is the assumed cooling load

per sq ft of a typical space and what the economizer will fully compensate for during free cooling temperatures.

3) Annual free cooling hour derived using local TMY weather data as an average for the years 1992-2022, with outdoor temperature between 60°F and 70°F.
4) Engineering judgement: Federal standards Minimum Cooling Efficiency for Air Conditioning and Heating Equipment between 65,000 and 135,000 Btu/h. Weblink. Assumes for a 10-year effective measure age, which is two-thirds through a 15-year equipment life and average size of DX cooling equipment gathered from the Act 129 2023 Pennsylvania Non-Residential Baseline Study (72 kBtuh). Weblink

3.2.12. Computer Room Air Conditioner

Target Sector	Commercial and Industrial
Measure Unit	Computer Room Air Conditioner unit
Measure Life	15 years Source 1
Measure Vintage	Replace on Burnout, New Construction, or Early Replacement

This protocol builds upon the existing HVAC Systems protocol (3.2.1) to include computer room air conditioners, given their specific baseline efficiency requirements.

Eligibility

The energy and demand savings for commercial and industrial HVAC systems are determined from the algorithms shown below. Computer room air conditioner (CRAC) systems that exceed the baseline efficiencies (in SCOP) outlined in Table 3-61 or Table 3-62 are eligible for this measure. VFDs and other CRAC measures can be found in other sections of the TRM.

Algorithms

SCOP is the only recognized efficiency metric for data center equipment. Energy and demand savings should be calculated according to the specifications of the efficient equipment and the mandated baseline efficiencies listed in Table 3-61 or Table 3-62

$$\Delta kWh = \left(\frac{Btu_{cool,sensible}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \frac{1\ \text{Wh}}{3.412\ \text{Btu}} \times \left(\frac{1}{SCOP_{base}} - \frac{1}{SCOP_{ee}}\right) \times EFLH_{cool}$$

$$\Delta kW_{summer\ peak} = \left(\frac{Btu_{cool,sensible}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \frac{1\ \text{Wh}}{3.412\ \text{Btu}} \times \left(\frac{1}{SCOP_{base}} - \frac{1}{SCOP_{ee}}\right) \times CF$$

$$\Delta kW_{winter\ peak} = \left(\frac{Btu_{cool,sensible}}{hr} \times \frac{1\ kW}{1{,}000\ W}\right) \times \frac{1\ \text{Wh}}{3.412\ \text{Btu}} \times \left(\frac{1}{SCOP_{base}} - \frac{1}{SCOP_{ee}}\right) \times CF$$

Definition of Terms

Table 3-60: Terms, Values, and References for Computer Room Air Conditioners

Term	Unit	Values	Source
$\frac{Btu_{cool,sensible}}{hr}$, Rated cooling capacity of the energy efficient unit	$\frac{Btu}{hr}$	Nameplate data (AHRI)	EDC Data Gathering
$SCOP_{base}$, Sensible Coefficient of Performance of the baseline unit.	None	Early Replacement: Nameplate data	EDC Data Gathering
		New Construction or Replace on Burnout: Default values from Table 3-61 or Table 3-62	2
$SCOP_{ee}$, Sensible Coefficient of Performance of the energy efficient unit.	None	Nameplate data (AHRI)	EDC Data Gathering
CF, Coincidence factor	*Decimal*	Default = 1.0 or EDC Data Gathering	3
$EFLH_{cool}$, Equivalent Full Load Hours for the cooling season – the kWh during the entire operating season divided by the kW at design conditions	$\frac{Hours}{Year}$	Based on Logging, BMS data or Modeling	EDC Data Gathering
1,000, conversion from kilowatts to watts	$\frac{W}{kW}$	1,000	Conversion Factor
$\frac{1}{3.412}$, conversion from Btu to watt-hours	$\frac{Wh}{Btu}$	$\frac{1}{3.412}$	Conversion Factor

Table 3-61: Minimum Efficiency Standards for Floor-Mounted Computer Room Air Conditioners

Equipment Type	Downflow and upflow ducted			Upflow non-ducted and horizontal flow		
	Net Sensible Cooling Capacity	Minimum NSenCOP efficiency		Net Sensible Cooling Capacity	Minimum NSenCOP efficiency	
		Downflow	Upflow ducted		Upflow non-ducted	Horizontal flow
Air-Cooled	<80,000 Btu/h	2.7	2.67	<65,000 Btu/h	2.16	2.65
	≥ 80,000 Btu/h and < 295,000 Btu/h	2.58	2.55	≥ 65,000 Btu/h and < 240,000 Btu/h	2.04	2.55
	≥ 295,000 Btu/h and < 930,000 Btu/h	2.36	2.33	≥ 240,000 Btu/h and < 760,000 Btu/h	1.89	2.47
Air-Cooled with Fluid Economizer	<80,000 Btu/h	2.7	2.67	<65,000 Btu/h	2.09	2.65
	≥ 80,000 Btu/h and < 295,000 Btu/h	2.58	2.55	≥ 65,000 Btu/h and < 240,000 Btu/h	1.99	2.55
	≥ 295,000 Btu/h and < 930,000 Btu/h	2.36	2.33	≥ 240,000 Btu/h and < 760,000 Btu/h	1.81	2.47

Water-Cooled	<80,000 Btu/h	2.82	2.79	<65,000 Btu/h	2.43	2.79
	≥ 80,000 Btu/h and < 295,000 Btu/h	2.73	2.7	≥ 65,000 Btu/h and < 240,000 Btu/h	2.32	2.68
	≥ 295,000 Btu/h and < 930,000 Btu/h	2.67	2.64	≥ 240,000 Btu/h and < 760,000 Btu/h	2.2	2.6
Water-Cooled with Fluid Economizer	<80,000 Btu/h	2.77	2.74	<65,000 Btu/h	2.35	2.71
	≥ 80,000 Btu/h and < 295,000 Btu/h	2.68	2.65	≥ 65,000 Btu/h and < 240,000 Btu/h	2.24	2.6
	≥ 295,000 Btu/h and < 930,000 Btu/h	2.61	2.58	≥ 240,000 Btu/h and < 760,000 Btu/h	2.12	2.54
Glyco-Cooled	<80,000 Btu/h	2.56	2.53	<65,000 Btu/h	2.08	2.48
	≥ 80,000 Btu/h and < 295,000 Btu/h	2.24	2.21	≥ 65,000 Btu/h and < 240,000 Btu/h	1.9	2.18
	≥ 295,000 Btu/h and < 930,000 Btu/h	2.21	2.18	≥ 240,000 Btu/h and < 760,000 Btu/h	1.81	2.18
Glyco-Cooled with Fluid Economizer	<80,000 Btu/h	2.51	2.48	<65,000 Btu/h	2	2.44
	≥ 80,000 Btu/h and < 295,000 Btu/h	2.19	2.16	≥ 65,000 Btu/h and < 240,000 Btu/h	1.82	2.1
	≥ 295,000 Btu/h and < 930,000 Btu/h	2.15	2.12	≥ 240,000 Btu/h and < 760,000 Btu/h	1.73	2.1

Table 3-62: Minimum Efficiency Standards for Ceiling-Mounted Computer Room Air Conditioners

Equipment Type	Net Sensible Cooling Capacity	Minimum NSenCOP efficiency	
		Ducted	Non-ducted
Air-Cooled with Free Air Discharge Condenser	<29,000 Btu/h	2.05	2.08
	≥ 29,000 Btu/h and < 65,000 Btu/h	2.02	2.05
	≥ 65,000 Btu/h and < 760,000 Btu/h	1.92	1.94
Air-Cooled with Free Air Discharge Condenser and Fluid Economizer	<29,000 Btu/h	2.01	2.04
	≥ 29,000 Btu/h and < 65,000 Btu/h	1.97	2
	≥ 65,000 Btu/h and < 760,000 Btu/h	1.87	1.89
Air-Cooled with Ducted Condenser	<29,000 Btu/h	1.86	1.89
	≥ 29,000 Btu/h and < 65,000 Btu/h	1.83	1.86
	≥ 65,000 Btu/h and < 760,000 Btu/h	1.73	1.75
Air-Cooled with Fluid Economizer and Ducted Condenser	<29,000 Btu/h	1.82	1.85
	≥ 29,000 Btu/h and < 65,000 Btu/h	1.78	1.81
	≥ 65,000 Btu/h and < 760,000 Btu/h	1.68	1.7
Water-Cooled	<29,000 Btu/h	2.38	2.41
	≥ 29,000 Btu/h and < 65,000 Btu/h	2.28	2.31
	≥ 65,000 Btu/h and < 760,000 Btu/h	2.18	2.2
Water-Cooled with Fluid Economizer	<29,000 Btu/h	2.33	2.36
	≥ 29,000 Btu/h and < 65,000 Btu/h	2.23	2.26
	≥ 65,000 Btu/h and < 760,000 Btu/h	2.13	2.16
Glyco-Cooled	<29,000 Btu/h	1.97	2
	≥ 29,000 Btu/h and < 65,000 Btu/h	1.93	1.98
	≥ 65,000 Btu/h and < 760,000 Btu/h	1.78	1.81
Glyco-Cooled with Fluid Economizer	<29,000 Btu/h	1.92	1.95
	≥ 29,000 Btu/h and < 65,000 Btu/h	1.88	1.93
	≥ 65,000 Btu/h and < 760,000 Btu/h	1.73	1.76

Default Savings

There are no default savings for this measure.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Phase II Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Air Conditioners (air-cooled, split and unitary)" and "Air Conditioners (water-cooled, split and unitary)". Accessed April 2024. Weblink
2) U.S. Department of Energy. 10 CFR Part 431. Energy Efficiency Program for Certain Commercial and Industrial Equipment: Subpart F—Commercial Air Conditioners and Heat Pumps. Table 13 431.97(e)(2) and Table 14 431.97(e)(2). Accessed October 2023. Weblink
3) Xcel Energy, Data Center Efficiency Deemed Savings 2016. Weblink

3.2.13. Computer Room Air Conditioner/Handler Electronically Commutated Plug Fans

Target Sector	Commercial and Industrial
Measure Unit	Fan Size (HP) Installed
Measure Life	15 years Source 1
Measure Vintage	Retrofit

Data centers have significant cooling loads, due to the large internal heat gains from IT equipment. Cooling for these spaces is typically provided by computer room air conditioners (CRAC) or computer room air handlers (CRAH). CRAH units differ from CRAC units by supplying cooling via chilled water instead of direct expansion.

Since CRAH units lack compressors and condensers, fan energy comprises the majority of their energy usage.[Source 2] This protocol is concerned with installing or replacing the existing fans with electronically commutated (EC) plug fans. The term "plug fan" refers to a fan with no housing, typically utilizing an airfoil, backward inclined or backward curved impeller design.[Source 3]

Baseline fans are typically centrifugal, belt-driven fans mounted in the CRAC unit, powered by three-phase AC motors. The protocol estimates energy and demand savings when upgrading these with EC plug fans which are direct-driven and can be mounted in-unit or underfloor. Underfloor mounting offers additional energy savings by providing a more efficient airflow path and reducing resistance on the blower.

Eligibility

This measure requires the installation of EC plug fans in CRAC and CRAH units. This applies to new construction applications where EC plug fans were specified instead of belt-driven fans or retrofit applications in which conventional, belt-driven fans were replaced with EC plug fans.

Installing any mechanism that could potentially modify the airflow of the supply fan on a DX system has potential to freeze the coil. Installation of any ECM on a CRAC unit should be verified with the manufacturer.

Algorithms

The annual energy and peak demand savings are obtained through the following formulas shown below. These formulas are adopted from Xcel Energy's Deemed Savings Technical Assumptions for the Data Center Efficiency Program.[Source 4]

$$\Delta kWh = \Delta Fan\ Power \times \left[HOU_{Fan} + \left(\frac{3{,}413}{12{,}000} \times \eta_{cooling}\right) \times HOU_{Fan}\right]$$

$$\Delta kW_{summer\ peak} = \Delta Fan\ Power \times \left(1 + \frac{3{,}413}{12{,}000} \times \eta_{cooling}\right) \times CF$$

$$\Delta kW_{winter\ peak} = \Delta Fan\ Power \times \left(1 + \frac{3{,}413}{12{,}000} \times \eta_{cooling}\right) \times CF$$

$$\Delta Fan\ Power = HP \times (1 - CLF) \times 0.746 \times UF$$

$$CLF = \left(\frac{\eta_{base\ fan} \times \eta_{base\ belt} \times \eta_{base\ motor}}{\eta_{EC\ fan} \times \eta_{EC\ drive} \times \eta_{EC\ motor}}\right) - UDSF$$

Definition of Terms

Table 3-63: Terms, Values, and References for CRAC/CRAH EC Plug Fans

Term	Unit	Values	Source
$\eta_{base\ fan}$, Efficiency of baseline centrifugal, forward-curved fans	None	EDC Data Gathering Default = 53.81%	4
$\eta_{base\ belt}$, Efficiency of baseline belt	None	EDC Data Gathering Default = 95%	6
$\eta_{base\ motor}$, Efficiency of baseline AC motor	None	EDC Data Gathering Default = 91.18%	4
$\eta_{EC\ fan}$, Efficiency of EC plug fan	None	EDC Data Gathering Default = 65.97%	4
$\eta_{EC\ drive}$, Efficiency of EC motor drive	None	EDC Data Gathering Default = 99.5%	4
$\eta_{EC\ motor}$, Efficiency of EC motor	None	EDC Data Gathering Default = 88.96%	4
$UDSF$, Underfloor distribution savings factor	None	If fans are located: In Unit = 0% Underfloor = 12.7%	5
CLF, Comparison Load Factor. This term compares the baseline and EC system efficiencies and accounts for underfloor location (if applicable) to provide an estimate of the load on the EC system.	None	Calculated	4
$\Delta Fan\ Power$, Fan power reduction	kW	Calculated	4
HP, Fan power replaced	HP	EDC Data Gathering	-
UF, % of CRAC/CRAH units in use	None	EDC Data Gathering Default = 83%	7
$\eta_{cooling}$, Efficiency of cooling system	kW/ton	EDC Data Gathering Default = 0.95	*
HOU_{Fan}, Annual hours of fan operation	Hours/year	EDC Data Gathering Default = 8,760	**
0.746, kilowatt to hp conversion factor	kW/HP	0.746	-
3,413, Btu to kWh conversion factor	Btu/kWh	3,413	-
12,000, Btu to ton (cooling) conversion factor	Btu/ton	12,000	-
CF, Coincidence factor	None	EDC Data Gathering Default = 1.0	**

* Assumes an average of air-cooled chillers and DX (all sizes) and water-cooled DX efficiencies. Water-cooled chillers were excluded from the average since they are assumed to be baseline for data centers greater than 1 MW. Source 7, pages 32, 36 and 38.
** Assumes data center CRAC/CRAH fans operates continuously. This is consistent with the HVAC hours for data center applications. Additionally, the CRAC/CRAH fans are assumed to operating regardless of economizer operation.

Default Savings

Table 3-64: Default 'per HP' Savings for CRAC/CRAH EC Plug Fans

Location of Plug Fan	Energy Savings (kWh/HP)	Peak Demand Reduction (kW/HP)
In Unit	1,390	0.1587
Underfloor	2,306	0.2633
If Unknown	1,848	0.2110

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) U.S. Department of Energy, Energy Savings Potential and Opportunities for High-Efficiency Electric Motors in Residential and Commercial Equipment, December 2013. Weblink
2) Emerson Network Power, Technical Note: Using EC Plug Fans to Improve Energy Efficiency of Chilled Water Cooling Systems in Large Data Centers. Weblink
3) ASHRAE, 2016 ASHRAE Handbook: HVAC Systems and Equipment.
4) Xcel Energy Data Center Efficiency Program, Deemed Savings Technical Assumptions. Weblink
5) Technical Note: Using EC Plug Fans to Improve Energy Efficiency of Chilled Water Cooling Systems in Large Data Centers, by Emerson Power Network (Weblink) [UDSF value derived from EC Plug Fans vs. VFD savings table on page 5, savings from base at 100% speed.]
6) U.S. Department of Energy, Replace V-Belts with Notched or Synchronous Belt Drives, November 2012. Weblink
7) Integral Group, Energy Efficiency Baselines for Data Centers, March 1, 2013. Weblink (Usage factor assumes 5 of 6 units operating, based on a “Redundancy = N+1” and “Safety factor on capacity = design load × 1.20”)

3.2.14. Computer Room Air Conditioner/Handler VSD on AC Fan Motors

Target Sector	Commercial and Industrial
Measure Unit	Size (HP) of Fan
Measure Life	15 years Source 1
Measure Vintage	Retrofit

Data centers have significant cooling loads, due to the large internal heat gains from IT equipment. Cooling for these spaces is typically provided by computer room air conditioners (CRAC) or computer room air handlers (CRAH). CRAH units differ from CRAC units by supplying cooling via chilled water instead of direct expansion.

Since CRAH units lack compressors and condensers, fan energy comprises the majority of their energy usage.[Source 2] In addition to saving fan energy, cooling load is also reduced, resulting from the decreased energy consumption by motors within the conditioned space. This measure protocol is concerned with installing or–upgrading to variable speed drives (VSDs) on existing CRAC or CRAH units.

Eligibility

This measure requires the installation of a VSD to control AC fan motors in CRAC and CRAH units. This applies to new construction and retrofit applications where constant speed AC fan motors are retrofitted with VSD controls.

Installing any mechanism that could potentially modify the airflow of the supply fan on a DX system has potential to freeze the coil. Installation of any VSD on a CRAC unit should be verified with the manufacturer.

Algorithms

The annual energy and peak demand savings are obtained through the following formulas:

$$\Delta kWh = \Delta kWh_{fan} + \Delta kWh_{cooling}$$

$$\Delta kW_{summer\ peak} = \frac{\Delta kWh}{HOU} \times CF$$

$$\Delta kW_{winter\ peak} = \frac{\Delta kWh}{HOU} \times CF$$

$$\Delta kWh_{fan} = HP \times \frac{LF}{\eta_{motor}} \times 0.746 \times ESF \times UF \times HOU$$

$$\Delta kWh_{cooling} = \Delta kWh_{fan} \times \frac{3{,}413}{12{,}000} \times \eta_{cooling}$$

Definition of Terms

Table 3-65: Terms, Values, and References for CRAC/CRAH VSD on AC Fan Motors

Term	Unit	Values	Source
HP, Fan motor power	HP	EDC Data Gathering	-
LF, Load factor of fan motor	None	EDC Data Gathering Default = 75%	4
η_{motor}, Efficiency of AC motor	None	EDC Data Gathering Default = 91.18%	4
0.746, HP to kW conversion factor	kW/HP	0.746	-
HOU, Annual hours of fan operation	Hours/year	8,760	4
ESF, Energy savings factor	None	0.40	5
UF, % of CRAC/CRAH units in use (usage factor)	None	EDC Data Gathering Default = 83%	4
3,143, conversion factor from BTU/hr to kW	BTU/hr-kW	3,143	-
12,000, conversion factor from BTUs/hr to tons of cooling	BTU/hr-ton	12,000	-
CF, Coincidence factor	None	EDC Data Gathering Default = 1	4
$\eta_{cooling}$, Efficiency of cooling system	kW/ton	EDC Data Gathering Default = 0.95	3

Default Savings

Default savings for this measure are shown in the table below.

Table 3-66: Default Savings for CRAC/CRAH VSD on AC Fan Motors

Annual Energy Savings (kWh/HP)	Peak Demand Reduction (kW/HP)
2,267	0.2588

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Efficiency Vermont Technical Reference User Manual (TRM), March 16, 2015. (15 years is given for non-process VSDs.) Weblink
2) *Technical Note: Using EC Plug Fans to Improve Energy Efficiency of Chilled Water Cooling Systems in Large Data Centers*, Emerson Network Power. Page 2. Weblink
3) Integral Group, Energy Efficiency Baselines for Data Centers, March 1, 2013. Weblink (Usage factor derived from an assumption that 5 of 6 units operating, based on a "Redundancy = N+1" and "Safety factor on capacity = design load × 1.20". Cooling system efficiency assumes an average of air-cooled chillers and DX (all sizes) and water-cooled DX efficiencies. Water-cooled chillers were excluded from the average since they are assumed to be baseline for data centers greater than 1 MW.)
4) Xcel Energy Data Center Efficiency Program, Deemed Savings Technical Assumptions. Weblink
5) Electric Power Research Institute. The energy savings factor comes from a conservative estimate based on reducing fan speed to approximately 85% (0.853= 0.61 under ideal

conditions). Supported by EPRI case study: EPRI "was able to reduce is fan power use by 77%." Weblink

3.2.15. Circulation Fan: High-Volume Low-Speed

Target Sector	Commercial and Industrial
Measure Unit	Number of Fans Installed
Measure Life	15 years Source 1
Measure Vintage	Replace on Burnout, Early Replacement, Retrofit, New Construction

This protocol covers energy and demand savings associated with the installation of high-volume low-speed (HVLS) circulating fans to replace conventional circulating fans. HVLS fans generally range from 8 feet to 24 feet in diameter and move more cubic feet of air per Watt than conventional circulating fans.[Source 2] This measure is for use in commercial and industrial applications only. For agricultural applications, please refer to TRM Measure 4.1.5 High Volume Low Speed Fans.

This measure borrows data from the certified products directory of AMCA's Large Diameter Fans [Source 3]. Qualifying fans meet Federal baseline standards with Ceiling Fan Energy Index (CFEI) >= 1.31 at 40% rated RPM and CFEI >=1.00 at 100% rated RPM.[Source 4]

Eligibility

This measure requires the installation of HVLS fans (diameters ranging from 8 to 24 feet) in either new construction or retrofit applications where conventional circulating fans are replaced.

Algorithms

The annual energy and peak demand savings are obtained through the following formulas:

$$\Delta kWh = \left[\frac{1}{Eff_{ee}} - \frac{1}{Eff_{base}}\right] \times CFM \times \frac{1}{1000} \times HOU$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_S$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_W$$

Definition of Terms

Table 3-67: Terms, Values, and References for HVLS Fans

Term	Unit	Values	Source
Eff_{base}, Conventional fan efficiency	$\frac{CFM}{Watt}$	EDC Data Gathering Default: 22.7	5
Eff_{ee}, HVLS fan efficiency	$\frac{CFM}{Watt}$	EDC Data Gathering Default values in Table 3-68	3
CFM, Cubic feet per minute of air movement	$\frac{ft^3}{Minute}$	EDC Data Gathering	-
HOU, Annual hours of fan operation	$\frac{Hours}{Year}$	EDC Data Gathering Default values in Table 3-69	6
$1{,}000$, Conversion factor	$\frac{Watts}{Kilowatt}$	1,000	-
$ETDF_S$, Summer Energy to Demand Factor $ETDF_W$, Winter Energy to Demand Factor	$\frac{kW}{kWh}$	Default values in Table 3-27	7

Table 3-68: Default Values for HVLS Fan Efficiencies

Fan Diameter (ft)	Eff_{ee}
≥ 8 and < 10	116
≥ 10 and < 12	144
≥ 12 and < 14	152
≥ 14 and < 16	165
≥ 16 and < 18	206
≥ 18 and < 20	230
≥ 20 and < 24	257
≥ 24	169

Note: Fan wattage defaults represented in Table 3-68 are an aggregate of datapoints surveyed across multiple fan manufacturers and product types. Exercising engineering judgment, we assume fans to be operating at 80% of their rated RPM.

Table 3-69: Default Hours of Use by Building Type and Region

Space and/or Building Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsport
Education - College/University	1,525	1,420	1,451	1,427	1,171	1,313	1,293	1,474	1,307
Education - Other	942	1,071	1,079	850	937	1,002	1,127	1,125	901
Grocery	1,556	1,605	1,683	1,359	1,518	1,749	1,266	2,149	1,866
Health - Hospital	1,535	1,048	1,420	1,527	1,279	1,602	1,310	1,515	1,303
Health - Other	1,508	1,825	1,905	1,829	1,283	1,559	1,534	1,711	1,462
Industrial Manufacturing	1,145	857	924	992	983	1,137	989	1,011	877
Institutional/Public Service	2,096	2,000	2,128	2,123	1,789	2,335	1,891	2,121	1,804
Lodging	4,043	4,412	4,853	4,673	3,418	3,928	3,938	4,180	3,885

Space and/or Building Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsport
Multifamily (Common Areas)	2,149	967	1,110	1,355	1,855	2,242	1,628	1,628	1,466
Office	915	370	907	948	891	1,112	1,164	988	858
Restaurant	1,795	2,290	2,355	2,215	1,487	1,859	1,965	2,061	1,869
Retail	1,736	1,615	1,707	1,734	1,342	1,680	1,674	1,599	1,387
Warehouse - Other	1,007	1,204	1,214	1,150	935	1,232	1,117	1,078	971
Warehouse - Refrigerated	4,587	3,631	4,765	4,756	3,757	4,104	4,049	4,691	3,889

Note: Default hours represent the aggregate of Cooling and Heating hours.

Default Savings

There are no default savings for this measure.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) State of Wisconsin. Focus on Energy Evaluation, Business Program: Measure Life Study Final Report: August 25, 2009. Appendix B, pages 65-66. Weblink
2) Engineering judgement from survey of various available HVLS fans from various manufacturers.
3) Large Diameter Ceiling Fans, certified and listed products directory by AMCA. Weblink
4) Large-diameter ceiling fans, 10 CFR 430.32(s)(2)(ii). Weblink
5) Engineering judgement: Assuming for a 48” conventional fan to provide comparable volume of air as a HVLS. KEMA Inc. for Interstate Power and Light Company. (2012, February). Interstate Power and Light Company Docket EEP-08-1, Appendix H; Table H-5.
6) Hours of use are assumed to match the HOU of circulating fans (the sum of $EFLH_{Heat}$ and $EFLH_{Cool}$). EFLHs and CFs for Pennsylvania are calculated based on Nexant’s eQuest modeling analysis 2014 and updated based on the latest CDD and HDD values from NOAA’s 15-year annual climate Normals (2006–2020). Weblink
7) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.2.16. Demand Controlled Ventilation

Target Sector	Commercial and Industrial
Measure Unit	HVAC System
Measure Life	15 years[Source 1]
Measure Vintage	Retrofit

The Demand Controlled Ventilation (DCV) adjusts outside ventilation air flow based on the number of occupants and the ventilation demand that those occupants create. DCV is part of a building's ventilation system control strategy.

Eligibility

This protocol is applicable for commercial and institutional market segments only. The base case for this measure is conditioned space with no DCV capability. For heating savings, this measure does not apply to any system with terminal reheat (constant volume or variable air volume). This protocol is intended for DCV retrofits on HVAC systems without economizers installed. Units with economizers may be eligible for the Advanced Rooftop Controls measure (3.2.17).

Algorithms

Energy Savings and Demand Reduction

DCV installations save energy in both heating and cooling modes. Energy savings and demand reductions are assigned on the basis of normalized units of 1,000 ft2 of conditioned floorspace according to heating and cooling type, business type, and geographical location.

For facilities heated by natural gas,

$$\Delta kWh = \frac{Conditioned\ Space}{1{,}000} * SF_{Cooling} + \frac{Conditioned\ Space}{1{,}000} * SF_{Electric\ Fan}$$

For facilities heated by heat pumps,

$$\Delta kWh = \frac{Conditioned\ Space}{1{,}000} * SF_{Cooling} + \frac{Conditioned\ Space}{1{,}000} * SF_{Heat\ HP}$$

For facilities heated by electric resistance,

$$\Delta kWh = \frac{Conditioned\ Space}{1{,}000} * SF_{Cooling} + \frac{Conditioned\ Space}{1{,}000} * SF_{Heat\ ER}$$

For all facilities,

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-70: Terms, Values, and References

Term	Unit	Values	Source
Conditioned Space	ft^2	Actual square footage of conditioned space controlled by sensor	EDC Data Gathering
$SF_{Cooling}$, Electric savings factor for cooling	$\frac{kWh}{1{,}000\ ft^2}$	See Table 3-71	2
$SF_{Heat\ HP}$, Electric savings factor for heat pumps	$\frac{kWh}{1{,}000\ ft^2}$	See Table 3-71	2
$SF_{Heat\ ER}$, Electric savings factor for electric resistance heating	$\frac{kWh}{1{,}000\ ft^2}$	See Table 3-71	2
$SF_{Electric\ Fan}$, Electric Savings factor for electric air handler savings during non-electric fueled heating	$\frac{kWh}{1{,}000\ ft^2}$	See Table 3-71	3
$ETDF_{summer}$, Energy to Demand Factor Summer	$\frac{kW}{kWh}$	Default: Table 3-27	4
$ETDF_{winter}$, Energy to Demand Factor Summer			

Table 3-71: Saving factor by heating/cooling type, Building type, and Zone

Building Type	Climate Region	Reference City	Savings Factors ($kWh/1{,}000\ ft^2$)			
			SFCooling	SFHeat pump	SFElectric Fan	SFHeat ER
Data Center - No Economizer	A	Binghamton, NY	148	131	9	393
Data Center - With Economizer			148	131	9	393
Education - College/University			329	1,251	83	3,752
Education - Other			318	645	43	1,935
Education - Other			310	629	42	1,888
Grocery			341	178	12	535
Health - Hospital			312	440	29	1,319
Health - Other			312	440	29	1,319
Industrial Manufacturing - 1 Shift			148	131	9	393
Industrial Manufacturing - 2 Shift			148	131	9	393
Industrial Manufacturing - 3 Shift			148	131	9	393
Institutional/Public Service			653	1,482	98	4,446

Building Type	Climate Region	Reference City	Savings Factors (kWh/1,000 ft²)			
			SFCooling	SFHeat pump	SFElectric Fan	SFHeat ER
Large Office			257	208	14	624
Lodging - Large Hotel			391	203	13	609
Lodging - Small Hotel			391	203	13	609
Medium Office			218	155	10	464
Multifamily Common Areas			459	1,742	115	5,225
Restaurant - Full Service			413	1,056	70	3,168
Restaurant - Quick Service			413	1,056	70	3,168
Retail - Standalone			364	363	24	1,089
Retail – Strip mall			255	241	16	724
Small Office			273	231	20	692
Warehouse - Other			148	131	9	393
Warehouse - Refrigerated			148	131	9	393
Data Center - No Economizer	B	Scranton	162	124	8	372
Data Center - With Economizer			162	124	8	372
Education - College/University			369	1,105	73	3,316
Education - Other			340	569	38	1,708
Education - Other			333	555	37	1,666
Grocery			349	160	11	479
Health - Hospital			331	392	26	1,177
Health - Other			331	392	26	1,177
Industrial Manufacturing - 1 Shift			162	124	8	372
Industrial Manufacturing - 2 Shift			162	124	8	372
Industrial Manufacturing - 3 Shift			162	124	8	372
Institutional/Public Service			712	1,323	88	3,970
Large Office			263	183	12	550
Lodging - Large Hotel			400	180	12	541
Lodging - Small Hotel			400	180	12	541
Medium Office			222	137	9	410
Multifamily Common Areas			514	1,569	104	4,706
Restaurant - Full Service			457	945	63	2,835
Restaurant - Quick Service			457	945	63	2,835

Building Type	Climate Region	Reference City	Savings Factors (kWh/1,000 ft²)			
			SFCooling	SFHeat pump	SFElectric Fan	SFHeat ER
Retail - Standalone			377	326	22	978
Retail - Strip mall			262	216	14	648
Small Office			280	203	13	610
Warehouse - Other			162	124	8	372
Warehouse - Refrigerated			162	124	8	372
Data Center - No Economizer	C	Allentown	174	119	8	358
Data Center - With Economizer			174	119	8	358
Education - College/University			402	1,002	66	3,006
Education - Other			358	516	34	1,548
Education - Other			351	503	33	1,508
Grocery			354	146	10	439
Health - Hospital			348	359	24	1,076
Health - Other			348	359	24	1,076
Industrial Manufacturing - 1 Shift			174	119	8	358
Industrial Manufacturing - 2 Shift			174	119	8	358
Industrial Manufacturing - 3 Shift			174	119	8	358
Institutional/Public Service			760	1,210	80	3,631
Large Office			268	166	11	498
Lodging - Large Hotel			406	165	11	494
Lodging - Small Hotel			406	165	11	494
Medium Office			226	124	8	371
Multifamily Common Areas			560	1,446	96	4,338
Restaurant - Full Service			494	866	57	2,598
Restaurant - Quick Service			494	866	57	2,598
Retail - Standalone			387	300	20	899
Retail - Strip mall			269	198	13	595
Small Office			285	184	12	552
Warehouse - Other			174	119	8	358
Warehouse - Refrigerated			174	119	8	358
Data Center - No Economizer	D	Philadelphia	202	112	7	336
Data Center - With Economizer			202	112	7	336

Building Type	Climate Region	Reference City	Savings Factors (kWh/1,000 ft^2)			
			SFCooling	SFHeat pump	SFElectric Fan	SFHeat ER
Education - College/University			485	849	56	2,548
Education - Other			404	437	29	1,310
Education - Other			395	425	28	1,274
Grocery			369	126	8	379
Health - Hospital			388	309	20	926
Health - Other			388	309	20	926
Industrial Manufacturing - 1 Shift			202	112	7	336
Industrial Manufacturing - 2 Shift			202	112	7	336
Industrial Manufacturing - 3 Shift			202	112	7	336
Institutional/Public Service			880	1,043	69	3,131
Large Office			279	140	9	420
Lodging - Large Hotel			423	141	9	423
Lodging - Small Hotel			423	141	9	423
Medium Office			234	105	7	314
Multifamily Common Areas			672	1,264	84	3,793
Restaurant - Full Service			584	750	50	2,249
Restaurant - Quick Service			584	750	50	2,249
Retail - Standalone			413	260	17	782
Retail - Strip mall			285	172	11	515
Small Office			299	156	10	466
Warehouse - Other			202	112	7	336
Warehouse - Refrigerated			202	112	7	336
Data Center - No Economizer	E	Harrisburg	197	123	8	370
Data Center - With Economizer			197	123	8	370
Education - College/University			472	1,086	72	3,256
Education - Other			397	559	37	1,678
Education - Other			388	545	36	1,636
Grocery			367	157	10	471
Health - Hospital			382	386	26	1,157
Health - Other			382	386	26	1,157
Industrial Manufacturing - 1 Shift			197	123	8	370

Building Type	Climate Region	Reference City	Savings Factors (kWh/1,000 ft²)			
			SFCooling	SFHeat pump	SFElectric Fan	SFHeat ER
Industrial Manufacturing - 2 Shift			197	123	8	370
Industrial Manufacturing - 3 Shift			197	123	8	370
Institutional/Public Service			862	1,302	86	3,905
Large Office			278	180	12	540
Lodging - Large Hotel			420	177	12	532
Lodging - Small Hotel			420	177	12	532
Medium Office			233	134	9	402
Multifamily Common Areas			655	1,545	102	4,636
Restaurant - Full Service			570	930	62	2,789
Restaurant - Quick Service			570	930	62	2,789
Retail - Standalone			409	321	21	963
Retail - Strip mall			282	213	14	638
Small Office			297	200	13	599
Warehouse - Other			197	123	8	370
Warehouse - Refrigerated			197	123	8	370
Data Center - No Economizer	F	Williamsport	173	120	8	361
Data Center - With Economizer			173	120	8	361
Education - College/University			400	1,023	68	3,069
Education - Other			357	527	35	1,580
Education - Other			349	513	34	1,540
Grocery			354	149	10	447
Health - Hospital			346	366	24	1,096
Health - Other			346	366	24	1,096
Industrial Manufacturing - 1 Shift			173	120	8	361
Industrial Manufacturing - 2 Shift			173	120	8	361
Industrial Manufacturing - 3 Shift			173	120	8	361
Institutional/Public Service			756	1,233	82	3,700
Large Office			267	170	11	508
Lodging - Large Hotel			406	168	11	503
Lodging - Small Hotel			406	168	11	503
Medium Office			225	126	8	379

Building Type	Climate Region	Reference City	Savings Factors (kWh/1,000 ft²)			
			SFCooling	SFHeat pump	SFElectric Fan	SFHeat ER
Multifamily Common Areas			556	1,471	97	4,413
Restaurant - Full Service			491	882	58	2,647
Restaurant - Quick Service			491	882	58	2,647
Retail - Standalone			387	305	20	915
Retail - Strip mall			268	202	13	606
Small Office			285	188	12	564
Warehouse - Other			173	120	8	361
Warehouse - Refrigerated			173	120	8	361
Data Center - No Economizer	G	Bradford	135	141	9	424
Data Center - With Economizer			135	141	9	424
Education - College/University			288	1,467	97	4,401
Education - Other			295	757	50	2,272
Education - Other			289	740	49	2,220
Grocery			334	207	14	620
Health - Hospital			292	510	34	1,530
Health - Other			292	510	34	1,530
Industrial Manufacturing - 1 Shift			135	141	9	424
Industrial Manufacturing - 2 Shift			135	141	9	424
Industrial Manufacturing - 3 Shift			135	141	9	424
Institutional/Public Service			594	1,719	114	5,156
Large Office			251	244	16	733
Lodging - Large Hotel			383	236	16	709
Lodging - Small Hotel			383	236	16	709
Medium Office			214	182	12	545
Multifamily Common Areas			404	1,999	132	5,997
Restaurant - Full Service			369	1,221	81	3,663
Restaurant - Quick Service			369	1,221	81	3,663
Retail - Standalone			352	419	28	1,255
Retail - Strip mall			247	279	18	836
Small Office			266	271	18	815
Warehouse - Other			135	141	9	424

Building Type	Climate Region	Reference City	Savings Factors (kWh/1,000 ft²)			
			SFCooling	SFHeat pump	SFElectric Fan	SFHeat ER
Warehouse - Refrigerated			135	141	9	424
Data Center - No Economizer	H	Pittsburgh	170	122	8	365
Data Center - With Economizer			170	122	8	365
Education - College/University			393	1,053	70	3,158
Education - Other			353	542	36	1,627
Education - Other			345	529	35	1,586
Grocery			353	153	10	458
Health - Hospital			343	375	25	1,125
Health - Other			343	375	25	1,125
Industrial Manufacturing - 1 Shift			170	122	8	365
Industrial Manufacturing - 2 Shift			170	122	8	365
Industrial Manufacturing - 3 Shift			170	122	8	365
Institutional/Public Service			747	1,266	84	3,798
Large Office			266	175	12	523
Lodging - Large Hotel			404	172	11	517
Lodging - Small Hotel			404	172	11	517
Medium Office			225	130	9	390
Multifamily Common Areas			547	1,506	100	4,519
Restaurant - Full Service			483	905	60	2,715
Restaurant - Quick Service			483	905	60	2,715
Retail - Standalone			384	313	21	938
Retail - Strip mall			267	207	14	621
Small Office			284	194	13	581
Warehouse - Other			170	122	8	365
Warehouse - Refrigerated			170	122	8	365
Data Center - No Economizer	I	Erie	160	126	8	379
Data Center - With Economizer			160	126	8	379
Education - College/University			363	1,149	76	3,447
Education - Other			337	592	39	1,777
Education - Other			329	578	38	1,733
Grocery			347	165	11	496

Building Type	Climate Region	Reference City	Savings Factors (kWh/1,000 ft²)			
			SFCooling	SFHeat pump	SFElectric Fan	SFHeat ER
Health - Hospital			329	406	27	1,219
Health - Other			329	406	27	1,219
Industrial Manufacturing - 1 Shift			160	126	8	379
Industrial Manufacturing - 2 Shift			160	126	8	379
Industrial Manufacturing - 3 Shift			160	126	8	379
Institutional/Public Service			704	1,371	91	4,113
Large Office			262	191	13	572
Lodging - Large Hotel			398	187	12	562
Lodging - Small Hotel			398	187	12	562
Medium Office			222	142	9	426
Multifamily Common Areas			506	1,621	107	4,862
Restaurant - Full Service			451	978	65	2,935
Restaurant - Quick Service			451	978	65	2,935
Retail - Standalone			375	337	22	1,011
Retail - Strip mall			261	224	15	671
Small Office			279	212	14	635
Warehouse - Other			160	126	8	379
Warehouse - Refrigerated			160	126	8	379

Default Savings

There are no default savings for this measure.

Evaluation Protocols

The appropriate evaluation protocol is to verify installation of DCV through inspection of work orders and invoices and customer interviews, and to verify the proper collection of square footage information.

Sources

1) California Electronic Technical Reference Manual. “Demand Control Ventilation”. Accessed March 2024. Weblink
2) The Saving Factors for different climate zones and heating/cooling type are sourced from the 2021 Illinois Statewide Technical Reference Manual for Energy Efficiency Version 12.0 Volume 2: Commercial and Industrial Measures. Accessed March 2024. Weblink
The IL TRM provides impacts for five climate zones. The PA TRM authors regressed the energy savings in the IL TRM against CDD and HDD based on TMY3 data. The regression yielded climate-dependent saving factors that allowed calculation of impacts for the nine reference cities in the PA TRM.

3) Engineering judgement: A kWh to therm ratio for air handlers is calculated from typical capacities and efficiencies from a literature review sample of 12 small commercial rooftop systems ranging from 3 to 10 tons in cooling capacity. The average system air handler power is 0.1 kW per ton of heating, calculated from fan horsepower and assumed efficiencies
4) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.2.17. Advanced Rooftop Controls

Target Sector	Commercial and Industrial
Measure Unit	HVAC System
Measure Life	10 years Source 1
Measure Vintage	Retrofit, New Construction
Effective Date	June 1, 2021

The Advanced Rooftop Control (ARC) measure involves adding demand-controlled ventilation (DCV) and may also include an optional supply-fan multi speed or variable frequency drive (VFD). The ARC measure must provide demand control ventilation and economizer functionality as well as fan speed reduction. The measure has three variants, each with different savings values in Table 3-73.

DCV = Installation of DCV, without motor drive improvements

DVC_VFD2 = Installation of DCV with a two-speed controls

DCV_VFD3 = Installation of DCV with a three-speed controls or VFD

Eligibility

This protocol is only applicable for commercial and institutional market segments with buildings served by single-zone packaged HVAC units that include functional integrated economizers. The measure is eligible as retrofit or new construction vintages, if demand control ventilation or drives on air handlers are not specifically required by code. To be eligible for a retrofit, the baseline HVAC system must have a functioning economizer, but it must lack DCV and must operate as a constant-volume, constant-ventilation unit. VFD installations that do not involve integrated DCV and economizer controls are not eligible for this protocol but may be eligible for the Variable Frequency Drive (VFD) Improvements protocol (3.3.2). HVAC units without economizers may be eligible for the standalone Demand Controlled Ventilation (3.2.16).

Algorithms

Energy Savings and Demand Reduction

ARC installations save energy in both heating and cooling modes. Energy savings and demand reductions are assigned on a per-ton basis according to heating and cooling capacity.

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat}$$

$$\Delta kWh_{cool} = CCAP \times NECES$$

$$\Delta kWh_{heat} = HCAP \times (NEHES \times Heat_{electric} + NHFES \times Heat_{non-electric})$$

$$\Delta kW_{summer\ peak} = \Delta kWh_{cool} \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh_{heat} \times ETDF_{winter}$$

Definition of Terms

Table 3-72: Terms, Values, and References

Term	Unit	Values	Source
CCAP, Rated cooling capacity	$tons$	Nameplate	EDC Data Gathering
HCAP, Rated heating capacity	$tons$	Nameplate	EDC Data Gathering
NECES, Normalized electric cooling energy savings	$\frac{kWh}{ton}$	See Table 3-73	2
NEHES, Normalized electric heating energy savings	$\frac{kWh}{ton}$	See Table 3-73	2
NHFES, Normalized heating fan energy savings	$\frac{kWh}{ton}$	See Table 3-73	3, 4
$Heat_{electric}$, Binary variable to dictate type of heat	$None$	1 : electric space heating 0 : otherwise	Logic
$Heat_{non-electric}$, Binary variable to dictate type of heat	*None*	1 : non-electric space heating 0 : otherwise	Logic
$ETDF_{summer}$, Energy to Demand Factor Summer $ETDF_{winter}$, Energy to Demand Factor Summer	$\frac{kW}{kWh}$	See Table 3-27	5

Table 3-73: Per-ton Savings by Measure, Building type, and Zone

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton) (NECES)	Electric Heating Savings (kWh/ton) (NEHES)	Heating Fan Savings (kWh/ton) (NHFES)
Data Center - No Economizer	A	Binghamton, NY	DCV	-4	305	20
Data Center - With Economizer			DCV	-4	305	20
Education - College/University			DCV	-34	898	59
Education - Other			DCV	-34	898	59
Education - Other			DCV	-34	898	59
Grocery			DCV	4	901	60
Health - Hospital			DCV	1	114	8
Health - Other			DCV	1	114	8
Industrial Manufacturing - 1 Shift			DCV	-13	59	4
Industrial Manufacturing - 2 Shift			DCV	-13	59	4
Industrial Manufacturing - 3 Shift			DCV	-13	59	4
Institutional/Public Service			DCV	-1	105	7
Large Office			DCV	3	338	22
Lodging - Large Hotel			DCV	1	114	8

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton)	Electric Heating Savings (kWh/ton)	Heating Fan Savings (kWh/ton)
				(NECES)	(NEHES)	(NHFES)
Lodging - Small Hotel			DCV	1	114	8
Medium Office			DCV	3	338	22
Multifamily Common Areas			DCV	16	875	58
Restaurant - Full Service			DCV	2	341	23
Restaurant - Quick Service			DCV	2	341	23
Retail - Standalone			DCV	9	301	20
Retail - Strip mall			DCV	8	281	19
Small Office			DCV	3	338	22
Warehouse - Other			DCV	-4	305	20
Warehouse - Refrigerated			DCV	-4	305	20
Data Center - No Economizer	B	Scranton	DCV	-1	268	18
Data Center - With Economizer	B	Scranton	DCV	-1	268	18
Education - College/University	B	Scranton	DCV	7	731	48
Education - Other	B	Scranton	DCV	7	731	48
Education - Other	B	Scranton	DCV	7	731	48
Grocery	B	Scranton	DCV	23	776	51
Health - Hospital	B	Scranton	DCV	5	99	7
Health - Other	B	Scranton	DCV	5	99	7
Industrial Manufacturing - 1 Shift	B	Scranton	DCV	-3	49	3
Industrial Manufacturing - 2 Shift	B	Scranton	DCV	-3	49	3
Industrial Manufacturing - 3 Shift	B	Scranton	DCV	-3	49	3
Institutional/Public Service	B	Scranton	DCV	3	93	6
Large Office	B	Scranton	DCV	10	281	19
Lodging - Large Hotel	B	Scranton	DCV	5	99	7
Lodging - Small Hotel	B	Scranton	DCV	5	99	7
Medium Office	B	Scranton	DCV	10	281	19
Multifamily Common Areas	B	Scranton	DCV	34	821	54
Restaurant - Full Service	B	Scranton	DCV	8	296	20
Restaurant - Quick Service	B	Scranton	DCV	8	296	20
Retail - Standalone	B	Scranton	DCV	21	263	17
Retail - Strip mall	B	Scranton	DCV	20	247	16
Small Office	B	Scranton	DCV	10	281	19
Warehouse - Other	B	Scranton	DCV	-1	268	18
Warehouse - Refrigerated	B	Scranton	DCV	-1	268	18
Data Center - No Economizer	C	Allentown	DCV	2	242	16
Data Center - With Economizer	C	Allentown	DCV	2	242	16
Education - College/University	C	Allentown	DCV	41	612	41

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton) (NECES)	Electric Heating Savings (kWh/ton) (NEHES)	Heating Fan Savings (kWh/ton) (NHFES)
Education - Other			DCV	41	612	41
Education - Other			DCV	41	612	41
Grocery			DCV	38	688	46
Health - Hospital			DCV	8	89	6
Health - Other			DCV	8	89	6
Industrial Manufacturing - 1 Shift			DCV	6	42	3
Industrial Manufacturing - 2 Shift			DCV	6	42	3
Industrial Manufacturing - 3 Shift			DCV	6	42	3
Institutional/Public Service			DCV	6	84	6
Large Office			DCV	15	241	16
Lodging - Large Hotel			DCV	8	89	6
Lodging - Small Hotel			DCV	8	89	6
Medium Office			DCV	15	241	16
Multifamily Common Areas			DCV	49	783	52
Restaurant - Full Service			DCV	13	264	17
Restaurant - Quick Service			DCV	13	264	17
Retail - Standalone			DCV	32	236	16
Retail - Strip mall			DCV	29	222	15
Small Office			DCV	15	241	16
Warehouse - Other			DCV	2	242	16
Warehouse - Refrigerated			DCV	2	242	16
Data Center - No Economizer	D	Philadelphia	DCV	8	204	14
Data Center - With Economizer			DCV	8	204	14
Education - College/University			DCV	126	437	29
Education - Other			DCV	126	437	29
Education - Other			DCV	126	437	29
Grocery			DCV	76	556	37
Health - Hospital			DCV	15	74	5
Health - Other			DCV	15	74	5
Industrial Manufacturing - 1 Shift			DCV	26	31	2
Industrial Manufacturing - 2 Shift			DCV	26	31	2
Industrial Manufacturing - 3 Shift			DCV	26	31	2
Institutional/Public Service			DCV	13	71	5
Large Office			DCV	27	181	12
Lodging - Large Hotel			DCV	15	74	5
Lodging - Small Hotel			DCV	15	74	5
Medium Office			DCV	27	181	12

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton) (NECES)	Electric Heating Savings (kWh/ton) (NEHES)	Heating Fan Savings (kWh/ton) (NHFES)
Multifamily Common Areas			DCV	85	727	48
Restaurant - Full Service			DCV	25	217	14
Restaurant - Quick Service			DCV	25	217	14
Retail - Standalone			DCV	57	196	13
Retail - Strip mall			DCV	53	186	12
Small Office			DCV	27	181	12
Warehouse - Other			DCV	8	204	14
Warehouse - Refrigerated			DCV	8	204	14
Data Center - No Economizer	E	Harrisburg	DCV	7	263	17
Data Center - With Economizer	E	Harrisburg	DCV	7	263	17
Education - College/University	E	Harrisburg	DCV	113	708	47
Education - Other	E	Harrisburg	DCV	113	708	47
Education - Other	E	Harrisburg	DCV	113	708	47
Grocery	E	Harrisburg	DCV	70	759	50
Health - Hospital	E	Harrisburg	DCV	14	97	6
Health - Other	E	Harrisburg	DCV	14	97	6
Industrial Manufacturing - 1 Shift	E	Harrisburg	DCV	23	48	3
Industrial Manufacturing - 2 Shift	E	Harrisburg	DCV	23	48	3
Industrial Manufacturing - 3 Shift	E	Harrisburg	DCV	23	48	3
Institutional/Public Service	E	Harrisburg	DCV	12	91	6
Large Office	E	Harrisburg	DCV	25	273	18
Lodging - Large Hotel	E	Harrisburg	DCV	14	97	6
Lodging - Small Hotel	E	Harrisburg	DCV	14	97	6
Medium Office	E	Harrisburg	DCV	25	273	18
Multifamily Common Areas	E	Harrisburg	DCV	80	814	54
Restaurant - Full Service	E	Harrisburg	DCV	23	290	19
Restaurant - Quick Service	E	Harrisburg	DCV	23	290	19
Retail - Standalone	E	Harrisburg	DCV	53	258	17
Retail - Strip mall	E	Harrisburg	DCV	49	242	16
Small Office	E	Harrisburg	DCV	25	273	18
Warehouse - Other	E	Harrisburg	DCV	7	263	17
Warehouse - Refrigerated	E	Harrisburg	DCV	7	263	17
Data Center - No Economizer	F	Williamsport	DCV	2	248	16
Data Center - With Economizer	F	Williamsport	DCV	2	248	16
Education - College/University	F	Williamsport	DCV	38	636	42
Education - Other	F	Williamsport	DCV	38	636	42
Education - Other	F	Williamsport	DCV	38	636	42

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton) (NECES)	Electric Heating Savings (kWh/ton) (NEHES)	Heating Fan Savings (kWh/ton) (NHFES)
Grocery			DCV	37	706	47
Health - Hospital			DCV	7	91	6
Health - Other			DCV	7	91	6
Industrial Manufacturing - 1 Shift			DCV	5	43	3
Industrial Manufacturing - 2 Shift			DCV	5	43	3
Industrial Manufacturing - 3 Shift			DCV	5	43	3
Institutional/Public Service			DCV	5	86	6
Large Office			DCV	14	249	16
Lodging - Large Hotel			DCV	7	91	6
Lodging - Small Hotel			DCV	7	91	6
Medium Office			DCV	14	249	16
Multifamily Common Areas			DCV	47	791	52
Restaurant - Full Service			DCV	13	270	18
Restaurant - Quick Service			DCV	13	270	18
Retail - Standalone			DCV	31	242	16
Retail - Strip mall			DCV	29	227	15
Small Office			DCV	14	249	16
Warehouse - Other			DCV	2	248	16
Warehouse - Refrigerated			DCV	2	248	16
Data Center - No Economizer	G	Bradford	DCV	-7	359	24
Data Center - With Economizer			DCV	-7	359	24
Education - College/University			DCV	-76	1,147	76
Education - Other			DCV	-76	1,147	76
Education - Other			DCV	-76	1,147	76
Grocery			DCV	-14	1,087	72
Health - Hospital			DCV	-2	135	9
Health - Other			DCV	-2	135	9
Industrial Manufacturing - 1 Shift			DCV	-23	75	5
Industrial Manufacturing - 2 Shift			DCV	-23	75	5
Industrial Manufacturing - 3 Shift			DCV	-23	75	5
Institutional/Public Service			DCV	-5	124	8
Large Office			DCV	-3	423	28
Lodging - Large Hotel			DCV	-2	135	9
Lodging - Small Hotel			DCV	-2	135	9
Medium Office			DCV	-3	423	28
Multifamily Common Areas			DCV	-2	955	63
Restaurant - Full Service			DCV	-3	408	27

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton) (NECES)	Electric Heating Savings (kWh/ton) (NEHES)	Heating Fan Savings (kWh/ton) (NHFES)
Restaurant - Quick Service			DCV	-3	408	27
Retail - Standalone			DCV	-4	358	24
Retail - Strip mall			DCV	-3	333	22
Small Office			DCV	-3	423	28
Warehouse - Other			DCV	-7	359	24
Warehouse - Refrigerated			DCV	-7	359	24
Data Center - No Economizer	H	Pittsburgh	DCV	1	255	17
Data Center - With Economizer	H	Pittsburgh	DCV	1	255	17
Education - College/University	H	Pittsburgh	DCV	32	671	44
Education - Other	H	Pittsburgh	DCV	32	671	44
Education - Other	H	Pittsburgh	DCV	32	671	44
Grocery	H	Pittsburgh	DCV	34	731	48
Health - Hospital	H	Pittsburgh	DCV	7	94	6
Health - Other	H	Pittsburgh	DCV	7	94	6
Industrial Manufacturing - 1 Shift	H	Pittsburgh	DCV	3	45	3
Industrial Manufacturing - 2 Shift	H	Pittsburgh	DCV	3	45	3
Industrial Manufacturing - 3 Shift	H	Pittsburgh	DCV	3	45	3
Institutional/Public Service	H	Pittsburgh	DCV	5	89	6
Large Office	H	Pittsburgh	DCV	13	261	17
Lodging - Large Hotel	H	Pittsburgh	DCV	7	94	6
Lodging - Small Hotel	H	Pittsburgh	DCV	7	94	6
Medium Office	H	Pittsburgh	DCV	13	261	17
Multifamily Common Areas	H	Pittsburgh	DCV	44	802	53
Restaurant - Full Service	H	Pittsburgh	DCV	12	279	19
Restaurant - Quick Service	H	Pittsburgh	DCV	12	279	19
Retail - Standalone	H	Pittsburgh	DCV	29	249	17
Retail - Strip mall	H	Pittsburgh	DCV	27	234	16
Small Office	H	Pittsburgh	DCV	13	261	17
Warehouse - Other	H	Pittsburgh	DCV	1	255	17
Warehouse - Refrigerated	H	Pittsburgh	DCV	1	255	17
Data Center - No Economizer	I	Erie	DCV	-1	279	18
Data Center - With Economizer	I	Erie	DCV	-1	279	18
Education - College/University	I	Erie	DCV	1	781	52
Education - Other	I	Erie	DCV	1	781	52
Education - Other	I	Erie	DCV	1	781	52
Grocery	I	Erie	DCV	20	814	54
Health - Hospital	I	Erie	DCV	4	103	7

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton) (NECES)	Electric Heating Savings (kWh/ton) (NEHES)	Heating Fan Savings (kWh/ton) (NHFES)
Health - Other			DCV	4	103	7
Industrial Manufacturing - 1 Shift			DCV	-4	52	3
Industrial Manufacturing - 2 Shift			DCV	-4	52	3
Industrial Manufacturing - 3 Shift			DCV	-4	52	3
Institutional/Public Service			DCV	2	97	6
Large Office			DCV	9	298	20
Lodging - Large Hotel			DCV	4	103	7
Lodging - Small Hotel			DCV	4	103	7
Medium Office			DCV	9	298	20
Multifamily Common Areas			DCV	31	838	55
Restaurant - Full Service			DCV	7	309	20
Restaurant - Quick Service			DCV	7	309	20
Retail - Standalone			DCV	20	275	18
Retail - Strip mall			DCV	18	257	17
Small Office			DCV	9	298	20
Warehouse - Other			DCV	-1	279	18
Warehouse - Refrigerated			DCV	-1	279	18
Data Center - No Economizer	A	Binghamton, NY	DCV_VFD2	345	170	11
Data Center - With Economizer			DCV_VFD2	345	170	11
Education - College/University			DCV_VFD2	322	850	56
Education - Other			DCV_VFD2	322	850	56
Education - Other			DCV_VFD2	322	850	56
Grocery			DCV_VFD2	436	840	56
Health - Hospital			DCV_VFD2	561	51	3
Health - Other			DCV_VFD2	561	51	3
Industrial Manufacturing - 1 Shift			DCV_VFD2	749	45	3
Industrial Manufacturing - 2 Shift			DCV_VFD2	749	45	3
Industrial Manufacturing - 3 Shift			DCV_VFD2	749	45	3
Institutional/Public Service			DCV_VFD2	752	128	8
Large Office			DCV_VFD2	1,076	143	9
Lodging - Large Hotel			DCV_VFD2	561	51	3
Lodging - Small Hotel			DCV_VFD2	561	51	3
Medium Office			DCV_VFD2	1,076	143	9
Multifamily Common Areas			DCV_VFD2	105	894	59
Restaurant - Full Service			DCV_VFD2	530	253	17
Restaurant - Quick Service			DCV_VFD2	530	253	17
Retail - Standalone			DCV_VFD2	669	176	12

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton)	Electric Heating Savings (kWh/ton)	Heating Fan Savings (kWh/ton)
				(NECES)	(NEHES)	(NHFES)
Retail - Strip mall			DCV_VFD2	719	219	15
Small Office			DCV_VFD2	1,076	143	9
Warehouse - Other			DCV_VFD2	345	170	11
Warehouse - Refrigerated			DCV_VFD2	345	170	11
Data Center - No Economizer	B	Scranton	DCV_VFD2	346	134	9
Data Center - With Economizer			DCV_VFD2	346	134	9
Education - College/University			DCV_VFD2	365	695	46
Education - Other			DCV_VFD2	365	695	46
Education - Other			DCV_VFD2	365	695	46
Grocery			DCV_VFD2	459	723	48
Health - Hospital			DCV_VFD2	569	51	3
Health - Other			DCV_VFD2	569	51	3
Industrial Manufacturing - 1 Shift			DCV_VFD2	758	38	3
Industrial Manufacturing - 2 Shift			DCV_VFD2	758	38	3
Industrial Manufacturing - 3 Shift			DCV_VFD2	758	38	3
Institutional/Public Service			DCV_VFD2	813	110	7
Large Office			DCV_VFD2	1,073	108	7
Lodging - Large Hotel			DCV_VFD2	569	51	3
Lodging - Small Hotel			DCV_VFD2	569	51	3
Medium Office			DCV_VFD2	1,073	108	7
Multifamily Common Areas			DCV_VFD2	127	856	57
Restaurant - Full Service			DCV_VFD2	545	221	15
Restaurant - Quick Service			DCV_VFD2	545	221	15
Retail - Standalone			DCV_VFD2	682	154	10
Retail - Strip mall			DCV_VFD2	728	194	13
Small Office			DCV_VFD2	1,073	108	7
Warehouse - Other			DCV_VFD2	346	134	9
Warehouse - Refrigerated			DCV_VFD2	346	134	9
Data Center - No Economizer	C	Allentown	DCV_VFD2	347	108	7
Data Center - With Economizer			DCV_VFD2	347	108	7
Education - College/University			DCV_VFD2	400	584	39
Education - Other			DCV_VFD2	400	584	39
Education - Other			DCV_VFD2	400	584	39
Grocery			DCV_VFD2	477	641	42
Health - Hospital			DCV_VFD2	574	52	3
Health - Other			DCV_VFD2	574	52	3
Industrial Manufacturing - 1 Shift			DCV_VFD2	765	32	2

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton) (NECES)	Electric Heating Savings (kWh/ton) (NEHES)	Heating Fan Savings (kWh/ton) (NHFES)
Industrial Manufacturing - 2 Shift			DCV_VFD2	765	32	2
Industrial Manufacturing - 3 Shift			DCV_VFD2	765	32	2
Institutional/Public Service			DCV_VFD2	862	98	6
Large Office			DCV_VFD2	1,071	84	6
Lodging - Large Hotel			DCV_VFD2	574	52	3
Lodging - Small Hotel			DCV_VFD2	574	52	3
Medium Office			DCV_VFD2	1,071	84	6
Multifamily Common Areas			DCV_VFD2	146	829	55
Restaurant - Full Service			DCV_VFD2	558	199	13
Restaurant - Quick Service			DCV_VFD2	558	199	13
Retail - Standalone			DCV_VFD2	692	138	9
Retail - Strip mall			DCV_VFD2	735	176	12
Small Office			DCV_VFD2	1,071	84	6
Warehouse - Other			DCV_VFD2	347	108	7
Warehouse - Refrigerated			DCV_VFD2	347	108	7
Data Center - No Economizer	D	Philadelphia	DCV_VFD2	349	70	5
Data Center - With Economizer			DCV_VFD2	349	70	5
Education - College/University			DCV_VFD2	487	421	28
Education - Other			DCV_VFD2	487	421	28
Education - Other			DCV_VFD2	487	421	28
Grocery			DCV_VFD2	522	519	34
Health - Hospital			DCV_VFD2	589	53	3
Health - Other			DCV_VFD2	589	53	3
Industrial Manufacturing - 1 Shift			DCV_VFD2	784	25	2
Industrial Manufacturing - 2 Shift			DCV_VFD2	784	25	2
Industrial Manufacturing - 3 Shift			DCV_VFD2	784	25	2
Institutional/Public Service			DCV_VFD2	986	80	5
Large Office			DCV_VFD2	1,065	47	3
Lodging - Large Hotel			DCV_VFD2	589	53	3
Lodging - Small Hotel			DCV_VFD2	589	53	3
Medium Office			DCV_VFD2	1,065	47	3
Multifamily Common Areas			DCV_VFD2	191	790	52
Restaurant - Full Service			DCV_VFD2	590	165	11
Restaurant - Quick Service			DCV_VFD2	590	165	11
Retail - Standalone			DCV_VFD2	718	115	8
Retail - Strip mall			DCV_VFD2	753	149	10
Small Office			DCV_VFD2	1,065	47	3

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton)	Electric Heating Savings (kWh/ton)	Heating Fan Savings (kWh/ton)
				(NECES)	(NEHES)	(NHFES)
Warehouse - Other			DCV_VFD2	349	70	5
Warehouse - Refrigerated			DCV_VFD2	349	70	5
Data Center - No Economizer	E	Harrisburg	DCV_VFD2	348	129	9
Data Center - With Economizer	E	Harrisburg	DCV_VFD2	348	129	9
Education - College/University	E	Harrisburg	DCV_VFD2	474	673	45
Education - Other	E	Harrisburg	DCV_VFD2	474	673	45
Education - Other	E	Harrisburg	DCV_VFD2	474	673	45
Grocery	E	Harrisburg	DCV_VFD2	515	708	47
Health - Hospital	E	Harrisburg	DCV_VFD2	587	52	3
Health - Other	E	Harrisburg	DCV_VFD2	587	52	3
Industrial Manufacturing - 1 Shift	E	Harrisburg	DCV_VFD2	781	37	2
Industrial Manufacturing - 2 Shift	E	Harrisburg	DCV_VFD2	781	37	2
Industrial Manufacturing - 3 Shift	E	Harrisburg	DCV_VFD2	781	37	2
Institutional/Public Service	E	Harrisburg	DCV_VFD2	967	108	7
Large Office	E	Harrisburg	DCV_VFD2	1,066	104	7
Lodging - Large Hotel	E	Harrisburg	DCV_VFD2	587	52	3
Lodging - Small Hotel	E	Harrisburg	DCV_VFD2	587	52	3
Medium Office	E	Harrisburg	DCV_VFD2	1,066	104	7
Multifamily Common Areas	E	Harrisburg	DCV_VFD2	184	851	56
Restaurant - Full Service	E	Harrisburg	DCV_VFD2	585	217	14
Restaurant - Quick Service	E	Harrisburg	DCV_VFD2	585	217	14
Retail - Standalone	E	Harrisburg	DCV_VFD2	714	151	10
Retail - Strip mall	E	Harrisburg	DCV_VFD2	750	190	13
Small Office	E	Harrisburg	DCV_VFD2	1,066	104	7
Warehouse - Other	E	Harrisburg	DCV_VFD2	348	129	9
Warehouse - Refrigerated	E	Harrisburg	DCV_VFD2	348	129	9
Data Center - No Economizer	F	Williamsport	DCV_VFD2	346	113	7
Data Center - With Economizer	F	Williamsport	DCV_VFD2	346	113	7
Education - College/University	F	Williamsport	DCV_VFD2	397	607	40
Education - Other	F	Williamsport	DCV_VFD2	397	607	40
Education - Other	F	Williamsport	DCV_VFD2	397	607	40
Grocery	F	Williamsport	DCV_VFD2	475	658	44
Health - Hospital	F	Williamsport	DCV_VFD2	574	52	3
Health - Other	F	Williamsport	DCV_VFD2	574	52	3
Industrial Manufacturing - 1 Shift	F	Williamsport	DCV_VFD2	765	34	2
Industrial Manufacturing - 2 Shift	F	Williamsport	DCV_VFD2	765	34	2
Industrial Manufacturing - 3 Shift	F	Williamsport	DCV_VFD2	765	34	2

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton)	Electric Heating Savings (kWh/ton)	Heating Fan Savings (kWh/ton)
				(NECES)	(NEHES)	(NHFES)
Institutional/Public Service			DCV_VFD2	858	100	7
Large Office			DCV_VFD2	1,071	89	6
Lodging - Large Hotel			DCV_VFD2	574	52	3
Lodging - Small Hotel			DCV_VFD2	574	52	3
Medium Office			DCV_VFD2	1,071	89	6
Multifamily Common Areas			DCV_VFD2	144	835	55
Restaurant - Full Service			DCV_VFD2	557	203	13
Restaurant - Quick Service			DCV_VFD2	557	203	13
Retail - Standalone			DCV_VFD2	692	141	9
Retail - Strip mall			DCV_VFD2	735	179	12
Small Office			DCV_VFD2	1,071	89	6
Warehouse - Other			DCV_VFD2	346	113	7
Warehouse - Refrigerated			DCV_VFD2	346	113	7
Data Center - No Economizer	G	Bradford	DCV_VFD2	344	224	15
Data Center - With Economizer	G	Bradford	DCV_VFD2	344	224	15
Education - College/University	G	Bradford	DCV_VFD2	280	1081	72
Education - Other	G	Bradford	DCV_VFD2	280	1,081	72
Education - Other	G	Bradford	DCV_VFD2	280	1,081	72
Grocery	G	Bradford	DCV_VFD2	414	1,012	67
Health - Hospital	G	Bradford	DCV_VFD2	554	50	3
Health - Other	G	Bradford	DCV_VFD2	554	50	3
Industrial Manufacturing - 1 Shift	G	Bradford	DCV_VFD2	740	56	4
Industrial Manufacturing - 2 Shift	G	Bradford	DCV_VFD2	740	56	4
Industrial Manufacturing - 3 Shift	G	Bradford	DCV_VFD2	740	56	4
Institutional/Public Service	G	Bradford	DCV_VFD2	692	154	10
Large Office	G	Bradford	DCV_VFD2	1,079	195	13
Lodging - Large Hotel	G	Bradford	DCV_VFD2	554	50	3
Lodging - Small Hotel	G	Bradford	DCV_VFD2	554	50	3
Medium Office	G	Bradford	DCV_VFD2	1,079	195	13
Multifamily Common Areas	G	Bradford	DCV_VFD2	83	950	63
Restaurant - Full Service	G	Bradford	DCV_VFD2	514	301	20
Restaurant - Quick Service	G	Bradford	DCV_VFD2	514	301	20
Retail - Standalone	G	Bradford	DCV_VFD2	657	209	14
Retail - Strip mall	G	Bradford	DCV_VFD2	711	258	17
Small Office	G	Bradford	DCV_VFD2	1,079	195	13
Warehouse - Other	G	Bradford	DCV_VFD2	344	224	15
Warehouse - Refrigerated	G	Bradford	DCV_VFD2	344	224	15
Data Center - No Economizer	H	Pittsburgh	DCV_VFD2	346	121	8
Data Center - With Economizer	H	Pittsburgh	DCV_VFD2	346	121	8

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton)	Electric Heating Savings (kWh/ton)	Heating Fan Savings (kWh/ton)
				(NECES)	(NEHES)	(NHFES)
Education - College/University			DCV_VFD2	390	639	42
Education - Other			DCV_VFD2	390	639	42
Education - Other			DCV_VFD2	390	639	42
Grocery			DCV_VFD2	472	682	45
Health - Hospital			DCV_VFD2	573	52	3
Health - Other			DCV_VFD2	573	52	3
Industrial Manufacturing - 1 Shift			DCV_VFD2	763	35	2
Industrial Manufacturing - 2 Shift			DCV_VFD2	763	35	2
Industrial Manufacturing - 3 Shift			DCV_VFD2	763	35	2
Institutional/Public Service			DCV_VFD2	848	104	7
Large Office			DCV_VFD2	1,071	96	6
Lodging - Large Hotel			DCV_VFD2	573	52	3
Lodging - Small Hotel			DCV_VFD2	573	52	3
Medium Office			DCV_VFD2	1,071	96	6
Multifamily Common Areas			DCV_VFD2	140	843	56
Restaurant - Full Service			DCV_VFD2	554	210	14
Restaurant - Quick Service			DCV_VFD2	554	210	14
Retail - Standalone			DCV_VFD2	689	146	10
Retail - Strip mall			DCV_VFD2	733	185	12
Small Office			DCV_VFD2	1,071	96	6
Warehouse - Other			DCV_VFD2	346	121	8
Warehouse - Refrigerated			DCV_VFD2	346	121	8
Data Center - No Economizer	I	Erie	DCV_VFD2	346	145	10
Data Center - With Economizer	I	Erie	DCV_VFD2	346	145	10
Education - College/University	I	Erie	DCV_VFD2	359	741	49
Education - Other	I	Erie	DCV_VFD2	359	741	49
Education - Other	I	Erie	DCV_VFD2	359	741	49
Grocery	I	Erie	DCV_VFD2	455	758	50
Health - Hospital	I	Erie	DCV_VFD2	568	51	3
Health - Other	I	Erie	DCV_VFD2	568	51	3
Industrial Manufacturing - 1 Shift	I	Erie	DCV_VFD2	757	40	3
Industrial Manufacturing - 2 Shift	I	Erie	DCV_VFD2	757	40	3
Industrial Manufacturing - 3 Shift	I	Erie	DCV_VFD2	757	40	3
Institutional/Public Service	I	Erie	DCV_VFD2	804	116	8
Large Office	I	Erie	DCV_VFD2	1,073	119	8
Lodging - Large Hotel	I	Erie	DCV_VFD2	568	51	3
Lodging - Small Hotel	I	Erie	DCV_VFD2	568	51	3
Medium Office	I	Erie	DCV_VFD2	1,073	119	8
Multifamily Common Areas	I	Erie	DCV_VFD2	124	868	57

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton)	Electric Heating Savings (kWh/ton)	Heating Fan Savings (kWh/ton)
				(NECES)	(NEHES)	(NHFES)
Restaurant - Full Service			DCV_VFD2	543	231	15
Restaurant - Quick Service			DCV_VFD2	543	231	15
Retail - Standalone			DCV_VFD2	680	160	11
Retail - Strip mall			DCV_VFD2	727	202	13
Small Office			DCV_VFD2	1,073	119	8
Warehouse - Other			DCV_VFD2	346	145	10
Warehouse - Refrigerated			DCV_VFD2	346	145	10
Data Center - No Economizer	A	Binghamton, NY	DCV_VFD3	417	143	9
Data Center - With Economizer	A	Binghamton, NY	DCV_VFD3	417	143	9
Education - College/University	A	Binghamton, NY	DCV_VFD3	372	825	55
Education - Other	A	Binghamton, NY	DCV_VFD3	372	825	55
Education - Other	A	Binghamton, NY	DCV_VFD3	372	825	55
Grocery	A	Binghamton, NY	DCV_VFD3	470	819	54
Health - Hospital	A	Binghamton, NY	DCV_VFD3	599	18	1
Health - Other	A	Binghamton, NY	DCV_VFD3	599	18	1
Industrial Manufacturing - 1 Shift	A	Binghamton, NY	DCV_VFD3	820	36	2
Industrial Manufacturing - 2 Shift	A	Binghamton, NY	DCV_VFD3	820	36	2
Industrial Manufacturing - 3 Shift	A	Binghamton, NY	DCV_VFD3	820	36	2
Institutional/Public Service	A	Binghamton, NY	DCV_VFD3	938	152	10
Large Office	A	Binghamton, NY	DCV_VFD3	1,178	116	8
Lodging - Large Hotel	A	Binghamton, NY	DCV_VFD3	599	18	1
Lodging - Small Hotel	A	Binghamton, NY	DCV_VFD3	599	18	1
Medium Office	A	Binghamton, NY	DCV_VFD3	1,178	116	8
Multifamily Common Areas	A	Binghamton, NY	DCV_VFD3	136	895	59
Restaurant - Full Service	A	Binghamton, NY	DCV_VFD3	582	221	15
Restaurant - Quick Service	A	Binghamton, NY	DCV_VFD3	582	221	15
Retail - Standalone	A	Binghamton, NY	DCV_VFD3	749	159	11
Retail - Strip mall	A	Binghamton, NY	DCV_VFD3	779	200	13
Small Office	A	Binghamton, NY	DCV_VFD3	1,178	116	8
Warehouse - Other	A	Binghamton, NY	DCV_VFD3	417	143	9
Warehouse - Refrigerated	A	Binghamton, NY	DCV_VFD3	417	143	9
Data Center - No Economizer	B	Scranton	DCV_VFD3	409	409	409
Data Center - With Economizer	B	Scranton	DCV_VFD3	409	409	409
Education - College/University	B	Scranton	DCV_VFD3	408	408	408
Education - Other	B	Scranton	DCV_VFD3	408	408	408
Education - Other	B	Scranton	DCV_VFD3	408	408	408
Grocery	B	Scranton	DCV_VFD3	487	487	487
Health - Hospital	B	Scranton	DCV_VFD3	601	601	601
Health - Other	B	Scranton	DCV_VFD3	601	601	601

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton)	Electric Heating Savings (kWh/ton)	Heating Fan Savings (kWh/ton)
				(NECES)	(NEHES)	(NHFES)
Industrial Manufacturing - 1 Shift			DCV_VFD3	818	818	818
Industrial Manufacturing - 2 Shift			DCV_VFD3	818	818	818
Industrial Manufacturing - 3 Shift			DCV_VFD3	818	818	818
Institutional/Public Service			DCV_VFD3	978	978	978
Large Office			DCV_VFD3	1,160	1,160	1,160
Lodging - Large Hotel			DCV_VFD3	601	601	601
Lodging - Small Hotel			DCV_VFD3	601	601	601
Medium Office			DCV_VFD3	1,160	1,160	1,160
Multifamily Common Areas			DCV_VFD3	154	154	154
Restaurant - Full Service			DCV_VFD3	592	592	592
Restaurant - Quick Service			DCV_VFD3	592	592	592
Retail - Standalone			DCV_VFD3	750	750	750
Retail - Strip mall			DCV_VFD3	778	778	778
Small Office			DCV_VFD3	1,160	1,160	1,160
Warehouse - Other			DCV_VFD3	409	409	409
Warehouse - Refrigerated			DCV_VFD3	409	409	409
Data Center - No Economizer	C	Allentown	DCV_VFD3	401	86	6
Data Center - With Economizer	C	Allentown	DCV_VFD3	401	86	6
Education - College/University	C	Allentown	DCV_VFD3	437	565	37
Education - Other	C	Allentown	DCV_VFD3	437	565	37
Education - Other	C	Allentown	DCV_VFD3	437	565	37
Grocery	C	Allentown	DCV_VFD3	501	625	41
Health - Hospital	C	Allentown	DCV_VFD3	603	19	1
Health - Other	C	Allentown	DCV_VFD3	603	19	1
Industrial Manufacturing - 1 Shift	C	Allentown	DCV_VFD3	817	28	2
Industrial Manufacturing - 2 Shift	C	Allentown	DCV_VFD3	817	28	2
Industrial Manufacturing - 3 Shift	C	Allentown	DCV_VFD3	817	28	2
Institutional/Public Service	C	Allentown	DCV_VFD3	1,010	114	8
Large Office	C	Allentown	DCV_VFD3	1,146	68	5
Lodging - Large Hotel	C	Allentown	DCV_VFD3	603	19	1
Lodging - Small Hotel	C	Allentown	DCV_VFD3	603	19	1
Medium Office	C	Allentown	DCV_VFD3	1,146	68	5
Multifamily Common Areas	C	Allentown	DCV_VFD3	169	822	54
Restaurant - Full Service	C	Allentown	DCV_VFD3	600	170	11
Restaurant - Quick Service	C	Allentown	DCV_VFD3	600	170	11
Retail - Standalone	C	Allentown	DCV_VFD3	751	121	8
Retail - Strip mall	C	Allentown	DCV_VFD3	778	162	11
Small Office	C	Allentown	DCV_VFD3	1,146	68	5
Warehouse - Other	C	Allentown	DCV_VFD3	401	86	6

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton)	Electric Heating Savings (kWh/ton)	Heating Fan Savings (kWh/ton)
				(NECES)	(NEHES)	(NHFES)
Warehouse - Refrigerated			DCV_VFD3	401	86	6
Data Center - No Economizer	D	Philadelphia	DCV_VFD3	383	51	3
Data Center - With Economizer			DCV_VFD3	383	51	3
Education - College/University			DCV_VFD3	510	406	27
Education - Other			DCV_VFD3	510	406	27
Education - Other			DCV_VFD3	510	406	27
Grocery			DCV_VFD3	536	506	33
Health - Hospital			DCV_VFD3	608	20	1
Health - Other			DCV_VFD3	608	20	1
Industrial Manufacturing - 1 Shift			DCV_VFD3	815	23	2
Industrial Manufacturing - 2 Shift			DCV_VFD3	815	23	2
Industrial Manufacturing - 3 Shift			DCV_VFD3	815	23	2
Institutional/Public Service			DCV_VFD3	1,090	91	6
Large Office			DCV_VFD3	1,111	39	3
Lodging - Large Hotel			DCV_VFD3	608	20	1
Lodging - Small Hotel			DCV_VFD3	608	20	1
Medium Office			DCV_VFD3	1,111	39	3
Multifamily Common Areas			DCV_VFD3	205	777	51
Restaurant - Full Service			DCV_VFD3	620	139	9
Restaurant - Quick Service			DCV_VFD3	620	139	9
Retail - Standalone			DCV_VFD3	753	98	6
Retail - Strip mall			DCV_VFD3	776	138	9
Small Office			DCV_VFD3	1,111	39	3
Warehouse - Other			DCV_VFD3	383	51	3
Warehouse - Refrigerated			DCV_VFD3	383	51	3
Data Center - No Economizer	E	Harrisburg	DCV_VFD3	386	105	7
Data Center - With Economizer			DCV_VFD3	386	105	7
Education - College/University			DCV_VFD3	499	652	43
Education - Other			DCV_VFD3	499	652	43
Education - Other			DCV_VFD3	499	652	43
Grocery			DCV_VFD3	531	690	46
Health - Hospital			DCV_VFD3	607	19	1
Health - Other			DCV_VFD3	607	19	1
Industrial Manufacturing - 1 Shift			DCV_VFD3	815	31	2
Industrial Manufacturing - 2 Shift			DCV_VFD3	815	31	2
Industrial Manufacturing - 3 Shift			DCV_VFD3	815	31	2
Institutional/Public Service			DCV_VFD3	1,078	127	8
Large Office			DCV_VFD3	1,116	84	6
Lodging - Large Hotel			DCV_VFD3	607	19	1

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton)	Electric Heating Savings (kWh/ton)	Heating Fan Savings (kWh/ton)
				(NECES)	(NEHES)	(NHFES)
Lodging - Small Hotel			DCV_VFD3	607	19	1
Medium Office			DCV_VFD3	1,116	84	6
Multifamily Common Areas			DCV_VFD3	200	846	56
Restaurant - Full Service			DCV_VFD3	617	187	12
Restaurant - Quick Service			DCV_VFD3	617	187	12
Retail - Standalone			DCV_VFD3	753	134	9
Retail - Strip mall			DCV_VFD3	776	175	12
Small Office			DCV_VFD3	1,116	84	6
Warehouse - Other			DCV_VFD3	386	105	7
Warehouse - Refrigerated			DCV_VFD3	386	105	7
Data Center - No Economizer	F	Williamsport	DCV_VFD3	402	91	6
Data Center - With Economizer	F	Williamsport	DCV_VFD3	402	91	6
Education - College/University	F	Williamsport	DCV_VFD3	435	587	39
Education - Other	F	Williamsport	DCV_VFD3	435	587	39
Education - Other	F	Williamsport	DCV_VFD3	435	587	39
Grocery	F	Williamsport	DCV_VFD3	500	641	42
Health - Hospital	F	Williamsport	DCV_VFD3	603	19	1
Health - Other	F	Williamsport	DCV_VFD3	603	19	1
Industrial Manufacturing - 1 Shift	F	Williamsport	DCV_VFD3	817	29	2
Industrial Manufacturing - 2 Shift	F	Williamsport	DCV_VFD3	817	29	2
Industrial Manufacturing - 3 Shift	F	Williamsport	DCV_VFD3	817	29	2
Institutional/Public Service	F	Williamsport	DCV_VFD3	1,007	117	8
Large Office	F	Williamsport	DCV_VFD3	1,147	72	5
Lodging - Large Hotel	F	Williamsport	DCV_VFD3	603	19	1
Lodging - Small Hotel	F	Williamsport	DCV_VFD3	603	19	1
Medium Office	F	Williamsport	DCV_VFD3	1,147	72	5
Multifamily Common Areas	F	Williamsport	DCV_VFD3	168	828	55
Restaurant - Full Service	F	Williamsport	DCV_VFD3	599	175	12
Restaurant - Quick Service	F	Williamsport	DCV_VFD3	599	175	12
Retail - Standalone	F	Williamsport	DCV_VFD3	751	124	8
Retail - Strip mall	F	Williamsport	DCV_VFD3	778	165	11
Small Office	F	Williamsport	DCV_VFD3	1,147	72	5
Warehouse - Other	F	Williamsport	DCV_VFD3	402	91	6
Warehouse - Refrigerated	F	Williamsport	DCV_VFD3	402	91	6
Data Center - No Economizer	G	Bradford	DCV_VFD3	426	193	13
Data Center - With Economizer	G	Bradford	DCV_VFD3	426	193	13
Education - College/University	G	Bradford	DCV_VFD3	337	1,050	70
Education - Other	G	Bradford	DCV_VFD3	337	1,050	70
Education - Other	G	Bradford	DCV_VFD3	337	1,050	70

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton) (NECES)	Electric Heating Savings (kWh/ton) (NEHES)	Heating Fan Savings (kWh/ton) (NHFES)
Grocery			DCV_VFD3	453	987	65
Health - Hospital			DCV_VFD3	597	17	1
Health - Other			DCV_VFD3	597	17	1
Industrial Manufacturing - 1 Shift			DCV_VFD3	821	43	3
Industrial Manufacturing - 2 Shift			DCV_VFD3	821	43	3
Industrial Manufacturing - 3 Shift			DCV_VFD3	821	43	3
Institutional/Public Service			DCV_VFD3	899	185	12
Large Office			DCV_VFD3	1,195	157	10
Lodging - Large Hotel			DCV_VFD3	597	17	1
Lodging - Small Hotel			DCV_VFD3	597	17	1
Medium Office			DCV_VFD3	1,195	157	10
Multifamily Common Areas			DCV_VFD3	118	958	63
Restaurant - Full Service			DCV_VFD3	572	265	18
Restaurant - Quick Service			DCV_VFD3	572	265	18
Retail - Standalone			DCV_VFD3	748	192	13
Retail - Strip mall			DCV_VFD3	780	233	15
Small Office			DCV_VFD3	1,195	157	10
Warehouse - Other			DCV_VFD3	426	193	13
Warehouse - Refrigerated			DCV_VFD3	426	193	13
Data Center - No Economizer	H	Pittsburgh	DCV_VFD3	403	98	6
Data Center - With Economizer	H	Pittsburgh	DCV_VFD3	403	98	6
Education - College/University	H	Pittsburgh	DCV_VFD3	429	618	41
Education - Other	H	Pittsburgh	DCV_VFD3	429	618	41
Education - Other	H	Pittsburgh	DCV_VFD3	429	618	41
Grocery	H	Pittsburgh	DCV_VFD3	497	664	44
Health - Hospital	H	Pittsburgh	DCV_VFD3	603	19	1
Health - Other	H	Pittsburgh	DCV_VFD3	603	19	1
Industrial Manufacturing - 1 Shift	H	Pittsburgh	DCV_VFD3	818	30	2
Industrial Manufacturing - 2 Shift	H	Pittsburgh	DCV_VFD3	818	30	2
Industrial Manufacturing - 3 Shift	H	Pittsburgh	DCV_VFD3	818	30	2
Institutional/Public Service	H	Pittsburgh	DCV_VFD3	1,001	122	8
Large Office	H	Pittsburgh	DCV_VFD3	1,150	78	5
Lodging - Large Hotel	H	Pittsburgh	DCV_VFD3	603	19	1
Lodging - Small Hotel	H	Pittsburgh	DCV_VFD3	603	19	1
Medium Office	H	Pittsburgh	DCV_VFD3	1,150	78	5
Multifamily Common Areas	H	Pittsburgh	DCV_VFD3	165	836	55
Restaurant - Full Service	H	Pittsburgh	DCV_VFD3	598	181	12
Restaurant - Quick Service	H	Pittsburgh	DCV_VFD3	598	181	12
Retail - Standalone	H	Pittsburgh	DCV_VFD3	751	129	9

Building Type	Climate Region	Reference City	Sub-Measure Type	Cooling Savings (kWh/ton)	Electric Heating Savings (kWh/ton)	Heating Fan Savings (kWh/ton)
				(NECES)	(NEHES)	(NHFES)
Retail - Strip mall			DCV_VFD3	778	170	11
Small Office			DCV_VFD3	1,150	78	5
Warehouse - Other			DCV_VFD3	403	98	6
Warehouse - Refrigerated			DCV_VFD3	403	98	6
Data Center - No Economizer	I	Erie	DCV_VFD3	410	120	8
Data Center - With Economizer			DCV_VFD3	410	120	8
Education - College/University			DCV_VFD3	403	718	48
Education - Other			DCV_VFD3	403	718	48
Education - Other			DCV_VFD3	403	718	48
Grocery			DCV_VFD3	485	739	49
Health - Hospital			DCV_VFD3	601	19	1
Health - Other			DCV_VFD3	601	19	1
Industrial Manufacturing - 1 Shift			DCV_VFD3	818	33	2
Industrial Manufacturing - 2 Shift			DCV_VFD3	818	33	2
Industrial Manufacturing - 3 Shift			DCV_VFD3	818	33	2
Institutional/Public Service			DCV_VFD3	972	137	9
Large Office			DCV_VFD3	1,163	96	6
Lodging - Large Hotel			DCV_VFD3	601	19	1
Lodging - Small Hotel			DCV_VFD3	601	19	1
Medium Office			DCV_VFD3	1,163	96	6
Multifamily Common Areas			DCV_VFD3	152	865	57
Restaurant - Full Service			DCV_VFD3	591	200	13
Restaurant - Quick Service			DCV_VFD3	591	200	13
Retail - Standalone			DCV_VFD3	750	143	10
Retail - Strip mall			DCV_VFD3	778	184	12
Small Office			DCV_VFD3	1,163	96	6
Warehouse - Other			DCV_VFD3	410	120	8
Warehouse - Refrigerated			DCV_VFD3	410	120	8

Default Savings

There are no default savings for this measure.

Evaluation Protocols

The appropriate evaluation protocol is to verify that the baseline unit was eligible (e.g., economizer functional but not required by code, DCV not required by code, and constant volume operation) for installation of the ARC unit and to verify the proper selection of parameters such as system capacities and building types. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

SOURCES

1) IL TRM (2024, Version 11). "Advanced Rooftop Controls (4.4.41)". Weblink
2) The NECES, NEHES, and NECDR are adapted from the protocol for this measure in the Illinois TRM, version 12.0 Volume 2: Commercial and industrial measures (Accessed March 2024). Weblink
   The authors of the IL TRM adapted the eQuest simulation models that were used to develop cooling and heating EFLH for the five climate zones in the IL TRM. The authors of this IMP developed regressions with the energy savings or demand reduction as the dependent variable and the measure type, building type, and cooling/heating degree days as independent variables. Once the regression coefficients were determined, the authors used cooling and heating degree days for the nine climate zones in the PA TRM to develop PA-specific impacts. Note that some of the NECES values for the DCV-only measure are slightly negative, but they are generally outweighed by the NHFES.

3) The NGHES is a simple unit conversion from the NEHES, accounting for the assumed efficiencies of furnaces and heat pumps in the eQuest models that support the IL TRM:

$$NGHES = NEHES \times \frac{2.3\ COP}{0.80\ AFUE} \times \frac{0.03413\ Therm}{1\ kWh}$$

4) The authors determined the NFHES by comparing fan horsepower to heating capacity for nine contemporary RTUs (3-ton,4-ton, and 5-ton units from three leading manufacturers). The motor horsepower was converted to kW using a load factor of 0.76. Regional Technical Forum, Proposed Standard Savings Estimation Protocol for Ultra-Premium Efficiency Motors. November 5, 2012. Appendix C, Table 6 (Meeting minutes: Weblink Box file: Weblink), consistent with Section 3.3.1 of this TRM and federal baseline motor efficiencies for the stated horsepower (Energy Conservation Program: Energy Conservation Standards for Commercial and Industrial Electric Motors; Final Rule, 79 Federal Register 103 (29 May 2014) Weblink and Energy Conservation Program: Energy Conservation Standards for Small Motors 86 Federal Register 4885 (19 January 2021) Weblink. The average air handler motor kW/ton is 0.1 for gas-heated systems.
5) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.2.18. C&I ENERGY STAR® Certified Connected Thermostats

Target Sector	Commercial and Industrial
Measure Unit	Commercial Thermostat
Measure Life	11 years Source 1
Vintage	Retrofit, Replace on Burnout, or New Construction

ENERGY STAR® certified connected thermostats (CT) save heating and cooling energy by operating HVAC systems more efficiently. CTs that meet the ENERGY STAR® specification[2] have functions that can be accessed onboard the device or through an internet connection . Businesses must have Wi-Fi to enable full operating capabilities.

ENERGY STAR® certified connected thermostats may replace either a manual thermostat or a conventional programmable thermostat. The energy savings assume an existing ducted HVAC system with either a heat pump, fossil fuel heating with central AC, or an electric furnace with central AC. CT or line voltage thermostats controlling radiant floor heating or window type air conditioning units are not eligible.

Eligibility

This measure documents the energy savings resulting from the installation of ENERGY STAR®-certified connected thermostats (CT) in non-residential facilities with central cooling or heating or line voltage heating (assuming that installers use aftermarket transformers to step down the line voltage to 24V). The thermostat must be installed to control a single-zone, packaged HVAC system. of 10 tons or less. Both programmable and manual thermostats are acceptable baselines.

Algorithms

Energy Savings

Total savings are calculated as a combination of heating and cooling season savings. The basic formulation is to calculate the baseline annual energy usage and then to apply an energy savings factor (ESF). The ESFs are based on a review of technical reference manuals that include protocols for CTs in commercial settings. Estimates ranged from 2% to 18%, with a mean of approximately 9% and this analysis applies a derate factor of 0.75 to account for uncertainty in these savings metrics.

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat}$$

$$\Delta kWh_{cool} = CAPY_{cool} \times \frac{EFLH_{cool}}{SEER \times Eff_{duct}} \times ESF_{cool}$$

$$\Delta kWh_{heat,HP} = CAPY_{HP} \times \frac{EFLH_{hea}}{HSPF \times Eff_{duct}} \times ESF_{hea}$$

$$\Delta kWh_{heat,elecresistance} = CAPY_{elecfurn} \times \frac{EFLH_{heat}}{3.412 \times Eff_{duct}} \times ESF_{heat} \times DF_{elecresistance}$$

$$\Delta kWh_{heat,fuelfurn} = \frac{HP_{motor} \times 0.746}{\eta_{motor}} \times EFLH_{heat} \times ESF_{heat}$$

Demand Savings

Savings from connected thermostats installed in commercial systems with ducted air conditioning have been shown to generally follow cooling load, however the percent reduction during system peak hours is expected to be lower than off-peak hours. This is reflected in the literature, with five of seven reviewed protocols assuming that demand reductions are zero. A peak demand savings factor (PDSF) of 0.25 is applied to demand reduction calculation. The PDSF term reduces the ESF value used to calculate energy savings by 75%. Peak demand savings are a function of the system size, efficiency, installation type, and energy to demand factor.

While it's plausible that demand reductions are quite low, zero is likely an underestimate since many businesses in the service sector can be closed on one or more weekdays (often Mondays), and certain establishments close before 6 PM. Others may not open or experience typical occupancy until the late afternoon or early evening, overlapping with winter peak hours. Lastly, connected thermostats may save disproportionate amounts when commercial facilities are not vacant.

$$\Delta kW_{summer\ peak} = \Delta kWh_{cool} \times PDSF \times ETDF_{summer}$$
$$\Delta kW_{winter\ peak} = \Delta kWh_{heat} \times PDSF \times ETDF_{winter}$$

Blended Baseline

The ESF value applied in the equations above is determined based on the type of thermostat being replaced (manual, programmable, or unknown baseline thermostat), the controlled heating and/or cooling HVAC equipment, and the program design type. When the type of the baseline thermostat is not known, the following equation may be used to find the appropriate ESF value for the blended baseline.

$$ESF_{connected\ over\ mixed} = (ESF_{connected\ over\ manual} \times \%_{Manual}) + (ESF_{connected\ over\ prog.} \times \%_{Programmable})$$

If the system type is not known, such as in a possible midstream application, the default system should be an air conditioner with a fossil fuel furnace. The 2018 PA Nonresidential Baseline Study found that fossil fuels accounted for about 93% of heating, weighted by capacity, for both the small and large commercial sectors.

Definition of Terms

Table 3-74: Commercial HVAC Calculation Assumptions

Term	Unit	Value	Sources
$CAPY_{cool}$, Capacity of air conditioning unit	$\frac{kBTU}{h}$	EDC Data Gathering of Nameplate data	EDC Data Gathering
		Default = 33.56 / unit	3
$CAPY_{HP}$, Normal heat capacity of Heat Pump System.	$\frac{kBTU}{h}$	EDC Data Gathering of Nameplate Data	EDC Data Gathering
		Default = 31.37 / unit	3
$CAPY_{elecfurn}$, Normal heat capacity of Electric Furnace systems	$\frac{kBTU}{h}$	EDC Data Gathering of Nameplate data	EDC Data Gathering
		Default = 54.10 / unit	3
SEER, *SEER2* Seasonal Energy Efficiency Ratio	$\frac{BTU}{W \cdot h}$	EDC Data Gathering of Nameplate data	EDC Data Gathering
		Default SEER2: CAC = 13.2 Heat Pump = 14.3	4
EER, EER2, Energy Efficiency Ratio	$\frac{BTU}{W \cdot h}$	EDC Data Gathering of Nameplate data	EDC Data Gathering
		Default EER2: CAC = 11.1 Heat Pump = 11.7 GSHP: Water to air, ground water = 17.1 Brine to air, ground loop = 14.1 Water to water, ground water = 16.3 Brine to water, ground loop = 12.1	4
$HSPF2_{heat\ pump}$, Heating Seasonal Performance Factor of Heat Pump	$\frac{BTU}{W \cdot h}$	EDC Data Gathering of Nameplate data	EDC Data Gathering
		Default HSPF2: Heat Pump = 7.5 GSHP: Water to air, ground water = 12.6 Brine to air, ground loop = 10.9	4

Term	Unit	Value	Sources
		Water to water, ground water = 10.6 Brine to water, ground loop = 8.5	
Eff_{duct}, Duct System Efficiency	*None*	0.83	5
$EFLH_{cool}$, Equivalent Full Load Hours for Cooling	$\frac{hours}{yr}$	See Table 3-25	6
$EFLH_{heat}$, Equivalent Full Load Hours for Heating	$\frac{hours}{yr}$	See Table 3-28	6
HP_{motor}, Gas furnace blower motor horsepower	*Hp*	EDC Data Gathering of Nameplate data	EDC Data Gathering
		Default = 0.5	Average blower motor capacity for gas furnace (typical range = 0.25 to 0.75 hp)
η_{motor}, Efficiency of furnace blower motor	*%*	EDC Data Gathering Default = 50%	Typical efficiency of 0.5 hp blower motor
$\%_{Programmable}$, % central AC systems with a programmable thermostat	*None*	EDC Data Gathering	EDC Data Gathering
		Default = 62%	3
$\%_{Manual}$, % central AC systems with a manual thermostat	*None*	EDC Data Gathering	EDC Data Gathering
		Default = 38%	3
ESF_{cool}, cooling energy saving factor	*None*	See Table 3-75	Composite of multiple sources
ESF_{heat}, heating energy saving factor	*None*	See Table 3-75	Composite of multiple sources
$ETDF_{summer}$, Energy to Demand Factor Summer	$\frac{kW}{kWh}$	Default: Table 3-27	7
$ETDF_{winter}$, Energy to Demand Factor Summer			
$DF_{elecresistance}$, Derate Factor for Electric Resistance Heating Systems	*None*	0.85	Professional Judgement
PDSF, peak demand savings factor relative to ESF_{cool}	*None*	0.25	Professional Judgement

Note: Where appropriate, nameplate data collected for usage in savings calculations (i.e., SEER, EER, HSPF) should be converted to new efficiency metrics (i.e., SEER2, EER2, HSPF2) using conversion equations laid out in Vol 1. App. A

Table 3-75 shows ESF values for cooling and heating (percentage of heating or cooling consumption saved by thermostat type and baseline thermostat). Each value is taken from a secondary literature study and has a footnote with its corresponding reference.

Table 3-75: Energy Savings Factors (ESF_{cool} and ESF_{heat})

Baseline	Cooling ESF	Heating ESF
Manual	6.9%	6.5%
Conventional programmable	4.9%	4.5%
Unknown Mix Default	6.2%	5.8%

Note: Manual Baselines are calculated as an average of heating and cooling savings estimates from multiple studies. Sources: 8,9,10,11,12,13,14. Conventional baselines the ESF value applied here subtracts the assumed savings value from programmable thermostats, (2.0%, Source 7), from the manual thermostat baseline ESF. Mixed Default ESF values are based on a weighted average of savings from manual and conventional programmable thermostats with 38% and 62% weights respectively (Source 4)

Default Savings

There are no default savings for this measure.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer-specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. Evaluation contractors may choose to propose independent assessments of the ESF factors to the SWE in their EM&V plans. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Smart Thermostat Residential". Accessed August 2023. Weblink
2) Products ENERGY STAR Program Requirements for Connected Thermostat. Weblink
3) Demand Side Analytics for the Pennsylvania Public Utility Commission. (2024, March). Pennsylvania Act 129 2023 Non-Residential Baseline Study (Pages 95 & 112, Tables 25 & 29). Weblink
4) Act 129 Pennsylvania 2023 Residential Baseline Study, (Pages 105,114,115,116 Tables 87,96,97,98) Weblink. Engineering judgement: It is assumed that commercial and residential HVAC systems under five tons have similar capacity and efficiency distributions. With larger buildings and equipment being served by complex building management systems. For Early Replacement GSHP: existing systems were assumed to be two-thirds through an assumed 15-year equipment life. Therefore, the minimum required efficiency at the date of installation for an existing GSHP system is estimated to have been set by IECC 2021 requirements. The values in the table represent the minimum efficiency values from IECC 2021. Weblink
5) Better Duct Systems for Home Heating and Cooling, U.S. Department of Energy. Assuming for an improved duct system with insulation levels at R-8 and leakage at 5% of the system fan flow. Weblink
6) EFLHs, and CFs for Pennsylvania are calculated based on Nexant's eQuest modeling analysis 2014 and updated based on the latest CDD and HDD values from NOAA's 15-year annual climate Normals (2006–2020).Weblink
7) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink
8) IL TRM v9.0 Volume 2, pages 441-444. Weblink
9) Mid-Atlantic TRM v10, pages 317-320. Weblink
10) Wisconsin Focus on Energy 2020 TRM, pages 244-251. Weblink
11) Efficiency Vermont TRM, issued December 31, 2018, pages 25-29. Weblink
12) California Municipal Utilities Association 2017 TRM, pages 17-2 – 17-5. Weblink
13) 2021 Michigan Energy Measures Database. Weblink. Savings are provided on a per-square-foot basis. The PA TRM authors estimated relative savings (ESF) by comparing savings from thermostats with savings from efficient HVAC systems, which have known efficiency increases over baseline systems.
14) Regional Technical Forum: Commercial Connected Thermostat Unit Energy Savings. Weblink

3.2.19. Adjustment of Programmable Thermostats

Target Sector	Commercial and Industrial
Measure Unit	Adjustment of Programmable Thermostats
Measure Life	11 years Source 1
Vintage	Behavioral
Effective Date	6/1/2023

This measure involves adjustment of programmable thermostat schedules in existing commercial and industrial businesses, where the current HVAC operating schedules do not align with the building occupancy, temperature setpoints during occupied periods, and temperature set-back during unoccupied times need to be adjusted. Savings can be obtained from adjusting setback or setpoint temperatures or by moving certain hours from setpoint to setback mode.

Eligibility

This measure is targeted to non-residential establishments with single zone HVAC units. The baseline for this measure is an existing programmable thermostat installed on a single zone HVAC unit.

Algorithms

The savings calculation methodology uses a regression equation to calculate the energy savings for a variety of common situations. For efficiency of ASHP units < 65,000 Btu/hr, use SEER or SEER2, as available, to calculate ΔkWh_{cool} and HSPF or HSPF2, as available, to calculate ΔkWh_{heat}. For larger systems, use EER, IEER, COP, or kW/ton as available. For units rated in both EER and IEER, use IEER for energy savings calculations. The provided calculator will convert the provided efficiency rating to EER for peak demand reduction calculations.

Electric Energy Savings

$$\Delta kWh = \Delta kWh_{Cool} + \Delta kWh_{Heat}$$

$$\Delta kWh_{cool} = Baseline\ Cooling\ Energy\ Use\ (kWh) \times Percent\ Cooling\ Energy\ Savings$$

$$\Delta kWh_{heat} = Baseline\ Heating\ Energy\ Use\ (kWh) \times Percent\ Heating\ Energy\ Savings$$

$$Baseline\ Cooling\ Energy\ Use\ (kWh) = EFLH_{cool} \times Capacity_{cool}/Efficiency_{cool}$$

$$Baseline\ Heating\ Energy\ Use\ (kWh) = EFLH_{heat} \times Capacity_{heat}/Efficiency_{heat}$$

Electric Demand Reduction

$$\Delta kW_{summer\ peak} = \Delta kWh_{cool} \times {}^{\Delta avgCDH_{Peak}}/_{\Delta CDH_{Total}}$$

$$\Delta kW_{winter\ peak} = \Delta kWh_{heat} \times {}^{\Delta avgHDH_{Peak}}/_{\Delta HDH_{Total}}$$

Where $\Delta CDH_{Total}/\ \Delta HDH_{Total}$ represents the change in annual cooling/heating degree hours that results from the measure, and $\Delta avgCDH_{Peak}/\Delta avgHDH_{Peak}$ represents the change in average cooling/heating degree hours during the Act 129 peak demand window that results from the measure.

Parametric simulation runs were made for each ten distinct building types (Retail, Office, Restaurant, School, College, Manufacturing, Assembly, Hospital, Lodging, and Warehouse), using eQuest prototypes

Source 4 to determine energy savings with varying thermostat setpoints. The baseline and post models were identical except for the thermostat schedules, and six runs with varying set point schedules were conducted for each building type.

Simulation results were tabulated, and the relationships between cooling degree hours (CDH) or heating degree hours (HDH) reductions and cooling and heating energy savings were established through linear regressions for each building type. The cooling energy savings tend to diverge from linearity for aggressive thermostat adjustments, but most thermostat adjustments should result in CDH reductions under 4,000 CDH. The calculator caps savings at 5,000 CDH reduction and 6,000 HDH reduction, corresponding to approximately 6% and 15% maximum possible relative savings for cooling and heating respectively for this measure.

After defining the baseline and proposed cooling and heating schedules, the calculator calculates CDH and HDH for a specific location and building type and then uses regression equations to determine savings as a percentage of overall energy usage.

$$Percent\ Cooling\ Savings\ (kWh) = Intercept \times X\ Variable \times \Delta CDH$$

$$\Delta CDH = Baseline\ CDH - Proposed\ CDH$$

$$Percent\ Heating\ Savings\ (kWh) = Intercept \times X\ Variable \times \Delta HDH$$

$$\Delta HDH = Baseline\ HDH - Proposed\ HDH$$

Table 3-76: Terms, Values, and References for HVAC Systems

Term	Unit	Values	Source
$Capacity_{Cool}$, Rated cooling capacity of the energy efficient unit	Tons , $\frac{kBtu}{hr}$	Nameplate data (AHRI)	EDC Data Gathering
$Capacity_{Cool}$, Rated cooling capacity of the energy efficient unit	Tons, $\frac{kBtu}{hr}$	Nameplate data (AHRI)	EDC Data Gathering
$Efficiency_{Cool}$ energy efficiency ratio of the unit, (EER/EER2, SEER/SEER2, IEER, COP, or kW/ton)	$\frac{Btu/hr}{W}, \frac{kW}{Ton}$ $unitless\ for\ COP$	Nameplate data (AHRI)	EDC Data Gathering
$Efficiency_{Heat}$ energy efficiency ratio of the unit, (HSPF/HSPF2, COP, or kW/ton for electric systems, AFUE for gas systems)	$\frac{Btu/hr}{W}, \frac{kW}{Ton}$, $unitless\ for\ COP$	Nameplate data (AHRI)	EDC Data Gathering
$EFLH_{cool}$, Equivalent Full Load Hours for the cooling season – The kWh during the entire operating season divided by the kW at design conditions.	$\frac{Hours}{Year}$	Table 3-25	Provided by lookup in calculator
$EFLH_{heat}$ Equivalent Full Load Hours for the heating season – The kWh during the entire operating season divided by the kW at design conditions.	$\frac{Hours}{Year}$	Table 3-28	Provided by lookup in calculator
$\Delta avgCDH_{Peak}$, Average hourly reduction in peak-period cooling degree-hours due to thermostat adjustment	°F	Calculated	Calculated according to baseline and post thermostat schedules

Term	Unit	Values	Source
$\Delta avgHDH_{Peak}$, Average hourly reduction in peak-period heating degree-hours due to thermostat adjustment	°F	Calculated	Calculated according to baseline and post thermostat schedules
ΔCDH_{Total},Reduction in annual cooling degree-hours due to thermostat adjustment	°F-h	Calculated	Calculated according to baseline and post thermostat schedules
ΔHDH_{Total},Reduction in annual heating degree-hours due to thermostat adjustment	°F-h	Calculated	Calculated according to baseline and post thermostat schedules
$Percent\ Cooling\ Savings$	kWh	Calculated	Calculated according to baseline and post thermostat schedules
$Percent\ Heating\ Savings$	kWh	Calculated	Calculated according to baseline and post thermostat schedules

Default Savings

There are no default savings for this measure.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify the heating and cooling schedules for each thermostat.

Sources

1) California Electronic Technical Reference Manual. "Smart Thermostat Residential". Accessed August 2023. Weblink
2) Appendix G of Volume 1 of the 2026 TRM (Adjustment of Programmable Thermostats Calculator). Weblink
3) eQuest, the Quick Energy Simulation Tool. Weblink

3.2.20. Duct Sealing And Insulation

Target Sector	Commercial and Industrial
Measure Unit	Duct Sealing and Insulation
Measure Life	15 years[Source1]
Measure Vintage	Retrofit
Effective Date	June 1, 2022

Supply ducts are a critical component of an HVAC system where conditioned air is transferred through the ducts to the occupied spaces. Duct insulation provides a thermal barrier against heat transfer between ambient conditions and the conditioned air, while duct sealing prevents the unnecessary loss of conditioned air out of the duct and into unconditioned spaces. This measure involves the installation of R-6 insulation on previously uninsulated ducts, and the reduction of duct leakage through taping, caulking, and other conventional means. International energy conservation code (IECC) 2021 Section C403.12.1[Source 2] requires new construction ductwork passing through unconditioned spaces to have a minimum R-12 insulation in Climate Zones 5 through 8.

Retrofit duct sealing and insulation can be applied to distribution ducts, air handlers, and filter boxes. New construction is required by code to include duct insulation, therefore new construction is not eligible for duct insulation rebates. Duct insulation improvements are to be verified visually, while duct leakage rates are to be determined by a duct leakage test pre- and post-retrofit at 25 Pascals of pressure differential.

Eligibility

This measure documents the energy savings resulting from the installation of duct insulation, sealing ducts passing through unconditioned spaces, or both sealing and insulation. The baseline condition for this measure is a duct system in a non-residential facility, with sub-optimal sealing, insulation, or both. An eligible system must have the following to be eligible for this measure:

- HVAC supply ducts passing through an unconditioned space
- Existing Construction (System Retrofit Only)

Algorithms

The energy savings and peak demand reduction for this measure may be calculated using the following algorithms. Note: Efficiency metrics have been identified with old terminology for simplification of algorithms. New efficiency metrics have to be used where applicable: SEER2, EER2 and HSPF2.

$$\Delta kWh = \Delta kWh_{Cool} + \Delta kWh_{Heat}$$

For AC and Heat Pump units with Cooling Capacity <65,000 BTU/h

$$\Delta kWh_{Cool} = kBTU/h_{Out,Cool} \times \frac{1}{SEER} \times EFLH_{Cool} \times \left(1 - \frac{Eff_{Dist,Cool,base}}{Eff_{Dist,Cool,ee}}\right) \times (1 - TRF_{Cool})$$

$$\Delta kWh_{Heat} = kBTU/h_{Out,Heat} \times \frac{1}{HSPF} \times EFLH_{Heat} \times \left(1 - \frac{Eff_{Dist,Heat,Base}}{Eff_{Dist,Heat,ee}}\right) \times (1 - TRF_{Heat})$$

For AC and Heat Pump units with Cooling Capacity >65,000 BTU/h

$$\Delta kWh_{Cool} = kBTU/h_{Out,Cool} \times \frac{1}{IEER} \times EFLH_{Cool} \times \left(1 - \frac{Eff_{Dist,Cool,base}}{Eff_{Dist,Cool,ee}}\right) \times (1 - TRF_{Cool})$$

$$\Delta kWh_{Heat} = kBTU/h_{Out,Heat} \times \frac{1}{3.412} \times \frac{1}{COP} \times EFLH_{Heat} \times \left(1 - \frac{Eff_{Dist,Heat,Base}}{Eff_{Dist,Heat,ee}}\right) \times (1 - TRF_{Heat})$$

For Electric Furnaces

$$\Delta kWh_{Heat} = kW_{in} \times EFLH_{Heat} \times \left(1 - \frac{Eff_{Dist,Heat,Base}}{Eff_{Dist,Heat,ee}}\right) \times (1 - TRF_{Heat})$$

Peak Demand Savings

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\boldsymbol{\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}}$$

Fossil Fuel Savings for Furnaces with Heating Capacity <225,000 BTU/h

$$\Delta MMBTU = \frac{kBTU/h_{In,Heat}}{1{,}000} \times EFLH_{Heat} \times \left(1 - \frac{Eff_{Dist,Heat,Base}}{Eff_{Dist,Heat,ee}}\right) \times (1 - TRF_{Heat})$$

Definition of Terms

Table 3-77: Terms, Values, and References for Insulating HVAC Ducts

Term	Unit	Value	Sources
$kBTU/h_{Out,Cool}$, nameplate rated output cooling capacity of the HVAC unit.	$\frac{kBTU}{h}$	Nameplate data (AHRI)	EDC Data Gathering
$kBTU/h_{Out,Heat}$, nameplate rated output heating capacity of the HVAC unit.	$\frac{kBTU}{h}$	Nameplate data (AHRI)	EDC Data Gathering
$kBTU/h_{in,Heat}$, nameplate rated input heating capacity of the fossil fuel fired unit.	$\frac{kBTU}{h}$	Nameplate data (AHRI)	EDC Data Gathering
kW_{in}, nameplate rated input heating capacity of the electric furnace.	kW	Nameplate data (AHRI)	EDC Data Gathering
$EFLH_{Cool}$, equivalent full-load hours of the cooling system.	hrs	Table 3-25	5
$EFLH_{Heat}$, equivalent full-load hours of the heating system.	hrs	Table 3-28	5
$IEER$, integrated energy efficiency ratio of the energy efficient unit.	$\frac{Btu/hr}{W}$	Nameplate data (AHRI)	EDC Data Gathering
$EER2$, energy efficiency ratio of the energy efficient unit.	$\frac{Btu/hr}{W}$	Nameplate data (AHRI)	EDC Data Gathering
$SEER2$, seasonal energy efficiency ratio of the energy efficient unit.	$\frac{Btu/hr}{W}$	Nameplate data (AHRI)	EDC Data Gathering
COP, coefficient of performance of the energy efficient unit.	None	Nameplate data (AHRI)	EDC Data Gathering
$HSPF2$, heating seasonal performance factor of the energy efficiency unit.	$\frac{Btu/hr}{W}$	Nameplate data (AHRI)	EDC Data Gathering
$EFF_{Dist,Cool}$, duct system distribution efficiency for cooling.	None	Table 3-78	3
$EFF_{Dist,Heat}$, duct system distribution efficiency for heating.	None	Table 3-79	3
TRF_{Cool}, thermal regain factor for cooling.	kWh	Table 3-80	4
TRF_{Heat}, thermal regain factor for heating.	kWh	Table 3-80	4

Term	Unit	Value	Sources
ΔkWh, annual electric energy savings.	kWh	Calculated	-
ΔkW_{peak}, annual electric demand peak savings.	kW	Calculated	-
1,000, conversion factor from kBTU to MMBtu	$\frac{MMBTU}{kBTU}$	1,000	Conversion Factor
3.412, conversion factor from kWh to kBTU	$\frac{kBTU}{kWh}$	3.412	Conversion Factor
$ETDF_{summer}$, Energy to Demand Factor Summer $ETDF_{winter}$, Energy to Demand Factor Summer	$\frac{kW}{kWh}$	Default: Table 3-27	6

Note: Where appropriate, nameplate data collected for usage in savings calculations (i.e., SEER, EER, HSPF) should be converted to new efficiency metrics (i.e., SEER2, EER2, HSPF2) using conversion equations laid out in Vol 1. App. A

Table 3-78: Duct Cooling Distribution Efficiency in Select Building Types

Duct total leakage (%)	Duct system R-value (supply and return)	Restaurant	Retail	Other
2%	Uninsulated	0.862	0.836	0.832
3%	Uninsulated	0.860	0.835	0.831
4%	Uninsulated	0.859	0.835	0.830
5%	Uninsulated	0.857	0.834	0.828
6%	Uninsulated	0.855	0.833	0.827
7%	Uninsulated	0.854	0.832	0.826
8%	Uninsulated	0.852	0.832	0.825
9%	Uninsulated	0.851	0.831	0.823
10%	Uninsulated	0.849	0.830	0.822
11%	Uninsulated	0.847	0.830	0.821
12%	Uninsulated	0.846	0.829	0.820
13%	Uninsulated	0.844	0.828	0.818
14%	Uninsulated	0.843	0.827	0.817
15%	Uninsulated	0.841	0.827	0.816
16%	Uninsulated	0.839	0.826	0.815
17%	Uninsulated	0.838	0.825	0.813
18%	Uninsulated	0.836	0.825	0.812
19%	Uninsulated	0.835	0.824	0.811
20%	Uninsulated	0.833	0.823	0.810
21%	Uninsulated	0.831	0.822	0.808
22%	Uninsulated	0.830	0.822	0.807
23%	Uninsulated	0.828	0.821	0.806
24%	Uninsulated	0.827	0.820	0.805
25%	Uninsulated	0.825	0.820	0.803
26%	Uninsulated	0.823	0.819	0.802

27%	Uninsulated	0.822	0.818	0.801
28%	Uninsulated	0.820	0.817	0.800
29%	Uninsulated	0.819	0.817	0.798
30%	Uninsulated	0.817	0.816	0.797
2%	R-6	0.965	0.970	0.943
3%	R-6	0.962	0.969	0.941
4%	R-6	0.960	0.968	0.939
5%	R-6	0.957	0.967	0.937
6%	R-6	0.954	0.966	0.936
7%	R-6	0.952	0.965	0.934
8%	R-6	0.949	0.964	0.932
9%	R-6	0.947	0.963	0.930
10%	R-6	0.944	0.961	0.928
11%	R-6	0.942	0.960	0.927
12%	R-6	0.939	0.959	0.925
13%	R-6	0.937	0.958	0.923
14%	R-6	0.934	0.957	0.921
15%	R-6	0.932	0.956	0.919
16%	R-6	0.929	0.955	0.917
17%	R-6	0.927	0.954	0.916
18%	R-6	0.924	0.953	0.914
19%	R-6	0.921	0.951	0.912
20%	R-6	0.919	0.950	0.910
21%	R-6	0.916	0.949	0.908
22%	R-6	0.914	0.948	0.906
23%	R-6	0.911	0.947	0.905
24%	R-6	0.909	0.946	0.903
25%	R-6	0.906	0.945	0.901
26%	R-6	0.904	0.944	0.899
27%	R-6	0.901	0.943	0.897
28%	R-6	0.899	0.941	0.895
29%	R-6	0.896	0.940	0.894
30%	R-6	0.894	0.939	0.892

Table 3-79: Duct Heating Distribution Efficiency in Select Building Types

Duct total leakage (%)	Duct system R-value (supply and return)	Restaurant	Retail	Other
2%	Uninsulated	0.822	0.834	0.672
3%	Uninsulated	0.818	0.830	0.668
4%	Uninsulated	0.815	0.827	0.664
5%	Uninsulated	0.811	0.823	0.659
6%	Uninsulated	0.808	0.819	0.655
7%	Uninsulated	0.804	0.816	0.651
8%	Uninsulated	0.801	0.812	0.647
9%	Uninsulated	0.798	0.809	0.643
10%	Uninsulated	0.794	0.805	0.638

Duct total leakage (%)	Duct system R-value (supply and return)	Restaurant	Retail	Other
11%	Uninsulated	0.791	0.801	0.634
12%	Uninsulated	0.787	0.798	0.630
13%	Uninsulated	0.784	0.794	0.626
14%	Uninsulated	0.780	0.791	0.621
15%	Uninsulated	0.777	0.787	0.617
16%	Uninsulated	0.773	0.783	0.613
17%	Uninsulated	0.770	0.780	0.609
18%	Uninsulated	0.767	0.776	0.605
19%	Uninsulated	0.763	0.773	0.600
20%	Uninsulated	0.760	0.769	0.596
21%	Uninsulated	0.756	0.765	0.592
22%	Uninsulated	0.753	0.762	0.588
23%	Uninsulated	0.749	0.758	0.583
24%	Uninsulated	0.746	0.755	0.579
25%	Uninsulated	0.742	0.751	0.575
26%	Uninsulated	0.739	0.747	0.571
27%	Uninsulated	0.736	0.744	0.567
28%	Uninsulated	0.732	0.740	0.562
29%	Uninsulated	0.729	0.737	0.558
30%	Uninsulated	0.725	0.733	0.554
2%	R-6	0.925	0.931	0.822
3%	R-6	0.920	0.926	0.815
4%	R-6	0.915	0.921	0.809
5%	R-6	0.910	0.916	0.803
6%	R-6	0.905	0.911	0.796
7%	R-6	0.900	0.906	0.790
8%	R-6	0.895	0.901	0.783
9%	R-6	0.890	0.896	0.777
10%	R-6	0.885	0.891	0.771
11%	R-6	0.880	0.886	0.764
12%	R-6	0.874	0.881	0.758
13%	R-6	0.869	0.876	0.751
14%	R-6	0.864	0.871	0.745
15%	R-6	0.859	0.866	0.739
16%	R-6	0.854	0.861	0.732
17%	R-6	0.849	0.856	0.726
18%	R-6	0.844	0.851	0.719
19%	R-6	0.839	0.846	0.713
20%	R-6	0.834	0.841	0.707
21%	R-6	0.829	0.836	0.700
22%	R-6	0.824	0.831	0.694
23%	R-6	0.818	0.826	0.687
24%	R-6	0.813	0.821	0.681
25%	R-6	0.808	0.816	0.675
26%	R-6	0.803	0.811	0.668
27%	R-6	0.798	0.806	0.662

Duct total leakage (%)	Duct system R-value (supply and return)	Restaurant	Retail	Other
28%	R-6	0.793	0.801	0.655
29%	R-6	0.788	0.796	0.649
30%	R-6	0.783	0.791	0.643

Table 3-80: Thermal Regain Factors

Duct Location	TRFcooling	TRFheating
Attic	0.10	0.10
Garage	0.10	0.10
Crawl space, unvented, uninsulated	0.60	0.60
Crawl Space, Unvented, Insulated Building Floor and Crawl Space walls	0.60	0.30
Crawl Space, Unvented, Insulated Floor Only	0.30	0.30
Crawl Space, Vented, Uninsulated	0.60	0.55
Crawl Space, Insulated Building Floor and Crawl Space Walls	0.63	0.60
Crawl Space, Vented, Insulated Floor Only	0.30	0.30
Basement, Uninsulated	0.50	0.50
Basement, Insulated Walls	0.60	0.60
Under-slab	0.20	0.20

Default Savings

There are no default savings for this measure.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Duct Seal, Residential" Building weatherization EUL. Accessed February 2024. Weblink. (Engineering judgement: Duct sealing and duct insulation for measure life work agnostic to the sector)
2) 2021 International Energy Conservation Code (IECC), Chapter 4 Commercial Energy Efficiency, Section C403 Building Mechanical Systems, Sub-section 12 Construction of HVAC System Elements, Part 1 Duct and plenum insulation and sealing (Mandatory). Weblink
3) Engineering judgement: Assuming for equivalency with conditions in NY, data borrowed from New York State Technical Reference Manual V10, Appendix H. Weblink
4) Home Energy Saver & Score: Engineering Documentation, Thermal Distribution Efficiency Thermal Distribution Efficiency – Home Energy Saver & Score: Engineering Documentation (lbl.gov). Weblink
5) EFLHs and CFs for Pennsylvania are calculated based on Nexant's eQuest modeling analysis 2014 and updated based on the latest CDD and HDD values from NOAA's 15-year annual climate Normals (2006–2020). Weblink
6) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.2.21. Chilled Water Pipe Insulation

Target Sector	Commercial and Industrial
Measure Unit	Per Linear Foot of Insulation
Measure Life	15 years Source 1
Measure Vintage	Retrofit

Chilled water (CHW) distribution pipe is a critical component of an HVAC system where energy is transferred through the CHW medium. A chiller or series of chillers generate CHW which is then distributed to end uses such as air-handling units (AHUs) throughout a building or complex. CHW pipe insulation provides a thermal barrier against heat transfer between ambient conditions and the working fluid. International energy conservation code (IECC) 2021 Section C403.12.3 Source 2 requires new construction to have a minimum CHW pipe insulation. Insulation requirements are explicitly listed in Table C403.12.3: Minimum Pipe Insulation Thickness.

Retrofit CHW pipe insulation can be applied to both supply and return distribution pipes between an electric chiller and CHW end-use equipment. Chillers that use other fuels, such as absorption chillers, are not eligible for this measure. New construction is required by code to include CHW pipe insulation, therefore new construction is not eligible for CHW pipe insulation rebates.

Eligibility

This measure documents the energy savings resulting from the installation of CHW pipe insulation in non-residential facilities. The baseline condition for this measure is an uninsulated indoor CHW pipe. An eligible CHW system must have the following to be eligible for this measure:

- Electric Chiller
- Existing Construction (System Retrofit Only)
- CHW pipe requires a minimum of 1-inch of insulation that is in compliance with the specifications above
- Deemed savings are not provided for Data Centers through this protocol. Savings for Data Center projects should be calculated using custom measure protocols.

Algorithms

Energy savings for this measure may be calculated using the following formulas:

$$\Delta kWh = \frac{\Delta kWh}{ft} \cdot L$$

$$\Delta kW_{summer\ peak} = \frac{\Delta kWh}{EFLH_{Chill}} \cdot ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \frac{\Delta kWh}{EFLH_{Chi}} \cdot ETDF_{winter}$$

Energy savings calculations are performed on a per linear foot basis, resulting in energy saving values per linear foot. Factors for the amount of energy saved per linear foot have been developed (see Table 2) using methodology outlined in the *2021 ASHRAE Fundamentals Handbook Chapter 4: Heat Transfer*[3]. In this methodology, each thermal layer of the pipe-insulation assembly is treated as a thermally resistive element in a thermal circuit. Conductive, convective, and radiant heat transfer are considered on a per linear foot basis as follows:

$$R_{Cond} = \frac{r_o \cdot ln\frac{r_o}{r_i}}{CIR_S \cdot k}$$

$$R_{Conv} = \frac{1}{CIR_S \cdot h_{Conv}}$$

$$R_{Rad} = \frac{1}{CIR_S \cdot h_{Rad}}$$

$$R_{Bare},\ R_{Ins} = R_{Cond} + R_{Conv} + R_{Rad} \quad \text{(calculated for bare and insulation cases)}$$

The difference in total thermal resistance for the pipe assembly is used to calculate the change in heat gain per linear foot of pipe due to the added insulation using:

$$\frac{\Delta\dot{Q}}{ft} = (T_x - T_\infty) \times \left(\frac{1}{R_{Bare} - R_{Ins}}\right)$$

The total energy savings per linear foot is calculated by applying the chiller efficiency and EFLH:

$$\frac{\Delta kWh}{ft} = \frac{\Delta\dot{Q}}{ft} \cdot EFLH_{Chiller} \cdot \eta_{Chiller} \cdot \frac{1\ Ton}{12{,}000\ BTU/hr}$$

Definition of Terms

Table 3-81: Terms, Values, and References for Insulating Bare CHW Pipes

Term	Unit	Value	Sources
CIR_s is the exterior circumference of the assembly layer under consideration	ft	Un-insulated: 2.26 Insulated: 2.51	2,7
$ETDF_{summer}$, Energy to Demand Factor Summer $ETDF_{winter}$, Energy to Demand Factor Winter	$\frac{kW}{kWh}$	Default: Table 3-27	4
$EFLH_{Chiller}$ is the equivalent full-load hours of the chiller system that produces the working fluid	hrs	TRM Table 3-35	5
h_{Conv} is the total convective heat transfer coefficient	$\frac{BTU}{hr \cdot ft^2 \cdot °F}$	Calculated	-
h_{Rad} is the total radiative heat transfer coefficient	$\frac{BTU}{hr \cdot ft^2 \cdot °F}$	Calculated	-
k is the thermal conductivity of the assembly layer under consideration	$\frac{BTU}{hr \cdot ft \cdot °F}$	Pipe: 26.2 Insulation: 0.231	2
L, Total Length of Insulated Pipe	ft	EDC Data Gathering	
$\frac{\Delta\dot{Q}}{ft}$, the total heat transfer between the pipe assembly and the environment, per linear foot	$\frac{BTU}{hr \cdot ft}$	462	Calculated
R_{Bare} is the thermal resistance of the uninsulated pipe assembly	$\frac{hr \cdot °F \cdot ft}{BTU}$	Calculated	-
R_{Cond} is the thermal resistance of the pipe assembly due to conduction	$\frac{hr \cdot °F \cdot ft}{BTU}$	Calculated	-
R_{Conv} is the thermal resistance of the pipe assembly due to convection	$\frac{hr \cdot °F \cdot ft}{BTU}$	Calculated	-
R_{Ins} is the thermal resistance of the insulated pipe assembly	$\frac{hr \cdot °F \cdot ft}{BTU}$	Calculated	-
R_{Rad} is the thermal resistance of the pipe assembly due to radiation	$\frac{hr \cdot °F \cdot ft}{BTU}$	Calculated	-

r_o is the distance from the center of the pipe assembly to the exterior-most surface of the assembly layer under consideration	ft	Un-insulated: 0.359 Insulated: 0.443	2, 6
r_i is the distance from the center of the pipe assembly to the inner-most surface of the assembly layer under consideration	ft	0.333	2, 6
T_x is the temperature of the internal pipe fluid	°F	44	7
T_∞ is the ambient temperature on the pipe assembly exterior	°F	70	Professional Judgment
$\frac{\Delta kWh}{ft}$, is the annual energy savings per unit length of insulation	$\frac{kWh}{ft}$	Table 3-82	Calculated
ΔkWh is the annual electric energy savings	kWh	Calculated	-
ΔkW_{peak} is the annual electric demand peak savings	kW	Calculated	-
$\eta_{Chiller}$ is the chiller efficiency	$\frac{\text{kW}}{\text{Ton}}$	0.8	8

Default Savings

Table 3-82 shows default energy savings *per linear foot* for this measure. Calculation of annual energy savings may be performed by multiplying the values shown in Table 3-84 by the total insulation length ($\boldsymbol{L}$).

Table 3-82: Energy Loss Due to Bare Uninsulated CHW Pipe Compared to 1" Insulated CHW Pipe in Select Building Types

	Energy Loss Per Linear Foot [$\frac{kWh}{ft}$]								
Space/Building Type	**Allentown**	**Binghamton**	**Bradford**	**Erie**	**Harrisburg**	**Philadelphia**	**Pittsburgh**	**Scranton**	**Williamsport**
Education - College/University	41.44	18.87	23.44	31.20	35.39	43.04	32.44	33.37	32.33
Education - Other	17.13	8.25	10.25	13.63	17.49	21.74	15.25	15.54	16.50
Health - Hospital	77.26	42.41	52.54	70.05	69.26	86.97	64.06	72.22	63.09
Health - Other	28.60	15.74	19.49	25.98	26.44	34.77	25.52	26.62	24.13
Industrial Manufacturing	44.11	20.37	25.15	33.56	35.60	43.60	34.11	36.55	32.07
Lodging	87.04	53.43	62.92	83.87	76.84	92.45	77.42	86.10	73.90
Office	27.79	15.15	18.79	25.03	26.50	32.75	23.95	26.11	23.66
Retail	46.67	23.49	29.10	38.78	42.51	50.14	37.79	41.97	38.75

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, June 2007. Weblink
2) 2021 International Energy Conservation Code (IECC), Chapter 4 Commercial Energy Efficiency, Section C403 Building Mechanical Systems, Sub-section 12 Construction of HVAC System Elements, Part 3 Piping Insulation Table C403.12.3 Minimum Pipe Insulation Thickness. Weblink
3) American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) 2021 Fundamentals Handbook, Chapter 4 Heat Transfer
4) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink
5) EFLHs and CFs for Pennsylvania are calculated based on Nexant's eQuest modeling analysis 2014 and updated based on the latest CDD and HDD values from NOAA's 15-year annual climate Normals (2006–2020). Weblink
6) American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) 2021 Fundamentals Handbook, Chapter 22 Pipe Sizing
7) 2021 International Energy Conservation Code (IECC), Chapter 4 Commercial Energy Efficiency, Section C407 Total Building Performance, Sub-section 4 Calculation Procedure, Part 1 Building Specifications, Table C407.4.1(3) Specifications for the Standard Reference Design HVAC System Descriptions, Footnote e. Weblink
8) Demand Side Analytics for the Pennsylvania Public Utility Commission. (2024, March). Pennsylvania Act 129 2023 Non-Residential Baseline Study (Page 95 and Table 25). Weblink

3.3. Motors and VFDs

3.3.1. Premium Efficiency Motors

Target Sector	Commercial and Industrial Establishments
Measure Unit	Motor
Measure Life	15 years [Source 1]
Measure Vintage	Replace on Burnout, New Construction, or Early Replacement

Eligibility

For constant speed and uniformly loaded motors, the prescriptive measurement and verification protocols described below apply to the replacement of old motors with new energy efficient motors of the same rated horsepower and for New Construction. Replacements where the old motor and new motor have different horsepower ratings are considered custom measures. Motors with variable speeds, variable loading, or industrial-specific applications are also considered custom measures.

Note that the Energy to Demand Factors (ETDFs) and Run Hours of Use (RHRS) for motors specified below do not consider systems with multiple motors serving the same load, such as duplex motor sets with a lead-lag setup. Under these circumstances, a custom measure protocol is required.

Algorithms

The energy and demand savings for this measure depend on the size and efficiency of the efficient motor, calculated according to the following algorithms. There are no default savings for this measure.

$$\Delta kWh = kWh_{base} - kWh_{ee}$$

$$kWh_{base} = 0.746 \times HP \times \frac{LF}{\eta_{base}} \times RHRS$$

$$kWh_{ee} = 0.746 \times HP \times \frac{LF}{\eta_{ee}} \times RHRS$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-83: Terms, Values, and References for Premium Efficiency Motors

Term	Unit	Value	Source
HP, Rated horsepower of the baseline and energy efficient motor	*HP*	Nameplate	EDC Data Gathering
0.746, Conversion factor for HP to kWh	$\frac{kWh}{HP}$	0.746	Conversion factor
$RHRS$, Annual run hours of the motor	$\frac{Hours}{Year}$	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-87 to Table 3-91	2
LF, Load Factor. Ratio between the actual load and the rated load. Variable loaded motors should use custom measure protocols.	*None*	Based on spot metering and nameplate	EDC Data Gathering
		Default, fans: 0.76 Default, pumps: 0.79	3
η_{base}, Efficiency of the baseline motor. If a new motor was purchased as an alternative to rewinding an old motor, the nameplate efficiency of the old motor may be used as the baseline.	*None*	Early Replacement: Nameplate	EDC Data Gathering
		New Construction or Replace on Burnout: Default comparable standard motor. See Table 3-84 through Table 3-87	4
η_{ee}, Efficiency of the energy-efficient motor	*None*	Nameplate	EDC Data Gathering

<table>
<tr>
<td rowspan="2">ETDF$ETDF_{summer}$, Summer Energy to Demand Factor</td>
<td rowspan="2">$\frac{kW}{kWh}$</td>
<td>See Table 3-92: Default ETDFs for Fan and Pump Motors in Commercial Buildings</td>
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<table>
<tr><th>Facility Type</th><th>Param</th></tr>
<tr><td rowspan="2">Education – College / University</td><td>ETDF me</td></tr>
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<tr><td rowspan="2">Education – Other</td><td>ETDF me</td></tr>
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<tr><td rowspan="2">Grocery</td><td>ETDF me</td></tr>
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<tr><td rowspan="2">Health – Hospital</td><td>ETDF me</td></tr>
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<tr><td rowspan="2">Office</td><td>ETDF me</td></tr>
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Term	Unit	Value		Source
		Restaurant	*ETDF me*	
			ETDFv r	
		Retail	*ETDF me*	
			ETDFv r	
		Warehouse – Other	*ETDF me*	
			ETDFv r	
		Warehouse – Refrigerated	*ETDF me*	
			ETDFv r	

<table>
<tr>
<td>$ETDF_{winter}$, Winter Energy to Demand Factor</td>
<td>$\frac{kW}{kWh}$</td>
<td>See Table 3-92: Default ETDFs for Fan and Pump Motors in Commercial Buildings
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<tr><td rowspan="2">Education – Other</td><td>ETDF me</td></tr>
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<tr><td rowspan="2">Office</td><td>ETDF me</td></tr>
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Term	Unit	Value		Source
		Restaurant	*ETDF me*	
			ETDFv r	
		Retail	*ETDF me*	
			ETDFv r	
		Warehouse – Other	*ETDF me*	
			ETDFv r	
		Warehouse – Refrigerated	*ETDF me*	
			ETDFv r	

Table 3-84: Pre-July 2027 Baseline Efficiencies for NEMA Design A and B, IEC Design N, NE, NEY, or NY Motors

Motor HP / kW Equivalent	Motor Nominal Full-Load Efficiencies (%)							
	2 Pole (3600 RPM)		4 pole (1800 RPM)		6 Pole (1200 RPM)		8 Pole (900 RPM)	
	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
1 / 0.75	77.0	77.0	85.5	85.5	82.5	82.5	75.5	75.5
1.5 / 1.1	84.0	84.0	86.5	86.5	87.5	86.5	78.5	77.0
2 / 1.5	85.5	85.5	86.5	86.5	88.5	87.5	84.0	86.5
3 / 2.2	86.5	85.5	89.5	89.5	89.5	88.5	85.5	87.5
5 / 3.7	88.5	86.5	89.5	89.5	89.5	89.5	86.5	88.5
7.5 / 5.5	89.5	88.5	91.7	91.0	91.0	90.2	86.5	89.5
10 / 7.5	90.2	89.5	91.7	91.7	91.0	91.7	89.5	90.2
15 / 11	91.0	90.2	92.4	93.0	91.7	91.7	89.5	90.2
20 / 15	91.0	91.0	93.0	93.0	91.7	92.4	90.2	91.0
25 / 18.5	91.7	91.7	93.6	93.6	93.0	93.0	90.2	91.0
30 / 22	91.7	91.7	93.6	94.1	93.0	93.6	91.7	91.7
40 / 30	92.4	92.4	94.1	94.1	94.1	94.1	91.7	91.7
50 / 37	93.0	93.0	94.5	94.5	94.1	94.1	92.4	92.4
60 / 45	93.6	93.6	95.0	95.0	94.5	94.5	92.4	93.0
75 / 55	93.6	93.6	95.4	95.0	94.5	94.5	93.6	94.1
100 / 75	94.1	93.6	95.4	95.4	95.0	95.0	93.6	94.1
125 / 90	95.0	94.1	95.4	95.4	95.0	95.0	94.1	94.1
150 / 110	95.0	94.1	95.8	95.8	95.8	95.4	94.1	94.1
200 / 150	95.4	95.0	96.2	95.8	95.8	95.4	94.5	94.1
250 / 186	95.8	95.0	96.2	95.8	95.8	95.8	95.0	95.0
300 / 224	95.8	95.4	96.2	95.8	95.8	95.8	N/A	N/A
350 / 261	95.8	95.4	96.2	95.8	95.8	95.8	N/A	N/A
400 / 298	95.8	95.8	96.2	95.8	N/A	N/A	N/A	N/A
450 / 336	95.8	96.2	96.2	96.2	N/A	N/A	N/A	N/A
500 / 373	95.8	96.2	96.2	96.2	N/A	N/A	N/A	N/A

Starting on July 1, 2027, efficiency ratings for motor horsepower between 100 and 250 hp change to the values listed in Table 3-85. Baseline efficiencies for all other motors sizes remain aligned with Table 3-84.

Table 3-85: Post June 2027 Baseline Efficiencies for NEMA Design A and B, IEC Design N, NE, NEY, or NY Motors

Motor HP / kW Equivalent	Motor Nominal Full-Load Efficiencies (%)							
	2 Pole (3600 RPM)		4 pole (1800 RPM)		6 Pole (1200 RPM)		8 Pole (900 RPM)	
	Enclosed	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open
100 / 75	95.0	94.5	96.2	96.2	95.8	95.8	94.5	95.0
125 / 90	95.4	94.5	96.2	96.2	95.8	95.8	95.0	95.0
150 / 110	95.4	94.5	96.2	96.2	96.2	95.8	95.0	95.0
200 / 150	95.8	95.4	96.5	96.2	96.2	95.8	95.4	95.0
250 / 186	96.2	95.4	96.5	96.2	96.2	96.2	95.4	95.4

Table 3-86: Baseline Motor Efficiencies for NEMA Design C Motors

Motor HP / kW Equivalent	Motor Nominal Full-Load Efficiencies (%)					
	4 Pole (1800 RPM)		6 Pole (1200 RPM)		8 Pole (900 RPM)	
	Enclosed	Open	Enclosed	Open	Enclosed	Open
1 / 0.75	85.5	85.5	82.5	82.5	75.5	75.5
1.5 / 1.1	86.5	86.5	87.5	86.5	78.5	77.0
2 / 1.5	86.5	86.5	88.5	87.5	84.0	86.5
3 / 2.2	89.5	89.5	89.5	88.5	85.5	87.5
5 / 3.7	89.5	89.5	89.5	89.5	86.5	88.5
7.5 / 5.5	91.7	91.0	91.0	90.2	86.5	89.5
10 / 7.5	91.7	91.7	91.0	91.7	89.5	90.2
15 / 11	92.4	93.0	91.7	91.7	89.5	90.2
20 / 15	93.0	93.0	91.7	92.4	90.2	91.0
25 / 18.5	93.6	93.6	93.0	93.0	90.2	91.0
30 / 22	93.6	94.1	93.0	93.6	91.7	91.7
40 / 30	94.1	94.1	94.1	94.1	91.7	91.7
50 / 37	94.5	94.5	94.1	94.1	92.4	92.4

Motor HP / kW Equivalent	Motor Nominal Full-Load Efficiencies (%)					
	4 Pole (1800 RPM)		6 Pole (1200 RPM)		8 Pole (900 RPM)	
	Enclosed	Open	Enclosed	Open	Enclosed	Open
60 / 45	95.0	95.0	94.5	94.5	92.4	93.0
75 / 55	95.4	95.0	94.5	94.5	93.6	94.1
100 / 75	95.4	95.4	95.0	95.0	93.6	94.1
125 / 90	95.4	95.4	95.0	95.0	94.1	94.1
150 / 110	95.8	95.8	95.8	95.4	94.1	94.1
200 / 150	96.2	95.8	95.8	95.4	94.5	94.1

Table 3-87: Default RHRS for Supply Fan Motors in Commercial Buildings

Facility Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsburg
Education – College / University	5,798	6,028	5,419	5,720	4,955	5,756	5,646	5,513	5,818
Education – Other	4,203	4,563	4,174	4,260	3,647	4,230	4,167	4,212	4,313
Grocery	6,437	6,735	6,024	6,278	5,659	6,435	6,340	6,309	6,612
Health – Hospital	8,406	8,722	7,749	8,162	7,407	8,452	8,268	8,219	8,631
Health – Other	8,406	8,722	7,749	8,162	7,407	8,452	8,268	8,219	8,631
Industrial Manufacturing	3,676	3,964	3,609	3,705	3,187	3,703	3,652	3,661	3,773
Institutional / Public Service	4,979	5,201	4,643	4,861	4,373	5,004	4,909	4,885	5,108
Lodging	8,406	8,722	7,749	8,162	7,407	8,452	8,268	8,219	8,631
Office	4,026	4,454	4,157	4,138	3,456	3,920	4,002	3,967	4,078
Restaurant	6,028	2,668	5,739	5,930	5,287	6,007	5,946	5,925	6,194
Retail	4,930	5,166	4,630	4,806	4,319	4,913	4,857	4,831	5,059
Warehouse – Other	4,834	5,167	4,652	4,865	4,211	4,987	4,823	4,867	4,954
Warehouse – Refrigerated	3,878	4,024	3,575	3,765	3,417	3,899	3,814	3,791	3,982

Table 3-88: Default RHRS for Chilled Water Pump (CHWP) Motors in Commercial Buildings

Facility Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsburg
Education – College / University	5,450	3,402	4,303	5,061	4,503	5,259	4,621	5,321	4,414
Education – Other	3,701	1,831	2,267	3,023	3,030	4,276	3,158	3,211	2,933
Health – Hospital	7,600	4,753	5,792	7,102	6,346	7,425	6,600	7,320	6,416
Health – Other	5,293	3,062	3,603	4,804	4,555	5,533	4,602	5,157	4,353
Industrial Manufacturing	2,360	1,293	1,510	2,013	1,934	2,307	1,895	2,166	1,862
Lodging	7,949	4,992	6,177	7,225	6,710	7,516	6,709	7,860	6,585
Office	2,433	1,388	1,653	2,203	2,002	2,484	2,052	2,277	1,951
Retail	4,022	2,392	2,797	3,688	3,424	3,935	3,298	3,802	3,304

Table 3-89: Default RHRS for Cooling Tower Fan (CTF) Motors in Commercial Buildings

Facility Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsburg
Education – College / University	5,448	3,401	4,303	5,061	4,503	5,257	4,619	5,320	4,413
Education – Other	3,729	1,832	2,271	3,027	3,046	4,291	3,168	3,215	2,969
Health – Hospital	7,598	4,750	5,789	7,099	6,343	7,422	6,597	7,316	6,414
Health – Other	5,296	3,062	3,604	4,805	4,558	5,535	4,604	5,158	4,354
Industrial Manufacturing	2,360	1,293	1,510	2,013	1,934	2,307	1,895	2,166	1,862
Lodging	7,948	4,989	6,174	7,224	6,708	7,514	6,706	7,856	6,581
Office	2,433	1,388	1,653	2,203	2,002	2,484	2,052	2,277	1,951
Retail	4,022	2,392	2,797	3,688	3,424	3,936	3,298	3,803	3,304

Table 3-90: Default RHRS for Heating Hot Water Pump (HHWP) Motors in Commercial Buildings

Facility Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsburg
Education – College / University	4,548	5,271	5,900	5,036	4,250	4,014	4,572	4,638	4,487
Education – Other	3,651	4,251	4,722	4,080	3,492	3,341	3,705	3,830	3,658
Health – Hospital	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760
Health – Other	5,934	6,627	7,170	6,280	5,823	5,477	5,991	6,223	6,045
Industrial Manufacturing	1,258	1,684	1,944	1,555	1,184	1,028	1,287	1,393	1,277
Lodging	6,469	7,072	7,587	6,829	6,155	6,077	6,574	6,628	6,387
Office	3,214	3,876	4,446	3,611	3,014	2,690	3,246	3,336	3,169
Retail	2,676	3,183	3,568	2,960	2,561	2,398	2,908	2,841	2,660

Table 3-91: Default RHRS for Condenser Water Pump Motors in Commercial Buildings

Facility Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsburg
Education – College / University	4,797	2,909	3,428	4,258	3,998	4,917	4,424	4,865	3,977
Education – Other	3,329	1,716	2,125	2,834	2,818	4,082	2,843	3,008	2,762
Health – Hospital	5,372	3,511	4,577	5,140	4,093	5,085	4,830	5,161	4,184
Health – Other	4,998	3,069	3,593	4,718	4,135	5,251	4,214	5,125	4,243
Industrial Manufacturing	2,360	1,292	1,507	2,009	1,928	2,305	1,890	2,166	1,860
Lodging	7,540	4,545	5,475	6,625	6,182	7,181	6,182	7,441	6,074
Office	2,422	1,375	1,636	2,181	1,989	2,473	2,041	2,267	1,940
Retail	3,929	2,357	2,761	3,636	3,358	3,886	3,253	3,756	3,246

Table 3-92: Default ETDFs for Fan and Pump Motors in Commercial Buildings

Facility Type	Parameter	Supply Fan Motors	Chilled Water Pump (CHWP) Motors	Cooling Tower Fan (CTF) Motors	Heating Hot Water Pump (HHWP) Motors	Condenser Water Pump Motors
Education – College / University	$ETDF_{summer}$	0.0001630	0.0005511	0.0004543	0.0000789	0.0005511
	$ETDF_{winter}$	0.0001443	0.0000076	0.0000133	0.0002103	0.0000076
Education – Other	$ETDF_{summer}$	0.0001630	0.0005511	0.0004543	0.0000789	0.0005511
	$ETDF_{winter}$	0.0001443	0.0000076	0.0000133	0.0002103	0.0000076
Grocery	$ETDF_{summer}$	0.0001853	0.0000000	0.0000000	0.0000000	0.0000000
	$ETDF_{winter}$	0.0001143	0.0000000	0.0000000	0.0000000	0.0000000
Health – Hospital	$ETDF_{summer}$	0.0001222	0.0003023	0.0002982	0.0001047	0.0003023
	$ETDF_{winter}$	0.0001036	0.0000115	0.0000104	0.0001320	0.0000115
Health – Other	$ETDF_{summer}$	0.0001509	0.0003904	0.0003793	0.0001393	0.0003904
	$ETDF_{winter}$	0.0001266	0.0000177	0.0000118	0.0001220	0.0000177
Industrial Manufacturing	$ETDF_{summer}$	0.0001950	0.0006284	0.0006211	0.0000000	0.0006284
	$ETDF_{winter}$	0.0001268	0.0000040	0.0000002	0.0000000	0.0000040
Institutional / Public Service	$ETDF_{summer}$	0.0001674	0.0000000	0.0000000	0.0000000	0.0000000
	$ETDF_{winter}$	0.0001136	0.0000000	0.0000000	0.0000000	0.0000000
Lodging	$ETDF_{summer}$	0.0001845	0.0002853	0.0002514	0.0000862	0.0002853
	$ETDF_{winter}$	0.0001160	0.0000465	0.0000052	0.0001165	0.0000465
Office	$ETDF_{summer}$	0.0001769	0.0005857	0.0005877	0.0001947	0.0005857
	$ETDF_{winter}$	0.0001345	0.0000050	0.0000034	0.0001874	0.0000050
Restaurant	$ETDF_{summer}$	0.0001565	0.0000000	0.0000000	0.0000000	0.0000000
	$ETDF_{winter}$	0.0001305	0.0000000	0.0000000	0.0000000	0.0000000
Retail	$ETDF_{summer}$	0.0001770	0.0004720	0.0002762	0.0001031	0.0004720
	$ETDF_{winter}$	0.0001180	0.0000119	0.0000130	0.0000945	0.0000119
Warehouse – Other	$ETDF_{summer}$	0.0001950	0.0000000	0.0000000	0.0000000	0.0000000
	$ETDF_{winter}$	0.0001268	0.0000000	0.0000000	0.0000000	0.0000000

Warehouse – Refrigerated	$ETDF_{summer}$	0.0001950	0.0000000	0.0000000	0.0000000	0.0000000
	$ETDF_{winter}$	0.0001268	0.0000000	0.0000000	0.0000000	0.0000000

Evaluation Protocols

Default TRM values can be used by the EDC but will be subject to metering and adjustment by evaluators or SWE. Motor projects achieving expected kWh savings of 250,000 kWh or higher must be metered to calculate ex ante and/or ex post savings. EDCs are allowed to use alternative methods for obtaining customer-specific data when customer processes do not support metering and are required to provide supporting documentation to the SWE for review if there are any such exceptions. Modeling is an acceptable substitute to metering and panel data if modeling is conducted using building- and equipment-specific information at the site and the facility consumption is calibrated using 12 months of billing data (pre-retrofit). Metering is not mandatory where the motors in question are constant speed and hours can be easily verified through a building automation system schedule that clearly shows motor run time.

Sources

1) California Electronic Technical Reference Manual. “CPUC Support Tables”. “Effective Useful Life and Remaining Useful Life”. Effective Useful Life ID: HiEff Motors. Accessed Nov 2023. Weblink

2) Pennsylvania Public Utility Commission. (2014, September). 2015 TRM Annual Update Tentative Order. Docket No. M-2012-2313373. Motor run hours are based on Act 129 Phase II SWE energy models, updated to reflect Ph V cooling and heating EFLH. Weblink

3) Cascade Energy (2012, November). Proposed Standard Savings Estimation Protocol for Ultra-Premium Efficiency Motors. Appendix C: NW Industrial Motors Database Analysis Table 6: Load Factor by nameplate hp and end use load factor for air compressors and average motor efficiency. Average efficiency for NEMA premium efficiency 1800 RPM ODP motors with 75% and 100% load factors from 1HP to 200HP. Weblink

4) “Energy Conservation Program: Energy Conservation Standards for Commercial and Industrial Electric Motors; Final Rule,” Vol. 79 10 C.F.R § 431 Table I.2 and Table I.3 Weblink

5) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.3.2. Variable Frequency Drive (VFD) Improvements

Target Sector	Commercial and Industrial Establishments
Measure Unit	Variable Frequency Drive
Measure Life	15 years Source 1
Measure Vintage	New Construction or Retrofit

Eligibility

This measure defines the methods for determining the annual electric energy and peak demand savings from installation of Variable Frequency Drives (VFDs) on non-residential cooling and heating equipment including supply and return fans, cooling tower fans, chilled water pumps, and heating water pumps. The baseline condition is a motor without a VFD control. The efficient condition is a motor with a VFD control. This measure is also available for mid-stream delivery of equipment sold to trade allies and customers through commercial channels such as HVAC distributors, supply houses, and direct relationships with manufacturers provided they meet the maximum motor size requirement in Table 3-97.

Installations of new equipment with VFDs which are required by energy codes adopted by the State of Pennsylvania are not eligible for incentives.

Algorithms

The energy and demand savings associated with this measure depend on the size of the affected motor and the motor's load profile. Savings are calculated using the following algorithms and there are no default savings for this measure.

$$\Delta kWh = kWh_{base} - kWh_{ee}$$

$$kWh_{base} = 0.746 \times HP \times \frac{LF}{\eta_{motor}} \times RHRS \times \sum_{0\%}^{100\%} (\%FF \times PLR_{base})$$

$$kWh_{ee} = 0.746 \times HP \times \frac{LF}{\eta_{motor}} \times RHRS \times \sum_{0\%}^{100\%} (\%FF \times PLR_{ee})$$

$$kW_{summer\ peak} = 0.746 \times HP \times \frac{LF}{\eta_{motor}} \times \left(PLR_{summer\ peak,base} - PLR_{summer\ peak,ee}\right)$$

$$kW_{winter\ peak} = 0.746 \times HP \times \frac{LF}{\eta_{motor}} \times \left(PLR_{winter\ peak,base} - PLR_{winter\ peak,ee}\right)$$

DEFINITION OF TERMS

Table 3-93: Terms, Values, and References for VFDs

Term	Unit	Values	Source
HP, Rated horsepower of the motor	*HP*	Nameplate	EDC Data Gathering
0.746, Conversion factor for HP to kWh	$\frac{kWh}{HP}$	0.746	Conversion factor
$RHRS$, Annual run hours of the baseline motor	$\frac{Hours}{Year}$	Based on logging, panel data, or modeling	EDC Data Gathering
		Default: Table 3-87 to Table 3-91	2
LF, Load Factor. Ratio between the actual load and the rated load.	*None*	Based on spot metering and nameplate	EDC Data Gathering
		Default for fans: 0.76 Default for pumps: 0.79	3
η_{motor}, Motor efficiency at the full-rated load. For VFD installations, this can be either an energy efficient motor or standard efficiency motor.	*Percent*	Nameplate	EDC Data Gathering
$\%FF$, Percentage of runtime spent within a given flow fraction range	*Percent*	Based on logging, panel data, or modeling	EDC Data Gathering
		Default: Table 3-94	4
PLR_{base}, Part load ratio for a given flow fraction range based on the baseline flow control type	*Percent*	Default: Table 3-95 to Table 3-96	4
PLR_{ee}, Part load ratio for a given flow fraction range with installed VFD	*Percent*	Default: Table 3-95 to Table 3-96	4
$PLR_{summer\ peak,base}$, Part load ratio for the average flow fraction during the peak period on the baseline flow control type during summer peak hours	*Percent*	Based on logging, panel data, or modeling	EDC Data Gathering
		Fan and Pump Default: $PLR_{base,90\%}$	5
$PLR_{summer\ peak,ee}$, Part load ratio for the average flow fraction during the peak period on the efficient flow control type during summer peak hours	*Percent*	Based on logging, panel data, or modeling	EDC Data Gathering
		Fan and Pump Default: $PLR_{ee,90\%}$	5
		Based on logging, panel	EDC Data

$PLR_{winter\ peak,base}$, Part load ratio for the average flow fraction during the peak period on the baseline flow control type during winter peak hours	*Percent*	data, or modeling	Gathering
		Default: $PLR_{base,70\%}$	6
$PLR_{winter\ peak,ee}$, Part load ratio for the average flow fraction during the peak period on the efficient flow control type during winter peak hours	*Percent*	Based on logging, panel data, or modeling	EDC Data Gathering
		Fan Default: $PLR_{base,70\%}$	5

Table 3-94: Default Load Profiles for HVAC Fans and Pumps

Equipment Type	Flow Fraction (%)										
	0	10	20	30	40	50	60	70	80	90	100
HVAC Fan	0%	0%	1%	5%	16%	22%	25%	19%	9%	3%	0%
HVAC Pump	0%	0%	0%	5%	10%	20%	30%	20%	10%	5%	0%

Table 3-95: Supply/Return and Cooling Tower Fan Power Part Load Ratios

Control Type	Flow Fraction (%)										
	0	10	20	30	40	50	60	70	80	90	100
Constant Volume	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Two-Speed	0.50	0.50	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00
Air Foil/Backward Incline	0.53	0.53	0.53	0.57	0.64	0.72	0.80	0.89	0.96	1.02	1.05
Air Foil/Backward Incline with Inlet Guide Vanes	0.47	0.53	0.56	0.57	0.59	0.60	0.62	0.67	0.74	0.85	1.00
Outlet Damper Forward Curved	0.20	0.22	0.26	0.30	0.37	0.45	0.54	0.65	0.77	0.91	1.06
Forward Curved with Inlet Guide Vanes	0.20	0.21	0.22	0.23	0.26	0.31	0.39	0.49	0.63	0.81	1.04
Variable Frequency Drive	0.05	0.05	0.05	0.08	0.13	0.20	0.30	0.43	0.60	0.80	1.03

Table 3-96: HVAC Pump Power Part Load Ratios

Control Type	Flow Fraction (%)										
	0	10	20	30	40	50	60	70	80	90	100
Constant Volume	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Throttle Valve	0.55	0.61	0.67	0.73	0.78	0.82	0.87	0.90	0.94	0.97	1.00
Variable Frequency Drive	0.27	0.19	0.14	0.13	0.15	0.21	0.30	0.43	0.60	0.79	1.03

Table 3-97: Maximum Motor Size by Midstream End-use

Application	Maximum Motor Size (HP)
HVAC Supply Fan	200
HVAC Return Fan	200
Cooling Tower Fan	150
Chilled Water Pump	75
Condenser Water Pump	100
Heating Hot Water Pump	65

Evaluation Protocol

Methods for Determining Baseline Conditions

The following are acceptable methods for determining baseline motor control conditions when verification by direct inspection is not possible as may occur in a rebate program where customers submit an application and equipment receipts only after installing the variable frequency drive(s), or for a retroactive project as allowed by Act 129. In order of preference:

- Examination of disengaged baseline motor control equipment or equipment that has been removed but is still on site waiting to be recycled or otherwise disposed of
- Interviews with and written statements from customers, facility managers, building engineers or others with firsthand knowledge about operating practices at the affected site(s) identifying the baseline motor control strategy
- Interviews with and written statements from the project's mechanical contractor identifying the baseline motor control strategy

Appendix D: Motor and VFD Calculator

Appendix D: Motor and VFD Calculator was developed to automate the calculation of energy and demand impacts for retrofit VFD projects, based on a series of entries by the user defining key characteristics of the retrofit project. The "General Information" sheet is provided for the user to identify facility-specific details of the project that have an effect on the calculation of gross savings. Facility-specific details include contact information, electric utility, and facility type. The "VFD Inventory" sheet is the main worksheet that calculates energy savings and peak demand reduction for the user-specified motors and motor control improvements. This form follows the algorithms presented above and facilitates the calculation of gross savings for implementation and evaluation purposes. Each line item on this tab represents a single type of motor.

Custom Load Profiles

Default fan and pump load profiles as defined in
Table 3-94 are included in the calculator, but users may also customize the load profile to reflect site specific conditions. Annual motor run hours may also be customized. For all projects, annual hours are subject to adjustment by EDC evaluators or SWE.

Metering

VFD projects achieving expected kWh savings of 250,000 kWh or higher must be metered to calculate ex ante and/or ex post savings. Metering should be conducted using standalone power logging equipment and/or trend data from a BMS or other control system. Metering completed by the implementation contractor may be leveraged by the evaluation contractor, subject to a reasonableness review. Additional descriptions of the metering requirements for projects exceeding the 250,000 kWh savings threshold are described in Section 1.3.3.

Sources

1) California Electronic Technical Reference Manual. “CPUC Support Tables”. “Effective Useful Life and Remaining Useful Life”. Effective Useful Life ID: HiEff Motors. Accessed Nov 2023. Weblink
2) Pennsylvania Public Utility Commission. (2014, September). 2015 TRM Annual Update Tentative Order. Docket No. M-2012-2313373. Motor run hours are based on Act 129 Phase II SWE energy models, updated to reflect Ph V cooling and heating EFLH. Weblink
3) Cascade Energy (2012, November). Proposed Standard Savings Estimation Protocol for Ultra-Premium Efficiency Motors. Appendix C: NW Industrial Motors Database Analysis Table 6: Load Factor by nameplate hp and end use load factor for air compressors and average motor efficiency. Average efficiency for NEMA premium efficiency 1800 RPM ODP motors with 75% and 100% load factors from 1HP to 200HP. Weblink
4) Savings Estimation Technical Reference Manual for the California Municipal Utilities Association. (2016). “8.1 Pump and Fan Variable Frequency Drive Control”. 8.1.1 Performance Curve Charts. Weblink
5) Illinois Statewide Technical Reference Manual for Energy Efficiency Vol.2 Commercial and Industrial Measures (2024, Version 12.0). "4.4.26 Variable Speed Drives for HVAC Supply and Return Fans”. Weblink
6) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Calculated from Pennsylvania commercial fan and pump consumption load shapes. Weblink

3.3.3. ECM Circulating Fan

Target Sector	Commercial and Industrial Establishments
Measure Unit	ECM Circulating Fan
Measure Life	5 years Source 1
Measure Vintage	Early Replacement

This protocol covers energy and demand savings associated with retrofit of existing shaded-pole (SP) or permanent-split capacitor (PSC) circulator fan motors in an air handling unit with an electronically commutated motor (ECM).

Eligibility

This measure is targeted to non-residential customers whose air handling equipment currently uses an SP or PSC fan motor rather than an ECM. This measure applies only to circulating fan motors of 1 HP or less. Motors larger than 1 HP are governed by NEMA standards and would see little to no efficiency benefit by adding an ECM. Additionally, new construction and replace-on-burnout vintages are not eligible to participate, as ECM technology is required in new equipment by federal efficiency standards. Source 2

The targeted fan can supply heating, cooling, ventilation, or any combination of these. A default savings option is offered if the motor input wattage is not known. However, these parameters should be collected by EDCs for greatest accuracy. Acceptable baseline conditions are an existing circulating fan with a SP or PSC fan motor 1 HP or less. Efficient conditions are a circulating fan with an ECM.

Algorithms

The energy and demand savings associated with this measure depend on the wattage of the baseline and efficient motor. Unknown motor wattages can be estimated using the motor efficiency values listed in Table 3-100

Savings are calculated using the following algorithms. There are no default savings for this measure.

$$\Delta kWh = \Delta kWh_{heat} + \Delta kWh_{cool} + \Delta kWh_{vent}$$

$$\Delta kW_{summer\ peak} = \Delta kW_{cool} + \Delta kW_{vent}$$

$$\Delta kW_{winter\ peak} = \Delta kW_{heat}$$

Heating

$$\Delta kWh_{heat} = \frac{(WATTS_{base} - WATTS_{ee})}{1{,}000} \times LF \times EFLH_{heat}$$

$$\Delta kW_{heat} = \Delta kWh_{heat} \times ETDF_{winter}$$

Cooling

Interactive factors should be applied for motors that supply cooling to account for the reduced cooling load associated with the lower wattage ECM motor. Interactive factors do not apply if the motor is located outside of the conditioned air pathway.

$$\Delta kWh_{cool} = \frac{(WATTS_{base} - WATTS_{ee})}{1{,}000} \times LF \times EFLH_{cool} \times (1 + IF_{kWh})$$

$$\Delta kW_{cool} = \Delta kWh_{cool} \times ETDF_{summer}$$

Ventilation

Fans that provide ventilation, such as introduction of outdoor air, may operate continuously or may follow a building occupancy schedule, regardless of heating or cooling requirements. Default hours and coincidence factor are not provided for this type of fan usage. EDCs must collect fan hours of operation to calculate savings for fans providing only ventilation. If a fan provides ventilation as well as either heating or cooling, then any heating or cooling hours should be removed from the calculation of operating hours for ventilation only.

$$\Delta kWh_{vent} = \frac{(WATTS_{base} - WATTS_{ee})}{1{,}000} \times LF \times HOURS_{vent}$$

$$\Delta kW_{vent} = \Delta kWh_{vent} \times ETDF_{summer}$$

Motor Wattage

Motor wattage may be estimated if unknown using this algorithm.

$$WATTS = \frac{0.746 \times HP}{\eta_{motor}}$$

Definition of Terms

Table 3-98: Terms, Values, and References for ECM Circulating Fans

Term	Unit	Values	Source
$WATTS_{base}$, Baseline watts	*W*	Nameplate data	EDC Data Gathering
$WATTS_{ee}$, Energy efficient watts	*W*	Nameplate data	EDC Data Gathering
LF, Load factor	*None*	Default: 0.9	3
$EFLH_{heat}$, Equivalent Full-Load Hours for heating only	$\frac{Hours}{year}$	Based on logging, panel data, or modeling	EDC Data Gathering
		Default: Table 3-28	4
$EFLH_{cool}$, Equivalent Full-Load Hours for cooling only	$\frac{Hours}{year}$	Based on logging, panel data, or modeling	EDC Data Gathering
		Default: Table 3-25	4
$HOURS_{vent}$, Hours for ventilation only, separate from cooling or heating operation	$\frac{Hours}{year}$	Based on logging, panel data, or modeling	EDC Data Gathering
		Default: 0	n/a
$ETDF_{summer}$, Summer Energy to Demand Factor	$\frac{kW}{kWh}$	See Table 3-80	5
$ETDF_{winter}$, Winter Energy to Demand Factor	$\frac{kW}{kWh}$	See Table 3-80	5
IF_{kWh}, Energy Interactive Factor	*None*	Default: 26.2%	6
HP, Rated horsepower of the motor	*HP*	Nameplate	EDC Data Gathering
η_{motor}, Default motor efficiency for motor type.	*Percent*	Default: Table 3-100	8
0.746, Conversion factor for HP to kWh	$\frac{kWh}{HP}$	0.746	Conversion factor

Table 3-99: Default ETDF by Season and End-Use

Building Type	$ETDF_{summer}$	$ETDF_{winter}$
Education - College / University	0.0001630	0.0001443
Education - Other	0.0001630	0.0001443
Grocery	0.0001633	0.0001241
Health - Hospital	0.0001222	0.0001036
Health - Other	0.0001509	0.0001266
Industrial Manufacturing	0.0001950	0.0001268
Institutional / Public Service	0.0001674	0.0001136
Lodging	0.0001847	0.0001175
Office	0.0001665	0.0001242
Restaurant	0.0001566	0.0001309
Retail	0.0001633	0.0001241
Warehouse - Other	0.0001950	0.0001268
Warehouse - Refrigerated	0.0001950	0.0001268

Table 3-100: Default Motor Efficiency by Motor Type

Motor Type	Assumed Efficiency
SP	0.40
PSC	0.50
ECM	0.70

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. “CPUC Support Tables”. “Effective Useful Life and Remaining Useful Life”. Effective Useful Life ID: HiEff Motors. Accessed Nov 2023. Weblink

2) Federal standards: U.S. Department of Energy, Federal Register. 164th ed. Vol. 79 C.F.R. §. Weblink

3) New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs – Residential Multi-Family, and Commercial/Industrial Measures. (2024, Version 11) page 697 Electronically Commutated (EC) Motor – HVAC Blower Fan, Summary of Variables and Data Sources table. Weblink

4) Pennsylvania Public Utility Commission. (2014, September11). Public Meeting 2015 TRM Annual Update Tentative Order Docket No. M-2012-2313373. Weblink

6) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

5) Assuming that the waste heat is within the conditioned air stream, then the energy associated with removing the waste heat during the year is approximated as the inverse of the COP, or 3.412/SEER = 0.30 if one uses 13 as a default value for cooling system SEER.

6) United States Department of Energy Building Technologies Office. (2014). Energy Savings Potential and Opportunities for High-Efficiency Electric Motors in Residential and Commercial Equipment. page 5 Table 2.1 Summary of Single-Phase AC Induction Motor Characteristics. Weblink

7) United States Department of Energy Building Technologies Office. (2014). Energy Savings Potential and Opportunities for High-Efficiency Electric Motors in Residential and Commercial Equipment. Section 2.4.3 Electronically Commutated Motors (ECMs) with Integrated Controls page 16. Weblink

3.3.4. VSD on Kitchen Exhaust Fan

Target Sector	Commercial and Industrial Establishments
Measure Unit	VSD on Kitchen Exhaust Fan
Measure Life	15 years Source 1
Measure Vintage	New Construction or Retrofit

Installation of variable speed drives (VSD) on commercial kitchen exhaust fans allows the variation of ventilation based on cooking load and/or time of day.

Eligibility

This measure is targeted to non-residential customers whose kitchen exhaust fans are equipped with a VSD that varies the exhaust rate of kitchen ventilation based on the energy and effluent output from the cooking appliances (i.e., the more heat and smoke/vapors generated, the more ventilation needed). This involves installing a temperature sensor in the hood exhaust collar and/or an optic sensor on the end of the hood that sense cooking conditions which allows the system to automatically vary the rate of exhaust to what is needed by adjusting the fan speed.

The baseline equipment is kitchen ventilation that has a constant speed ventilation motor.

The energy efficient condition is a kitchen ventilation system equipped with a VSD and demand ventilation controls and sensors.

Algorithms

Annual energy and demand savings values are based on monitoring results from five different types of sites, as summarized in the PG&E work paper.Source 2 The sites included an institutional cafeteria, a casual dining restaurant, a hotel kitchen, a supermarket kitchen, and a university dining facility. Units are based on savings per total exhaust fan rated horsepower. Savings values are applicable to new and retrofit units. There are no default savings for this measure.

$$\Delta kWh = HP \times 4{,}423$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-101: Terms, Values, and References for VSD on Kitchen Exhaust Fans

Term	Unit	Values	Source
$4{,}423$, Annual energy savings per total exhaust fan horsepower	$\frac{kWh}{HP}$	4,423	2
$ETDF_{summer}$, Summer Energy to Demand Factor	$\frac{kW}{kWh}$	0.0001566	3
$ETDF_{winter}$, Winter Energy to Demand Factor	$\frac{kW}{kWh}$	0.0001309	3
HP, Horsepower rating of the exhaust fan	*HP*	Nameplate data	EDC Data Gathering

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. “CPUC Support Tables”. “Effective Useful Life and Remaining Useful Life”. Effective Useful Life ID: HiEff Motors. Accessed Nov 2023. Weblink

2) Southern California Edison Workpaper. (2014, June). “Commercial Kitchen Exhaust Hoods Demand Controlled Ventilation”.

3) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Fans end-use, weighted average of full and quick service restaurants. Weblink

3.3.5. ECM Circulator Pump

Target Sector	Commercial and Industrial Establishments
Measure Unit	Per Pump
Measure Life	15 years Source 1
Measure Vintage	Replace on Burnout, Early Replacement, Retrofit, New Construction

This protocol covers energy and demand savings associated with replacing single-speed induction motor circulator pumps with electronically commutated motor (ECM)—also called brushless permanent magnet (BPM) motor—circulator pumps. Circulator pumps are used to circulate water for space heating in residential and commercial buildings. Typical applications include baseboard and radiant floor heating systems that utilize a primary/secondary loop system in multifamily residences and small commercial buildings. Circulator pumps for domestic hot water applications are commonly used in multifamily and commercial buildings to shorten the amount of time it takes for hot water to reach the occupants on upper floors and those with long piping runs. These recirculator pumps can be operated continuously or be controlled by a timer or an aquastat, which turns on the pump only when the temperature of the return line falls below a certain set point.[Source 1] Circulator pumps that use ECMs are more efficient because they lack brushes that add friction to the motor and have the ability to modulate their speed to match the load.

Eligibility

This measure targets non-residential customers who purchase and install an ECM or BPM circulator pump, replacing single-speed induction motor circulator pumps in space heating and hot water applications. For all vintages except New Construction, the baseline pump control is the existing pump control, whether continuously running or controlled by a timer or aquastat. For New Construction, the baseline pump control method is the same as the energy efficient pump control method as installed.

Algorithms

Algorithms are defined for heating circulation pumps and domestic hot water recirculation pumps separately. Both algorithms depend on the wattage of the ECM motor. There are no default savings for this measure.

Heating Circulation Pumps

$$\Delta kWh = \frac{(Watts_{base} - Watts_{ee})}{1{,}000} \times EFLH_{heat} \times LF$$

$$\Delta kW_{summer\ peak} = 0$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

$$Watts_{base} = \frac{Watts_{ee}}{SF}$$

DHW Recirculation Pumps

Some DHW recirculation pumps incorporate aquastat controls, so replacing the single-speed motor may also result in a reduction in hours of use. The following algorithm allows for hours of use that differ between the baseline and energy efficient scenarios.

$$\Delta kWh = (Watts_{base} \times HOU_{DHW-base} - Watts_{ee} \times HOU_{DHW-ee}) \times \frac{1}{1{,}000} \times LF$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

$$Watts_{base} = \frac{Watts_{ee}}{SF}$$

ECM Motor Wattage

ECM motor wattage may be estimated if unknown using this algorithm.

$$WATTS_{ee} = \frac{0.746 \times HP}{\eta_{ee}}$$

Definition of Terms

Table 3-102: Terms, Values, and References for ECM Circulator Pumps

Term	Unit	Values	Source
$WATTS_{ee}$, Energy efficient watts	*W*	Nameplate data	EDC Data Gathering
$WATTS_{base}$, Baseline watts	*W*	Calculated	N/A
SF, Savings factor	*None*	18%	2
$EFLH_{heat}$, Equivalent Full-Load Hours for heating only	$\frac{Hours}{year}$	Based on logging, panel data, or modeling	EDC Data Gathering
		Default: Table 3-28	3
LF, Load Factor. Ratio between the actual load and the rated load.	*None*	Default: 0.90	4
$HOU_{DHW-base}$, Average annual pump run hours for baseline DHW recirculating pump	$\frac{Hours}{year}$	Based on logging, panel data, or modeling	EDC Data Gathering
		For continuously running pump: 8,760 For timer or aquastat-controlled pumps: 2,190	5
		Based on logging, panel data, or modeling	EDC Data Gathering

Term	Unit	Values	Source
HOU_{DHW} , Average annual pump run hours for ECM DHW recirculating pump	$\frac{Hours}{year}$	For continuously running pump: 8,760 For timer or aquastat-controlled pumps: 2,190	5
$ETDF_{summer}$, Summer Energy to Demand Factor	$\frac{kW}{kWh}$	See Table 3-82	6
$ETDF_{winter}$, Winter Energy to Demand Factor	$\frac{kW}{kWh}$	See Table 3-82	6
HP, Rated horsepower of the motor	*HP*	Nameplate	EDC Data Gathering
0.746, Conversion factor for HP to kWh	$\frac{kWh}{HP}$	0.746	Conversion factor
η_{ee}, Efficiency of ECM motor	*Percent*	85%	7

Table 3-103: Default ETDF by Season and End-Use

Building Type	$ETDF_{summer}$	$ETDF_{winter}$
Education - College / University	0.0002026	0.0001374
Education - Other	0.0001630	0.0001443
Grocery	0.0001633	0.0001241
Health - Hospital	0.0001222	0.0001036
Health - Other	0.0001509	0.0001266
Industrial Manufacturing	0.0001950	0.0001268
Institutional / Public Service	0.0001674	0.0001136
Lodging	0.0001847	0.0001175
Office	0.0001665	0.0001242
Restaurant	0.0001566	0.0001309
Retail	0.0001633	0.0001241
Warehouse - Other	0.0001950	0.0001268
Warehouse - Refrigerated	0.0001950	0.0001268

EVALUATION PROTOCOLS

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "CPUC Support Tables". "Effective Useful Life and Remaining Useful Life". Effective Useful Life ID: HiEff Motors. Accessed Nov 2023. Weblink

2) Cadmus. (2012, October). Impact Evaluation of the 2011–2012 ECM Circulator Pump Pilot Program. Table 2. Pump Spot Measurements.

3) Pennsylvania Public Utility Commission. (2014 September 11). Public Meeting 2015 TRM Annual Update Tentative Order Docket No. M-2012-2313373. Weblink

4) Cascade Energy (2012, November). Proposed Standard Savings Estimation Protocol for Ultra-Premium Efficiency Motors. Appendix C: NW Industrial Motors Database Analysis Table 6: Load Factor by nameplate hp and end use load factor for air compressors and average motor efficiency. Average efficiency for NEMA premium efficiency 1800 RPM ODP motors with 75% and 100% load factors from 1HP to 200HP. Weblink

5) DHW Recirculation System Control Strategies Final Report. (1999, January). 99-1 Hours of use for pumps with an aquastat control in multifamily applications, pages 3-30

6) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Pumps end-use. Weblink

7) Average efficiency levels for ECM fans calculated using a market average for the product category.

3.3.6. High Efficiency Pumps

Target Sector	Commercial and Industrial Establishments, Agricultural
Measure Unit	Pump
Measure Life	13.3 years Source 1
Measure Vintage	Replace on Burnout, New Construction, or Early Replacement

Eligibility

All pumps manufactured after January 27, 2020, must comply with the DOE's energy conservation standard as described in 10 CFR 431 Subpart Y.Source 2 This standard is applicable to the following clean water pump types:

- End Suction Closed Coupled (ESCC)
- End Suction Frame Mounted (ESFM)
- In-Line (IL)
- Radially Split Multi-Stage In-Line Diffuser Casing (RSV)
- Submersible Turbine (ST)

This measure does not apply to dedicated-purpose pool pumps or circulator pumps. Savings for dedicated pool pumps should follow the guidance in Section 1.16 of this TRM. This standard requires that pumps be tested for compliance with the standard and labeled with a Pump Energy Index (PEI). Compliant pumps will achieve a PEI of 1.0 or less. Pumps that achieve lower PEI values will save energy.

Conversions from constant speed to variable speed pumping are not covered under this measure. Default hours of use and coincidence factor values are provided for chilled water, heating water, and condenser water pumps only.

Algorithms

The energy and demand savings for this measure depend on the size and efficiency of the motor driving the pump, as well as the pump PEI. Savings are calculated according to the following algorithms. There are no default savings for this measure.

$$\Delta kWh = kWh_{base} - kWh_{ee}$$

$$kWh_{base} = 0.746 \times HP \times \frac{LF}{\eta} \times PEI_{base} \times RHRS$$

$$kWh_{ee} = 0.746 \times HP \times \frac{LF}{\eta} \times PEI_{ee} \times RHRS$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-104: Terms, Values, and References for Premium Efficiency Motors

Term	Unit	Value	Source
HP, Rated horsepower of the baseline and energy efficient motor	*HP*	Nameplate	EDC Data Gathering
0.746, Conversion factor for HP to kWh	$\frac{kWh}{HP}$	0.746	Conversion factor
$RHRS$, Annual run hours of the motor	$\frac{Hours}{Year}$	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-88, Table 3-89, Table 3-91	3
LF, Load Factor. Ratio between the actual load and the rated load. Variable loaded motors should use custom measure protocols.	*None*	Based on spot metering and nameplate	EDC Data Gathering
		Default: 0.79 for pumps	4
η, Efficiency of the motor. PEI values for pump packages include motor efficiency.	*None*	Motor nameplate or 1.0 for pump packages	EDC Data Gathering
		Default: Table 3-84 and Table 3-86	5
PEI_{base}, Baseline pump energy index.	*None*	Default: Table **3-105**	1
PEI_{ee}, Rated pump energy index of installed high efficiency pump or pumping package.	*None*	Nameplate	EDC Data Gathering
$ETDF_{summer}$, Summer Energy to Demand Factor	$\frac{kW}{kWh}$	See Table 3-106	6
$ETDF_{winter}$, Winter Energy to Demand Factor	$\frac{kW}{kWh}$	See Table 3-106	6

Table 3-105: Baseline Pump Energy Indices

Pump Type	PEI_{base}	
	Constant Speed	Variable Speed
ESCC, 1800 RPM	1.00	0.49
ESCC, 3600 RPM	0.96	0.51
ESFM, 1800 RPM	0.98	0.49
ESFM, 3600 RPM	0.99	0.51
IL	0.99	0.50
RSV	0.98	0.50
ST	0.96	0.60

Table 3-106: Default ETDF by Season and End-Use

Building Type	$ETDF_{summer}$	$ETDF_{winter}$
Education - College / University	0.0002026	0.0001374
Education - Other	0.0001630	0.0001443
Grocery	0.0001633	0.0001241
Health - Hospital	0.0001222	0.0001036
Health - Other	0.0001509	0.0001266
Industrial Manufacturing	0.0001950	0.0001268
Institutional / Public Service	0.0001674	0.0001136
Lodging	0.0001847	0.0001175
Office	0.0001665	0.0001242
Restaurant	0.0001566	0.0001309
Retail	0.0001633	0.0001241
Warehouse - Other	0.0001950	0.0001268
Warehouse - Refrigerated	0.0001950	0.0001268

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. Default values can be used by EDC but it is subject to metering and adjustment by evaluators or SWE. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures. Modeling is an acceptable substitute to metering and panel data if modeling is conducted using building- and equipment-specific information at the site and the facility consumption is calibrated using 12 months of billing data (pre-retrofit).

Sources

1) Regional Technical Forum. UES Measure – Efficient Pumps. Commercial/Industrial/Agricultural Pumps v4.1 Workbook. Weblink
2) United States Department of Energy. Energy Efficiency Program for Certain Commercial and Industrial Equipment: Subpart Y—Pumps. 10 C.F.R §431.464 Test Procedure for the measurement of energy efficiency, energy consumption, and other performance factors of pumps. Weblink
3) Pennsylvania Public Utility Commission. (2014 September 11). Public Meeting 2015 TRM Annual Update Tentative Order Docket No. M-2012-2313373. Weblink
4) Cascade Energy (2012, November). Proposed Standard Savings Estimation Protocol for Ultra-Premium Efficiency Motors. Appendix C: NW Industrial Motors Database Analysis Table 6: Load Factor by nameplate hp and end use load factor for air compressors and average motor efficiency. Average efficiency for NEMA premium efficiency 1800 RPM ODP motors with 75% and 100% load factors from 1HP to 200HP. Weblink
5) "Energy Conservation Program: Energy Conservation Standards for Commercial and Industrial Electric Motors; Final Rule," Vol. 79 10 C.F.R § 431 Table I.2 and Table I.3 Weblink
8) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.4. DOMESTIC HOT WATER

3.4.1. HEAT PUMP WATER HEATERS

Target Sector	Commercial and Industrial
Measure Unit	Heat Pump Water Heater
Measure Life	10 years Source 1
Measure Vintage	New Construction, Replace on Burnout

Heat pump water heaters take heat from the surrounding air and transfer it to the water in the tank, unlike conventional electrical water heaters which use resistive heating coils to heat the water.

ELIGIBILITY

This protocol documents the energy savings attributed to heat pump water heaters with uniform energy factors meeting the minimum ENERGY STAR Version 5.0 criteria.Source 2 However, uniform energy factors that exceed the ENERGY STAR minimums are accommodated with the partially deemed scheme. The measure described here involves the installation of a heat pump water heater instead of a code minimum electric water heater. It is important to note that federal standards require efficiency levels only achievable by heat pump water heaters at certain tank sizes. Therefore, the baseline condition is effectively an electric resistance water heater at smaller tank sizes and code minimum heat pump water heater for larger tank sizes. It does not cover systems where the heat pump is a pre-heater or is combined with other water heating sources. More complicated installations can be treated as custom projects.

MID-STREAM DOMESTIC HOT WATER OVERVIEW

Commercial Heat Pump Water Heaters for Midstream Delivery Programs will offer incentives on eligible products sold to trade allies and customers through commercial sales channels such as distributors of heat pump water heating products. This complements other delivery channels (such as downstream rebates to trade allies and customers) by providing incentives to encourage distributors to stock, promote, and sell more-efficient systems. In a Midstream Delivery program, less information is available about the business and installation setting so additional default values are required to calculate energy and peak demand savings.

ALGORITHMS

The energy savings calculation compares performance ratings for heat pump and code minimum water heaters and uses typical hot water usages. The energy savings are obtained through the following formula:

$$\Delta kWh = \frac{\left\{\left(\frac{1}{UEF_{base}} - \left(\frac{1}{UEF_{proposed}} \times \frac{1}{F_{adjust}}\right)\right) \times GPY \times 8.3 \times 1.0 \times (T_{hot} - T_{cold})\right\}}{3{,}412}$$

The summer and winter peak demand reduction is calculated as the annual energy savings multiplied by the ratio of the average energy usage during summer peak hours and winter peak hours to the total annual energy usage (ETDF).

$$\Delta kW_{summer\ peak} = ETDF_{summer} \times \Delta kWh$$

$$\Delta kW_{winter\ peak} = ETDF_{winter} \times \Delta kWh$$

The Energy to Demand Factor uses hourly load data for specific types of buildings to create load shapes.Source 3 Because Source 3 does not provide hourly load data for the institutional/public service building type, the summer and winter ETDFs calculated for the miscellaneous/other building type are used instead (Table 3-107).

Gallons Per Year per square foot estimates are provided in Table 3-107. Multiplying GPY per square foot for the appropriate building type times the square footage of the area served by the water heater will provide the needed GPY.

$$GPY = GPY\ per\ Square\ Foot \times SF$$

Table 3-107: Typical water heating Gallons per Year and Energy to Demand Factors

Commercial Building	GPY per Square Foot	Summer ETDF	Winter ETDF
Education – Other	3.81	0.0002545	0.0001161
Health – Hospital	4.97	0.0002011	0.0001158
Health – Other	3.09	0.0003020	0.0001311
Institutional/Public Service	5.90	0.0002588	0.0001413
Lodging	17.33	0.0001210	0.0001626
Miscellaneous/Other	2.04	0.0002588	0.0001413
Office	1.33	0.0002490	0.0001606
Restaurant	94.04	0.0001525	0.0001461
Retail	0.80	0.0002560	0.0001426
Warehouse – Refrigerated	0.22	0.0003018	0.0000816

Heat Pump COP Adjustment Factor

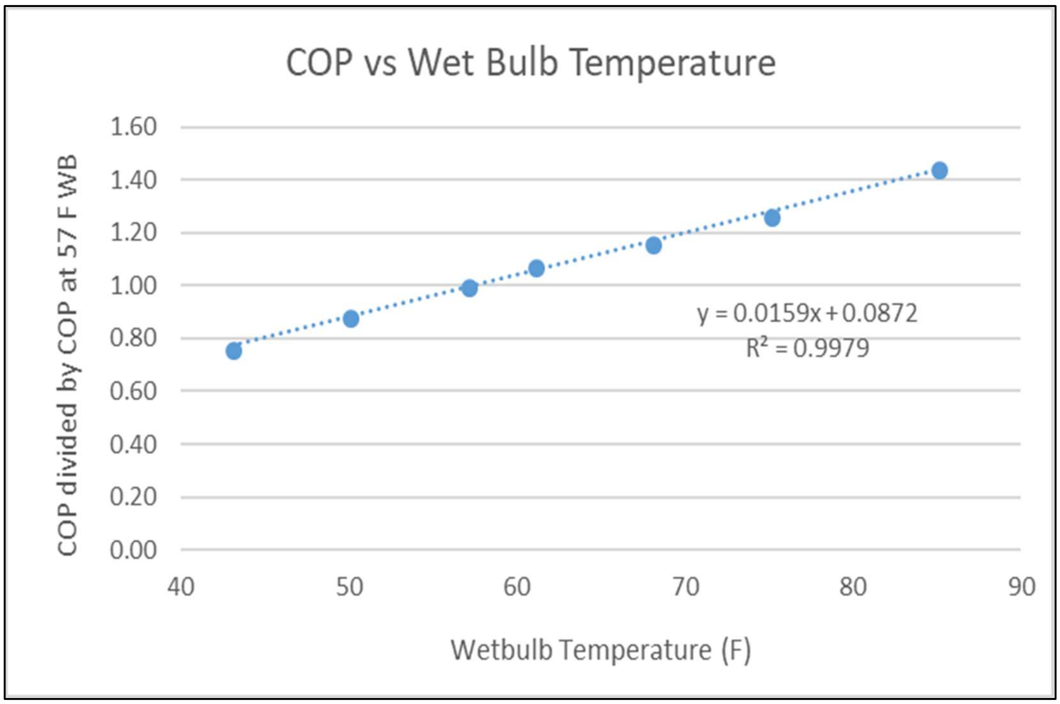
Heat pump performance is temperature and humidity dependent. The Uniform Energy Factors are determined from a DOE testing procedure that is carried out at 57°F wet bulb temperature. However, the average outdoor wet bulb temperature in PA is closer to 43°F Source 4, while the average wet bulb temperature in conditioned spaces typically ranges from 50°F to 80°F.

Figure 3-1 below shows relative coefficient of performance (COP) compared to the COP at rated conditions.Source 5 According to the plotted profile, the following adjustments provided in Table 3-108 are recommended. For midstream delivery programs, the heat pump location is unknown, but both the typical wet bulb (WB) temperature and the COP adjustment factor can be estimated using a weighted average. The percentages of heat pumps placed in unconditioned and conditioned spaces are provided by the Pennsylvania 2023 Non-Residential Baseline study and can be used as weights when estimating the typical WB temperature and COP adjustment factor for midstream delivery programs. Typical WB temperatures and COP adjustment factors can be found in Table 3-108.

Table 3-108: COP Adjustment Factors, F_{adjust}

Heat Pump Placement	Weight (%)	Typical WB Temperature °F	COP Adjustment Factor (F_{adjust})
Unconditioned Space	27.9	43	0.77
Conditioned Space	72.1	68	1.16
Kitchen	0.0	85	1.45
Unknown (Midstream Delivery)	N/A	61	1.06

Figure 3-1: Dependence of COP on Outdoor Wet Bulb Temperature



DEFINITION OF TERMS

Table 3-109: Terms, Values, and References for Heat Pump Water Heaters

Term	Unit	Values	Source
UEF_{base}, Uniform Energy Factor of baseline water heater	*None*	See Table 3-110	6
$UEF_{proposed}$, Uniform Energy Factor of proposed efficient water heater	*None*	Default: Integrated HPWH: 3.30 Integrated HPWH, 120 Volt / 15 Amp Circuit: 2.20 Split-System HPWH: 2.20	2
		Nameplate	EDC Data Gathering
T_{hot}, Temperature of hot water	*°F*	119	9
T_{cold}, Temperature of cold water supply	*°F*	53	8
$ETDF_{summer}$, Summer Energy to Demand Factor	*kW/kWh*	Default: Table 3-107	3
$ETDF_{winter}$, Winter Energy to Demand Factor	*kW/kWh*	Default: Table 3-107	3
F_{adjust}, COP Adjustment factor	*None*	Default: Table 3-108	5, 10
SF, Square footage	ft^2	Default Unknown/Midstream: 18,152	7
		EDC Data Gathering	EDC Data Gathering
GPY, Average annual gallons per year	*Gallons*	Default: Table 3-107	Calculation
		EDC Data Gathering	EDC Data Gathering

Uniform Energy Factors Based on Storage Volume
For water heaters delivered through midstream channels, the storage volume of the baseline system will be assumed to be the same as that of the proposed system. The storage volume can be determined from the manufacturer and model number of the incented heat pump water heater.

The current Federal Standards for electric water heater Uniform Energy Factors vary based on draw pattern. This standard, which went into effect at the end of 2016, replaces the old federal standard equal to 0.96 – (0.0003×Rated Storage Volume in Gallons) for tanks equal to or smaller than 55 gallons and 2.057 – (0.00113×Rated Storage Volume) for tanks larger than 55 gallons. The following table shows the Uniform Energy Factors for various storage volumes and for different draw patterns. Draw pattern is a parameter available for each product on the ENERGY STAR Qualified Products List.

Table 3-110: Minimum Baseline Uniform Energy Factor Based on Storage Volume

Rated Storage Volume (V_r)	Draw Pattern	Uniform Energy Factor
≥ 20 gal and ≤ 55 gal	Very Small	$0.8808 – (0.0008 \times V_r)$
	Low	$0.9254 - (0.0003\times V_r)$
	Medium	$0.9307 − (0.0002 \times V_r)$
	High	$0.9349 - (0.0001 \times V_r)$
> 55 gal and ≤ 120 gal	Very Small	$1.9236 − (0.0011 \times V_r)$
	Low	$2.0440 − (0.0011 \times V_r)$
	Medium	$2.1171 − (0.0011 \times V_r)$
	High	$2.2418 − (0.0011 \times V_r)$

Default Savings

The default savings presented below represent the installation of heat pump electric water heaters in the case that the business type, square footage, and location are unknown, and the Uniform Energy Factor is the ENERGY STAR minimum for an Integrated HPWH. For ≤ 55 gallons, default savings assume a 40-gallon tank. For > 55 gallons, default savings assume an 80-gallon tank. In addition, default savings assume a medium draw pattern. Remaining default values used in this calculation can be found in Table 3-111.

Table 3-111: Default Energy Savings

Location Installed	Storage Volume (gallons)	ΔkWh	$\Delta kW_{summer\ peak}$	$\Delta kW_{winter\ peak}$
Unknown (Midstream Delivery)	≥ 20 gal and ≤ 55 gal	4,744	1.23	0.67
	> 55 gal and ≤ 120 gal	1,230	0.32	0.17

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Heat Pump Water Heater, Commercial". Accessed January 2024. Weblink

2) ENERGY STAR Version 5.0 Residential Water Heater Final Draft Specification. Released June 1, 2022. Weblink

3) GPY per square foot is found in the Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Water Heating Equipment. Table 7.3.1, page186. ETDF values are calculated from load data provided in Appendix 7B, page 230. April 18, 2016. Weblink

4) SWE analysis of 15-year climate Normals for PA weather stations.

5) The performance curve is developed using the NREL's Heat Pump Water Heater Technology Assessment Based on Laboratory Research and Energy Simulation Models. Methodology can be seen: https://www.nrel.gov/docs/fy12osti/51433.pdf. Values are more easily viewed: https://www.nrel.gov/docs/fy14osti/52635.pdf. The COP adjustment values are an average of COP adjustment for Unit A, B, D, and E, where values are taken from the average tank temperature at 57 degrees F.

6) 10 C.F.R. § 430.32(d). Weblink

7) Demand Side Analytics for the Pennsylvania Public Utility Commission. (2024, March). Pennsylvania Act 129 2023 Non-Residential Baseline Study. Section 12, page 183, Table 43. Weblink

8) Using Rock Spring, PA (Site 2036) as a proxy, the mean of soil temperature at 40-inch depth is 52.502. Calculated using Daily SCAN Standard - Period of Record data from December 2003 to December 2023 from the Natural Resource Conservation Service Database. Weblink. Methodology follows Missouri TRM 2017 Volume 2: Commercial and Industrial Measures. (2017, March). "2.6.1 Water Heater". Page 78. Weblink

9) Natural Resources Conservation Service. October 6, 2018. Weblink

10) Pennsylvania Act 129 2014 Non-Residential End-Use and Saturation Study. Weblink

11) Assuming a 45% relative humidity, atmospheric pressure at the sea level value of 29.9 inHg, and the ground temperature calculation of 53 degrees F (Source 8), unconditioned wet bulb temperature is estimated to be 43 degrees F.

3.4.2. Low Flow Pre-Rinse Sprayers for Retrofit Programs and Time of Sale Programs

Target Sector	Commercial and Industrial
Measure Unit	Pre-Rinse Sprayer
Measure Life	8 years Source 1
Measure Vintage	Retrofit, Early Replacement, or Replace on Burnout

Eligibility

This protocol documents the energy savings and demand reductions attributed to efficient low flow pre-rinse sprayers in grocery and food service applications including fast food restaurants, full service restaurants, and others. The most likely areas of application are kitchens in restaurants and hotels. Only premises with electric water heating may qualify for this incentive. The replacement pre-rinse spray nozzles will fall into one of three categories:

(1) Product class 1: (≤ 5.0 ozf)
(2) Product class 2: (> 5.0 ozf and ≤ 8.0 ozf)
(3) Product class 3: (> 8.0 ozf)

Replacement pre-rinse spray nozzles falling under Product Class 1 must use less than 1 gallon per minute, nozzles falling under Product Class 2 must use less than 1.2 gallons per minute, and nozzles falling under Product Class 3 must use less than 1.28 gallons per minute.Source 2 Low flow pre-rinse sprayers reduce hot water usage and save energy associated with water heating.

The baseline for the Retrofit/Early Replacement vintage is assumed to be 1.6 GPM.Source 2 The baseline for the Replace on Burnout (Time of Sale) vintage is assumed to be equal to the current federal standard.Source 2

Algorithms

The energy savings and demand reduction are calculated through the protocols documented below.

$$\Delta kWh = \frac{\left((F_{base} \times U_{base}) - (F_{ee} \times U_{ee})\right) \times 365 \times 8.3 \times 1 \times (T_{hot} - T_{cold})}{UEF \times 3{,}412}$$

$$\Delta kW_{summer\ peak} = ETDF_{summer} \times \Delta kWh$$

$$\Delta kW_{winter\ peak} = ETDF_{winter} \times \Delta kWh$$

The summer and winter peak demand reduction is calculated as the annual energy savings multiplied by the ratio of the average energy usage during summer peak hours and winter peak hours to the total annual energy usage (ETDF). Summer and winter ETDFs are provided in Table 3-112.

Table 3-112: Typical Energy to Demand Factors

Commercial Prototype Building	Summer ETDF	Winter ETDF
Quick-service Restaurant	0.0001860	0.0000819
Full-service Restaurant	0.0001189	0.0002103
Standalone Retail (Grocery)	0.0002365	0.0001434
Default - Unknown	0.0002588	0.0001413

Summer and winter ETDFs for the default/unknown commercial building type are calculated by taking the average of the summer and winter ETDFs for all commercial building types.

Definition of Terms

The parameters in the above equation are listed in Table 3-113 below.

Table 3-113: Terms, Values, and References for Low Flow Pre-Rinse Sprayers

Term	Unit	Values	Source
F_{base}, Baseline flow rate of sprayer	*GPM*	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-114	2
F_{ee}, Post measure flow rate of sprayer	*GPM*	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-114	2
U, Daily water usage	$\frac{min}{day}$	EDC Data Gathering	EDC Data Gathering
		64.0	8
T_{hot}, Temperature of hot water	°F	Default: 127.5	4
T_{cold}, Incoming cold water temperature	°F	53	7
$UEF_{electric}$, Uniform energy factor of existing electric water heater system	*None*	EDC Data Gathering	EDC Data Gathering
		0.92	5
$ETDF_{summer}$, Summer Energy to Demand Factor	*kW/kWh*	0.0002588	3
$ETDF_{winter}$, Winter Energy to Demand Factor	*kW/kWh*	0.0001413	3
Specific mass in pounds of one gallon of water	$\frac{lb}{gal}$	8.3	6
Specific heat of water	$\frac{Btu}{lb*°F}$	1.0	6
Btu per kWh	$\frac{\text{Btu}}{\text{kWh}}$	3,412	Conversion Factor

Table 3-114: Flow Rate (GPM) by Vintage and Product Class

Program: Application	F_{base}	F_{ee}
Retrofit: Product Class 1 (≤ 5.0 ozf)	1.60	1.00
Retrofit: Product Class 2 (> 5.0 ozf and ≤ 8.0 ozf)	1.60	1.20
Retrofit: Product Class 3 (> 8.0 ozf)	1.60	1.28
Time of Sale: Product Class 1 (≤ 5.0 ozf)	1.00	EDC Data Gathering
Time of Sale: Product Class 2 (> 5.0 ozf and ≤ 8.0 ozf)	1.20	EDC Data Gathering
Time of Sale: Product Class 3 (> 8.0 ozf)	1.28	EDC Data Gathering

Default Savings

For retrofit programs, the default savings for the installation of a low flow pre-rinse sprayer compared to a standard efficiency sprayer is 2,822 kWh/year for sprayers in Product Class 1, 1,882 kWh/year for sprayers in Product Class 2, and 1,505 kWh/year for sprayers in Product Class 3.

The default summer and winter peak demand savings for the installation of a low flow pre-rinse sprayer compared to a standard efficiency sprayer for all Pre-Rinse Sprayer programs are listed below in Table 3-115. The summer and winter ETDF values used to calculate the default demand savings can be obtained from Table 3-112.

Table 3-115: Low Flow Pre-Rinse Sprayer Default Savings

Application	ΔkWh	$\Delta kW_{summer\ peak}$	$\Delta kW_{winter\ peak}$
Retrofit: Product Class 1 (≤ 5.0 ozf)	2,822	0.73	0.40
Retrofit: Product Class 2 (> 5.0 ozf and ≤ 8.0 ozf)	1,882	0.49	0.27
Retrofit: Product Class 3 (> 8.0 ozf)	1,505	0.39	0.21

Evaluation Protocol

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Impact Evaluation of Massachusetts Prescriptive Gas Pre-Rinse Spray Valve Measure, DNV-GL, 2014. Weblink
2) 10 C.F.R. § 431.266 (v). Weblink
3) Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Water Heating Equipment. ETDF

values are calculated from load data provided in Appendix 7B, page 230. April 18, 2016. Weblink

4) Impact and Process Evaluation Final Report for California Urban Water Conservation Council 2004-5 Pre-Rinse Spray Valve Installation Program (Phase 2), SBW Consulting, 2007, page 23, Table 3-5. Weblink
5) NMR Group for the Pennsylvania Public Utility Commission. (2024, March). 2023 Pennsylvania Statewide Act 129 Residential Baseline Study. Section 8, page 126, Table 109. Weblink
6) The Engineering ToolBox. “Water-Thermal Properties.” Weblink
7) Using Rock Spring, PA (Site 2036) as a proxy, the mean of soil temperature at 40-inch depth is 52.502. Calculated using Daily SCAN Standard - Period of Record data from December 2003 to December 2023 from the Natural Resource Conservation Service Database. Weblink. Methodology follows Missouri TRM 2017 Volume 2: Commercial and Industrial Measures. (2017, March). “2.6.1 Water Heater”. Page 78. Weblink
8) EPA WaterSense. (2013). WaterSense Specification for Commercial Pre-Rinse Spray Valves Supporting Statement. Weblink

3.4.3. Domestic Hot Water Pipe Insulation

Target Sector	Commercial and Industrial Establishments
Measure Unit	Per Linear Foot of Insulation
Measure Life	15 years Source1
Measure Vintage	Retrofit

Domestic hot water (DHW) distribution pipe is a critical component of a DHW system where a significant amount of energy is transferred through the DHW medium. A water heater or boiler either directly or indirectly heats potable water for distribution to end uses such as bathroom faucets, showers, and dish washing machines throughout a building. DHW pipe insulation provides a thermal barrier against heat transfer between ambient conditions and the working fluid. *International energy conservation code (IECC) 2021 Section C403.12.3* Source 2 requires new construction to have a minimum DHW pipe insulation. Insulation details are explicitly listed in Table C403.12.3: Minimum Pipe Insulation Thickness.

DHW pipe insulation applies to supply distribution pipe for an electric water heater system. Water heaters that use other fuels, such as natural gas, are not eligible for this measure. New construction is required by code to include DHW pipe insulation, therefore new construction is not eligible for DHW pipe insulation rebates.

Eligibility

This measure documents the energy savings resulting from the installation of DHW pipe insulation in non-residential facilities. The baseline condition for this measure is an uninsulated indoor DHW pipe. An eligible DHW system must have the following to be eligible for this measure:

- Non-residential building or complex
- Electrically Fueled Water Heater
- Existing Construction (System Retrofit Only)
- Looped System with Operational Circulation Pump
- DHW pipe requires 1-inch of insulation that complies with the IECC specifications Source 2

Algorithms

Energy savings for this measure may be calculated using the following formulas:

$$\Delta kWh = \frac{\Delta kWh}{ft} \cdot L$$

$$\Delta kW_{summer\ peak} = \Delta kWh \cdot ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \cdot ETDF_{winter}$$

Energy savings calculations are performed on a per linear foot basis, resulting in energy saving values per linear foot. Factors for the amount of energy saved per linear foot have been developed (See Table 3-117) using methodology outlined in the *2021 ASHRAE Fundamentals Handbook Chapter 4: Heat Transfer* Source 3. In this methodology, each thermal layer of the pipe-insulation assembly is treated as a thermally resistive element in a thermal circuit. Conductive, convective, and radiant heat loss are considered on a per linear foot basis as follows:

$$R_{Cond} = \frac{r_o \cdot ln\frac{r_o}{r_i}}{CIR_s \cdot k}$$

$$R_{Conv} = \frac{1}{CIR_s \cdot h_{Conv}}$$

$$R_{Rad} = \frac{1}{CIR_s \cdot h_{Rad}}$$

$$R_{Bare},\ R_{Ins} = R_{Cond} + R_{Conv} + R_{Rad}$$ (calculated for bare and insulation cases)

The difference in total thermal resistance for the pipe assembly is used to calculate the change in heat loss per linear foot of pipe due to the added insulation using:

$$\frac{\Delta\dot{Q}}{ft} = (T_x - T_\infty) \times \left(\frac{1}{R_{Bare} - R_{Ins}}\right)$$

The total energy savings per linear foot is calculated by applying the water heater efficiency and the system operating hours:

$$\frac{\Delta kWh}{ft} = \frac{\Delta\dot{Q}}{ft} \cdot HOU \cdot \frac{1}{\eta_{WH}} \cdot \frac{1}{3{,}412}$$

DEFINITION OF TERMS

Table 3-116: Terms, Values, and References for Insulating Bare DHW Pipes

Term	Unit	Value	Sources
CIR_s is the exterior circumference of the assembly layer under consideration	ft	Varies	2,4
ETDF_{summer} is the summer energy to demand factor	kW/kWh	Table 3-118	5
ETDF_{winter} is the winter energy to demand factor	kW/kWh	Table 3-118	5
h_{Conv} is the total convective heat transfer coefficient	$\frac{BTU}{hr \cdot ft^2 \cdot °F}$	Calculated	-
h_{Rad} is the total radiative heat transfer coefficient	$\frac{BTU}{hr \cdot ft^2 \cdot °F}$	Calculated	-
HOU is the hours of use or runtime of the DHW pump motor	hrs	8,760 for uncontrolled, 2,080 for runtime restricted	EDC Data Gathering
k is the thermal conductivity of the assembly layer under consideration	$\frac{BTU}{hr \cdot ft \cdot °F}$	Pipe: 26.2 Insulation: 0.231	2
L, Total Length of Insulated Pipe	ft	EDC Data Gathering	EDC Data Gathering
$\frac{\Delta\dot{Q}}{ft}$ is the total heat transfer between the pipe assembly and the environment	$\frac{BTU}{hr \cdot ft}$	Table 3-117	Calculated
R_{Bare} is the thermal resistance of the uninsulated pipe assembly	$\frac{hr \cdot °F \cdot ft}{BTU}$	Calculated	-
R_{Cond} is the thermal resistance of the pipe assembly due to conduction	$\frac{hr \cdot °F \cdot ft}{BTU}$	Calculated	-
R_{Conv} is the thermal resistance of the pipe assembly due to convection	$\frac{hr \cdot °F \cdot ft}{BTU}$	Calculated	-

R_{Ins} is the thermal resistance of the insulated pipe assembly	$\frac{hr \cdot {}^\circ F \cdot ft}{BTU}$	Calculated	-
R_{Rad} is the thermal resistance of the pipe assembly due to radiation	$\frac{hr \cdot {}^\circ F \cdot ft}{BTU}$	Calculated	-
r_o is the distance from the center of the pipe assembly to the exterior-most surface of the assembly layer under consideration	ft	Calculated from Diameter Selection	2,4
r_i is the distance from the center of the pipe assembly to the inner-most surface of the assembly layer under consideration	ft	Calculated from Diameter Selection	2,4
T_x is the temperature of the internal pipe fluid	°F	Table 3-117	-
T_∞ is the ambient temperature on the pipe assembly exterior	°F	70	Professional Judgement
$\frac{\Delta kWh}{ft}$, is the annual energy savings per unit length of insulation	$\frac{kWh}{ft}$	Table 3-120	Calculated
ΔkWh is the annual electric energy savings	kWh	Calculated	-
ΔkW_{peak} is the annual electric demand peak savings	kW	Calculated	-
η_{WH} is the water heater efficiency	%	Table 3-119	-

Heat loss rate per foot for specific combinations of pipe diameter and DHW supply temperature are listed in Table 3-117. Table 3-118 indicates the summer and winter ETDFs used to determine electric demand savings. Table 3-119 defines $\boldsymbol{\eta_{WH}}$, the water heater efficiency, for electric resistance and heat pump water heaters.

Table 3-117: Heat Loss Rate Due to Bare Uninsulated DHW Pipe Compared to 1" Insulated DHW Pipe

Nominal Pipe Diameter [in]	Heat Loss Savings Rate Per Linear Foot $[\frac{BTU}{hr \cdot ft}]$						
	DHW Supply Temperature						
	110 [°F]	115 [°F]	120 [°F]	125 [°F]	130 [°F]	135 [°F]	140 [°F]
½	18.4	21.4	24.7	28.0	31.6	35.2	39.2
¾	19.6	22.7	26.0	29.4	33.0	36.7	40.8
1	20.7	23.8	27.1	30.5	34.1	37.8	41.8

Table 3-118: Typical Water Heating Energy to Demand Factors Source 4

Space/Building Type	Summer ETDF	Winter ETDF
Education	0.0002545	0.0001161
Hospital	0.0002011	0.0001158

Outpatient	0.000302	0.0001311
Institutional/Public Service	0.000259	0.0001413
Lodging	0.0001210	0.0001626
Miscellaneous/Other	0.0002590	0.0001413
Office	0.0002490	0.0001606
Restaurant	0.0001525	0.0001426
Retail	0.0002560	0.0001426
Warehouse	0.0003018	0.0000816

Table 3-119: Default Water Heater Efficiency

Heating Method	Efficiency [%]				Source
	Unconditioned Space	Conditioned Space	Kitchen	Unknown	
Electric Resistance	98.0				Professional Judgement
Heat Pump ≤ 55 Gal	157	237	296	204	6,7
Heat Pump > 55 Gal	172	260	326	224	

The default efficiencies for heat pump water heaters are based on default UEF values and location adjustments presented in Heat Pump Water . The suggested COPs and COP adjustment factors have been combined to produce a table of efficiencies given the existing conditions.

Default Savings

Table 3-120Table 3-119 shows default energy savings per linear foot for this measure which is calculated from the heat loss rate listed in Table 3-117, assuming electric resistance water heating. Calculation of annual energy savings may be performed by multiplying the values shown in Table 3-120 by the total insulation length ($\boldsymbol{L}$). Electric peak demand savings may then be calculated by multiplying that result with the corresponding value from Table 3-118.

Table 3-120: Energy Loss Due to Bare Uninsulated DHW Pipe Compared to 1" Insulated DHW Pipe

Motor Controls	Nominal Pipe Diameter [in]	Annual Energy Savings Per Linear Foot [$\frac{kWh}{ft}$]						
		DHW Supply Temperature						
		110 [°F]	115 [°F]	120 [°F]	125 [°F]	130 [°F]	135 [°F]	140 [°F]
Uncontrolled (8,760 hrs)	½	48.3	56.2	64.6	73.4	82.7	92.3	102.6
	¾	51.4	59.5	68.1	77.0	86.5	96.3	106.8
	1	54.2	62.3	71.0	79.8	89.3	99.0	109.5
Runtime Restricted (2,080 hrs)	½	11.5	13.3	15.3	17.4	19.6	21.9	24.4
	¾	12.2	14.1	16.2	18.3	20.5	22.9	25.4
	1	12.9	14.8	16.8	19.0	21.2	23.5	26.0

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, June 2007. Weblink
2) 2021 International Energy Conservation Code (IECC), Chapter 4 Commercial Energy Efficiency, Section C403 Building Mechanical Systems, Sub-section 12 Construction of HVAC System Elements, Part 3 Piping Insulation Table C403.12.3 Minimum Pipe Insulation Thickness. Weblink
3) American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) 2021 Fundamentals Handbook, Chapter 4 Heat Transfer.
4) American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) 2021 Fundamentals Handbook, Chapter 22 Pipe Sizing.
5) Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Water Heating Equipment. ETDF values are calculated from load data provided in Appendix 7B, page 230. April 18, 2016. Weblink

3.5. REFRIGERATION

3.5.1. ENERGY STAR REFRIGERATION/FREEZER CASES

Target Sector	Commercial and Industrial
Measure Unit	Refrigeration/Freezer Case
Measure Life	12 years Source 1
Measure Vintage	Replace on Burnout

ELIGIBILITY

This protocol estimates savings for installing high efficiency refrigeration and freezer cases that exceed ENERGY STAR efficiency standards. Eligible refrigerators and freezers are self-contained with vertical-closed transparent or solid doors. The measurement of energy and demand savings is based on algorithms with volume as the key variable.

ALGORITHMS

Annual energy savings and peak demand savings calculations are shown below. Peak demand savings are expected to be largely uniform across both summer and winter peak periods; therefore, peak demand savings (ΔkW_{peak}) apply to both summer and winter peak periods.

$$\Delta kWh = (kWh_{base} - kWh_{ee}) \times \frac{days}{year}$$

$$\Delta kW_{peak} = \frac{(kWh_{base} - kWh_{ee})}{24}$$

DEFINITION OF TERMS

Table 3-121: Terms, Values, and References for High-Efficiency Refrigeration/Freezer Cases

Term	Unit	Values	Source
kWh_{base}, The unit energy consumption of a standard unit	$\frac{kWh}{day}$	See Table 3-122	2
kWh_{ee}, The unit energy consumption of the ENERGY STAR-qualified unit	$\frac{kWh}{day}$	See Table 3-122	3
V, Internal Volume	ft^3	EDC data gathering	EDC data gathering
$\frac{days}{year}$, days per year	$\frac{days}{year}$	EDC data gathering Default: 365	Conversion Factor

Table 3-122: Refrigeration and Freezer Case Efficiencies

<table>
<tr><th colspan="5">Refrigerators</th></tr>
<tr><th rowspan="2">Volume (ft^3)</th><th colspan="2">Transparent Door</th><th colspan="2">Solid Door</th></tr>
<tr><th>$\frac{kWh_{ee}}{day}$</th><th>$\frac{kWh_{base}}{day}$</th><th>$\frac{kWh_{ee}}{day}$</th><th>$\frac{kWh_{base}}{day}$</th></tr>
<tr><td>V < 15</td><td>0.095×V + 0.445</td><td rowspan="4">0.10×V + 0.86</td><td>0.026×V + 0.8</td><td rowspan="4">0.05×V + 1.36</td></tr>
<tr><td>15 ≤ V < 30</td><td>0.05×V + 1.12</td><td>0.05×V + 0.45</td></tr>
<tr><td>30 ≤ V < 50</td><td>0.076×V + 0.34</td><td>0.05×V + 0.45</td></tr>
<tr><td>50 ≤ V</td><td>0.105×V – 1.111</td><td>0.025×V + 1.6991</td></tr>
<tr><th colspan="5">Freezers</th></tr>
<tr><th rowspan="2">Volume (ft^3)</th><th colspan="2">Transparent Door</th><th colspan="2">Solid Door</th></tr>
<tr><th>$\frac{kWh_{ee}}{day}$</th><th>$\frac{kWh_{base}}{day}$</th><th>$\frac{kWh_{ee}}{day}$</th><th>$\frac{kWh_{base}}{day}$</th></tr>
<tr><td>V < 15</td><td rowspan="4">0.232×V + 2.36</td><td rowspan="4">0.29×V + 2.95</td><td>0.021×V + 0.9</td><td rowspan="4">0.22×V + 1.38</td></tr>
<tr><td>15 ≤ V < 30</td><td>0.12×V + 2.248</td></tr>
<tr><td>30 ≤ V < 50</td><td>0.2578×V – 1.8864</td></tr>
<tr><td>50 ≤ V</td><td>0.14×V + 4.0</td></tr>
</table>

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. “Medium or Low-Temperature Display Case With Doors”. Accessed March 2024. Weblink

2) Energy Conservation Program: Energy Conservation Standards for Commercial Refrigeration Equipment. Final Rule. Table I.1. Weblink

3) ENERGY STAR Program Requirements for Commercial Refrigerators and Freezers. Version 5.0. Weblink

3.5.2. High-Efficiency Evaporator Fan Motors for Walk-In or Reach-In Refrigerated Cases

Target Sector	Commercial and Industrial
Measure Unit	Evaporator Fan Motor
Measure Life	15 years Source 1
Measure Vintage	Early Replacement

Eligibility

This protocol covers energy and demand savings associated with the replacement of existing shaded-pole (SP) evaporator fan motors or Permanent Split Capacitor (PSC) motors in walk-in or reach-in refrigerated display cases with an Electronically Commutated motor (ECM) or a Permanent Magnet Synchronous (PMS) motor. The baseline condition assumes the evaporator fan motor is uncontrolled (i.e., it runs continuously). This measure is not applicable for new construction or replace on burnout projects. Savings are calculated per motor replaced.

There are two sources of energy and demand savings through this measure:

1) The direct savings associated with replacement of an inefficient motor with a more efficient one;
2) The indirect savings of a reduced cooling load on the refrigeration unit due to less heat gain from the more efficient evaporator fan motor in the airstream.
3)

Algorithms

The algorithms below are adapted from the Commercial Refrigeration Loadshape Project, a research effort from NEEP, Cadmus, and the Demand Management Institute.Source 2 The report notes that savings show minimal variation with the time of day or day type or seasons (summer/winter), thus peak demand savings are simply annual energy savings divided by 8,760 and apply to both summer and winter peak periods.

$$\Delta kWh = (kW_{base} - kW_{ee}) \times \%ON_{Uncontrolled} \times 8{,}760 \times WHF_e$$

$$kW_{base} = HP_{base} \times 0.746/\eta_{base} \times LF$$

$$kW_{ee} = HP_{ee} \times 0.746/\eta_{ee} \times LF$$

$$\Delta kW_{peak} = \frac{\Delta kWh}{8{,}760}$$

Definition of Terms

Table 3-123: Terms, Values, and References for High-Efficiency Evaporator Fan Motors

Term	Unit	Values	Source
kW_{base}, Input wattage of the baseline motor	*kW*	Nameplate	EDC Data Gathering
		Calculated value	Calculated value
kW_{ee}, Input wattage of the efficient motor	*kW*	Nameplate	EDC Data Gathering
		Calculated value	Calculated value
$\%ON_{Uncontrolled}$, Effective runtime of the motor without controls	%	EDC Data Gathering	EDC Data Gathering
		Default: 97.8%	2
$8{,}760$, Operating hours per year	$Hours$	8,760	Conversion factor
WHF_e, Waste heat factor for energy; represents the increased savings due to reduced waste heat from motors that must be rejected by the refrigeration equipment	*None*	SP Base, Cooler: 1.38 PSC Base, Cooler: 1.19 SP Base, Freezer 1.76 PSC Base, Freezer: 1.38	3
HP_{base}, Rated horsepower of the baseline motor	*HP*	Nameplate	EDC Data Gathering
HP_{ee}, Rated horsepower of the efficient motor	*HP*	Nameplate	EDC Data Gathering
η_{base}, Motor efficiency of the baseline motor	%	Default for SP: 30% Default for PSC: 60%	4
η_{ee}, Motor efficiency of the efficient motor	%	Default for ECM: 70% Default for PMS: 73%	4, 5
LF, Load factor. Ratio between the actual load and the rated load.	*%*	Based on spot metering and nameplate Default: 0.9	EDC Data Gathering 6
0.746, Conversion factor	*kW/HP*	0.746	Conversion factor

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Fan Motor Retrofit for a Refrigerated Display Case". Accessed January 2024. Weblink
2) Commercial Refrigeration Loadshape Project, Northeast Energy Efficiency Partnerships, October 2015. Weblink. Average wattage per rated horsepower (0.758 kW/HP) is based on an average of 66 ECMs. This represents a conservative estimate for PMS motors, as they are slightly more efficient than ECMs.
3) In cases where the baseline is an SP motor, waste heat factor is calculated by dividing the annual energy savings (kWh/HP) for "Equipment and Interactive" (shown in Table 43 of the report referenced in Source 2) by annual energy savings (kWh/HP) for the "Equipment Only" equipment type (also shown in Table 43). According to the DOE report noted in Source 4, PSC motors are approximately twice as efficient as SP motors. Thus, PSC motors will create less waste heat. The default waste heat factors for PSC motor baselines suppose PSC motors create half as much waste heat as SP motors.
4) Department of Energy. "Energy Savings Potential and Opportunities for High-Efficiency Electric Motors in Residential and Commercial Equipment." December 2013. Motor efficiencies for the baseline motors are drawn from Table 2.1, which provides peak efficiency ranges for a variety of motors. The motor efficiency for an ECM is drawn from the discussion in 2.4.3. Weblink
5) Fricke, B. and B. Becker, Oak Ridge National Laboratory. "Q-Sync Motors in Commercial Refrigeration: Preliminary Test Results and Projected Benefits." ORNL/TM-2015/466. 2015. PMS motor efficiency estimated to be 0.73. See Table 1. Weblink
6) New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs. (2024, Version 11). Weblink

3.5.3. Controls: Evaporator Fan Controllers

Target Sector	Commercial and Industrial
Measure Unit	Evaporator Fan Controller
Measure Life	15 years [Source 1]
Measure Vintage	Retrofit

This measure is for the installation of evaporator fan controls in walk-in coolers or freezers with no pre-existing controls. An evaporator fan controller is a device or system that lowers airflow across an evaporator when there is no refrigerant flow through the evaporator (i.e., when the compressor is in an off-cycle). Uncontrolled evaporator fans run constantly to provide cooling when the compressor is running, and to provide air circulation when the compressor is not running. Commercially available controllers offer two strategies; on/off and multispeed controls. The equations specified in the Algorithms section cover both control strategies.

A fan controller saves energy by reducing fan usage, by reducing the refrigeration load resulting from the heat given off by the fan and by reducing compressor energy resulting from the electronic temperature control. On/off controls save energy and reduce demand by reducing fan motor runtime. Multispeed controls use micro pulses to change fan motor speed, saving energy and reducing demand by reducing power and runtime. This protocol documents the energy savings attributed to evaporator fan controls.

Eligibility

This protocol documents the energy savings attributed to installation of evaporator fan controls in medium-temperature walk-in or reach-in coolers and low temperature walk-in or reach-in freezers. The baseline case is assumed to be a shaded pole (SP) motor without controls or an electronically commutated motor (ECM) without controls.

Algorithms

The algorithms used in this section are adapted from NEEP's Commercial Refrigeration Loadshape Project. [Source 2] Peak demand savings are expected to be largely uniform across both summer and winter peak periods; therefore, peak demand savings (ΔkW_{peak}) apply to both summer and winter peak periods.

$$\Delta kWh = kW_{hp} \times HP \times (\%ON_{Uncontrolled} - \%ON_{Controlled}) \times 8{,}760 \times WHF_e$$

$$\Delta kW_{peak} = \Delta kWh \times ETDF$$

Definition of Terms

Table 3-124: Terms, Values, and References for Evaporator Fan Controllers

Term	Unit	Values	Source
kW_{hp}, Connected load per horsepower of motor	*kW/HP*	Nameplate	EDC Data Gathering
		Default for SP: 2.088 Default for ECM: 0.758	2
HP, Rated horsepower of the motor	*HP*	Nameplate	EDC Data Gathering
$\%ON_{Uncontrolled}$, Effective runtime of the uncontrolled motor	*None*	EDC Data Gathering Default: 97.8%	EDC Data Gathering 2
$\%ON_{Controlled}$, Effective runtime of the controlled motor	*None*	EDC Data Gathering Default values: Unknown control style: 66.5% On/off control style: 63.6% Micro pulse control style: 69.2%	EDC Data Gathering 2
8,760, Operating hours per year	*Hours*	8,760	Conversion factor
WHF_e, Waste heat factor for energy; represents the increased savings due to reduced waste heat from motors that must be rejected by the refrigeration equipment	*None*	Cooler: 1.38 Freezer 1.76	3
0.746, Conversion factor	*kW/HP*	0.746	Conversion factor
ETDF, Energy To Demand Factor, applies to both summer and winter peak periods	*kW/kWh*	Default values: Unknown control style: 0.000094 ON/OFF control style: 0.000087 Micro pulse control style: 0.000102	4

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Evaporator Fan Controller for Walk-In Coolers" listed in the CPUC Support Table "Effective Useful Life and Remaining Useful Life" is 16 years. The default value is set to the legislated limit of 15 years. Accessed December 2023. Weblink
2) Northeast Energy Efficiency Partnerships. (October 2015). Commercial Refrigeration Loadshape Project. Weblink. The average kW per rated HP values is taken from Table 28. The effective runtime values are taken from Table 34.
3) Waste heat factor is calculated by dividing the annual energy savings (kWh/HP) for "Equipment and Interactive" (shown in Table 43 of Source 2) by annual energy savings (kWh/HP) for the "Equipment Only" equipment type (also shown in Table 43 of Source 2).
4) Energy to demand factors are developed by dividing the PJM summer peak kW/HP savings for evaporator fan controls (shown in Table 47 of Source 2) by the average annual energy savings (kWh/HP) for evaporator fan controls (also shown in Table 43 of Source 2).

3.5.4. Controls: Floating Head Pressure Controls

Target Sector	Commercial and Industrial
Measure Unit	Floating Head Pressure Control
Measure Life	15 years Source 1
Measure Vintage	Retrofit

Installers conventionally design a refrigeration system to condense at a set pressure-temperature point, typically 90 ºF. By installing a floating head pressure control (FHPC) condenser system, the refrigeration system can change condensing temperatures in response to different outdoor temperatures. This means that the minimum condensing head pressure from a fixed setting (180 psig for R-22) is lowered to a saturated pressure equivalent at 70 ºF or less. Either a balanced-port or electronic expansion valve that is sized to meet the load requirement at a 70 ºF condensing temperature must be installed. Alternatively, a device may be installed to supplement the refrigeration feed to each evaporator attached to a condenser that is reducing head pressure.

Eligibility

This protocol documents the energy savings attributed to FHPCs applied to a single-compressor refrigeration system in commercial applications. The baseline case is a refrigeration system without FHPC whereas the efficient case is a refrigeration system with FHPC. FHPCs must have a minimum Saturated Condensing Temperature (SCT) programmed for the floating head pressure control of ≤ 70 ºF. The use of FHPC would require balanced-port expansion valves, allowing satisfactory refrigerant flow over a range of head pressures. The compressor must be 1 HP or larger.

Algorithms

Annual energy savings algorithms are shown below.

$$\Delta kWh = HP_{compressor} \times \frac{kWh}{HP}$$

If the refrigeration system is rated in tonnage:

$$\Delta kWh = \frac{4.715}{COP} \times Tons \times \frac{kWh}{HP}$$

Peak demand savings algorithms are shown below. There are no summer peak demand savings for this measure because the refrigeration system is expected to run at full capacity during the summer peak demand period resulting in zero energy reduction from the FHPC.

$$\Delta kW_{summer\ peak} = 0$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_W$$

DEFINITION OF TERMS

Table 3-125: Terms, Values, and References for Floating Head Pressure Controls

Term	Unit	Values	Source
$HP_{compressor}$, Rated horsepower (HP) per compressor	*HP*	Nameplate	EDC Data Gathering
$\frac{kWh}{HP}$, Annual savings per HP	$\frac{kWh}{HP}$	See Table 3-126, Table 3-127	2, 3, 4, 5
COP, Coefficient of Performance	*None*	Based on design conditions	EDC Data Gathering
		Default: Unitary Condensing Unit; Refrigerator (Medium Temp: 28 °F – 40 °F): 2.60 Freezer (Low Temp: -20 °F – 0 °F): 1.40 Remote Condenser; Refrigerator (Medium Temp: 28 °F – 40 °F): 2.50 Freezer (Low Temp: -20 °F – 0 °F): 1.40	6
$Tons$, Refrigeration tonnage of the system	*ton*	EDC Data Gathering	EDC Data Gathering
4.715, Conversion factor to convert from ton to HP	$\frac{HP}{ton}$	Engineering Estimate	7
$ETDF_W$, Winter energy to demand Factor	*kW/kWh*	0.0000274	8

Table 3-126: Annual Savings kWh/HP by Location

Climate Zone	Unitary Condensing Unit (kWh/HP)			Remote Condenser (kWh/HP)		
	Refrigerator (Medium Temp)	Freezer (Low Temp)	Default (Temp Unknown)	Refrigerator (Medium Temp)	Freezer (Low Temp)	Default (Temp Unknown)
Allentown	658	788	695	372	465	398
Binghamton	738	841	767	409	502	435
Bradford	752	851	780	416	508	442
Erie	688	809	722	386	479	412
Harrisburg	635	773	673	361	454	387
Philadelphia	610	756	650	349	443	375
Pittsburgh	682	804	716	383	476	409
Scranton	683	805	717	384	477	410
Williamsport	681	803	715	382	476	408

Table 3-127: Default Condenser Type Annual Savings kWh/HP by Location

Climate Zone	Unknown Condenser Type Default (kWh/HP)		
	Refrigerator (Medium Temp)	Freezer (Low Temp)	Temp Unknown
Allentown	515	627	546
Binghamton	574	672	601
Bradford	584	680	611
Erie	537	644	567
Harrisburg	498	613	530
Philadelphia	479	599	513
Pittsburgh	532	640	562
Scranton	533	641	563
Williamsport	532	639	562

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Northwest Power and Conservation Council Regional Technical Forum. (2022, April). Floating Head Pressure Controls for Single Compressor Systems, V3.0. Summary. Weblink
2) Northwest Power and Conservation Council Regional Technical Forum. (2022, April). Floating Head Pressure Controls for Single Compressor Systems, V3.0. Savings Data & Analysis. Weblink
3) Northwest Power and Conservation Council Regional Technical Forum. (2022, December). Climate Zone Calculation Workbook, V3.2. Using RTF Deemed saving estimates for the NW climate zone, data was extrapolated to Pennsylvania climate zones by using cooling degree days comparison based on the locale. Weblink
4) Demand Side Analytics for the Pennsylvania Public Utility Commission. (2024, March). Pennsylvania Act 129 2023 Non-Residential Baseline Study. Page 147, figure 129. Weblink. Default based on split of roughly 72% medium temperature displays and 28% low temperature displays.
5) No data available to predict if condensing units or remote condensers will be more prevalent, assumed 50/50 split, based on discussion with Portland Energy Conservation, Inc. (PECI) GrocerySmart staff.
6) Northwest Power and Conservation Council Regional Technical Forum. (2022, April). Floating Head Pressure Controls for Single Compressor Systems, V3.0. Parameters. Weblink
7) Conversion factor for horsepower per ton: (12,000 BTU/ton) / (3.412 BTU/Watt) / (746 Watts/HP) = 4.715 HP/ton
8) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.5.5. Controls: Anti-Sweat Heater Controls

Target Sector	Commercial and Industrial
Measure Unit	Case door
Measure Life	12 years Source 1
Measure Vintage	Retrofit

Eligibility

Anti-sweat door heaters (ASDH) prevent condensation on cooler and freezer doors. Anti-sweat heater (ASH) controls sense the humidity in the store outside of reach-in, glass door refrigerated cases and turn off anti-sweat heaters during periods of low humidity. Without controls, anti-sweat heaters run continuously whether they are necessary or not.

There are two commercially available control strategies – (1) ON/OFF controls and (2) micro pulse controls that respond to a call for heating, which is typically determined using either a door moisture sensor or an indoor air temperature and humidity sensor to calculate the dew point. In the first strategy, the ON/OFF controls turn the heaters on and off for minutes at a time, resulting in a reduction in run time. In the second strategy, the micro pulse controls pulse the door heaters for fractions of a second, in response to the call for heating. Savings are realized from the reduction in energy used by not having the heaters running at all times. In addition, secondary savings result from reduced cooling load on the refrigeration unit when the heaters are off.

The baseline condition is assumed to be a commercial glass door cooler or refrigerator with heaters running 24 hours a day, seven days per week (24/7). Non-glass doors are not eligible. The savings given below are based on adding controls to doors with uncontrolled heaters utilizing either ON/OFF or micro pulse controls. The savings calculated from these algorithms is on a per door basis for two temperatures: Refrigerator/Coolers and Freezers. A default value to be used when the case service control strategies are unknown is also calculated.

Algorithms

Algorithms for annual energy savings and peak demand savings are shown below.

$$\Delta kWh = kW_d \times (\%ON_{NONE} - \%ON_{CONTROL}) \times N \times 8760 \times WHF_e$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_s$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_w$$

Definition of Terms

Table 3-128: Terms, Values, and References for Anti-Sweat Heater Controls

Term	Unit	Values	Source
N, Number of reach-in refrigerator or freezer doors controlled by sensors	*Doors*	# of doors	EDC Data Gathering
kW_d, Connected load kW per connected door	$\frac{kW}{Door}$	EDC Data Gathering Default: 0.13	2
$\%ON_{NONE}$, Effective runtime of uncontrolled ASDH	*None*	EDC Data Gathering Default: 90.7%	2
$\%ON_{CONTROL}$, Effective runtime of ASDH with controls	*None*	Unknown control style: 45.6% ON/OFF control style: 58.9% Micro pulse control style: 42.8%	2
8,760, Operating hours per year	*Hours*	8,760	Conversion Factor
WHF_e, Waste heat factor for energy; represents the increased savings due to reduced waste heat from heaters that must be rejected by the refrigeration equipment	*None*	Cooler: 1.26 Freezer 1.51	3
$ETDF_S$, Summer energy to demand factor	*kW/kWh*	0.0000346	4
$ETDF_W$, Winter energy to demand factor	*kW/kWh*	0.0000274	4

Default Savings

Table 3-129: Default Savings Per Door with ASDH

Description	Unknown Control	On/Off Control	Micro pulse Control
Refrigerator/Cooler			
Energy Impact (kWh/door)	647	456	687
Summer Peak Demand Impact (kW/door)	0.0224	0.0158	0.0238
Winter Peak Demand Impact (kW/door)	0.0178	0.0125	0.0189
Freezer			
Energy Impact (kWh/door)	776	547	824
Summer Peak Demand Impact (kW/door)	0.0268	0.0189	0.0285
Winter Peak Demand Impact (kW/door)	0.0213	0.0150	0.0226

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. “Anti-Sweat Heater Controls”. Accessed December 2023. Weblink

2) Cadmus for Northeast Energy Efficiency Partnerships. (2015, October). Commercial Refrigeration Load Shape Project Final Report. Page 7, Table 5. Weblink

3) Waste heat factor is calculated by dividing the PJM Summer Peak kW equipment and interactive savings for ASDH by the equipment only savings. Cadmus for Northeast Energy Efficiency Partnerships. (2015, October). Commercial Refrigeration Loadshape Project Final Report. Page 84, Table 52. Weblink

4) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.5.6. Controls: Evaporator Coil Defrost Control

Target Sector	Commercial and Industrial
Measure Unit	Evaporator Coil Defrost Control
Measure Life	10 years Source 1
Measure Vintage	Retrofit

This protocol applies to electric defrost control on small commercial walk-in cooler and freezer systems. A refrigeration system with electric defrost is set to run the defrost cycle periodically throughout the day. A defrost control uses temperature and pressure sensors to monitor system processes and statistical modeling to learn the operation and requirements of the system. When the system calls for a defrost cycle, the controller determines if it is necessary and skips the cycle if it is not.

Eligibility

This measure is targeted to non-residential customers whose equipment uses electric defrost controls on small commercial walk-in cooler or freezer systems. Acceptable baseline conditions are existing small commercial walk-in coolers or freezers without defrost controls. Efficient conditions are small commercial walk-in coolers or freezers with defrost controls installed.

Algorithms

Algorithms for annual energy savings and peak demand savings are shown below.

$$\Delta kWh = FANS \times kW_{DE} \times SVG \times HOURS \times \left(1 + \frac{3.412}{12 \times COP}\right)$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_s$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_w$$

Definition of Terms

Table 3-130: Terms, Values, and References for Evaporator Coil Defrost Controls

Term	Unit	Values	Source
$FANS$, Number of evaporator fans	*Fan*	EDC Data Gathering	EDC Data Gathering
kW_{DE}, kW of defrost element	*kW*	EDC Data Gathering Default: 0.9	EDC Data Gathering, 2
SVG, Savings percentage for reduced defrost cycles	*None*	30%	3
$HOURS$, Average annual full load defrost hours	$\frac{Hours}{year}$	EDC Data Gathering Default: 487	EDC Data Gathering, 4
COP, Coefficient of performance of refrigeration compressor	*None*	EDC Data Gathering Cooler: 3.42 Freezer: 1.00 Unknown: 2.74	EDC Data Gathering, 5
$ETDF_s$, Summer energy to demand factor	*kW/kWh*	0.0000346	6
$ETDF_w$, Winter energy to demand factor	*kW/kWh*	0.0000274	6

Default Savings

Table 3-131: Default Evaporator Coil Defrost Control Savings per Fan

Description	∆kWh	∆kW summer peak	∆kW winter peak
Cooler	142	0.0049	0.0039
Freezer	169	0.0058	0.0046
Unknown	145	0.0050	0.0040

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Efficiency Vermont Technical Reference User Manual (TRM). (2015). "Evaporator Coil Defrost Control". Page 171. Weblink. This is a conservative estimate based on a discussion with Heatcraft.
2) Efficiency Vermont Technical Reference User Manual (TRM). (2015). "Evaporator Coil Defrost Control". Page 170. Weblink. The total Defrost Element kW is proportional to the number of evaporator fans blowing over the coil. The typical wattage of the defrost element is 900W per fan.
3) Smart defrost kits claim 30-40% savings (with 43.6% savings by third party testing by Intertek Testing Service). MasterBilt Demand defrost claims 21% savings for northeast. Smart Defrost Kits are more common so the assumption of 30% is a conservative estimate. Weblink
4) Fricke, B. and Sharma, V. (2011, October). "Demand Defrost Strategies in Supermarket Refrigeration Systems". Page 2. Oak Ridge National Laboratory. Weblink. The refrigeration system is assumed to be in operation every day of the year, while savings from the evaporator coil defrost control will only occur during set defrost cycles. This is assumed to be (4) 20-minute cycles per day, for a total of 487 hours.
5) U.S. Department of Energy. (2009, September). Energy Savings Potential and R&D Opportunities for Commercial Refrigeration. Page 116, Table 4-4. Weblink. The default for the "unknown" case represents a weighted average of the cooler and freezer COPs. A split of 72/28 (coolers to freezers) is assumed based on the Pennsylvania Act 129 2018 and 2023 Non-Residential Baseline Studies.
6) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.5.7. Variable Speed Refrigeration Compressor

Target Sector	Commercial and Industrial
Measure Unit	VSD Refrigeration Compressor
Measure Life	15 years Source 1
Measure Vintage	Retrofit

Variable speed drive (VSD) compressors are used to control and reduce the speed of the compressor during times when the refrigeration system does not require the motor to run at full capacity. VSD control is an economical and efficient retrofit option for existing compressor installations. The performance of variable speed compressors can more closely match the variable refrigeration load requirements thus minimizing energy consumption.

Eligibility

This measure applies to retrofit construction in the commercial and industrial building sectors; it is most applicable to grocery stores or food processing applications with refrigeration systems.

Algorithms

The savings algorithms are shown below. There are no summer peak demand savings for this measure because the refrigeration system is expected to run at full capacity during the summer peak demand period.

$$\Delta kWh = HP \times LF \times 0.746 \times \eta \times 8{,}760 \times DC \times SVG$$

$$\Delta kW_{summer\ peak} = 0$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_w$$

Definition of Terms

Table 3-132: Terms, Values, and References for VSD Compressors

Term	Unit	Values	Sources
HP, Rated horsepower of compressor	*HP*	Nameplate	EDC Data Gathering
LF, Load factor. Ratio between the actual load and the rated load.	-	Based on spot metering and nameplate	EDC Data Gathering
		Default: 0.9	2
0.746, Conversion factor	$\frac{kW}{HP}$	0.746	Conversion factor
η, Compressor efficiency	-	88%	3
$8{,}760$, Operating hours per year	*Hours*	8,760	Conversion factor
DC, Duty cycle of the compressor	-	Data logging	EDC Data Gathering
		Default: Freezer: 85% Cooler/Unknown: 55%	4
SVG, Savings percentage for VSD on compressor	-	15%	5
$ETDF_W$, Winter energy to demand factor	$\frac{kW}{kWh}$	0.0000274	6

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Refrigeration Upgrades (Variable Speed Compressors)" listed in the CPUC Support Table "Effective Useful Life and Remaining Useful Life". Accessed December 2023. Weblink
2) No definitive sources could be found demonstrating achieved refrigeration compressor load factor, though this value reflects that compressors do not typically operate at 100% of their nameplate horsepower.
3) U.S. Department of Energy (2013, December) "Energy Savings Potential and Opportunities for High-Efficiency Electric Motors in Residential and Commercial Equipment". Table B.3. Weblink
4) Dieckmann, J., & Magid, H. (1999, August). "Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications". Section 8-2, page 8-3. Alliance for Responsible Atmospheric Policy. Weblink

5) U.S. Department of Energy (2013, December) "Energy Savings Potential and Opportunities for High-Efficiency Electric Motors in Residential and Commercial Equipment". Table 4.23. Weblink
6) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.5.8. Strip Curtains for Walk-In Freezers and Coolers

Target Sector	Commercial and Industrial
Measure Unit	Walk-in unit door
Measure Life	4 years Source 1
Measure Vintage	Retrofit

Strip curtains are used to reduce the refrigeration load associated with the infiltration of non-refrigerated air into the refrigerated spaces of walk-in coolers or freezers.

The primary cause of air infiltration into walk-in coolers and freezers is the air density difference between two adjacent spaces of different temperatures. The total refrigeration load due to infiltration through the main door into the unit depends on the temperature differential between the refrigerated and non-refrigerated airs, the door area and height, and the duration and frequency of door openings. The avoided infiltration depends on the efficacy of the newly installed strip curtains as infiltration barriers.[1] The calculation of the refrigeration load due to air infiltration and the energy required to meet that load is rather straightforward but relies on critical assumptions regarding the aforementioned operating parameters. The algorithm and most assumptions in this protocol is drawn from a Strip Curtains measure maintained by the RTF, which calculates savings using the formulas outlined in ASHRAE's Refrigeration Handbook for calculating refrigeration load from infiltration by air exchange.Source 2 Other assumptions, e.g. operating hours of the refrigeration system, are drawn from more-recent sources.Source 3

Eligibility

This protocol documents the energy savings attributed to strip curtains applied on walk-in cooler and freezer doors in commercial applications. The most likely areas of application are large and small grocery stores, supermarkets, restaurants, and refrigerated warehouses. The baseline case is a walk-in cooler or freezer that previously had no strip curtain installed. The efficient equipment is a strip curtain added to a walk-in cooler or freezer. Strip curtains must be at least 0.06 inches thick. Low temperature strip curtains must be used on low temperature applications.

Algorithms

Algorithms for annual energy savings and peak demand savings are shown below. Peak demand savings are expected to be largely uniform across both summer and winter peak periods; therefore, peak demand savings (ΔkW_{peak}) apply to both summer and winter peak periods.

$$\Delta kWh = \frac{\Delta kWh}{ft^2} \times A \times ISR$$

$$\Delta kW_{peak} = \frac{\Delta kW}{ft^2} \times A \times ISR$$

[1] We define *curtain efficacy* as the fraction of the potential airflow that is blocked by an infiltration barrier. For example, a brick wall would have an efficacy of 1.0, while the lack of any infiltration barrier corresponds to an efficacy of 0.

Definition of Terms

Table 3-133: Terms, Values, and References for Strip Curtains

Term	Unit	Values	Source
$\frac{\Delta kWh}{ft^2}$, Average annual kWh savings per square foot of infiltration barrier	$\frac{\Delta kWh}{ft^2}$	Default: Table 3-135	2
$\frac{\Delta kW}{ft^2}$, Average kW savings per square foot of infiltration barrier	$\frac{\Delta kW}{ft^2}$	Default: Table 3-135	2
A, Doorway area	ft^2	EDC Data Gathering **Default:** Table 3-134	2
ISR, In-service rate	*None*	EDC Data Gathering Default: 75%	2

Table 3-134: Doorway Area Assumptions

Type	Doorway Area, ft^2
Grocery - Cooler	21
Grocery - Freezer	21
Convenience Store - Cooler	21
Convenience Store - Freezer	21
Restaurant - Cooler	21
Restaurant - Freezer	21
Refrigerated Warehouse - Cooler	120

Default Savings

The default savings values, per square foot, are listed in Table 3-135. Default square footage values by facility type are listed in
Table 3-134. The defaults are drawn from a Strip Curtains measure maintained by the RTF[Source 2] and more-recent assumptions for select commercial buildings' effective full load hours (EFLH).[Source 3]

Table 3-135: Default Energy Savings and Demand Reductions for Strip Curtains per Square Foot

Type	Energy Savings, $\frac{\Delta kWh}{ft^2}$	Demand Savings, $\frac{\Delta kW}{ft^2}$
Grocery - Cooler	70	0.0129
Grocery - Freezer	290	0.0525
Convenience Store - Cooler	10	0.0022
Convenience Store - Freezer	20	0.0032
Restaurant - Cooler	10	0.0026
Restaurant - Freezer	70	0.0134
Refrigerated Warehouse - Cooler	250	0.0421

Evaluation Protocols

The most appropriate evaluation protocol for this measure is verification of installation coupled with assignment of stipulated energy savings according to store type. The strip curtains are not expected to be installed directly. As such, the program tracking/ evaluation effort must capture the following key information:

- Fraction of strip curtains installed in each of the categories (e.g. freezer/ cooler and store type)
- Doorway area

The rebate forms should track the above information. During the M&V process, interviews with site contacts should track this fraction, and savings should be adjusted accordingly.

Sources

1) California Electronic Technical Reference Manual. “Evaporator Fan Controller for Walk-In Coolers” listed in the CPUC Support Table “Effective Useful Life and Remaining Useful Life”. Accessed December 2023. Weblink

2) Database for UES Measures, Regional Technical Forum. (2023, version 3.1) “Strip Curtains”. Weblink

3) Cadmus Group for the Northwest Energy Efficiency Alliance. (2020, May). Commercial Building Stock Assessment. Appendix Tables (Weighted), Public Summary table, Buildings. Weblink

3.5.9. NIGHT COVERS FOR DISPLAY CASES

Target Sector	Commercial and Industrial
Measure Unit	Display Case
Measure Life	5 years [Source 1]
Measure Vintage	Retrofit

Night covers are deployed during the facility's unoccupied hours in order to reduce refrigeration energy consumption. They are retractable curtains on open horizontal or multi-deck refrigerated display cases. The main benefit of using night covers on open display cases is a reduction of infiltration and radiation cooling loads.

ELIGIBILITY

This measure documents the energy savings associated with the installation of night covers on existing vertical or horizontal open-type refrigerated display cases. Medium-temperature display cases are commercial refrigerators capable of operating at or below 40 °F. Low-temperature display cases are commercial freezers that are not ice-cream freezers. Ice-cream freezers are commercial freezers that are intended for the storing, displaying, or dispensing of ice cream or other frozen desserts.[Source 2]

Display cases manufactured on or after January 1, 2012, and before March 27, 2017, have separate federal requirements from those manufactured on or after March 27, 2017. Likewise, there are separate federal requirements depending on the orientation (vertical or horizontal) and condensing unit (remote or self-contained) of the display cases. [Source 3]

It is recommended that these covers have small, perforated holes to decrease moisture buildup.

ALGORITHMS

There are no demand savings for this measure because the covers are not typically used during the peak period. The annual energy savings are obtained through the calculation shown below.

$$\Delta kWh = \text{TDEC} \times \text{ESF} \times 365$$

$$\Delta kW_{summer\ peak} = 0$$

$$\Delta kW_{winter\ peak} = 0$$

Definition of Terms

Table 3-136: Terms, Values, and References for Night Covers

Term	Unit	Values	Source
$TDEC$, Total Daily Energy Consumption	$\frac{kWh}{day}$	Default: Table 3-137 or Table 3-138	3
TDA, Total Display Area of the open refrigerated case	ft^2	EDC Data Gathering	EDC Data Gathering
ESF, Energy Savings Factor	$None$	9.0%	4
L, Length of open refrigerated case	ft	EDC Data Gathering	EDC Data Gathering

Table 3-137: Total Daily Energy Consumption, Equipment Manufactured on or after March 27, 2017

Type	Condensing Unit Configuration	Cooler Case Rating Temperature	Total Daily Energy Consumption (TDEC)
Vertical Open	Remote	Medium (38°F)	0.64 × TDA + 4.07
		Low (0°F)	2.20 × TDA + 6.85
		Ice Cream (-15°F)	2.79 × TDA + 8.70
	Self-Contained	Medium (38°F)	1.69 × TDA + 4.71
		Low (0°F)	4.25 × TDA + 11.82
		Ice Cream (-15°F)	5.40 × TDA + 15.02
Horizontal Open	Remote	Medium (38°F)	0.35 × TDA + 2.88
		Low (0°F)	0.55 × TDA + 6.88
		Ice Cream (-15°F)	0.70 × TDA + 8.74
	Self-Contained	Medium (38°F)	0.72 × TDA + 5.55
		Low (0°F)	1.90 × TDA + 7.08
		Ice Cream (-15°F)	2.42 × TDA + 9.00

Table 3-138: Total Daily Energy Consumption, Equipment Manufactured before March 27, 2017

Type	Condensing Unit Configuration	Cooler Case Rating Temperature	Total Daily Energy Consumption (TDEC)
Vertical Open	Remote	Medium (38°F)	0.82 × TDA + 4.07
		Low (0°F)	2.27 × TDA + 6.85
		Ice Cream (-15°F)	2.89 × TDA + 8.70
	Self-Contained	Medium (38°F)	1.74 × TDA + 4.71
		Low (0°F)	4.37 × TDA + 11.82
		Ice Cream (-15°F)	5.55 × TDA + 15.02
Horizontal Open	Remote	Medium (38°F)	0.35 × TDA + 2.88
		Low (0°F)	0.57 × TDA + 6.88
		Ice Cream (-15°F)	0.72 × TDA + 8.74
	Self-Contained	Medium (38°F)	0.77 × TDA + 5.55
		Low (0°F)	1.92 × TDA + 7.08
		Ice Cream (-15°F)	2.44 × TDA + 9.00

The energy savings factor assumption is based on analysis performed by Southern California Edison (SCE). SCE conducted this test at its Refrigeration Technology and Test Center (RTTC). The RTTC's sophisticated instrumentation and data acquisition system provided detailed tracking of the refrigeration system's critical temperature and pressure points during the test period. These readings were then utilized to quantify various heat transfer and power related parameters within the refrigeration cycle. The results of SCE's test focused on three typical scenarios found mostly in supermarkets.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation, total display area, and proper selection of default values.

Sources

1) California Electronic Technical Reference Manual. "Night Covers for vertical and horizontal refrigerated display cases" listed in the CPUC Support Table "Effective Useful Life and Remaining Useful Life". Accessed December 2023. Weblink
2) 10 C.F.R. § 431.62. "Definitions concerning commercial refrigerators, freezers and refrigerator-freezers". Weblink
3) 10 C.F.R. § 431.66. "Energy conservation standards and their effective dates". Weblink
4) Southern California Edison (1997). Effects of the Low Emissive Shields on Performance and Power Use of a Refrigerated Display Case. Weblink

3.5.10. Auto Closers

Target Sector	Commercial and Industrial
Measure Unit	Walk-in Cooler and Freezer Door
Measure Life	8 years [Source 1]
Measure Vintage	Retrofit

The auto-closer should be applied to the main insulated opaque door(s) of a walk-in cooler or freezer. Auto-closers on freezers and coolers can reduce the amount of time that doors are open, thereby reducing infiltration and refrigeration loads. These measures are for retrofit of doors not previously equipped with auto-closers, and assume the doors have strip curtains.

Eligibility

This protocol documents the energy savings attributed to installation of auto closers in walk-in coolers and freezers. The auto-closer must be able to firmly close the door when it is within one inch of full closure. The walk-in door perimeter must be ≥ 16 feet.

Algorithms

The energy and demand savings for this measure were developed based on an SCE work paper regarding refrigerated storage auto closers.[Source 2] The paper notes that, "energy savings were determined through building simulation in eQUEST 3.65 Refrigeration. Only the Grocery building type was simulated, and its savings were used for other building types because walk-in coolers and freezers generally have the same characteristics regardless of building type." The work paper provided savings values for each of California's 16 climate zones. Energy savings for Pennsylvania climate zones were predicted via HDD and CDD-based regression models, fit separately for coolers and freezers, based on both HDD and CDD for each California climate zone.[Source 3]

Peak demand savings were calculated by averaging the demand during the DEER peak period. This period varies by California climate zone. Peak demand savings from the SCE study could not be modeled as a function of HDD and/or CDD, so the peak demand savings from the California climate zone most similar to the Pennsylvania weather cities (in terms of HDD and CDD) were chosen (California climate zone 16). Peak demand savings are expected to be largely uniform across both summer and winter peak periods; therefore, peak demand savings (ΔkW_{peak}) apply to both summer and winter peak periods.

Main Cooler Doors

$$\Delta kWh = \Delta kWh_{cooler}$$

$$\Delta kW_{peak} = \Delta kW_{cooler}$$

Main Freezer Doors

$$\Delta kWh = \Delta kWh_{freezer}$$

$$\Delta kW_{peak} = \Delta kW_{freezer}$$

Definition of Terms

Table 3-139: Terms, Values, and References for Auto Closers

Term	Unit	Valnues	Source
ΔkWh_{cooler}, Annual kWh savings for main cooler doors	kWh	Table 3-140	2
ΔkW_{cooler}, Summer and winter peak kW savings for main cooler doors	kW	Table 3-140	2
$\Delta kWh_{freezer}$, Annual kWh savings for main freezer doors	kWh	Table 3-140	2
$\Delta kW_{freezer}$, Summer and winter peak kW savings for main freezer doors	kW	Table 3-140	2

Default Savings

Table 3-140: Refrigeration Auto Closers Deemed Savings

Climate Zone	Reference Cities	Cooler/Unknown		Freezer	
		kWh_{cooler}	kW_{cooler}	$kWh_{freezer}$	$kW_{freezer}$
4A	Harrisburg; Philadelphia	1,363	0.463	2,810	0.488
5A	Allentown; Binghamton, NY; Bradford; Erie; Pittsburgh; Scranton; Williamsport	959	0.463	2,212	0.488

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of deemed values.

Sources

1) California Electronic Technical Reference Manual. “Auto-Closer for Walk-In Cooler/Freezer Doors” listed in the CPUC Support Table “Effective Useful Life and Remaining Useful Life”. Accessed December 2023. Weblink

2) Southern California Edison. (2017, October). “Refrigerated Storage Auto Closer”, Workpaper SCE17RN024, Measure R79 (Cooler) & R80 (Freezer). Weblink

3) California’s 16 climate zones referenced in this measure are those established by the California Energy Commission. Weblink. The two referenced Pennsylvania climate zones referenced in this measure (zone 4A and 5A) are those established by the 2021 IECC. Weblink

3.5.11. Door Gaskets for Walk-in and Reach-in Coolers and Freezers

Target Sector	Commercial and Industrial
Measure Unit	Door Gasket
Measure Life	3 years Source 1
Measure Vintage	Replace on Burnout

The following protocol for the measurement of energy and demand savings is applicable to commercial refrigeration and applies to the replacement of worn-out or missing gaskets with new gaskets, However, it is only applicable to commercial facilities without an existing maintenance contract that addresses gaskets. Applicable gaskets include those located on the doors of walk-in and/or reach-in coolers and freezers.

Tight fitting gaskets inhibit infiltration of warm, moist air into the cold refrigerated space, thereby reducing the cooling load. Aside from the direct reduction in cooling load, the associated decrease in moisture entering the refrigerated space also helps prevent frost on the cooling coils. Frost build-up adversely impacts the coil's heat transfer effectiveness, reduces air passage (lowering heat transfer efficiency), and increases energy use during the defrost cycle. Therefore, replacing defective door gaskets reduces compressor run time and improves the overall effectiveness of heat removal from a refrigerated cabinet.

Eligibility

This protocol applies to the main doors of both low-temperature ("freezer" – below 32°F) and medium-temperature ("cooler" – above 32°F) walk-in and reach-in refrigeration equipment.

Algorithms

The demand and energy savings assumptions are based on a door gasket replacement measure maintained by the RTF. Source 2 Peak demand savings are expected to be largely uniform across both summer and winter peak periods; therefore, peak demand savings (ΔkW_{peak}) apply to both summer and winter peak periods.

The energy savings and demand reduction are obtained through the following calculations:

$$\Delta kWh = \frac{\Delta kWh}{Door} \times Doors$$

$$\Delta kW_{peak} = \frac{\Delta kW}{Door} \times Doors$$

Definition of Terms

Table 3-141: Terms, Values, and References for Door Gaskets

Term	Unit	Values	Source
$\frac{\Delta kWh}{Door}$, Annual energy savings per gasket door	$\frac{\Delta kWh}{Door}$	Table 3-142	2
$\frac{\Delta kW}{Door}$, Demand savings per gasket door	$\frac{\Delta kW}{Door}$	Table 3-142	2
Doors, Total number of door gaskets replaced	*Doors*	As Measured	EDC Data Gathering

Default Savings

The deemed savings values below are drawn from the same RTF door gasket replacement measure.Source 2 Energy and demand savings are derived from a mixture of logger data, a commercial building baseline study, and ASHRAE specifications. Savings for freezers and walk-in equipment are higher than savings for coolers and reach-ins, respectively.

Table 3-142: Deemed Door Gasket Savings Per Door for Walk-in and Reach-in Coolers and Freezers

Type	Coolers		Freezers	
	$\Delta kW/Door$	$\Delta kWh/Door$	$\Delta kW/Door$	$\Delta kWh/Door$
Reach-in	0.015	118	0.026	211
Walk-in	0.049	394	0.089	711

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of deemed values.

Sources

1) California Electronic Technical Reference Manual. “Door Gaskets on Cooler/Freezer Doors” listed in the CPUC Support Table “Effective Useful Life and Remaining Useful Life”. Accessed December 2023. Weblink

2) Database for UES Measures, Regional Technical Forum. (2019, Version 2.0). “Door Gasket Replacement”. Weblink

3.5.12. Special Doors with Low or No Anti-Sweat Heat for Reach-In Freezers and Coolers

Target Sector	Commercial and Industrial
Measure Unit	Per Door
Measure Life	12 years Source 1
Measure Vintage	Retrofit

Traditional clear glass display case doors consist of two-pane glass (three-pane in low and medium temperature cases), aluminum doorframes, and door rails. Glass heaters may be included to eliminate condensation on the door or glass. The door heaters are traditionally designed to overcome the highest humidity conditions as cases are built for nationwide applications. New low heat/no heat door designs incorporate heat reflective coatings on the glass, gas inserted between the panes, non-metallic spacers to separate the glass panes, and/or non-metallic frames (such as fiberglass). Using low-heat or no-heat doors can reduce the energy consumption of the case by using lower wattage heaters or a reduced number of total heaters per door. The savings results from reduced electric energy consumed by the heaters, and from the reduced cooling load on the refrigeration system.

This protocol documents the energy savings attributed to the installation of special glass doors with low/no anti-sweat heaters for reach-in coolers or freezers.

Eligibility

For this measure, a no-heat/low-heat clear glass door must be installed on an upright display case. It is limited to door heights of 57 inches or more. Doors must have either heat reflective treated glass, be gas filled, or both. The baseline is assumed to be standard energy doors.

Algorithms

The energy savings and demand reduction are obtained through the following algorithms. Peak demand savings are expected to be largely uniform across both summer and winter peak periods; therefore, peak demand savings (ΔkW_{peak}) apply to both summer and winter peak periods.

$$\Delta kWh = \frac{1}{1{,}000} \times (Watts_{base} - Watts_{ee}) \times \left(1 + \frac{1}{COP}\right) \times HOU$$

$$\Delta kW_{peak} = \frac{\Delta kWh}{HOU}$$

Definition of Terms

Table 3-143: Terms, Values, and References for Special Doors with Low or No Anti-Sweat Heat

Term	Unit	Values	Source
$\frac{1}{1{,}000}$, Conversion from watts to kW	$\frac{kW}{W}$	$\frac{1}{1{,}000}$	Conversion factor
$Watts_{base}$, Wattage of standard door heaters, per door	*W*	Nameplate Input Wattage	EDC Data Gathering
		Default: Cooler: 20 Freezer: 71	2
$Watts_{ee}$, Wattage of low-heat or no-heat doors, per door	*W*	Nameplate Input Wattage	EDC Data Gathering
		Default: Cooler: 12 Freezer: 28	2
COP, Coefficient of performance	*None*	Cooler: 2.04 Freezer: 1.25	3
HOU, Annual hours of use	*Hours*	EDC Data Gathering Default: 8,760	Conversion factor

Default Savings

Table 3-144: Default Savings per Door with Low or No Anti-Sweat Heat for Reach-In Coolers and Freezers

Type	$\Delta kWh/Door$	$\Delta kW_{peak}/Door$
Cooler (medium temperature)	93.3	0.011
Freezer (low temperature)	674	0.077

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Zero Heat Reach-in Glass Doors" listed in the CPUC Support Table "Effective Useful Life and Remaining Useful Life". Accessed January 2024. Weblink

2) Default values derived from a review of anti-sweat heater wattage data listed in three commercial refrigeration manufacturers' (Hillphoenix, Hussmann, and Zero-Zone) equipment specification sheets as of January 2024.

3) U.S. Department of Energy. (2009, September). Energy Savings Potential and R&D Opportunities for Commercial Refrigeration. Page 116, Table 4-4. Weblink

3.5.13. Suction Pipe Insulation for Walk-In Coolers and Freezers

Target Sector	Commercial and Industrial
Measure Unit	Per Linear Foot of Insulation
Measure Life	11 years Source 1
Measure Vintage	Retrofit

This measure applies to the installation of insulation on existing bare suction lines (the larger diameter lines that run from the evaporator to the compressor) that are located outside of the refrigerated space for walk-in coolers and freezers. Insulation impedes heat transfer from the ambient air to the suction lines, thereby reducing undesirable system superheat. This decreases the load on the compressor, resulting in decreased compressor operating hours, and energy savings.

Eligibility

This protocol documents the energy savings attributed to insulation of bare refrigeration suction pipes. The following are the eligibility requirements:

- Must insulate bare refrigeration suction lines 1-5/8 inches in diameter or less on existing equipment only;
- Medium temperature lines require 3/4 inch flexible, closed-cell, nitrite rubber or an equivalent insulation;
- Low temperature lines require 1-inch flexible, closed-cell, nitrite rubber or an equivalent insulation; and
- Insulation exposed to the outdoors must be protected from the weather (i.e. jacketed with a medium-gauge aluminum jacket).

Algorithms

The energy savings assumptions are based analysis performed by Southern California Edison (SCE), which calculated measure savings per linear foot of insulation installed on bare suction lines for both low and medium temperature refrigeration applications across California's 16 climate zones.[Source 1] Measure savings from California weather locations were applied to Pennsylvania weather locations based on a CDD regression analysis.

$$\Delta kWh = \frac{\Delta kWh}{ft} \times L$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_s$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_w$$

Definition of Terms

Table 3-145: Terms, Values, and References for Insulate Bare Refrigeration Suction Pipes

Term	Unit	Values	Source
$\frac{\Delta kWh}{ft}$, Annual energy savings per linear foot of insulation	$\frac{\Delta kWh}{ft}$	Table 3-146	2
$ETDF_s$, Summer energy to demand factor	$\frac{kW}{kWh}$	0.0000346	3
$ETDF_w$, Winter energy to demand factor	$\frac{kW}{kWh}$	0.0000274	3
L, Total insulation length	*ft*	As Measured	EDC Data Gathering

Default Savings

Table 3-146 shows default savings per linear foot for this measure. To calculate annual energy savings and peak demand savings, multiply the values shown by the total insulation length (L).

Table 3-146: Deemed Bare Refrigeration Suction Pipe Insulation Savings per Linear Foot

City	Medium-Temperature Walk-in Coolers			Low-Temperature Walk-in Freezers		
	ΔkW/ft		ΔkWh/ft	ΔkW/ft		ΔkWh/ft
	Summer	Winter	-	Summer	Winter	-
Allentown	0.00146	0.00116	42.1	0.00430	0.00341	124.3
Binghamton, NY	0.00113	0.00089	32.6	0.00356	0.00282	103.0
Bradford	0.00107	0.00085	30.9	0.00343	0.00272	99.1
Erie	0.00133	0.00106	38.5	0.00402	0.00319	116.2
Harrisburg	0.00155	0.00123	44.9	0.00452	0.00358	130.6
Philadelphia	0.00166	0.00132	48.0	0.00475	0.00377	137.5
Pittsburgh	0.00136	0.00108	39.3	0.00408	0.00324	118.1
Scranton	0.00135	0.00107	39.1	0.00407	0.00323	117.6
Williamsport	0.00136	0.00108	39.4	0.00409	0.00325	118.3

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Bare Suction Line Insulation". Accessed January 2024. Weblink

2) Southern California Edison Company. (2016, February) "Insulation of Bare Refrigeration Suction Lines", Work Paper SCE13RN003 Revision 1. Weblink

3) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.5.14. Refrigerated Display Cases with Doors Replacing Open Cases

Target Sector	Commercial and Industrial
Measure Unit	Refrigerated Display Case
Measure Life	12 years [Source 1]
Measure Vintage	Early Replacement

This measure considers the replacement of existing vertical open display cases with new closed display cases. The baseline equipment is an average existing medium temperature vertical open display case. The doors on the new cases must be no sweat (also known as zero heat). The display cases should be medium temperature (typically for dairy, meats, or beverages) as opposed to low temperature (typically for frozen food and ice cream). This calculation quantifies the infiltration savings seen by the compressor and interactive effects seen by the building's HVAC system. Lighting or other upgrades should be considered as separate projects.

Eligibility

The eligible equipment is a new case with no sweat doors that meets federal standard requirements.[Source 2] If a lighting retrofit is included with the new case, it must consume the same amount of energy or less than the old lighting. Upgrades to lighting or other system components should be processed separately. Horizontal cases are not eligible and should be processed as custom.

Algorithms

The energy savings and demand reduction are obtained through the following algorithms. Demand savings assume flat energy savings throughout the day but include seasonal interactive effects.

$$\Delta kWh = \left[\Delta kWh_{case} - \left(\frac{\Delta CLR \times EFLH_{cool}}{IEER \times 1{,}000}\right) + \left(\frac{\Delta CLR \times EFLH_{heat}}{COP \times 3.412 \times 1{,}000}\right)\right] \times W$$

$$\Delta kW_{summer\ peak} = \left[\frac{\Delta kWh_{case}}{8{,}760} - \left(\frac{\Delta CLR}{IEER \times 1{,}000}\right)\right] \times W$$

$$\Delta kW_{winter\ peak} = \left[\frac{\Delta kWh_{case}}{8{,}760} + \left(\frac{\Delta CLR}{COP \times 3.412 \times 1{,}000}\right)\right] \times W$$

DEFINITION OF TERMS

Table 3-147: Terms, Values, and References for Refrigerated Display Cases with Doors Replacing Open Cases

Term	Unit	Values	Source
ΔkWh_{case}, Deemed energy savings per linear foot of case width	$\frac{kWh}{ft}$	404.4	3
W, Width of case opening in feet	*ft*	EDC Data Gathering	EDC Data Gathering
ΔCLR, Cooling load reduction of display case, per foot of display case width	$\frac{Btu/hr}{ft}$	722	3
$EFLH_{cool}$, Equivalent full load hours of cooling performed by the building HVAC system	$\frac{Hours}{Year}$	Table 3-25: Cooling EFLHs for Pennsylvania Cities	4
IEER, Integrated energy efficiency ratio of the building HVAC system. For air-source AC and ASHP units < 65,000 $\frac{Btu}{hr}$, SEER should be used for cooling savings	$\frac{Btu/hr}{W}$	HVAC Equipment Nameplate	EDC Data Gathering
		Default: Table 3-24,: HVAC Baseline Efficiencies	5
1,000, conversion factor	$\frac{W}{kW}$	1,000	Conversion factor
$EFLH_{heat}$, Equivalent full load hours of heating performed by the building HVAC system	$\frac{Hours}{Year}$	Table 3-28: Heating EFLHs for Pennsylvania Cities	4
COP, coeffient of performance of the building HVAC system. This is applicable for electric heating systems only. For air-source ASHP units < 65,000 $\frac{Btu}{hr}$, use COP = HSPF / 3.412.	$\frac{Btu/hr}{W}$	HVAC Equipment Nameplate	EDC Data Gathering
		Default: Table 3-24: HVAC Baseline Efficiencies	5, 6
8,760, Operating hours per year	*Hours*	8,760	Conversion factor

EVALUATION PROTOCOLS

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. “New Case With Doors” listed in the CPUC Support Table “Effective Useful Life and Remaining Useful Life”. Accessed December 2023. Weblink
2) 10 CFR 431.66(e). Weblink
3) Fricke, Brian and Becker, Bryan. (2010). "Energy Use of Doored and Open Vertical Refrigerated Display Cases". International Refrigeration and Air Conditioning Conference. Values derived from Table 1 and the relative width of the display cases used in the study (without anti-sweat heaters). Energy savings assume 365.25 days of annual operation. Demand savings assume consistent energy savings throughout the day. The study found that replacing a 24-foot refrigerated open display case with a 24-foot doored display case resulted in reducing the cooling load by 72%: 7,027 – 25,082) / 25,082 = 72%. Therefore, the cooling load reduction per foot of display case is (25,082 / 24) × 72% = 722 BTU/hr-ft. Weblink
4) EFLHs for Pennsylvania are calculated based on Nexant’s eQuest modeling analysis 2014.
5) International Energy Conservation Code 2021. Table C403.3.2(1) Weblink
6) U.S. Department of Energy. 10 CFR Part 431. Energy Efficiency Standards and their compliance dates. Weblink

3.5.15. Adding Doors to Existing Refrigerated Display Cases

Target Sector	Commercial and Industrial
Measure Unit	Refrigerated Display Case
Measure Life	12 years Source 1
Measure Vintage	Retrofit

This measure considers adding doors to existing vertical open display cases. The baseline equipment is an existing vertical display case of medium temperature with no doors. The display cases should be medium temperature (typically for dairy, meats, or beverages) as opposed to low temperature (typically for frozen food and ice cream). The added doors may be no sweat (also known as zero heat) or they may contain anti-sweat heaters. This calculation quantifies infiltration savings which are realized at the compressor due to reduced load and interactive effects with the building's HVAC system. Lighting or other upgrades should be considered as separate projects.

Eligibility

The eligible retrofit equipment is either no sweat doors or doors with anti-sweat heaters. If a lighting retrofit is included with the new doors, it must consume the same amount of energy or less energy than the old lighting. Upgrades to lighting or other system components should be processed separately. Horizontal cases are not eligible and should be processed as custom.

Algorithms

Algorithms for annual energy savings and peak demand savings are shown below. Demand savings assume flat energy savings throughout the day but include seasonal interactive effects.

$$\Delta kWh = \left[\left(ESF \times kWh_{comp} \times Days\right) - \left(\frac{\Delta CLR \times EFLH_{cool}}{IEER \times 1{,}000}\right) + \left(\frac{\Delta CLR \times EFLH_{heat}}{COP \times 3.412 \times 1{,}000}\right)\right] \times W$$

$$\Delta kW_{summer\ peak} = \left[\frac{\left(ESF \times kWh_{comp} \times Days\right)}{8{,}760} - \left(\frac{\Delta CLR}{IEER \times 1{,}000}\right)\right] \times W$$

$$\Delta kW_{winter\ peak} = \left[\frac{\left(ESF \times kWh_{comp} \times Days\right)}{8{,}760} + \left(\frac{\Delta CLR}{COP \times 3.412 \times 1{,}000}\right)\right] \times W$$

Definition of Terms

Table 3-148: Terms, Values, and References for Adding Doors to Refrigerated Display Cases

Term	Unit	Values	Source
ESF, Energy savings factor. Percent of baseline energy consumption saved by adding doors.	$None$	Default without anti-sweat heaters: 72% Default with anti-sweat heaters: 37%	2
kWh_{comp}, Average daily compressor energy usage per linear foot of display case	$\frac{kWh/day}{ft}$	EDC Data Gathering Default = 1.76	2
$Days$, Annual days of operation	$Days$	EDC Data Gathering Default = 365.25	EDC Data Gathering
ΔCLR, Cooling load reduction of display case, per foot of display case width	$\frac{Btu/hr}{ft}$	722	2
$EFLH_{cool}$, Equivalent full load hours of cooling performed by the building HVAC system	$\frac{Hours}{Year}$	Table 3-25	3
IEER, Integrated energy efficiency ratio of the building HVAC system. For air-source AC and ASHP units < 65,000 $\frac{Btu}{hr}$, SEER should be used for cooling savings	$\frac{Btu/hr}{W}$	HVAC Equipment Nameplate	EDC Data Gathering
		Default: Table 3-24	4
1,000, conversion factor	$\frac{W}{kW}$	1,000	Conversion factor
$EFLH_{heat}$, Equivalent full load hours of heating performed by the building HVAC system	$\frac{Hours}{Year}$	Default: Table 3-28	3
COP, coeffient of performance of the building HVAC system. This is applicable for electric heating systems only. For air-source ASHP units < 65,000 $\frac{Btu}{hr}$, use COP = HSPF / 3.412.	$\frac{Btu/hr}{W}$	HVAC Equipment Nameplate	EDC Data Gathering
		Default: Table 3-24	4, 5
W, Width of case opening in feet	*ft*	EDC Data Gathering	EDC Data Gathering
8,760, Operating hours per year	$Hours$	8,760	Conversion factor

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Zero Heat Reach-in Glass Doors" listed in the CPUC Support Table "Effective Useful Life and Remaining Useful Life". Accessed December 2023. Weblink
2) Fricke, Brian and Becker, Bryan, "Energy Use of Doored and Open Vertical Refrigerated Display Cases" (2010). International Refrigeration and Air Conditioning Conference. Paper 1154. For a 24-ft open display case line-up, average daily compressor energy consumption was 42.20 kWh (Table 1), or 1.76 kWh/ft. For a 24-ft closed display case line-up, average daily compressor energy consumption was 11.70 kWh (Table 1). Thus, adding doors to a refrigerated display case results in a 72% reduction in compressor power demand: 11.70 – 42.20 / 42.20 = 72%. The average daily energy consumption of anti-sweat heaters is estimated to be 0.61 kWh/ft – about 35% of baseline compressor energy usage. The ESF is then estimated to be 37% (72% - 35%) in cases where anti-sweat heaters are added. The study also found that replacing a 24-foot refrigerated open display case with a 24-foot doored display case resulted in reducing the cooling load by 72%: 7,027 – 25,082) / 25,082 = 72%. Therefore, the cooling load reduction per foot of display case is (25,082 / 24) × 72% = 722 BTU/hr-ft. Weblink
3) EFLHs for Pennsylvania are calculated based on Nexant's eQuest modeling analysis 2014.
4) International Energy Conservation Code 2021. Table C403.3.2(1) Weblink
5) U.S. Department of Energy. 10 CFR Part 431. Energy Efficiency Standards and their compliance dates Weblink

3.5.16. Air-Cooled Refrigeration Condenser

Target Sector	Commercial and Industrial
Measure Unit	Refrigeration Condenser
Measure Life	15 years Source 1
Measure Vintage	Replace on Burnout, Early Replacement, Retrofit, New Construction

This measure involves installing an efficient, close-approach ("Approach" or "TD" refers to the temperature difference between the design condensing temperature and the design ambient outdoor temperature) air-cooled refrigeration system condenser, which saves energy by reducing condensing temperatures and improving the efficiency of the condenser fan system.

Eligibility

This protocol documents energy savings attributed to providing an efficient air-cooled refrigeration system condenser for commercial and industrial refrigeration applications. This measure requires new equipment with an approach temperature of 13ºF or less on low-temperature applications and an approach temperature of 8ºF or less on medium-temperature applications. Specific fan power must be greater than or equal to 85 Btu/hr of heat rejection capacity per watt of fan power.

Algorithms

The baseline condition is assumed to be a standard efficiency air-cooled refrigeration system condenser with a 20ºF approach temperature on low-temperature applications and a 15ºF approach temperature on medium-temperature applications. The baseline equipment incorporates a fan with 45 Btu/hr of heat rejection capacity per watt of fan power. The unit energy savings and peak demand reduction are obtained through the following formulas and applies to both summer and winter:

$$\Delta kWh = \frac{tons}{unit} \times \frac{\Delta kWh}{ton}$$

$$\Delta kW_{peak} = \frac{tons}{unit} \times \frac{\Delta kW}{ton}$$

Definition of Terms

Table 3-149: Terms, Values, and References for Air-Cooled Refrigeration Condensers

Term	Unit	Values	Source
$tons/unit$, Capacity of refrigeration system compressor	*Tons*	EDC Data Gathering	-
$\frac{\Delta kWh}{ton}$, Change in unit energy consumption	*kWh/ton*	Default: Table 3-150	2
$\frac{\Delta kW}{ton}$, Change in unit power demand	*kW/ton*	Default: Table 3-150	2

Default Savings

The unit energy and peak demand savings per ton of compressor capacity were approximated for Pennsylvania cities based on an extrapolation from New York state data, calculated from a DOE-2.2 simulation of a prototypical grocery store, which include refrigerated and non-refrigerated food sales convenience stores and specialty food sales.[Source 2] The New York TRM assumes that grocery stores and convenience stores are the primary application for this measure, which is a reasonable assumption for applications in Pennsylvania as well. The energy savings were modified using proxy variables for outdoor air temperature, which has a direct effect on the energy savings that can be achieved with this measure using a linear regression model. The proxy variables, chosen as heating and cooling equivalent full-load hours (EFLH, as defined Table 3-25), were used to approximate the relationship between the projected energy savings in New York cities and the outdoor temperature in those cities. Using a linear regression analysis, data was extrapolated to estimate the energy savings that can be achieved in Pennsylvania cities. For peak demand reduction, a similar methodology was used, applying EFLH cooling data only, as peak demand reduction occurs during cooling season. The unit energy and peak demand savings per ton of capacity for seven different cities (grocery/convenience stores only) in Pennsylvania are shown below. The EDC should use the system capacity data collected to derive the final savings estimate.

Table 3-150: Default Savings for Air-Cooled Refrigeration Condensers

City	Annual Energy Savings per Ton of Capacity ($\triangle \text{kWh}/_{\text{ton}}$)	Peak Demand Savings per Ton of Capacity ($\triangle \text{kW}/_{\text{ton}}$)
Allentown	1,307	0.1252
Binghamton	1,290	0.1430
Bradford	1,296	0.1429
Erie	1,318	0.1244
Harrisburg	1,318	0.1171
Philadelphia	1,312	0.1204
Pittsburgh	1,308	0.1245
Scranton	1,318	0.1164
Williamsport	1,323	0.1167

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. “Efficient Adiabatic Condenser”. Accessed month year. Weblink

2) New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs. (2024, Version 11). Weblink

3.5.17. Refrigerated Case Light Occupancy Sensors

Target Sector	Commercial and Industrial
Measure Unit	Per watt of controlled lighting
Measure Life	8 years Source 1
Measure Vintage	Retrofit or New Construction

This protocol documents the energy savings attributed to installing occupancy sensors to control LED refrigerated case lighting. Energy savings can be achieved from the installation of sensors which dim or turn off the lights when the space or aisle is unoccupied. Energy savings result from a combination of reduced lighting energy as well reduced cooling load within the case.

Eligibility

This measure requires the installation of motion-based lighting controls that allow the LED case lighting to be dimmed or turned off completely during unoccupied conditions. Eligible controls dim the LED case lighting to at most 50% of full lighting power when the space is unoccupied.

Algorithms

The algorithm shown below shall be used to calculate the annual energy savings for this measure. There are no peak demand savings associated with this measure, as the savings are assumed to occur off-peak.

$$\Delta kWh = \frac{WATTS}{1{,}000} \times HOURS \times RRF \times (1 - Dim_{min}) \times (1 + IF_e)$$

$$\Delta kW_{summer\ peak} = 0$$

$$\Delta kW_{winter\ peak} = 0$$

Definition of Terms

Table 3-151: Terms, Values, and References for Refrigerated Case Light Occupancy Sensors

Term	Unit	Values	Source
$WATTS$, Connected wattage of controlled refrigerated lighting fixtures	*W*	EDC Data Gathering	EDC Data Gathering
$HOURS$, Annual operating hours	*Hours/year*	EDC Data Gathering	EDC Data Gathering
		Default: 24-hr facilities = 8,760 18-hr facilities = 6,570	2
RRF, Runtime reduction factor	*None*	EDC Data Gathering	EDC Data Gathering
		Default: 24-hr facilities = 0.39 18-hr facilities = 0.29	2
Dim_{min}, Minimum dimming level to account for non-zero lighting load from dimmed case lighting	*None*	EDC Data Gathering	EDC Data Gathering
		Default: No dimming capabilities = 0% Dimming capabilities = 50%	3
IF_e, Interactive effects factor for energy to account for cooling savings from offset refrigeration load	*None*	High-temperature (40 °F – 60 °F) = 0.18 Medium-temperature (20 °F – 40 °F = 0.29 Freezer (-35 °F – 20 °F) = 0.50	4
$1{,}000$, Conversion factor	*W/kW*	1,000	Conversion factor

Default Savings

Default savings per controlled watt are shown below.

Table 3-152: Default annual energy (kWh) savings values, per watt of controlled lighting

Facility Operating Hours Per Day	Annual savings (kWh/W controlled lighting)		
	High-Temperature Application	Medium-Temperatur Application	Freezer Application
18 hr/day	2.2	2.4	2.8
24 hr/day	4.0	4.4	5.1

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation, watts of controlled lighting, and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of

TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Occupancy Sensors" listed in the CPUC Support Table "Effective Useful Life and Remaining Useful Life". Accessed December 2023. Weblink
2) Database for UES Measures, Regional Technical Forum. (2016, version 3.3). "Display Case Motion Sensors". Weblink
3) International Code Council. (2021). International Energy Conservation Code 2021, C405.2.3.1 Weblink
4) Table 3-5: Interactive Factors for Refrigerated Spaces

3.5.18. REFRIGERATION ECONOMIZERS

Target Sector	Commercial and Industrial
Measure Unit	Economizer
Measure Life	10 years Source 1
Measure Vintage	Retrofit

ELIGIBILITY

This measure applies to economizers installed on a walk-in refrigeration system. Economizers bring in outside air when weather conditions allow, rather than operating the compressor, thereby saving energy. This measure includes economizers with evaporator fan controls, with or without a circulation fan.

Walk-in refrigeration system evaporator fans run 24 hours per day (except during active defrost) for 365 days per year to provide cooling when the compressor is running and air circulation when the compressor is not running. However, evaporator fans are inefficient for air circulation, and it is more efficient to install an evaporator fan control system to turn off the evaporator fans when the compressor is not running and turn on an efficient 35-watt fan to provide air circulation.

ALGORITHMS

With Fan Control Installed

$$\Delta kWh = [HP \times kWh_{cond}] + \left[\left(\left(kW_{evap} \times N_{fans}\right) - kW_{Circ}\right) \times HRS \times DC_{Comp} \times BF\right] - [kW_{econ} \times DC_{econ} \times HRS]$$

$$\Delta kW_{summer\ peak} = 0\ kW \text{ Source 2}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_w$$

Without Fan Control Installed

$$\Delta kWh = [HP \times kWh_{cond}] - [kW_{econ} \times DC_{econ} \times HRS]$$

$$\Delta kW_{summer\ peak} = 0\ kW \text{ Source 2}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_w$$

DEFINITION OF TERMS

Table 3-153: Terms, Values, and References for Refrigeration Economizers

Term	Unit	Values	Source
HP, Horsepower of the compressor	*HP*	Nameplate	EDC Data Gathering
kWh_{cond}, Condensing unit savings, per hp	*kWh/HP*	Default values from Table 3-154	3
kW_{evap}, Connected load kW of each evaporator fan	*kW*	Nameplate Input Wattage	EDC Data Gathering
		Calculated value	Calculated value
N_{fans}, Number of fans	*None*	EDC Data Gathering	EDC Data Gathering
kW_{Circ}, Connected load of the circulating fan	*kW*	EDC Data Gathering	EDC Data Gathering
		Default: 0.035 kW	4
HRS, Annual hours that the economizer operates	$\frac{Hours}{Year}$	Default values from Table 3-154	5
DC_{Comp}, Duty cycle of the compressor	*None*	66%	6
BF, bonus factor for reduced cooling load from running the evaporator fan less	*None*	Default: 1.29	6
kW_{econ}, Connected load of the economizer fan	*kW*	Nameplate Input Wattage	EDC Data Gathering
		Default: 0.227 kW	7
DC_{econ}, Duty cycle of the economizer fan on days that are cool enough for the economizer to be working	*None*	EDC Data Gathering	EDC Data Gathering
		Default: 63%	8
$ETDF_w$, Winter energy to demand factor	*kW/kWh*	0.0001142	9

Default values for kWh_{cond} and HRS are shown in Table 3-154. If the type of compressor is unknown, EDCs may assume the “Discus” option for kWh_{cond}.

Table 3-154: Hours for Refrigeration Economizers

City	Hours	kWh Savings per HP		
		Hermetic / Semi-Hermetic	Scroll	Discus
Allentown	1,188	1,110	962	905
Binghamton	2,527	1,183	1,036	978
Bradford	2,654	1,190	1,043	985
Erie	1,656	1,135	988	930
Harrisburg	956	1,097	949	892
Philadelphia	362	1,064	917	859
Pittsburgh	1,618	1,133	986	928
Scranton	1,695	1,137	990	933
Williamsport	1,541	1,129	981	924

Evaluation Protocol

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. “Add Economizer” listed in the CPUC Support Table “Effective Useful Life and Remaining Useful Life”. Accessed December 2023. Weblink. There are limited resources available providing the expected useful life of a refrigeration economizer. Since a refrigeration economizer’s technology and use is analogous to economizers serving HVAC systems, the expected useful life for this measure references an HVAC economizer life.
2) Refrigeration economizers are assumed to not operate during high outdoor air temperature and humidity conditions, which occur during the summer peak demand period.
3) Analysis based on U.S. Weather Normals (2006-2020) bin data for each location. Assume 5HP compressor size used to develop kWh/HP value. No floating head pressure controls and compressor is located outdoors.
4) Wattage of fan used by Freeaire and Cooltrol. This fan is used to circulate air in the cooler when the evaporator fan is turned off. As such, it is not used when fan control is not present.
5) Economizer hours are based on a 38° F cooler setpoint, with a 5-degree economizer deadband. They were calculated by using U.S. Weather Normals (2006-2020) bin data for each location (number of hours < 33° F at each location is the Hours value).
6) Navigant Consulting Inc. for U.S. Department of Energy (2009, September) “*Energy Savings Potential and R&D Opportunities for Commercial Refrigeration,*”. Table 4-4: Walk-In Coolers.

Weblink. Compressor COP for walk-in coolers is 3.42 The bonus factor is calculated as (1 + 1/COP).

7) The 227 watts for an economizer is calculated from the average of three manufacturers: Freeaire (186 Watts), Cooltrol (285 Watts), and Natural Cool (218 Watts).

8) Average of two manufacturer estimates of 50% and 75%.

9) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.5.19. Food Service Equipment Novelty Cooler Shutoff

Target Sector	Commercial and Industrial
Measure Unit	Novelty Cooler Controller
Measure Life	10 years Source 1
Measure Vintage	Retrofit

Reach-in novelty coolers are often used by stores to position beverages for quick access and purchase. Some novelty coolers are not thermostatically regulated, but run on a continuous basis while plugged in. A novelty cooler shutoff timer can save energy in these cases by turning the cooler off while the store is closed for business.

Eligibility

This measure is applicable to existing reach-in novelty coolers with single-speed, self-contained, refrigeration compressors that run continuously when the device is powered on. The baseline device cannot modulate compressor speed or cycle the compressor to maintain a desired temperature. The efficient measure adds a control system feature to automatically shut off novelty coolers based on pre-set store operating hours. Based on programmed hours, the control mechanism shuts off the cooler at end of business and begins operation on reduced cycles. Regular operation begins the following day an hour before the start of business.

Algorithms

The annual electric energy savings and demand reduction are calculated according as follows:

$$\Delta kWh = \frac{V \times A \times PF}{1000} \times \sqrt{Phase} \times DC \times HoursOff \times Weeks$$

$$\Delta kW_{summer\ peak} = \text{Assumed } 0, \text{or}$$

$$= \frac{V \times A \times PF}{1000} \times \sqrt{Phase} \times DC \times CF_{summer}$$

$$\Delta kW_{winter\ peak} = \text{Assumed } 0, \text{or}$$

$$= \frac{V \times A \times PF}{1000} \times \sqrt{Phase} \times DC \times CF_{winter}$$

Definition of Terms

Table 3-155: Terms, Values, and References for HVAC Systems

Term	Unit	Values	Source
V, unit rated voltage	$Volts$	Nameplate data	EDC Data Gathering
A, unit rated amps	Amp	Nameplate data	EDC Data Gathering
PF, power factor	$None$	0.85	2

Term	Unit	Values	Source
$Phase$, the phase of the refrigerator (1 for single phase and 3 for 3-phase)	$None$	Nameplate data	EDC Data Gathering
DC, compressor duty cycle	$None$	0.45	3
$Weeks$	Weeks/year	52	Calendar
$HoursOff$, weekly hours that cooler is shut off by timer	Hours/week	Verify the controller settings or calculated assuming the novelty cooler shutoff turns the cooler on one hour before the store opens and turns the cooler off as the store closes.	EDC Data Gathering
CF_{summer}, summer coincidence factor	*None*	Assumed 0 without data gathering The fraction of hours during the summer peak demand window (June-August weekdays from 2 PM to 6 PM) that the cooler is shut off by the controller.	EDC Data Gathering
CF_{winter}, winter coincidence factor	*None*	Assumed 0 without data gathering The fraction of hours during the winter peak demand window (January-February, weekdays 7am to 9am and 6pm to 8pm) the cooler is shut off by the controller.	EDC Data Gathering

Evaluation Protocols

The appropriate evaluation protocol is to verify that the novelty cooler shutoff is installed, confirm weekly hours programmed in the off position, establish that the novelty cooler was not thermostatically (or otherwise) controlled, and that its baseline refrigeration system previously operated continuously at full speed while the device was powered.

Sources

1) Energy & Resource Solutions (2005). Measure Life Study – cooler shutoff retrofit. Prepared for The Massachusetts Joint Utilities.
2) Estimated value from National Resource Management (NRM) based on their experience of monitoring the equipment at various sites.
3) Duty Cycles are consistent with third-party study done by Select Energy for NSTAR "Cooler Control Measure Impact Spreadsheet User's Manual," page 5, March 9, 2004

3.6. APPLIANCES

3.6.1. ENERGY STAR CLOTHES WASHER

Target Sector	Commercial and Industrial
Measure Unit	Clothes Washer
Measure Life	11.3 years for Multifamily; 7.1 years for Laundromats Source 1
Measure Vintage	Replace on Burnout

This protocol discusses the calculation methodology and the assumptions regarding baseline equipment, efficient equipment, and usage patterns used to estimate the annual energy and peak demand savings expected from the installation of an ENERGY STAR certified clothes washer in lieu of a standard clothes washer. ENERGY STAR certification requires a minimum Modified Energy Factor (MEFJ2) of ≥ 2.2 $(ft^3 \times cycle)/kWh$.Source 2 The Federal efficiency standard is ≥ 1.35 $(ft^3 \times cycle)/kWh$ for Top Loading washers and ≥ 2.0 $(ft^3 \times cycle)/kWh$ for Front Loading washers.Source 1

ELIGIBILITY

This protocol documents the energy and peak demand savings attributed to ENERGY STAR certified clothes washers or better in small commercial applications. This protocol is limited to clothes washers in laundry rooms of multifamily complexes and commercial laundromats. ENERGY STAR certification of commercial clothes washers is limited to units with capacities greater than 1.6 ft^3 and less than 8.0 ft^3. There are no ENERGY STAR certified top-loading commercial clothes washers, so this measure is only applicable to front-loading washers.

ALGORITHMS

The general form of the equation for the ENERGY STAR Clothes Washer measure savings algorithm is:

$$Total\ Savings = Number\ of\ Clothes\ Washers \times Savings\ per\ Clothes\ Washer$$

To determine resource savings, the per-unit estimates in the algorithms will be multiplied by the number of clothes washers.

Per unit energy and peak demand savings are obtained through the following calculations:

$$\Delta kWh = N * \left[\left(HE_{t,base} - HE_{t,ee}\right) \times P_{WH} + \left(ME_{t,base} - ME_{t,ee}\right) * P_W + \left(D_{e,base} - D_{e,ee}\right) * P_D\right]$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_s$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_w$$

Where:

$D_{e,base}$ $= LAF \times WGHT_{max} \times DEF \times DUF \times (\mathrm{RMC_{base}} - 4\%)$

$D_{e,ee}$ $= LAF \times WGHT_{max} \times DEF \times DUF \times (\mathrm{RMC_{ee}} - 4\%)$

$\mathrm{RMC_{base}}$ $= (-\,0.156 \times MEF_{J2,base}) + 0.734$

$\mathrm{RMC_{ee}}$ $= (-\,0.156 \times MEF_{J2,ee}) + 0.734$

$HE_{t,base}$ $= \left(\frac{Cap}{MEF_{J2,base}}\right) - ME_t - D_{e,base}$

$HE_{t,ee}$ $= \left(\frac{Cap}{MEF_{J2,ee}}\right) - ME_t - D_{e,ee}$

The algorithms used to calculate energy savings are taken from the Energy Conservation Program: Test Procedures for Clothes Washers; Final rule.[Source 3] Commercial clothes washer per-cycle energy consumption is composed of three components: water-heating energy, machine energy, and drying energy. DOE established the annual energy consumption of commercial clothes washers by multiplying the per-cycle energy and water use by the number of cycles per year.

In the above equations, MEF_{J2} is the Modified Energy Factor, which is the energy performance metric for clothes washers. MEF_{J2} is defined as:

> *MEF_{J2} is the quotient of the capacity of the clothes container, C, divided by the total clothes washer energy consumption per cycle, with such energy consumption expressed as the sum of the machine electrical energy consumption, M, the hot water energy consumption, E, and the energy required for removal of the remaining moisture in the wash load, D. The higher the value, the more efficient the clothes washer is. The equation is shown below, and the metric units are ft3/kWh/cycle:*
>
> $MEF_{J2} = \frac{C}{M+E+D}$. [Source 2]

The following steps should be taken to determine per-cycle energy consumption for front-loading commercial clothes washers for both baseline and ENERGY STAR clothes washers. Per-cycle energy use is disaggregated into water heating, machine, and clothes drying.

1) Calculate the remaining moisture content (RMC) based on the relationship between RMC and MEF.
2) Calculate the per-cycle clothes-drying energy use using the equation that determines the per-cycle energy consumption for the removal of moisture.
3) Use the per-cycle machine energy use value of 0.133 $kWh/cycle$ for MEFs up to 1.40 and 0.114 $kWh/cycle$ for MEFs greater than 1.40.[Source 1]
4) With the per-cycle clothes dryer and machine energy known, determine the per-cycle water-heating energy use by first determining the total per-cycle energy use (the clothes container volume divided by the MEF) and then subtracting from it the per-cycle clothes-drying and machine energy.

The Energy to Demand Factor (ETDF) is the average energy consumption (or savings) during peak hours divided by the total annual energy use (or savings). ETDFs for commercial clothes washers were derived as follows:

(1) Obtain hourly load shapes for multi-family (5+ units) clothes washers and dryers. This data can be found through the National Renewable Energy Laboratory (NREL). NREL provides end-use profiles for a variety of residential and commercial measures, including clothes washers and dryers.
(2) Normalize the load shapes to the total annual energy use (or savings).
(3) Average the normalized energy use during peak winter or summer hours to arrive at the winter or summer ETDF.

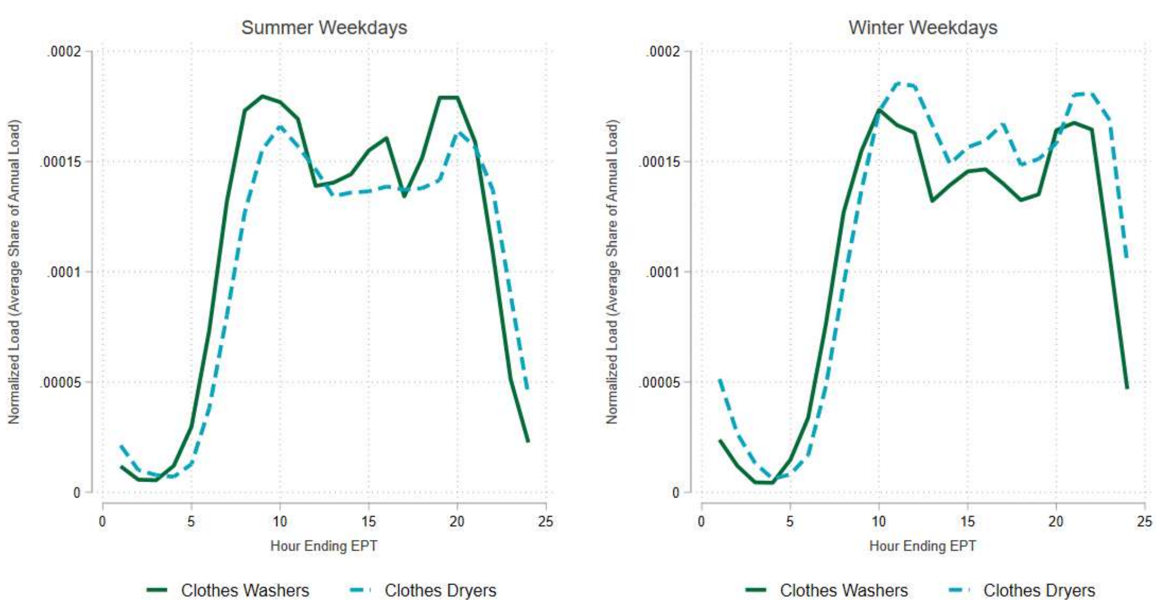
Table 3-156 shows the winter and summer ETDFs for Pennsylvania. The load shapes are taken from NREL's 2022 TMY (typical meteorological year) release of residential end-use profiles, Furthermore, the ETDFs are calculated using load shapes from only multifamily (5+ units) buildings. We can average clothes washer and dryer ETDFs to obtain a single ETDF for summer and winter as the two load shapes are similar.

Table 3-156: Summer and winter ETDFs for clothes washers and clothes dryers

Season	Clothes Washer	Clothes Dryer	Average
Summer Peak	0.0001507	0.0001378	0.0001443
Winter Peak	0.0001462	0.0001343	0.0001403

Table 3-156 compares the daily normalized load shapes for summer and winter weekdays between clothes washers and dryers. The normalized load shapes for the two end uses are very similar (Figure 3-2).

Figure 3-2: Normalized Load Shape Comparison: Summer and Winter Weekdays



Definition of Terms

Table 3-157: Terms, Values, and References for Commercial Clothes Washers

Term	Unit	Values	Source
$MEF_{J2,base}$, Base Federal Standard Modified Energy Factor	$(ft^3 \times cycle)/kWh$	Front loading: 2.0	1
$MEF_{J2,ee}$, Modified Energy Factor of ENERGY STAR Qualified Washing Machine	$(ft^3 \times cycle)/kWh$	Nameplate	EDC Data Gathering
	None	Default: 2.2	2
$HE_{t,base}$, $HE_{t,ee}$ Per-cycle water heating consumption for baseline and energy efficient clothes washers	$\frac{kWh}{cycle}$	Calculation	EDC Data Gathering
$D_{e,base}$, $D_{e,ee}$ Per-cycle energy consumption for removal of moisture i.e. dryer energy consumption for baseline and energy efficient dryers	$\frac{kWh}{cycle}$	Calculation	EDC Data Gathering
$ME_{t,base}$, $ME_{t,ee}$ Per-cycle machine electrical energy consumption for baseline and energy efficiency clothes washers	$\frac{kWh}{cycle}$	0.14	3
Cap, Capacity of baseline and energy efficient clothes washer	ft^3	Nameplate	EDC Data Gathering
		Default: 3.62	5
LAF, Load adjustment factor	*None*	0.52	3
DEF, Nominal energy required for clothes dryer to remove moisture from clothes	$\frac{kWh}{lb}$	0.5	3
DUF, Dryer usage factor, percentage of washer loads dried in a clothes dryer	*None*	0.91	3
$WGHT_{max}$, Maximum test-load weight	$\frac{lbs}{cycle}$	14.1	3
RMC, Remaining moisture content	lbs	Calculation	EDC Data Gathering
N, Number of cycles per year	*Cycle*	Multifamily: 1,074 Laundromats: 1,483	1
$ETDF_s$, Summer energy to demand factor	*kW/kWh*	0.0001443	4
$ETDF_w$, Winter energy to demand factor	*kW/kWh*	0.0001543	4
P_D, Proportion of electric dryers	*None*	0.52	7
P_W, Proportion of electric clothes washers (100% in all scenarios)	*None*	1	EDC Data Gathering
P_{WH}, Proportion of electric water heaters	*None*	0.34	6

DEFAULT SAVINGS

The default savings for the installation of a washing machine with a MEFJ2 of 2.2 or higher is dependent on the energy source for the washer. Table 3-159 and Table 3-160 show savings for ENERGY STAR washing machines with different combinations of water heater and dryer types in multifamily buildings and laundromats. The values are based on the difference between the baseline front loading clothes washer meeting federal efficiency standards and that of an ENERGY STAR certified front loading washer of ≥ 2.2 $(ft^3 \times cycle)/kWh$. ENERGY STAR certified commercial clothes washers are only front-loading units as there are no top-loading commercial clothes washers that meet the standards. While there are top loading commercial machines on the market because this is a replace-on-burnout measure the front-loading washer federal minimum standard will be used as a comparison point.

For clothes washers where water heating and dryer fuel is not collected as a part of program delivery, calculate default savings using the algorithms below and EDC-specific fuel shares (if available) or the default statewide fuel shares provided in Table 3-158. Table 3-159 and Table 3-160 provide the calculated values by fuel configuration along with weighted average values calculated using the default fuel shares.

$$ESav_{cw} = kWh_{gwh-gd} \times (1 - \mathrm{P_{WH}}) \times (1 - \mathrm{P_D}) + kWh_{gwh-ed} \times (1 - \mathrm{P_{WH}}) \times (\mathrm{P_D}) + kWh_{ewh} \times (\mathrm{P_{WH}}) \times (1 - \mathrm{P_D}) + kWh_{ewh-ed} \times (\mathrm{P_{WH}}) \times (\mathrm{P_D})$$

Where:

kWh_{gwh-gd} = Energy savings for clothes washers with gas water heater and non-electric dryer fuel from tables below

kWh_{gwh-ed} = Energy savings for clothes washers with gas water heater and electric dryer fuel from tables below

kWh_{ewh-gd} = Energy savings for clothes washers with electric water heater and non-electric dryer fuel from tables below

kWh_{ewh-ed} = Energy savings for clothes washers with electric water heater and electric dryer fuel from tables below

Table 3-158: Default Fuel Shares for Water Heaters and Dryers

Equipment Type	Electric	Non-Electric
Water Heaters [Source 6]	49%	51%
Clothes Dryers [Source 7,8]	57%	42%

Table 3-159: Default Savings for Replacing Front-Loading Clothes Washer in Multifamily Buildings with ENERGY STAR Clothes Washer

Fuel Source	Cycles/ Year	Energy Savings (kWh)	Summer Peak Demand Savings (kW)	Winter Peak Demand Savings (kW)
Electric Hot Water Heater, Electric Dryer (kWh_{ewh-ed})	1,074	168	0.024	0.0234
Electric Hot Water Heater, Gas Dryer (kWh_{ewh-gd})	1,074	56	0.008	0.008
Gas Hot Water Heater, Electric Dryer (kWh_{gwh-ed})	1,074	112	0.016	0.016
Gas Hot Water Heater, Gas Dryer (kWh_{gwh-gd})	1,074	0	0	0
Default (49% Electric WH and 57% Electric Dryer)	1,074	91.23	0.013	0.013

Table 3-160: Default Savings for Replacing Front-Loading Clothes Washer in Laundromats with ENERGY STAR Clothes Washer

Fuel Source	Cycles/ Year	Energy Savings (kWh)	Summer Peak Demand Savings (kW)	Winter Peak Demand Savings (kW)
Electric Hot Water Heater, Electric Dryer (kWh_{ewh-ed})	1,483	232	0.034	0.033
Electric Hot Water Heater, Gas Dryer (kWh_{ewh-gd})	1,483	77	0.011	0.011
Gas Hot Water Heater, Electric Dryer (kWh_{gwh-ed})	1,483	154	0.022	0.022
Gas Hot Water Heater, Gas Dryer (kWh_{gwh-gd})	1,483	0	0	0
Default (49% Electric WH 57% Electric Dryer)	1,483	125.97	0.018	0.018

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) 10 C.F.R § 431.56 Weblink
2) U.S. EPA. (2021) Energy Star Clothes Washers Key Product Criteria. Weblink
3) 10 C.F.R § 430.23 Weblink
4) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink
5) U.S. EPA. ENERGY STAR Certified Clothes Washers. Accessed July 26, 2023. Weblink (Based on the average commercial clothes washer volume of all units)
6) Demand Side Analytics for the Pennsylvania Public Utility Commission. (2024, March). Pennsylvania Act 129 Non-Residential Baseline Study. Section 4, page 56, Table 20. Weblink
7) NMR Group for the Pennsylvania Public Utility Commission. (2024, March). Pennsylvania Statewide Act 129 2023 Residential Baseline Study. Section 9.8, page 161. Weblink. Combined data from the 2018 and 2023 residential baseline studies in order to calculate fuel shares for clothes dryers.
8) NMR Group for the Pennsylvania Public Utility Commission. (2018, February). Pennsylvania Statewide Act 129 2018 Residential Baseline Study. Section 9.8, page 121. Weblink

3.6.2. ENERGY STAR Bathroom Ventilation Fan in Commercial Applications

Target Sector	Commercial and Industrial
Measure Unit	Number of Fans Installed
Measure Life	12 years Source 1
Measure Vintage	Replace on Burnout, Early Replacement, Retrofit, New Construction

This protocol covers the energy and demand savings associated with installing ENERGY STAR certified bathroom ventilation fans to replace conventional bathroom ventilation fans in a non-residential application. ENERGY STAR certifies ventilation fans based on minimum efficacy (CFM/W) and maximum allowable sound level (sones). This certification may include fans that are appropriate for light commercial applications but does not include whole-house fans or attic ventilators.Source 2

Eligibility

This measure requires the installation of an ENERGY STAR certified bathroom ventilation fan in a commercial or industrial facility. See Table 3-161 for minimum efficacy and maximum sound level eligibility requirements.

Table 3-161: Criteria for ENERGY STAR Certified Bathroom Ventilation Fans Source 2

Product Type	Rated Airflow Range (CFM)	Minimum Efficacy Level (CFM/W)*	Maximum Allowable Sound Level (Sones)*
Bathroom and Utility Room Fans	10 – 89	2.8	2.0
	90 – 200	3.5	2.0
	201 - 500	4.0	3.0
*Products will meet requirements at all speeds, based on static pressure reference measurement as specified in Section 4.C. of the ENERGY STAR specification.Source 2			

Algorithms

The annual energy and peak demand savings are obtained through the following formulas:

$$\Delta kWh = CFM * \left(\frac{1}{\eta_{base}} - \frac{1}{\eta_{ee}}\right) \times HOU \times \frac{1}{1{,}000}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_w$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_s$$

The Energy to Demand Factor (ETDF) is the average energy consumption (or savings) during peak hours divided by the total annual energy use (or savings). ETDFs for commercial fans were derived as follows:

(1) Obtain hourly load shapes for commercial fans. This data can be found through the National Renewable Energy Laboratory (NREL). NREL provides end-use profiles for a variety of residential and commercial measures[Source 6].
(2) Normalize the load shapes to the total annual energy use (or savings).
(3) Average the normalized energy use during peak winter or summer hours to arrive at the winter or summer ETDF.

Table 3-162 shows the winter and summer ETDFs for Pennsylvania. The load shapes are taken from NREL's 2023 AMY (actual meteorological year) release of commercial end-use profiles. The ETDFs are calculated using load shapes for a variety of commercial building types with a floorspace-weighted average used to arrive at a single ETDF for summer and winter. The floor area is based off of NREL's floor area assumptions for modeling energy usage for commercial end uses.

Table 3-162. Summer and Winter Peak ETDFs for Commercial Fans

Building Type	Floor Area (million ft^2)	$ETDF_{summer}$	$ETDF_{winter}$
Full-Service Restaurant	57.3	0.0001565	0.0001305
Hospital	84.4	0.0001222	0.0001036
Large Hotel	66.70	0.0001847	0.0001175
Large Office	191.6	0.0001674	0.0001136
Medium Office	213.4	0.000156	0.0001244
Outpatient	63.4	0.0001509	0.0001266
Primary School	200.8	0.0001957	0.0001948
Quick Service Restaurant	7.2	0.0001572	0.0001339
Retail Standalone	175.7	0.0001633	0.0001241
Retail Strip Mall	291.2	0.0001853	0.0001143
Secondary School	128.5	0.000163	0.0001443
Small Hotel	16.89	0.0001837	0.000110
Small Office	197.3	0.0001769	0.0001345
Warehouse	573.3	0.000195	0.0001268
Weighted Average		**0.0001765**	**0.0001302**

Definition of Terms

Table 3-163: Terms, Values, and References for ENERGY STAR Bathroom Ventilation Fans

Term	Unit	Values	Source
CFM, Nominal capacity of the exhaust fan	CFM	EDC Data Gathering Default ranges in Table 3-164	3
η_{base}, Baseline fan efficacy	CFM/W	EDC Data Gathering Default = 2.6	4
η_{ee}, ENERGY STAR fan efficacy	CFM/W	EDC Data Gathering Default = 5.1	4
HOU, Annual hours of use	Hours/year	EDC Data Gathering Default = 2,870	5
$\frac{1}{1,000}$, watts to kilowatt conversion factor	$\frac{kW}{W}$	$\frac{1}{1,000}$	Conversion factor
$ETDF_w$, Winter energy to Demand Factor	kW/kWh	0.0001302	6
$ETDF_s$, Summer energy to Demand Factor	kW/kWh	0.0001765	6

Default Savings

Table 3-164: Default Savings for ENERGY STAR Bathroom Ventilation Fans in Commercial Applications

Capacity Range (CFM)	Assumed Capacity (CFM)[Source 4]	Energy Savings (kWh)	Summer Peak Demand Reduction (kW)	Winter Peak Demand Reduction (kW)
10 – 89	63	34	0.006	0.005
90 – 150	109	59	0.010	0.008
151 – 250	176	95	0.017	0.012
251 – 500	276	149	0.026	0.020

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Davis Energy Group. (2004, April). "Analysis of Standard Options for Residential Exhaust Fans." Page 3. Davis Energy Group. April 27, 2004. Weblink

2) U.S. EPA. (2015) ENERGY STAR® Program Requirements Product Specification for Residential Ventilating Fans, Eligibility Criteria Version 4.0. Weblink

3) Efficiency Vermont, Technical Reference User Manual (TRM), March 16, 2015. Pages 52-53. Typical sizes assumed within the ranges given in Table 3-164.

4) Home Ventilating Institute. (2016) HVI-Certified Products Directory. Weblink. Default fan efficacies are based on average values for non-ENERGY STAR and ENERGY STAR, 10-500 CFM Bathroom Exhaust Fans.

5) Efficiency Vermont Technical Reference User Manual (2018). "Commercial Ventilation Fan". Weblink. Median run-hours of fans installed through Efficiency Vermont custom projects 2008-2011.

6) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.7. Food Service Equipment

3.7.1. ENERGY STAR Ice Machines

Target Sector	Commercial and Industrial
Measure Unit	Ice Machine
Measure Life	H ≥ 100 lb/day: 8.5 Years Source 1 H < 100 lb/day: 7.5 Years
Measure Vintage	Replace on Burnout, New Construction

Eligibility

This measure applies to the installation of a high-efficiency ice machine as either a new item or replacement for an existing unit. The machine must be air-cooled batch-type or continuous ice makers to qualify, which can include self-contained, ice-making heads, or remote-condensing units. The baseline equipment is a commercial ice machine that meets federal equipment standards. The efficient machine must conform to the minimum ENERGY STAR efficiency requirements and meet the ENERGY STAR requirements for water usage given under the same criteria.

Algorithms

The energy savings are dependent on the capacity of ice produced on a daily basis and the duty cycle. A machine's capacity is generally reported as an ice harvest rate, or amount of ice produced each day.

$$\Delta kWh = \frac{(kWh_{base} - kWh_{ee})}{100} \times H \times 365 \times D$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

The reference values for each component of the energy impact algorithm are shown in Table 3-165. A default duty cycle (D) is provided as based on referenced values from several studies, however, EDC data gathering may be used to adjust the duty cycle for custom applications.

Table 3-165: Terms, Values, and References for High-Efficiency Ice Machines

Term	Unit	Values	Source
kWh_{base}, Baseline ice machine energy usage per 100 lbs. of ice	$\frac{kWh}{100\ lbs}$	Table 3-166, Table 3-167	1
kWh_{ee}, High-efficiency ice machine energy usage per 100 lbs. of ice	$\frac{kWh}{100\ lbs}$	Manufacturer Specs	EDC Data Gathering
		Default: Table 3-168, Table 3-169	2
H, Ice harvest rate per 24 hrs.	$\frac{lbs}{day}$	Manufacturer Specs	EDC Data Gathering
D, Duty cycle of ice machine expressed as a percentage of time machine produces ice	*None*	EDC Data Gathering	EDC Data Gathering
		Default ≤ 50 H: 0.14 Default > 50 H: 0.42	1
365, Days per year	$\frac{Days}{year}$	365	Conversion Factor
100, Conversion to obtain energy per pound of ice	$\frac{lbs}{100\ lbs}$	100	Conversion Factor
$ETDF_{summer}$, Summer energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001863	3
$ETDF_{winter}$, Winter energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001192	3

Table 3-166: Batch-Type Ice Machine Baseline Efficiencies

Ice Machine Type	Ice Harvest Rate (H) $\left(\frac{lbs}{day}\right)$	Baseline Energy Use per 100 lbs. of Ice (kWh_{base})
Ice-Making Head	> 50 and < 300	9.4-0.01233×H
	≥ 300 and < 727	6.45-0.0025×H
	≥ 727 and < 1,500	5.09-0.00063×H
	≥ 1,500 and < 4,000	4.23
Remote-Condensing w/out remote compressor	≥ 50 and < 988	7.83-0.00342×H
	≥ 988 and < 4,000	4.45
Remote-Condensing with remote compressor	> 50 and < 930	7.82-0.00342×H
	≥ 930 and < 4,000	4.64
Self-Contained, portable	≤ 38	19.43-0.27613×H
	> 38 and ≤ 50	8.94
Self-Contained, refrigerated storage	≤ 50	29.8-0.37063×H
Self-Contained	≤ 50	21.08-0.19634×H
	>50 and < 134	13.61-0.0469×H
	≥ 134 and < 200	10.72-0.02533×H
	≥ 200 and < 4,000	5.65

Table 3-167: Continuous Type Ice Machine Baseline Efficiencies

Ice Machine Type	Ice Harvest Rate (H) $\left(\frac{lbs}{day}\right)$	Baseline Energy Use per 100 lbs. of Ice (kWh_{base})
Ice-Making Head	> 50 and < 310	7.49-0.00629×H
	≥ 310 and < 820	6.53-0.0032×H
	≥ 820 and < 1,500	3.91
	≥ 1,500 and < 4,000	4.67
Remote-Condensing w/out remote compressor	> 50 and < 800	9.24-0.0058×H
	≥ 800 and < 4,000	4.6
Remote-Condensing with remote compressor	> 50 and < 800	9.42-0.0058×H
	≥ 800 and < 4,000	4.78
Self-Contained, portable	≤ 50	22.99-0.27789×H
Self-Contained	≤ 50	24.51-0.29623×H
	> 50 and < 149	11.2-0.03×H
	≥ 149 and < 700	7.66-0.00624×H

Ice Machine Type	Ice Harvest Rate (H) $\left(\frac{lbs}{day}\right)$	Baseline Energy Use per 100 lbs. of Ice (kWh_{base})
	≥ 700 and < 4,000	3.29

Table 3-168: Batch-Type Ice Machine ENERGY STAR Efficiencies

Ice Machine Type	Ice Harvest Rate (H) $\left(\frac{lbs}{day}\right)$	Efficient Energy Use per 100 lbs. of Ice (kWh_{ee})
Ice-Making Head	H < 300	≤ 9.20 – 0.01134H
	300 ≤ H ≤ 800	≤ 6.49 – 0.0023H
	800 ≤ H ≤ 1,500	≤ 5.11 – 0.00058H
	1,500 ≤ H ≤ 4,000	≤ 4.24
Remote-Condensing Unit	H < 988	≤ 7.17 – 0.00308H
	988 ≤ H ≤ 4,000	≤ 4.13
Self-Contained	H < 110	≤ 12.57 – 0.0399H
	110 ≤ H ≤ 200	≤ 10.56 – 0.0215H
	200 ≤ H ≤ 4,000	≤ 6.25

Table 3-169: Continuous Type Ice Machine ENERGY STAR Efficiencies

Ice Machine Type	Ice Harvest Rate (H) $\left(\frac{lbs}{day}\right)$	Efficient Energy Use per 100 lbs. of Ice (kWh_{ee})
Ice-Making Head	H < 310	≤ 7.90 – 0.005409H
	310 ≤ H ≤ 820	≤ 7.08 – 0.002752H
	820 ≤ H ≤ 4,000	≤ 4.82
Remote-Condensing Unit	H < 800	≤ 7.76 – 0.00464H
	800 ≤ H ≤ 4,000	≤ 4.05
Self-Contained	H < 200	≤ 12.37 – 0.0261H
	200 ≤ H ≤ 700	≤ 8.24 – 0.005492H
	700 ≤ H ≤ 4,000	≤ 4.44

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer-specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Energy Conservation Program: Energy Conservation Standards for Automatic Commercial Ice Makers; Proposed Rule. Federal Register / Vol. 88, No. 91. May 11, 2023. Weblink
2) U.S EPA. ENERGY STAR Program Requirements Product Specification for Automatic Commercial Ice Makers Eligibility Criteria Version 3.0 Weblink
3) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.7.2. Controls: Beverage and Snack Machine Controls

Target Sector	Commercial and Industrial
Measure Unit	Machine Control
Measure Life	5 years Source 1
Measure Vintage	Retrofit

Eligibility

This measure is intended for the addition of control systems to existing, non-ENERGY STAR, beverage and snack vending machines. The applicable machines contain non-perishable beverages and snacks that are kept at an appropriate temperature. The control systems are intended to reduce energy consumption due to lighting and/or refrigeration during times of lower customer sales. Typical control systems contain a passive infrared occupancy sensor to shut down the machine after a period of inactivity in the area. The compressor will power on for one-to-three-hour intervals, sufficient to maintain beverage temperature, and when powered on at any time will be allowed to complete at least one cycle to prevent excessive wear and tear. This measure should not be applied to ENERGY STAR qualified vending machines, as they already have built-in controls.

The baseline equipment is an existing, standard, beverage or snack vending machine that does not contain control systems to shut down the refrigeration components and/or lighting during times of low customer use. The Code of Federal Regulations Source 2 defines refrigerated vending machines as:

> ***Refrigerated bottled or canned beverage vending machine*** *means a commercial refrigerator that cools bottled or canned beverages and dispenses the bottled or canned beverages (beverages in a sealed container) on payment.*
>
> > ***Class A*** *means a refrigerated bottled or canned beverage vending machine that is not a combination vending machine and in which 25 percent or more of the surface area on the front side of the beverage vending machine is transparent.*
> >
> > ***Class B*** *means a refrigerated bottled or canned beverage vending machine that is not considered to be Class A and is not a combination vending machine.*
>
> ***Combination vending machine*** *means a bottled or canned beverage vending machine containing two or more compartments separated by a solid partition, that may or may not share a product delivery chute, in which at least one compartment is designed to be refrigerated, as demonstrated by the presence of temperature controls, and at least one compartment is not.*
>
> > ***Combination A*** *means a combination vending machine where 25 percent or more of the surface area on the front side of the beverage vending machine is transparent.*

***Combination B** means a combination vending machine that is not considered to be Combination A.*

ALGORITHMS

Energy savings are dependent on decreased machine lighting and/or cooling loads during times of lower customer sales. The savings will be dependent on the machine environment, noting that machines placed in locations such as day-use offices will result in greater savings than those placed in high-traffic areas such as hospitals that operate around the clock. The algorithm below considers varying scenarios and can be taken as representative of a typical application.

$$\Delta kWh = \Delta kWh_{Lighting} + \Delta kWh_{Ref\ BMC}$$

$$\Delta kWh_{Lighting} = \frac{(HOU_{VM} - HOU_{Facility}) \times W_{bulb}}{1000}$$

$$\Delta kWh_{Ref\ BMC} = MDEC \times \frac{Hours_{Sleep}}{24} \times Days$$

$$\Delta kW_{summer\ peak} = 0$$

$$\Delta kW_{winter\ peak} = 0$$

There are no peak demand savings because this measure is aimed at reducing demand during times of low beverage machine use, which will typically occur during off-peak hours.

DEFINITION OF TERMS

Table 3-170: Terms, Values, and References for Beverage and Snack Machine Controls

Term	Unit	Values	Source
$\Delta kWh_{Ref\ BMC}$, Refrigeration savings, beverage machine control	*kWh*	Refrigerated machine: calculated value Non-refrigerated machine: 0	-
W_{bulb}, Wattage of bulbs within vending machine	*W*	EDC Data Gathering Default: 29.5 W (two four-foot linear LED lamps)	EDC Data Gathering 6,7,8
MDEC, Maximum Daily Energy Consumption, beverage machine	$\frac{kWh}{Day}$	Table 3-138 Unknown: 3.29	2 5
V_{ref}, Volume of refrigerated space within beverage machine	*ft³*	Default: 21 ft³	4
HOU_{VM}, Annual hours of use, vending machine	$\frac{Hours}{Year}$	EDC Data Gathering Default: 8,760	EDC Data Gathering
$HOU_{Facility}$, Annual hours of use, facility	$\frac{Hours}{Year}$	EDC Data Gathering Default: Table 3-3	EDC Data Gathering Table 3-3

Term	Unit	Values	Source
$Hours_{Sleep}$, Hours of sleep from beverage machine control	$\frac{Hours}{Day}$	EDC Data Gathering Default: 4	EDC Data Gathering 3
Days, Annual days of use, beverage machine	$\frac{Days}{Year}$	EDC Data Gathering Default: 365	EDC Data Gathering

Table 3-171 Maximum Daily Energy Consumption for Beverage Machines

Manufactured Date	Class	MDEC (kWh/day)	Default MDEC
August 31, 2012 through January 7, 2019	Class A	$\mathbf{0.055} \times \boldsymbol{V_{ref}} + \mathbf{2.56}$	3.72
	Class B	$\mathbf{0.073} \times \boldsymbol{V_{ref}} + \mathbf{3.16}$	4.69
On or after January 8, 2019	Class A	$\mathbf{0.052} \times \boldsymbol{V_{ref}} + \mathbf{2.43}$	3.52
	Class B	$\mathbf{0.052} \times \boldsymbol{V_{ref}} + \mathbf{2.20}$	3.29
	Combination A	$\mathbf{0.086} \times \boldsymbol{V_{ref}} + \mathbf{2.66}$	4.47
	Combination B	$\mathbf{0.111} \times \boldsymbol{V_{ref}} + \mathbf{2.04}$	4.37

EVALUATION PROTOCOLS

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer-specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

SOURCES

1) California Electronic Technical Reference Manual. "Vending and Beverage Merchandise Controller". Accessed January 2024. Weblink
2) 10 CFR 431.296 Weblink
3) Itron, Inc. for Southern California Edison. (2005). 2004-2005 Database for Energy Efficiency Resources (DEER) Update Study - Final Report. Section 3.5, page 3-22. Weblink
4) Federal Energy Management Program. (2021, December). Purchasing Energy-Efficient Refrigerated Beverage Vending Machines. Weblink
5) MDEC of 3.29 reflects the most conservative value from the default MDEC table.
6) Based on the average tested wattage from DesignLights Consortium SSL QPL for DLC 5.1 eligible T8 Four-Foot UL Type A, B and A/B Lamps. Accessed January 23, 2023. Weblink
7) Southern California Edison (2023). SWAP011-04_Webscraping_Analysis. Weblink
8) Comments from Royal Vendors stating it already uses LED lighting in its class A machines to meet the current standard, page 1057 section f. U.S. Department of Energy (DOE). 2016. Federal Register. Vol. 81, No. 5. January 8. Weblink

3.7.3. ENERGY STAR Electric Steam Cooker

Target Sector	Commercial and Industrial
Measure Unit	Electric Steam Cooker
Measure Life	12 years Source 1
Measure Vintage	Replace on Burnout, New Construction

Eligibility

This measure applies to the installation of electric ENERGY STAR steam cookers as either a new item or replacement for an existing unit. Gas steam cookers are not eligible. A qualifying steam cooker must exceed the efficiency standards as outlined by the baselines in Table 3-173 Source 2.

Algorithms

The savings depend primarily on the pounds of food steam cooked per day, pan capacity, cooking efficiency, and idle power consumption.

$$\Delta kWh = \left(\Delta kWh_{cooking} + \Delta kWh_{idle}\right) \times Days$$

$$\Delta kWh_{cooking} = lbsFood \times EnergyToFood \times \left(\frac{1}{Eff_{base}} - \frac{1}{Eff_{ee}}\right)$$

$$\Delta kWh_{idle} = Daily\ kWh_{base} - Daily\ kWh_{ee}$$

$$Daily\ kWh_{base} = \Bigg(Power_{idle,base} \times (1 - \%HOURS_{consteam}) + \%HOURS_{consteam} \times CAPY_{base} \times Qty_{pans} \times \left(\frac{EnergyToFood}{Eff_{base}}\right) \times \left(HOURS_{op} - \left(\frac{lbsFood}{CAPY_{base} \times Qty_{pans}}\right)\right)\Bigg)$$

$$Daily\ kWh_{ee} = \Bigg(Power_{idle,ee} \times (1 - \%HOURS_{consteam}) + \%HOURS_{consteam} \times CAPY_{ee} \times Qty_{pans} \times \left(\frac{EnergyToFood}{Eff_{ee}}\right) \times \left(HOURS_{op} - \left(\frac{lbsFood}{CAPY_{ee} \times Qty_{pans}}\right)\right)\Bigg)$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-172: Terms, Values, and References for ENERGY STAR Electric Steam Cookers

Term	Unit	Values	Source
$lbsFood$, Pounds of food cooked per day in the steam cooker	lbs	EDC Data Gathering	EDC Data Gathering
		Default =100	1
$EnergyToFood$, ASTM energy to food ratio; energy (kilowatt-hours) required per pound of food during cooking	$\frac{kWh}{pound}$	0.0308	1
Eff_{ee}, Cooking energy efficiency of the new unit	%	Nameplate	EDC Data Gathering
Eff_{base}, Cooking energy efficiency of the baseline unit	%	See Table 3-173	2
$Power_{idle,base}$, Idle power of the baseline unit	kW	See Table 3-173	2
$Power_{idle,ee}$, Idle power of the new unit	kW	Nameplate	EDC Data Gathering
$HOURS_{op}$, assumed daily hours of operation	Hours	EDC Data Gathering	EDC Data Gathering
		9 hours	1
$\%HOURS_{consteam}$, Percentage of idle time per day the steamer is in continuous steam mode instead of timed cooking. The power used in this mode is the same as the power in cooking mode.	%	40%	1
$CAPY_{base}$, Production capacity per pan of the baseline unit	$\frac{lb}{hr}/pan$	16.7	1
$CAPY_{ee}$, Production capacity per pan of the new unit	$\frac{lb}{hr}/pan$	EDC Data Gathering	EDC Data Gathering
		Default = 16.7	1
Qty_{pans}, Quantity of pans in the unit	Pan	Nameplate	EDC Data Gathering
$Days$, Days of steamer operation per year	$\frac{Days}{Year}$	311	1
$ETDF_{summer}$, Summer energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001863	3
$ETDF_{winter}$, Winter energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001192	3

Table 3-173: Baseline Values for Electric Steam Cookers by Number of Pans

# of Pans	Parameter	Baseline Model
3	$Power_{idle}$ (kW)	0.40
	Eff	50%
4	$Power_{idle}$ (kW)	0.53
	Eff	50%
5	$Power_{idle}$ (kW)	0.67
	Eff	50%
6	$Power_{idle}$ (kW)	0.80
	Eff	50%

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) ENERGY STAR (2021). Savings Calculator for ENERGY STAR Commercial Food Service (CFS) Products. U.S. EPA. Weblink

2) 2021 International Energy Conservation Code, September 2021. Table C406.12(2). Weblink

3) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.7.4. ENERGY STAR Combination Oven

Target Sector	Commercial and Industrial
Measure Unit	Number of Ovens Installed
Measure Life	12 years Source 1
Measure Vintage	Replace on Burnout, New Construction

A combination oven is a convection oven that includes the added capability to inject steam into the oven cavity and typically offers at least three distinct cooking modes.

Eligibility

To qualify for this measure, the installed equipment must be a new electric combination oven with a 5-40 pan capacity that meets the ENERGY STAR idle rate and cooking efficiency requirements as specified in Table 3-174.Source 2 *P* represents the pan capacity of the oven.

Table 3-174: Combination Oven Eligibility Requirements

Fuel Type	Capacity	Operation	Idle Rate (kW)	Cooking-Energy Efficiency (%)
Electric	5-40 Pan Capacity	Steam Mode Convection Mode	≤ 0.133P + 0.6400 ≤ 0.083P + 0.35	≥ 55 ≥ 78

Algorithms

The following algorithms are used to quantify the annual energy and coincident peak demand savings, accounting for the convection-mode cooking energy, the steam-mode cooking energy, and the idle-mode energy consumption.

$$\Delta kWh = (\Delta CookingEnergy_{ConvElec} + \Delta CookingEnergy_{SteamElec} + \Delta IdleEnergy_{ConvElec} + \Delta IdleEnergy_{SteamElec}) \times Days \times \frac{1}{1{,}000}$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Where:

$$\Delta CookingEnergy_{ConvElec} = LB_{Elec} \times (EFOOD_{ConvElec} \,/\, ElecEFF_{ConvBase} - EFOOD_{ConvElec} \,/\, ElecEFF_{ConvEE}) \times \%_{Conv}$$

$$\Delta CookingEnergy_{SteamElec} = LB_{Elec} * (EFOOD_{SteamElec}/ElecEFF_{SteamBase} - EFOOD_{SteamElec}/ElecEFF_{SteamEE}) * \%_{Steam}$$

$$\Delta IdleEnergy_{ConvElec} = [(ElecIDLE_{ConvBase} \times (HOURS - LB_{Elec}/ElecPC_{ConvBase}) \times \%_{Conv}) - (ElecIDLE_{ConvEE} \times (HOURS - LB_{Elec}/ElecPC_{ConvEE}) \times \%_{Conv})]$$

$$\Delta IdleEnergy_{SteamElec} = [(ElecIDLE_{SteamBase} \times (HOURS - LB_{Elec}/ElecPC_{SteamBase}) \times \%_{Steam}) - (ElecIDLE_{SteamEE} \times (HOURS - LB_{Elec}/ElecPC_{SteamEE}) \times \%_{Steam})]$$

Definition of Terms

Table 3-175: Terms, Values, and References for ENERGY STAR Combination Ovens

Term	Unit	Values	Source
P, Pan capacity - The number of steam table pans the combination oven is able to accommodate as per the ASTM F-1495-05 standard specification.	Pans	EDC Data Gathering	EDC Data Gathering
$\Delta CookingEnergy_{ConvElec}$, change in total daily cooking energy consumed by electric oven in convection mode	$\frac{Wh}{Day}$	Calculated	1
$\Delta CookingEnergy_{SteamElec}$, change in total daily cooking energy consumed by electric oven in steam mode	$\frac{Wh}{Day}$	Calculated	1
$\Delta IdleEnergy_{ConvElec}$, change in total daily idle energy consumed by electric oven in convection mode	$\frac{Wh}{Day}$	Calculated	1
$\Delta IdleEnergy_{SteamElec}$, change in total daily idle energy consumed by electric oven in convection mode	$\frac{Wh}{Day}$	Calculated	1
$HOURS$, average daily operating hours	$\frac{Hours}{Day}$	EDC Data Gathering Default = 12 hours	1
$DAYS$, annual days of operation	$\frac{Days}{Year}$	EDC Data Gathering Default = 365	1
$EFOOD_{ConvElec}$, energy absorbed by food product for electric oven in convection mode	$\frac{Wh}{lb}$	EDC Data Gathering Default = 73.2	1
LB_{Elec}, estimated mass of food cooked per day for electric oven	$\frac{lbs}{Day}$	EDC Data Gathering Default = 200 (If P < 15) or 250 (If P ≥ 15)	1
$ElecEFF$, cooking energy efficiency of electric oven	%	EDC Data Gathering Default: Table 3-176	2,3

Term	Unit	Values	Source
$\%_{Conv}$, percentage of time in convection mode	%	EDC Data Gathering Default = 50	1
$EFOOD_{SteamElec}$, energy absorbed by food product for electric oven in steam mode	$\frac{Wh}{lb}$	EDC Data Gathering Default = 30.8	1
$\%_{steam}$, percentage of time in steam mode	%	$1 - \%_{conv}$	1
$ElecIDLE_{ConvBase}$, Idle energy rate of baseline electric oven in convection mode	W	EDC Data Gathering Default= (0.08 * P + 0.4989) * 1,000	3
$ElecIDLE_{SteamBase}$, Idle energy rate of baseline electric oven in steam mode	W	EDC Data Gathering Default = (0.133* P + 0.64) * 1,000	3
$ElecPC_{ConvBase}$, production capacity of baseline electric oven in convection mode	$\frac{lbs}{Hour}$	EDC Data Gathering Default: Table 3-177	4
$ElecPC_{SteamBase}$, production capacity of baseline electric oven in steam mode	$\frac{lbs}{Hour}$	EDC Data Gathering Default: Table 3-177	4
$ElecIDLE_{ConvEE}$, Idle energy rate of ENERGY STAR electric oven in convection mode	W	EDC Data Gathering Default = $(0.083 * P + 0.35) * 1{,}000$	2
$ElecPC_{ConvEE}$, Production capacity of ENERGY STAR electric oven in convection mode	$\frac{lbs}{Hour}$	EDC Data Gathering Default: Table 3-178	5
$ElecPC_{SteamEE}$, Production capacity of ENERGY STAR electric oven in steam mode	$\frac{lbs}{Hour}$	EDC Data Gathering Default: Table 3-178	5
$ElecIDLE_{SteamEE}$, Idle energy rate of ENERGY STAR electric oven in steam mode	W	EDC Data Gathering Default = $(0.133 * P + 0.64) * 1{,}000$	2

Term	Unit	Values	Source
$\frac{1}{1,000}$, W to kW conversion factor	$\frac{kW}{W}$	$\frac{1}{1,000}$	1
$ETDF_{summer}$, Summer energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001863	6
$ETDF_{winter}$, Winter energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001192	6

Table 3-176: Default Baseline and Efficient-Case Values for ElecEFF

Value	Base	EE
$ElecEFF_{Conv}$	76%	78%
$ElecEFF_{Steam}$	55%	55%

Table 3-177: Default Baseline Values for ElecPC

Pan Capacity	Convection Mode ($ElecPC_{ConvBase}$)	Steam Mode ($ElecPC_{SteamBase}$)
< 15	76.29	108.47
15-28	181.60	298.80
> 28	314.00	478

Table 3-178: Default Efficient-Case Values for ElecPC

Pan Capacity	Convection Mode ($ElecPC_{ConvEE}$)	Steam Mode ($ElecPC_{SteamEE}$)
< 15	95.79	128.11
15-28	200.00	276.33
> 28	387.67	462.00

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) ENERGY STAR (2021). Savings Calculator for ENERGY STAR Commercial Food Service (CFS) Products. U.S. EPA. Weblink

2) U.S. EPA. (2023). ENERGY STAR Program Requirements Product Specification for Commercial Ovens Eligibility Criteria Version 3.0 Weblink

3) 2021 International Energy Conservation Code, September 2021. Table C406.12(4). Weblink

4) Food Service Technology Center (2022). Baseline Performance Data 2022. Weblink

5) Southern California Gas Company (2022). Combination Oven Qualified Product List 2022. Weblink

6) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.7.5. ENERGY STAR Commercial Convection Oven

Target Sector	Commercial and Industrial
Measure Unit	Number of Convection Ovens Installed
Measure Life	12 years Source 1
Measure Vintage	Replace on Burnout, New Construction

Commercial convection ovens that meet ENERGY STAR requirements Source 2 utilize improved gaskets for faster and more uniform cooking processes to achieve higher heavy load cooking efficiencies and lower idle energy rates, making them on average about 20 percent more efficient than standard models. The baseline equipment is assumed to be IECC 2021 code complaint convection ovensSource 3.

Eligibility

This measure targets non-residential customers who purchase and install an electric convection oven that meets ENERGY STAR specifications rather than a non-ENERGY STAR unit. The energy efficient convection oven can be new or rebuilt.

Table 3-179: Convection Oven Eligibility Requirements

Fuel Type	Capacity	Idle Rate (kW)	Cooking-Energy Efficiency (%)
Electric	Half-Size	≤ 1.00	≥ 71
Electric	Full size < 5 Pans	≤ 1.00	≥ 76
Electric	Full size ≥ 5 Pans	≤ 1.40	≥ 76

Algorithms

The annual energy savings calculation utilizes the idle energy rate of an ENERGY STAR electric convection oven and a typical electric convection oven, along with estimated annual hours of operation for cooking activities. The energy savings and peak demand reductions are obtained through the following formulas shown below.Source 1, 2

$$\Delta kWh = kWh_{base} - kWh_{ee}$$

$$kWh_i = (kWh_{cooking,i} + kWh_{idle,i}) \times DAYS$$

$$kWh_{cooking,i} = LB \times \frac{E_{food}}{EFF_i}$$

$$kWh_{idle,i} = IDLE_i \times (HOURS_{DAY} - \frac{LB}{PC_i})$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-180: Terms, Values, and References for ENERGY STAR Commercial Electric Convection Ovens

Term	Unit	Values	Source
i, Either "base" or "ee" depending on whether the calculation of energy consumption is being performed for the baseline or efficient case, respectively.	None	EDC Data Gathering	---
kWh_{base}, Annual energy usage of the baseline equipment calculated using baseline values	$\frac{kWh}{Year}$	Calculated	---
kWh_{ee}, Annual energy usage of the efficient equipment calculated using efficient values	$\frac{kWh}{Year}$	Calculated	---
$kWh_{cooking}$, Daily cooking energy consumption	$\frac{kWh}{Day}$	Calculated	---
kWh_{idle}, Daily idle energy consumption	$\frac{kWh}{Day}$	Calculated	---
$HOURS_{DAY}$, Average daily operating hours	$\frac{Hours}{Day}$	EDC Data Gathering Default = 12	1
$DAYS$, Annual days of operation	$\frac{Days}{Year}$	EDC Data Gathering Default = 365	1
E_{food}, ASTM energy to food; amount of energy absorbed by the food per pound during cooking	$\frac{kWh}{lb}$	EDC Data Gathering Default = 0.0732	1
LB, Pounds of food cooked per day	$\frac{lbs}{Day}$	EDC Data Gathering Default = 100	1
EFF, Heavy load cooking energy efficiency	%	EDC Data Gathering Default: Table 3-181	2, 3
$IDLE$, Idle demand rate	kW	Default: Table 3-181	2, 3
PC, Production capacity	$\frac{lbs}{Hour}$	EDC Data Gathering Default: Table 3-181	1, 2
$ETDF_s$, Summer energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001863	4
$ETDF_w$, Winter energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001192	4

Table 3-181: Electric Oven Performance Metrics: Baseline and Efficient Default Values

Parameter	Half Size		Full Size < 5 Pans		Full Size ≥ 5 Pans	
	Baseline Model	Efficient Model	Baseline Model	Efficient Model	Baseline Model	Efficient Model
IDLE	1.0	1.0	1.6	1.0	1.6	1.4
EFF	71%	71%	71%	76%	71%	76%
PC	50	50	90	90	90	90

Default Savings

Table 3-182: Default Unit Savings and Demand Reduction for ENERGY STAR Commercial Electric Convection Ovens.

Parameter	ENERGY STAR Convection Oven Savings		
	ΔkWh	$\Delta kW_{summer\ peak}$	$\Delta kW_{winter\ peak}$
Half Size	0	0	0
Full Size < 5 Pans	2,632	0.490	0.314
Full Size ≥ 5 Pans	1,042	0.194	0.124

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) ENERGY STAR (2021). Savings Calculator for ENERGY STAR Commercial Food Service (CFS) Products. U.S. EPA. Weblink

2) U.S. EPA (2023). ENERGY STAR Program Requirements Product Specification for Commercial Ovens Eligibility Criteria Version 3.0. Weblink

3) 2021 International Energy Conservation Code, September 2021. Table C406.12(4) Weblink

4) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.7.6. ENERGY STAR Commercial Fryer

Target Sector	Commercial and Industrial
Measure Unit	Number of Commercial Fryers Installed
Measure Life	12 years Source 1
Measure Vintage	Replace on Burnout, New Construction

Commercial fryers that meet ENERGY STAR Source 2 specifications offer shorter cook times and higher production rates through advanced burner and heat exchanger designs.

Eligibility

This measure applies to electric ENERGY STAR fryers installed in a commercial kitchen. To qualify for this measure, the customer must install a commercial electric fryer that has earned the ENERGY STAR label.

Algorithms

The annual energy savings calculation utilizes the idle energy rate of ENERGY STAR electric fryers and a typical electric fryer, along with estimated annual hours of operation for cooking activities. Energy savings estimates are provided for both standard and large vat fryers. The unit energy savings and peak demand reduction are obtained through the following formulas:

$$\Delta kWh = kWh_{base} - kWh_{ee}$$

$$kWh_i = (kWh_{cooking,i} + kWh_{idle,i}) \times DAYS$$

$$kWh_{cooking,i} = LB \times \frac{E_{food}}{EFF_i}$$

$$kWh_{idle,i} = IDLE_i \times (HOURS_{Day} - \frac{LB}{PC_i})$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-183: Terms, Values, and References for ENERGY STAR Commercial Fryers

Term	Unit	Values	Source
i, Either “base” or “ee” depending on whether the calculation of energy consumption is being performed for the baseline or efficient case, respectively.	None	EDC Data Gathering	---
kWh_{base}, Annual energy usage of the baseline equipment calculated using baseline values	$\frac{kWh}{year}$	Calculated	---
kWh_{ee}, Annual energy usage of the efficient equipment calculated using efficient values	$\frac{kWh}{year}$	Calculated	---
$kWh_{cooking}$, Daily cooking energy consumption	$\frac{kWh}{day}$	Calculated	---
kWh_{idle}, Daily idle energy consumption	$\frac{kWh}{day}$	Calculated	---
$HOURS_{Day}$, Average daily operating hours	$\frac{Hours}{Day}$	EDC Data Gathering See Table 3-184	1
$DAYS$, Annual days of operation	$\frac{Days}{Year}$	EDC Data Gathering Default = 365	1
E_{food}, ASTM energy to food; amount of energy absorbed by the food per pound during cooking	$\frac{kWh}{lb}$	EDC Data Gathering Default = 0.167	1
LB, Pounds of food cooked per day	$\frac{lbs}{Day}$	EDC Data Gathering Default = 150	1
EFF, Heavy load cooking energy efficiency	%	Base: See Table 3-184 EE: Nameplate	3
$IDLE$, Idle energy rate	kW	Base: See Table 3-184 EE: Nameplate	3
PC, Production capacity	$\frac{lbs}{Hour}$	See Table 3-184	1
$ETDF_{summer}$, Summer energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001863	3
$ETDF_{winter}$, Winter energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001192	3

Table 3-184: Electric Fryer Performance Metrics: Baseline Default Values

Parameter	Standard Fryer	Large Vat Fryer
$HOURS_{Day}$	16	12
$IDLE$	0.80	1.10
EFF	83%	80%
PC	70	110

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) ENERGY STAR (2021). Savings Calculator for ENERGY STAR Commercial Food Service (CFS) Products. U.S. EPA. Weblink
2) U.S. EPA. (2020). ENERGY STAR Program Requirements Product Specification for Commercial Fryers Eligibility Criteria Version 3.0 (Rev. December - 2020) Weblink
3) 2021 International Energy Conservation Code, September 2021. Table C406.12(1) Weblink
4) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.7.7. ENERGY STAR Commercial Hot Food Holding Cabinet

Target Sector	Commercial and Industrial
Measure Unit	Number of Hot Food Holding Cabinets Installed
Measure Life	12 years Source 1
Measure Vintage	Replace on Burnout, New Construction

Commercial electric hot food holding cabinet models that are ENERGY STAR certified and incorporate better insulation to reduce heat loss and may also offer additional energy saving devices such as more precise controls, full-perimeter door gaskets, magnetic door handles, or Dutch doors. The insulation of the cabinet also offers better temperature uniformity within the cabinet from top to bottom. This means that qualified hot food holding cabinets are more efficient at maintaining food temperature while using less energy. The baseline equipment is assumed to be a standard efficiency hot food holding cabinet that is not ENERGY STAR certified.

Eligibility

This measure targets non-residential customers who purchase and install a hot food holding cabinet that is ENERGY STAR certified rather than a non-ENERGY STAR unit. The energy efficient hot food holding cabinet can be new or rebuilt. It can include glass or solid door cabinets (fully closed compartment with one or more doors).

Algorithms

The annual energy savings calculation utilizes idle energy rates of an ENERGY STAR hot food holding cabinet and a typical hot food holding cabinet, along with estimated annual hours of operation. The unit energy savings and peak demand reduction are obtained through the following formulas:

$$\Delta kWh = (IDLE_{base} - IDLE_{ee}) \times 0.001 \times HOURS_{Day} \times DAYS$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-185: Terms, Values, and References for ENERGY STAR Commercial Hot Food Holding Cabinets

Term	Unit	Values	Source
$Idle_{base}$, Idle energy rate of the baseline equipment	$Watts$	EDC Data Gathering (see Table 3-186	1, 2
$Idle_{ee}$, Idle energy rate of the efficient equipment	$Watts$	EDC Data Gathering (see Table 3-186)	1, 2
0.001, Conversion of W to kW	$\frac{kW}{W}$	0.001	Conversion Factor
$HOURS_{Day}$, Average daily operating hours	$\frac{Hours}{Day}$	EDC Data Gathering Default = 9	1
$DAYS$, annual days of operation	$\frac{Days}{Year}$	EDC Data Gathering Default = 365	1
V, the internal volume of the holding cabinet	$\frac{ft^3}{unit}$	EDC Data Gathering	EDC Data Gathering
$ETDF_{summer}$, Summer energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001863	3
$ETDF_{winter}$, Winter energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001192	3

Table 3-186: Hot Food Holding Cabinet Performance Metrics: Default Baseline and Efficient Value Equations

Internal Volume	Product Idle Energy Consumption Rate	
	Baseline Model ($IDLE_{base}$)	Efficient Model ($IDLE_{ee}$)
0 < V < 13	30 x V	21.5 x V
13 ≤ V < 28	30 x V	2.0 x V + 254.0
28 ≤ V	30 x V	3.8 x V + 203.5

Default Savings

The default annual energy savings value for ENERGY STAR Commercial Hot Food Holding Cabinet is shown in Table 3-186.

Table 3-187: Hot Food Holding Cabinet Default Savings

Internal Volume	ΔkWh	$\Delta kW_{summer\ peak}$	$\Delta kW_{winter\ peak}$
0 < V < 13	27.9 x V	0.0052 x V	0.0033 x V
13 ≤ V < 28	3.285 x (28 x V - 254)	0.00061 x (28 x V - 254)	0.00039 x (28 x V - 254)
28 ≤ V	3.285 x (26.2 x V – 203.5)	0.00061 x (26.2 x V – 203.5)	0.00039 x (26.2 x V – 203.5)

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) ENERGY STAR (2021). Savings Calculator for ENERGY STAR Commercial Food Service (CFS) Products. U.S. EPA. Weblink
2) U.S. EPA. (2022). ENERGY STAR Program Requirements Product Specification for Commercial Hot Food Holding Cabinets Eligibility Criteria Version 2.0 (Rev. Dec – 2022) Weblink
3) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.7.8. ENERGY STAR Commercial Dishwasher

Target Sector	Commercial and Industrial
Measure Unit	Dishwasher
Measure Life	10 years Source 1
Measure Vintage	Replace on Burnout, New Construction

This measure describes the energy savings from installing an ENERGY STAR certified commercial dishwasher in applicable commercial settings. The measure includes stationary rack machines (undercounter; single tank door-type; pot, pan, and utensil; and glass washing) and conveyor machines (rack and rackless/flight type, multi and single tank). Products must meet idle energy rate and water consumption limits, as determined by both machine type and sanitation approach (chemical/low temp versus high temp).

A high temp machine is defined as a machine that applies hot water to the surfaces of dishes to achieve sanitization. A low temp machine is defined as a machine that applies a chemical sanitizing solution to the surfaces of dishes to achieve sanitization. Source 2

Eligibility

To be eligible, commercial dishwashers must meet the Version 3.0 ENERGY STAR Program Requirements for Commercial Dishwashers, September 2021 Revision.Source 2

Algorithms

Electric energy savings are composed of three parts: electric energy savings from the building water heater, electric energy savings from the booster water heater, and idle electric energy savings. Note that if a building only has a natural gas water heater, then there will still be savings from reduction in idle energy.

$$\Delta kWh = \Delta kWh_{WaterHeater} + \Delta kWh_{BoosterHeater} + \Delta kWh_{Idle}$$

$$\Delta kWh_{WaterHeater} = \left((WU_{base} - WU_{ee}) \times RW \times Days\right) \times \frac{\Delta T_{in} \times c \times \rho}{RE \times 3{,}412}$$

$$\Delta kWh_{BoosterHeater} = \left((WU_{base} - WU_{ee}) \times RW \times Days\right) \times \frac{\Delta T_{in} \times c \times \rho}{RE \times 3{,}412}$$

$$\Delta kWh_{Idle} = (kW_{base} \times Days \times (HD - RW \times WT/60\ ) - \left(kW_{ee} \times Days \times (HD - \frac{(RW \times WT)}{60}\right)$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} \quad = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-188: Terms, Values, and References for ENERGY STAR Commercial Dishwashers

Term	Unit	Values	Source
WU_{base}, Water use per rack of baseline dishwasher, varies by machine type and sanitation method	*Gallons*	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-189	3
WU_{ee}, Water use per rack of ENERGY STAR dishwasher, varies by machine type and sanitation method	*Gallons*	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-189	3
RW, Number of racks washed per day, varies by machine type and sanitation method	$\frac{Racks\ Washed}{Day}$	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-189	3
$Days$, Annual days of dishwasher consumption per year	$\frac{Days}{Year}$	EDC Data Gathering	EDC Data Gathering
		Default = 365	3
ΔT_{in}, Temperature rise in water delivered by building water heater or booster water heater, value varies by type of water heater source	*°F*	EDC Data Gathering	EDC Data Gathering
		Building WH = 70 Booster WH = 40	3
RE, Recovery efficiency of electric water heater	Decimal	0.98	3
kW_{base}, Idle power draw of baseline dishwasher, varies by machine type and sanitation method	*kW*	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-189	3
HD, Hours per day of dishwasher operation	$\frac{Hours}{Day}$	EDC Data Gathering	EDC Data Gathering
		Default = 18	3
WT, Wash time per dishwasher, varies by machine type and sanitation method	*Minutes*	EDC Data Gathering	EDC Data Gathering,
		Default: Table 3-189	3
kW_{ee}, Idle power draw of ENERGY STAR dishwasher, varies by machine type and sanitation method	*kW*	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-189	3

Term	Unit	Values	Source
ρ, Density of water	$\frac{lb}{gallon}$	8.207	4
c, Specific heat of water	$\frac{Btu}{lb \cdot °F}$	1	
60, Conversion of hours to minutes	$\frac{Minutes}{Hour}$	60	Conversion Factor
$3{,}412$, Conversion of kWh to Btu	$\frac{Btu}{kWh}$	3,412	Conversion Factor
$ETDF_{summer}$, Summer energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001863	5
$ETDF_{winter}$, Winter energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001192	5

Table 3-189 shows the default values for water user per rack, racks washed per day, wash time per dishwasher, and idle power draws by machine type and sanitation method.

Table 3-189: Default Inputs for ENERGY STAR Commercial Dishwasher

Machine Type	WU_{base}	WU_{ee}	RW	WT	kW_{base}	kW_{ee}
Low Temperature						
Under Counter	1.73	1.19	75	2.0	0.50	0.25
Stationary Single Tank Door	2.10	1.18	280	1.5	0.60	0.30
Single Tank Conveyor	1.31	0.79	400	0.3	1.60	0.85
Multi Tank Conveyor	1.04	0.54	600	0.3	2.00	1.00
High Temperature						
Under Counter	1.09	0.86	75	2.0	0.76	0.30
Stationary Single Tank Door	1.29	0.89	280	1.0	0.87	0.55
Single Tank Conveyor	0.87	0.70	400	0.3	1.93	1.20
Multi Tank Conveyor	0.97	0.54	600	0.2	2.59	1.85
Pot, Pan, and Utensil	0.70	0.58	280	3.0	1.20	0.90

DEFAULT SAVINGS

Using the defaults provided above, the savings per component are shown in Table 3-190.

Table 3-190: Default Annual Energy and Peak Demand Savings for ENERGY STAR Commercial Dishwashers

Machine Type	$\Delta kWh_{WaterHeater}$	$\Delta kWh_{BoosterHeater}$	ΔkWh_{Idle}	ΔkWh (if Electric Water Heater and Booster Water Heater)	$\Delta kW_{summer\ peak}$	$\Delta kW_{winter\ peak}$
Low Temperature						
Under Counter	2,540	N/A	1,414	3,954	0.74	0.47
Stationary Single Tank Door	16,153	N/A	1,205	17,358	3.23	2.07
Single Tank Conveyor	13,042	N/A	4,380	17,422	3.25	2.08
Multi Tank Conveyor	18,811	N/A	5,475	24,286	4.52	2.89
High Temperature						
Under Counter	1,082	618	2,602	4,302	0.80	0.51
Stationary Single Tank Door	7,023	4,013	1,557	12,593	2.35	1.50
Single Tank Conveyor	4,264	2,436	4,263	10,963	2.04	1.31
Multi Tank Conveyor	16,178	9,244	4,322	29,743	5.54	3.55
Pot, Pan, and Utensil	2,107	1,204	438	3,749	0.70	0.70

Evaluation Protocol

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) PA Consulting Group Inc. "State of Wisconsin Public Service Commission of Wisconsin Focus on Energy Evaluation Business Programs: Measure Life Study Final Report." August 25, 2009. Weblink

2) U.S. EPA. (2021). ENERGY STAR Program Requirements Product Specification for Commercial Dishwashers Eligibility Criteria Version 3.0 (Rev. – September 2021). Weblink

3) ENERGY STAR (2021). Savings Calculator for ENERGY STAR Commercial Food Service (CFS) Products. U.S. EPA. Weblink

4) Dishwasher inlet temperature assumed at 140 degrees F. Weblink

5) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.7.9. ENERGY STAR Commercial Griddle

Target Sector	Commercial and Industrial
Measure Unit	Electric Griddle
Measure Life	12 years Source 1
Measure Vintage	Replace on Burnout, New Construction

Eligibility

This measure applies to the installation of electric ENERGY STAR griddles as either a new item or replacement for an existing unit. The griddles must be ENERGY STAR certified. Commercial griddles that are ENERGY STAR are about 10% to 11% more energy efficient than standard models, due to the use of highly conductive or reflective plate materials, improved thermostatic controls, and strategic placement of thermocouples.

The baseline equipment is a unit with efficiency specifications that do not meet the minimum ENERGY STAR efficiency requirements.

Algorithms

Energy savings for griddles come from increased efficiency during three modes: cooking, idle, and preheating. Algorithms for annual energy savings and peak demand savings are shown below.

$$\Delta kWh = \left(\Delta Wh_{Cooking} + \Delta Wh_{Idle} + \Delta Wh_{PreHeat}\right) \times Days \times \frac{1}{1{,}000}$$

$$\Delta Wh_{Cooking} = Lb_F \times EnergyToFood \times \left(\frac{1}{Eff_{base}} - \frac{1}{Eff_{ee}}\right)$$

$$\Delta Wh_{Idle} = \left[I_{base} \times A \times \left(OH - \frac{Lb_F}{PC_{base} \times A} - \frac{PHN \times PHT}{60}\right)\right] - \left[I_{ee} \times A \times \left(OH - \frac{Lb_F}{PC_{ee} \times A} - \frac{PHN \times PHT}{60}\right)\right]$$

$$\Delta Wh_{PreHeat} = (PHE_{base} - PHE_{ee}) \times PHN$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-191: Terms, Values, and References for ENERGY STAR Griddles

Term	Unit	Values	Source
$Days$, Operating days per year	$\frac{Days}{Year}$	EDC Data Gathering	EDC Data Gathering
		Default = 365	2

Term	Unit	Values	Source
Lb_F, Pounds of food cooked per day	*lbs*	EDC Data Gathering	EDC Data Gathering
		Default = 100	2
$EnergyToFood$, ASTM energy to food	$\frac{Wh}{lb}$	Default = 139	2
Eff_{base}, Baseline cooking efficiency	%	EDC Data Gathering	EDC Data Gathering
		Default Table 3-192	2
Eff_{ee}, ENERGY STAR cooking efficiency	%	EDC Data Gathering	EDC Data Gathering
		Default Table 3-192	2
I_{base}, Baseline idle energy rate	$\frac{W}{ft^2}$	EDC Data Gathering	EDC Data Gathering
		Default = 400	2
I_{ee}, ENERGY STAR idle energy rate	$\frac{W}{ft^2}$	EDC Data Gathering	EDC Data Gathering
		Default = 320	3
A, Area of griddle	ft^2	EDC Data Gathering	EDC Data Gathering
		Default = 2ft x 3ft = 6ft^2	2
OH, Operating hours per day	$\frac{Hours}{Day}$	EDC Data Gathering	EDC Data Gathering
		Default = 12	2
PC_{base}, Baseline production capacity	$\frac{lb}{hours \cdot ft^2}$	EDC Data Gathering	EDC Data Gathering
		Default Table 3-192	2
PC_{ee}, ENERGY STAR production capacity	$\frac{lb}{hours \cdot ft^2}$	EDC Data Gathering	EDC Data Gathering
		Default Table 3-192	2
PHN, Number of preheats per day	$\frac{Preheats}{Day}$	EDC Data Gathering	EDC Data Gathering
		Default = 1	2
PHT, Time per preheat	$\frac{Minutes}{Preheat}$	EDC Data Gathering	EDC Data Gathering
		Default = 15	2
PHE_{base}, Energy per preheat	$\frac{Wh}{Preheat}$	EDC Data Gathering	EDC Data Gathering
		Default = 4,000	2
PHE_{ee}, Energy per preheat	$\frac{Wh}{Preheat}$	EDC Data Gathering	EDC Data Gathering
		Default = 2,000	2

Term	Unit	Values	Source
60, Conversion of hours to minutes	$\frac{Minutes}{Hour}$	60	Conversion Factor
$ETDF_{summer}$, Summer energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001863	4
$ETDF_{winter}$, Winter energy to demand factor	$\frac{kW}{kWh}$	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001192	4

Table 3-192: Default Inputs for ENERGY STAR Commercial Griddle

Machine Type	Eff_{base}	Eff_{ee}	PC_{base}	PC_{ee}
Single Sided	65%	70%	5.83	6.67
Double Sided	65%	72%	11.67	13.92

Default Savings

Table 3-193 provides the default savings, using the default values in Table 3-191.

Table 3-193: Default Savings for ENERGY STAR Griddles

Griddle Type	$\Delta Wh_{Cooking}$	ΔWh_{Idle}	$\Delta Wh_{PreHeat}$	ΔkWh	$\Delta kW_{summer\ peak}$	$\Delta kW_{winter\ peak}$
Single Sided	1,527	3,583	2,000	2,595	0.48	0.31
Double Sided	2,079	4,631	2,000	3,179	0.59	0.38

Evaluation Protocol

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. “Griddle, Commercial”. Accessed December 2023. Weblink

2) ENERGY STAR (2021). Savings Calculator for ENERGY STAR Commercial Food Service (CFS) Products. U.S. EPA. Weblink

3) U.S. EPA. (2020). ENERGY STAR® Program Requirements Product Specification for Commercial Griddles Eligibility Criteria Version 1.2 Weblink

4) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.7.10. Commercial Induction Cooktops

Target Sector	Commercial and Industrial Establishments
Measure Unit	Induction Cooktop
Measure Life	10 years source 1
Vintage	Retrofit, Replace on Burnout, or New Construction

Eligibility

Electric induction cooktops are either a freestanding cooktop that heats cooking vessels using electrical induction or a range with an electric resistance oven and an electric induction cooktop. Electric induction cooktops save energy by heating the cookware directly as opposed to the surface of the range as seen in traditional electric resistance cooktops.

Electric induction cooktops may replace electric ovens with electric resistance cooktops or freestanding electric resistance cooktops.

Each cooking unit/zone within the induction cooktop must meet a minimum 80% cooking (boil) energy efficiency percentage as determined by the ASTM F1521-22 test method. Source 2

Algorithms

Total savings are calculated based on the increased cooking efficiency of an electric induction cooktop over an existing electric resistance cooktop. Cooking efficiency is defined as the ratio of energy absorbed by the object being heated (food, water, etc.) and the energy consumed by the appliance.

$$\Delta kWh = lbsFood \times EnergyToFood \times \left(\frac{1}{Eff_{base}} - \frac{1}{Eff_{ee}}\right) \times Days \times Burners \times \%_{elec}$$

$$\Delta kW_{peak,summer} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{peak,winter} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-194: Terms, Values, and References for Electric Induction Cooktops

Term	Unit	Value	Sources
lbsFood, Pounds of food cooked per day per burner	$\frac{lbs}{day}/burner$	EDC Data Gathering	EDC Data Gathering
		Default = 128	3
$EnergyToFood$, ASTM energy to food ratio; energy (kilowatt-hours) required per pound of food during cooking	$\frac{kWh}{pound}$	0.0308	
Eff_{ee}, Efficiency of electric induction cooktop	%	EDC Data Gathering of Nameplate data	EDC Data Gathering
		Default = 85	1

Term	Unit	Value	Sources
Eff_{base}, Efficiency of baseline electric resistance cooktop	%	EDC Data Gathering of Nameplate data	EDC Data Gathering
		Default = 80	1
$Burners$, Number of burners on efficient cooktop	*None*	EDC Data Gathering of Nameplate data	EDC Data Gathering
$ETDF_{summer}$, summer peak energy to demand factor	*Decimal*	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001863	4
$ETDF_{winter}$, winter peak energy to demand factor	*Decimal*	EDC Data Gathering	EDC Data Gathering
		Default = 0.0001192	4
Days, Days of use per year	$\frac{Days}{Year}$	312	1
$\%_{elec}$, electric cooktop penetration	%	EDC Data Gathering	EDC Data Gathering
		10.25%	5

Default Savings

Default savings for this measure are based on the default food consumption and efficiencies for the efficient induction and baseline electric resistance measure.

$$\Delta kWh = lbsFood \times EnergyToFood \times \left(\frac{1}{Eff_{base}} - \frac{1}{Eff_{ee}}\right) \times Days \times Burners \times \%_{elec}$$

$$= 128 \times 0.0308 \times \left(\frac{1}{0.80} - \frac{1}{0.85}\right) \times 312 \times Burners \times 0.1025$$

$$= 9.3 \times Burners$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$= 9.3 \times Burners \times 0.0001863$$

$$= 0.0012738 \times Burners$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

$$= 9.3 \times Burners \times 0.0001192$$

$$= 0.0081056 \times Burners$$

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer-specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. Evaluation contractors may choose to propose independent assessments of the ESF factors to the SWE in their EM&V plans. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) ENERGY STAR® Commercial Electric Cooktop Version 1.0 Data and Analysis. Weblink
2) ENERGY STAR® Program Requirements for Commercial Electric Cooktops Version 1.0. Weblink
3) California Electronic Technical Reference Manual. "Cooktop, Commercial." Accessed November 2023. Reference R2104. Frontier Energy, Inc. 2023. "Cooktop Supporting Data - Final.xlsx." Weblink
4) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink
5) Demand Side Analytics for the Pennsylvania Public Utility Commission. (2024, March). Pennsylvania Act 129 2023 Non-Residential Baseline Study. Page 170, Figure 158. Weblink

3.8. BUILDING SHELL

3.8.1. WALL AND CEILING INSULATION

Target Sector	Commercial and Industrial
Measure Unit	Wall and Ceiling Insulation
Measure Life	20 years Source 1
Measure Vintage	New Construction or Retrofit

Wall and ceiling insulation is one of the most important aspects of the energy system of a building.

An R-value indicates the insulation's resistance to heat flow – the higher the R-value, the greater the insulating effectiveness. The R-value depends on the type of insulation and its material, thickness, and density. When calculating the R-value of a multilayered installation, add the R-values of the individual layers.

ELIGIBILITY

This measure applies to non-residential buildings or common areas in multifamily complexes heated and/or cooled using electricity. Existing construction buildings are required to meet or exceed the code requirement. New construction buildings must exceed the code requirement. Eligibility may vary by PA EDC. Buildings with Central AC systems or Air Source Heat Pumps (ASHP) are eligible. Buildings cooled with other systems (e.g., chilled water systems) are not eligible.

ALGORITHMS

The savings depend on the area and R-value of baseline and upgraded walls/ceilings, heating and/or cooling system type and size, and location.

$$\Delta kWh = \Delta kWh_{cool} + \Delta kWh_{heat}$$

$$\Delta kWh_{cool} = \left(\frac{CDD \times 24}{Eff \times 1{,}000}\right) \times \left[A_{ceiling}\left(\frac{1}{Ceiling\ R_i} - \frac{1}{Ceiling\ R_f}\right) + A_{wall}\left(\frac{1}{WallR_i} - \frac{1}{Wall\ R_f}\right)\right]$$

$$\Delta kWh_{heat} = \left(\frac{HDD \times 24}{COP \times 3{,}412}\right) \times \left[A_{ceiling}\left(\frac{1}{Ceiling\ R_i} - \frac{1}{Ceiling\ R_f}\right) + A_{wall}\left(\frac{1}{WallR_i} - \frac{1}{Wall\ R_f}\right)\right]$$

$$\Delta kW_{summer\ peak} = \Delta kWh_{cool} \times ETDF_s$$

$$\Delta kW_{winter\ peak} = \Delta kWh_{hea} \times ETDF_w$$

Definition of Terms

Table 3-195: Terms, Values, and References for Wall and Ceiling Insulation

Term	Unit	Values	Source
$A_{ceiling}$, Area of the ceiling/attic insulation that was installed	ft^2	EDC Data Gathering	EDC Data Gathering
A_{wall}, Area of the wall insulation that was installed	ft^2	EDC Data Gathering	EDC Data Gathering
HDD, Heating degree days with a 65 degree base	$°\text{F} \cdot Days$	See Table 1-7 in Appendix A	2
CDD, Cooling degree days with a 65 degree base	$°\text{F} \cdot Days$	See Table 1-7 in Appendix A	2
24, Hours per day	$\frac{Hours}{Day}$	24	Conversion Factor
$1{,}000$, Watts per kilowatt	$\frac{W}{kW}$	1,000	Conversion Factor
$3{,}412$, Btu per kWh	$\frac{Btu}{kWh}$	3,412	Conversion Factor
$Ceiling\ R_i$, the R-value of the ceiling insulation and support structure before the additional insulation is installed	$\frac{°F \cdot ft^2 \cdot hr}{Btu}$	Default: Table 3-196	EDC Data Gathering; 3
$Wall\ R_i$, the R-value of the wall insulation and support structure before the additional insulation is installed	$\frac{°F \cdot ft^2 \cdot hr}{Btu}$	Default: Table 3-196 Table 3-196	EDC Data Gathering; 3
$Ceiling\ R_f$, Total R-value of all ceiling/attic insulation after the additional insulation is installed	$\frac{°F \cdot ft^2 \cdot hr}{Btu}$	EDC Data Gathering	EDC Data Gathering
$Wall\ R_f$, Total R-value of all wall insulation after the additional insulation is installed	$\frac{°F \cdot ft^2 \cdot hr}{Btu}$	EDC Data Gathering	EDC Data Gathering
$ETDF_s$,summer energy to demand factor	*kW/kWh*	Default: Table 3-197	4
$ETDF_w$, winter energy to demand factor	*kW/kWh*	Default: Table 3-197	4
Eff, Efficiency of existing cooling equipment. Depending on the size and age, this will either be the SEER, IEER, or EER (use EER only if SEER or IEER are not available)	$\frac{Btu/hr}{W}$	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-24	Table 3-24
COP, Efficiency of the heating system	*None*	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-24	Table 3-24

In determining Eff, site specific design values should be used in the calculations wherever possible to avoid overestimating the savings using the default minimally compliant EERs.

Table 3-196: Initial R-Values

Structure and Type	R_i-Value (New Construction) – IECC Zone 4	R_i-Value (New Construction) – IECC Zone 5	R_i-Value (New Construction) – IECC Zone 6	R_i-Value (Existing)
Ceilings				
Insulation entirely above roof deck	R-30ci[1]	R-30ci	R-30ci	EDC Data Gathering
Metal buildings	R-19 + R-11 LS[2]	R-19 + R-11 LS	R-25 + R-11 LS	
Attic and other	R-49	R-49	R-49	
Walls				
Mass	R-9.5ci	R-11.4ci	R-13.3ci	EDC Data Gathering
Metal building	R-13 + R-13ci	R-13 + R-14ci	R-13 + R-14ci	
Metal framed	R-13 + R-7.5ci	R-13 + R-10ci	R-13 + R-12.5ci	
Wood framed and other	R-13 + R-3.8ci OR R-20	R-13 + R-7.5ci OR R-20 + R-3.8ci	R-13 + R-7.5ci OR R-20 + R-3.8ci	
Below-grade wall	R-7.5ci	R-7.5ci	R-10ci	
Floor				
Mass	R-14.6ci	R-14.6ci	R-16.7ci	EDC Data Gathering
Joists/framing	R-30	R-30	R-38	
Unheated slabs	R-15 for 24" below	R-15 for 24" below	R-20 for 24" below	
Heated slabs	R-15 for 24" below + R-5 full slab	R-15 for 36" below + R-5 full slab	R-15 for 36" below + R-5 full slab	

[1] ci = Continuous insulation
[2] LS = Liner system

Table 3-197: Summer cooling and winter heating ETDFs for various commercial building types.

Building Type	Summer Cooling ETDF ($ETDF_S$)	Winter Heating ETDF ($ETDF_W$)
Full-Service Restaurant	0.0004849	0.0003026
Hospital	0.0003023	0.0002953
Large Hotel	0.0002949	0.0003758
Large Office	0.0003164	0.0003064
Medium Office	0.0004272	0.0003594
Outpatient	0.0003904	0.0003181
Primary School	0.0005402	0.0003855
Quick Service Restaurant	0.0003590	0.0003348
Retail Standalone	0.0004876	0.0003260
Retail Strip Mall	0.0004625	0.0003507
Secondary School	0.0005511	0.0003992
Small Hotel	0.0002474	0.0004112
Small Ofice	0.0005857	0.0004040
Warehouse	0.0006284	0.0003786

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. “Roof/Ceiling Insulation - Commercial” listed in the CPUC Support Table “Effective Useful Life and Remaining Useful Life”. Accessed December 2023. Weblink
2) SWE analysis of 15-year climate Normals for PA weather stations.
3) The initial R-value for new construction buildings is based on IECC 2021 code for climate zones 4, 5, and 6. Weblink
4) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Weblink

3.9. Consumer Electronics

3.9.1. Advanced Power Strips

Target Sector	Commercial and Industrial
Measure Unit	Per Advanced Power Strip
Measure Life	5 years source 1
Measure Vintage	Retrofit

Plug and process loads (PPLs) are building electrical loads that are not related to lighting, heating, ventilation, cooling, and water heating, and typically do not provide comfort to the occupants. PPLs in commercial buildings account for almost 33% of U.S. commercial building electricity use. Minimizing PPLs is a critical part of the design and operation of an energy-efficient building.

Advanced Power Strips (APS) are surge protectors that contain a number of power-saver sockets. There are two types of APS: Tier 1 and Tier 2.

Tier 1 APS have a master control socket arrangement and will shut off the items plugged into the controlled power-saver sockets when they sense that the appliance plugged into the master socket has been turned off. Conversely, the appliance plugged into the master control socket has to be turned on and left on for the devices plugged into the power-saver sockets to function.

Tier 2 APS deliver additional functionality beyond that of a Tier 1 unit, as Tier 2 units manage both standby and active power consumption. The Tier 2 APS manage standby power consumption by turning off devices from a control event. Active power consumption is managed by the Tier 2 unit by monitoring a user's engagement or presence in the workstation area by either localized motion detection or the use of installed software to monitor keyboard strokes and mouse movement. After a period of user absence or inactivity the Tier 2 unit will shut off all items plugged into the controlled outlets, thus saving energy.

Eligibility

This protocol documents the energy savings attributed to the installation of APS. The protocol considers usage of APS with office workstations.

Mid-stream program evaluation can collect data on APS type and workstation end-use to identify savings from Table 3-199.

Algorithms

The annual energy savings are calculated for office workstations for both Tier 1 and Tier 2 APS. If the presence of power management, either at the local- or network-level, is unknown the average energy reduction percentage shall be used.

Tier 1 Advanced Power Strip:

$$\Delta kWh = Annual\_Usage_{workstation} \times ERP_{T1\_workstation}$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Tier 2 Advanced Power Strip:

$$\Delta kWh = Annual\_Usage_{workstation} \times ERP_{T2\_workstation}$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-198: Terms, Values, and References for Smart Strip Plug Outlets

Term	Unit	Value	Source
$Annual\_Usage_{workstation}$, Annual consumption of workstation	kWh	543 kWh	2
$\%ERP$, Energy Reduction Percent	%	Default: Table 3-199	2, 3, 4
$ETDF_{summer}$, Summer energy to demand factor	$\frac{kW}{kWh}$	0.0001181	5
$ETDF_{winter}$, Winter energy to demand factor	$\frac{kW}{kWh}$	0.0001227	5

Table 3-199: Impact Factors for APS Strip Types

Strip Type	End-Use	ERP
Tier 1	Workstation	24.7%
Tier 1	Workstation with power management (network or local)	4.0%
Tier 1	Workstation with unknown power management	14.3%
Tier 2	Workstation	30.0%
Tier 2	Workstation with power management (network or local)	4.0%
Tier 2	Workstation with unknown power management	17.0%

Default Savings

The default savings calculated based on the parameters identified above are provided in Table 3-200.

Table 3-200: Default Savings for APS Strip Types

Strip Type	Use	ΔkWh	$\Delta kW_{Summer\ Peak}$	$\Delta kW_{Winter\ Peak}$
Tier 1	Workstation	134	0.016	0.016
Tier 1	Workstation with power management (network or local)	22	0.003	0.003
Tier 1	Workstation with unknown power management	78	0.009	0.010
Tier 2	Workstation	163	0.019	0.020
Tier 2	Workstation with power management (network or local)	22	0.003	0.003
Tier 2	Workstation with unknown power management	92	0.011	0.011

Evaluation Protocols

The most appropriate evaluation protocol for this measure is verification of installation coupled with assignment of stipulated energy savings.

Sources

1) California Electronic Technical Reference Manual. "Smart Connected Power Strip". SWAP010-01. Accessed January 2024. Weblink
2) Lobato, C. et al. (2012, September). "Selecting a Control Strategy for Plug and Process Loads". NREL/TP-5500-51708. Weblink
3) Acker, B. et al. (2012, August). "Office Space Plug Load Profiles and Energy Savings Interventions". University of Idaho. ACEEE Summer Study on Energy Efficiency in Buildings. Weblink
4) Slipstream for Minnesota Department of Commerce. (2019, January). "Field Study of Tier 2 Advanced Power Strips". Page 27, Table 3. Tier 2 savings (30%) found in this study provide confidence that savings from older studies in Sources 2 and 3 are still achievable. Weblink
5) Wilson et al. 2021. End-Use Load Profiles for the U.S. Building Stock: Methodology and Results of Model Calibration, Validation, and Uncertainty Quantification. NREL/TP-5500-80889. Commercial office facilities, weighted average. Weblink

3.9.2. ENERGY STAR Servers

Target Sector	Commercial and Industrial Establishments
Measure Unit	Variable
Measure Life	4 years source 1
Measure Vintage	Replace on Burnout

According to energystar.gov, data centers consume approximately 2% of the electricity in the United States. Servers and mainframes in these data centers provide email service, information storage, and other information technology services to the businesses that run them. Many servers and mainframes are located not in large data centers, but in closets within individual businesses. ENERGY STAR certified servers and mainframes can cut energy usage by 30% on average, and each watt saved at the server or mainframe level can translate to 1.9 watts saved when interactive effects are included.

Eligibility

This measure applies to the replacement of existing servers in a data center or server closet with new ENERGY STAR servers of similar computing capacity. On average, ENERGY STAR servers are 30% more efficient than standard servers. To qualify for this measure, the installed equipment must be a server system or mainframe that has earned the ENERGY STAR label.source 2

Algorithms

Annual energy savings and peak demand savings can be calculated using the algorithms shown below.

$$\Delta kWh = UES \times n$$

$$\Delta kW_{\text{summer peak}} = \Delta kWh \times ETDF_{summer}$$

$$\Delta kW_{\text{winter peak}} = \Delta kWh \times ETDF_{winter}$$

Definition of Terms

Table 3-201: Terms, Values, and References for ENERGY STAR Servers

Term	Unit	Values	Source
UES, unit energy savings	*kWh*	EDC Data Gathering Default: Table **3-202**	EDC Data Gathering 1
n, Number of ENERGY STAR servers	*Servers*	EDC Data Gathering	EDC Data Gathering
$ETDF_s$, Summer energy to demand factor	$\frac{kW}{kWh}$	0.0001181	2
$ETDF_w$, Winter energy to demand factor	$\frac{kW}{kWh}$	0.0001227	2

Table 3-202: ENERGY STAR v4.0 Annual Unit Energy Savings

Processors	Equipment Type	ΔkWh	$\Delta kW_{Summer\ Peak}$	$\Delta kW_{Winter\ Peak}$
One Installed Processor	Rack	1,459	0.172	0.179
	Tower	723	0.085	0.089
	Resilient	1,474	0.174	0.181
Two Installed Processors	Rack	2,542	0.300	0.312
	Tower	2,028	0.240	0.249
	Blade or Multi-node	1,574	0.186	0.193
Greater Than Two Installed Processors	Rack	10,218	1.207	1.254
	Blade or Multi-node	3,903	0.461	0.479

Default Savings

Default savings may be claimed using the algorithms above and the variable defaults. EDCs may also claim savings using customer specific data and following the protocols provide in v4.0 of the product eligibility criteria.[source 2]

Evaluation Protocols

When possible, perform M&V to assess the energy consumption. However, where metering of IT equipment in a data center is not allowed, follow the steps outlined.

- Invoices should be checked to confirm the number and type of ENERGY STAR servers purchased.
- If using their own estimate of active power draw, kW_{es}, the manager should provide a week's worth of active power draw data gathered from the uninterruptible power supply, PDUs, in-rack smart power strips, or the server itself.
- Idle power draws of servers, $kW_{es,idle}$, should be confirmed in the "Idle Power Typical or Single Configuration (W)" on the ENERGY STAR qualified product list.[3]
- If not using the default values listed in
- Table **3-202**, utilization rates should be confirmed by examining the data center's server performance software.

Sources

1) U.S. EPA. (2023, April). "ENERGY STAR Version 4.0 Computer Servers Final Data and Analysis Package". Calculated through the ratio of annual and lifetime savings. Weblink
2) U.S. EPA. (2023, April). "ENERGY STAR Version 4.0 Computer Servers Final Specification". Workbook in source 1 is based this final specification and certified equipment. Weblink
3) U.S. EPA. ENERGY STAR Certified Enterprise Servers Product List. Accessed January 2024. Weblink

3.9.3. Server Virtualization

Target Sector	Commercial and Industrial Establishments
Measure Unit	Per server
Measure Life	4 years source 1
Measure Vintage	Replace on Burnout

Data centers consume approximately 2% of the electricity in the United States. Servers in these data centers provide email service, information storage, and other information technology services to the businesses that run them. Most servers are installed for one specific function, for example email. This leads to up to 90% of servers in the US running at 5-10% utilization. Server virtualization allows companies to consolidate excess servers performing multiple tasks into a single physical server, saving the associated energy of the servers removed.

Eligibility

To qualify for this rebate, servers must be consolidated to increase utilization of the remaining servers, and the virtualized servers must be either a) removed or b) physically disconnected from power.

Algorithms

Annual energy savings and peak demand savings can be calculated using the algorithms shown below. The demand reduction associated with this measure is assumed to be constant since the servers operate 24 hours per day, 365 days per year.

$$\Delta kWh = (kW_{base} - kW_{ee}) \times 8{,}760$$

$$kW_{base} = \sum_{1}^{m} U_p \times \left(\frac{kW_{p,idle}}{b} - kW_{p,idle}\right) + kW_{p,idle}$$

$$kW_{ee} = U_v \times \left(\frac{kW_{v,idle}}{b} - kW_{v,idle}\right) + kW_{v,idle}$$

$$\Delta kW_{\text{summer peak}} = \frac{\Delta kWh}{8{,}760}$$

$$\Delta kW_{\text{winter peak}} = \frac{\Delta kWh}{8{,}760}$$

Definition of Terms

Table 3-203: Terms, Values, and References for Server Virtualization

Term	Unit	Values	Source
$kW_{v,idle}$, Power draw of virtualized server in idle mode	kW	EDC Data Gathering	2
$kW_{p,idle}$, Power draw of single application server in idle mode	kW	EDC Data Gathering	2
U_p, Utilization of single application server	%	EDC Data Gathering Default: 9%	EDC Data Gathering 3, 4
U_v, Utilization of virtualized host server	%	EDC Data Gathering Default: 50%	EDC Data Gathering 3, 5
b, Ratio of idle power to full load power for server	None	EDC Data Gathering Default: Table 3-204	EDC Data Gathering 6
m, number of single application servers	Servers	EDC Data Gathering	EDC Data Gathering

Table 3-204: ENERGY STAR Server Ratio of Idle Power to Full Load Power Factors

Server Installed Processors	b, Ratio of idle power to full load power for server
1	52.6%
2 or more	58.5%

Default Savings

Default savings may be claimed using the algorithms above and the variable defaults. EDCs may also claim savings using customer specific data.

Evaluation Protocols

When possible, perform M&V to assess the energy consumption. However, where metering of IT equipment in a data center is not allowed, follow the steps outlined.

- Invoices should be checked to confirm the number and type of servers virtualized.
- If not using the default values listed in Table 3-203, utilization rates should be confirmed by examining the data center's server performance software.

Sources

1) U.S. EPA. (2023, April). "ENERGY STAR Version 4.0 Computer Servers Final Data and Analysis Package". Calculated through the ratio of annual and lifetime savings. Weblink
2) U.S. EPA. ENERGY STAR Certified Enterprise Servers Product List. Accessed January 2024. Weblink
3) Utilization of a server can be derived from a data center's server performance software. This data should be used, instead of the default values listed in Table 3-203, when possible.
4) Glanz, J. (2012, September). "Power Pollution and The Internet". The New York Times. This article cited sources of average utilization rates between 6 to 12%. Weblink
5) Talaber, R. (2009). "Using Virtualization to Improve Data Center Efficiency". The Green Grid. VMWare. Page. 6, Table 1. A target of 50% server utilization is recommended when setting up a virtual host. Weblink
6) U.S. EPA. (2013, November). ENERGY STAR Certified Enterprise Servers Product List. The idle to full load power ratios were estimated based on the ENERGY STAR qualified product list from November 18, 2013, as ENERGY STAR stopped including full load power data in December 2013 The ratios listed in Table 3-204 are based on the average idle to full load ratios for all ENERGY STAR qualified servers in each server category.

3.10. Compressed Air

3.10.1. Cycling Refrigerated Thermal Mass Dryer

Target Sector	Commercial and Industrial
Measure Unit	Cycling Refrigerated Thermal Mass Dryer
Measure Life	10 years Source 1
Measure Vintage	Early Replacement

When air is compressed, water vapor in the air condenses and collects in liquid form. Some of this condensate collects in the air distribution system and can contaminate downstream components such as air tools with rust, oil, and pipe debris. Refrigerated air dryers remove the water vapor by cooling the air to its dew point and separating the condensate. Changes in production and seasonal variations in ambient air temperature leads to partial loading conditions on the dryer. Standard refrigerated thermal mass air dryers use a hot gas bypass system that is inefficient at partial loads. A cycling refrigerated thermal mass dryer uses a thermal storage medium to store cooling capacity when the system is operated at partial loads allowing the dryer refrigerant compressor to cycle.

Eligibility

This measure is targeted to non-residential customers whose equipment is a non-cycling refrigerated air dryer with a capacity of 600 CFM or below.

Acceptable baseline conditions are a non-cycling (e.g., continuous) air dryer with a capacity of 600 CFM or below. The replacement of desiccant, deliquescent, heat-of-compression, membrane, or other types of dryers does not qualify under this measure.

Efficient conditions are a cycling thermal mass dryer with a capacity of 600 CFM or below.

Algorithms

$$\Delta kWh = ((CFM \times HP_{compressor} \times \frac{kW_{dryer}}{\text{CFM}} \times HOURS \times (1 - APC)) \times RTD)$$

$$\Delta kW_{summer\ peak} = \frac{\Delta kWh}{HOURS} \times CF$$

$$\Delta kW_{winter\ peak} = \frac{\Delta kWh}{HOURS} \times \text{CF}$$

Definition of Terms

Table 3-205: Terms, Values, and References for Cycling Refrigerated Thermal Mass Dryers

Term	Unit	Values	Source
CFM, Compressor output per HP	$\frac{CFM}{HP}$	EDC Data Gathering Default: 4	EDC Data Gathering 2
$HP_{compressor}$, Nominal HP rating of the air compressor motor	*HP*	Nameplate data	EDC Data Gathering
kW_{dryer}/CFM, Ratio of dryer kW to compressor CFM	$\frac{kW}{CFM}$	EDC Data Gathering Default: 0.0079	EDC Data Gathering 3
RTD, Chilled coil response time derate	*Hours*	EDC Data Gathering Default: 0.925	EDC Data Gathering 4
APC, Average compressor operating capacity	*None*	EDC Data Gathering Default: 65%	EDC Data Gathering 5
$HOURS$, Annual hours of compressor operation	$\frac{Hours}{year}$	EDC Data Gathering Default: Table 3-206	EDC Data Gathering 6
CF, Coincident Factor	$None$	EDC Data Gathering Default: Table 3-206	EDC Data Gathering 5

Table 3-206: Default Hours and Coincidence Factors by Shift Type

Shift Type	Hours Per Year	CF	Description
Single Shift (8/5)	1,976	0.24*	7 AM – 3 PM, weekdays, minus 110 hours of holidays and scheduled downtime
2-shift (16/5)	3,952	0.95	7 AM – 11 PM, weekdays, minus 220 hours holidays and scheduled downtime
3-shift (24/5)	5,928	0.95	24 hours per day, weekdays, minus 330 hours holidays and scheduled downtime
Continual Operation (24/7)	8,320	0.95	24 hours per day, 7 days a week minus 440 hours holidays and scheduled downtime
* Note: This value is derived by adjusting the coincidence factor to account for assumed compressor operation (7 a.m. to 3 p.m.) during only one of the four hours of peak period (2 p.m. to 6 p.m.). 0.95 * (1/4) = 0.2375.			

Default Savings

Default savings per compressor motor HP for four shift types are shown below. EDCs may also claim savings using customer specific data.

Table 3-207: Default Savings per HP for Cycling Refrigerated Thermal Mass Dryers

Shift Type	Annual Energy Savings ($\Delta kWh/HP$)	Summer Peak Demand Savings ($\Delta kW_{summer\ peak}/HP$)	Winter Peak Demand Savings ($\Delta kW_{winter\ peak}/HP$)
Single Shift (8/5)	20.1	0.0024	0.0024
2-shift (16/5)	40.1	0.0096	0.0096
3-shift (24/5)	60.2	0.0096	0.0096
Continual Operation (24/7)	84.5	0.0096	0.0096

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Energy and Resource Solutions. (2005, November). Measure Life Study prepared for the Massachusetts Joint Utilities. Section 4.2.5 C&I New Construction Program – Prescriptive pages 4-10, Table 4-5 C&I New Construction Common Measure Lives. Weblink
2) PA PUC SWE internal air compressor calculation workbook created and maintained by the SWE (2024, Jan); originally sourced from the Vermont Technical Reference Manual. The CFM/HP default value is derived from nameplate ratings of (20) varying compressor models with nameplate brake horsepower (bhp) ratings between 10 and 40 bhp and CFM at full-load pressure between 55 and 185 psig.
3) PA PUC SWE internal air compressor calculation workbook created and maintained by the SWE (2024, Jan); originally sourced from the Vermont Technical Reference Manual. This conversion factor is based on a linear regression analysis of the relationship between air compressor full load capacity and non-cycling dryer full load kW. Calculations assume that the dryer is sized to accommodate the maximum compressor capacity.
4) PA PUC SWE Air Compressor TRM Workbook, adapted from the Efficiency Vermont Technical Reference User Manual (TRM) compressed-air-analysis-xlsx workbook. RTD Chilled Coil Response Time defined by VT.
5) PA PUC SWE internal air compressor calculation workbook created and maintained by the SWE (2024, Jan); originally sourced from the Vermont Technical Reference Manual A study of (72) air compressors recorded their operating hours at various operating capacities. The average operating capacity parameter is calculated from these metrics.
6) United States Department of Energy. (2004) Evaluation of the Compressed Air Challenge Training Program 3rd Edition. Hours of operation are based on section 2.1.5 Facility Operating Schedule. Specific shift operating hours and non-operating hours are assumptions. Weblink

3.10.2. Air-Entraining Air Nozzle

Target Sector	Commercial and Industrial
Measure Unit	Air-entraining Air Nozzle
Measure Life	15 years Source 1
Measure Vintage	Early Replacement

Air entraining air nozzles use compressed air to entrain and amplify atmospheric air into a stream, increasing pressure with minimal compressed air use. This decreases the compressor work necessary to provide the nozzles with compressed air. Air entraining nozzles can also reduce noise in systems with air at pressures greater than 30 psig.

Eligibility

This measure is targeted to non-residential customers whose compressed air equipment uses stationary air nozzles in a production application with an open copper tube of 1/8” or 1/4” orifice diameter.

Energy efficient conditions require replacement of an inefficient, non-air entraining air nozzle with an energy efficient air-entraining air nozzle that use less than 15 CFM at 100 psig for industrial applications.

Algorithms

$$\Delta kWh = (CFM_{base} - CFM_{ee}) \times COMP \times HOURS \times \%\, USE$$

$$\Delta kW_{summer\ peak} = \frac{\Delta kWh}{HOURS} \times CF$$

$$\Delta kW_{winter\ peak} = \frac{\Delta kWh}{HOURS} \times CF$$

Definition of Terms

Table 3-208: Terms, Values, and References for Air-entraining Air Nozzles

Term	Unit	Values	Source
CFM_{base}, Baseline nozzle air flow	CFM $\left(\frac{ft^3}{min}\right)$	EDC Data Gathering Default: Table 3-209	EDC Data Gathering 2
CFM_{ee}, Energy efficient nozzle air flow	CFM $\left(\frac{ft^3}{min}\right)$	EDC Data Gathering Default: Table 3-210	EDC Data Gathering 3
$COMP$, Ratio of compressor kW to CFM	$\frac{kW}{CFM}$	EDC Data Gathering Default: Table 3-211	EDC Data Gathering 4
$HOURS$, Annual hours of compressor operation	$\frac{Hours}{year}$	EDC Data Gathering Default: Table 3-212	EDC Data Gathering 5
$\%\ USE$, Percent of hours when nozzle is in use	None	EDC Data Gathering Default: 5%	EDC Data Gathering 6
CF, Coincident Factor	$None$	EDC Data Gathering Default: Table 3-212	EDC Data Gathering 5

Table 3-209: Baseline Nozzle Flow

Nozzle Diameter	Air Mass Flow (CFM) @ 80 psig
1/8”	21
1/4"	58

Table 3-210: Air Entraining Nozzle Flow

Nozzle Diameter	Air Mass Flow (CFM) @ 80 psig
1/8”	6
1/4"	11

Table 3-211: Average Compressor kW / CFM (COMP)

Compressor Control Type	Average Compressor kW/CFM (COMP)
Modulating w/ Blowdown	0.18
Load/No Load w/ 1 gal/CFM Storage	0.18
Load/No Load w/ 3 gal/CFM Storage	0.16
Load/No Load w/ 5 gal/CFM Storage	0.16
Variable Speed w/ Unloading	0.13
Unknown	0.16

Table 3-212: Default Hours and Coincidence Factors by Shift Type

Shift Type	Hours Per Year	CF	Description
Single Shift (8/5)	1,976	0.24*	7 AM – 3 PM, weekdays, minus 110 hours from holidays and scheduled downtime
2-shift (16/5)	3,952	0.95	7 AM – 11 PM, weekdays, minus 220 hours from holidays and scheduled downtime
3-shift (24/5)	5,928	0.95	24 hours per day, weekdays, minus 330 hours from holidays and scheduled downtime
Continual Operation (24/7)	8,320	0.95	24 hours per day, 7 days a week minus 440 hours from holidays and scheduled downtime
* Note: This value is derived by adjusting the coincidence factor to account for assumed compressor operation (7 a.m. to 3 p.m.) during only one of the four hours of peak period (2 p.m. to 6 p.m.). 0.95 * (1/4) = 0.2375.			

Default Savings

Default savings may be claimed using the algorithms above and the variable defaults. EDCs may also claim savings using customer specific data.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Energy and Resource Solutions. (2005, November). Measure Life Study prepared for the Massachusetts Joint Utilities. Section 4.2.5 C&I New Construction Program – Prescriptive pages 4-10, Table 4-5 C&I New Construction Common Measure Lives. Weblink

2) Oberg, E. (1997). Machinery's Handbook (25th Edition). Industrial Press, Inc.

3) Survey of Engineered Nozzle Suppliers.

4) PA PUC SWE internal air compressor calculation workbook created and maintained by the SW (2024, Jan); originally sourced from the Vermont Technical Reference Manual. The average compressor kW/CFM values were calculated using DOE part load curves and load profile data from 50 facilities employing compressors less than or equal to 40 hp.

5) United States Department of Energy. (2004) Evaluation of the Compressed Air Challenge Training Program. Hours of operation are based on section 2.1.5 Facility Operating Schedule. Specific shift operating hours and non-operating hours are assumptions. Weblink

6) Vermont Efficiency Technical Reference User Manual. (Dec, 2018). "Air-Entraining Air Nozzles". "Algorithms". Assumes 50% handheld air guns and 50% stationary air nozzles. Manual air guns tend to be used less than stationary air nozzles, and a conservative estimate of 1 second of blow-off per minute of compressor run time is assumed. Stationary air nozzles are commonly more wasteful as they are often mounted on machine tools and can be manually operated resulting in the possibility of a long term open blow situation. An assumption of 5 seconds of blow-off per minute of compressor run time is used. Weblink

3.10.3. No-Loss Condensate Drains

Target Sector	Commercial and Industrial
Measure Unit	No-loss Condensate Drain
Measure Life	10 years Source 1
Measure Vintage	Early Replacement

When air is compressed, water vapor in the air condenses and collects in the system. The water must be drained to prevent corrosion to the storage tank and piping system, and to prevent interference with other components of the compressed air system such as air dryers and filters. Many drains are controlled by a timer and are opened for a fixed amount of time on regular intervals regardless of the amount of condensate. When the drains are opened compressed air is allowed to escape without doing any purposeful work. No-loss Condensate Drains are controlled by a sensor that monitors the level of condensate and only open when there is a need to drain condensate. They close before compressed air is allowed to escape.

Eligibility

This measure is targeted to non-residential customers whose equipment is a timed drain that operates on a pre-set schedule.

Acceptable baseline conditions are compressed air systems with standard condensate drains operated by a solenoid and timer.

Energy efficient conditions are systems retrofitted with new no-loss condensate drains properly sized for the compressed air system.

Algorithms

The following algorithms apply for No-loss Condensate Drains.

$$\Delta kWh = ALR \times COMP \times OPEN \times AF \times PNC$$

$$\Delta kW_{summer\ peak} = \frac{\Delta kWh}{HOURS} \times CF$$

$$\Delta kW_{winter\ peak} = \frac{\Delta kWh}{HOURS} \times CF$$

Definition of Terms

Table 3-213: Terms, Values, and References for No-loss Condensate Drains

Term	Unit	Values	Source
ALR, Air Loss Rate; an hourly average rate for the timed drain dependent on drain orifice diameter and system pressure.	$CFM\left(\frac{ft^3}{min}\right)$	EDC Data Gathering Default: Table **3-214**	EDC Data Gathering 2
$COMP$, Compressor kW / CFM; the amount of electrical demand in KW required to generate one cubic foot of air at 100 psig.	$\frac{kW}{CFM}$	EDC Data Gathering Default: Table 3-215	EDC Data Gathering 3
$OPEN$, Hours per year drain is open	$\frac{Hours}{year}$	EDC Data Gathering Default: 146	EDC Data Gathering 4
AF, Adjustment Factor; accounts for periods when compressor is not running and the system depressurizes due to leaks and operation of time drains.	$None$	EDC Data Gathering Default: Table 3-216	EDC Data Gathering 5
PNC, Percent Not Condensate; accounts for air loss through the drain after the condensate has been cleared and the drain remains open.	$None$	EDC Data Gathering Default: 0.75	EDC Data Gathering 6
$HOURS$, Annual hours of compressor operation	$\frac{Hours}{year}$	EDC Data Gathering Default: Table 3-217	EDC Data Gathering 7
CF, Coincident Factor	$None$	EDC Data Gathering Default: Table 3-206	EDC Data Gathering 7

Table 3-214: Average Air Loss Rates (ALR)

Pressure (psig)	Orifice Diameter (inches)					
	1/64	1/32	1/16	1/8	1/4	3/8
70	0.29	1.16	4.66	18.62	74.4	167.8
80	0.32	1.26	5.24	20.76	83.1	187.2
90	0.36	1.46	5.72	23.1	92	206.6
95	0.38	1.51	6.02	24.16	96.5	216.8
100	0.4	1.55	6.31	25.22	100.9	227
105	0.42	1.63	6.58	26.31	105.2	236.7
110	0.43	1.71	6.85	27.39	109.4	246.4
115	0.45	1.78	7.12	28.48	113.7	256.1
120	0.46	1.86	7.39	29.56	117.9	265.8
125	0.48	1.94	7.66	30.65	122.2	275.5
For well-rounded orifices, values should be multiplied by 0.97. For sharp orifices, values should be multiplied by 0.61. When the baseline value is unknown, use 100.9 CFM.						

Table 3-215: Average Compressor kW/CFM (COMP)

Compressor Control Type	Average Compressor kW/CFM (COMP)
Modulating w/ Blowdown	0.18
Load/No Load w/ 1 gal/CFM Storage	0.18
Load/No Load w/ 3 gal/CFM Storage	0.16
Load/No Load w/ 5 gal/CFM Storage	0.16
Variable Speed w/ Unloading	0.13
Unknown	0.16

Table 3-216: Adjustment Factor (AF)

Compressor Operating Hours	AF
Single Shift (8/5)	0.62
2-Shift (16/5)	0.74
3-Shift (24/5)	0.86
Continual Operation (24/7)	0.97

Table 3-217: Default Hours and Coincidence Factors by Shift Type

Shift Type	Hours Per Year	CF	Description
Single Shift (8/5)	1,976	0.24*	7 AM – 3 PM, weekdays, minus 110 hours for holidays and scheduled downtime
2-shift (16/5)	3,952	0.95	7 AM – 11 PM, weekdays, minus 220 hours for holidays and scheduled downtime
3-shift (24/5)	5,928	0.95	24 hours per day, weekdays, minus 330 hours for holidays and scheduled downtime
Continual Operation (24/7)	8,320	0.95	24 hours per day, 7 days a week minus 440 hours for holidays and scheduled downtime
* Note: This value is derived by adjusting the coincidence factor to account for assumed compressor operation (7 a.m. to 3 p.m.) during only one of the four hours of peak period (2 p.m. to 6 p.m.). 0.95 * (1/4) = 0.2375.			

Default Savings

Default savings may be claimed using the algorithms above and the variable defaults. EDCs may also claim savings using customer specific data.

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Illinois Statewide Technical Reference Manual. (2024, version 12.0). "4.7.3 Compressed Air No-Loss Condensate Drains". Weblink
2) DOE. (2004). Energy Tips – Compressed Air, Compressed Air Tip Sheet #3. Weblink
3) PA PUC SWE internal air compressor calculation workbook created and maintained by the SW (2024, Jan); originally sourced from the Vermont Technical Reference Manual. The average compressor kW/CFM values were calculated using DOE part

load curves and load profile data from 50 facilities employing compressors less than or equal to 40 hp.

4) Vermont Efficiency Technical Reference User Manual. (Dec, 2018). “No Loss Condensate Drains”. Algorithms table. Assumes a baseline of 8,760 air compressor operation. Weblink

5) Vermont Efficiency Technical Reference User Manual. (Dec, 2018). “No Loss Condensate Drains”. Reference Tables. Adjustment Factors (AF) by Compressor Operating Hours. Weblink

6) Vermont Efficiency Technical Reference User Manual. (Dec, 2018). “No Loss Condensate Drains”. Algorithms table. PNC value is a conservative estimate based on professional judgement. Weblink

7) United States Department of Energy. (2014). Evaluation of the Compressed Air Challenge Training Program. Hours of operation are based on section 2.1.5 Facility Operating Schedule. Specific shift operating hours and non-operating hours are assumptions. Weblink

3.10.4. AIR TANKS FOR LOAD/NO LOAD COMPRESSORS

Target Sector	Commercial and Industrial
Measure Unit	Receiver Tank Addition
Measure Life	15 years Source 1
Measure Vintage	Early Replacement

This measure protocol applies to the installation of air receivers with pressure/flow controls to load/no load compressors. Load/no load compressors unload when there is low demand. The process of unloading is done over a period of time to avoid foaming of the lubrication oil. Using a storage tank with pressure/flow control will buffer the air demands on the compressor. Reducing the number of cycles in turn reduces the number of transition times from load to no load and saves energy. The baseline equipment is a load/no load compressor with a 1 gal/ CFM storage ratio or a modulating compressor with blowdown.

ELIGIBILITY

This measure protocol applies to the installation of new air receivers with pressure/flow controls to load/no load compressors. The high efficiency equipment is a load/no load compressor with a minimum storage ratio of 4 gallons of storage per CFM.

ALGORITHMS

$$\Delta kWh = \frac{HP \times 0.746 \times HOURS \times LF \times LR}{\eta}$$

$$\Delta kW_{summer\ peak} = \frac{\Delta kWh}{HOURS} \times CF$$

$$\Delta kW_{winter\ peak} = \frac{\Delta kWh}{HOURS} \times CF$$

Definition of Terms

Table 3-218: Terms, Values, and References for Air Tanks for Load/No Load Compressors

Term	Unit	Values	Source
HP, Horsepower of compressor motor	HP	Nameplate	EDC Data Gathering
0.746, Conversion factor	$\frac{kW}{HP}$	0.746	Conversion factor
$HOURS$, Annual hours of compressor operation	hr	Based on logging, panel data or modeling Default: Table 3-219	EDC Data Gathering 2
LF, Load factor, average load on compressor motor	Fraction	Default = 0.92	EDC Data Gathering 3
LR, Load reduction	Fraction	Default = 0.10	EDC Data Gathering 4
η, Efficiency of compressor motor	%	Default = 91%	EDC Data Gathering 5
CF, Coincident Factor	$None$	EDC Data Gathering Default: Table 3-219	EDC Data Gathering 2

Table 3-219: Default Hours and Coincidence Factors by Shift Type

Shift Type	Hours Per Year	CF	Description
Single Shift (8/5)	1,976	0.24*	7 AM – 3 PM, weekdays, minus 110 hours from holidays and scheduled downtime
2-shift (16/5)	3,952	0.95	7 AM – 11 PM, weekdays, minus 220 hours from holidays and scheduled downtime
3-shift (24/5)	5,928	0.95	24 hours per day, weekdays, minus 330 hours from holidays and scheduled downtime
Continual Operation (24/7)	8,320	0.95	24 hours per day, 7 days a week minus 440 hours from holidays and scheduled downtime
* Note: This value is derived by adjusting the coincidence factor to account for assumed compressor operation (7 a.m. to 3 p.m.) during only one of the four hours of peak period (2 p.m. to 6 p.m.). 0.95 * (1/4) = 0.2375.			

Default Savings

Default savings per compressor motor HP for four shift types are shown below. EDCs may also claim savings using customer specific data.

Table 3-220: Default Savings per HP for Air Tanks for Load/No Load Compressors

Shift Type	Annual Energy Savings $(\Delta kWh/HP)$	Summer Peak Demand Savings $(\Delta kW_{summer\ peak}/HP)$	Winter Peak Demand Savings $(\Delta kW_{winter\ peak}/HP)$
Single Shift (8/5)	149.0	0.018	0.018
2-shift (16/5)	298.1	0.072	0.072
3-shift (24/5)	447.1	0.072	0.072
Continual Operation (24/7)	627.5	0.072	0.072

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Energy and Resource Solutions. (2005, November). Measure Life Study prepared for the Massachusetts Joint Utilities. Section 4.2.5 C&I New Construction Program – Prescriptive pages 4-10, Table 4-5 C&I New Construction Common Measure Lives. Weblink
2) United States Department of Energy. (2014). Evaluation of the Compressed Air Challenge Training Program. Hours of operation are based on section 2.1.5 Facility Operating Schedule. Specific shift operating hours and non-operating hours are assumptions. Weblink
3) Cascade Energy (2012, November). Proposed Standard Savings Estimation Protocol for Ultra-Premium Efficiency Motors. Appendix C: NW Industrial Motors Database Analysis Table 6: Load Factor by nameplate hp and end use load. Weblink
4) United States Department of Energy. (2016). Improving Compressed Air System Performance 3rd Edition. Weblink
5) Cascade Energy (2012, November). Proposed Standard Savings Estimation Protocol for Ultra-Premium Efficiency Motors. Appendix C: NW Industrial Motors Database Analysis Table 6: Load Factor by nameplate hp and end use load factor for air compressors and average motor efficiency. The average efficiency for a NEMA premium efficiency 1800 RPM ODP motors with 75% and 100% load factors from 1HP to 200HP yields an average motor efficiency of 91%. Weblink

3.10.5. Variable-Speed Drive Air Compressor

Target Sector	Commercial and Industrial
Measure Unit	Compressor Motor
Measure Life	13 years Source 1
Measure Vintage	Replace on Burnout, Early Replacement, Retrofit, New Construction

Variable-Speed Drive (VSD) Air Compressors use a variable speed drive on the motor to match motor output to the load, resulting in greater efficiency than fixed-speed air compressors. Baseline compressors choke off inlet air to modulate the compressor output, resulting in increased energy consumption and peak demand.

Eligibility

To qualify for this measure, a participating commercial or industrial establishment must install or retrofit a ≤ 40 HP compressor with variable speed control. Projects involving compressors larger than 40 HP should be treated as custom projects.

Algorithms

Savings are calculated using representative baseline and efficient demand numbers for compressor capacities according to the facility's load shape and runtime. Demand curves are derived from DOE data for a variable speed compressor versus a modulating compressor. The following formulas are used to quantify the annual energy and coincident peak demand savings.

$$\Delta kWh = \frac{0.9 \times HP_{compressor} \times HOURS \times (CLF_{base} - CLF_{VSD})}{\eta}$$

$$\Delta kW_{summer\ peak} = \frac{\Delta kWh}{HOURS} \times CF$$

$$\Delta kW_{winter\ peak} = \frac{\Delta kWh}{HOURS} \times CF$$

Definition of Terms

Table 3-221: Terms, Values, and References for Variable-Speed Drive Air Compressors

Term	Unit	Values	Source
$HOURS$, compressor total hours of operation below depending on shift	$\frac{Hours}{Year}$	EDC Data Gathering Default: Table 3-222	EDC Data Gathering 2
$HP_{compressor}$, compressor motor nominal HP	HP	Nameplate	EDC Data Gathering
CLF_{base}, baseline compressor factor	None	EDC Data Gathering Default = 0.890	EDC Data Gathering 3
CLF_{VSD}, efficient compressor factor	None	EDC Data Gathering Default = 0.675	EDC Data Gathering 3
CF, Coincident Factor	$None$	EDC Data Gathering Default: Table 3-222	EDC Data Gathering 2
η, Efficiency of compressor motor	%	EDC Data Gathering Default = 91%	EDC Data Gathering 4
0.9, Compressor motor nominal HP to full load kW conversion factor.	$\frac{kW}{HP}$	Default = 0.9	5

Table 3-222: Default Hours and Coincidence Factors by Shift Type

Shift Type	Hours Per Year	CF	Description
Single Shift (8/5)	1,976	0.24*	7 AM – 3 PM, weekdays, minus 110 hours for holidays and scheduled downtime
2-shift (16/5)	3,952	0.95	7 AM – 11 PM, weekdays, minus 220 hours for holidays and scheduled downtime
3-shift (24/5)	5,928	0.95	24 hours per day, weekdays, minus 330 hours for holidays and scheduled downtime
Continual Operation (24/7)	8,320	0.95	24 hours per day, 7 days a week minus 440 hours for holidays and scheduled downtime
* Note: This value is derived by adjusting the coincidence factor to account for assumed compressor operation (7 a.m. to 3 p.m.) during only one of the four hours of peak period (2 p.m. to 6 p.m.). 0.95 * (1/4) = 0.2375.			

DEFAULT SAVINGS

Default savings per compressor motor HP for four shift types are shown below. EDCs may also claim savings using customer specific data.

Table 3-223: Default Savings per HP for Variable-Speed Drive Air Compressors

Shift Type	Annual Energy Savings ($\Delta kWh/HP$)	Summer Peak Demand Savings ($\Delta kW_{summer\ peak}/HP$)	Winter Peak Demand Savings ($\Delta kW_{winter\ peak}/HP$)
Single Shift (8/5)	420	0.051	0.051
2-shift (16/5)	840	0.202	0.202
3-shift (24/5)	1,261	0.202	0.202
Continual Operation (24/7)	1,769	0.202	0.202

EVALUATION PROTOCOLS

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

SOURCES

1) California Electronic Technical Reference Manual. “CPUC Support Tables”. “Effective Useful Life and Remaining Useful Life”. Accessed Nov 2023 Weblink

2) United States Department of Energy. (2004) Evaluation of the Compressed Air Challenge Training Program. Hours of operation are based on section 2.1.5 Facility Operating Schedule. Specific shift operating hours and non-operating hours are assumptions. Weblink

3) PA PUC SWE internal air compressor calculation workbook created and maintained by the SW (2024, Jan); originally sourced from the Vermont Technical Reference Manual. Compressor factors are derived from part-load power curves developed from observation of (72) compressors with nameplate brake horsepower (bhp) ratings between 10 and 40 bhp. The baseline factor assumes a “Modulating w/ Blow-Down” system type and the efficient condition assumes a “Variable Speed w/Unloading” system type.

4) Cascade Energy (2012, November). Proposed Standard Savings Estimation Protocol for Ultra-Premium Efficiency Motors. Appendix C: NW Industrial Motors Database Analysis Table 6: Load Factor by nameplate hp and end use load factor for air compressors and average motor efficiency. The average efficiency for a NEMA premium efficiency 1800 RPM ODP motors with 75% and 100% load factors from 1HP to 200HP yields an average motor efficiency of 91%. Weblink

5) Internal air compressor calculation workbook created and maintained by the PA Statewide Evaluator (2024, Jan); originally sourced from the Vermont Technical Reference Manual. The 0.9 value is derived from nameplate ratings of (20) varying compressor models.

3.10.6. Compressed Air Controller

Target Sector	Commercial and Industrial
Measure Unit	Per Compressed Air System
Measure Life	13 years Source 1
Measure Vintage	Replace on Burnout, New Construction, or Retrofit

Eligibility

The following protocol for the measurement of energy and demand savings applies to the installation of a compressed air pressure or flow controller for compressed air systems in commercial or industrial facilities.

A pressure/flow controller can greatly increase the control of an air storage system. These units, also called demand valves, precision flow controllers, or pilot-operated regulators, are precision pressure regulators that allow the airflow to fluctuate while maintaining a constant pressure to the facility's air distribution piping network. Installing a pressure/flow controller on the downstream side of an air storage receiver creates a pressure differential entering and leaving the vessel. This pressure differential stores energy in the form of readily available compressed air, which can be used to supply the peak air demand for short duration events, in place of using more compressor horsepower to feed this peak demand. The benefits of having a pressure/flow controller include:

- Reducing the kilowatts of peak demand, especially with multiple compressor configurations.
- Saving kilowatt-hours by allowing the compressor to run at most efficient loads, then turn itself off in low demand and no demand periods.
- Saving kilowatt-hours by reducing plant air pressure to the minimum allowable. This leads to reduced loads on the electric motors and greater system efficiency. For every 2 psi reduced in the system, 1% of energy is saved[2].
- Maintaining a reduced, constant pressure in the facility wastes less air due to leakage, and less volume is required by the compressor.
- Ensuring quality control of the process by the constant pressure: machines can produce an enhanced product quality when the pressure is allowed to fluctuate.

The baseline condition is having no existing pressure/flow controller and an existing compressed air system with a total compressor motor capacity ≥ 40 hp. This measure requires a minimum storage of 3gal/ CFM. This protocol is not applicable for compressed air systems with total motor nameplate capacity < 40 hp. This measure is not replacing drop-line regulators or filter-regulator lubricators.

ALGORITHMS

$$\Delta kWh = HP \times \frac{0.746}{\eta_{motor}} \times LF \times HOURS \times \%Decrease$$

$$\Delta kW_{summer\ peak} = \frac{\Delta kWh}{HOURS} \times CF$$

$$\Delta kW_{winter\ peak} = \frac{\Delta kWh}{HOURS} \times CF$$

DEFINITION OF TERMS

Table 3-224: Terms, Values, and References for Compressed Air Controllers

Term	Unit	Values	Source
HP, total air compressor motor nameplate horsepower	HP	Nameplate	EDC Data Gathering
0.746, conversion factor from kW to HP	$\frac{kW}{HP}$	Constant	Constant
$HOURS$, average annual run hours of compressed air system	$\frac{Hours}{Year}$	Based on logging, panel data or modeling Default: Table 3-225	EDC Data Gathering 3
LF, load factor; ratio between the actual load on the compressor motor and the rated load	$\%$	Based on spot metering and nameplate Default: 0.92	EDC Data Gathering 4
η_{motor}, compressor motor efficiency at the full-rated load	$\%$	Nameplate Default: 91%	EDC Data Gathering 5
$\%Decrease$, percentage decrease in power input	$\%$	Default: 5%	2
CF, Coincident Factor	$None$	EDC Data Gathering Default: Table 3-225	EDC Data Gathering 3

Table 3-225: Default Hours and Coincidence Factors by Shift Type

Shift Type	Hours Per Year	CF	Description
Single Shift (8/5)	1,976	0.24*	7 AM – 3 PM, weekdays, minus 110 hours for holidays and scheduled downtime
2-shift (16/5)	3,952	0.95	7 AM – 11 PM, weekdays, minus 220 hours holidays and scheduled downtime
3-shift (24/5)	5,928	0.95	24 hours per day, weekdays, minus 330 hours for holidays and scheduled downtime
Continual Operation (24/7)	8,320	0.95	24 hours per day, 7 days a week 440 hours for some holidays and scheduled downtime
* Note: This value is derived by adjusting the coincidence factor to account for assumed compressor operation (7 a.m. to 3 p.m.) during only one of the four hours of peak period (2 p.m. to 6 p.m.). 0.95 * (1/4) = 0.2375.			

DEFAULT SAVINGS

Default savings per compressor motor HP for four shift types are shown below. EDCs may also claim savings using customer specific data.

Table 3-226: Default Savings per HP for Compressed Air Controllers

Shift Type	Annual Energy Savings ($\Delta kWh/HP$)	Summer Peak Demand Savings ($\Delta kW_{summer\ peak}/HP$)	Winter Peak Demand Savings ($\Delta kW_{winter\ peak}/HP$)
Single Shift (8/5)	74.5	0.009	0.009
2-shift (16/5)	149.0	0.036	0.036
3-shift (24/5)	223.5	0.036	0.036
Continual Operation (24/7)	313.7	0.036	0.036

EVALUATION PROTOCOL

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

SOURCES

1) California Electronic Technical Reference Manual. “CPUC Support Tables”. “Effective Useful Life and Remaining Useful Life”. Accessed Nov 2023 Weblink

2) United States Department of Energy. (2003). Improving Compressed Air System Performance: A Sourcebook for Industry. page 31. For every 2 psi increase in discharge pressure, energy consumption will increase by approximately 1% at full output flow (performance curves vary). A properly designed system should have a pressure loss of much less than 10% of the

compressor's discharge pressure. This measure assumes a discharge pressure of 100 psig with an optimally controlled system resulting in 90 psig at the end uses. Weblink

3) United States Department of Energy. (2004) Evaluation of the Compressed Air Challenge Training Program. Hours of operation are based on section 2.1.5 Facility Operating Schedule. Specific shift operating hours and non-operating hours are assumptions. Weblink

4) Cascade Energy.(2012, November). Standard Savings Estimation Protocol for Ultra-Premium Efficiency Motors. Appendix C: NW Industrial Motors Database Analysis Table 6: Load Factor by Nameplate hp and end use load. Load factor for air compressors. Weblink

5) Cascade Energy. (2012, November). Standard Savings Estimation Protocol for Ultra-Premium Efficiency Motors. Appendix B: NEMA Premium Motor Efficiency Standards Table 4: Average motor efficiency for MotorMaster+ motors with data at four load factors, filtered by HP, enclosure, and RPM. Average efficiency for 1800 RPM ODP motors with 75% and 100% load factors. Weblink

3.10.7. Compressed Air Low Pressure Drop Filters

Target Sector	Commercial and Industrial Establishments
Measure Unit	Per Compressed Air System
Measure Life	10 years Source 1
Measure Vintage	Replace on Burnout, New Construction, or Retrofit

Eligibility

The following protocol for the measurement of energy and demand savings applies to the installation of low pressure drop air filters for compressed air systems in commercial and industrial facilities. Low pressure drop filters remove solids and aerosols from compressed air systems with a longer life and lower pressure drop than standard coalescing filters, resulting in better efficiencies.

The baseline condition is a standard coalescing filter with a pressure drop of 3 psi when new and 5 psi or more at element change. The efficient condition is a low pressure drop filter with pressure drop not exceeding 1 psi when new and 3 psi at element change.

Algorithms

$$\Delta kWh = \frac{\mathrm{HP} \times 0.746 \times LF \times DP \times SF \times HOURS}{\eta_{motor}}$$

$$\Delta kW_{summer\ peak} = \frac{\Delta kWh}{HOURS} \times \mathrm{CF}$$

$$\Delta kW_{winter\ peak} = \frac{\Delta kWh}{HOURS} \times CF$$

Definition of Terms

Table 3-227: Terms, Values, and References for Compressed Air Low Pressure Drop Filters

Term	Unit	Values	Source
HP, total air compressor motor nameplate horsepower	HP	Nameplate	EDC Data Gathering
0.746, conversion factor	$\frac{kW}{HP}$	0.746	Conversion factor
DP, reduced filter pressure loss	psi	Default: 2.0	2
HP, total air compressor motor nameplate horsepower	$\%$	Nameplate Default: 0.91	EDC Data Gathering 3
LF, load factor; ratio between the actual load on the compressor motor and the rated load	$\%$	Default: 0.92	3
SF, savings factor	$\%/psig$	Default: 0.005	4
$HOURS$, compressed air system total annual hours of operation	$\frac{Hours}{Year}$	Based on logging and panel data Default: Table 3-228	EDC Data Gathering 5
CF, Coincident Factor	$None$	EDC Data Gathering Default: Table 3-228	EDC Data Gathering 5

Table 3-228: Default Hours and Coincidence Factors by Shift Type

Shift Type	Hours Per Year	CF	Description
Single Shift (8/5)	1,976	0.24*	7 AM – 3 PM, weekdays, minus 110 hours from holidays and scheduled downtime
2-shift (16/5)	3,952	0.95	7 AM – 11 PM, weekdays, minus 220 hours from holidays and scheduled downtime
3-shift (24/5)	5,928	0.95	24 hours per day, weekdays, minus 330 hours from holidays and scheduled downtime
Continual Operation (24/7)	8,320	0.95	24 hours per day, 7 days a week minus 440 hours from holidays and scheduled downtime

* Note: This value is derived by adjusting the coincidence factor to account for assumed compressor operation (7 a.m. to 3 p.m.) during only one of the four hours of peak period (2 p.m. to 6 p.m.). 0.95 * (1/4) = 0.2375.

Default Savings

Default savings per compressor motor HP for four shift types are shown below. EDCs may also claim savings using customer specific data.

Table 3-229: Default Savings per HP for Compressed Air Low Pressure Drop Filters

Shift Type	Annual Energy Savings ($\Delta kWh/HP$)	Summer Peak Demand Savings ($\Delta kW_{summer\ peak}/HP$)	Winter Peak Demand Savings ($\Delta kW_{winter\ peak}/HP$)
Single Shift (8/5)	14.9	0.0018	0.0018
2-shift (16/5)	29.8	0.0072	0.0072
3-shift (24/5)	44.7	0.0072	0.0072
Continual Operation (24/7)	62.7	0.0072	0.0072

Evaluation Protocol

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Navigant. (2018, May). "ComEd Useful Life Research Report." Appendix D. Measure EUL Table A-4. Preliminary Assessment of Changing Technical EULs – TRM Measures. Weblink
2) Illinois State Technical Reference Manual Volume 2: Commercial and Industrial Measures. (2024, Version 12.0). "4.7.2 Compressed Air Low Pressure Drop Filters". Assumed that pressure will be reduced from a roughly 3 psi through a filter to less than 1 psi, for 2 psi savings. Weblink
3) Cascade Energy (2012, November). Proposed Standard Savings Estimation Protocol for Ultra-Premium Efficiency Motors. Appendix C: NW Industrial Motors Database Analysis Table 6: Load Factor by nameplate hp and end use load. Weblink
4) United States Department of Energy. (2003). Improving Compressed Air System Performance: A Sourcebook for Industry. page 31. For every 2 psi increase in discharge pressure, energy consumption will increase by approximately 1% at full output flow (performance curves vary). A properly designed system should have a pressure loss of much less than 10% of the compressor's discharge pressure. This measure assumes a discharge pressure of 100 psig with an optimally controlled system resulting in 90 psig at the end uses. Weblink
5) United States Department of Energy. (2014). Evaluation of the Compressed Air Challenge Training Program. Hours of operation are based on section 2.1.5 Facility Operating Schedule. Specific shift operating hours and non-operating hours are assumptions. Weblink

3.10.8. Compressed Air Mist Eliminators

Target Sector	Commercial and Industrial
Measure Unit	Per Air Mist Eliminator
Measure Life	5 years [Source 1]
Measure Vintage	Replace on Burnout, New Construction, or Retrofit

Eligibility

The following protocol for the measurement of energy and demand savings applies to the installation of mist eliminator air filters for compressed air systems in commercial and industrial facilities.

Large compressed air systems require air filtration for proper operation. These filters remove oil mist from the supply air of lubricated compressors, protecting the distribution system and end-use devices. While these filters are important to the operation of the system, they do have a pressure drop across them, and thus require a slightly higher operating pressure. Typical coalescing oil filters will operate with a 2 psi to 10 psi pressure drop. Mist eliminator air filters operate at a 0.5 psi pressure drop that increases to 3 psi over time before replacement is recommended.

This reduction in pressure drop allows the compressed air system to operate at a reduced pressure and, in turn, reduces the energy consumption of the system. In general, the energy consumption will decrease by 1% for every 2 psi the operating pressure is reduced. Lowering the operating pressure has the secondary benefit of decreasing the demand of all unregulated usage, such as leaks and open blowing. The equipment is mist eliminator air filters. The compressed air system must be greater than 50 HP to qualify, and the mist eliminator must have less than a 1 psi pressure drop and replace a coalescing filter.

The baseline condition is a standard coalescing filter. The efficient condition is a mist eliminator air filter that replaces a standard coalescing filter. This protocol is not applicable for compressed air systems with total air compressor nameplate horsepower < 40 HP or mist eliminators with ≥ 1 psi pressure drop.

Algorithms

$$\Delta kWh = HP \times \frac{0.746}{\eta_{motor}} \times LF \times HOURS \times \%Savings$$

$$\%Savings = Total_{PR} \times RS$$

$$\Delta kW_{summer\ peak} = \frac{\Delta kWh}{HOURS} \times \mathrm{CF}$$

$$\Delta kW_{winter\ peak} = \frac{\Delta kWh}{HOURS} \times \mathrm{CF}$$

Definition of Terms

Table 3-230: Terms, Values, and References for Compressed Air Mist Eliminators

Term	Unit	Values	Source
HP, Rated horsepower of the air compressor motor	HP	Nameplate	EDC Data Gathering
0.746, conversion factor from horsepower to kW	$\frac{kW}{HP}$	Constant	Constant
η_{motor}, compressor motor efficiency at the full-rated load	$\%$	Nameplate Default: 91%	EDC Data Gathering 3
LF, load factor; ratio between the actual load on the compressor motor and the rated load	$\%$	Based on spot metering and nameplate Default: 0.92	EDC Data Gathering 4
$HOURS$, average annual run hours of the compressed air system	$\frac{Hours}{Year}$	Based on logging, panel data or modeling Default: Table 3-231	EDC Data Gathering 5
$\%Savings$, percentage of energy saved	$\%/psi$	Default: 2%	6
$Total_{PR}$, total pressure reduction from replacing filter	$psig$	Default: 4 psi	6
RS, percentage of energy saved for each psi reduced	$\%$	Default: 0.5%	2
CF, Coincident Factor	$None$	EDC Data Gathering Default: Table 3-231	EDC Data Gathering 5

Table 3-231: Default Hours and Coincidence Factors by Shift Type

Shift Type	Hours Per Year	CF	Description
Single Shift (8/5)	1,976	0.24*	7 AM – 3 PM, weekdays, minus 110 hours for holidays and scheduled downtime
2-shift (16/5)	3,952	0.95	7 AM – 11 PM, weekdays, minus 220 hours for holidays and scheduled downtime
3-shift (24/5)	5,928	0.95	24 hours per day, weekdays, minus 330 hours for holidays and scheduled downtime
Continual Operation (24/7)	8,320	0.95	24 hours per day, 7 days a week minus 440 hours for holidays and scheduled downtime
* Note: This value is derived by adjusting the coincidence factor to account for assumed compressor operation (7 a.m. to 3 p.m.) during only one of the four hours of peak period (2 p.m. to 6 p.m.). 0.95 * (1/4) = 0.2375.			

Default Savings

Default savings per compressor motor HP for four shift types are shown below. EDCs may also claim savings using customer specific data.

Table 3-232: Default Savings per HP for Compressed Air Mist Eliminators

Shift Type	Annual Energy Savings ($\Delta kWh/HP$)	Summer Peak Demand Savings ($\Delta kW_{summer\ peak}/HP$)	Winter Peak Demand Savings ($\Delta kW_{winter\ peak}/HP$)
Single Shift (8/5)	29.8	0.0036	0.0036
2-shift (16/5)	59.6	0.0143	0.0143
3-shift (24/5)	89.4	0.0143	0.0143
Continual Operation (24/7)	125.5	0.0143	0.0143

Evaluation Protocol

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Sullair. (2011). Compressed Air Filtration and Mist Eliminators page 4 All Inclusive “Peace of Mind” Warranty. Weblink

2) United States Department of Energy. (2003). Improving Compressed Air System Performance: A Sourcebook for Industry. page 31. For every 2 psi increase in discharge pressure, energy consumption will increase by approximately 1% at full output flow (performance curves vary). Weblink

3) Cascade Energy (2012, November). Proposed Standard Savings Estimation Protocol for Ultra-Premium Efficiency Motors. Appendix B: NEMA Premium Motor Efficiency Standards Table 4: Average motor efficiency for MotorMaster+ motors with data at four load factors, filtered by HP, enclosure, and RPM. Average efficiency for 1800 RPM ODP motors with 75% and 100% load factors. Weblink
4) Cascade Energy, Prepared for Regional Technical Forum. Standard Savings Estimation Protocol for Ultra-Premium Efficiency Motors. Load factor for air compressors and average motor efficiency. Weblink
5) Hours of operation are based on DOE evaluation of the Compressed Air Challenge, section 2.1.5 Facility Operating Schedule. Specific shift operating hours and non-operating hours are assumptions. Weblink
6) Sullair. (2011). Compressed Air Filtration and Mist Eliminators page 7 Low Pressure Drop and Operating Costs. Weblink

3.11. MISCELLANEOUS

3.11.1. HIGH EFFICIENCY TRANSFORMER

Target Sector	Commercial, Industrial, and Agricultural
Measure Unit	Transformer
Measure Life	15 years Source 1
Measure Vintage	Retrofit, New Construction

ELIGIBILITY

Distribution transformers are used in some multifamily, commercial, and industrial applications to step down power from distribution voltage to be used in HVAC or process loads (208V or 480V) or to serve plug loads (120V).

Distribution transformers that are more efficient than the required minimum federal standard efficiency qualify for this measure. If there is no specific standard efficiency requirement, the transformer does not qualify (because the baseline cannot be defined). For example, although the federal standards increased the minimum required efficiency in 2016, most transformers with a NEMA premium or CEE Tier 2 rating will still achieve energy conservation. Standards are defined for low-voltage dry-type distribution transformers (up to 333kVA single-phase and 1000kVA 3-phase.

The baseline equipment is a transformer that meets the minimum federal efficiency requirement. Standards are developed by the DOE and published in Federal Register 10 CFR 431. Transformers more efficient than the federal minimum standard are eligible. This includes CEE Tier II (single or three phase) and most NEMA premium efficiency rated products. Projects with liquid-immersed distribution transformers and medium voltage dry type transformer energy savings should be treated as custom projects.

ALGORITHMS

$$\Delta kWh = Losses_{base} - Losses_{ee}$$

$$Losses_{base} = PowerRating \times LF \times PF \times \left(\frac{1}{EFF_{base}} - 1\right) \times 8{,}760$$

$$Losses_{ee} = PowerRating \times LF \times PF \times \left(\frac{1}{EFF_{ee}} - 1\right) \times 8{,}760$$

$$\Delta kW_{summer\ peak} = \frac{\Delta kWh}{8{,}760}$$

$$\Delta kW_{winter\ peak} = \frac{\Delta kWh}{8{,}760}$$

Definition of Terms

Table 3-233: Terms, Values, and References for High Efficiency Transformers

Term	Unit	Values	Source
$PowerRating$, kVA rating of the transformer	*kVA*	EDC Data Gathering	EDC Data Gathering
EFF_{base}, Baseline total efficiency rating of federal minimum standard transformer	*Percent*	Default: Table 3-234	2
EFF_{ee}, Installed total efficiency rating of the transformer	*Percent*	EDC Data Gathering	EDC Data Gathering
LF, Load factor for the transformer	*Percent*	EDC Data Gathering Default: 35%	EDC Data Gathering 3
PF, Power factor for the load served by the transformer	*Decimal*	EDC Data Gathering[2]	EDC Data Gathering
		Default: 1.0	1

Table 3-234: Baseline Efficiencies for Low-Voltage Dry-Type Distribution Transformers

Single-phase		Three-phase	
kVA	**Efficiency (%)**	**kVA**	**Efficiency (%)**
15	97.70	15	97.89
25	98.00	30	98.23
37.5	98.20	45	98.40
50	98.30	75	98.60
75	98.50	112.5	98.74
100	98.60	150	98.83
167	98.70	225	98.94
250	98.80	300	99.02
333	98.90	500	99.14
---	---	750	99.23
---	---	1,000	99.28

[2] Use the actual power factor for the network segment served.

Evaluation Protocol

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Federal Register, Vol 78, No. 75, proposed April 18, 2023, Table IV.6, page 23,373. Weblink
2) 10 CFR 431.196(a)(2). Weblink
3) 10 CFR Appendix-A-to-Subpart-K-of-Part-431 2.02.1. Weblink

3.11.2. Engine Block Heater Timer

Target Sector	Commercial, Industrial, and Agricultural
Measure Unit	Engine Block Heater Timer
Measure Life	15 years source 1
Measure Vintage	Retrofit

Eligibility

This protocol documents the energy savings attributed to installation of engine block heater timers in commercial, industrial, and agricultural establishments. The baseline for this measure is an engine block heater in use without a timer.

Algorithms

Engine block heater timers save energy by reducing the time that engine block heaters operate. Typically, block heaters are plugged in throughout the night. Using timers allows the heater to come on at a preset time during the night in lieu of operating continuously. This measure does not affect peak period usage due to expected nighttime operation and there are no summer or winter peak demand savings associated with the measure.

$$\Delta kWh = P \times Hours \times Days \times UF$$

$$\Delta kW_{summer\ peak} = 0$$

$$\Delta kW_{winter\ peak} = 0$$

Definition of Terms

Table 3-235: Terms, Values, and References for Engine Block Heater Timer

Term	Unit	Values	Source
P, Average power consumption of engine block heater	kW	EDC Data Gathering	EDC Data Gathering
		Default = 1.3	2
$Hours$, Reduction in number of hours block heater is used per night	$\frac{Hours}{Day}$	EDC Data Gathering	EDC Data Gathering
		Default = 9	2
$Days$, Number of operating days per year	$\frac{Days}{Year}$	EDC Data Gathering	EDC Data Gathering
		Default = 65	2
UF, Usage factor	None	EDC Data Gathering	EDC Data Gathering
		Default = 0.97	2

Default Savings

Default savings for this measure are shown in the table below.

Table 3-236: Default Savings for Engine Block Heater Timer

Energy Savings (ΔkWh)	Peak Demand Reduction (ΔkW)
737.7	0

Evaluation Protocol

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Gutierrez, A. (2015, April) "Circulating Block Heater". California Technical Forum. Weblink

2) Consultant for Cadmus. (2015, October). Private research for Wisconsin Focus on Energy 2024 Technical Reference Manual. "Engine Block Heater Timer".

3.11.3. High Frequency Battery Chargers

Target Sector	Commercial and Industrial
Measure Unit	Charger
Measure Life	15 years source 1
Measure Vintage	New Construction, Replace on Burnout

Eligibility

This measure applies to industrial high frequency battery chargers, used for industrial equipment such as forklifts, replacing existing silicon controlled rectifier (SCR) or ferroresonant charging technology. They have a greater efficiency than SCR or ferroresonant chargers.

The baseline equipment is a SCR or ferroresonant battery charger system with minimum 8-hour shift operation five days per week. The energy efficient equipment is a high frequency battery charger system with a minimum power conversion efficiency of 90% and 8-hour shift operation five days per week.

Algorithms

Algorithms for annual energy savings and peak demand savings are shown below.

$$\Delta kWh = (CAP \times DOD) \times CHG \times \left(\frac{CR_{base}}{PC_{base}} - \frac{CR_{ee}}{PC_{ee}}\right)$$

$$\Delta kW_{summer\ peak} = \left(\frac{PF_{base}}{PC_{base}} - \frac{PF_{ee}}{PC_{ee}}\right) \times Volts_{DC} \times \frac{Amps_{DC}}{1{,}000} \times CF$$

$$\Delta kW_{winter\ peak} = \left(\frac{PF_{base}}{PC_{base}} - \frac{PF_{ee}}{PC_{ee}}\right) \times Volts_{DC} \times \frac{Amps_{DC}}{1{,}000} \times CF$$

Definition of Terms

Table 3-237: Terms, Values, and References for High Frequency Battery Chargers

Term	Unit	Values	Source
CAP, Capacity of battery	*kWh*	EDC Data Gathering	EDC Data Gathering
		Default: 35	2
DOD, Depth of discharge	*Percent*	Default: 80%	3
CHG, Number of charges per year	*N*	EDC Data Gathering	EDC Data Gathering
		Default: Table 3-238	
CR_{base}, Baseline charge return factor	*Decimal*	Default: Table 3-239	3
PC_{base}, Baseline power conversion efficiency	*Decimal*		
PF_{base}, Power factor of baseline charger	*Decimal*		
CR_{ee}, Efficient power conversion efficiency	*Decimal*	EDC Data Gathering	EDC Data Gathering
		Default: 1.15	3
PC_{ee}, Efficient power conversion efficiency	*Decimal*	EDC Data Gathering	EDC Data Gathering
		Default: 0.92	3
PF_{ee}, Power factor of high frequency charger	*Decimal*	EDC Data Gathering	EDC Data Gathering
		Default: 0.96	3
$Volts_{DC}$, DC rated voltage of charger	*V*	EDC Data Gathering	EDC Data Gathering
		Default: 48	4
$Amps_{DC}$, DC rated amerage of charger	*A*	EDC Data Gathering	EDC Data Gathering
		Default: 81	4
1,000, Conversion factor	$\frac{W}{kW}$	1,000	Conversion Factor
CF, Coincidence factor	*Decimal*	Default for single shift or 2-shift: 0 Default for 3-shift or 4-shift: 1	5

Table 3-238: Default Values for Number of Charges Per Year (assumes 1 charge per shift)

Operation Facility Schedule (hours per day / days per week)	Number of Charges Per Year
Single Shift (8/5)	260
2-Shift (16/5)	520
3-Shift (24/5)	780
4-Shift (24/7)	1,092

Table 3-239: Default Savings for High Frequency Battery Charging

Equipment Type	CR_{base}	PC_{base}	PF_{base}
Ferroresonant	1.15	0.85	0.92
SCR	1.18	0.85	0.76
Hybrid	1.12	0.86	0.91
Unknown	1.16	0.85	0.86

Evaluation Protocol

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Ecos Consulting for California IOUs. (2010, October). Analysis of Standards Options for Battery Charger Systems. Section 7.2, page 43, Table 17, large non-consumer equipment. Weblink
2) Renquist, J; Dickman, B; and Bradley, T. (2012, September) "Economic comparison of fuel cell powered forklifts to battery powered forklifts", International Journal of Hydrogen Energy. Volume 37, Issue 17. Weblink
3) Matley, R. (2009, May) "Measuring energy efficiency improvements in industrial battery chargers". Energy Systems Laboratory. Baseline charge return factor is average of SCR and ferroresonant. Section 5, Table 3, page 8. Weblink
4) Ecos Consulting for Pacific Gas & Electric. (2009, May). "Emerging Technologies Program Application Assessment Report #0808", Industrial Battery Charger Energy Savings Opportunities". Page 8, Table 3. Weblink
5) Ecos Consulting for Pacific Gas & Electric. (2009, May). "Emerging Technologies Program Application Assessment Report #0808", Industrial Battery Charger Energy Savings Opportunities". Section 5, page 12. Weblink

3.11.4. Uninterruptible Power Supply (UPS)

Target Sector	Commercial and Industrial
Measure Unit	Uninterruptible Power Supply (UPS)
Measure Life	7 years source 1
Vintage	Replace on Burnout, New Construction

In the event of a power failure, an Uninterruptible Power Supply (UPS) provides emergency instantaneous power to critical devices - computers, data centers, and telecommunications equipment through energy that is typically stored in a battery. The UPS will temporarily provide power to allow equipment to proper shut down (e.g., computers) or for a standby power generator to start up (e.g., at data centers). In addition, an UPS protect against power surges, voltage drops, and frequency distortions. ENERGY STAR certified UPS can cut energy losses by 15% source 1 over previous standards.

Eligibility

This measure applies to electric ENERGY STAR version 2.0 UPS alternating current output systems installed in conjunction with a replace on burnout or new construction project. To qualify for this measure, the installed equipment must be a UPS system less than 2 kW which connects to a 15A single phase 120V outlet (NEMA 5-15A) and has earned the ENERGY STAR label source 4. UPS systems larger than 2 kW should follow a custom measure savings track to adequately consider variable parameters for these conditions.

Algorithms

The energy savings algorithms are shown below. The key variables affecting energy savings are the UPS system capacity and product type.

$$\Delta kWh = \frac{P}{1{,}000} \times \left(\frac{1}{Eff_{Base}} - \frac{1}{Eff_{EE}}\right) \times EFLH$$

$$\Delta kW_{summer\ peak} = \frac{P}{1{,}000} \times \left(\frac{1}{Eff_{Base}} - \frac{1}{Eff_{EE}}\right) \times CF$$

$$\Delta kW_{winter\ peak} = \frac{P}{1{,}000} \times \left(\frac{1}{Eff_{Base}} - \frac{1}{Eff_{EE}}\right) \times CF$$

Multiple Normal Mode (if applicable):

$$Eff_{EE\ or\ Base} = 0.75 \times Eff_{LOW} + 0.25 \times Eff_{HIGH}$$

where:

Eff_{LOW} *is lowest input mode efficiency (i.e. VFI or VI)*

Eff_{HIGH} *is highest input mode efficiency (i.e. VFD)*

Definition of Terms

Voltage and Frequency Dependent (VFD) UPS : A UPS that produces an alternating current (AC) output where the output voltage and frequency are dependent on the input voltage and frequency.

Voltage Independent (VI) UPS : Capable of protecting the load as required for VFD, above, plus additional protection from under- or over-voltage applied continuously to the input.

Voltage and Frequency Independent (VFI) : A UPS where the device remains in normal mode producing an AC output voltage and frequency that is independent of input voltage and frequency variations as it protects the load against adverse effects from waveform variations without depleting the stored energy source.

Single Normal Mode: A UPS that functions in Normal Mode within the parameters of only one set of input dependency characteristics. For example, a UPS that functions only as VFI.

Multiple Normal Mode: A UPS that functions in Normal Mode within the parameters of more than one set of input dependency characteristics. For example, a UPS that can function as either VFI or VFD.

Table 3-240: Terms, Values, and References for Uninterruptible Power Supplies (UPS)

Term	Unit	Values	Source
P, *Capacity* of UPS in rated output active power	W	P = 90% x VA rating	2 EDC Data Gathering
Eff_{Base}, Baseline UPS efficiency	%	Table 3-241	3
Eff_{EE}, New UPS efficiency	%	Table 3-242	EDC Data Gathering 4
$EFLH$, Equivalent Full Load Hours	$\frac{Hours}{Year}$	Table 3-243	5
CF, Coincidence factor	None	$\frac{EFLH}{8,760}$	-

Table 3-241: Baseline UPS Efficiencies

UPS Product Type	Rated Power Output (P)	Baseline Efficiency
Voltage and Frequency Dependent (VFD)	P ≤ 300 W	$-1.20\times10^{-6} \times P^2 + 7.17 \times 10^{-4} \times P + 0.862$
	300 W < P ≤ 700 W	$-7.85\times10^{-8} \times P^2 + 1.01 \times 10^{-4} \times P + 0.946$
	P > 700 W	$-7.23\times10^{-9} \times P^2 + 7.52 \times 10^{-6} \times P + 0.977$
Voltage Independent (VI)	P ≤ 300 W	$-1.20\times10^{-8} \times P^2 + 7.19 \times 10^{-4} \times P + 0.863$
	300 W < P ≤ 700 W	$-7.67\times10^{-8} \times P^2 + 1.05 \times 10^{-4} \times P + 0.946$
	P > 700 W	$-4.62\times10^{-9} \times P^2 + 8.54 \times 10^{-6} \times P + 0.979$
Voltage and Frequency Independent (VFI)	P ≤ 300 W	$-3.13\times10^{-8} \times P^2 + 1.96 \times 10^{-4} \times P + 0.543$
	300 W < P ≤ 700 W	$-2.60\times10^{-8} \times P^2 + 3.65 \times 10^{-4} \times P + 0.764$
	P > 700 W	$-1.70\times10^{-8} \times P^2 + 3.85 \times 10^{-6} \times P + 0.876$

Table 3-242: Energy Star Minimum Value for Efficiency of UPS

Rated Output Power	UPS Product Type		
	VFD	VI	VFI
P ≤ 350 W	$5.71 \times 10^{-5} \times P + 0.962$	$5.71 \times 10^{-5} \times P + 0.964$	$0.011 \times \ln(P) + 0.824$
350 W < P ≤ 1,500 W	0.982	0.984	$0.011 \times \ln(P) + 0.824$
1,500 W < P ≤ 2,000 W	$0.981 - E_{MOD}$	$0.981 - E_{MOD}$	$0.0145 \times \ln(P) + 0.8 - E_{MOD}$

where:

E_{MOD} = an allowance of 0.004 for Modular UPSs applicable in the commercial 1,500W to 10,000W range

Table 3-243: AC-Output UPS Loading Assumptions for Calculating Average Efficiency

Rated Output Power (P) in Watts	UPS Product Type	Time spent at specified proportion of reference test load (t)				EFLH
		25%	50%	75%	100%	
P ≤ 1,500 W	VFD	0.2	0.2	0.3	0.3	5,913
	VI or VFI	0	0.3	0.4	0.3	6,570
1,500 W ≤ P ≤ 2,000 W	VFD, VI or VFI	0	0.3	0.4	0.3	6,570

Evaluation Protocols

For most installations, the appropriate evaluation protocol is to verify installation, the system capacity, and UPS product type. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Federal Register, Vol. 85, No. 7 (January 10, 2020), Table IV-3 UPS Product Lifetimes From Literature and Manufacturer Input. Weblink
2) Engineering assumption of power factor = 90%
3) Federal Register, Vol. 85, No. 7 (January 10, 2020), Table I-1 Energy Conservation Standards for Uninterruptible Power Supplies. Weblink
4) ENERGY STAR. (2019). Program Requirements for Uninterruptible Power Supplies. Weblink
5) 10 CFR Appendix-Y-to-Subpart-B-of-Part-430 4.3.5.(a). Weblink

3.11.5. Building Operator Certification Training

Measure Unit	Building Tune Up
Measure Life	13 years source 1
Measure Vintage	Retrofit
Effective Date	June 1, 2022

Building Operator Certification (BOC) is a nationally recognized training program for commercial and public sector building operators. BOC participants receive training on energy efficiency, sustainability, HVAC and lighting fundamentals, energy conservation opportunities, measuring and benchmarking energy performance, and other topics depending on the course level. Two levels of participation are offered, BOC Level I and BOC Level II.

Eligibility

This protocol is only applicable for commercial and public sector buildings that exceed 20,000 ft^2. Energy savings are associated with facilities the participants manage at the time they complete the certification.

One energy savings submission can be submitted per facility, regardless of the number of staff who complete the BOC. The coursework must be offered by an institution that is accredited to provide such training by the National BOC Advisory Commission, which is provided by the Pennsylvania College of Technology for the Mid-Atlantic region. A certificate of completion from an accredited institution is required for eligibility.

Algorithms

Energy Savings and Demand Reduction

Energy impact calculation algorithms are provided in the PA TRM Appendix F, a spreadsheet-based calculator, that accompanies this protocol as an appendix.[Source 7] The general logic of the algorithm is described below:

1. Estimate end-use energy usage intensity (EUI) in terms of kWh/ft^2 and $therms/ft^2$ based on the building type, location, and information entered about the building, such as heating and cooling system types, the presence of commercial refrigeration, and other fields. Estimate whole building energy usage by summing up the end-use EUIs and multiplying by floorspace. These EUIs are informed by the Act 129 Pennsylvania Non-Residential Baseline Study[3] and the Commercial Building Energy Consumption Survey (CBECS)[4]. Note that only electric savings in terms of kWh and demand savings in terms of kW can be claimed as per the requirements of Pennsylvania Act 129.

2. Assign relative energy savings factors to each end-use. These savings factors are estimated from past studies on BOC [Sources 5,6,7] or by evaluator judgment in cases where historical program evaluation data were not available in adequate detail.

3. Calculate a weighted energy to demand factor (ETDF) for each end-use using TRM energy and demand algorithms for measures such as lighting, cooling, heating, refrigeration, and food-service efficiency improvements.

4. The products of the end-use energy intensities, savings factors, and building floorspace constitute preliminary whole-building savings. Divide this by the whole-building estimated energy use calculated in step 1 to obtain a relative energy savings for the building.

5. Estimate the building's annual electric and gas consumption. Either averaged or weather-normalized historical data are acceptable for use in this protocol.

6. Calibrate the calculation to the specific building by multiplying the electric and gas relative savings factor to the estimated annual electric and gas consumption of the building.

7. Calculate demand impacts with the ETDF developed in step 3.

A participant can complete BOC Level I and BOC Level II. Since BOC Level II can have incremental savings over Level I, the energy savings for a participant that completes both courses can be combined to achieve additional savings.

Evaluation Protocol

The participant will complete the associated spreadsheet. The evaluator will verify the building's use-type and annual energy usage, as well as confirm the certification status of building operators at the facility under review.

Sources

1) Illinois Statewide Technical Reference Manual for Energy Efficiency (2024, v12.0); Volume 2, page 972, "4.8.24 Building Operator Certification". Weighted average of equipment and O&M savings across several program evaluations. Weblink
2) Demand Side Analytics for the Pennsylvania Public Utility Commission. (2024, March). Pennsylvania Act 129 2023 Non-Residential Baseline Study. Weblink
3) US Energy Information Administration. (2018). Commercial Buildings Energy Consumption Survey (CBECS). End-use consumption Table E6 for kWh and E8 for natural gas. Weblink, kWh and Weblink, natural gas
4) Guidehouse for ComEd. (2021, April). Building Operator Certification Pilot Impact Evaluation Report. Section A.3, Table A-2. Weblink
5) Opinion Dynamics for Ameren Illinois. (2020, April). 2019 Business Program Impact Evaluation Report. Section 3.5.4. Weblink
6) Opinion Dynamics for Ameren Illinois. (2021, April). 2020 Business Program Impact Evaluation Report. Section 3.6.4. Weblink
7) 2026 Pennsylvania TRM, Volume 1, Appendix F Building Operator Certification Audit and Design Tool. Weblink

3.11.6. Photovoltaic (PV) Solar Generation

Target Sector	Commercial and Industrial Establishments
Measure Unit	Photovoltaic (PV) array
Measure Life	15 years Source 1
Vintage	Retrofit or New Construction

Eligibility

Photovoltaic (PV) solar systems consist of an array of panels or thin-film substrates that generate direct current (DC) power when exposed to sunlight. These surfaces are tied together into a single circuit to expand generation levels. The DC power output is converted to alternating current (AC) power through inverter(s) that transform the electricity into the type of power used in commercial and industrial facilities. Generated power must be used to offset concurrent building loads and feed onto the local power grid through net metering to meet the needs of other customers. Charging of on-site battery systems is permitted, however peak demand savings as defined by this measure assumes non-tracking arrays without battery backup.

The goals of Pennsylvania Act 129 are to reduce consumption and congestion on the state's power grid. Projects that generate savings for Act 129 programs must offset existing facility loads. Virtual metering of multiple sites, within the guidelines provided by 52 Pa. Code § 75.14.(e), Source 2 will be permitted to define existing facility loads. Annual generated AC power from the PV array must not exceed 110% of the annual electric energy load of the customer's utility metered consumption.

Default values for project generation estimates can be developed using the National Renewable Energy Laboratory PV Watts® calculator. Source 3 Additional details on required inputs for the PV Watts® model are included in the *Algorithms* section below. Demand savings estimated in this measure assume no tracking, panel tilt of 20°, and instantaneous fulfillment of on-site loads or back feeding to the grid. For systems exceeding annual generation of 2,000,000 kWh on-site EM&V will be required in a similar approach to other large Act 129 projects.

Algorithms

All energy savings will be determined by the PV Watts® model and installed system specifications. System losses defined below will be the sum of PV Watts® deemed losses (14.08%) and an estimated in-situ loss factor to align model capacity factors with a Pennsylvania statewide analysis of PV system production and expected PV Watts® estimates4. If the array contains non-tracking panels at varying azimuths or tilts, a new PV Watts® model must be completed for each array with the results combined to estimate project savings. There are no default savings for this measure.

$$System\ Losses = Default\ Model\ Losses + In\text{-}situ\ Losses$$

$$\Delta kWh = Provided\ by\ PV\ Watts$$

$$\Delta kW_{peak,summer} = \Delta kWh \times ETDF_{summer}$$

$$ETDF_{summer} = ETDF_{summer,ordinal} + (\Delta Azimuth * ETDF_{summer,incremental})$$

$$\Delta Azimuth = Difference\ between\ PV\ array\ azimuth\ and\ closest,\ smaller\ ordinal\ direction\ (90,\ 135,\ 180,\ or\ 225)$$

$$\Delta kW_{peak,winter} = \Delta kWh \times ETDF_{winter}$$

$$ETDF_{winter} = ETDF_{winter,ordinal} + (\Delta Azimuth * ETDF_{winter,incremental})$$

Definition of Terms

Table 3-244 Terms, Values, and References for Solar PV

Term	Unit	Value		Sources
Location	*n/a*	EDC Data Gathering		EDC Data Gathering
DC System Size	kW	EDC Data Gathering		EDC Data Gathering
Module Type	n/a	Standard		Default
Array Type	n/a	EDC Data Gathering		EDC Data Gathering
System Losses	$\%$	Default Model Losses + In-situ Losses		Calculated
Default Model Losses	$\%$	14.08%		PV Watts Model
In-situ Losses	$\%$	Up to 15 kW_{DC}	2.1%	4
		15+ to 250 kW_{DC}	4.1%	
		250+ to 1,000 kW_{DC}	11.0%	
		1,000+ to 5,000 kW_{DC}	9.7%	
Array Tilt	$degrees$	EDC Data Gathering		EDC Data Gathering
Array Azimuth	$degrees$	EDC Data Gathering		EDC Data Gathering
∆Aziumth	$degrees$	Calculated		Calculation
Advanced Parameters	n/a	As defined by PV Watts		PV Watts Model
DC to AC Size Ratio	n/a	1.2		Default
Inverter Efficiency	$\%$	96		Default
Ground Coverage Ratio	n/a	0.4		Default
Albedo	n/a	Varies by location		Default
Bifacial	n/a	No		Default
Monthly Irradiance Loss	$\%$	0 for all months		Default
$ETDF_{summer,ordinal}$	$\frac{kW}{kWh}$	See Table 3-245		5
$ETDF_{summer,increments}$	$\frac{kW}{kWh}$	See Table 3-246		Calculated
$ETDF_{winter,ordinal}$	$\frac{kW}{kWh}$	See Table 3-247		6
$ETDF_{winter,increments}$	$\frac{kW}{kWh}$	See Table 3-248		Calculated

Table 3-245: Summer Energy to Demand Factor, East to West facing Ordinal Numbers ($ETDF_{summer,ordinal}$)

Climate Region	Reference City	Array Azimuth				
		90°	135°	180°	225°	270°
C	Allentown	0.0624265	0.0651860	0.0817416	0.1044553	0.1245200
A	Binghamton	0.0678131	0.0719111	0.0907818	0.1150982	0.1357120
G	Bradford	0.0699694	0.0740833	0.0928029	0.1162379	0.1357924
I	Erie	0.0788975	0.0851381	0.1067952	0.1320825	0.1520063
E	Harrisburg	0.0647908	0.0680365	0.0857973	0.1096607	0.1307424
D	Philadelphia	0.0600152	0.0620246	0.0772186	0.0988952	0.1185881
H	Pittsburgh	0.0722741	0.0765022	0.0948878	0.1179122	0.1370800
B	Scranton	0.0630191	0.0664687	0.0836893	0.1063465	0.1257134
F	Williamsport	0.0679989	0.0712337	0.0883588	0.1107460	0.1301680

Table 3-246: Summer Energy to Demand Factor Increments, ($ETDF_{summer,increments}$)

Climate Region	Reference City	Array Azimuth Range			
		90 to 135	135 to 180	180 to 225	225 to 270
C	Allentown	0.0000613	0.0003679	0.0005047	0.0004459
A	Binghamton	0.0000911	0.0004193	0.0005404	0.0004581
G	Bradford	0.0000914	0.0004160	0.0005208	0.0004345
I	Erie	0.0001387	0.0004813	0.0005619	0.0004428
E	Harrisburg	0.0000721	0.0003947	0.0005303	0.0004685
D	Philadelphia	0.0000447	0.0003376	0.0004817	0.0004376
H	Pittsburgh	0.0000940	0.0004086	0.0005117	0.0004260
B	Scranton	0.0000767	0.0003827	0.0005035	0.0004304
F	Williamsport	0.0000719	0.0003806	0.0004975	0.0004316

Table 3-247: Winter Energy to Demand Factor Ordinal, East to West facing Ordinal Numbers ($ETDF_{winter,ordinal}$)

Climate Region	Reference City	Array Azimuth				
		90°	135°	180°	225°	270°
C	Allentown	0.0121198	0.0113890	0.0085075	0.0035736	0.0019462
A	Binghamton	0.0099532	0.0092431	0.0070935	0.0033193	0.0022980
G	Bradford	0.0074126	0.0068730	0.0052236	0.0022748	0.0017657
I	Erie	0.0045040	0.0041701	0.0030910	0.0013280	0.0011115
E	Harrisburg	0.0099236	0.0092490	0.0068901	0.0029286	0.0018332
D	Philadelphia	0.0125401	0.0118317	0.0088548	0.0037608	0.0020548
H	Pittsburgh	0.0060367	0.0056171	0.0043588	0.0019083	0.0015966
B	Scranton	0.0106358	0.0100137	0.0076209	0.0034986	0.0021796
F	Williamsport	0.0096529	0.0089461	0.0067885	0.0030166	0.0020645

Table 3-248: Winter Energy to Demand Factor Increments, ($ETDF_{winter,increments}$)

Climate Region	Reference City	Array Azimuth Range			
		90° to 135°	135° to 180°	180° to 225°	225° to 270°
C	Allentown	(0.0000162)	(0.0000640)	(0.0001096)	(0.0000362)
A	Binghamton	(0.0000158)	(0.0000478)	(0.0000839)	(0.0000227)
G	Bradford	(0.0000120)	(0.0000367)	(0.0000655)	(0.0000113)
I	Erie	(0.0000074)	(0.0000240)	(0.0000392)	(0.0000048)
E	Harrisburg	(0.0000150)	(0.0000524)	(0.0000880)	(0.0000243)
D	Philadelphia	(0.0000157)	(0.0000662)	(0.0001132)	(0.0000379)
H	Pittsburgh	(0.0000093)	(0.0000280)	(0.0000545)	(0.0000069)
B	Scranton	(0.0000138)	(0.0000532)	(0.0000916)	(0.0000293)
F	Williamsport	(0.0000157)	(0.0000479)	(0.0000838)	(0.0000212)

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify system specifications (array size, azimuth, tilt, etc.) through document or on-site review and ensure PV Watts® model inputs align with the design parameters used for system generation estimates. For projects exceeding the 2,000,000 kWh savings cap actual M&V requirements can consider on-site metering or outputs from inverter software with continual tracking of system generation.

Sources

1) Wisler, R. Bolinger, M. Seel, J. (2020, June). "Benchmarking Utility-Scale PV Operational Expenses and Project Lifetimes: Results from a Survey of U.S. Solar Industry Professionals".

Current EUL assumptions are 25-35 years with an average of 32.5 years. Act 129 caps lifetime at 15 years. Weblink

2) 52 Pa. Code § 75.14.(e). Weblink
3) PV Watts® Calculator. National Renewable Energy Lab (NREL). Weblink
4) InClime for PA PUC. (2024, February). "Capacity Factor Analysis EY2014-EY2023". Analysis of Pennsylvania Alternative Energy Portfolio Standards (AEPS) Program and additional losses needed to align PV Watts capacity factor output with AEPS Program DC capacity factor analysis.
5) Calculated through the ratio of PV Array total summer peak demand savings (aligned with PA Ph V peak demand definitions) and the annual electric generation for a given array azimuth installed at 20° tilt. Incremental $ETDF_{summer}$ calculated assuming linear changes between two ordinal values.
6) Calculated through the ratio of PV Array total winter peak demand savings (aligned with PA Ph V peak demand definitions) and the annual electric generation for a given array azimuth installed at 20° tilt. Incremental $ETDF_{winter}$ calculated assuming linear changes between two ordinal values.

3.12. Demand Response

3.12.1. Load Curtailment for Commercial and Industrial Programs

Target Sector	Commercial and Industrial Establishments
Measure Unit	N/A
Measure Life	1 year
Measure Vintage	Demand Response

In a C&I Load Curtailment (LC) program, end-use customers are provided a financial incentive to reduce the amount of electricity they take from the EDC during Demand Response events. This temporary reduction in electricity consumption can be achieved in a number of ways. The specific load curtailment actions taken by program participants are outside of the scope of this protocol. Load curtailment is a dispatchable, event-based resource because the load impacts are only expected to occur on days when DR events are called. This is fundamentally different from non-dispatchable DR options such as dynamic pricing or permanent load shifting. This protocol only applies to dispatchable resources.

Peak demand reductions associated with DR resources are defined as the difference between a customer's actual (measured) electricity demand and the amount of electricity the customer would have demanded in the absence of the DR program incentive. The latter is inherently counterfactual because it never occurred and therefore cannot be measured and must be estimated. This estimate of how much electricity would have been consumed absent the DR program is analogous to the baseline condition for an energy efficiency measure. In this protocol, this estimate is referred to as the reference load.

The reference load used to determine impacts from a LC program participant during a DR event shall be estimated using one of the following methods. The Pennsylvania Evaluation Framework contains additional technical guidance on each method. The methods are in hierarchical order of preference based on expected accuracy. The EDCs are strongly encouraged to utilize the first three methodologies to verify achievement of demand reductions targets for the phase. In scenarios where an EDC determines a Customer Baseline (CBL) approach is more appropriate, the EDC should provide sound reasoning for the choice of the CBL approach as opposed to the first three methodologies.

1) A comparison group analysis where the loads of a group of non-participating customers that are similar to participating customers with respect to observable characteristics (e.g. non-event weekday consumption) are used to estimate the reference load. A variety of matching techniques are available, and the EDC evaluation contractor can choose the technique used to select the comparison group based on their professional judgment. The primary objective of statistical matching is to eliminate bias in the reference load during the most relevant load hours. The most relevant hours are those during the event, but hours immediately prior to and immediately following the event period are also important. As such, matching methods should focus on finding customers with loads during these critical hours that are as close as possible to the loads of participating customers for days that have weather and perhaps other conditions very similar to event days. If events are most likely to be called on hot days, hot non-event days should be used for statistical matching (and mild days should be excluded). If need be, difference-in-differences techniques can be utilized to eliminate any pre-existing differences in consumption between the treatment and matched control group during estimation.
2) A 'within-subjects' regression analysis where the loads of participating customers on non-event days are used to estimate the reference load. The regression equation should include temperature and other variables that influence usage as explanatory variables. This method is superior to the baseline methods discussed in (4).

3) A hybrid Regression-Matching method where matching is used for most customers and regression methods are used to predict reference loads for any large customers who are too unique to have a good matching candidate. This approach allows for matching methods to be used when good matches are available without dropping unique customers who do not have valid matches from the analysis. The hybrid approach is also superior to the baseline methods discussed in (4).
4) A CBL approach (1) with a weather adjustment to account for the more extreme conditions in place on event days or (2) without a weather adjustment in cases where loads are associated with non-weather-sensitive end-uses. In this approach, the reference load is estimated by calculating the average usage in the corresponding hours for selected days leading up to or following an event day. Multiplicative or additive same-day adjustments for the CBL are prohibited if participants receive day-ahead event notification. A variety of CBL methods are available to be used and the EDC contractor should provide justification for the specific method that is selected. Reference loads should generally be calculated separately for each participant, but aggregation of accounts or meters is permissible at the discretion of the EDC evaluation contractor. CBL methods are the least preferred of the four approaches but may produce valid results in situations where customer loads are fairly constant and are not highly sensitive or insensitive to weather conditions.

The weather conditions in place at the time of the event are always used to claim savings. Weather-normalized or extrapolation of impacts to other weather conditions is not permitted.

Other curtailment event days – either Act 129 or PJM – should be removed when estimating the reference load for an Act 129 event day. Additionally, weekends, holidays, and shut down days may be removed when estimating reference loads.

Where feasible, matching-based methods are capable of effectively removing selection bias and providing accurate impact estimates that are comparable to results from a randomized experiment and are generally superior to within-subjects approaches. Because of this, in situations where large and representative control pools are available, it is suggested that the comparison group approach be used.

ELIGIBILITY

In order to be eligible for an EDC Load Curtailment program, a customer must have an hourly or sub-hourly revenue meter. Interval demand readings are necessary to calculate the reference load and estimate load impacts from DR events. Sub-metered loads may be used for accounts which do not have interval meters at the discretion of the SWE.

ALGORITHMS

Annual peak demand savings must be estimated using individual customer data (e.g. account, meter, or site as defined by program rules) regardless of which evaluation method is used. Program savings are the sum of the load impacts across all participants. The equations below provide mathematical definitions of the average peak period load impact estimate that would be calculated using an approved method.

$$\Delta kW_{summer\ peak} = \frac{\sum_{i=1}^{n\_summer} \Delta kW_i}{n\_summer}$$

$$\Delta kW_{winter\ peak} = \frac{\sum_{i=1}^{n\_winter} \Delta kW_i}{n\_winter}$$

$$\Delta kW_i = kW_{Reference_i} - kW_{Metered_i}$$

Definition of Terms

Table 3-249: Terms, Values, and References for C&I Load Curtailment

Term	Unit	Values	Source
N_summer, Number of summer DR event hours during a program year for the EDC	Hours	EDC Data Gathering	EDC Data Gathering
N_winter, Number of winter DR event hours during a program year for the EDC	Hours	EDC Data Gathering	EDC Data Gathering
ΔkW_i, Estimated load impact achieved by an LC participant in hour i. This term can be positive (a load reduction) or negative (a load increase).	kW	EDC Data Gathering	EDC Data Gathering
$kW\_Reference_i$, Estimated customer load absent DR during hour i	kW	EDC Data Gathering	EDC Data Gathering
$kW\_Metered_i$, Measured customer load during hour i	kW	EDC Data Gathering	EDC Data Gathering

Default Savings

There are no default savings for this measure.

Evaluation Protocols

The evaluation protocols for the Load Curtailment measure follow the calculation methodologies described in this document. Evaluation of the measure should rely on a census of program participants unless a sampling approach (either of days or participants) is approved by the SWE. Detailed protocols for implementing the methodologies described above and the outputs that must be produced are provided in the Evaluation Framework.

4. AGRICULTURAL MEASURES

4.1. AGRICULTURAL

4.1.1. AUTOMATIC MILKER TAKEOFFS

Target Sector	Agriculture
Measure Unit	Milker Takeoff System
Measure Life	10 years Source1
Measure Vintage	Retrofit

ELIGIBILITY

The following protocol for the calculation of energy and demand savings applies to the installation of automatic milker takeoffs on dairy milking vacuum pump systems. Automatic milker takeoffs shut off the suction on teats once a minimum flow rate is achieved. This reduces the load on the vacuum pump.

This measure requires the installation of automatic milker takeoffs to replace pre-existing manual takeoffs on dairy milking vacuum pump systems. Equipment with existing automatic milker takeoffs is not eligible. In addition, the vacuum pump system serving the impacted milking units must be equipped with a variable speed drive (VSD) to qualify for incentives. Without a VSD, little or no savings will be realized.

ALGORITHMS

The annual energy savings are obtained through the following formulas. Since the number of cows milked per day remains the same irrespective of the seasons, the summer and winter peak demand savings are considered to be the same.

$$\Delta kWh = COWS \times ESC$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_s$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_w$$

DEFINITION OF TERMS

Table 4-1: Terms, Values, and References for Automatic Milker Takeoffs

Term	Unit	Values	Source
$COWS$, Number of cows milked per day (not the number of individual milkings; each cow is assumed to be milked twice per day)	*Cows*	Based on customer application	EDC Data Gathering
ESC, Annual Energy Savings per cow	$\frac{kWh}{cow}$	34	2, 3, 4, 5, 6
$ETDF_s = ETDF_w$, summer and winter energy-to-demand factor	$\frac{kW}{kWh}$	0.00017	7

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) Idaho Power Demand Side Management Potential Study – Volume II Appendices, Nexant, 2009.
2) The ESC was calculated based on the following assumptions:
    a. Average herd size is 102 cows in PA (Source 3)
    b. The typical dairy vacuum pump size for the average herd size is 10 horsepower (Source 4)
    c. Based on the herd size, average pump operating hours are estimated at 10 hours per day (or 0.10 hours per cow per day) (Source 5)
    d. A 12.5% annual energy saving factor (Source 6)
3) Nicholson, C., Stephenson M., and Novakovic, A. (2017). "Study to Support Growth and Competitiveness of the Pennsylvania Dairy Industry". Weblink
4) Average dairy vacuum pump size was estimated based on the Minnesota Dairy Project literature.
5) Mayer, M. and Kammel, D. (2008). "Dairy Modernization Works for Family Farms". Weblink. The paper asserts an average of 22.7 cows milked per hour prior to modernization. This TRM adopts a conservative estimate of 20 cows milked per hour. Annual pump operating hours are based on the assumption that 20 cows are milked per hour and two milkings occur per day.
6) Savings are based on the assumption that automatic milker take-offs eliminate open vacuum pump time associated with milker take-offs separating from the cow or falling off during the milking process. The following conservative assumptions were made to determine energy savings associated with the automatic milker take-offs:
    a. There is 30 seconds of open vacuum pump time for every 8 cows milked.
    b. The vacuum pump has the ability to turn down during these open-vacuum pump times from a 90% VFD speed to a 40% VFD speed.
    c. Additionally, several case studies from the Minnesota Dairy Project include dairy pump VFD and automatic milker take-off energy savings that are estimated at 50-70% pump savings. It is assumed that the pump VFD savings are 46%; therefore, the average remaining savings can be attributed to automatic milker take-offs.
7) Regional Technical Forum (RTF) as part of the Northwest Power & Conservation Council, Deemed Measures List. Agricultural: Variable Frequency Drives-Dairy, FY2012, V1.2. Weblink

4.1.2. Dairy Scroll Compressors

Target Sector	Agriculture
Measure Unit	Compressor
Measure Life	15 years Source 1
Measure Vintage	Replace on Burnout

Eligibility

The following protocol for the calculation of energy and demand savings applies to the installation of a scroll compressor to replace an existing reciprocating compressor or the installation of a scroll compressor in a new construction application. The compressor is used to cool milk for preservation and packaging. The energy and demand savings per cow will depend on the installed scroll compressor energy efficiency ratio (EER), operating days per year, and the presence of a precooler in the refrigeration system.

This measure requires the installation of a scroll compressor to replace an existing reciprocating compressor or to be installed in a new construction application. Existing farms replacing existing scroll compressors are not eligible.

Algorithms

The energy and peak demand savings are dependent on the presence of a precooler in the system and are obtained through the formulas below. The milking process is year-round and the cooling process is not influenced by the seasonal changes. As a result, the summer and winter peak demands are considered to be the same.

$$\Delta kWh = \left(\frac{CBTU}{EER_{base}} - \frac{CBTU}{EER_{ee}}\right) \times \frac{1}{1{,}000} \times DAYS \times COWS$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_s$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_w$$

Definition of Terms

Table 4-2: Terms, Values, and References for Dairy Scroll Compressors

Term	Unit	Values	Source
EER_{base}, Baseline compressor efficiency	$\frac{Btu}{hr \cdot W}$	Baseline compressor manufacturers data based upon customer application	EDC Data Gathering
		Default: 0.85 × EER_{ee}	2
EER_{ee}, Installed compressor efficiency	$\frac{Btu}{hr \cdot W}$	From nameplate	EDC Data Gathering
$CBTU$, Heat load of milk per cow per day for a given refrigeration system	$\frac{Btu}{Cow \cdot day}$	System without precooler: 2,864 System with precooler: 922	3, 4
$DAYS$, Milking days per year	*Days*	Based on customer application	EDC Data Gathering
		Default: 365 days/year	4, 5
$COWS$, Average number of cows milked per day (not the number of individual milkings; each cow is assumed to be milked twice per day)	*Cows*	Based on customer application	EDC Data Gathering
$ETDF_s = ETDF_w$, energy-to-demand factor	$\frac{kW}{kWh}$	0.00017	6

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) PA Consulting Group for the State of Wisconsin Public Service Commission. (2009, August). Focus on Energy Evaluation Business Programs: Measure Life Study. Appendix B. Weblink

2) GDS Associates for the Massachusetts Farm Energy Program. (2012). Massachusetts Farm Energy Best Management Practices for Dairy Farms. Page 65. Weblink

3) American Society of Heating Refrigeration and Air-conditioning Engineers Refrigeration Handbook. (2022). Ch.19.5, Table 3, dairy, whole milk. Based on a specific heat value of 0.93 Btu/lb deg F and density of 8.7 lb/gallon for whole milk.

4) KEMA for IPL. (2009). Evaluation of IPL Energy Efficiency Programs. Appendix F, page 347. Based on delta T (temperature difference between the milk leaving the cow and the cooled milk in tank storage) of 59 °F for a system with no pre-cooler and 19 °F for a system with a pre-cooler. It was also assumed that an average cow produces 6 gallons of milk per day.

5) Based on typical dairy parlor operating hours referenced for agriculture measures in California. California Public Utility Commission. Database for Energy Efficiency Resources (DEER) 2005. The DEER database assumes 20 hours of operation per day but is based on much larger dairy farms (e.g. herd sizes > 300 cows). Therefore, the DEER default value was lowered to 8 hours per day.

6) Regional Technical Forum (RTF) as part of the Northwest Power & Conservation Council, Deemed Measures List. Agricultural: Variable Frequency Drives-Dairy, FY2012, V1.2. Weblink

4.1.3. High-Efficiency Ventilation Fans with and without Thermostats

Target Sector	Agriculture
Measure Unit	Fan
Measure Life	13 years Source 1
Measure Vintage	Replace on Burnout or New Construction

Eligibility

The following protocol for the calculation of energy and demand savings applies to the installation of high efficiency ventilation fans to replace standard efficiency ventilation fans or the installation of high efficiency ventilation fans in a new construction application. The high efficiency fans move more cubic feet of air per watt compared to standard efficiency ventilation fans. Adding a thermostat control will reduce the number of hours that the ventilation fans operate. This protocol does not apply to circulation fans.

This protocol applies to: (1) the installation of high efficiency ventilation fans in either new construction or retrofit applications where standard efficiency ventilation fans are replaced, and/or (2) the installation of a thermostat controlling either new efficient fans or existing fans. Default values are provided for dairy and swine applications. Other facility types are eligible; however, data must be collected for all default values. Note that savings are calculated per fan.

Midstream High-Efficiency Ventilation Fans with and without Thermostats Overview

This protocol can be used for fans that are sold to trade allies and customers through commercial channels such as distributors, suppliers, and direct relationships with manufacturers. This complements other delivery channels (such as downstream rebates to trade allies and customers) by providing incentives to encourage distributors to stock, promote, and sell high-efficiency ventilation fans.

To be eligible under this protocol, the qualifying equipment must be purchased through a commercial channel (such as a commercial contractor or distributor) for installation at a farm. The distributor will need to collect information on the premise type and installation address for verification purposes.

Algorithms

The annual energy savings are obtained through the following formulas:

$$\Delta kWh = \left(\frac{1}{Eff_{std}} - \frac{1}{Eff_{high}}\right) \times CFM \times HOURS_{with\ or\ w/o\ tstats} \times \frac{1}{1{,}000}$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_s$$

$$\Delta kW_{winter\ peak} = 0$$

Please note that the hours of operation in the above equation will be the same, meaning the standard and efficient fans will both either have thermostats or no thermostats.

The annual energy savings for installation of high efficiency ventilation fans and a thermostat control in either new construction or retrofit applications where standard efficiency ventilation fans without thermostat controls are replaced are obtained through the following formulas:

$$\Delta kWh = \left(\frac{1}{Eff_{std}} \times HOURS_{w/o\ tstats} - \frac{1}{Eff_{high}} \times HOURS_{tstats}\right) \times \mathrm{CFM} \times \frac{1}{1{,}000}$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_s$$

$$\Delta kW_{winter\ peak} = 0$$

The annual energy savings for the installation of a thermostat controlling either new efficient fans or existing fans are obtained through the following formulas:

$$\Delta kWh = \frac{1}{Eff_{std/high}} \times CFM \times (\mathrm{HOURS}_{w/o\ tstats} - HOURS_{tstats}) \times \frac{1}{1{,}000}$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_s$$

$$\Delta kW_{winter\ peak} = 0$$

Definition of Terms

Table 4-3: Terms, Values, and References for Ventilation Fans

Term	Unit	Values	Source
Eff_{std}, Efficiency of the standard efficiency fan at a static pressure of 0.1 inches water	$\frac{CFM}{W}$	Based on customer application	EDC Data Gathering
		Default: Table 4-4	2
Eff_{high}, Efficiency of the high efficiency fan at a static pressure of 0.1 inches water	$\frac{CFM}{W}$	Based on customer application.	EDC Data Gathering
		Default: Table 4-4	2, 3, 4
$HOURS$, operating hours per year of the fan	*Hours*	Based on customer application	EDC Data Gathering
		Default without thermostat: Table 4-5 Default with thermostat: Table 4-6	2, 5
CFM, cubic feet per minute of air movement	$\frac{ft^3}{min}$	Based on customer application. This can vary for pre- and post-installation if the information is known for the pre-installation case.	EDC Data Gathering
		Default: Table 4-4	2
1,000, watts per kilowatt	$\frac{W}{kW}$	1,000	Conversion Factor
$ETDF_s$, summer energy-to-demand factor	$\frac{kW}{kWh}$	0.0001970	Engineering calculations

Table 4-4: Default values for standard and high efficiency ventilation fans for dairy and swine facilities

Fan Size (inches)	High Efficiency Fan (cfm/W at 0.1 inches water)	Standard Efficiency Fan (cfm/W at 0.1 inches water)	CFM
14 - 23	12.4	9.2	3,600
24 - 35	15.3	11.2	6,274
36 - 47	19.2	15.0	10,837
48 - 61	22.7	17.8	22,626

Table 4-5: Default Hours for Ventilation Fans by Facility Type by Location (No Thermostat)

Facility Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsport
Dairy - Stall Barn	5,071	4,596	4,336	4,807	5,163	5,390	5,010	4,843	5,020
Dairy – Free-Stall or Cross-Ventilated Barn	3,299	2,665	2,365	2,984	3,436	3,732	3,231	2,985	3,241
Hog Nursery or Sow House	5,864								
Hog Finishing House	4,729								
Unknown	3,299	2,665	2,365	2,984	3,436	3,732	3,231	2,985	3,241

Table 4-6: Default Hours for Ventilation Fans by Facility Type by Location (With Thermostat)

Facility Type	Allentown	Binghamton	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh	Scranton	Williamsport
Dairy - Stall Barn	3,457	3,562	3,526	3,458	3,367	3,285	3,441	3,594	3,448
Dairy – Free-Stall or Cross-Ventilated Barn	1,685	1,663	1,574	1,635	1,640	1,627	1,662	1,736	1,669
Hog Nursery or Sow House	3,235	2,581	2,139	2,879	3,541	3,685	3,132	2,979	3,198
Hog Finishing House*	4,729	4,729	4,729	4,729	4,729	4,729	4,729	4,729	4,729
Unknown	1,685	1,663	1,574	1,635	1,640	1,627	1,662	1,736	1,669
* Hog finishing house ventilation needs are based on humidity; therefore, a thermostat will not reduce the number of hours the fans operate.									

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Ventilation Fan (Agricultural)". Accessed December 2023. Weblink
2) KEMA for IPL. (2009). Evaluation of IPL Energy Efficiency Programs. Appendix F, Table H-5.
3) Tyson, J., McFarland, D., and Graves, R. (2014, June). "Tunnel Ventilation for Tie Stall Dairy Barns". Penn State Extension. G-78. Weblink. Static pressure reference point for dairy barns comes from page 3. The recommended static pressure is 0.125 to 0.1-inch water gauge.
4) Iowa State University. (1999). Mechanical Ventilation Design Worksheet for Swine Housing. Weblink. Static pressure reference point for swine housing comes from page 2. The recommended static pressure is 0.125 to 0.1 inches water for winter fans and 0.05 to 0.08 inches water for summer fans. A static pressure of 0.1 inches water was assumed for dairy barns and swine houses as it is a midpoint for the recommended values.
5) Based on the methodology in KEMA's evaluation of the Alliant Energy Agriculture Program (Source 2). Updated the hours for dairies and thermostats using TMY3 temperature data for PA, as fan run time is dependent on ambient dry-bulb temperature. For a stall barn, it was assumed 33% of fans are on 8,760 hours per year, 67% of fans are on when the temperature is above 50°F, and 100% of the fans are on when the temperature is above 70°F. For a cross-ventilated or free-stall barn, it was assumed 10% of fans are on 8,760 hours per year, 40% of fans are on when the temperature is above 50°F, and 100% of the fans are on when the temperature is above 70°F. The hours for hog facilities are based on humidity. These hours were not updated as the methodology and temperatures for determining these hours was not described in KEMA's evaluation report and could not be found elsewhere. However, Pennsylvania and Iowa are in the same ASHRAE climate zone (5A) and so the Iowa hours provide a good estimate for hog facilities in Pennsylvania.

4.1.4. Heat Reclaimers

Target Sector	Agriculture
Measure Unit	Heat Reclaimer System
Measure Life	15 years Source 1
Measure Vintage	Replace on Burnout or New Construction

Eligibility

The following protocol for the calculation of energy and demand savings applies to the installation of heat recovery equipment on dairy parlor milk refrigeration systems. The heat reclaimers recover heat from the refrigeration system and use it to preheat water used for sanitation, sterilization, and cow washing.

This measure requires the installation of heat recovery equipment on dairy parlor milk refrigeration systems to preheat water. This measure only applies to dairy parlors with electric water heating equipment.

Midstream Heat Reclaimers Overview

This protocol can be used for heat reclaimers sold to trade allies and customers through commercial channels such as distributors, suppliers, and direct relationships with manufacturers. This complements other delivery channels (such as downstream rebates to trade allies and customers) by providing incentives to encourage distributors to stock, promote, and sell heat recovery systems. The distributor will need to collect information on the premise type and installation address for verification purposes.

Algorithms

The annual energy and peak demand savings are dependent on the presence of a precooler in the refrigeration system, and are obtained through the following formulas:

$$\Delta kWh = \frac{ES}{\eta_{water\ heater}} \times DAYS \times COWS \times HEF$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_s$$

$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_w$$

Definition of Terms

Table 4-7: Terms, Values, and References for Heat Reclaimers

Term	Unit	Values	Source
ES, Energy savings for specified system	$\frac{kWh}{cow \cdot day}$	System with precooler = 0.29 System without precooler = 0.38	2, 3
$DAYS$, Milking days per year	$\frac{days}{year}$	Based on customer application	EDC Data Gathering
		Default: 365	3
$COWS$, Average number of cows milked per day (not the number of individual milkings; each cow is assumed to be milked twice per day)	*Cows*	Based on customer application	EDC Data Gathering
		Default: 57	4
HEF, Heating element factor	*None*	Heat reclaimers with no back-up heat = 1.0 Heat reclaimers with back-up heating elements = 0.50	4
$\eta_{water\ heater}$, Electric water heater efficiency	*None*	Electric tank water heater = 0.92 Heat pump water heater = 3.2	5
$ETDF_S$, Summer energy-to-demand factor	$\frac{kW}{kWh}$	0.00017	6
$ETDF_W$, Winter energy-to-demand factor	$\frac{kW}{kWh}$	0.00018	6

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) PA Consulting Group for Public Service Commission of Wisconsin. (2009). Focus on Energy Evaluation, Business Program: Measure Life Study. Appendix B. Weblink

2) American Society of Heating Refrigeration and Air-conditioning Engineers Refrigeration Handbook. (2022). Ch.19.5, Table 3, dairy, whole milk. Based on a specific heat value of 0.93 Btu/lb deg F and density of 8.7 lb/gallon for whole milk.

3) Evaluation of Alliant Energy Agriculture Program (2008). Appendix F. Based on a delta T (temperature difference between the milk leaving the cow and the cooled milk in tank storage) of 59°F for a system without a pre-cooler and 19°F for a system with a pre-cooler. It was also assumed that a cow produces 6 gallons of milk per day (based on two milkings per day),

requires 2.2 gallons of hot water per day, and the water heater delta T (between ground water and hot water) is 70°F.

4) Center for Dairy Excellence. (2021, February 23). 2020 PA Dairy Producer Survey Results. Weblink. According to the survey results, the average number of cows milked per day are 136 and they produce 65.8 lbs of milk per day. 68% of the farms have less than 99 cows. The weighted average of the number of cows milked for these farms is 57.

5) Some smaller dairy farms may not have enough space for an additional water storage tank and will opt to install a heat reclaimer with a back-up electric resistance element. The HEF used in the savings algorithm is a conservative savings de-ration factor to account for the presence of back-up electric resistance heat. The HEF is based on the assumption that the electric resistance element in a heat reclaimer will increase the incoming ground water temperature by 40-50°F before the water is heated by the heat reclaim coil.

6) NMR Group for the Pennsylvania Public Utility Commission. (2024, March). 2023 Pennsylvania Statewide Act 129 Residential Baseline Study. Section 8, page 90. Weblink

7) Regional Technical Forum (RTF) as part of the Northwest Power & Conservation Council, Deemed Measures List. Agricultural: Variable Frequency Drives-Dairy, FY2012, V1.2. Weblink. The winter demand factor was calculated as a proportion of the summer demand factor. The proportionality used was from the SWE ETDF spreadsheet.

4.1.5. High Volume Low Speed Fans

Target Sector	Agriculture
Measure Unit	Fan
Measure Life	15 years Source 1
Measure Vintage	Replace on Burnout or New Construction

Eligibility

The following protocol for the calculation of energy and demand savings applies to the installation of high volume low speed (HVLS) fans to replace conventional circulating fans. HVLS fans move more cubic feet of air per watt than conventional circulating fans. Default values are provided for dairy, poultry, and swine applications. This measure borrows data from the certified products directory of AMCA's Large Diameter Fans[3]. With qualifying fans meeting Federal baseline standards with ceiling fan energy index (CEI) that meets or exceeds 1.31 at 40% rated RPM and CEI greater than or equal to 1.00 at 100% rated RPM. This measure is for agriculture applications only. For all other building types please refer to measure 3.2.14.

Midstream HVLS Fans Overview

This protocol can be used for HVLS fans that are sold to trade allies and customers through commercial channels such as distributors, suppliers, and direct relationships with manufacturers. This complements other delivery channels (such as downstream rebates to trade allies and customers) by providing incentives to encourage distributors to stock, promote, and sell HVLS fans.

To be eligible under this protocol, the qualifying equipment must be purchased through a commercial channel (such as a commercial contractor or distributor) for installation at a farm. The distributor will need to collect information on the premise type, application, and installation address for verification purposes. To qualify for this measure, the customer must purchase HVLS fans for use in the dairy, poultry, and swine applications.[3]

Algorithms

The annual energy and peak demand savings are obtained through the following formulas:

$$\Delta kWh = \left(\frac{1}{Eff_{HVLS}} - \frac{1}{Eff_{baseline}}\right) \times \frac{CFM}{1{,}000} \times HOU$$

$$\Delta kW_{summer\ peak} = \frac{\Delta kWh}{HOU} \times CF$$

$$\Delta kW_{winter\ peak} = 0$$

Definition of Terms

[3] Other facility types are eligible, however, the operating hours assumptions should be collected, reviewed and modified as appropriate.

Table 4-8: Terms, Values, and References for HVLS Fans

Term	Unit	Values	Source
$Eff_{baseline}$, efficiency of the baseline conventional fan	$\frac{CFM}{W}$	Based on customer application	EDC Data Gathering
		Default: 22.7	3
Eff_{HVLS}, efficiency of the installed HVLS fan	$\frac{CFM}{W}$	Based on customer application	EDC Data Gathering
		Default: Table 4-9	2
$HOURS$, annual hours of operation of the fans	*Hours*	Based on customer application	EDC Data Gathering
		Default: Table 4-10	4
$1{,}000$, watts per kilowatt	$\frac{W}{kW}$	1,000	Conversion factor
CF, Coincidence factor	*Decimal*	1.0	4

Table 4-9: Default Values for HVLS Fan Efficiency Wattages

Fan Size (ft)	$HVLS\ (W/_{CFM})$
≥ 8 and < 10	116
≥ 10 and < 12	144
≥ 12 and < 14	152
≥ 14 and < 16	165
≥ 16 and < 18	206
≥ 18 and < 20	230
≥ 20 and < 24	257
≥ 24	169

Note: Fan wattage defaults represented in Table 3-70 are an aggregate of datapoints surveyed across multiple fan manufacturers and product types. Exercising engineering judgment, we assume fans to be operating at 80% of their rated RPM.

Table 4-10: Default Hours by Location for Dairy/Poultry/Swine Applications

Location	*Hours*
Allentown	2,459
Binghamton	1,526
Bradford	1,340
Erie	2,124
Harrisburg	2,718
Philadelphia	2,914
Pittsburgh	2,296
Scranton	2,154
Williamsport	2,371

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) PA Consulting Group for Public Service Commission of Wisconsin. (2009). Focus on Energy Evaluation, Business Program: Measure Life Study. Appendix B. Weblink

2) Large Diameter Ceiling Fans, certified and listed products directory by AMCA. Weblink

3) Engineering judgement: Assuming for a 48" conventional fan to provide comparable volume of air as a HVLS. KEMA Inc. for Interstate Power and Light Company. (2012, February). Interstate Power and Light Company Docket EEP-08-1, Appendix H; Table H-5.

4) Number of hours above 65°F. Based on TMY3 data. The coincidence factor has been set at 1.0 as the SWE believes all hours during the peak window will be above 65°F.

4.1.6. Livestock Waterer

Target Sector	Agriculture
Measure Unit	Livestock Waterer System
Measure Life	10 years Source 1
Measure Vintage	Replace on Burnout or New Construction

Eligibility

The following protocol for the calculation of energy and demand savings applies to the installation of energy-efficient livestock waterers. In freezing climates no or low energy livestock waterers are used to prevent livestock water from freezing. These systems are closed watering containers that typically use super insulation, relatively warmer ground water temperatures, and the livestock's use of the waterer to keep water from freezing.

This measure requires the installation of an energy-efficient livestock watering system that is thermostatically controlled and has factory-installed insulation with a minimum thickness of two inches. Savings algorithms are for one unit.

Midstream Livestock Waterer Overview

This protocol can be used for energy-efficient livestock waterers that are sold to trade allies and customers through commercial channels such as distributors, suppliers, and direct relationships with manufacturers. This complements other delivery channels (such as downstream rebates to trade allies and customers) by providing incentives to encourage distributors to stock, promote, and sell livestock waterer systems.

To be eligible under this protocol, the qualifying equipment must be purchased through a commercial channel (such as a commercial contractor or distributor) for installation at a farm. The distributor will need to collect information on the premise type and installation address for verification purposes.

Algorithms

As the energy savings occur during the winter months, only winter peak demand savings are expected. The annual energy savings are obtained through the following formula:

$$\Delta kWh = OPRHS \times ESW \times HRT$$

$$\Delta kW_{summer\ peak} = 0$$

$$\Delta kW_{winter\ peak} = ESW \times HRT \times CF_w$$

Definition of Terms

Table 4-11: Terms, Values, and References for Livestock Waterers

Term	Unit	Values	Source
$OPRHS$, Annual operating hours	*Hours*	Allentown = 1,498 Binghamton = 2,083 Bradford = 2,510 Erie = 1,778 Harrisburg = 1,309 Philadelphia = 1,090 Pittsburgh = 1,360 Scranton = 1,718 Williamsport = 1,575	2
ESW, change in connected load (deemed)	$\frac{kW}{waterer}$	0.50	3, 4, 5, 7
HRT, % heater run time	*None*	80%	6
CF_w	*None*	1.0	3, 4, 5, 7

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation, confirm the quantity of waterer systems installed, and ensure the proper application of TRM protocols. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) PA Consulting Group for Public Service Commission of Wisconsin. (2009). Focus on Energy Evaluation, Business Program: Measure Life Study. Appendix B. Weblink
2) Based on TMY3 data for various climate zones in Pennsylvania. The annual operating hours represent the annual hours when the outdoor air dry-bulb temperature is less than 32 °F, and it is assumed that the livestock waterer electric resistance heaters are required below this temperature to prevent water freezing.
3) Prairie Agricultural Machinery Institute. (1991, August). Field Study of Electrically Heated and Energy Free Automated Livestock Water Fountains. Weblink
4) Alberta Agriculture and Rural Development. (2008, December). Facts Automatic Livestock Waterers Fact Sheet. Weblink
5) Connecticut Farm Energy Program. (2010). Energy Best Management Practices Guide. Weblink
6) The Regional Technical Forum. (2023, July 18). “Agricultural: Energy-Free Stock Watering Tanks”. Weblink. The Regional Technical Forum (RTF) analyzed metered data from three baseline livestock waterers and found the average run time of electric resistance heaters in the waterers to be approximately 80% for average monthly temperatures similar to Pennsylvania climate zones. This run time factor accounts for warmer make-up water being introduced to the tank as livestock drinking occurs.

7) Wisconsin Focus on Energy Technical Reference Manual. (2020). “Energy Efficient or Energy Free Livestock Waterer”. Weblink

4.1.7. Variable Speed Drive (VSD) Controller on Dairy Vacuum Pumps

Target Sector	Agriculture
Measure Unit	Dairy Vacuum Pump VSD
Measure Life	15 years Source 1
Measure Vintage	Retrofit, New Construction, Replace on Burnout

Eligibility

The following protocol for the calculation of energy and demand savings applies to the installation of a variable speed drive (VSD) and controls on a dairy vacuum pump. The vacuum pump operates during the milk harvest and equipment washing on a dairy farm. The vacuum pump creates negative air pressure that draws milk from the cow and assists in the milk flow from the milk receiver to either the bulk tank or receiver bowl.

Dairy vacuum pumps are more efficient with VSDs since they enable the motor to speed up or slow down depending on the pressure demand. The energy savings for this measure is based on pump capacity and hours of use of the pump.

This measure requires the installation of a VSD and controls on dairy vacuum pumps, or the purchase of dairy vacuum pumps with variable speed capability. Pre-existing pumps with VSD's are not eligible for this measure.

Midstream VSD for Dairy Vacuum Pumps Overview

This protocol can be used for VSDs on vacuum pump motors that are sold to trade allies and customers through commercial channels such as pump distributors, suppliers, and direct relationships with manufacturers. This complements other delivery channels (such as downstream rebates to trade allies and customers) by providing incentives to encourage distributors to stock, promote, and sell VSDs.

To be eligible under this protocol, the qualifying equipment must be purchased through a commercial channel (such as a commercial contractor or distributor) for installation at a dairy farm. The distributor will need to collect information on the premise type and installation address for verification purposes. To qualify for this measure, the customer must purchase dairy vacuum pumps with variable speed capability or variable speed drives to replace failed non-VSD drives on existing vacuum pumps.

Algorithms

The annual energy savings are obtained through the following formulae:

$$\Delta kWh = HP \times 0.746 \times \frac{LF}{\eta_{motor}} \times ESF \times DHRS \times ADAYS$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_s$$

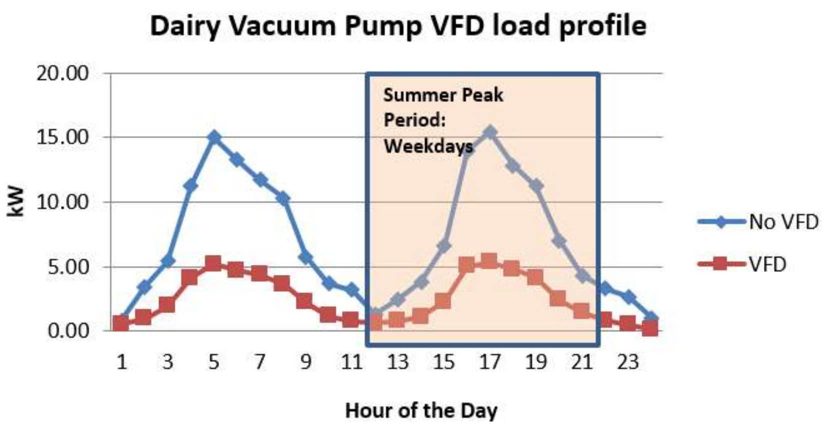
$$\Delta kW_{winter\ peak} = \Delta kWh \times ETDF_w$$

Energy to Demand Factor

An average of pre- and post-kW vacuum pump power meter data from five dairy farms in the Pacific Northwest are used to create the vacuum pump demand load profile in Figure 4-1[2]. Dairy vacuum pump operation does not vary based on geographical location, so the average peak demand reduction obtained from these five sites can be applied to Pennsylvania. There are no seasonal variations in cow milking times, as dairy farms milk cows year-round, so the load profile below applies to 365 days of operation. The average percent demand reduction for these five sites during the coincident peak demand period of June through September between noon and 8 pm is 46%, which is consistent with the energy savings factors and demand savings estimated for the sources cited in this protocol.

Based on this data, the energy to demand factor is estimated by dividing the average peak coincident demand kW reduction by ∆kWh savings for a 1 horsepower motor. The result is an energy to demand factor equal to 0.00014. Note that this value has been adapted from a definition of peak period that differs from the definition in Pennsylvania.

Figure 4-1: Typical Dairy Vacuum Pump Coincident Peak Demand Reduction



Definition of Terms

Table 4-12: Terms, Values, and References for VSD Controller on Dairy Vacuum Pump

Term	Unit	Values	Source
$Motor\ HP$, Rated horsepower of the motor	*HP*	Nameplate	EDC Data Gathering
0.746, conversion factor from horsepower to kW	$\frac{kW}{HP}$	0.746	Conversion Factor
LF, Load Factor. Ratio between the actual load and the rated load. The default value is 0.90	*None*	EDC data gathering	EDC Data Gathering
		Default: 90%	3
η_{motor}, Motor efficiency at the full-rated load. For VFD installations, this can be either an energy-efficient motor or standard efficiency motor.	*None*	Nameplate	Table 4-13 or EDC Data Gathering
ESF, Energy Savings Factor. Percent of baseline energy consumption saved by installing VFD.	*None*	46%	4, 5
$DHRS$, Daily run hours of the motor	*Hours/Day*	Based on customer application	EDC Data Gathering
		Default: 8	4, 5
$ADAYS$, Annual operating days	*Days*	Based on customer application	EDC Data Gathering
		Default: 365	4, 5
$ETDF_s = ETDF_w$, summer and winter energy-to-demand factor	$\frac{kW}{kWh}$	0.0001400	5

Table 4-13: Nominal Full-Load Efficiencies of NEMA Design A, B, IEC Design N, NE, NEY, or NY Motors Source 6

Motor horsepower/Standard kilowatt equivalent	Nominal full-load efficiency					
	Open Motors (number of poles)			Closed Motors (number of poles)		
	6	4	2	6	4	2
1/.75	82.5	85.5	77.0	82.5	85.5	77.0
1.5/1.1	86.5	86.5	84.0	87.5	86.5	84.0
2/1.5	87.5	86.5	85.5	88.5	86.5	85.5
3/2.2	88.5	89.5	85.5	89.5	89.5	86.5
5/3.7	89.5	89.5	86.5	89.5	89.5	88.5
7.5/5.5	90.2	91.0	88.5	91.0	91.7	89.5
10/7.5	91.7	91.7	89.5	91.0	91.7	90.2
15/11	91.7	93.0	90.2	91.7	92.4	91.0
20/15	92.4	93.0	91.0	91.7	93.0	91.0

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. Effective Useful Life and Remaining Useful Life Support Table. Accessed December 2023. Weblink

2) Regional Technical Forum (RTF) as part of the Northwest Power & Conservation Council, Deemed Measures List. Agricultural: Variable Frequency Drives-Dairy, FY2012, V1.2. Weblink. Pre- and post-power meter data for five sites were used to establish RTF energy savings for this measure. Raw data used to generate the load profile referenced in this protocol can be found in the zip file on the "BPA Case Studies" tab.

3) Southern California Edison, Dairy Farm Energy Management Guide: California, page 11, 2004.

4) California Public Utility Commission. (2005). Database for Energy Efficiency Resources (DEER). The DEER database assumes 20 hours of operation per day but is based on much larger dairy farms (e.g. herd sizes > 300 cows). Therefore, the DEER default value was lowered to 8 hours per day, as the average heard size is significantly less in Pennsylvania. Regional Technical Forum (RTF) as part of the Northwest Power & Conservation Council, Deemed Measures List. Agricultural: Variable Frequency Drives-Dairy, FY2012, V1.2. Accessed February 2013. Weblink

5) Regional Technical Forum (RTF) as part of the Northwest Power & Conservation Council, Deemed Measures List. Agricultural: Variable Frequency Drives-Dairy, FY2012, V1.2. Weblink

6) 10 CFR 431.25(a), Table 5 to Paragraph (h) Weblink

4.1.8. Low Pressure Irrigation System

Target Sector	Agriculture and Golf Courses
Measure Unit	Irrigation System
Measure Life	5 years Source 1
Measure Vintage	Replace on Burnout or New Construction

Eligibility

The following protocol for the measurements of energy and demand savings applies to the installation of a low-pressure irrigation system, which reduces the amount of energy required to apply the same amount of water as a baseline system.

The amount of energy saved per acre will depend on the actual operating pressure decrease, the pumping plant efficiency, the amount of water applied, and the number of nozzle, sprinkler, or micro irrigation system conversions made to the system.

This measure requires a minimum of 50% reduction in irrigation pumping pressure through the installation of a low-pressure irrigation system in agriculture or golf course applications. The pressure reduction can be achieved in several ways, such as nozzle or valve replacement, sprinkler head replacement, alterations or retrofits to the pumping plant, or drip irrigation system installation, and is left up to the discretion of the owner. Pre- and post-retrofit pump pressure measurements are required.

Algorithms

The annual energy savings are obtained through the following formulas:

Agriculture applications:

$$\Delta kWh = \frac{ACRES \times (PSI_{base} - PSI_{eff}) \times GPM1}{1{,}714 \times \eta_{motor}} \times 0.746 \times OPRHS$$

$$\Delta kW_{summer\ peak} = \Delta kWh \times ETDF_s$$

$$\Delta kW_{winter\ peak} = 0$$

Golf Course applications:

$$\Delta kWh = \frac{ACRES \times (PSI_{base} - PSI_{eff}) \times GPM2}{1{,}714 \times \eta_{motor}} \times 0.746 \times DHRS \times ADAYS$$

No peak demand savings may be claimed for golf course applications as watering typically occurs during non-peak demand hours.

DEFINITION OF TERMS

Table 4-14: Terms, Values, and References for Low Pressure Irrigation Systems

Term	Unit	Values	Source
$ACRES$, Number of acres irrigated	*Acres*	Based on customer application	EDC Data Gathering
PSI_{base}, Baseline pump pressure, must be measured and recorded prior to installing low-pressure irrigation equipment	*Pounds per square inch (psi)*	Based on pre retrofit pressure measurements taken by the installer	EDC Data Gathering
PSI_{eff}, Installed pump pressure, must be measured and recorded after the installation of low-pressure irrigation equipment by the installer	*Pounds per square inch (psi)*	Based on post retrofit pressure measurements taken by the installer	EDC Data Gathering
$GPM1$, Pump flow rate per acre for agriculture applications.	*Gallons per minute (gpm) per acre*	Based on pre retrofit flow measurements taken by the installer	EDC Data Gathering
$GPM2$, Pump flow rate for pumping system for golf courses	*Gallons per minute (gpm)*	Based on pre retrofit flow measurements taken by the installer	EDC Data Gathering
$1{,}714$, Constant used to calculate hydraulic horsepower for conversion between horsepower and pressure and flow	$\frac{PSI \times GPM}{HP}$	$1{,}714$	Conversion Factor
$OPHRS$, Average irrigation hours per growing season for agriculture	*Hours*	Based on customer application	EDC Data Gathering
$DHRS$, Hours of watering per day for golf courses	*Hours/Day*	Based on customer application	EDC Data Gathering
$ADAYS$, Annual operating days of irrigation for golf courses	*Days*	Based on customer application	EDC Data Gathering
η_{motor}, Pump motor efficiency	*None*	Based on customer application	EDC Data Gathering
		Look up pump motor efficiency based on the pump nameplate horsepower (HP) from customer application and nominal efficiencies defined in Table 3-84 and Table 3-86	2
$ETDF_s$, summer energy-to-demand factor	$\frac{kW}{kWh}$	0.0026000	3, 4

Evaluation Protocols

For most projects, the appropriate evaluation protocol is to verify installation and proper selection of default values. For projects using customer specific data for open variables, the appropriate evaluation protocol is to verify installation and proper application of TRM protocol along with verification of open variables. The Pennsylvania Evaluation Framework provides specific guidelines and requirements for evaluation procedures.

Sources

1) California Electronic Technical Reference Manual. "Low Pressure Sprinkler Nozzles (permanent)". Accessed December 2023. Weblink

2) Table 3-84 and Table 3-86 contain federal motor efficiency values by motor size and type. If existing motor nameplate data is not available, these tables will be used to establish motor efficiencies. The CF was only estimated for agricultural applications and was determined by using the following formula $CF = \frac{\Delta kW\ savings\ per\ acre}{\frac{\Delta kW}{yr}\ savings\ per\ acre}$.

3) Pennsylvania census data was used to estimate an average ΔkW savings/acre and ΔkWh/yr/savings/acre value. Kanagy, P. "Farm and Ranch Irrigation". Pennsylvania Agricultural Statistics 2009-2010. Weblink

4) Dieter, C., Maupin, M., Caldwell, R., Harris, M., Ivahnenko, T., Lovelace, J., Barber, N., and Linsey, K. (2018). "Estimated use of water in the United States in 2015". U.S. Geological Survey Circular 1441. Weblink