TENNESSEE VALLEY AUTHORITY

Technical Resource Manual Appendix

Version 5.0

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1 DEFINITIONS

AC	Air conditioning
ACH	Air changes per hour
AHRI	Air Conditioning, Heating and Refrigeration Institute
Annual Energy Savings	Electricity savings in kWh over the span of a year due to a measure
ANSI	American National Standards Institute
ASH	Anti-sweat heater
ASTM	American Society for Testing and Materials
AV	Adjusted volume
Baseline	Refers to the Baseline building model; this is the reference energy model that the measure savings are determined from.
BEF	ballast efficiency factor
BTU	British thermal unit
Btuh	BTU per hour
Building Prototype	Refers to the 'average' building stock of the TVA region. Building prototype models were used as baseline reference models to calculate measure savings, and to calculate NWS peak load factors.
CADMAC/CALMAC	California DSM Measurement Advisory Council
CCFL	Cold-cathode compact fluorescent lamp
CDF	coincident diversity factor
CEC	California Energy Commission
CEE	Consortium for Energy Efficiency
Central District	Describes the cities or climate zones within TVA that are located in the central time zone (CPT). These districts are Huntsville, Memphis, and Nashville.
Central Prevailing Time (CPT)	Time zone in U.S. that is 5 hours behind the Coordinated Universal Time. This is the time zone that TVA savings are analyzed in.
CFL	Compact fluorescent lamp
cfm	Cubic feet per minute
Coincident	Refers to whether hourly electric load coincides with the peak times of the system.
COP	Coefficient of performance. The COP of a heat pump is the ratio of the change in heat at the "output" (the heat reservoir of interest) to the supplied work.
CPUC	California Public Utilities Commission
CRI	Color rendering index
Custom (Calculated)	Refers to measures that require full-detailed analysis. Examples of these types of measures are EMS installation, process improvements, etc.
Customer	Refers to the level at which savings are determined. Customer-level savings do not include savings (or costs) associated with transmission and/or distribution.
CZ	Climate zone; synonymous with weather zone (WZ)
Deemed	Refers to prescriptive measures whose savings are claimed based on the work paper assumptions, measure specifications, and methodology.
DEER	Database for Energy Efficiency Resources
degF	Degrees Fahrenheit
Demand Reduction	Difference between electric loads; usually between the electric load of the baseline and measure units.
DOE	(United States) Department of Energy

Eastern District	Describes the cities or climate zones within TVA that are located in the eastern time zone. These districts are Chattanooga and Knoxville.
Eastern Time Zone	Time zone in U.S. that is four hours behind the Coordinated Universal Time
ECM	Electronically commutated motor
EEM	Energy-efficiency measure; a physical device or consumer practice that is implemented to realize electricity savings
EER	Energy-Efficiency Ratio (EER) is a measure of the instantaneous energy-efficiency of cooling equipment. EER is the steady-state rate of heat energy removal (e.g., cooling capacity) by the equipment in Btuh divided by the steady-state rate of energy input to the equipment in watts. This ratio is expressed in Btuh per watt (Btuh/watt). EER is based on tests performed in accordance with AHRI 210/240 (formerly ARI Standard 210/240).
EF	Energy factor
EPAct	Energy Policy Act, Department of Energy
eQuest	Graphical User Interface utilizing DOE-2 modeling software. This program was used to model prototype building models and measure simulations.
EUL	Effective useful life
ft	Foot, unit of distance
gpm	Gallons per minute
HID	High-intensity discharge
HO	High output
HP	Horsepower
hr	Hour, unit of time
HSPF	Heating Seasonal Performance Factor (HSPF) is a measure of a heat pump's energy-efficiency over one heating season. It represents the total heating output of a heat pump (including supplementary electric heat) during the normal heating season (in Btu) as compared to the total electricity consumed (in watt-hours) during the same period. HSPF is based on tests performed in accordance with AHRI 210/240 (formerly ARI Standard 210/240).
HVAC	Heating, ventilation, and air conditioning
Implementer	Refers to program or project implementation
IPLV	Integrated part load value
ipm	Images per minute
IPMVP	International Performance Measurement and Verification Protocol - Documentation to assist in guiding M&V protocol
kBtuh	1,000 Btu per hour = 1,000 Btuh
kW	Kilowatt
kWh	Kilowatt hour
lb	Pound (Used as unit of mass)
LED	Light emitting diode
Load Shape	A set of hourly electric loads (usually in kW) that usually describe the daily usage of certain equipment or practices. When the hourly kW load is plotted against hours during the day, the kW load creates a 'shape' of relative load magnitude over those 24 hours.
Low-E	Low emissivity
M&V	Measurement and verification; usually refers to evaluation protocol
Measure	Short for Energy-Efficiency Measure (EEM), a physical device or consumer

	practice that is implemented to realize electricity savings.
Measurement	Documentation of the effects of application of a measure, or EEM.
MEF	Modified energy factor
MF	Multifamily
MH	Metal halide or mobile home (depending on context)
MLPW	Mean lumens per Watt
NAECA	National Appliance Energy Conservation Act
NEMA	The National Electrical Manufacturers Association
NWS	Non-weather-sensitive. The value is independent of the climate and will not change, regardless of which weather-zone is used during building simulation.
ODP	Open drip proof
OSA	Outside Air. Usually refers to a ratio or temperature value, like OSA Temp, Supply-OSA ratio.
Peak Demand	Electric load, usually expressed in kW, that coincides with the peak generation times of the utility or authority
PG&E	Pacific Gas and Electric Company
Prescriptive	Refers to measures that have prescribed specifications, assumptions, methodology, and savings calculations. Typically, the incentive amount is also prescribed per predefined unit
Project	Typically refers to a measure or a set of measures that is part of an application.
PTAC	Package-terminal air conditioners
PTHP	Package-terminal heat pumps
RASS	Residential Appliance Saturation Study
RPM	Revolutions per minute
RUL	Remaining useful life
SCE	Southern California Edison Company
SEER	Seasonal Energy-Efficiency Ratio (SEER) is a measure of equipment energy-efficiency over the cooling season. It represents the total cooling of a central air conditioner or heat pump (in Btu) during the normal cooling season as compared to the total electric energy input (in watt-hours) consumed during the same period. SEER is based on tests performed in accordance with AHRI 210/240 (formerly ARI Standard 210/240).
sf	Square feet. 'sq ft' is also used. Note capitalized 'SF' is another abbreviation
SF	Single-family
SHGC	Solar heat gain coefficient
SIM Report	An in-depth report of the eQuest model results. The file extension is .SIM
sq. ft.	Square feet
TEFC	Totally enclosed fan cooled
Therm	(thm) non-SI unit equal to 100,000 BTU
TMY	Typical Meteorological Year. A set of data describing average climate patterns depending on geographical area.
tombstones	Refer to the lamp holders or sockets that linear fluorescents are held in a fixture
TV	Television

TVA	Tennessee Valley Authority
UEC	Unit energy consumption
VFD	Variable-frequency drives; synonymous with VSD
VSD	Variable-speed drives; synonymous with VFD
W	Watt
WS	Weather sensitive. The value is dependent on the climate and will change depending on which weather-zone is used during building simulation.
WZ	Weather zone; synonymous with climate zone (CZ)

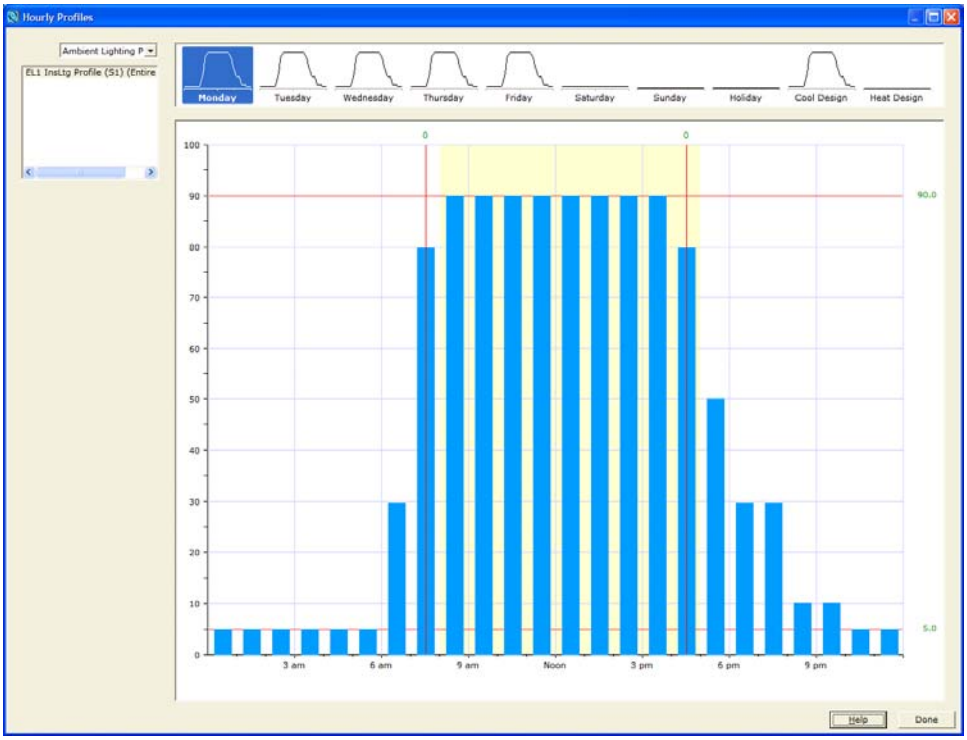
2 CALCULATING LIGHTING FACTORS

To calculate the lighting factors, the following steps are taken. Please refer to Lighting CDF 2016.xls and Lighting Interactive Effects_2016.xls for the analysis. The lighting factors include the coincidence diversity factor (CDF), energy interactive factor (EIF), and demand interactive factor (DIF). These values are extracted from output data of the building prototype model results and are specified by building type and weather zone. The models developed are described in the Technical Resource Manual version 5.0 Section 2. They are highly dependent on user input to the prototypes. The prototypes are based on the California Database for Energy Efficiency Resources (DEER).[1] The models developed for DEER are based on California studies such as the California Commercial End Use Survey (CEUS), Residential Appliance Saturation Survey (RASS), evaluation reports, and more. For TVA specific data, studies must be conducted in the TVA region.

2.1 Coincidence Diversity Factor

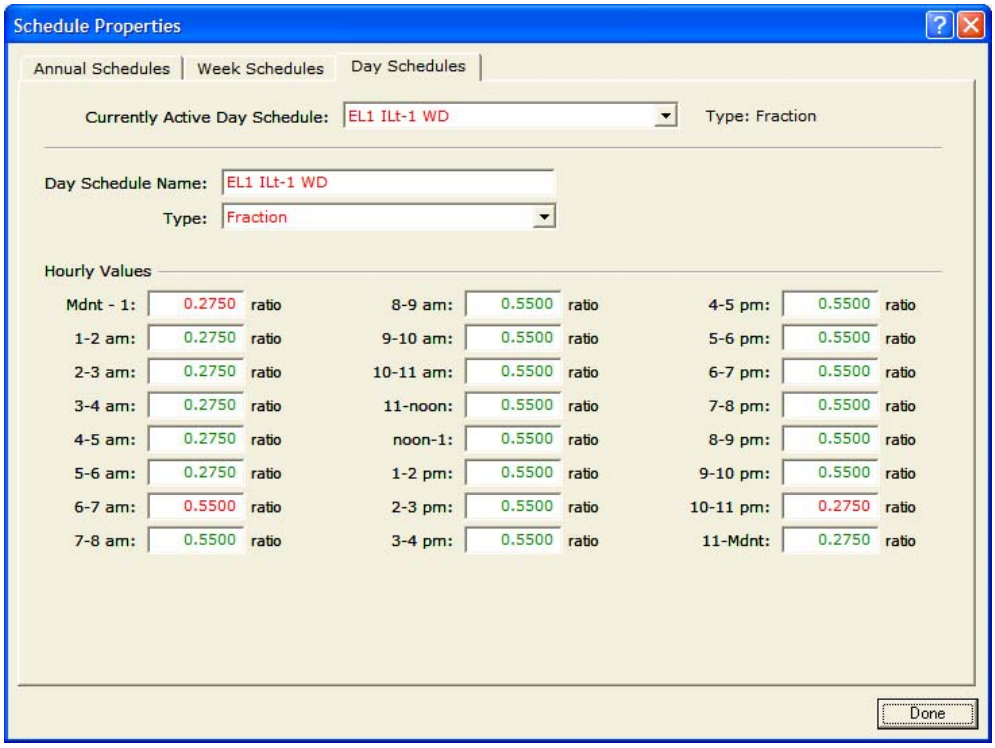
Coincidence diversity factor (CDF) indicates the fraction of fixtures that are typically operating during the peak period. These inputs include the fraction of total active lighting that is on per hour and its operating schedule. The bases for these prototype lighting schedules are from California DEER schedules. For TVA specific lighting schedules, a lighting metering study must be conducted. Below are two examples of schedules for lighting found in the prototypes.

Figure 1. Operating Schedule in Wizard Model



[1] www.deeresources.com

Figure 2. Operating Schedule in Detailed Mode



To calculate each factor, the following steps are taken (Lighting CDF.xls snapshot shown in Table 1 below):

1. Determine the total lighting load for the modeled building.[2]

   Connected lighting load (kW) = Lighting power density per zone (W/sf) x Square foot per zone (sf) x kW/1,000W

2. Extract the lighting end-use annual consumption for the prototype (independent of weather zone).
3. Determine the non-weather-sensitive summer and winter peak load shape factors (LSF) for lighting
4. Calculate the peak CDF.

   CDF = (Total annual lighting kWh x LSF) / Connected lighting load

Table 1. Sample CDF Calculation

Building Type	Time Zone	Footprint (ft2)	LPD (W/ft2)	Total Ltg (kWh)	Summer LSF	Winter LSF	Connected Load (kW)	Summer CDF	Winter CDF
Assembly	Eastern	34,000	1.45	210,774	0.0002095	0.0001194	49.3	0.90	0.51
Assembly	Central	34,000	1.45	210,774	0.0002064	0.0001113	49.3	0.88	0.48

[2] In the Lighting CDF.xls analysis, the weighted average lighting power density (LPD) and the total footprint square footage is used instead of calculating per zone.

Small Office Building	Eastern	10,000	1.38	38,667	0.0001543	0.0002460	13.84	0.43	0.69
Small Office Building	Central	10,000	1.38	38,667	0.0002112	0.0001735	13.84	0.59	0.48
Large Office Building	Eastern	175,000	1.8	879,439	0.0001543	0.0002460	315	0.43	0.69
Large Office Building	Central	175,000	1.8	879,439	0.0002112	0.0001735	315	0.59	0.48

Table 2 provides the summarized results of the analysis by building type and by eastern (Chattanooga and Knoxville) and central (Memphis, Nashville, and Huntsville) weather zones.[3] The lighting peak load shape factors used in the analysis are dependent on building and weather zone (weather sensitive); they use each weather zone's top ten hottest and coldest hours to determine which hours' load shape factors will average in to the peak factor.

Table 2. Lighting Peak Coincidence Factors

Building Type	Central		Eastern	
	Summer	Winter	Summer	Winter
Assembly	0.500	0.270	0.510	0.290
Education - College/Secondary	0.461	0.551	0.383	0.674
Education - Primary School	0.240	0.160	0.220	0.340
Education – University	0.592	0.548	0.530	0.617
Grocery (Large)	0.906	0.811	0.895	0.894
Health/Medical	0.679	0.652	0.618	0.755
Lodging – Hotel	0.170	0.240	0.260	0.240
Lodging – Motel	0.140	0.200	0.210	0.200
Manufacturing - Bio/Tech	0.758	0.794	0.758	0.794
Manufacturing - Light Industrial	0.758	0.794	0.758	0.794
Municipal	0.547	0.429	0.452	0.602
Office – Large	0.687	0.589	0.586	0.720
Office – Small	0.672	0.576	0.573	0.704
Other	0.700	0.488	0.655	0.607
Refrigerated Warehouse	0.560	0.050	0.460	0.390
Religious	0.349	0.324	0.321	0.488
Restaurant - Fast-Food	0.650	0.580	0.650	0.640
Restaurant - Sit-Down	0.770	0.120	0.770	0.220
Retail - Mall Department Store	0.720	0.300	0.680	0.570

[3] Differentiation is required for eastern and central weather zones. The buildings have the same operating schedule across zones; however, the CDF is calculated based on the peak period which occurs for the summer during 2-5 pm central prevailing time. Therefore, if the schedule shows 40% of load from the hour of 5 to 6, then this hour is part of the CDF (peak) for eastern weather zones, but not considered for the central weather zones.

Building Type	Central		Eastern	
	Summer	Winter	Summer	Winter
Retail - Single-Story, Large	0.770	0.290	0.770	0.580
Retail – Small	0.990	0.390	0.880	0.810
Service	0.862	0.454	0.759	0.703
Storage – Air Conditioned	0.860	0.150	0.710	0.650
Storage - Unconditioned	1.000	0.330	0.790	0.650
Industrial/Warehouse 1-shiftOther	0.7580	0.794	0.758	0.794
Industrial/Warehouse 2-shiftReligious	0.831	0.977	0.831	0.977
Industrial/Warehouse 3-shiftService	0.993	0.999	0.993	0.999

2.2 Non-residential HVAC Interactive Effects

HVAC interactive effects (EIF and DIF) are building type and weather zone dependent and can be used for quantifying lighting savings. These values are different for annual energy usage and peak kW load and are extracted from the building prototypes; they are highly dependent on the building's HVAC type. The vintage as well as the efficiency of the HVAC equipment influences the overall interactive effect; therefore, the prototype assumptions (efficiencies of HVAC systems) dictate the calculated interactive effect. If the lighting is not in conditioned space, the HVAC interaction effect is 1.0. The calculations for the interactive effect are shown in the following steps (Lighting Interactive Effects_2016.xls snapshot shown in the following table).

- Using the prototype building models, make an energy-efficiency measure (EEM) by reducing lighting power density (LPD) by 20% for each zone in the eQuest wizard mode.
- Run measure and extract the total end-use kWh and weather-sensitive[4] peak load shape factor (LSF) for lighting and whole building from the prototype and measure hourly output data..
- Calculate the interactive effect:

Energy Interactive Factor (EIF) = [(Prototype Whole-Building End-Use kWh – Measure Whole-Building End-Use kWh) / (Prototype Lighting End-Use kWh – Measure Lighting End-Use kWh)]

Demand Interactive Factor (DIF) = [(Prototype Whole-Building End-Use kWh – Measure Whole-Building End-Use kWh) x Whole-Building LSF] / [(Prototype Lighting End-Use kWh – Measure Lighting End-Use kWh) x Lighting LSF]

Table 3. Sample HVAC Interactive Factor Calculation

Weather Zone	Building Type	Fuel Type	Run Type	Lighting EU kWh	Building EU kWh	Ltg Sum LSF	Ltg Winter LSF	Building Summer LSF	Building Winter LSF
Chattanooga	Assembly	Elec	Prototype	210,774	501,418	0.000209	0.000118	0.000327	0.000102
Chattanooga	Assembly	Elec	LPD Measure	168,619	452,899	0.000209	0.000118	0.000335	0.000104
Lighting Summer Peak	Lighting Winter Peak	Building Summer Peak kW	Building Winter Peak kW	EIF	Summer DIF	Winter DIF			

[4] Weather sensitive peak load shape factor refers to using the top ten hottest and coldest hours average instead of the throughout the peak period.

kW	kW					
44	25	164	51			
35	20	152	47	1.151	1.364	0.841

The following table provides the summarized results of the analysis by building type, weather zone, and HVAC type.

Table 4. Lighting Energy Interactive Effects

Building Type	Chattanooga	Huntsville	Knoxville	Memphis	Nashville
Assembly	1.208	1.200	1.177	1.220	1.186
Education – College/Secondary	1.291	1.280	1.255	1.289	1.259
Education – Primary School	1.231	1.231	1.195	1.251	1.212
Education – University	1.358	1.364	1.338	1.351	1.332
Grocery (Large)	1.264	1.267	1.250	1.312	1.284
Grocery (Small)	1.264	1.267	1.250	1.312	1.284
Health/Medical	1.323	1.316	1.315	1.333	1.319
Lodging – Hotel	1.118	1.070	1.048	1.116	1.096
Lodging – Motel	0.985	0.982	0.931	1.021	0.966
Manufacturing – Bio/Tech	1.000	1.000	1.000	1.000	1.000
Manufacturing – Lighting Industrial	1.000	1.000	1.000	1.000	1.000
Municipal	1.083	1.075	1.083	1.083	1.075
Office – Large	1.394	1.378	1.390	1.415	1.409
Office – Small	1.109	1.106	1.077	1.140	1.097
Other	1.038	1.033	1.038	1.038	1.032
Refrigerated Warehouse	1.625	1.626	1.620	1.634	1.634
Religious	1.146	1.134	1.146	1.146	1.135
Restaurant – Fast-Food	1.192	1.184	1.165	1.201	1.174
Restaurant – Sit-Down	1.235	1.216	1.195	1.237	1.200
Retail – Mall Department Store	1.474	1.424	1.423	1.408	1.388
Retail – Single-Story, Large	1.29	1.278	1.260	1.292	1.269
Retail-Small	1.191	1.179	1.163	1.204	1.172
Service	1.109	1.101	1.109	1.109	1.099
Storage – Conditioned	1.191	1.179	1.163	1.204	1.172
Storage – Unconditioned	1.000	1.000	1.000	1.000	1.000
Industrial/ Warehouse 1-shift	1.000	1.000	1.000	1.000	1.000
Industrial/ Warehouse 2-shift	1.000	1.000	1.000	1.000	1.000
Industrial/Warehouse 3-shift	1.000	1.000	1.000	1.000	1.000

Table 5. Lighting Summer Demand Interactive Effects

Building Type	Chattanooga	Huntsville	Knoxville	Memphis	Nashville

Building Type	Chattanooga	Huntsville	Knoxville	Memphis	Nashville
Assembly	1.379	1.375	1.369	1.372	1.371
Education – College/Secondary	1.446	1.434	1.414	1.399	1.388
Education – Primary School	1.416	1.416	1.374	1.439	1.394
Education – University	1.469	1.419	1.374	1.439	1.415
Grocery (Large)	1.375	1.350	1.356	1.356	1.362
Grocery (Small)	1.375	1.350	1.356	1.356	1.362
Health/Medical	1.378	1.364	1.361	1.371	1.371
Lodging – Hotel	1.367	1.403	1.342	1.418	1.497
Lodging – Motel	1.326	1.382	1.321	1.380	1.387
Manufacturing – Bio/Tech	1.000	1.000	1.000	1.000	1.000
Manufacturing – Lighting Industrial	1.000	1.000	1.000	1.000	1.000
Municipal	1.163	1.163	1.163	1.163	1.163
Office – Large	1.564	1.475	1.564	1.486	1.484
Office – Small	1.419	1.406	1.401	1.406	1.403
Other	1.087	1.087	1.087	1.087	1.087
Refrigerated Warehouse	1.711	1.712	1.705	1.720	1.720
Religious	1.273	1.273	1.273	1.273	1.273
Restaurant – Fast-Food	1.362	1.358	1.350	1.365	1.356
Restaurant – Sit-Down	1.351	1.264	1.346	1.349	1.348
Retail – Mall Department Store	1.503	1.446	1.473	1.443	1.447
Retail – Single-Story, Large	1.346	1.340	1.312	1.340	1.339
Retail-Small	1.353	1.315	1.350	1.330	1.328
Service	1.199	1.199	1.199	1.199	1.199
Storage – Conditioned	1.353	1.315	1.350	1.330	1.328
Storage – Unconditioned	1.000	1.000	1.000	1.000	1.000
Industrial/ Warehouse 1-shift	1.000	1.000	1.000	1.000	1.000
Industrial/ Warehouse 2-shift	1.000	1.000	1.000	1.000	1.000
Industrial/Warehouse 3-shift	1.000	1.000	1.000	1.000	1.000

The EIF and DIF values can quickly describe the interaction between the lighting measure and HVAC energy use; below are the simplified EIF/DIF formulas and explanation of their values (Note that the bullet explanations below extend to both EIF and DIF values):

$$\text{EIF} = \frac{\Delta\text{Whole Building kWh}}{\Delta\text{Lighting kWh}}$$

$$\text{DIF} = \frac{\Delta\text{Whole Building Peak kW}}{\Delta\text{Lighting Peak kW}}$$

- EIF < 0 → ΔWholeBuildingkWh is negative. The lighting reduction has caused a negative savings impact; the HVAC system has to consume more energy than the lighting reduction has saved. This

case would only be seen where the internal heat gain from the lighting during the winter offsets the heating energy needed from the HVAC more than the cooling energy needed from the HVAC offsets the internal heat gain from the lighting during the summer. For winter DIF, this could be significant especially for electric heating systems.

- $0 < EIF < 1 \rightarrow \Delta WholeBuildingkWh < \Delta LightingkWh$. The lighting reduction has caused a negative HVAC impact, but still provides net savings; the HVAC system has to consume more energy but the savings from lighting reduction offsets this increase. This also impacts the winter DIF.
- $EIF > 1 \rightarrow \Delta WholeBuildingkWh > \Delta LightingkWh$. The lighting reduction has caused a positive HVAC impact, and thus positive net savings; the HVAC system consumes less energy because of the lighting reduction so net savings are from the lighting reduction and from reduction in HVAC energy consumption. Summer DIF is typically greater than 1 for the same reason.

Other considerations should also be evaluated and realized when using these values:

- The factors are dependent on the type of lighting fixture, such as, if the fixture is recessed or not.
- Interactive effects can be greater than 2 since the HVAC (or refrigeration system) load has been reduced which could affect compressor, ventilation, and pumping usage.

3 CALCULATING NON-RESIDENTIAL HVAC FACTORS

This section is intended to provide background knowledge on the method for calculating the equivalent full-load hours (EFLH) and coincident diversity factors (CDF) of an air-conditioning unit or heat pump. The EFLCH and EFLHH (equivalent full-load cooling/heating hours) refers to the number of hours the air-conditioner or heat pump would be running at full load based on the conditions. The CDF describes the fraction of the air-conditioner or heat pump's full load that is expected to be running during peak periods (or the equivalent of the fraction of the population of air conditioners or heat pumps operating during the peak period). EFLH and CDF values were calculated from the TVA HVAC baseline and measure building simulation outputs based on the five weather zones of TVA. These values can then later be used to estimate energy savings using just the change in HVAC equipment efficiency. This section will demonstrate how the EFLH and CDF values were calculated and how they can be applied to estimate energy and peak-demand savings.

3.1 Equivalent Full-Load Hours (EFLH)

EFLH are usually categorized by weather zone and building type. Each building has its own unique cooling and heating load, schedule, and thus the amount of cooling or heating hours for properly sized HVAC equipment will vary. Many studies have been conducted by California IOUs that present conflicting ranges of EFLH values which demonstrates the delicate nature of EFLH accuracy, and the importance of properly modeled buildings or regional HVAC metering studies.[5]

The following procedure was used to calculate ELFCH and EFLHH of HVAC equipment:

- DOE-2 eQuest building prototype models for the TVA region were simulated for TVA's five different weather zones and for the various HVAC measures. The hourly results of the energy consumption of the buildings were output in a spreadsheet format.
- The HVAC equipment's annual energy consumption in kWh, as well as, the buildings cooling load (and heating load for heat pumps) were collected from these output files.[6] The rated efficiency of the HVAC equipment (SEER, EER, HSPF, etc.) was also recorded and converted in to kW/ton, using the following formulas:[7]

$$EER = (SEER + 1.4) \times 0.778$$

$$kW/ton = \frac{12}{EER}$$

$$HSPF = (3.2 \times COP) - 2.4$$

$$kW/ton = \frac{12}{COP \times 3.412}$$

The building cooling and heating loads were output in units of kBtuh. The following formula was used to convert to tons of refrigeration:

[5] 2004/2005 Statewide express efficiency and Upstream HVAC Program Impact Evaluation (page 5-7 to 5-21), CALMAC Study ID# PGE0272.01, prepared for the California Public Utilities Commission and California Investor Owned Utilities, 2008.

[6] The cooling and heating loads were collected from the SS-A or SS-D report in the SIM file.

[7] SEER to EER conversion is from ASHRAE Appendix G (and used within DOE 2.2). HSPF to COP conversion is from the residential California Title 24 Alternate Calculation Manual (ACM), equation R4-33 (2005 and 2008).

$$\text{Cooling/Heating Load (Tons)} = \frac{\text{Peak Cooling/Heating Load (kBtuh)}}{12\ \text{kBtuh}/\text{ton}}$$

- EFLHs are calculated using the HVAC equipment's annual cooling and heating energy consumption in kWh, efficiency in kW/ton, and the building oversized cooling/heating load in tons:[8]

$$\text{EFLCH (Hours)} = \frac{\text{Annual Cooling Energy (kWh)}}{\text{HVAC Efficiency (kW/ton)} \times \text{Rated Cooling Load (tons)}}$$

$$\text{EFLHH (Hours)} = \frac{\text{Annual Heating Energy (kWh)}}{\text{HVAC Efficiency (kW/ton)} \times \text{Rated Heating Load (tons)}}$$

For buildings where they have more than one type of cooling and/or heating system (for example, a DX system for one zone and a chiller for the other zones), the energy end-use consumption for cooling and/or heating were aggregated with other HVAC equipment, the EFLH are calculated by using the differences between baseline and measure energy consumptions and efficiencies. The annual cooling/heating energy savings in kWh, non-coincident demand reduction in kW/ton, and the building cooling/heating load in tons are used to calculate the EFLH instead. This method was used for the Grocery, Hotel, High School/College, Hospital, and Refrigerated Warehouse models because of their mixed HVAC systems. The following formula shows this method:

$$\text{EFLCH (Hours)} = \frac{\text{Cooling Energy Savings (kWh)}}{\text{Demand Reduction (kW/ton)} \times \text{Rated Cooling Load (tons)}}$$

$$\text{EFLHH (Hours)} = \frac{\text{Heating Energy Savings (kWh)}}{\text{Demand Reduction (kW/ton)} \times \text{Rated Heating Load (tons)}}$$

The following table lists the EFLCH and EFLHH for an air-conditioner or heat pump based on building type and weather zone.

Table 6. Non-residential Equivalent Full-Load Hours (Cooling and Heating)

Building Type	Weather Zone	EFLCH	EFLHH
Assembly	Chattanooga	927	423
	Huntsville	1,072	488
	Knoxville	841	566
	Memphis	1,056	351
	Nashville	979	554
Fast Food Restaurant	Chattanooga	1,368	473
	Huntsville	1,366	424
	Knoxville	1,168	576
	Memphis	1,455	400

[8] Oversized refers to calculating the system rated tons that is installed and not the actual building load. The ASHRAE rule of thumb is 15% for cooling and 25% for heating.

Building Type	Weather Zone	EFLCH	EFLHH
	Nashville	1,376	537
Full Service Restaurant	Chattanooga	1,141	324
	Huntsville	1,150	352
	Knoxville	1,056	520
	Memphis	1,260	297
	Nashville	1,166	484
Grocery	Chattanooga	664	1,491
	Huntsville	714	1,220
	Knoxville	551	1,554
	Memphis	891	1,238
	Nashville	766	1,410
Hospital	Chattanooga	1,660	na
	Huntsville	1,782	na
	Knoxville	1,569	na
	Memphis	1,922	na
	Nashville	1,767	na
Hotel	Chattanooga	1,528	na
	Huntsville	1,537	na
	Knoxville	1,417	na
	Memphis	1,731	na
	Nashville	1,587	na
High School/College	Chattanooga	1,042	311
	Huntsville	1,089	198
	Knoxville	1,001	295
	Memphis	1,137	229
	Nashville	1,135	277
Large Retail	Chattanooga	1,280	213
	Huntsville	1,356	173
	Knoxville	1,147	267
	Memphis	1,418	156
	Nashville	1,337	221
Primary School	Chattanooga	477	307
	Huntsville	510	322
	Knoxville	465	441
	Memphis	555	322
	Nashville	549	372
Refrigerated Warehouse	Chattanooga	810	336
	Huntsville	828	355
	Knoxville	684	440
	Memphis	867	327
	Nashville	823	406

Building Type	Weather Zone	EFLCH	EFLHH
Small Office	Chattanooga	733	530
	Huntsville	751	586
	Knoxville	657	741
	Memphis	826	579
	Nashville	769	678
Small Retail	Chattanooga	947	436
	Huntsville	909	411
	Knoxville	846	629
	Memphis	1,048	364
	Nashville	963	559

3.2 Non-residential Coincident Demand Factor

Coincident demand factors describe the fractional full load of a system during peak periods and can be used to determine peak-demand savings when the efficiency and rated capacity of a HVAC system are known. CDF in this manual are dependent on building, weather zone, HVAC efficiency, and building characteristics specific to the HVAC operating schedule.

The following procedure was used to calculate coincident demand factors:

- DOE-2 eQuest non-residential building prototype models for the TVA region were simulated for TVA's five different weather zones and for the various HVAC measures. The hourly results of the energy consumption of the buildings were output in a spreadsheet format.
- Weather-sensitive, peak-load shape factors (LSF) were developed from the simulation output files and TMY weather data specific to the TVA region (see Manual, section 2.4 for description of calculating load shape factors). They are an average of the normalized hourly demand of the 10 hottest or coldest hours of the year that coincide with TVA summer or winter peak periods, respectively.
- Normalized summer and winter peak demand values (in kW) were calculated using the LSF and their associated annual energy use (kWh):

$$\text{Summer Peak kW} = \text{Cooling Energy Use (kWh)} \times \text{Summer Cooling LSF}$$

$$\text{Winter Peak kW} = \text{Heating Energy Use (kWh)} \times \text{Winter Heating LSF}$$

- Full-load electric demand (kW) of the HVAC equipment was determined using the peak cooling/heating load of the building (tons)[9] and the efficiency of the equipment (converted to kW/ton using the conversions under (2) of the EFLH section:

[9] Oversized refers to calculating the system rated tons that is installed and not the actual building load. The ASHRAE rule of thumb is 15% for cooling and 25% for heating. The rated capacity assumed for residential is provided in the Technical Resource Manual.

$$\text{Summer Full Load kW} = \text{Cooling Efficiency (kW/ton)} \times \text{Rated Cooling Load (tons)}$$

$$\text{Winter Full Load kW} = \text{Heating Efficiency (kW/ton)} \times \text{Rated Heating Load (tons)}$$

- The summer and/or winter CDF were calculated using the summer and/or winter peak demand values from (3) and the cooling and/or heating full load kW from (4):

$$\text{Summer CDF} = \frac{\text{Summer Peak kW}}{\text{Summer Full Load kW}}$$

$$\text{Winter CDF} = \frac{\text{Winter Peak kW}}{\text{Winter Full Load kW}}$$

Table 7. Non-residential Coincident Diversity Factor (Summer and Winter)

Building Type	Weather Zone	Summer	Winter
Assembly	Chattanooga	0.664	0.224
	Huntsville	0.742	0.165
	Knoxville	0.606	0.289
	Memphis	0.685	0.088
	Nashville	0.665	0.192
Fast Food Restaurant	Chattanooga	0.691	0.969
	Huntsville	0.650	1.463
	Knoxville	0.595	1.470
	Memphis	0.670	1.053
	Nashville	0.653	1.779
Full Service Restaurant	Chattanooga	0.662	0.544
	Huntsville	0.648	0.934
	Knoxville	0.609	1.150
	Memphis	0.674	0.489
	Nashville	0.655	1.257
Grocery	Chattanooga	0.779	0.704
	Huntsville	0.812	0.386
	Knoxville	0.664	0.470
	Memphis	0.843	0.634
	Nashville	0.826	0.404
Hospital	Chattanooga	0.780	
	Huntsville	0.791	
	Knoxville	0.725	
	Memphis	0.819	
	Nashville	0.804	
Hotel	Chattanooga	0.697	
	Huntsville	0.655	
	Knoxville	0.669	
	Memphis	0.721	

Building Type	Weather Zone	Summer	Winter
	Nashville	0.694	
High School/College	Chattanooga	0.587	0.527
	Huntsville	0.576	0.239
	Knoxville	0.554	0.259
	Memphis	0.705	0.441
	Nashville	0.700	0.269
Large Retail	Chattanooga	0.680	0.070
	Huntsville	0.684	0.000
	Knoxville	0.606	0.129
	Memphis	0.695	0.000
	Nashville	0.690	0.035
Primary School	Chattanooga	0.190	0.543
	Huntsville	0.335	0.366
	Knoxville	0.178	0.810
	Memphis	0.237	0.289
	Nashville	0.197	0.436
Refrigerated Warehouse	Chattanooga	0.577	0.613
	Huntsville	0.557	0.298
	Knoxville	0.518	0.458
	Memphis	0.736	0.434
	Nashville	0.720	0.340
Small Office	Chattanooga	0.518	0.989
	Huntsville	0.616	0.952
	Knoxville	0.429	1.426
	Memphis	0.669	0.817
	Nashville	0.678	1.159
Small Retail	Chattanooga	0.658	0.295
	Huntsville	0.567	0.399
	Knoxville	0.598	0.424
	Memphis	0.688	0.223
	Nashville	0.663	0.477

There are some values in the above tables that are greater than 1.0 (for winter). These are from the buildings where electric heat pump is used and supplemental heat may be used (the auxiliary electric resistance heating of the heat pump). Since the CDF is calculated with the heating load in tons as the normalizing factor, the electric strip heat capacity is not considered in the ratio. Therefore, the winter peak coincidence factor is not relevant for these situations. An alternate must be calculated to account for electric resistance (strip) heat.

The weather-sensitive, peak-load shape factors are used. These are based on the top ten hottest and coldest hours during the respective peak period. In some cases, for certain building types and weather zones, these top ten hours catches the "extremes" in the models. DOE-2.2 models HVAC usage by modeling

the building load variations to reach the set point. In order to reach the set point, the HVAC is made to over-compensate (overheat or overcool). Therefore, in some of the outputs, it is believed that the top ten hours catches these extreme values which then show up in the savings.

4 EQUEST OUTPUT DESCRIPTIONS

This appendix provides descriptions of the end uses provided in eQuest hourly output file and of the SIM reports used in the manual.

4.1 Hourly Output

The hourly output file available via eQuest models includes a standard list of outputs. Many of these reported end-uses are used to post-process the measure savings, develop load shape factors, and other values used for the manual. To access the hourly output, the hourly results CSV file is generated by clicking the Hourly Results button at the top of BEPU or BEPS report. Thee hourly figures are in kWh (electricity) and MBtu (gas).

The summary description of the end uses on the hourly report is provided here, but is also available within eQuest user manuals.[10]

LIGHTS: Indoor overhead (ambient) lighting energy.

TASK LIGHTS: Indoor task lighting that cannot be controlled by daylighting controls.

MISC EQUIP: Indoor equipment energy which includes electric plug loads, process loads, and other indoor energy sources.

SPACE HEATING: Space heating by boilers, furnaces, heat-pumps, etc. Note that includes heat-pump energy use during heating mode only. This end use includes the impact of outdoor ventilation air, air-side economizers, fan heat, and pump heat in heating mode. It also includes heat pump condenser fan electric energy and boiler draft fan electric use.

SPACE COOLING: Space cooling by chillers and package DX systems. Note that this includes heat pump energy use during cooling mode only. This end use includes the impact of outdoor ventilation air, air-side economizers, fan heat and pump heat in cooling mode. It also includes DX condenser fan electric energy and desiccant cooling.

HEAT REJECT: Cooling towers and other heat rejection devices. Note that this includes heat rejection (tower) fan energy only. Condenser water pump energy is reported under PUMPS & AUX.

PUMPS & AUX: All circulation pumps and auxiliary power consumed by various components, for example, chilled water, condenser water, space heat hot water, domestic hot water, and including all pumps attached directly to loops or primary equipment.

Auxiliary power requirements include control panels, gas pilot lights, solution pumps, crankcase heaters, heat tracing on a pipe and others. In general, energy use is treated as auxiliary if it is incidental to the principal equipment, (e.g., draft fans on DHW heaters, heat-recovery pumps on electric generators, and cooling tower filet pump). Note that condenser water pump energy is reported under PUMPS & AUX. Boiler draft fan electric energy use is included under SPACE HEATING, not PUMPS & AUX.

[10] Source: eQuest Detailed Simulation Reports Summary – Reporting End Uses Categories. James J. Hirsch & Associates, February 2009.

VENT FANS: All ventilation fans, e.g., supply, return, and exhaust fans (does not include condenser fans or draft fans). Note that the condenser fan energy is reported under HEAT REJECT. Boiler draft fan electric is reported under SPACE HEATING.

REFRIG DISPLAY: Refrigerated display cases, and associated refrigeration systems.

HT PUMP SUPPLEM: Heat pump supplemental (electric strip heat when the temperature falls below 40°F).

DOMESTIC HOT WTR: Domestic hot water energy.

EXT USAGE: Energy usage exterior to building, such as exterior lighting (including parking lots and signage).

4.2 SIM Reports

The SIM (extension .sim) reports are produced when an eQuest model is generated. The reports provided the details of the results in many different formats. The reports provide information of the different systems by building zones. There are a handful of reports that are used to document the model outputs for calculating measure energy savings. The summary descriptions of these SIM reports are provided here, but are also available within eQuest user manuals.[11]

SS-D: Building HVAC Summary report. The loads reported are coil loads which include outside ventilation air, duct loss/gain, fan heat and economizer effects. SS-D reports provide the building total coil loads, i.e., unitary and built-up equipment.

SS-A: System Loads Summary report for each system. The loads reported are coil loads which include outside ventilation air, duct loss/gain, fan heat, and economizer effects. SS-A reports provide coil load only for one zone. An SS-A report is available for all zones in a modeled building.

BEPS: Building Energy Performance report. The BEPS report includes energy (by end use) across the building boundary.

BEPU: Building Utility Performance report. The BEPU report includes energy (by end-use) drawn or supplied across the building boundary. The BEPU report provides the same results found on the BEPS report. The only difference is the reporting units: BEPU uses conventional utility units (e.g., kWh, therms), while the BEPS report uses MBTU (Btu x 1,000,000).

[11] Source: Sec6-eQ-Sample-Output, JAMES.J HIRSCH & ASSOCIATES, February 2009.

5 EQUEST FILE DOCUMENTATION AND ARCHIVING

All of the eQuest building simulations have been organized and archived for easier storage and retrieval. We have included sets of files that constitute a complete eQuest building simulation. The following files are included in each simulation set:

- DOE-2 input file (*.inp). This file is generated by eQuest and interpreted by the DOE-2 engine that ultimately simulates the building model. This is the most important file of the set. Every simulation has its own .inp file, so for example, a baseline model that has 3 parametric measure runs will have four .inp files (3 measures and one baseline file) associated with that measure and model.
- eQuest project file (*.pd2). The file contains the front end graphical interface of the building model and is interpreted by eQuest. It contains the same input values that are contained within the .inp file, and can generate new .inp files when changes are made to a model. The .pd2 also houses the collection of simulation runs performed on the model; organization and editing of the EEM or parametric runs is performed through eQuest and saved in the .pd2 file.
- Hourly Results Output spreadsheet (.csv). These files contain the building simulation's annual electric and gas consumption categorized under the following end uses:
    - Interior Lighting
    - Task Lighting (lighting not controlled by day lighting controls)
    - Miscellaneous equipment
    - Heating end-use
    - Cooling end-use
    - Heat Rejection
    - Auxiliary equipment
    - Ventilation Fan
    - Refrigeration equipment
    - Supplemental heat pump
    - Domestic hot water (DHW)
    - Exterior to building equipment
    - Total building end-use

Each category has a set of 8,760 values that correspond to an hour block of time in the year and represent the kW load during that hour.

- eQUEST simulation reports file (*.SIM). This file contains all of the eQUEST simulation reports for the corresponding .inp file, or run. The available reports in the .SIM file depend on which reports the user decides to allow or suppress when selecting reports. Building load, component level HVAC, economic, scheduling, building shell, and many other detailed reports are available, many of which are in monthly, peak, and total summary form. This file will likely be used in conjunction with the hourly results output file to determine measure savings.

Building prototypes and all measure baseline and retrofit simulations have been given file names following a systematic structure. Naming structure and lists of all eQuest simulations archived and included with this manual can be found in eQuestFiles.xls.

6 USING BUILDING PROTOTYPES FOR MEASURE SAVINGS

This appendix provides guidelines to using the eQuest building prototypes (or models with the measures). These guidelines are intended to assist the user to make modifications to a building model to assess deemed measure savings or for custom measure savings analysis. This could occur for the following reasons:

- Building is on a different schedule than the one in the prototype, for example, some schools are on a year round schedule
- Building square footage is found to be different
- Measure baseline and/or retrofit efficiency, window U-value, etc. are different than the ones specified
- Use for custom measures such as energy management system installations where the building varies in square footage, schedule, HVAC equipment, etc. that can be modified to more closely resemble the actual building where the measure is to be installed. Additionally, the measure will require specific adjustments to building operation that can be made within a model.

The process for determining savings is summarized (details follow):

1. Choose the closest match from the representative prototype (or measure) models.
2. Include a scaling factor to the model such that the floor area building being analyzed matches the floor area of the model where the DOE-2 simulation will be performed.
3. Perform additional modifications to the model such that the baseline parameters in the model match the building under analysis. This prototype model becomes the 'baseline' model after these alterations. The 'baseline' should now match the existing building under analysis more closely.
4. Re-file the model under another name and change the appropriate parameters to match the proposed measure specification. This is the enhanced (or retrofit) model.
5. Run simulations for both baseline and enhanced models. The difference in energy use is the calculated savings.

The following presents the steps in greater detail.

Choose Prototype:

The building prototype models available are summarized in the table below (details can be found at TVA_ModelingAssumptions.xls).

Table 8. Commercial Building Prototypes and HVAC System Type

Building Type	HVAC System Type
Assembly	Packaged Single Zone HP or AC w/ gas furnace
Fast Food Restaurant	Packaged Single Zone HP or AC w/ gas furnace
Full Service Restaurant	Packaged Single Zone HP or AC w/ gas furnace
Grocery Store	Packaged Single Zone HP or AC w/ gas furnace
High School/College	Packaged Single Zone HP, 4 pipe fan coils with HW heat and packaged single zone AC w/gas furnace, or Standard VAV with HW reheat and packaged single zone AC w/gas furnace
Hospital	4-pipe fan coils with HW heat and packaged AC w/ gas furnace or heat pump
Hotel	Built-up VAV w/reheat (boiler and W/C central chiller), Packaged VAV

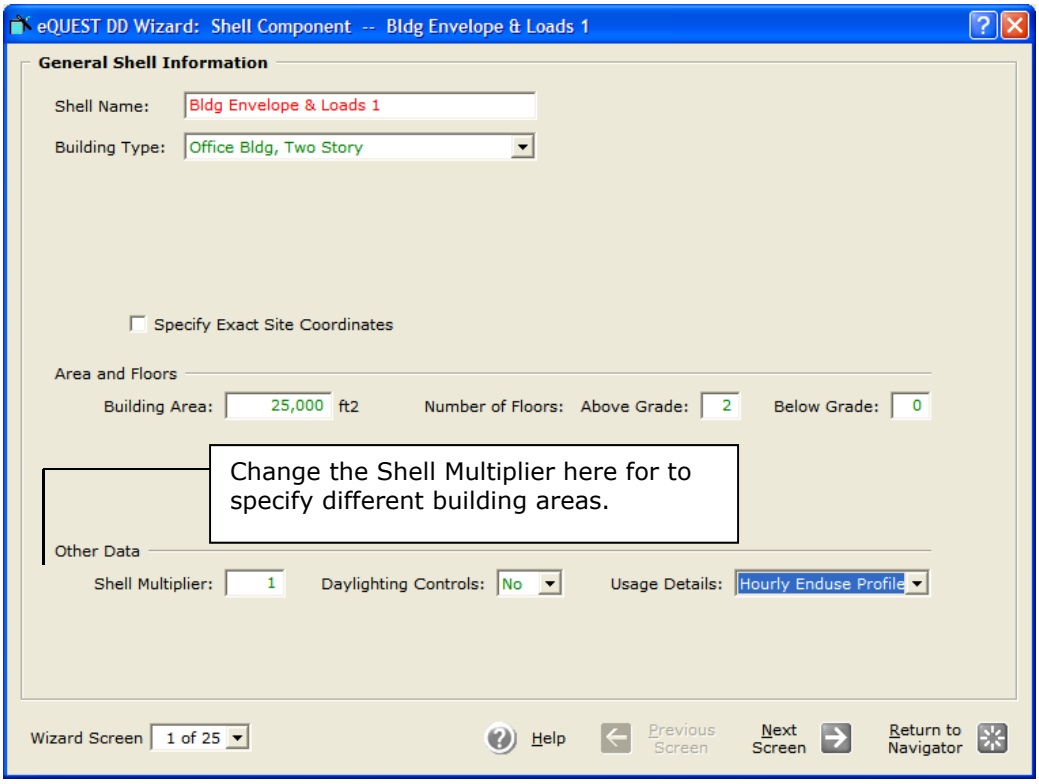
Building Type	HVAC System Type
	HW reheat and packaged single zone DX w/gas furnace, or Standard VAV with HW reheat and packaged single zone DX w/gas furnace[12]
Large Office	Built-up VAV w/reheat (boiler and W/C central chiller)
Large Big Box Retail	Packaged Single Zone HP or AC w/ gas furnace
Mall Department Store	Built-up VAV w/reheat (boiler and W/C central chiller)
Motel	PTAC with elec resist or PTHP
Primary School	Packaged Single Zone HP or AC w/ gas furnace
Refrigerated Warehouse	Packaged Single Zone HP or AC w/ gas furnace
Small Office	Packaged Single Zone HP or AC w/ gas furnace or PTAC with elec resist
Small Retail	Packaged Single Zone HP or AC w/ gas furnace
University	Built-up VAV w/reheat (boiler and W/C central chiller)
Unrefrigerated Warehouse	NA

Scale Prototype:

Obtain total building floor area and the floor area affected by the measures (they will be the same if the upgrade affects the entire building).

In the General Shell Information screen of eQuest, enter a "shell multiplier" (bottom left) such that the component area of the model will match the actual building area. For example, if the representative building area is 175,000 sqft, and the actual building under analysis is 200,000 sqft, the shell multiplier will be 1.14 (200/175=1.14). Do not directly change the floor area of the model on this screen. Such a change will cause other changes to ripple throughout that model that may result in errors during the model run.

[12] Guest room conditioning is 4-pipe, PTHP, and PTAC with electric resistance heating respectively.



Modify Prototype:

This document presents a basic outline of modeling procedure involved in modifying the prototype building-model in eQuest. There are three different ways to alter the model:

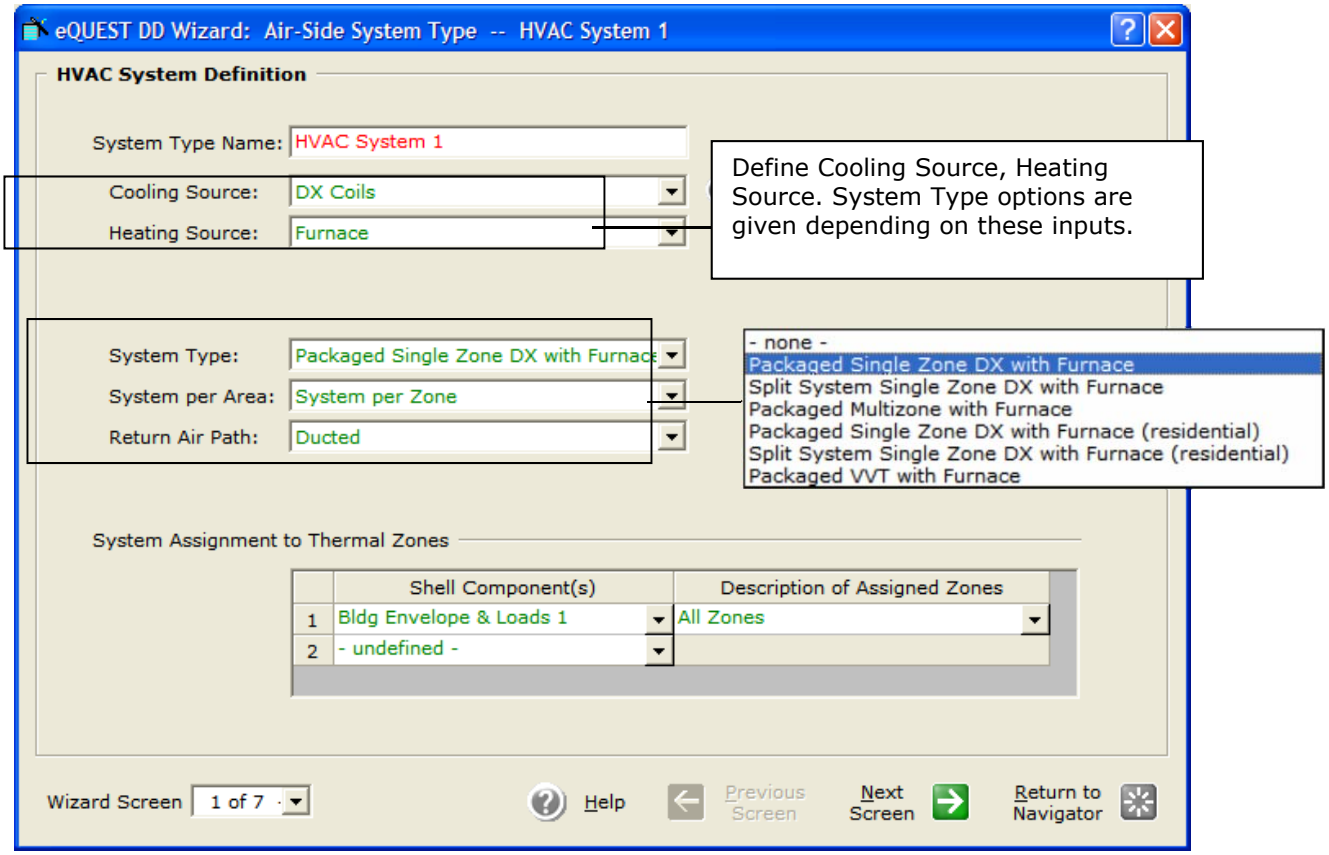
- Change Baseline - The building envelope, load, HVAC system and schedule components of the prototype model can be adjusted and the energy savings comparisons can be made between the prototype and the edited version.
- EEM - Energy-efficiency measures (EEM) can be applied to the baseline run (of the prototype model) in the form of parallel runs through the Energy Efficiency Measure wizard of the software.
- Parametric Runs - Parametric Runs (similar to Energy Efficiency Measure Wizard but a lot more detailed) can be set up in the Detailed Interface of the software.

For a more extensive training on eQUEST Wizard and Detailed Interface mode, please see the KEMA eQuest Training Presentation.

Steps to take for modifying the prototype or measure are provided below. Some additional steps should be taken for certain measures. The detailed interface may be required for some more complicated or specialized measures (for example to input duct losses, detailed interface is required).

Changes may be made to various building systems and operating schedule. This may include insulation, fenestration, lighting and equipment power density, and other features. The following provides details on HVAC and water heating equipment. However, similar steps are required for the other building systems.

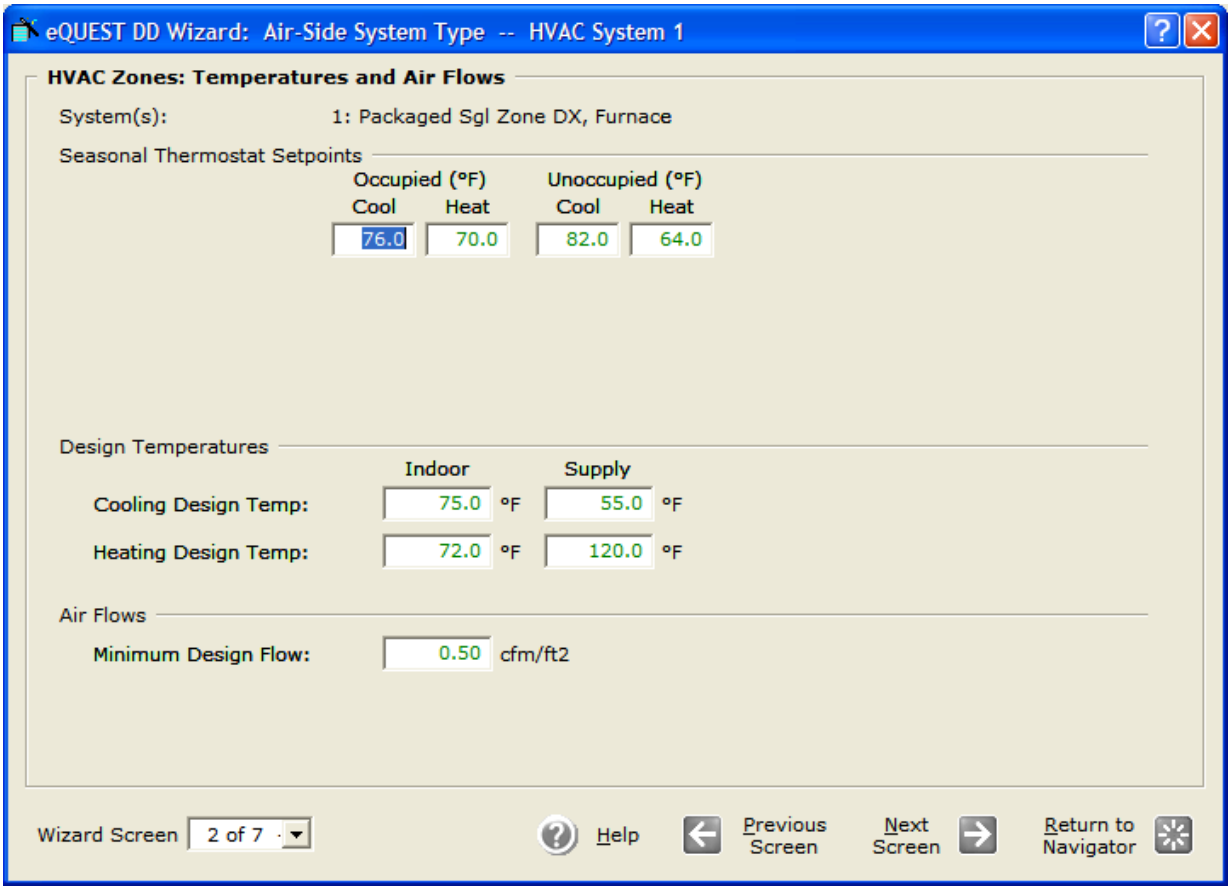
Open the HVAC type and make adjustments for the baseline based on the pre-retrofit condition of the building. Change "cooling source", "heating source", and "system type" based on the specific building.[13] Keep "system per area" and "return air path" to the same options. The "system type" descriptions need further explanation:



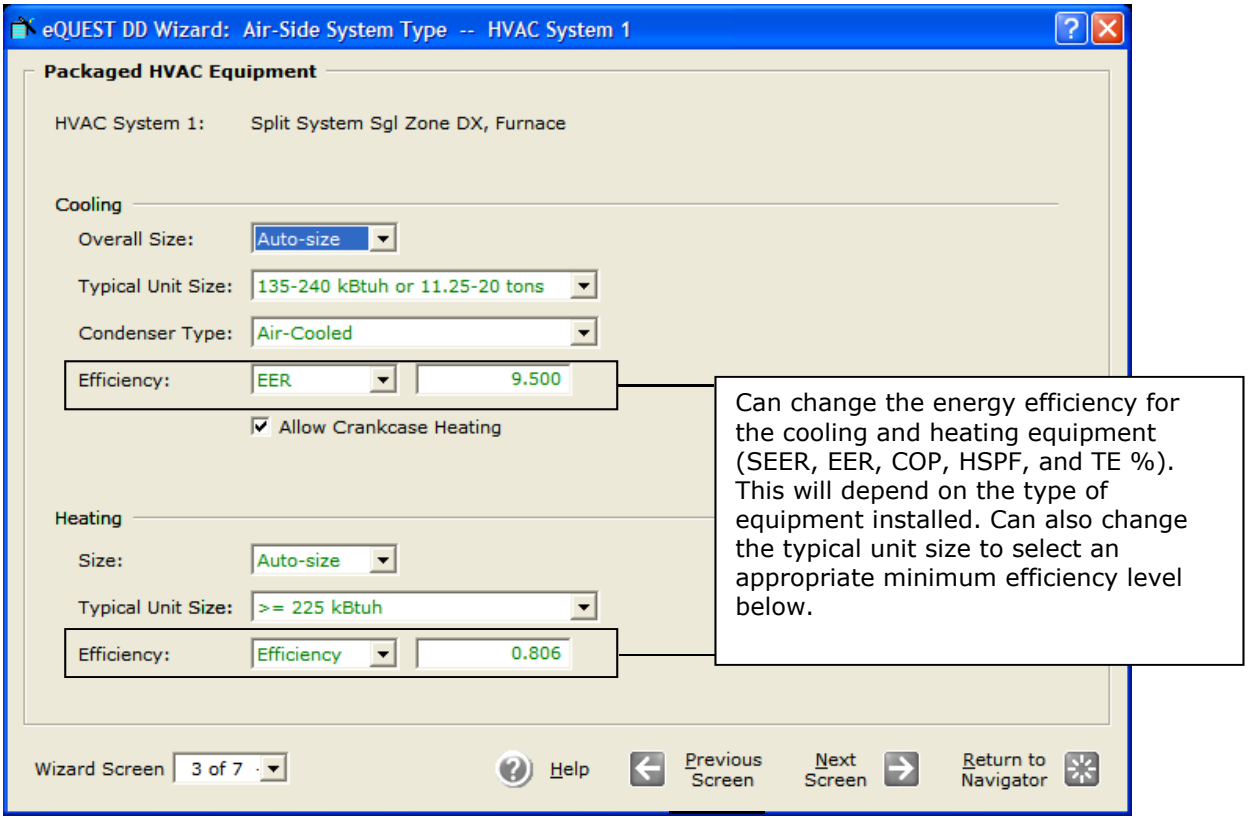
On HVAC Zones: Temperatures and Air Flows

It may be required to add space temperatures and supply air temperatures. If the unit runs 24/7 regardless of business schedule or occupancy, the identical values for thermostat set points during occupied and unoccupied will be entered. If the unit is off during unoccupied hours, enter 90°F for cool and 50°F for heat.

[13] Selecting the Help button can access all possible HVAC system types that can be defined in eQUEST software.


eQUEST DD Wizard: Air-Side System Type -- HVAC System 1
HVAC Zones: Temperatures and Air Flows
System(s): 1: Packaged Sgl Zone DX, Furnace
Seasonal Thermostat Setpoints
Occupied (°F)
Unoccupied (°F)
Cool
Heat
Cool
Heat
76.0
70.0
82.0
64.0
Design Temperatures
Indoor
Supply
Cooling Design Temp: 75.0 °F 55.0 °F
Heating Design Temp: 72.0 °F 120.0 °F
Air Flows
Minimum Design Flow: 0.50 cfm/ft2
Wizard Screen 2 of 7
Help
Previous Screen
Next Screen
Return to Navigator

Packaged HVAC Equipment

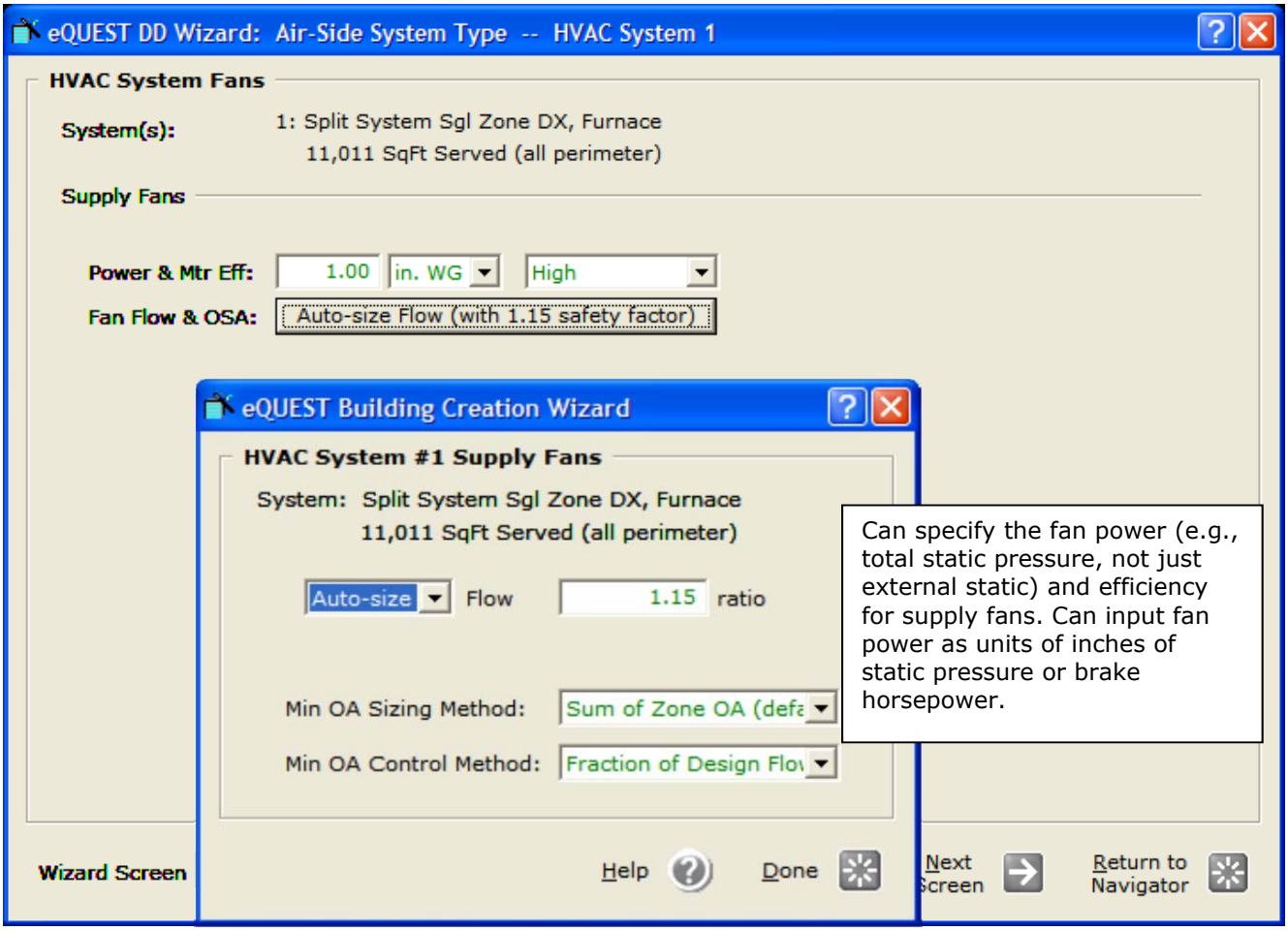


HVAC System Fans

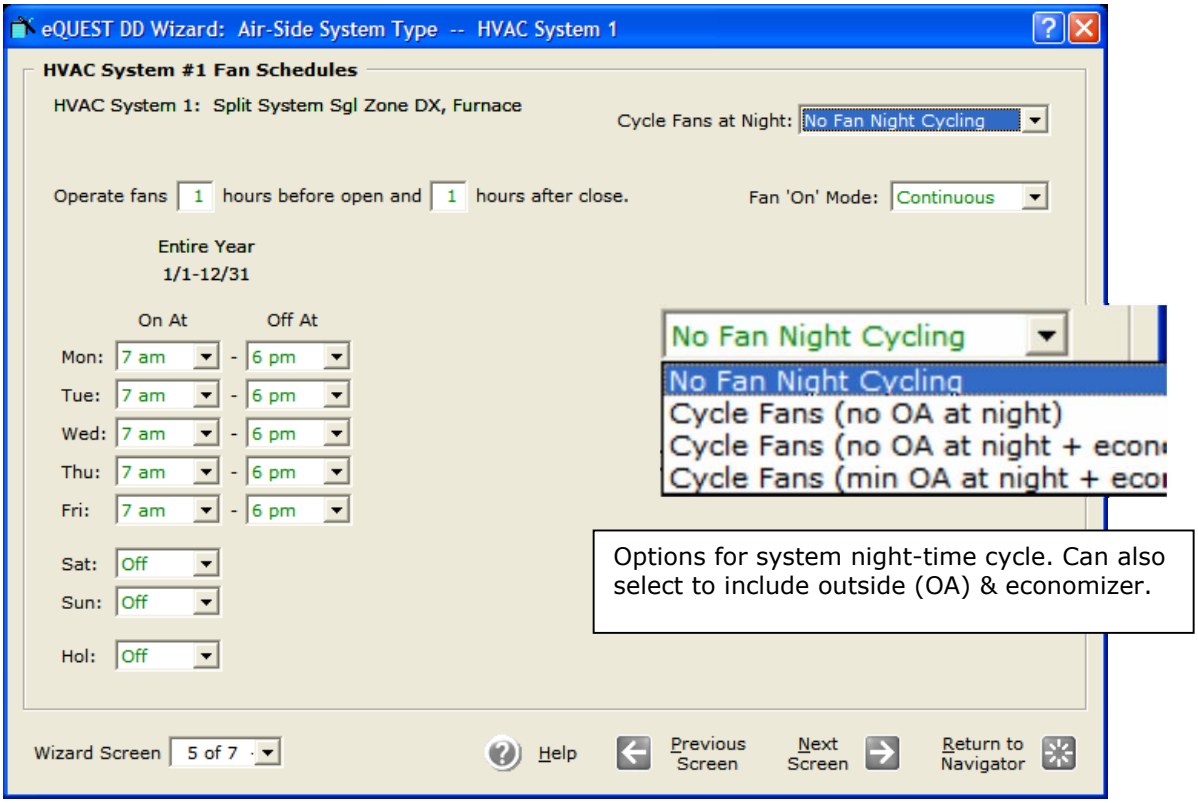
The fan type is specified here. The options in the menu are pretty standard for an HVAC system. Most systems use centrifugal fans. The most important parameters to enter are whether or not the fan flow is controlled by a VFD or by other means.

The other options on this screen include being able to enter fan brake horsepower and system design air flow directly. If these values are known, they can be entered, but the default used in the representative model simply auto-sizes these parameters.

If the measure involves adding a VFD or multiple VFDs, fan brake horsepower and system design flow should be entered directly. In the eQuest model the HVAC system for the component or activity area represents the sum of all HVAC systems in the building serving that particular area; so one eQuest HVAC system can represent many in the actual building.

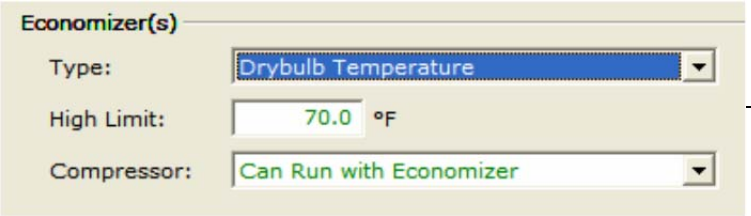


This screen can be edited if the HVAC fan schedule differs from the building operation schedule, or if there is night time fan cycling.



HVAC Economizers

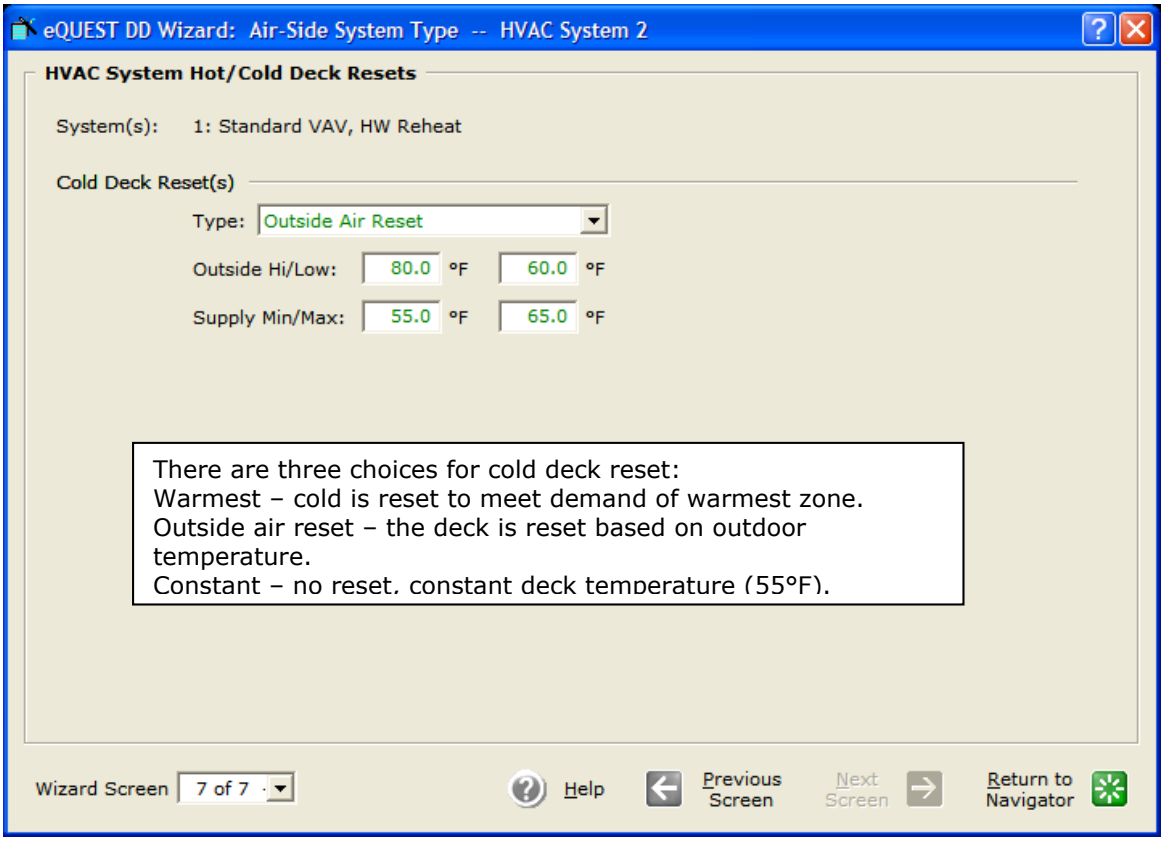
Specify the different types of economizers.



Can choose dry bulb, enthalpy, or dual enthalpy for air-side economizer type. Also select the high limit economizer temperature – primary high limit for dry bulb and as a secondary limit for enthalpy economizers.
For compressor systems, a compressor lock-out option is also displayed.

HVAC System Hot/Cold Deck Resets

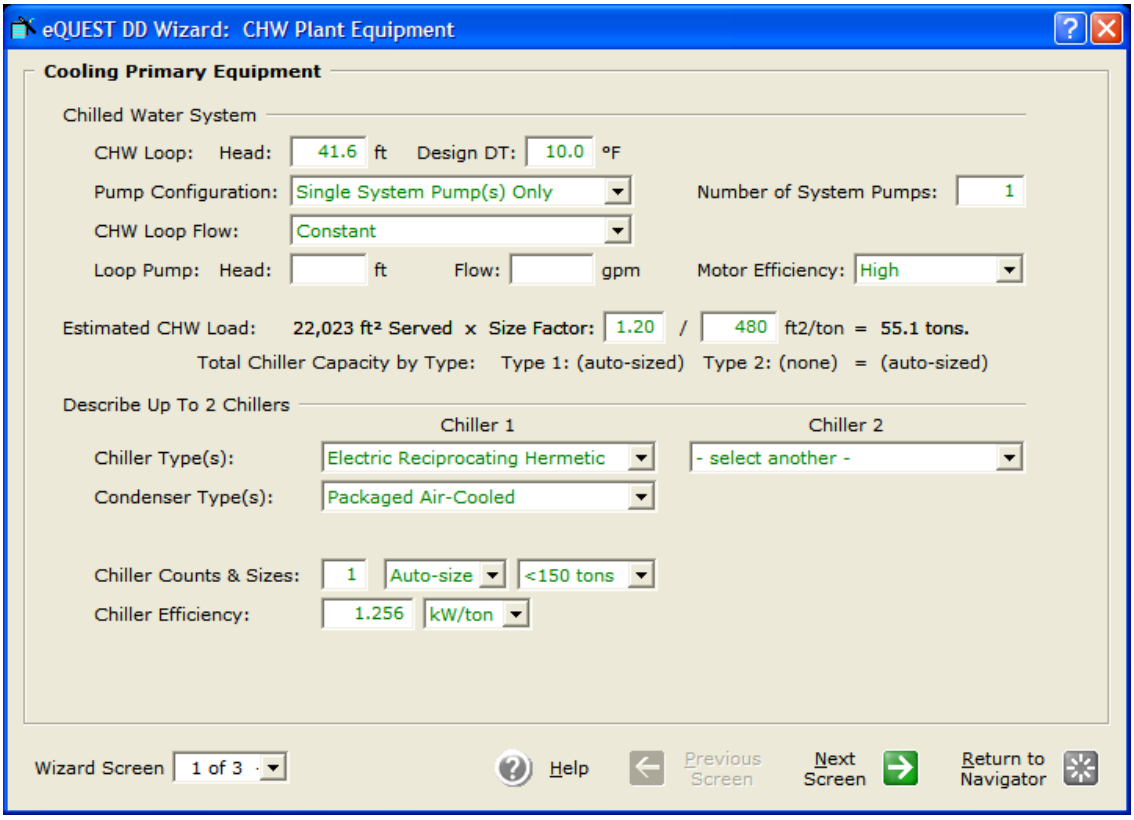
On this screen you can apply any supply air temperature reset schedules if applicable. This can be relative to outside air temperatures or to building demand (warmest zone). Reset based on warmest zone can only occur if there is direct digital control (DDC) of the building's terminal boxes.



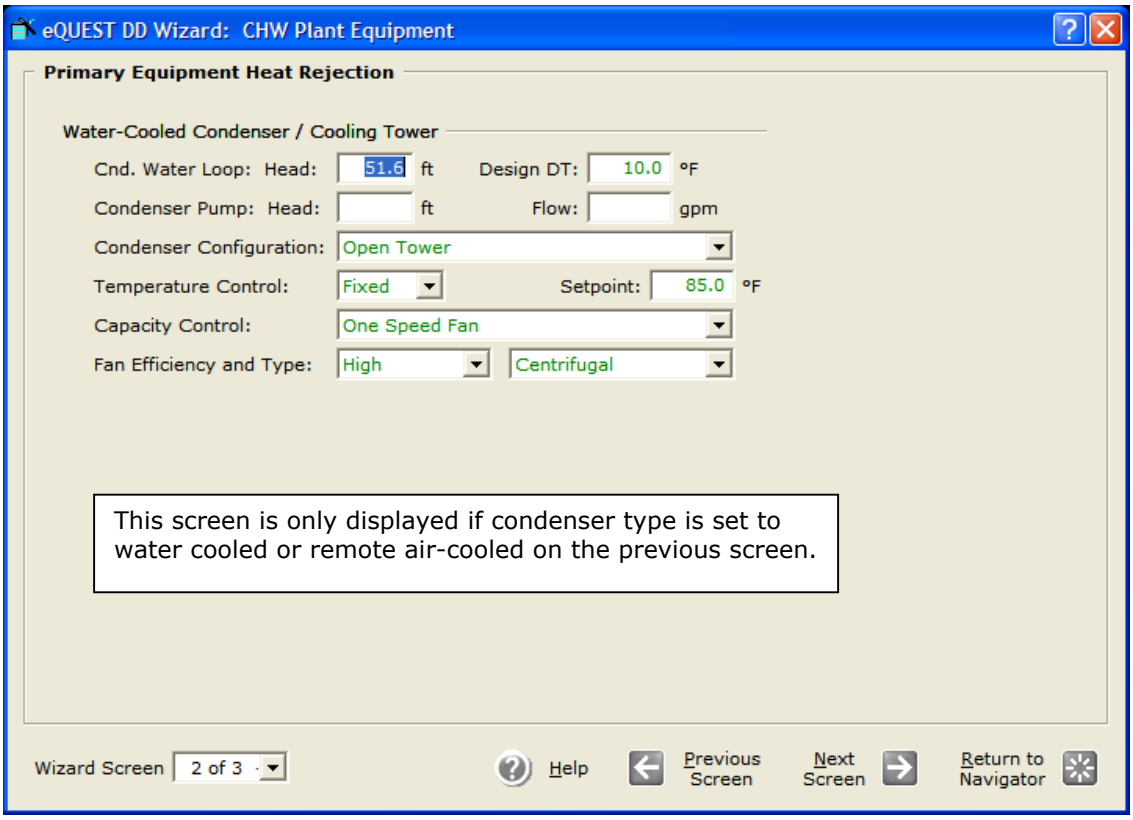
Cooling Primary Equipment

If the building has a chilled water system, those parameters must be entered.

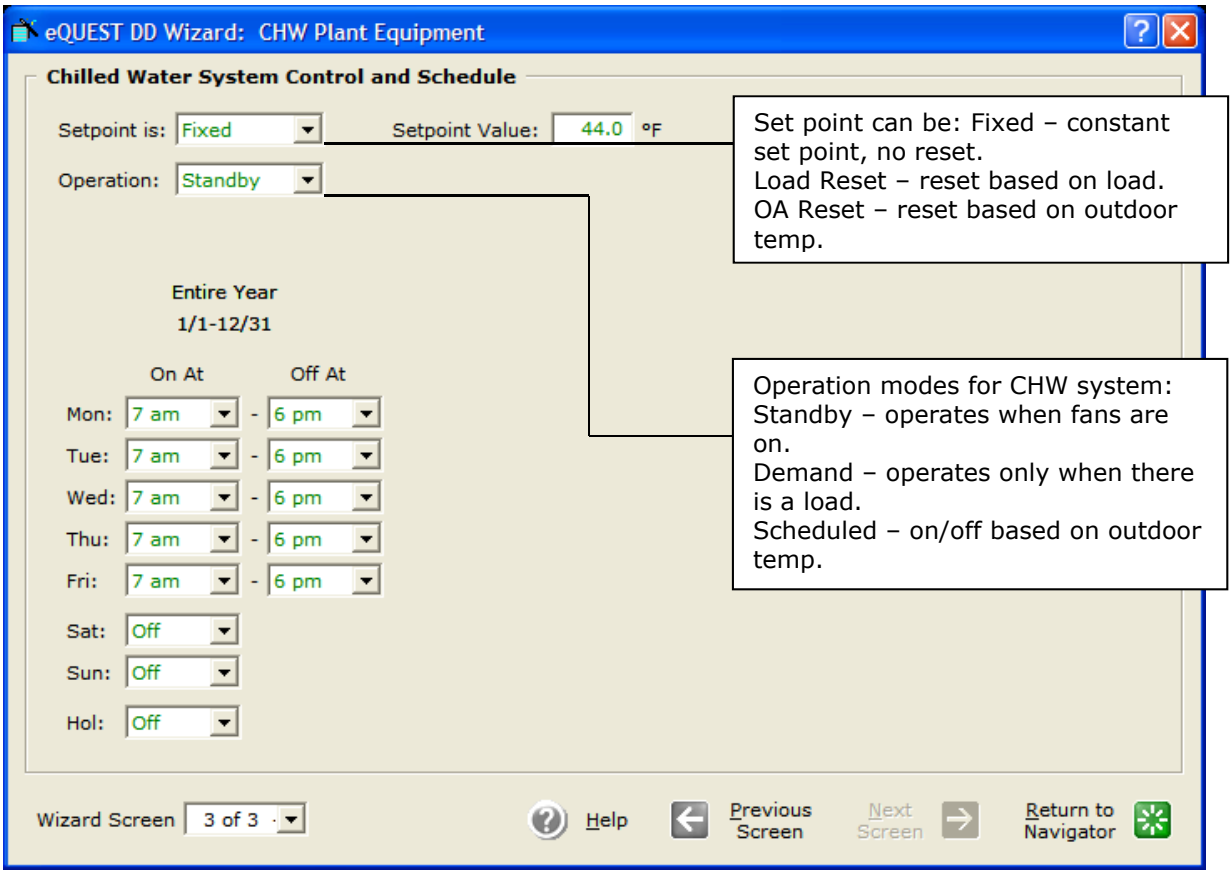
Under CHW Plant Equipment, enter whether the chilled water loop is constant or variable speed. Also enter the chiller type and other specifications if known. If the age of the chiller is known, but the efficiency is not, utilize the minimum chiller efficiencies from the applicable code (such as IECC 2009).


eQUEST DD Wizard: CHW Plant Equipment
Cooling Primary Equipment
Chilled Water System
CHW Loop: Head: 41.6 ft Design DT: 10.0 °F
Pump Configuration: Single System Pump(s) Only
Number of System Pumps: 1
CHW Loop Flow: Constant
Loop Pump: Head: ft Flow: gpm
Motor Efficiency: High
Estimated CHW Load: 22,023 ft² Served x Size Factor: 1.20 / 480 ft2/ton = 55.1 tons.
Total Chiller Capacity by Type: Type 1: (auto-sized) Type 2: (none) = (auto-sized)
Describe Up To 2 Chillers
Chiller 1
Chiller 2
Chiller Type(s): Electric Reciprocating Hermetic
- select another -
Condenser Type(s): Packaged Air-Cooled
Chiller Counts & Sizes: 1 Auto-size <150 tons
Chiller Efficiency: 1.256 kW/ton
Wizard Screen 1 of 3
Help
Previous Screen
Next Screen
Return to Navigator

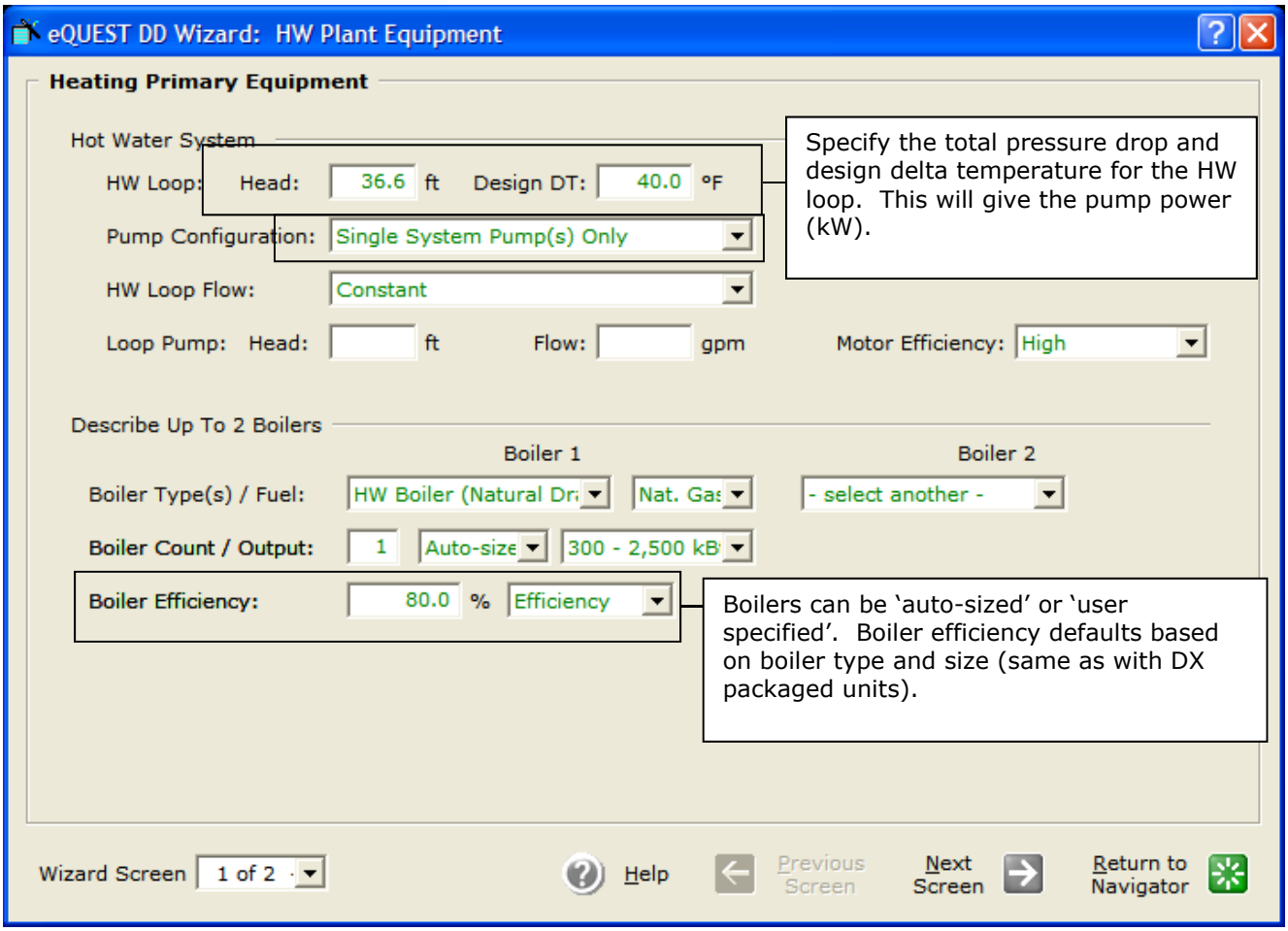
Primary Equipment Heat Rejection



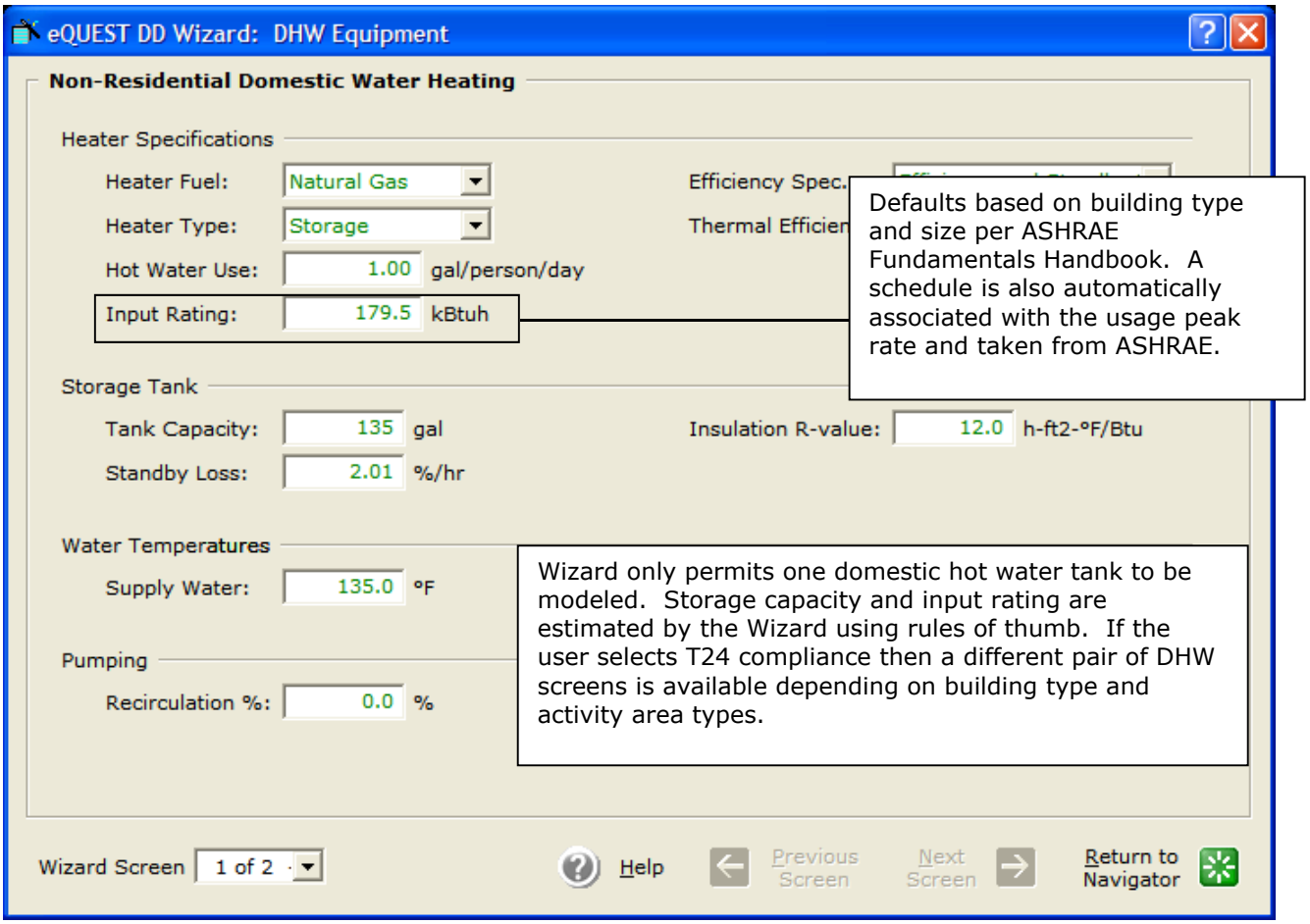
Chilled Water System Control and Schedule



Heating Primary Equipment

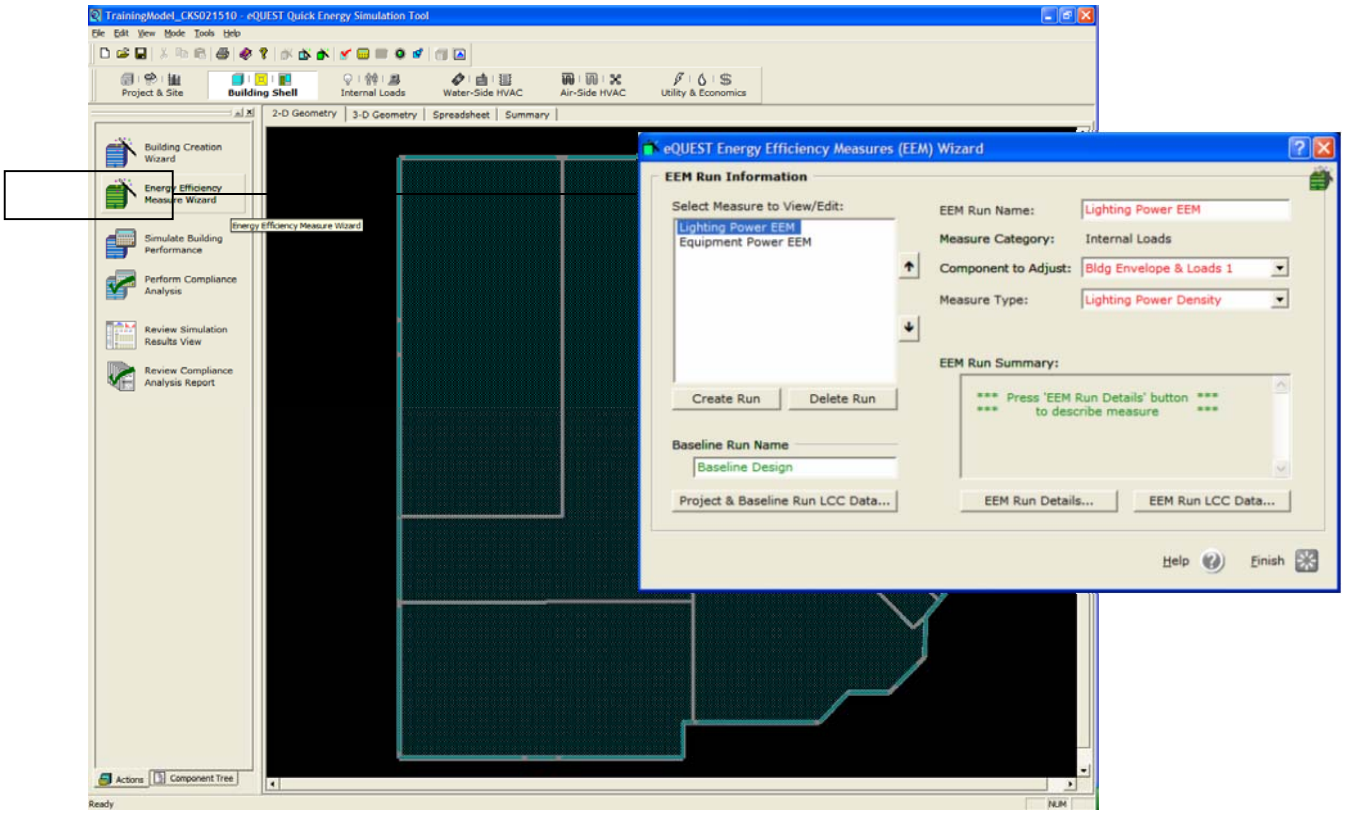


Domestic Hot Water Equipment



EEM and Parametric Runs:

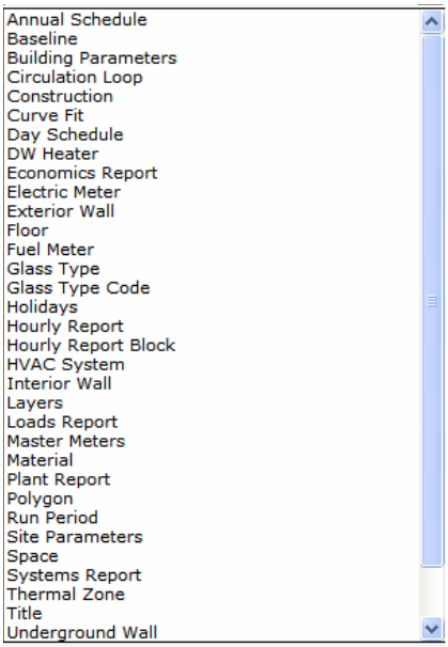
Instead of varying the actual model in eQuest, energy-efficiency measures can be applied through the Energy Efficiency Measure Wizard or through creating Parametric Runs in the Detailed Interface.



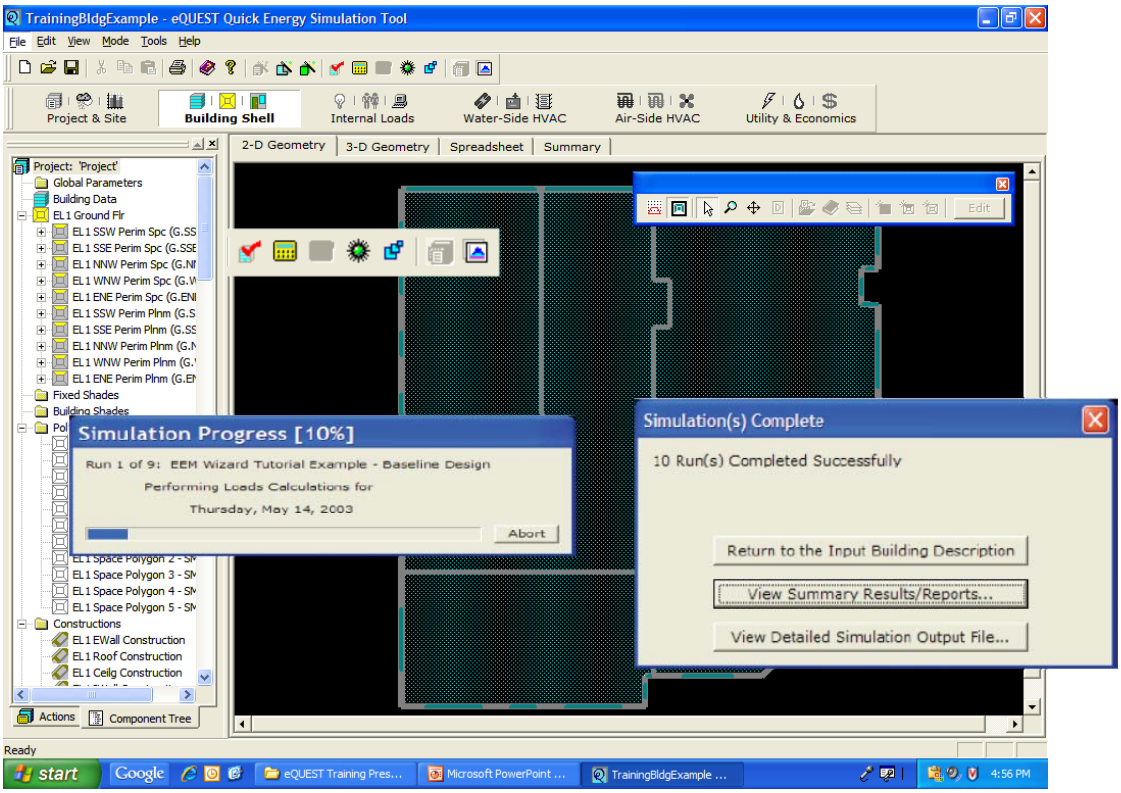
Either option will provide the ability to alter different parameters of the model and investigate incremental or independent savings as a result. Parametric Runs provide much more extensive efficiency options that are best suited for buildings with more complex systems. Both will enable basic measures such as different glazing, envelope constructions, shading devices, interior loads, and HVAC systems and related HVAC equipment components. The EEM wizard is a quick, easy way to explore different measures energy and cost affects.

EEM Wizard Building Components

Parametric Run Building Components



Once the baseline model is complete, run a simulation.



7 DETAILED PLANS

7.1 Overview

This appendix includes guidelines for the technical review (implementer) on what to require in the measurements and analysis of various types of custom projects. The measurement (or M&V) plans provided here also serve as the M&V protocols that the evaluator will base its site specific studies on.

The first two sections of this appendix provide a discussion of generic measurement plans including minimum content requirements selection of an acceptable analysis approach and discussion of key evaluation issues and variables. The next sections provide a more detailed discussion of measurement plans for the following:

- Custom lighting and controls
- Constant-load motors
- Variable-speed drives (VSDs)
- Chiller installations
- Generic-variable loads
- Energy-savings device

Additionally this appendix provides a detailed discussion of the M&V evaluation issues encountered when using billing analysis and calibrated simulations as the evaluation approach for measuring energy savings and demand impacts of custom measures.

7.2 Measurement Plan Minimum Requirements

Measurement plans must document all collected information and inputs in a format that allows due diligence review. Inadequate or disorganized documentation can be the basis for rejecting a submittal. All measurement plans must at a minimum include the following:

Concise project description including how the equipment is used

- Equipment inventory including the quantity, make, model number and rated capacity of both the existing and the new equipment that is being installed. (When appropriate, other nameplate information like operating voltage and rated full load amps).
- Manufacturer's specification sheets and/or performance rating sheets and the Web site address where further technical information about the equipment performance might be found.
- Plans, sketches, drawings, equipment lists, or inventories that help to clarify the scope.
- Description of the locations where the equipment is installed.
- The facility operating hours and the equipment operating schedule for each day of the week and by season if there is seasonal variation and whether the equipment loading is weather dependent.
- Equipment load conditions for the hours the equipment typically operates.
- Annotation of all assumptions or constants used in engineering calculations.
- Statement on the remaining useful life of equipment if existing equipment is to be considered as baseline.

Calculating energy and demand savings typically are based on the following basic equations.

$$\text{Annual energy savings} = \text{kWh}_{\text{base}} - \text{kWh}_{\text{retrofit}}$$

$$\text{Peak demand savings} = kW_{base} - kW_{retrofit}$$

In general terms the measurement plan must describe the installed measures and energy savings calculation with sufficient detail so that a technical auditor with no prior knowledge of the site could verify the installation of the measures or changes to operating schedules. Additionally the savings calculations should be documented in such a way that they are transparent and repeatable.

7.3 Generic Measurement Plan Issues

There are some generic issues that must be addressed in all measurement plans regardless of the type of energy-efficiency measure(s) being installed. Due to the highly variable nature of custom measures it is particularly important that these issues be addressed with the proper level of detail and rigor.

The first step in any measurement plan is to identify the measurement approach that will be utilized to quantify the impacts of the measure. The M&V procedures provided in this manual are generally derived from the 2009 International Performance Measurement and Verification Protocol (IPMVP). The IPMVP offers four main options:

Option A—Retrofit Isolation: Key Parameter Measurement. This option allows savings to be predicted using short-term or continuous measurements of the key operating parameter(s) along with estimated values. Key performance parameters are defined as the factors that affect the energy use of the ECM's system(s) and/or the project's success. The estimated (stipulated) parameters can be based on manufacturer's specifications, historical data, or engineering judgment; however, backup documentation and/or justification of the estimated parameter(s) is required. For example, a control measure that reduces the operating hours of a motor would require that the pre and post operating hours of the motor are measured; however the motor load could be estimated using other variables that correlate to power without a direct power measurement. This option is not preferred because of the estimated or stipulated component and any submission using this approach must provide a compelling reason why measuring the estimated parameter would result in an unreasonable burden.

Option B—Retrofit Isolation: All Parameter Measurement. Option B involves the short-term or continuous metering of the baseline and reporting-period energy (installed measure energy) to determine energy consumption. Measurements are usually taken at the device or system level. This option is preferred for M&V plans because savings are determined for each efficiency measure. A typical application of this option would be a measurement of a VSD to control the flow of an electric pump motor. Initial monitoring would include the installation of a kW meter on the baseline motor for a period of time to confirm constant loading. The meter would then remain in place throughout the reporting period to track variations in power use.

Option C—Whole Facility Analysis Using Regression Models. Option C involves (1) comparing monthly billing data recorded by a utility meter or sub-meters for the whole facility or sub-facility level, before and after project installation, and (2) analyzing the data to account for any variables, such as weather or occupancy levels. Energy savings can be determined once the variables are recognized and adjusted to match pre-installation conditions. This method is only applicable to measures that cannot be isolated easily so that options A or B could be used. The savings attributable to the measure(s) must be at least 10% of the total load for this method to yield statistically significant results. A more detailed discussion of this method is provided

Option D—Computer Simulation. Option D involves using software to create a simulated model of a building based on blueprints and site surveys. The model is calibrated by comparing it with end-use monitoring data or billing data. Models of the project are constructed for (1) the existing base case, (2) a base case complying with minimum standards, and (3) a case with the energy measures installed. This option is suited for multifaceted energy management measures affecting many systems in a facility but where no meter existed in the baseline period.

The following issues need to be addressed in the measurement plan:

- Baseline conditions
- Defining operating schedules
- Measurement uncertainty and statistical sampling
- Metering standards

7.3.1 Baseline Conditions

Measuring the baseline conditions for custom measures is typically far more challenging than for prescriptive measures as custom measures tend to be more site-specific and involve control strategies and/or equipment with non-linear operating characteristics. As a result of this complexity greater effort needs to be expended to define the variables that impact the annual operation of the equipment outside of the metering period. The baseline conditions are defined as the interval power consumption of the baseline equipment and/or controls observed under normal baseline operating conditions.

For example, the operation of a chilled water system for space cooling is dependent on the time of day, day type, cooling temperature set points and ambient temperatures as well as internal loads in the space due to occupancy levels, lighting and plug loads. A process chilled water system may involve similar equipment, but the loading on the system will be much more dependent on production schedule of the material being cooled. As a result the process chiller may have greater loading and energy usage during cooler weather periods, because the increased load on the equipment is greater than the increase in operating efficiency of the equipment due to lower ambient temperatures.

In some cases the custom measures may only impact the efficiency of the equipment being replaced, and in other cases it may include changes to the operating schedule or a combination of the two. The equipment itself can also have efficiency curves that vary as a function of ambient weather conditions and loading. Chillers typically have their efficiency defined in terms of the leaving chilled water temperature and the entering condenser water temperature as well as the part load ratio of the chiller. All variables that impact the power consumption of the equipment should be measured. Under all circumstances the baseline equipment and operation should be measured in such a way that the metering period is sufficient to extrapolate the data out to the annual operation of the measure. Weather-dependent measures must include observations with ambient conditions that are at or close to peak conditions so that the loading during peak periods can be reliably estimated. Extrapolating models outside of the range of observed data points is extremely problematic and may be disqualified for the purposes of calculating peak demand impacts.

In the absence of a measured baseline (such as new construction), or in the case where the equipment is being replaced on failure, the baseline values shall be the level of efficiency required by applicable state code or federal standard. If there is no applicable state code or federal standard then standard practice may be used as long as the assumptions are documented and reviewed by TVA.

7.3.2 Operating Schedules

Defining the operating schedules for custom energy-efficiency measures can also be somewhat challenging particularly for measures that involve enhancements or modifications to control strategies. The operating schedule of equipment is defined as the interval power consumption of installed equipment and/or control measure during a period of interest. Metering equipment is typically installed to collect 15-minute interval true power data, or in cases of constant load equipment, a spot power measurement and the installation of an on/off event longer can be used to measure the operating schedule of the equipment. The metered data are then used to create hourly-interval load profiles that can be linked to other hourly variables such as temperature that may impact the operating profile of the measure.

As with the baseline, the measurement of the operating schedule must be done so that the sample measurement period can be reliably extrapolated to an annual operating schedule. This is particularly important for weather-sensitive measures, and involves collecting measured data during the proper periods so that peak ambient conditions are represented in the data. For example, it is not acceptable to monitor the March operation of a chiller, when peak temperatures are 80ºF, and use these data to predict impacts during 98ºF peak temperature hours. If the installed measure can be reliably modeled using short-term measurement data that contain peak ambient conditions, then monitoring throughout the TVA peak period is not necessary. However if the operation of the measure is highly variable then the measure may need to be monitored throughout TVA peak period to establish peak demand impacts.

7.3.3 Measurement Uncertainty and Statistical Sampling

Limiting measurement error and bias is perhaps the single most important factor in producing reliable and accurate energy-efficiency savings estimates. Measurement error is typically defined as random or nonsystematic error that tends to both understate and overstate the actual measurement, and ultimately tend to cancel each other out. Bias on the other hand is far more troubling because it is a systematic error that favors a particular result either overstating or understating the true value of a measurement. Bias can arise from many sources, but the primary sources of concern are measurement bias from oversimplified engineering, inaccurate calibration of measurement equipment and choosing an appropriate baseline.

The effect of bias can be quite important if it exists and every effort should be made to identify and limit all sources of bias. A combination of a large bias and small measurement error can produce results that are quite precise, but are wrong. Any M&V plan that contains substantial or obvious sources of bias with no attempt to mitigate them will be rejected. One example of obvious bias would be performing baseline metering for a space cooling measure during the summer and then metering the post-installation measure during the fall and using the results without weather adjustments to calculate the savings.

Components of a monitoring plan and energy savings estimates that should be carefully reviewed to manage uncertainty are:

- Instrumentation –measurement equipment errors due to improper calibration, inexact measurement, or improper meter selection, installation, or operation.
- Modeling – the inability to find mathematical forms that fully account for all variations in energy use. Modeling errors can be due to inappropriate functional form, inclusion of irrelevant variables, or exclusion of relevant variables.
- Sampling – use of a sample of the full population of items or events to represent the entire population introduces error. The error is a result of the variation in values within the population or biased sampling.

The issue of statistical sampling is a complex one that involves the measurement of several variables. Statistical precision is typically expressed in terms of a relative precision across a confidence interval, and, although this provides a good estimate of the uncertainty associated with a particular sample, the importance of developing an unbiased and representative sample is crucial. In terms of an M&V plan statistical sampling is most likely to occur when there are a large number of similar measures and it is not practical to measure the entire population. This situation often arises with lighting measures in large facilities with thousands of fixtures it is not practical to monitor the operation of all of the fixtures so a representative sample is selected.

Programs do not typically specify relative precision requirements for sampling at the site or measure level that become part of the measurement plan. However, both the ISO-New England (ISO-NE) and PJM Interconnection (PJM)[14] do specify similar relative precision levels when statistical sampling is used for calculating demand reduction values at the program or portfolio level. The required sample size to achieve a target relative precision at 90% confidence interval using a one-tail test is given by the following equation:

$$n_0 = \left(\frac{z * cv}{D} \right)^2 \qquad n_1 = \left(\frac{n_0}{1 + \frac{n_0}{N}} \right)$$

Where,

n0 = the required sample size before adjusting for the size of the population,

z = a constant based on the desired level of confidence, e.g., 1.282 for 90% one tail,

cv = coefficient of variation = standard deviation / mean,

D = desired relative precision = 0.10,

n1 = the required sample size after adjusting for the size of the population using the finite population correction factor, and

N = the population size, i.e., the number of program participants.

In most cases determining the coefficient of variation (cv) for a particular variable may not be known prior to the selection of the sample. If the cv is not known then a default value of not less than 0.5 should be used for homogenous samples and a cv of 1.0 or greater should be used for heterogeneous samples.

7.3.4 Metering Standards

The metering equipment used to monitor the baseline and operating schedules for installed energy-efficiency measures must meet certain minimum standards with regard to measurement accuracy and maintenance and calibration. Both the ISO-NE and PJM have established similar standards for metering equipment used for M&V activities to determine demand reduction values for energy-efficiency measures submitted into their capacity market. The TVA standards are as follows:

- All power measurement, monitoring, and data recording equipment must meet or exceed the relevant standards set by the American National Standard Institute (ANSI) or equivalent standard.

[14] PJM Manual # : Energy Efficiency Measurement & Verification Revision: 0 and ISO New England Manual for Measurement and Verification of Demand Reduction Value from Demand Resources, Manual M-MVDR, October 1, 2007

- Any measurement or monitoring equipment that directly measures electrical demand (kW) must be a true RMS measurement device with an accuracy of no less than ± 2%.
- Any measurement or monitoring equipment that directly measures electrical demand from three-phase devices must be installed such that measurements are taken on all three-phases to account for any phase imbalance or an equivalent method that can measure electrical demand using two phases.
- Any measurement or monitoring equipment that directly measures electrical demand on circuits with significant harmonics must have a digital sampling rate of at least 2.6 kHz as defined in the relevant IEEE Standards.
- Any measurement or monitoring equipment of current (amps) and nominal voltage used to calculate electrical demand must include the power factor of the end-uses in the demand (kW) calculations.
- Data recorders must be synchronized in time, within an accuracy of ± 2 minutes per month, with the National Institute of Standards and Technology (NIST).
- All measurement, monitoring and data recording equipment must be calibrated in such a way to meet or exceed the Federal Energy Management Program (FEMP) Measurement and Verification Guidelines, applicable American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) standards, NIST, or equivalent standard.

7.4 Lighting

This section discusses the measurement methods for projects that involve the replacement of lighting fixtures and/or the installation of lighting controls. The following key issues should be noted:

- A lighting audit is required and should identify all fixtures, lamps, and ballasts by area for both before and after installation. New Construction projects will have savings determined by lighting power density reductions from the applicable space type or building type code requirement
- Fixture wattage specifications shall be provided, unless it is provided from a documented standard fixture wattage table, such as the one that is a part of the TVA lighting worksheet.xls.[15]
- Monitoring of operating hours of a sample of the fixtures is required for projects claiming greater than 200 peak kW savings or a $25,000 incentive. Self-reported values may be sufficient and should be compared for reasonableness to the deemed hours (see tables 85 & 87) in the main document, if appropriate. For lighting control measures, both pre- and post-installation monitoring for hours of operation may be required.

Section 8 of in the manual also provides details on custom lighting project savings analysis. This section provides details on measurements for lighting projects, if they are required.

7.4.1 Lighting Equipment Survey Table (Audit)

The lighting audit is required for each custom lighting project. The TVA Nexant "Lighting calc.xls" spreadsheet is an audit form that provides the inventory of the existing lighting equipment and specifies the new equipment to be installed, as well as controls. It is recommended that audit data follow this format. The information on this form can be manually inputted or automatically calculated by the spreadsheet. The lighting table documents savings information for each line item. The look up values can be updated using the deemed values for CDF and HVAC interactive factors from Appendix 2 and operating hours from section

[15] These standard fixture wattages are a part of the existing TVA program and developed by Nexant. This table is similar to others commonly used in the industry.

5.2.1. If these values are to be overridden with measured data, the lighting spreadsheet calculator should note these changes and logger data or other supporting data should be provided.

7.4.2 Non-operating Fixtures

The audit should note non-operating fixtures and adjustments to the baseline demand may need to be made to account for non-operating fixtures. All of the existing fixtures that are typically operating but have failed and are intended for repair are considered to be non-operating fixtures. Non-operating fixtures must be identified if they will be retrofitted or replaced with this project. Calculations of the baseline demand may include fixture wattages for up to 10% of the building's non-operating fixtures. Therefore, if 10% or fewer of the existing fixtures in the building are non-operating, these fixtures and their functioning wattages should be included on the equipment survey as part of the baseline fixture demand. If more than 10% of the total numbers of fixtures are non-operating, the baseline demand needs to be adjusted downwards by the items that are non-operating.

7.4.3 Using the Standard Fixture Wattage Table

The Standard Fixture Wattage Table (found in the TVA – NR Ltg 2016.xlsb) includes wattages that are an average of many different manufacturers' wattages for each fixture. Fixture wattages in this table should meet or exceed minimum federal energy-efficiency standards. It is encouraged to conduct an annual review of the wattages in this table and assess the need to add or remove fixtures or revise fixture wattages.[16]

7.4.4 Metering Fixture Wattage

To measure the energy use of a fixture that does not appear in the Standard Fixture Wattage Table or have a manufacturer specification sheet, then the following metering protocol should be considered. Readings must be taken on fixtures that have been operating for at least 100 hours. The meters used for this task must be calibrated and have an accuracy of ± 2% or better for true RMS power.

- Identify lighting circuits or switches with preferably six or more identical fixtures and take spot true RMS power measurement using handheld meter.
- Repeat measurement procedure at least three times.
- Average all readings to determine the per fixture wattage values.

7.4.5 Monitoring Operating Hours

To determine hours of operation, a sample of fixtures or rooms needs to be monitored for a reasonable period and provisions should be made to account for any seasonal or other variations. A minimum monitoring period of two to four weeks should be required. If a building has more than one season, two weeks per season is monitored. Pre- and post-installation metering should be required for when new controls are installed as part of the measure. The sample size should assume a confidence interval of 80% and precision of 20% with a coefficient of variation of 0.5 as previously discussed.

To finalize the savings for a lighting project, a summary of the monitoring results must be provided. The results need to be incorporated into the lighting worksheet. Raw data files for all data loggers should be provided.

7.4.6 Calculating Savings

[16] Recent changes to metal halide standards have been adopted and TVA should consider revising specifications (the minimum baseline in the next year). Additionally, the industry has also been adopting new guideline published by Consortium for Energy Efficiency (CEE). TVA should make sure to follow these advances and evolve the program savings estimates accordingly.

Energy savings are based on the following:

kW savings = kWpre – kWpost

kWh savings = kWpre x OHpre – kWpost x OHpost

If controls are not installed, OHpre = OHpost

Where,

kWpre and kWpost is the sum of the fixture wattages before and after the retrofit, respectively

OHpre and OHpost is the operating hours before and after the retrofit, respectively.

For peak demand savings, either the default CDF values are used from Appendix section 2.1 or the monitored load (or usage) during the peak period hours (i.e. 2-5 p.m. in the summer and 6-8 a.m. in the winter CPT) is used. The monitoring can be used only if it can be shown to represent the peak period, meaning, if metering does not occur during the summer or winter peak period, the data from the hours of the day should be representative of the peak period. The calculation of savings using the monitored data would be:

$$\text{Peak demand savings, kW} = \frac{\left(\text{kW}_{\text{pre}} \times OH_{pre} - kW_{post} \times OH_{post}\right)_{\text{during peak period only}}}{\text{Total \# hours during peak period}}$$

The summer peak period is 258 hours and winter peak period is 170 hours.

7.5 Constant-Load Motors

This section involves the replacement of motors that drive a constant load system, such as:

- Motors replaced with high-efficiency motors with the same capacity rating (horsepower)
- Oversized motors replaced with smaller-capacity, high-efficiency motors

Alternative M&V methods must be used for projects in which motor changes are accompanied by the installation of variable-speed control or by system modifications that affect the load on the motor (described in the next section). If the pre-installation and post-installation motors will have different operating hours, then it is required to have both pre- and post-installation monitoring of the hours of operation. The M&V method described here involves calculating energy savings based on rated efficiencies and short-term or continuous metering of operating hours. The following issues are important to consider for this measure:

- Minimum equipment efficiency standards apply. The baseline efficiency for motors is defined by EPAct, which refers to the National Electrical Manufacturers Association (NEMA) efficiency standards.
- Considerations should be made to use deemed savings for motors replacing motors of the same capacity rating. If the project includes replacement of less than ten motors at one time and is less than $50,000 in incentives, then consider using deemed savings.
- Metering of motor electricity consumption to determine load factor is required.
- Run-time hours should be monitored, especially if change in hours will occur with retrofit.

High-efficiency motors may exhibit less slip and thus operate at a higher speed than the baseline motor unless motor-drive systems are modified, and should be taken into consideration.

7.5.1 Savings Calculation Methodology

The steps to calculate savings include determining existing and retrofit motor kW and operating hours. The first step is to conduct a complete survey of all the motors to be replaced and verify that they operate at constant load. If they are, the following methodology is used (otherwise use the variable load motor methodology). Using this approach, surveys are required to document existing (baseline) motor operations and new (post-installation) motor operations. The following list provides the key components for determining savings:

- Pre-installation equipment survey
- Establishment of baseline kW
- Verifying constant load
- Post installation short term monitoring
- Sampling
- Determining operating hours

The following sections will provide a detailed discussion of each of these components.

Pre-installation Equipment Survey

The equipment to be retrofitted must be inventoried in a survey. To facilitate the equipment inspection, location and corresponding building floor plans should be included with the survey submittal. The surveys must include the following:

- Motor horsepower, type and electrical efficiency
- Motor application or load served (for example, second-floor exhaust fan motors)
- Operating schedule (e.g., 6 a.m. to 6 p.m. weekdays)
- Existing and proposed controls
- Spot and short-term metering data (true RMS power)
- Location in the facility

Establishing Baseline Motor kW

The baseline efficiency for any motor can be determined if the following are known: horsepower; full-load (rated) RPM or number of poles; and enclosure type--open drip proof (ODP) or totally enclosed fan cooled (TEFC). The minimum efficiency can be determined from section 5.2.2 for motors less than 200 horsepower or by review of the Motor Master database for minimum efficiency currently available in the market for the baseline.

For measuring instantaneous power draw of the motors, baseline-motor spot metering of power must be recorded. Such measurements must be made using a true RMS meter with an accuracy at or approaching ± 2% of reading. A sample of motors can be spot metered, using the sampling criteria in above if a large number of similarly loaded motors are to be replaced within a single facility. There are three ways to determine baseline motor power draw, kW:

- Measured motor power draw (if the baseline motor exceeds minimum efficiency standard)
- If the motor exceeds the minimum energy-efficiency standard and is being replaced with the same size (horsepower) motor, then the baseline kW will be determined by multiplying the post-

installation motor kW by the ratio of the applicable minimum standard efficiency to the post-installation motor nameplate efficiency:

$$kWbase = kWpost \times effmin\ std/eff\ post$$

Where,

kWbase = the demand for the baseline motor

kWpost = the average of the metered energy demand for the new motor

effmin std = the efficiency of the minimum standard of the baseline motor

effpost = the efficiency of the new motor taken from its nameplate

- If the motor exceeds minimum energy-efficiency standards and is being replaced with a smaller size (horsepower) motor, then the baseline motor power measurement must be adjusted. This adjustment may be accomplished with a ratio of the minimum standard efficiency and the efficiency of the existing motor taken from nameplate data to estimate the baseline demand for the project. If the nameplate data are not available, an average efficiency value should be taken from the MotorMaster database for similar horsepower and type (ODP or TEFC) motors:

$$kWbase = kWexisting \times effmin\ std/effexisting$$

Where,

kWexisting = the average of the metered energy demand for the existing motor

effexisting = the efficiency of the new motor taken from its nameplate

Verifying Constant Load

There are two methods for verifying if motor loads are constant. One is short-term metering of the motor and the other is by observation during an inspection (not preferable). If the constant load cannot be verified through observation during the inspection, short-term metering is required on all baseline motors or a randomly selected sample of motors with the same application and operating hours. Short-term metering should be conducted for a period of time sufficient to capture the full range (or near full range) of operation of the motor and all variances in the load it serves.

During the short-term metering, each motor must be tested by modulating the applicable systems over their normal operating range to determine whether motor load remains constant over the full range of normal system operation. After this verification measurement, the following should be determined:

- Number of non-zero observations
- Number of observations within ± 10% of the average amperes or kW determined above
- Percent of observations within ± 10% of the average amperes or kW

A motor load is verified as constant if 90% of all non-zero observations are within ± 10% of the average amps determined above. If any motor application cannot be verified as constant load, the data should be examined to determine if the load varies on a systematic and predictable basis, or if the constant load was changed during the metering period, or if there is some system anomaly to be considered.

Post-Installation, Short-Term Monitoring

Post-installation, short-term monitoring is required for all constant load motor retrofits. The results from the monitoring are used to determine the following:

- kW demand of the retrofit motors
- Operating hours of the proposed motors
- Estimated kWh savings

The time period for which monitoring is required is determined by the type of application the motors serve. All post-installation short-term monitoring must be of a length of time sufficient to capture the full range of motor operation.

Sampling

The use of sampling may be necessary for projects with large numbers of similar motor installation measures. The spot-, short-, or long-term metering may only need to be done for a sample of motors from each usage group for determining (a) motor power draw in kW, (b) that the load is constant, and (c) operating hours. A usage group classifies the motors with identical operating characteristics and expected operating hours. Examples include HVAC constant-volume supply fans, cooling water pumps, and process applications. It is recommended that for each motor application or usage group at least one motor be metered.[17]

Determining Operating Hours

As part of the measurement plan, operating hours are recorded. If it is assumed that the operating hours are not affected by the motor upgrade, then the post-installation hours determined by monitoring are equal to the baseline operating hours.

If the control strategy of the motor(s) is changed and the operating hours of the motor are reduced, monitoring of operating hours for the baseline and the post-installation should be conducted on at least a sample of motors.

If short-term monitoring is used, the operating hours will be extrapolated to the full year. A minimum monitoring period of two and sometimes four weeks is recommended for almost all usage groups. If operating hours might vary seasonally or according to a scheduled activity, it will be required to monitor during periods where 90% of the conditions are experienced and are within 10% of the low and high loads. This may result in monitoring for at least two weeks each for two different periods.

7.5.2 Calculating Energy Savings

The equation for calculating the estimated annual kWh savings is:

$$kWhsaved = kWbase \times OHbase - kWpost \times OHpost$$

Where,

kWhsaved = estimated annual amount of kilowatt hours of saved

OHbase, OHpost = pre- and post-installation operating hours

kWbase, kWpost = pre- and post-installation demand

[17] If potential savings are small within a usage group (less than 10% of total population of motors replaced), then metering is not recommended.

In most cases, the retrofit will not affect the operating hours of the system. The equation reduces to:

kWhsaved = (kWbase– kWpost) x OHpost

To calculate peak demand savings, the kWh saved during the peak period divided by the number of hours in the peak use the following equation:

$$\text{Peak demand savings, kW} = \frac{\left(\text{kW}_{\text{pre}} \times \text{OH}_{\text{pre}} - \text{kW}_{\text{post}} \times \text{OH}_{\text{post}}\right)_{\text{during peak period only}}}{\text{Total \# hours during peak period}}$$

The average demand reduction during the peak period is sufficient. Additionally, if the monitoring period does not coincide with the peak period, but is considered representative of the peak period, then this method is sufficient.

7.6 Variable-Speed Drives

This section involves methods for calculating energy savings for the installation of VSDs[18] on motor-driven systems that serve either a constant speed or variable speed load. VSD projects involve the addition or replacement of existing (baseline) motor controllers with VSD motor controllers. These projects typically result in a reduction in motor system demand (kW) and energy use (kWh) but not necessarily a reduction in peak demand coincident with the TVA system peak that occurs reliably and consistently. The implementer must ensure that the motor system change and the power system impact measurement plan captures the new potential maximum load to verify that peak kW savings can be achieved reliably, and for the long term by the VSD and control system addition/modification. Examples of projects include:

- VSDs installed on chilled or hot water pump motors.
- Conversion of a constant volume HVAC system to a VAV system with VSD.
- VSDs installed on process motors.

Before proceeding with this measure, the implementer must make sure that the analysis performed determines the true kW impact during the customer's and the power systems peak period. Adding a VSD to a motor system controls when the system is operating at its maximum speed actually causes more power use and lower efficiency at the full load status then a non-VSD controlled system because of the additional power used by the VSD.[19] TVA does not claim power system demand savings for systems that have an increase in demand. Therefore, any motor that may operate at 100% load with the VSD is **NOT** eligible for **peak demand savings** even though significant energy savings may be achieved through the installation of the measure.

7.6.1 Peak-Demand Savings Definition

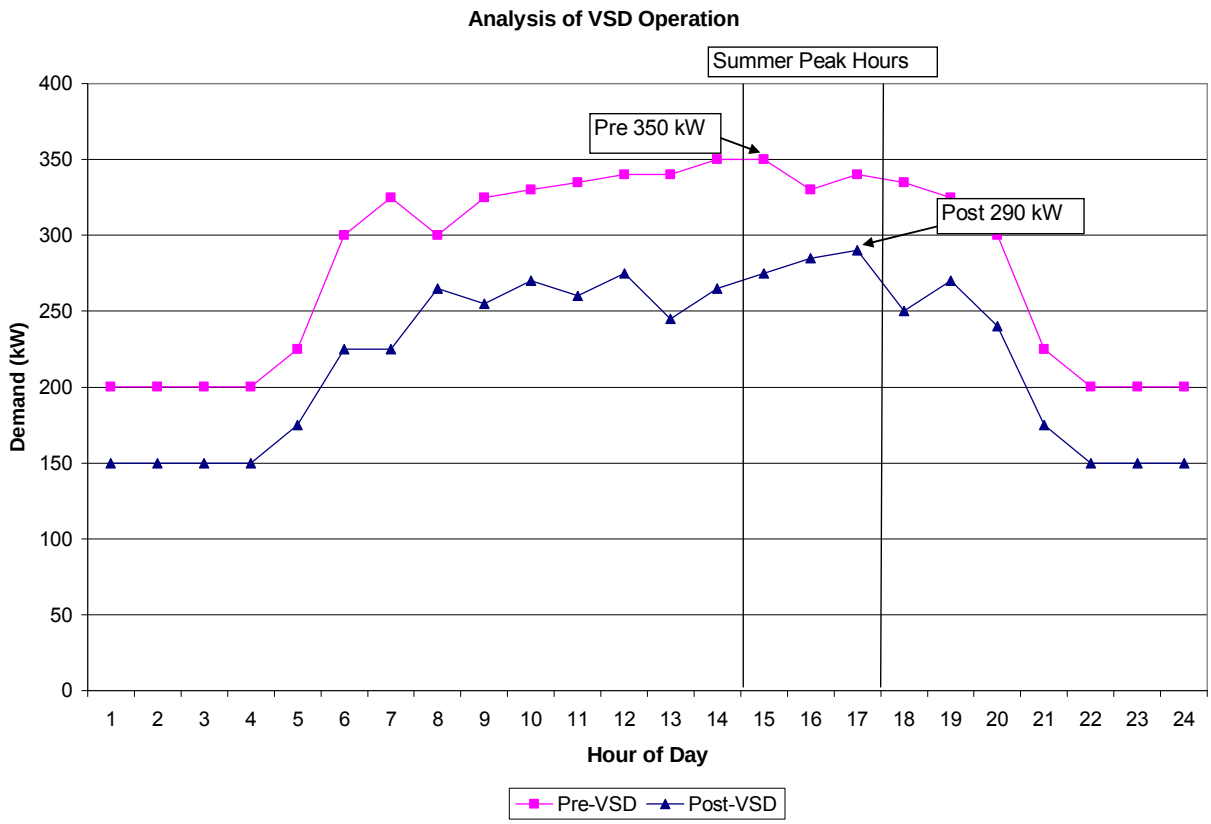
In order for a VSD to qualify for peak-demand savings, the peak demand of the VSD-controlled motor must not exceed the peak demand of the baseline motor for **any interval** during the metering period. If the metering period does not occur during the peak period, then it must be well documented that the metering period is representative of motor behavior during the peak period. Once this criterion has been satisfied, then the peak demand savings can be calculated using the peak-to-peak demand-savings method.

[18] VSD can be used synonymously with variable frequency drive (VFD) or adjustable speed drive (ASD).

[19] In many cases, VSDs used on motors operating at 100% load cause the total demand of the motor assembly to be greater than the motor demand without a VSD.

Figure 3 provides an example that shows how the peak-demand savings would be calculated using the peak-to-peak demand method. In the figure, the pre-VSD and post-VSD lines represent the power system peak period days, which are defined as the day with the maximum demand (observed during the pre- or post-measurement) during the peak performance hours. In this example the performance hours are summer non-holiday weekdays from 2 p.m. – 5 p.m. CPT. The peak demand interval observed in the pre-VSD data was 350 kW and the peak demand observed during in post-VSD data was 290 kW, resulting in a peak-demand savings of 60 kW.[20]

Figure 3. Peak-to-Peak Demand Calculation



7.6.2 Overview of VSD Savings Analysis Methods

The basis for selecting the methodology to calculate savings depends on whether the baseline consumption is constant or variable, and if variable, whether industry-recognized system performance curves for the system are available. All of the methods require baseline-power spot metering. Minimum-standard equipment efficiency applies if a new motor is installed as part of the project. There are three approaches using monitoring for calculating energy savings:[21]

- For the constant baseline approach (as defined in the previous section), the method uses post-installation monitoring of electricity consumption. This is used for constant load baseline systems.[22]

[20] If there are obvious data anomalies such as demand spikes in the pre VSD data TVA reserves the right to disqualify the results of this calculation method.

[21] Another measurement method must be used if the VSD is installed on a chiller.

[22] See Section 7.5 of this appendix for method to establish if a motor is constant load.

- For variable baseline load applications, the method, performance curve approach, uses part-load performance curves and post-installation electricity consumption monitoring. For this approach, the motor applications must have available performance curves (e.g., fan curves).[23] In any case, when using the performance curve approach, savings are based on:
  - kW spot measurements or short-term metering of existing motor(s).
  - System performance curves.
  - Measurements of post-installation kW, kWh, and/or operating hours.
- For variable baseline load applications and where no acceptable performance curves are available, the correlation method uses monitoring of pre- and post-installation energy use as well as any contributing parameters such as flow or production. Then correlations are established between baseline and post-installation electricity consumption with independent variable(s). When using the correlation approach, a regression analysis is performed to develop an equation that defines the relationship between baseline energy use and key factors that determine baseline energy use. For example, with a fan ventilation system the key variable(s) might be airflow, time of day, and/or outdoor air temperature. The regression equation must meet certain statistical criteria that indicate the equation is valid. These criteria are described later in this section.

An alternate approach for smaller programs (e.g., less than $25,000 in incentives) may be considered. This approach uses TVA VFD Worksheet.xls and the analysis uses assumptions based on spot measurements, interviews, and other observations to document the load profile, as well as motor operation to ensure that post-VSD motor system demand does not increase above 100% pre-load during the power system peak period.[24]

General Issues

The following is a list of issues that should be addressed in a measure-specific plan for VSD projects:

- Does the existing equipment meet minimum standards (if the motor is being replaced)?
- Is the baseline load constant or variable value?
- Are operating hours assumed to be constant before and after measure installation?
- Have the independent variables that determine how they impact power draw, as well as the range of values that they are anticipated to have, been identified?
- What is the time period of metering, metering protocol, and reporting format for documenting baseline and post-installation energy use, and their relationships to independent variables?
- Does the motor operate at a 100% load and if yes, when and what is the existing control method?

Acceptable Savings Estimate

The following methods are available for use in developing an initial savings estimate:

- Calculations and data analyses methods defined in the M&V data
- Computer simulation of the system using a building simulation program (e.g., DOE-2)
- Hourly or bin analysis using system performance curves (e.g., fan curves), estimated or spot measured motor kW readings, and load profile and operating hour estimates using TVA VFD Worksheet.xls

[23] Make sure performance curve data is from a recognized, acceptable source.

[24] At this time, TVA has not established deemed savings values for VFDs since careful analysis needs to be completed to ensure there is no increase in demand with this measure.

- Computer simulation of a motor and the fan or pump it serves using a VSD simulation program (e.g., QuickFan, AC Diskware)

Demand Savings Requirements

Since VSD measures have the potential for increasing the electrical demand of an existing motor system when the motor operates at full load, the metering requirements will be more stringent than for most measures. VSD installations can be broadly categorized as either weather dependent/driven (HVAC motors) or schedule driven (process equipment), and each of these provide a unique set of challenges for pre/post-metering to insure that actual peak-demand savings are achieved.

Weather-dependent VSD installations must be metered during times of ambient conditions when the summer and winter peaks are likely to occur so that regression models of performance can be reliably established for both the pre- and post-periods. HVAC equipment and refrigeration equipment consisting of fans and pumps will be the primary type of weather dependent equipment controlled by VSDs.

Figure 4 and Figure 5 provide generic plot curves that show percent of full-flow motor load as a function of flow for fans and pumps, respectively. Figure 4 includes three baseline control strategies for the fans, bypass, inlet guide vanes (IGV), and outlet damper with no control. The IGV and outlet damper fan controls have a maximum percent power of 109% and 111%, respectively at 100% flow, which is higher than the 105% power usage of a VSD-controlled fan at 100% flow. As a result, both of these baseline control types will have a higher demand at all loads than when a VSD is installed to control the fan. When fans are controlled using the bypass method the demand will be about 5% higher with a VSD if the fans are operating at 100% flow. However, under most loading, the bypass baseline-control method yields the highest demand reduction at less than 100% flow.[25]

Figure 4. Fan Power as a Function of Flow and Control Method

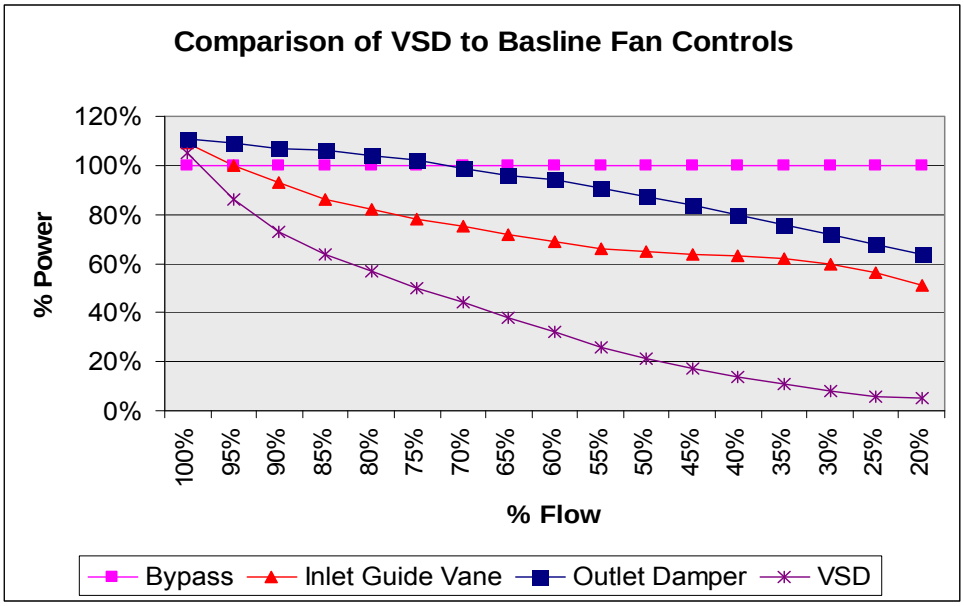
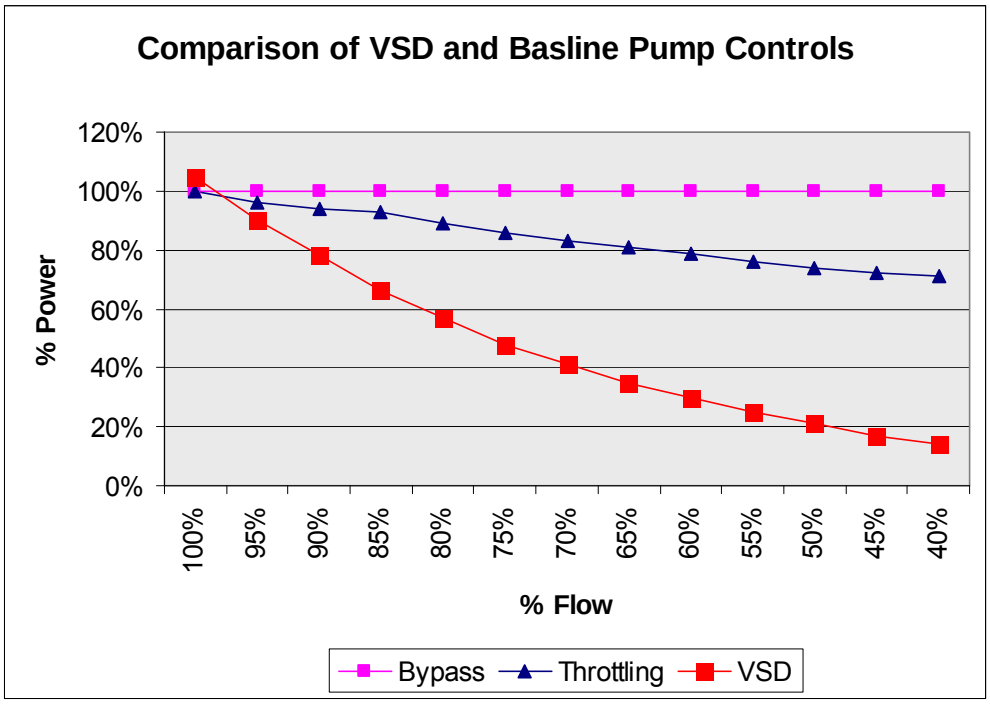


Figure 5 shows two baseline control methods for the pumps, bypass, and throttling. Both of these baseline controls use 100% power at 100% load and VSD-controlled pump motors have a 5% increase in demand at

[25] The source of these percentages is from Electric Power Research Institute Adjustable Speed Drives Directory, Table 3.1, 1991.

100% flow. Demand reductions are achieved at most flow rates below 100%, and, therefore, if the pre/post metered data indicate that the pump flows are always maintained below about 95% of maximum flow, there should be demand reduction for weather-sensitive pumps controlled by VSD.

Figure 5. Pump Power as a Function of Flow and Control Method



Process motor applications are an area of great concern when they are directly linked to the output of product because short-term metering provides no assurance that production schedules won't be increased to levels that negate any demand reduction observed during pre/post metering periods. In order to address this concern, it will be necessary to provide a thorough description of the process and the equipment that will be controlled by the VSDs and any factors within the production process itself that would limit the ability of the controlled equipment to operate at full speed. It must be clearly indicated that controls are in place that would physically limit operation of the VSD-controlled motor to less than 100% of full load. In some cases there is ancillary equipment, such as process chilled water pumps for cooling troughs that would operate at the same speed regardless of production rates. These types of applications need to be described in sufficient detail so that a qualified technical reviewer can determine that the pre/post-meter data provide an accurate estimate of the demand reduction that would be expected during TVA system peaks. If this criterion cannot be met, then the measure will not be credited for demand reduction.

7.6.3 VSD-Measurement Plan Requirements

The following sections describe the required elements for conducting a comprehensive plan for measure energy and demand use of motors with and without a VSD.

Equipment Surveys

A survey of the equipment affected with the retrofit is required. The surveys must include, in an organized format, the following:

- Motor horsepower, type, and electrical efficiency
- Motor application or load served (e.g., cooling tower fan motors)
- Operating schedule (e.g., 7 a.m. to 7 p.m. weekdays)
- Spot- and short-term metering data
- Location in the subject facility and corresponding building floor plans

For the post-installation survey, the VSDs should be inventoried with nameplate data. If new motors are installed, their nameplate data should also be reported.

Measurements

For the existing motors, a spot measurement of the full-load, kW energy demand is required. It may be necessary to manually adjust control devices to achieve the maximum motor loading, i.e., power draw. Such measurements should be made using a true RMS meter with accuracy at or approaching ± 2% of reading. A sample of motors can be spot metered using the sampling criteria described below if a large number of motors are to be replaced within a single facility.

Post-installation monitoring of kW is required for all VSD installation retrofits at 15-minute intervals continuously, or for a set period that can be extrapolated to the entire year. A minimum monitoring period of one month is recommended. For situations in which motor operating hours might vary seasonally or according to a scheduled activity, such as in HVAC systems, it may be necessary to collect data during different times of the year. The results from the monitoring are used to determine the kW peak demand and annual kWh consumption (as well as hours).

If monitoring is only for a set period, then this period should include typical motor operation during periods and at extreme maximum loads the motor may experience. For HVAC motors, in most cases, the fan and/or pump may be oversized. This "oversizing" must be analyzed using acceptable methods to show that they were oversized for design conditions, as well as maximum potential loads during the peak period (and if design conditions are ever met). For non-HVAC motors, the metering period must show the extreme conditions achievable. The variables monitored include:

- Motor power draw (kW or amps, typically at 15 minute intervals)
- Motor energy consumption (kWh) and run time (hours)

All short-term monitoring must be of a sufficient length of time to capture the full range of operation of the motors. A minimum monitoring period of one month is recommended for almost all applications. However, the actual time and frequency required will be specific to each project. Short-term monitoring can be conducted using current transducers and data loggers. The equipment for short-term metering needs to be accurate only within ± 2% of full scale, and the metering equipment must have been calibrated within the past two years. Data loggers must record readings on intervals of fifteen minutes or less.

Short-Term Monitoring

Baseline or post-installation monitoring, preferably at 15-minute intervals, is required for true RMS kW and all applicable variables. This information is used to establish a relationship between kW and the independent variables (such as outdoor air temperature or system pressure) prior to and post-installation of the VSD. The applicable variable can be time, so short-term monitoring is conducted to develop a motor schedule that

can be defined within bins. All short-term monitoring must be of a sufficient length of time to capture the full range of operation of the motors and particularly indicate the operation during the peak period. All the data input to the model must be thoroughly documented.

The statistical validity of the regression model will need to demonstrate that:

- The model explanatory variables are reasonable and the coefficients have the expected sign (positive or negative) and are within an expected magnitude.
- The modeled data represent the population.
- The T-statistic for all key parameters in the model is at least two (95% confidence that the coefficient is not zero). R2 values are at least 80%.
- The model is tested for possible statistical problems and, if present, appropriate statistical techniques are used to correct for them.

For post-installation monitoring, the motor (with VSD) kW, kWh, operating hours, and the relevant variables defined in the baseline model or equations must be monitored. The independent variables may be modeled/calculated/short term monitored to develop the equation that defines the relationship between the post-installation kW and the applicable variables.

Sampling

If VSDs are installed on a number of motors, the required metering may only need to be performed for a sample of motors. Similar motors in similar applications are considered to have similar energy use characteristics and savings. Thus, the sample results are applied to the entire population of retrofitted motors. With sampling, motors are classified into usage groups with other motors having similar operating characteristics and expected operating hours. Examples of usage groupings include constant-volume supply fans, process motors, and exhaust fans. To establish a statistically valid sample, the sample criteria need to be documented. It is recommended that a relative precision of ±10% at a confidence interval of 90% using a one-tail test be the target statistical precision. A more detailed discussion of statistical sampling is provided at the beginning of this appendix.

7.6.4 Calculating Energy Savings

The analysis depends on whether pre- and post-installation operating hours are assumed to be the same and if kW or kWh is monitored. The following methods apply only to the situation where **operating hours are the same before and after** measure installation:

- Using kW post-installation monitoring (assume 15 minute intervals) — Calculate energy during period and extrapolate to the whole year. Energy savings, kWh, for one data point equals 0.25 hr x (kWbase – kWpost)
- Using kWh and hours post-installation metering— Calculate the kWh savings for the monitoring period (e.g., one month), use the following equation, and then extrapolate for the year: (kWbase x operating hours – kWhpost)

Method: Constant Baseline

If the baseline energy use or power is a single, constant value while the existing motor is operating, the load is constant. The process of determining savings is reduced to monitoring the post-installation power consumption and subtracting it from the baseline (constant) power consumption to obtain the savings for the monitored time interval. No performance curves are required.

Method: Variable, Baseline-Performance Curves with Metering

This method makes use of industry accepted performance curves (in the form of equations) for fan and pumping systems to estimate a motor's energy consumption at different system output levels.[26] If the motor with the VSD installation is not changed from the system for which a performance curve was developed, then this method can be used.[27]

An equation is defined using performance curves (e.g., fan curves) prior to VSD installation that indicate the relationship between baseline energy use and applicable variables for each operating scenario (e.g., kW vs. flow). It is assumed that the installation of the VSD does not change the system requirements (e.g., water or air-flow), and that a common variable (e.g., ambient temperature or system pressure) can be used to relate the post-installation values of the variable(s) to the baseline energy consumption.[28]

Method: Variable Load--Correlating Power to Independent Variable Values

With this method, a regression-based equation is established between the baseline and post-installation energy consumption and all significant variables (such as flow). Then after VSD installation, demand- and operating-hour data are collected, and the same applicable significant variables defined for the baseline equation are monitored. Using the baseline equation, with the values of the applicable variables in the post-installation phase, the baseline kW values are determined ("adjusting the baseline"). Thus, demand savings are calculated for each post-installation time interval.

Calculating Baseline Energy Use with Post-Installation Data

After having developed the baseline regression model or equations, savings can be calculated using one of two different methods, depending on what data are collected after the VSD(s) are installed:

- If just post-installation power consumption is monitored. Insert the post-installation power-consumption data into the post-installation regression model or equations to determine the value of the applicable variables. Then insert the value of the applicable variables into the baseline model or equations to determine the baseline energy consumption given the same values of the applicable variables.
- If post-installation power consumption and the applicable variables are monitored. Inserting the values of the applicable variables into the baseline model or equations, determine what the baseline power consumption would have been, absent the installation of the VSDs, but under post-installation conditions.

Monitoring for Operating Hours

[26] Acceptable sources for performance curves are nationally recognized associations of professionals working in the industry, such as ASHRAE, or reliable scientific sources (such as the curves used in DOE-2 or BLAST).

[27] If the performance curve is for inlet vanes, then the curves cannot be used for fans using other flow control devices.

[28] A detailed discussion of this savings calculation is provided in ASHRAE Standard 90.1.

If the operating hours of the motors will change as a result of the project, the baseline and post-installation operating hours must be established separately with short-term (baseline) or long-term (post-installation) monitoring on at least a sample of motors.

The operating hours for the baseline motor and motor with VSD must provide the ability to model the runtime in bins (such as 4,000 hours per year at 50 kW, or 25% speed). The duration and timing of the installation of run-time monitoring have a strong influence on the accuracy of operating hours estimate. Run-time monitoring should not be installed during significant holiday or vacation periods, and if the VSD-controlled device has seasonally variable loading, then monitoring must be installed for each season.

7.7 Chiller Replacement M&V Guidelines

The measurement plan for chiller replacement includes a discussion of two approaches to conducting M&V: a simple, conservative approach based on rated equipment efficiencies and a more complex approach that captures variations in equipment performance. The methods discussed here can be applied when replacing existing chillers with high efficiency chillers and there is no change to the cooling load (methods assume the same load for the baseline and retrofit chiller).[29] These M&V methods are applicable to chillers used for space conditioning and process cooling and require the following:

- Minimum baseline-chiller-efficiency standards are applicable whether they are used for space conditioning or process applications
- Metering of the retrofit chiller electricity consumption

The following issues should be addressed in the M&V plan for chiller projects:

- M&V method selected
- Change in chiller capacity and how it impacts M&V
- If the existing chiller(s) meets minimum standards, if not, adjust the baseline to meeting standards
- The source for baseline and new chiller efficiencies
- The time period for monitoring of kW, independent variables, and/or operating hours

The baseline issues are important since demand and energy savings are due to increases in chiller efficiency above the minimum-efficiency standard, in this case IECC 2009 or other code based on the local jurisdiction. Efficiency is based on condenser type (air-cooled or water-cooled) and full-load capacity as rated by the Air Conditioning, Heating, and Refrigeration Institute (AHRI). Chiller efficiency standards are indicated by Integrated Part-Load Value (IPLV) and AHRI full-load-rated Coefficient of Performance (COP).

7.7.1 Approaches to Chiller M&V

There are two M&V methods described here:

- The simple approach only requires monitoring of the retrofit chiller electricity use and multiplying by the ratio of baseline efficiency to proposed efficiency. This method is limited to estimating savings based on changes to efficiency only and assumes that the baseline and retrofit chillers operate identically. The simple approach should provide a conservative estimate of savings under these assumptions however, if there are changes to the operation of the retrofit chiller then the complex method should be used.
- The complex approach requires monitoring post-installation chiller energy use and the cooling load.

[29] If there is a change in cooling, a different M&V method must be considered. This method is discussed in the section on Generic Variable Load M&V Guidelines.

This load is then applied to the baseline chiller efficiency curve[30] to capture increased part-load performance with extensive data collection and analysis. This method estimates savings for both efficiency improvements and changes in performance characteristics such as the part load efficiency.

- When considering what approach to use for M&V, the primary considerations are:
- Chiller unloading capability[31]
- Existing controls and instrumentation

If the chiller has unloading capabilities and instrumentation that monitors flow and supply and return chilled water temperatures, then the M&V plan should utilize the complex approach.[32] In order to properly capture the savings from improved part-load operation associated with the proposed chiller, monitoring of the post-installation temperature and flow data is necessary.[33]

Simple Method

The following steps are required with the simple method:

- Determine baseline/minimum-standard efficiency in terms of COP
- Determine new chiller-efficiency COP
- Measure new chiller interval energy-use (kWh)
- Calculate savings

Since this method uses only post-retrofit metered data, it is necessary to estimate the baseline energy consumption, and the savings are determined by using a savings ratio. The savings ratio is calculated by using the full load COP of the baseline chiller over the installed chiller. The applicable baseline COP is the higher of the existing chiller or the minimum standard. The following equations are used to calculate savings:

$$\text{kWh base} = \text{kWh new} \times (\text{COP base} / \text{COP new}) \quad \text{and}$$

$$\text{kWh savings} = \text{kWh base} - \text{kWh new} \quad \text{where,}$$

Where,

COP base = full load COP of the baseline chiller

COP new = full load COP of the new chiller

kWh new = annual energy consumption of new chiller measured

kWh base = annual energy consumption of baseline chiller calculated

kWh savings = annual energy savings of the chiller retrofit calculated

This calculation is sufficient if the existing and proposed chiller operate the same. Additionally, the monitored period must be representative of a year's worth of chiller operation for extrapolation. A similar equation is used to determine the peak-demand savings where the kW of the new chiller is measured during peak hours and the COP savings ratio is applied to calculate the baseline kW as shown below.

[30] This curve may not be easily available. Standard curves are available and discussed later in this section.

[31] Chiller unloading capability refers to how the chiller operates at part-load or non-standard conditions.

[32] This approach is not commonly used.

[33] Note that the collection of accurate temperature and flow data can be expensive, and the benefit of intensive analysis needs to be weighed against the cost of data collection. However, if the chiller is outfitted with controls and instrumentation to monitor flow rates and temperatures, then it may be advantageous to use the complex method.

$$kW\ base = kW\ new \times (COP\ base / COP\ new) \quad \text{and}$$

$$kW\ savings = kW\ base - kW\ new$$

Where,

COP base = full load COP of the baseline chiller

COP new = full load COP of the new chiller

kW new = peak demand of new chiller measured during TVA peak hours

kW base = peak demand of baseline chiller calculated

kW savings = peak demand savings of the chiller retrofit calculated

The peak demand of the retrofit chiller is typically not at 100% of the rated capacity of the new chiller because it is a function of the building cooling load or process cooling load at the time of the TVA system peak.

Complex Method

This method requires that the performance of the baseline chiller to be modeled using the operating characteristics defined by TVA and provided in the baseline chiller performance spreadsheet tool.[34] The steps needed to model the chiller's performance are:

- Calculate the current (post-installation) cooling load in tons.
- Calculate the current chiller capacity.
- Calculate the current part-load ratio (PLR).
- Calculate the correction-to-input power for the PLR.
- Calculate the correction-to-input power for current chilled water supply and condenser water return temperatures.
- Calculate the electrical demand for the current time period.
- Calculate the annual electricity savings.

Each of these steps is described in detail below. The following is a description of notation used for the calculations.

Table 9. Variables for M&V (Complex Method) of Chillers

Variable	Description
$Tons_i$	Current cooling output from chiller
CHWF	Chilled water flow (gallons per minute)
ECHWT	Entering chilled water temperature (return temperature, °F)
LCHWT	Leaving chilled water temperature (supply temperature, °F)
CWT	Condenser water temperature (°F)
500	Conversion from GPM to pounds per hour (Eqn. 1)
1	Btu per pound-degree Fahrenheit (Eqn. 1)

[34] TVA has adopted the baseline chiller performance curves developed by the California Energy Commission and provided in Appendix C Minimum Equipment Efficiency Standards dated April 2, 2010, which can be obtained at the following link. http://www.aesc-inc.com/download/spc/2007spcdocs/PGE/PG&E%20C%20Min%20Equipment%20Efficiency.pdf

Variable	Description
12,000	Conversion from Btuh to tons (Eqn. 1)
CAP_{nom}	Nominal capacity of chiller
kW_{nom}	Nominal or full-load chiller demand (kW)
$LCHWT_{nom}$	Leaving chilled water temperature (supply temp. °F) at nominal rating conditions
CWT_{nom}	Condenser water temperature (°F) at nominal rating conditions
CAP_{ref}	Reference capacity of chiller for a given curve
kW_{ref}	Reference full-load chiller demand (kW) for a given curve
CAP_{i}	Current capacity of chiller
PLR_{i}	Current part-load ratio
kW_{i}	Current chiller demand (kW)
PLR_{Adj}	Adjustment to input power due to part load
$Temp_{Adj}$	Adjustment to input power due to chilled and condenser water temperatures

Step 1

Calculate current cooling load based on the flow and temperature data collected with stand-alone instrumentation or, if possible, an energy management system (EMS). In the event that a Btu meter is used, this step will be simplified in that no conversion to tons will be required. Use the following Equation 1 to compute the tons of cooling currently being provided by the chiller.

Equation 1:

$$\mathrm{Tons_i} = \frac{(\mathrm{CHWF})(500)(\mathrm{ECHWT} - \mathrm{LWHWT})(1)}{12{,}000}$$

Step 2

Calculate the reference capacity and power for the chiller based on a nominal rating and the curve coefficients. The equation used is bi-quadratic, with the coefficients defined by the TVA.

Equation 2:

$$\mathrm{CAPFT}(\mathrm{LCHWT_{nom}}, \mathrm{CWT_{nom}}) = \mathrm{a} + \mathrm{b}(\mathrm{LCHWT_{nom}}) + \mathrm{c}(\mathrm{LCHWT_{nom}})^2 + \mathrm{d}(\mathrm{CWT_{nom}}) + \mathrm{e}(\mathrm{CWT_{nom}})^2 + \mathrm{f}((\mathrm{LCHWT_{nom}})(\mathrm{CWT_{nom}})$$

Where,

the coefficients a – f are provided in **Error! Reference source not found.** and **Error! Reference source not found.**, and the capacity as a function of LCHWTnom and CWTnom is provided as a decimal percentage of the nominal capacity. For most chillers the LCHWTnom is 44ºF and the CWTnom is 85ºF for water cooled chillers.

Equation 3:

$$\mathrm{EIRFT}(\mathrm{LCHWT_{nom}}, \mathrm{CWT_{nom}}) = \mathrm{a} + \mathrm{b}(\mathrm{LCHWT_{nom}}) + \mathrm{c}(\mathrm{LCHWT_{nom}})^2 + \mathrm{d}(\mathrm{CWT_{nom}}) + \mathrm{e}(\mathrm{CWT_{nom}})^2 + \mathrm{f}((\mathrm{LCHWT_{nom}})(\mathrm{CWT_{nom}})$$

Where,

the coefficients a – f are provided in Table 10 and Table 11**Error! Reference source not found.**, and the Electrical Input Ratio (EIR) as a function of LCHWTnom and CWTnom is provided as a decimal percentage of the nominal EIR. The EIR is equal to the inverse of the Coefficient of Performance (COP) which is the ratio of output (BTU) over input (BTU). Therefore, EIR is equal to the ratio of input (BTU) over the output (BTU). Table 10Table 10 is provided to show how common efficiency terms are converted to EIR values.

Table 10. Converting Common Efficiency Terms to EIR

kW/Ton	EER (BTU/W)	COP (BTU_{out}/BTU_{in})	EIR (BTU_{in}/BTU_{out})	kW/Ton
0.6	20	5.86	0.17065	0.6
Step 1: EER = 1/kW/Ton x 12				
Step 2: COP = EER x 1/3.413				
Step 3: EIR = 1/COP				
Step 4: kW/Ton = EIR x 12/3.413				

Equation 4:

$$\mathrm{EIRFPLR}(1.0) = \mathrm{a} + \mathrm{b} + \mathrm{c}$$

Equation 5:

$$\mathrm{CAP_{ref}} = \frac{\mathrm{CAP_{nom}}}{\mathrm{CAPFT}(\mathrm{LCHWT_{nom}}, \mathrm{CWT_{nom}})}$$

Equation 6:

$$\mathrm{kW_{ref}} = \frac{\mathrm{kW_{nom}}}{\mathrm{CAPFT}(\mathrm{LCHWT_{nom}}, \mathrm{CWT_{nom}}) \times \mathrm{EIRFT}(\mathrm{LCHWT_{nom}}, \mathrm{CWT_{nom}}) \times \mathrm{EIRPLR}(1.0)}$$

Step 3

Calculate current capacity. Since the capacity of the chiller will vary from the rated capacity depending on the actual supply and condenser water temperatures, a capacity adjustment must be calculated. The current capacity of any chiller is a function of the nominal capacity and the current chilled water and condenser water temperatures.

Equation 7:

$$CAP_i = CAP_{ref}\ [\ a + b(LCHWT) + c(LCHWT)^2 + d(CWT) + e(CWT)^2 + f(LCHWT)(CWT)]$$

Where,

the coefficients "a" through "f" are defined by the TVA based on the chiller capacity and condenser type. Coefficients for all chiller types can be found at the end of this section. The equation used is bi-quadratic, with the coefficients defined by the TVA and the resulting CAPi is the normalized decimal percentage value of the capacity. For example if the chillers capacity is 105% of the nominal value the current LCHWT and CWT values, then the CAPi would equal 1.05.

Step 4

Calculate the current part-load ratio: simply the ratio of current tons to current capacity, the two quantities that are calculated with equations 1 and 2.

Equation 8:

$$\mathrm{PLR_i} = \frac{\mathrm{Ton_i}}{\mathrm{Cap_i}(\mathrm{CAPFT}(\mathrm{LCWT_i}, \mathrm{CWT})_\mathrm{i})}$$

Where,

CAPFT is calculated using the actual measured temperature and the formula from Equation 2 above.

Step 5

Calculate the part-load adjustment to the nominal chiller kW. This adjustment is accounting for both the change in performance due to off-peak loading as well as the off-peak loading itself. The result of this equation is a multiplier to be used with the baseline chillers' nominal, full-load demand, to estimate consumption at the given part load.

Equation 9:

$$\mathrm{PLR_{Adj}} = \mathrm{a} + \mathrm{b}(\mathrm{PLR_i}) + \mathrm{c}(\mathrm{PLR_i})^2$$

The coefficients are provided in Table 13 and Table 15.

Step 6

Calculate the ambient adjustment to the nominal chiller kW. Similar to the part-load adjustment, this adjustment factor accounts for the change in nominal chiller performance as a function of condenser and supply water temperatures that are observed as the retrofit chiller is operating.

Equation 10:

$$\mathrm{Temp_{Adj}} = \mathrm{a} + \mathrm{b}(\mathrm{LCHW}) + \mathrm{c}(\mathrm{LCHW})^2 + \mathrm{d}(\mathrm{CWT}) + \mathrm{e}(\mathrm{CWT})^2 + \mathrm{f}(\mathrm{CHWT})(\mathrm{CWT})$$

Step 7

Calculate the current baseline chiller kW (kWi) using the measured demand from the post retrofit chiller kWref. Using the part-load and temperature adjustment, factors that have just been developed, calculate the current chiller demand as the product of nominal chiller demand, PLRAdj, and TempAdj.

Equation 11:

$$\mathrm{kW_i} = \mathrm{kW_{ref}}(\mathrm{PLR_{Adj}})(\mathrm{Temp_{Adj}})(\mathrm{CAPFT}(\mathrm{LCHW_i}, \mathrm{CWT_i}))$$

Note that the above equation produces the average baseline kW for the interval associated with the data collected. Given that data are logged during a 15-minute time interval, the average kW estimated will need to be multiplied by 0.25 hours to convert from kW to kWh. For M&V purposes, average hourly values for temperatures and flows will be computed summing the four 15-minute data points contributing to each hour's worth of data.

Step 8

Energy savings for each time interval (hour) will be calculated by determining the power reduction for that time interval and multiplying by the time interval, using the following equations:

$$\text{kWh Savings} = (\text{kW Savings}) \times (1 \text{ hour})$$

$$\text{kWh Savings}_{annual} = \text{Sum}(\text{kWh Savings for all time intervals in the year})$$

Where,

$\text{kWh Savings}_{annual}$ = annual energy savings [kWh]

kW Savings = ($kW_{baseline}$ - kW_{post}), the demand savings during a given metering time interval

$kW_{baseline}$ = kilowatt demand the baseline chiller would have required if the new chiller had not been installed, as calculated by the procedure presented above

kW_{post} = kilowatt demand of the new chiller during the post-installation time interval [kW] as recorded by the EMS, or data collection system

The following series of tables (Table 10 through Table 13) provide the default coefficients for the chiller types and condenser types. These are the default coefficients that should be used to calculate the baseline chiller demand procedures described above.

Table 11. Default Capacity Coefficients – Electric Air-Cooled Chillers

Coefficient	Scroll	Recip	Screw	Centrifugal
a	0.40070684	0.57617295	-0.09464899	N/A
b	0.01861548	0.02063133	0.03834070	N/A
c	0.00007199	0.00007769	-0.00009205	N/A
d	0.00177296	-0.00351183	0.00378007	N/A
e	-0.00002014	0.00000312	-0.00001375	N/A
f	-0.00008273	-0.00007865	-0.00015464	N/A

Table 12. Default Capacity Coefficients – Electric Water-Cooled Chillers

Coefficient	Scroll	Recip	Screw	Centrifugal
a	0.36131454	0.58531422	0.33269598	-0.29861976
b	0.01855477	0.01539593	0.00729116	0.02996076
c	0.00003011	0.00007296	-0.00049938	-0.00080125
d	0.00093592	-0.00212462	0.01598983	0.01736268
e	-0.00001518	-0.00000715	-0.00028254	-0.00032606
f	-0.00005481	-0.00004597	0.00052346	0.00063139

Table 13. Default Efficiency EIR-FT Coefficients – Electric Air-Cooled Chillers

Coefficient	Scroll	Recip	Screw	Centrifugal
a	0.99006553	0.66534403	0.13545636	N/A
b	-0.00584144	-0.01383821	0.02292946	N/A
c	0.00016454	0.00014736	-0.00016107	N/A
d	-0.00661136	0.00712808	-0.00235396	N/A
e	0.00016808	0.00004571	0.00012991	N/A
f	-0.00022501	-0.00010326	-0.00018685	N/A

Table 14. Default Efficiency EIR-FT Coefficients – Electric Water-Cooled Chillers

Coefficient	Scroll	Recip	Screw	Centrifugal
a	1.00121431	0.46140041	0.66625403	0.51777196
b	-0.01026981	-0.00882156	0.00068584	-0.00400363
c	0.00016703	0.00008223	0.00028498	0.00002028
d	-0.00128136	0.00926607	-0.00341677	0.00698793
e	0.00014613	0.00005722	0.00025484	0.0000829
f	-0.00021959	-0.00011594	-0.00048195	-0.00015467

Table 15. Default Efficiency EIR-FPLR Coefficients – Air-Cooled Chillers

Coefficient	Scroll	Recip	Screw	Centrifugal
a	0.06369119	0.11443742	0.03648722	N/A
b	0.58488832	0.5459334	0.73474298	N/A
c	0.35280274	0.34229861	0.21994748	N/A

Table 16. Default Efficiency EIR-FPLR Coefficients – Water-Cooled Chillers

Coefficient	Scroll	Recip	Screw	Centrifugal
a	0.04411957	0.08144133	0.33018833	0.17149273
b	0.64036703	0.41927141	0.23554291	0.58820208
c	0.31955532	0.49939604	0.46070828	0.23737257

7.8 Generic, Variable-Load / Process M&V Guidelines

This section discusses M&V methods for evaluating projects that result in improved efficiency where the end use has variable load or operating hours. These may include:

- Installing or upgrading an energy management system
- Installing new industrial process equipment or systems
- Comprehensive chiller plant modifications
- Air compressor system upgrades

Most measures can be monitored and savings verified using this method. However, measures that indirectly affect systems, such as envelope improvements, cannot be accurately quantified using post installation metering. The use of post-installation metering normally requires the following four steps:

- Auditing of the pre-installation system(s) and documenting relevant components (e.g., diagrams, existing controls, and equipment operation).
- Establishing a baseline model using key independent variables (e.g., weather or cooling load) to establish regression-based equations. Adjustments to the baseline may be required to comply with minimum energy-efficiency standards.
- Continuous monitoring or monitoring of a representative sample period (and extrapolate to a typical year) of energy use and/or independent variables such as weather for the installed project.
- Calculating the baseline energy use using the regression developed under step 2. Then calculate the savings by subtracting the post-installation energy use from the baseline energy use.

Two general approaches for determining savings are summarized here:

- Monitor energy use for a sufficient period of time and the appropriate independent variables of the

installed measure(s). Then use the post-installation variables monitored to create the baseline regression model used to calculate baseline energy use.

- Measure only the appropriate independent variables after measure installation for a sufficient period of time to reliably establish the annual operating schedule. Then the measured data are used with baseline and post installation models to calculate the baseline and retrofit energy use, respectively. This approach requires that the relationship between energy consumption and the independent variable be reliably established for both the pre- and post-retrofit conditions.

The second approach should only be utilized where there is a strong and stable correlation between the electrical power usage and the independent variables.

Specific M&V issues that need to be addressed prior to monitoring for generic variable-load projects include:

- Determine whether to monitor energy use or post-installation independent variables
- Determine modeling methodology for baseline and post-installation model (if used)
- Define baseline and how to incorporate minimum energy-efficiency standards, if necessary
- Identify appropriate variables
- Establish length of monitoring period(s)

7.8.1 Baseline M&V Activities

Prior to the installation of any energy efficiency measures, it is required that an audit of all existing equipment affected by the proposed measure(s) be completed, and a baseline energy consumption model be developed based on metered system data.

The audit of the baseline system should include documentation of all relevant components, such as motors, fans, pumps, refrigeration compressors, and controls. The data should include the manufacturer, model number, rated capacity, energy-use factors (e.g., voltage, amperage, and phase), nominal efficiency, the load served, and any independent variables that affect system energy consumption.

Establishing the Baseline or Retrofit Model

The first step is to monitor the following variables simultaneously, typically in 15-minute intervals:

- Independent variables that affect energy use, which may include outside air temperature, control signals, chilled-water flow rate, cooling tons, building occupancy, and production output.
- Meter energy use (e.g., kW, amps, hours, kWh, and/or other representative variable) of the equipment affected by the efficiency measure over a representative time period that is sufficient to document the full range of system operation. The M&V plan should include the proposed metering duration, which will be subject to the TVA program administrator's approval.

The energy use of most projects will be influenced by independent variables, and for these projects a model must be developed. The next step is to develop the regression equations[35] that link independent-variable data to energy use. The regression analysis used must be statistically valid, which is determined by the following criteria:

- The model/equation makes intuitive sense; such as, the independent variables are reasonable and the coefficients have the expected sign and are within an expected magnitude.
- The data represent the population and the range of operation.

[35] Other models to establish a relationship may be considered.

- The model's form conforms to standard statistical practice and modeling techniques for the system in question.
- The number of coefficients is appropriate for the number of observations.
- The T-statistic for all key parameters in the model is greater than or equal to two, to indicate 95% confidence, and that the coefficient is not zero.
- The R-squared is at least 80%.
- All data used by the model are thoroughly documented and the model validity limits (range of independent variables for which the model is valid) are specified.

Raw data must be included with the project submittal and reviewed by the implementer. TVA will make the final decision on the validity of the models and monitoring plans and may request additional documentation, analysis, or metering when needed.

7.9 Energy Savings Devices (ESDs)

When measurements are required to verify the performance of an energy-savings device, it should be the responsibility of the applicant. However, the implementer must ensure that the measurements are done correctly particularly for energy-savings devices. These devices are considered to be black boxes. These devices, in most cases, do not demonstrate measurable and verifiable energy and/or demand savings, but may be good energy management practices. Below is a list of the potential non-qualifying projects/ retrofits.

- Power Conditioning:
- Power-factor correction
    - Harmonic current reduction
    - Transient voltage protection
    - Installation of voltage- and power-reducing equipment
    - Lighting-voltage regulation devices. Such devices can immensely impact the lighting level and/or lights efficiency, but may be considered. If reducing light levels can be an option to reduce energy use, the customer is encouraged to elect different options such as partial delamping with lighting retrofits.
    - Other power-conditioning measures (e.g., uninterruptible power supplies, rectifiers)
- Black-Box Solutions:
    - Software, hardware, system, or material whose functioning cannot be explained by applying mainstream engineering knowledge and theories, and whose efficiency is not and/or cannot be supported with certified test results.[36]

To support energy-savings claims for questionable projects or technologies, third-party, independent test results that are recognized by the program implementation team as appropriate, or a proposed measurement and verification methodology (to be implemented by applicant) should be submitted directly to the program team for review. Below is a suggested M&V plan that implementers should have applicants use to ensure the device does save peak demand and energy.

7.9.1 Protocol for M&V of ESDs

[36] This could include refrigerant additives.

The implementer may just copy this protocol and send it to an applicant interested in pursuing the installation of an ESD.

The plan must include a project description:

- Describe the project, the products and technologies used, and how they will be employed. List all facilities, buildings, or equipment that will be affected by the project. State whether the project involves reduction of base-load demand, reduction of peak electricity demand or energy consumption, or load shifting.
- Current equipment configuration:
    - Concise description of the existing energy systems to be affected
    - Location of affected equipment
    - Condition and age of equipment if a degradation in nameplate efficiency is assumed
    - Hours of operation of the affected equipment
    - Number of existing units
    - Ratings of equipment (name, efficiency, capacity, wattage, nameplate, tonnage, voltage, etc.)
    - Facility physical description and occupancy (including activities, hours of operation).
    - Control and operating characteristics of affected equipment
    - New equipment configuration, including detailed description of the installed ESD
    - ESD information, such as name, model, efficiency, capacity, rating, performance specifications, and independent test results, as available and if different than existing equipment

The next step is to collect a set of measurements which should provide baseline and post-retrofit electrical-demand and energy-use levels. The following are suggested steps:

- Measure energy (kWh) and/or demand (kW) to establish a baseline level. The data provided for demand must cover the range of conditions experienced by the device. Provide descriptive information on the following:
    - Metering and other equipment used
    - Methodology:

Test durations
List of parameters monitored

- Energy and demand – In some cases, amps and/or amp-hours will be sufficient. In other case, three-phase measurements will be required, which will include amps and volts of each leg.
- Other variables that may affect energy savings, such as load variations, hours of operation, indoor/outdoor temperature, occupancy level, flow rates, and production volume.

Data analysis performed

- This may include regression analysis or other means of developing a baseline relationship between the variables and the level of demand or energy usage experienced; for example, a relation between flow rate and kW levels.
- Other data tabulations, summarizations, or analysis procedures.

Supporting calculations
Other, as applicable

- List all assumptions used in the calculations and operating conditions used to establish the baseline level.

- To the extent possible, the post-installation should be done under the same conditions and time periods as the baseline. Provide the same level of descriptive information on testing as was provided for the baseline testing.

  - List all assumptions used in the calculations and operating conditions used to establish the post-installation level.

To calculate the savings, the applicant should provide the following:

- Provide a tabulation of energy use and demand reduction based on the results of the pre- and post-installation testing. Describe any adjustments done to account for changes in variables, such as indoor/outdoor temperature, occupancy, flow rates, and production volumes.
- Project results to obtain annual energy (kWh) savings.
- Analyze results to determine summer and/or winter peak demand reduction.[37]

General Issues

The implementation team reserves the right to inspect the premises, be present for monitoring activities, require additional tests and/or calculations, and perform various checks, as needed, to determine the validity of claimed annual energy-savings and peak-demand reduction. In addition, the implementation team may do additional monitoring to duplicate results.

These guidelines must be followed in adequate depth to fully support all energy and/or demand savings claims. M&V results not accurate or detailed enough to fully support savings claims may result in a reduced or disallowed rebate award.

M&V conducted on one project may be applicable to a similar project, and may reduce requirements for detailed M&V. If more than one ESD is installed for a project, sampling may be appropriate.

Acceptable third-party verifiers of the ESD technology may be appropriate. This will be granted on a case-by-case basis.

7.10 Billing Analysis M&V Guidelines

To calculate energy savings, utility interval billing data[38] can be used to develop regression-based models. The use of utility billing analysis (Option C) should be limited to situations where the use of other options (primarily Options B or D) is not viable and when an accurate model can be developed. This option is considered to be the least-preferred M&V option because:

- Twenty-four months of historical billing data and independent variable data to establish the baseline is required.
- It is necessary to use at least nine months and preferably 12 months of post-installation billing data and independent-variable data prior to calculate first-year savings.
- It is difficult to accurately accomplish the following tasks:

[37] The peak demand period are between 6:00 a.m. and 8:00 a.m. Central Prevailing Time (CPT) during all weekdays from December 1 - March 31 for winter and 3:00 p.m. to 5:00 p.m. CPT, July 1 to August 31 for summer, inclusive, of such delivery year, that is not a weekend or federal holiday. The peak demand savings can be calculated as the average during the peak period, but must show that at no instance the post-installation demand during the peak period exceeds the pre-installation during the same period and operating conditions.

[38] Interval billing data is typically 15-minute (or hourly) kW which provides the necessary information to determine demand during the peak period.

- Adjust the baseline to meet minimum energy standards. If required, then an alternate method should be considered.
- Adjust the energy savings due to changes in facility operation or occupancy during the year-long M&V period.
- Obtain data for the relevant independent variables that affect savings.

- Conducting a billing analysis requires experience with statistical concepts and data analysis.

Billing regression analysis is appropriate for projects in which the affected equipment has a dedicated utility interval meter (such as a chiller plant), equipment is not subject to a minimum standard, and/or there are not too many (one or two) relevant independent variables.

Typically, multivariate regression is used to adjust baseline, and, in some cases, post-installation energy-consumption estimates for non-retrofit-related factors. If the necessary data on independent variables, such as weather, occupancy, and operating schedules are available, the technique will result in more accurate and reliable savings estimates than a simple comparison of pre-and post-installation consumption which is typically not acceptable for determining savings. Use of the multivariate regression approach is limited by the availability of data. It involves:

- 12-24 months of historical whole-facility/meter baseline energy use and 15-minute demand data, as well as whole-facility/meter energy use after measure installation.
- Development of baseline, and, possibly in some cases, retrofit regression models of energy consumption and peak demand.

There are two types of interval data required for this analysis: dependent (billing data) and independent variable data. The interval billing data serve as the dependent variable and non-energy data serve as independent variables that affect energy use and account for changes in energy use not associated with measure installation. Site data provide the information necessary to account for usage of, or changes in, energy consumption not associated with the retrofit equipment. Typical data that can be incorporated in regression models as independent variables include weather, occupancy, facility square footage, and changes in operation, such as hours of operation.

Savings calculation details depend on issues such as:

- Use of hourly (or 15-minute interval) versus monthly utility-meter billing data. Monthly is not sufficient for peak demand savings calculations.
- The billing/meter data must coincide with the independent variable data periods.
- Amount of available data.
- Whether actual or typical data are used to calculate savings.

7.10.1 Data Analysis

The criteria used for identifying and eliminating outliers need to be documented in the measurement plan. Outliers are data that are outside the range of expected values (typically more than two standard deviations away from the mean). If a point is considered as an outlier and eliminated, an explanation for the unexpected data should be provided. If a reason for the unexpected data is not clear, the data should be included in the analysis. Outliers will be defined based on sound engineering judgment as well as common statistical practice. Outliers may be defined in terms of consumption changes and actual consumption levels.

A list of explanatory variables that affect energy consumption needs to be specified in the M&V plan. Critical variables may include weather, occupancy patterns, and operating schedules. If the energy savings model incorporates weather in the form of heating degree-days (HDD) and cooling degree-days (CDD), the relationship between temperature and energy use, which tends to vary depending upon the time of year, must be considered. For example, a temperature of 55°F in January often has a different implication for HVAC. Seasonality should be addressed in the model. A building balance point temperature may be necessary for models that address HVAC energy use.

After the billing regression analysis is developed, it must be tested to determine if it is statistically valid. The criteria are:

- The model/equation makes intuitive sense; such as the independent variables are reasonable, and the coefficients have the expected sign and are within an expected magnitude.
- The data represent the population and the range of operation.
- The number of coefficients is appropriate for the number of observations.
- The T-statistic for all key parameters in the model is greater than or equal to two to indicate 95% confidence, and that the coefficient is not zero.
- The R-squared is at least 80%.
- All data used by the model are thoroughly documented and model validity limits (range of independent variables for which the model is valid) are specified.

The raw data used to create the models and calculate the savings results must be included with the project submittal and be reviewed by the implementer.

7.11 Calibrated Computer Simulation M&V Guidelines

The use of calibrated computer simulation M&V method is appropriate for complex project where multiple measures are installed or when complex building operations are affected. A building model provides the ability to estimate a project's energy savings including interactive effects. The downside to this method is that it is costly, time consuming and should be done only by an experienced building modeler. Only projects that generate enough savings to justify using calibrated building models should consider this approach. Projects where this method is appropriate include:

- Multiple measures which the savings cannot be determined independently
- Projects where energy usage is heavily dependent on the weather and/or other building operation conditions such as occupancy and equipment operation schedules

Specific projects examples include:

- Chiller-efficiency upgrade and the installation of a VSD on the cooling tower fan or additional pump controls
- Improvements to the building shell
- Control system upgrade
- New construction (above code)

The calibrated simulation M&V method does have limitations. It is not appropriate when the building cannot be properly defined in the simulation software program or the software cannot capture certain control algorithms such as optimal start/stop. Another limitation in using this approach is that an adequately calibrated model can only occur if there is sufficient utility or end-use meter data. Finally, lighting projects should use the lighting specific measurement (or deemed) savings approach.

The following are specific issues to be considered in reviewing projects using the calibrated simulation M&V method to calculate project savings:

- **Simulation Software** – Acceptable building simulation program for energy analyses is a whole facility, hourly simulation model software. This includes software that is DOE-2, BLAST or Energy-Plus based. If another approach (non-DOE-2 based) is used, the implementer may consider allowing it if it is:
  - Commercially available, supported and documented (such as Trane Trace or Carrier HAP)
  - Shown to adequately model the project and measures
  - Calibrated to a proper level of accuracy
  - The software has an HVAC library that closely represents the system of the modeled building.
- **Weather Data** - Actual weather data must be used for calibrating a computer simulation of a building for a specific year. The calibration documentation must specify which weather data sources are used such as the National Oceanographic Atmospheric Association (NOAA). The specific source of the data is significant, since multiple weather stations can be located in/around one city. Model calibration is most effective when the weather files contain real data for the same dates covered by the billing records. After the model is calibrated, the building's energy use may be normalized using average-year weather, such as using Typical Meteorological Year (TMY) weather data.
- **Monitoring of Building Subsystems** - Specific building subsystem metering may be required in addition to calibrating the whole-facility utility-bill data. Typically, it is the installed measures that are monitored. However, some measures, such as windows or insulation, cannot be monitored. Also, to improve the model calibration, it is recommended that the energy end uses for which the least information is available be monitored. The monitoring period should be sufficient to capture the full range of the equipment's operation. The data must also be collected in a way that facilitates comparison to the building model's end-use to the same end-use metered data.
- **Availability of Hourly Utility-Bill Data** – Ideally, calibration will be completed with hourly, whole-facility usage data. If not available, it may be necessary to use additional short-term monitoring of building sub-systems to improve the accuracy of the model.
- **Controls** – Most simulation software are limited in their ability to capture the effects of control systems. In addition, thoroughness is required to obtain close-to-exact sequencing of building controls. Sequencing of building controls is difficult to interpret from interviews, site surveys, manufacturer's data, and measurements.

7.11.1 Overview of Method

The M&V method described here is based on the following steps.

1. Model the existing building as-is. This model becomes the "existing" building model. The building model shall include information collected by a comprehensive onsite survey such as, but not limited to:[39]
   - Building geometry
   - Materials of construction
   - Building orientation and solar shading
   - Inventories and descriptions of all active building systems

[39] These building data become the model inputs. Surveys should collect all the information needed to properly define (and assist in calibration) the building in the model.

Heating and cooling plant (HVAC)
Lighting system
Plug loads
Occupancy rates
Building operation schedules

The existing building model is used as a basis for developing the baseline building model and the post-installation building model. In some cases, the existing building model and the baseline building model are the same.

2. Tune the existing building model to obtain reasonable agreement between the model whole-facility monthly usage and the previous 12 to 24 months of utility billing data and any sub-metering. This calibration is also required for the peak period and must be conducted using hourly data.
3. Change the efficiencies of the affected equipment to the minimum- state standard values to obtain the "baseline" building model. The baseline model starts as the existing building model calibrated to bills. However, the baseline model is adjusted for systems to meet code (only if existing equipment does not meet code).[40] Only the equipment efficiencies of systems that will be replaced must be changed from those in the existing building model.
4. Change the baseline model to reflect the proposed project. This becomes the "retrofit" model.
5. The initial savings estimate is determined from the predictions of uncalibrated models, unless the existing model can be calibrated with whole-facility usage data from the building's previous 12 to 24 months of utility bills, and then adjusted to the baseline model. If other data are available, such as trend logs of specific equipment energy usage, then it should also be used. The initial savings estimate is determined from the difference in annual energy usage and peak demand between the retrofit model and the baseline model.
6. Perform any building sub-system spot measurements or short-term monitoring required for use in calibrating the retrofit model.
7. Calibrate by selecting one of the following approaches, the retrofit model (the as-built) using the billing data, collected data, and actual weather data.

    - Whole facility usage to monthly utility-bill data
    - Whole facility usage to monthly utility-bill data in combination with specific sub-system, measured, hourly-usage data
    - Whole facility usage to hourly utility-bill data

8. If necessary, substitute the baseline building equipment efficiencies into the calibrated retrofit model to obtain the calibrated baseline building model.
9. The verified savings for the project are determined from calibrated models. Savings are determined from the difference in annual energy usage (and peak demand) between the calibrated post-installation model and the baseline model. To calibrate the post-installation model, it may be sufficient to only use six months of billing data.

7.11.2 Calibration Process

The following provides the guidelines for calibrating models.

1. Compare Outputs to Measured Data

[40] For new construction, this would be the building without the features that allow it to exceed code.

Compare the energy usage and demand projected by the model to that of the measured utility data. This step may require some post-processing to view the comparison. All utility billing data should be used in the analysis, including electric and heating fuels like natural gas. The calibration process must be documented to show the results from initial runs and what changes were made to bring the model into calibration. This information, as well as the actual calibration results, needs to be provided in post-installation submittals and annual reports.

2. Refine the Model

   If the statistical indices calculated during the previous step indicate that the model is not sufficiently calibrated, revise the model inputs, run the model, and compare its predictions to the measured data again. In this step, focus on the model's predictions of usage by the project measures. These results can be plotted and compared with short-term measured data and scheduling information to check if there are sources of error.

3. Continue with Steps 1 and 2

   Continue with steps 1 and 2 until the model compares within the specified ranges (provided below).

Calibrating the Building Model

This section describes the required tolerances for model calibration at the: (1) whole facility level using monthly data, (2) sub-system level using hourly data, and (3) whole facility level using hourly data. One of these three approaches should be chosen based on the available data. The first approach (monthly billing data) does not properly calculate peak demand reduction and is not acceptable for calculating demand savings. There are also graphical, as well as statistical methods to validate the calibration. Graphical techniques include:

- Hourly load profiles, which compare measured and simulated power for different day-types and seasons.
- Binned interquartile analysis using box-whisker-mean plots, which show both measured and simulated energy use by temperature bins.

Weather day-type, 24-hour profile plots show whole-facility electricity use versus the hour-of-the-day for both measured and simulated data for different weather day-types.

Whole-Facility-Level Calibration with Monthly Data

Monthly simulated energy consumption and monthly measured data are compared. Typically, they are plotted against each other for every month in the data set and must be aligned by the same calendar days as for each month's utility bill. The error in the monthly and annual energy consumption is calculated by the following equations:

$$\mathrm{Error}_{\mathrm{month}} = \frac{(\mathrm{M}-\mathrm{S})_{\mathrm{month}}}{\mathrm{M}_{\mathrm{month}}}$$

$$\mathrm{Error}_{\mathrm{year}} = \sum_{\mathrm{year}} \frac{\mathrm{Error}_{\mathrm{month}}}{\mathrm{N}_{\mathrm{month}}}$$

Where,

M indicates the measured kWh or kW and S the simulated kWh or kW. N_{month} is the number of utility bills in the year.

If the measured and simulated energy consumption are relatively close in value, they may cancel each other, resulting in a very small annual error. To ensure against cancellation of monthly errors, the coefficient of variation of the root-mean-squared monthly errors must also be checked.

The root-mean-squared monthly error is calculated by the following equation:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{\mathrm{month}} (\mathrm{M} - \mathrm{S})_{\mathrm{month}}^{2}}{\mathrm{N}_{\mathrm{month}}}}$$

The average of the monthly utility bills is:

$$\mathrm{A}_{\mathrm{month}} = \frac{\sum_{\mathrm{month}} \mathrm{M}_{\mathrm{month}}}{\mathrm{N}_{\mathrm{month}}}$$

The CV(RMSE) for the monthly billing data is:

$$\mathrm{CV}(\mathrm{RMSE}_{\mathrm{month}}) = \frac{\mathrm{RMSE}_{\mathrm{month}}}{\mathrm{A}_{\mathrm{month}}}$$

The combination of error and the CV(RMSE) can determine how well model predicts whole facility energy usage. The lower the error and CV(RMSE), the better the calibration. Table 17 specifies the acceptable tolerances.

Table 17. Acceptable Tolerances for Monthly Data Calibration

Variable	Value
$\mathrm{Error}_{\mathrm{month}}$	± 0.15
$\mathrm{Error}_{\mathrm{year}}$	± 0.10
$\mathrm{CV}(\mathrm{RMSE}_{\mathrm{month}})$	± 0.10

Sub-system-Level Calibration with Monitored Data

Calibration of a building model's sub-systems to measured data may be required to enhance the accuracy of the model. The model's hourly predicted energy usage (kWh, therms, or Btu) is compared to measured, hourly energy usage for the monitored building sub-systems. Peak kW will also be compared. The comparison should be completed during the peak period. This approach can only be accomplished with modeling software that provides hourly sub-system output data. The calibration must match the model results with the specific hours metered and should be done using weather data for the metering period as well. The calibration is done by comparing the measured and modeled data using the mean bias error (MBE) and the coefficient of variation of the root-mean-squared error [CV(RMSE)] to determ ine whether the model accurately predicts subsystem level usage. In this case, the MBE is defined as:

$$\mathrm{MBE} = \frac{\sum_{\mathrm{period}} (\mathrm{M} - \mathrm{S})_{\mathrm{hour}}}{\sum_{\mathrm{period}} (\mathrm{M})_{\mathrm{hour}}}$$

The RMSE is obtained by squaring the difference between paired hourly data points, summing the squared differences over each monitoring period, and then dividing by the number of points in the monitoring period. The square root of this quantity yields the root-mean-squared error. The CV(RMSE) is obtained by dividing the RMSE by the mean of the measured data for the monitoring period.

The root-mean-square error for the monitoring period is:

$$RMSE_{period} = \sqrt{\frac{\sum_{period} (M - S)_{hr}^2}{N_{hr}}}$$

Where,

N_{hr} are the number of hours in the monitoring period. The mean of the measured data for the period is:

$$A_{period} = \frac{\sum_{period} M_{hour}}{N_{hour}}$$

The CV(RSME) is:

$$CV(RMSE_{period}) = \frac{RMSE_{period}}{A_{period}}$$

The combination of MBE and CV(RMSE) can determine how well the model of the building sub-system fits the monitored data. The lower the MBE and CV(RMSE), the better the calibration. The acceptable tolerances are in the table below.

Table 18. Acceptable Tolerances for Hourly Data Calibration for Building Sub-Systems

Variable	Value
MBE_{period}	± 0.07
$CV(RMSE_{period})$	± 0.15

Whole Facility-Level Calibration with Hourly Data

If hourly data calibration is used, the monthly mean bias error (MBE) and the coefficient of variation of the root-mean- squared error (CV(RMSE)) must be calculated. The MBE is calculated as:

$$MBE = \frac{\sum_{month} (M - S)_{hour}}{\sum_{month} (M)_{hour}}$$

The MBE indicates how well the energy consumption is predicted by the model as compared to the measured data. To account for potential errors due to comparable measured and simulation values, the CV(RMSE) is also needed. The CV(RSME) is a normalized measure of variability between two sets of data. For calibrated simulation purposes, it is obtained by squaring the difference between paired hourly data points, summing

the squared differences over each month or billing period, and then dividing by the number of points, which yields the mean-squared error. The square root of this quantity yields the root-mean-squared error. The CV(RMSE), is obtained by dividing the RMSE by the mean of the measured data for the month or billing period. The root-mean-square error for the month is:

$$RMSE_{month} = \sqrt{\frac{\sum_{month} (M - S)_{hour}^{2}}{N_{hour}}}$$

The mean of the measured data for the month is:

$$A_{month} = \frac{\sum_{month} M_{hour}}{N_{hour}}$$

The CV(RSME) is:

$$CV(RMSE_{month}) = \frac{RMSE_{month}}{A_{month}}$$

The combination of MBE and CV(RMSE) allows one to determine how well a model fits the data: the lower the two values, the better the calibration. These indices may be calculated for the entire period, or for weekdays, weekends, and holidays separately. The tolerances required for an acceptable calibration result are summarized in Table 19.

Table 19. Acceptable Tolerances for Hourly Data Calibration

Variable	Value
MBE_{month}	± 0.10
$CV(RMSE_{month})$	± 0.25

7.11.3 Calculation of Energy Savings

Verified energy savings are determined from the calibrated retrofit building model and the calibrated baseline building model. The energy savings are the difference in annual energy usage between the two models. The peak demand savings are the difference in demand between the baseline and retrofit model during the TVA peak period.

8 REFRIGERATOR CALCULATOR ASSUMPTIONS

This appendix provides the key assumptions used in developing the refrigeration calculator. This calculator is based on Southern California Edison analysis methodology provided in their workpaper, WPSCNRRN002.1 – Infiltration Barriers – Strip Curtains, October 2007. This methodology is based on ASHRAE cooling load calculations, presented in ASHRAE 2002 Refrigeration Handbook. Other variables are based on an impact evaluation conducted in California for high impact measures in their 2006-2008 program years. These measures were strip curtains and gaskets. For this evaluation, the study included field measurements of variables that affect energy use as it is affected by these measures. The study results are used as inputs into the calculator.[41] Other variables are also used and based on engineering assumptions which is KEMA's best judgment for the refrigeration end-use.

8.1 Key Variables

The following lists all the key assumptions:

- Building Construction Data –assumptions in the following table (based on SCE workpapers):

Table 20. Refrigerator Construction Assumptions by Unit Type

Parameter	Notation	Walk-in Cooler	Walk-in Freezer	Cooler with Glass Doors	Freezer with Glass Doors	Source
Temp of Surroundings	DB_{adj}, °F	70	70	70	70	ADM
RH of Surroundings	RH_{adj}, %	37.5	37.5	37.5	37.5	ADM
Box Temp	DB_{refrig}, °F	40	0	40	0	ADM
Box RH	RH_{refrig}, %	78.3	63.5	78.3	63.5	ADM
Walk-in Length	L, ft	10	10	30	15	Assumption
Walk-in Width	W, ft	10	10	15	10	Assumption
Walk-in Height	H, ft	8	8	10	10	Assumption
Panel Thickness	D, in	2.5	2.5	2.5	2.5	SCE
Panel Thermal Conductivity	k_{panel}, Btu-in / hr-ft^2-°F	0.16	0.16	0.16	0.16	SCE
Main Door Quantity		1	1	1	1	SCE
Main Door Height	H_{door}, ft	7	7	7	7	SCE
Main Door Width	W_{door}, ft	3	3	3	3	SCE
Glass Door Quantity		0	0	8	4	Assumption
Glass Door Height	H_{glass}, ft	--	--	4.25'		SCE
Glass Door Width	W_{glass}, ft	--	--	2.5'		SCE
Glass Thickness	d_{glass}, in	--	--	1	1	SCE
Glass Thermal Conductivity	k_{glass}, Btu-in / hr-ft^2-	--	--	3.26	3.26	SCE

[41] "Commercial Facilities Contract Group Direct Impact Evaluation Draft Final Report: HIM Appendices". ADM Associates, Inc., prepared for the California Public Utilities Commission, December 8, 2009.

Parameter	Notation	Walk-in Cooler	Walk-in Freezer	Cooler with Glass Doors	Freezer with Glass Doors	Source
	°F					
Number of Evap Fan Motors		2	2	6	6	Assumption

- Compressor, condenser, and evaporator are the same for pre and post-retrofit (evaporator fan changes only for ECM measure).
- Compressor (SCE workpaper):
  - Single reciprocating compressor
  - 15% compressor over-sizing factor
  - For weather factor analysis, assume sealed compressor
- Condenser (SCE workpaper/engineering assumption):
  - Air cooled condenser
  - Condenser temperature difference (TD) of 20°F for medium-temperature applications (coolers)
  - Condenser TD of 15°F for low-temperature applications (freezers)
- Evaporator (SCE workpaper):
  - Evaporator TD of 10°F for both temperature groups (coolers and freezers)
  - 135.5 W motor[42] at 70% efficiency
- Anti-sweat heater load (SCE workpaper):
  - 35% of heat dissipated due to connected electrical load contributes to the refrigeration load
  - For main door of walk-in freezers, connected electrical load is 0.30 kW per door
  - No ASH for main door of walk-in coolers
  - For reach-in glass doors of walk-in coolers, connected electrical load is 0.045 kW per door
- Internal loads (SCE workpaper):
  - Evaporator fan motors (see above)
  - Lighting intensity of 0.75 W per square-foot of walk-ins
  - People: one person inside the walk-ins
  - Electric defrost (only for walk-in freezers) is currently not considered in the analysis
- Product load (SCE workpaper):
  - 40% space utilization factor
  - Product density (ρ) of 2 lb/ft^3 for coolers and 1 lb/ft^3 for freezers
  - Product specific heat (Cp) of 0.45 Btu/lb-°F
  - Post-defrost product temperature rise (ΔTpost-defrost) of 3°F
  - Temperature difference of 5°F between initial and final product temperature when shelving (ΔTshelving)

[42] Motor size is from FSTC report.

- Time required to lower the product temperature after shelving, 60 minutes
- Defrost frequency, 4 defrosts per day

- Infiltration load (ADM):
  - Proportion of doorway open time (Dt),time door simply stands open (minutes/day): 72 (cooler), 50 (freezer), 5 (glass door)
  - Doorway flow factor (Df): 0.552 (cooler), 0.643 (freezer)
  - Effectiveness against infiltration (E): 0.40
  - All main doors and glass doors are assumed to be tightly sealed
  - No air leakage through the walk-in panels

8.2 Calculation Analysis

The following are the guidelines used to calculate the potential savings of refrigeration measures.

- Cooling load analysis: The cooling load should change for existing and retrofit systems. The following lists the necessary variables for calculating cooling load (the sum of the individual loads) of walk-ins:
  - Air properties of refrigerated and adjacent spaces
  - Transmission or conduction load
  - Anti-sweat heater (ASH) load
  - Internal load – includes evaporator fans, lighting, and people (electric defrost could be included in this category)
  - Product load
  - Infiltration load
- EER and demand of the compressor:
  - Calculate using saturated condensing temperature (SCT), cooling load and compressor capacity for both pre and post retrofit.
  - Calculate power (kW) requirements by using EER and cooling load.
- Equivalent-full-load-hours (EFLH) of operation:
  - EFLH is determined by using annual available operation hours (8,760) and overall duty cycle factor.
  - Overall duty cycle factor is determined by taking into account compressor over-sizing factor (or part-load ratio), defrost periods, and weather.
- Compressor energy usage:
  - Determine energy consumption by using power requirements and EFLH.

8.3 Cooling Load Calculations

This section discusses the steps in calculating the total cooling load of the refrigerated spaces. These steps are repeated for each measure's baseline and retrofit assumptions.

- Air properties of refrigerated and adjacent spaces
- Transmission or conduction load

- Anti-sweat heater (ASH) load
- Internal load (load due to evaporator fan motors, lighting, people, and defrost)
- Product load (product shelving and product pull-down load)
- Infiltration load
- Total cooling load

Step 1: Air properties of refrigerated and adjacent spaces

Calculate air density, enthalpy, and absolute humidity ratio based on assumed dry-bulb and relative humidity for the surroundings and inside the walk-in. These are done by using Excel plug-in for psychometric chart (by HillsBrother).

Step 2: Transmission or conduction load

Calculate transmission or conduction load through the walls of the walk-in and glass doors.

- Calculate overall heat transfer coefficient (U) for conduction only:

$$U = \frac{1}{\sum R_{Total}} \rightarrow U = \frac{1}{R_{cond}} \rightarrow U = \frac{1}{\left(\frac{d}{k}\right)} = \frac{k}{d}$$

Where,

∑RTotal = Total thermal resistance, Btu/hr-ft2-°F

Rcond = thermal resistance for conduction, Btu/hr-ft2-°F

k = thermal conductivity, Btu-in/hr-ft2-°F

d = thickness, in

- Calculate total surface area (A_{total})[43] with no glass doors:

$$A_{total} = 2 * [(L * H) + (W * H)] + (L * W)$$

- Calculate total surface area (A_{total}) with glass doors:

$$A_{shell} = A_{total} = 2 * [(L * H) + (W * H)] + (L * W) - A_{glass}$$

$$A_{glass} = (W_{glass} * H_{glass}) * n$$

Where,

n = number of glass doors

- Calculate temperature differential (ΔT):

$$\Delta T = DB_{refrig} - DB_{adj}$$

Where,

[43] Assume floor is adiabatic.

DB_{refrig} = dry-bulb inside the refrigerated zone (box temperature), °F

DB_{adj} = dry-bulb of adjacent space where the walk-in reside, °F

- Calculate the conduction or transmission load (Q_{cond}):

  With no glass doors:

$$Q_{cond} = U * A_{total} * \Delta T$$

  With glass doors:

$$Q_{cond\text{-}shell} = U_{shell} * A_{shell} * \Delta T$$

$$Q_{cond\text{-}glass} = U_{glass} * A_{glass} * \Delta T$$

$$Q_{total-cond} = Q_{cond\text{-}shell} + Q_{cond\text{-}glass}$$

  Where,

  U = overall heat transfer coefficient, Btu/hr-ft^2-°F

  A = total surface area of insulated panels or doors, ft^2

  ΔT = temperature differential between refrigerated and adjacent zones, °F

Step 3: Anti-sweat heater (ASH) load

Main doors and glass doors are typically equipped with anti-sweat heaters (ASH). The heat dissipated due to the connected electrical load of ASH is also considered in the load.

- Calculate ASH load for the main or glass doors (Q_{ASH})

$$Q_{ASH\text{-}main} = kW_{main} * K_{ASH} * 3{,}413$$

$$Q_{ASH\text{-}glass} = n * kW_{glass} * K_{ASH} * 3{,}413$$

  Where,

  n = number of glass doors

  kW = ASH power for door, kW

  K_{ASH} = 35%, heat dissipated to refrigeration system due to electrical load

  Conversion Factor: 3,413 Btu/hr = 1 kW

$$Q_{ASH} = Q_{ASH\text{-}main} + Q_{ASH\text{-}glass}$$

Step 4: Internal Load

The internal load in refrigerated spaces is assumed to be evaporator-fan motors, lighting, people and defrost.

- Load due to evaporator fan motors for walk-ins ($Q_{evap\text{-}fans}$):

$$Q_{evap-fans} = n \times 3{,}413 \times hp \times 0.7457 \frac{1}{\eta}$$

Where,

n = number of fans

hp = motor horsepower, hp

η = motor efficiency, %

Conv. Factor: 0.7457 kW = 1 hp

- Load due to lighting for walk-ins (Q_{lights}):

$$Q_{lights} = 3{,}413 * \rho_{light} * (L * W)$$

Where,

ρ_{light} = light intensity, watts/ft^2

L = length of the walk-ins, ft

W = width of the walk-ins, ft

Conv. Factor: 3,413 Btu/hr = 1 kW

- Load due to people inside the walk-in ($Q_{people\text{-}total}$):
- Load due to people is dependent on room dry-bulb temperature and comprised of two components, latent and sensible:

$$Q_{people\text{-}total} = Q_{people\text{-}sensible} + Q_{people\text{-}latent}$$

$$Q_{people\text{-}total} = 1{,}295 - 11.5 DB_{refrig}$$

inside the refrigerated zone (box temperature), °F

$$Q_{people\text{-}sensible} = 61\% \; Q_{people\text{-}total}$$ [44]

Step 5: Product Load

This section describes the calculation of the load due to product shelving and post-defrost pull down load.

- The product load (Qproduct-load) is calculated using the following equation:

$$Q_{product-load} = WF_{product} * C_p * \Delta T$$

[44] According to ASHRAE, when doing "very light work" at room temperature of 75°F, 61% of people load is sensible and 39% latent. These ratios, however, are a function of room temperature. As the room temperature decreases, the contribution of sensible load is increased. Due to lack of such information about the relationship between these variables, a 61% sensible load ratio is used in the current analysis, although higher ratios are expected at lower room temperatures.

Where,

WF_{prod} = weight flow of product, lb/hr (see discussion below)

C_p = product specific heat, Btu/lb-°F

ΔT = temperature rise due to product shelving or defrost periods, °F

a. Determine the total product volume (V_{prod})

$$V_{prod} = (L \times W \times H) \times k_{SU}$$

Where,
V_{prod} = product volume, ft^3
k_{SU} = space utilization factor, %

b. Determine the total product mass (m_{prod})

$$m_{prod} = V_{prod} \times \rho_{prod}$$

Where,
m_{prod} = mass of product, lb
ρ_{prod} = product density, lb/ft^3

c. Determine the total product weight flow (WF_{prod}) assuming all product in the walk-in is replaced each day:

$$WF_{prod} = \frac{m_{prod}}{24}$$

Where,
WF_{prod} = weight flow of product, lb/hr

However, considering the assumptions made, the above equation can be simplified to determine the product shelving load and product pull-down load:

1. Determine product shelving load ($Q_{shelving\text{-}load}$):

$$Q_{shelving-load} = WF_{prod} \times C_p \times \Delta T_{shelving}$$

Where,
C_p = product specific heat, Btu/lb-°F
$\Delta T_{shelving}$ = Temperature difference between initial and final product temperature when shelving, °F

2. Determine product pull-down load ($Q_{pull\text{-}down\text{-}load}$):

$$Q_{pull\text{-}down\text{-}load} = \frac{m_{prod} \times C_p \times \Delta T_{post-defrost}}{t \times n}$$

Where,

t = time to lower product temp (during post-defrost), hr
$\Delta T_{post\text{-}defrost}$ = post-defrost product temperature rise, °F
n = number of defrost periods

Step 6: Infiltration Load

The infiltration load or the heat gain is a product of the following parameters.

- Refrigeration load for fully established flow (q)
- Portion of time doorway is open (Dt)
- Doorway flow factor (Df)
- Effectiveness of doorway protective device (E)
- Density factor (Fm)
- Portion of time doorway is closed (Dc)

1. Calculate the decimal portion of time doorway is open (D_t):

$$D_t = \frac{\text{Min Door Open per Day}}{\text{Minutes per Day}}$$

2. Calculate the density factor (F_m):

$$F_m = \left[\frac{2}{1 + \left(\frac{\rho_r}{\rho_i} \right)^{1/3}} \right]^{3/2}$$

Where,

ρ_r = density of air inside the refrigerated spaces (from step 1), lb/ft^3
ρ_i = density of adjacent space air that infiltrates into the refrigerated spaces (from step 1), lb/ft^3

3. Calculate refrigeration load for fully established flow (q):

$$q = 795.6 * A * (h_i - h_r) * \rho_r * \left(1 - \frac{\rho_i}{\rho_r} \right)^{1/2} * (32.174 * H)^{1/2} * F_m$$

Where,

A = doorway area, ft^2
h_i = enthalpy of adjacent space air that infiltrates into the refrigerated spaces (from step 1), Btu/lb
h_r = enthalpy of air inside the refrigerated spaces (from step 1), Btu/lb
ρ_i = density of adjacent space air that infiltrates into the refrigerated spaces (from step 1), lb/ft^3
ρ_r = density of air inside the refrigerated spaces (from step 1), lb/ft^3
H = doorway height, ft
F_m = density factor

4. Calculate the door open infiltration load (Q_{open}):

$$Q_{open} = q * D_t * D_f * (1 - E) * n$$

Where,

q = refrigeration load, Btu/hr
D_t = doorway open-time factor
D_f = doorway flow factor
E = effectiveness of doorway protective device
n = number of doorways (number of doors)

For the purpose of this analysis and to estimate the effectiveness of strip curtains for the baseline scenario, it was assumed that 50% of walk-ins have no strip curtains (zero effectiveness) and 50% of walk-ins have strip curtains where one of the strips is missing with 2 cm gap at the bottom (80% effectiveness). Accordingly, the average effectiveness of strip curtains for the baseline scenario is 40% or 0.40.

Infiltration through gaskets of closed main and glass doors (assuming no infiltration or air leakage through the walk-in panels):

5. Calculate the decimal portion of time doorway is closed (D_c):

$$D_c = 1 - D_t$$

6. Calculate the infiltration rate of the box ($\dot{V}_{closed}$ (ft^3/h)):[45]

$$\dot{V}_{closed} = 4.65(\Delta p)^{0.733} * K \qquad \text{for airtight room}$$

Where,

Δp = pressure differential between inside and outside of walk-in, mmWC
K = conversion factor, 35.315 ft^3/m^3

Note: The analysis focuses on infiltration through the door gaskets when the doors are closed.

7. Calculate refrigeration load for infiltration through gaskets (Q_{closed}):

$$\text{For main and glass doors}: \; Q_{closed} = \dot{V}_{closed} * (h_i - h_r) * \rho_i * D_c$$

Where,

h_i = enthalpy of adjacent space air that infiltrates into the refrigerated spaces (from step 1), Btu/lb
h_r = enthalpy of air inside the refrigerated spaces (from step 1), Btu/lb
ρ_i = density of adjacent space air that infiltrates into the refrigerated spaces (from step 1), lb/ft^3

8. Calculate the total infiltration load (Q_{inf}):

[45] This value is a point of controversy. The ADM report discusses measuring the infiltration rate, but does not quantify it in the study as a function of temperature, gasket condition, or other factor. Since the load calculated for infiltration using the approach discussed is small, the analysis at this time is based on the approach documented in the SCE workpaper.

$$Q_{inf} = Q_{open} + Q_{closed}$$

Step 7: Total Cooling Load

Calculate the total cooling load of refrigerated spaces ($Q_{total\text{-}cooling}$) by summing the calculated loads from the steps stated above.

$$Q_{total-cooling} = Q_{total-cond} + Q_{ASH} + Q_{internal} + Q_{shelving\text{-}load} + Q_{pull-down-load} + Q_{inf}$$

8.4 Compressor EER and Demand

To calculate compressor parameters:

- Determine the saturated condensing temperature (SCT)
- Determine the energy-efficiency ratio (EER) of the compressor based on SCT, cooling load, and cooling capacity of compressor
- Determine the power requirements (kW) of the compressor based on calculated EER and cooling load
- Determine the equivalent-full-load-hours (EFLH) of operation
- Determine the annual energy usage (kWh) by using compressor power (kW) and EFLH

Step 1: Determine the saturated condensing temperature (SCT)

For medium temperature (MT): $SCT = DB_{adj} + 20$

For low temperature (LT): $SCT = DB_{adj} + 15$

Where,

DBadj = dry-bulb temperature (°F) of ambient or adjacent space where the compressor/condensing units reside. Defaults are based on climate zone design values in the following table.

Table 21. Design Dry Bulb Temperature, 0.4% Column

Weather Zone	Summer Design Dry Bulb (°F) Temperature
Knoxville	92
Nashville	94
Chattanooga	94
Memphis	96
Huntsville	94

Step 2: Determine the EER for both MT and LT

Compressor performance curves were obtained from a review of manufacturer data for reciprocating compressors as a function of SCT, cooling load, and cooling capacity of compressor. To calculate the EER the following is needed:

Part-load ratio (PLR):

It is the ratio of total cooling load to compressor capacity. It indicates the percentage of compressor capacity needed to remove the total cooling load. It is calculated by following equation:

$$PLR = \frac{Q_{coolinge}}{Q_{capacity}}$$

Note: Compressor capacity is determined by multiplying baseline cooling load by compressor capacity factor of 15%. Compressor capacity remains unchanged even when cooling capacity decreases with a measure.

$$Q_{capacity} = Q_{cooling\text{-}baseline} * 1.15$$

For calculating compressor efficiency, EER (Btu/hr/watts), use the following:

$$EER = a + (b * SCT) + (c * PLR) + (d * SCT^2) + (e * PLR^2) + (f * SCT * PLR) + (g * SCT^3) + (h * PLR^3) + (i * SCT * PLR^2) + (j * SCT^2 * PLR)$$

Where the coefficients are summarized in the table below.

Table 22. Coefficients for Compressor Efficiency Calculation

Coefficient	Medium Temp	Low Temp
a	3.753460187	9.866509828
b	-0.049642253	-0.230356887
c	29.45898349	22.90555382
d	0.000342067	0.002188929
e	-11.77055838	-2.488667379
f	-0.212941093	-0.24805152
g	-1.46606E-06	-7.57495E-06
h	6.801701339	2.036062486
i	-0.02018724	-0.021477433
j	0.000657941	0.000938306

Step 3: Power used by the compressor (kW)

Power used by the compressor is determined based on calculated cooling load and EER, as outlined below.

$$kW_{comp} = \frac{Q_{cooling}}{(EER * 1000)}$$

8.5 Equivalent-full-load-hours (EFLH) of Operation

For compressors of walk-in cooler and freezer, EFLH was determined by multiplying annual available operation hours of 8,760 by the overall duty cycle factors. Duty cycle is a function of the compressor capacity, defrost, and weather factors.

The following equation shows the relationship between capacity, defrost, and weather factors. The capacity factor is a function of both compressor capacity and cooling load. In other words, the capacity factor is a function of PLR and is determined by subtracting PLR from 1. The defrost factor depends on the number and duration of defrost and is determined by simply dividing defrost duration (in hours) by 24 hours. The weather factor, however, is a function of weather. Using TMY3 dry bulb temperature, SCT, and design dry bulb temperature

Duty cycle = Capacity factor x Defrost factor x Weather factor

Where,

Capacity factor = function of PLR, (1 - $PLR_{baseline}$) or (1 – $PLR_{post\text{-}retrofit}$)

Defrost factor = 5.0% (1.2 hrs / 24 hrs), for freezers, (1 – 0.05)

Defrost factor = 10.0% (2.4 hrs /24 hrs), for coolers (1 – 0.10)

Weather factor = function of weather (described below)

To estimate the weather factor for each weather zone, use the following steps.

1. Calculated the net refrigeration effect (assume a sealed compressor). Calculation is based on ASHRAE HVAC Systems and Equipment Handbook, CH 35 Table 1.

   For medium temperature (coolers),

$$0.8 - \frac{(SCT - 90)}{40} * 0.1$$

   For low temperature (freezers),

$$0.64 - \frac{(SCT - 90)}{40} * 0.1$$

2. Calculate the net compressor load:

   1 – Net refrigeration effect

3. Sum the net compressor load across the 8,760 hourly weather data.
4. Calculate the net compressor load for the design temperature.
5. The ratio of the sum of the compressor load divided by the net compressor load for design temperature is the full load hours.
6. Normalize the full load hours to 8,760 to calculate the weather factor.

Table 23. Weather Factor

Weather Zone	Medium Temp	Low Temp
Knoxville	84%	90%
Nashville	83%	89%
Chattanooga	82%	89%
Memphis	82%	89%

Weather Zone	Medium Temp	Low Temp
Huntsville	83%	90%

Accordingly,

EFLH = 8,760 x Duty cycle (hrs/yr.)

8.6 Compressor Annual Energy Usage

Annual energy used by the compressor is determined based on calculated compressor power and EFLH.

kWhcomp= kWcomp x EFLH

8.7 Interactive Factor Calculation

To approximate the reduced-compressor energy consumption that results from reducing the case cooling load, KEMA developed interactive factors ratios for the medium- and low-temperature display cases with doors for each climate zone. These factors are calculated as the ratio of refrigeration compressor energy reduction to direct case load energy reduction that results from an electronically commutated evaporator fan motor replacing a shaded-pole evaporator fan motor in a walk-in refrigeration case. The equation below illustrates the variables used to calculate the interactive factor ratios:

$$\mathrm{IF_{CZ}} = \frac{\text{Compressor kWh reduction}}{\text{Motor kWh reduction}} = \frac{\left(\frac{\Delta\text{Case load}}{\mathrm{EER_{CZ}}} \times \mathrm{EFLH_{CZ}}\right)}{\Delta\ \text{Motor kWh}}$$

For display cases without doors, KEMA employed the lighting-energy and demand-interactive factors developed for TVA to account for the reduced HVAC-system compressor loads that are a result of reducing the building's internal heat load.

9 RESIDENTIAL WEATHER-SENSITIVE RESIDENTIAL MODELS

Residential building DOE2.1E simulation models consist of single-family, multifamily, and manufactured home models, all of which vary based upon heating, ventilation, and air-conditioning (HVAC) types. The model characteristics are based on DNV GL TVA residential impact studies where onsite data were collected and used to create the prototypical building models. Each detailed model represents observed housing stock dimensions and characteristics and is calibrated from metered, hourly end-use energy data.

Due to limitations in the DOE2.1E energy simulation software post processing of the hourly output energy use data is required. First is the inability of DOE2.1E to accommodate variable speed blowers and dual stage compressors in residential HVAC systems. Through rigorous analysis of the 2016 AHRI manufacturers performance data for residential high efficiency (above 15 SEER) AC and heat pumps the following method was derived to be applied to the DOE2.1E hourly blower energy use to get the predicted hourly energy from a VFD controlled blower.

Take the maximum of either A or B

A = Hourly Blower kW/4

B = Hourly Blower kW * (Hourly Blower kW/the maximum hourly kW)^(0.9)

Where:

The maximum hourly kW is the maximum blower kW for all 8760 blower hours

New Whole Building hourly kW = Old Whole Building hourly kW – Old Hourly Blower kW + New Hourly Blower kW

Measure Savings = Baseline Whole Building Energy – Measure New Whole Building Energy

This adjustment applies to ALL model output using AC and heat pumps with SEERs higher than 15. Although only the blower energy is changed the results apply to any high efficiency unit whether is has duel stage compressors of blower VFDs.

Second post processing of the DOE2.1E output is the smoothing of the hourly energy savings by applying the following equation:

$$\text{Retrofit Run Hourly Savings, kW} = \frac{\text{Baselines}}{\text{Retrofits}}$$

Where:

Baselines = Average kW (2 previous hours + next 2 hours +actual hour)

Retrofits = Average kW (previous 2 hours + next 2 hours +actual hour)

Finally the summer or winter coincident demand is calculated using the following formula:

$$Demand = \sum_{i=1}^{10} kWh \times h_{peak\ hour}$$

Where:

$h_{peak\ hour}$ = 1 if it is peak hour, and = 0 otherwise.

The peak hour is one of top ten hours that have the highest or lowest temperatures during the peak windows.

As determined by TVA, the peak window for summer is in June, July, and August, and between hour 15 and 17; and the winter peak window is in December, January, and February, and at 7 or 8 in the morning.

10 TRM REVISION LOGS

10.1 Revisions to Version Four

The following updates to the TRM were made for the Fiscal Year 2016 manual:

- Revision of the Residential, Non-Weather-Sensitive Measure Baseline and Quantifying Criteria table
- Elimination of high efficiency electric storage water heater measure
- Elimination of storage water heater (domestic) measure section
- Revision of the Residential, Weather-Sensitive Measure Baselines and Qualifying Criteria table
- Revision of the Annual Operating Hours by Building Types table
- Elimination of the Non-Residential Lighting Peak Load Shape Factors table
- Revision of the Non-Residential Lighting Peak Coincidence Factors table
- Update of single-family AC unit (central or split system) measure baseline
- Update of single-family heat pump unit measure baseline
- Update of residential (manufactured home and multifamily) AC units (central or split measure) measure baseline
- Update of residential (manufactured home and multifamily) heat pump unit measure baseline
- Elimination of EIR Equivalency to Air Conditioner SEER/EER table
- Elimination of Model Equivalent to Heat Pump SEER/EER/HSPF table
- Elimination of Cooling EIR eQUEST Efficiency table
- Revision of Baseline and Energy Efficiency Model Assumptions table
- Elimination of Cooling And Heating EIR eQUEST Efficiency Inputs < 65,000 kBtuh table
- Revision of Lighting Peak Coincidence Factor table
- Revision of Lighting Energy Interactive Effect table
- Revision of Summer Demand Interactive Effect table

10.2 Revisions to Version Three

The following changes to the TRM were made for the 2015 manual from the 2013 manual.

- Addition of section 1.5 Deemed Measure Baselines and Qualifying Criteria
- Revision of Table of Non-Weather-Sensitive, Load Shape End Uses
- Alignment of measure names in summary tables with measure section title
- Update of residential indoor CFL daily average hours based on TVA specific estimate
- Update of non-residential lighting annual operating hours for the retail, storage, and warehouse building types
- Correction of energy and demand savings values for linear fluorescent, LED, and metal-halide lighting measures
- Addition of the "LED, 4-foot Linear Replacement Lamps," measure within non-residential lighting
- Correction of energy (cooler and freezer cases) and demand savings (freezer cases) values for the refrigeration-case lighting controller measure
- Elimination of columns for cooler walk-in door ASH control savings for which the calculated energy or demand savings was zero
- Update of residential single-family heat pump measure baseline and savings values
- Addition of the following sections to the Non-Residential Custom/ Calculated Measure Analysis

- Proposed Energy Savings Calculation Methodology
- Plan for Capturing Operational Diversity
- Data Accuracy Review

10.3 Revisions to Version Two

The following tables provide the list of measures added, updated, or removed from the 2010 manual. Measures with no changes are not listed in the following tables.

Table 24. Residential Measures

End Use	Measure Description	Status/Updates Made
HVAC	Packaged/Split AC	Existing - no change to manufactured home and multifamily;[46] Single-family revised with savings from the In-Home Energy Evaluation (IHEE) evaluation results
HVAC	Heat Pump	Existing - no change to manufactured home and multifamily; Single-family revised with savings from IHEE evaluation results
HVAC	Ductless Heat Pump	New
HVAC	Ground Source Heat Pump	New
HVAC	Refrigerant Charge	Revised to HVAC Tune-up and no change to multifamily; Single-family revised with savings from IHEE evaluation results
HVAC	Duct Sealing	Existing - no change to multifamily; Single-family revised with savings from IHEE evaluation results
HVAC	Duct Insulation	New
Envelope	Weatherization	Existing - no change to manufactured home and multifamily; Single-family revised with savings from IHEE evaluation results
Envelope	Insulation - Attic	Existing - no change to manufactured home and multifamily; Single-family revised with savings from IHEE evaluation results
Envelope	Insulation – Kneewall	New
Envelope	Windows - Primary and Storm	Existing - no change to manufactured home and multifamily; Single-family revised with savings from IHEE evaluation results
Lighting	Outdoor Integral (Screw-in) CFL, Switch or Photocell Control	Existing - revised with updated baseline wattages
Lighting	Indoor Integral (Screw-in) CFL	Existing - revised with updated baseline wattages
Lighting	Outdoor Compact Fluorescent Fixture, Switch or Photocell Control	Existing - revised with updated baseline wattages
Lighting	Indoor Compact Fluorescent Fixture	Existing - revised with updated baseline wattages

[46] An update to the assumed unit size was made for multifamily, gas heat measures. Savings were updated accordingly.

End Use	Measure Description	Status/Updates Made
Lighting	ENERGY STAR® LED	New
Lighting	LED Night Light	Existing - revised in-service rate
Lighting	Multifamily Lighting Measure	Existing- revised with updated baseline wattages
Lighting	Fluorescent Replacement-Garage/Kitchen	New
Lighting	CFL Table Lamp	Existing - revised with updated baseline wattages
Appliance	ENERGY STAR Residential Clothes Washer	Existing - updated retrofit
Appliance	Energy-Efficient Clothes Dryer	Existing - updated baseline and retrofit
Appliance	ENERGY STAR Residential Dishwashers	Existing - updated retrofit and added compact dishwashers
Appliance	ENERGY STAR Residential Refrigerator	Existing - updated baseline and retrofit
Appliance	ENERGY STAR Residential Freezer	Existing - updated baseline and retrofit
Appliance	Residential Refrigerator Recycling	Updated savings and source
Appliance	Residential Freezer Recycling	Updated savings and source
Appliance	ENERGY STAR Televisions	Removed
Appliance	ENERGY STAR Room AC	New
Domestic Hot Water	High-Efficiency Water Heater - Electric Storage	Existing - updated baseline
Domestic Hot Water	High-Efficiency Water Heater - Solar with electric backup	Existing - updated baseline
Domestic Hot Water	High-Efficiency Water Heater - Heat Pump	Existing - updated baseline
Domestic Hot Water	Faucet Aerator	Existing - updated inputs from updated sources
Domestic Hot Water	Low-Flow Showerhead	Existing - updated inputs from updated sources
Domestic Hot Water	Water Pipe Insulation Wrap	Existing - revised and savings from IHEE evaluation results
Domestic Hot Water	Water Heater Tank Insulation Wrap	Existing - revised and savings from IHEE evaluation results
New Construction	Manufactured Home New Construction	Existing - updated per E&RS reported value

Table 25. Non-Residential Measures

End Use	Measure Description	Status/ Updates Made
HVAC	Packaged AC, 35 ton	Existing - updated retrofit EER
Lighting	Screw-in CFL (1-13W)	Existing - updated baseline and retrofit wattage
Lighting	Screw-in CFL (14-26W)	Existing - updated baseline and retrofit wattage
Lighting	Screw-in CFL (27-40W)	Existing - updated baseline and retrofit wattage

End Use	Measure Description	Status / Updates Made
Lighting	Hardwired CF Fixture (5-13W)	Existing - updated baseline and retrofit wattage
Lighting	Hardwired CF Fixture (14-26W)	Existing - updated baseline wattage
Lighting	Cold Cathode	Existing - updated baseline wattage
Lighting	T12 to T8 Lamp/Ballast Retrofit (2-foot)	Removed
Lighting	T12 to T8 Lamp/Ballast Retrofit (3-foot)	Removed
Lighting	T12 to T8 Lamp/Ballast Retrofit (4-foot)	Removed
Lighting	T12 to T8 Lamp/Ballast Retrofit (8-foot)	Removed
Lighting	De-lamping (2-foot)	Existing - updated baseline wattage
Lighting	De-lamping (3-foot)	Existing - updated baseline wattage
Lighting	De-lamping (4-foot)	Existing - updated baseline wattage
Lighting	De-lamping (8-foot)	Existing - updated baseline wattage
Lighting	High Performance 4-foot T8 Retrofit	Existing - updated baseline and retrofit wattage
Lighting	Reduced Wattage 4-foot T8 Retrofit	Existing - updated baseline and retrofit wattage
Lighting	Standard T8 to Reduced Wattage 4-foot T8 (lamp only)	Existing - updated baseline and retrofit wattage
Lighting	Screw-in LED Lamp	Existing - updated baseline and retrofit wattages, added categories based on ENERGY STAR
Lighting	Integrated Ballast Ceramic Metal-Halide (MH) Fixture	Existing - updated baseline wattage
Lighting	LED Traffic and Pedestrian Signal	Existing - updated baseline and retrofit
Motors	NEMA Premium-Efficiency Motors	Removed
Water Heating	Storage Water Heater	Existing - updated size used for efficiency calculation, for both baseline and retrofit
Water Heating	Low-Flow Pre-Rinse Sprayer	Existing - updated baseline and retrofit
Miscellaneous	High-Efficiency Office Copier	Removed
Miscellaneous	Plug Load Occupancy Sensor	Removed
Cooking	ENERGY STAR Convection Oven	Existing - updated baseline and retrofit
Cooking	ENERGY STAR Griddle	Existing - updated retrofit
Cooking	ENERGY STAR Fryer	Existing - updated baseline and retrofit
Cooking	ENERGY STAR Hot Food Holding Cabinets	Existing - updated baseline and retrofit
Cooking	ENERGY STAR Steam Cookers	Existing - updated retrofit
Cooking	Large Vat Fryers (18-inch commercial large vat)	Existing - updated baseline and retrofit
Cooking	Combination Oven	Existing - updated baseline and retrofit
Refrigeration	LED Refrigeration Case Lighting	Existing - updated retrofit, operating hours, and interactive effects
Refrigeration	Electronically Commutated (EC) Motor: Walk-ins	Existing - updated calculation inputs
Refrigeration	Evaporator Fan Controller	Existing - updated calculation inputs
Refrigeration	Strip Curtains	Existing - updated calculation inputs

End Use	Measure Description	Status / Updates Made
Refrigeration	Door Gaskets	Existing - updated calculation inputs
Refrigeration	Anti-Sweat Heater (ASH) Controls	Existing - updated calculation inputs
Refrigeration	Door Auto Closers: Walk-ins	Existing - updated calculation inputs
Refrigeration	Door Auto Closers: Glass Reach-in Cooler or Freezer Doors	Existing - updated calculation inputs
HVAC	Variable Speed Drives (VSD)	New
HVAC	Hotel Guest Room Energy Management	New
Agriculture	Engine Block Heater Timer	New
Agriculture	Low Pressure Nozzles (Portable)	New
Agriculture	Low Pressure Nozzles (Solid-Set)	New
Agriculture	VSD on Dairy Vacuum Pump	New
Agriculture	VSD on Dairy Transfer Pump	New
Refrigeration	ENERGY STAR Reach-in Cooler/Freezer Solid & Glass Door	New
Refrigeration	Freezer and Refrigerated Case Door	New
Refrigeration	Night Curtains for Open Display Case Coolers	New
Refrigeration	High Efficiency Open and Reach-in Display Cases	New
Refrigeration	Electronically Commutated Motor (ECM) – Reach-in Cases	New
Refrigeration	Floating Head Pressure Controls	New
Refrigeration	Case Lighting Controls	New
Envelope	Cool Roof	New
Envelope	High Efficiency Windows	New
Envelope	Reflective Window Film	New
Miscellaneous	High Efficiency Transformers	New
Miscellaneous	Battery Chargers	New
Miscellaneous	VSD on Air Compressor	New

The following sections have been updated with additional items to further supplement and clarify language from the previous version:

- Definitions for building types (Section 5.2.1)
- Additional lighting building types - religious, other, service, municipal, 1-shift industrial, 2-shift industrial, and 3-shift industrial/warehouse (Section 5.2.1)
- Ineligible Custom Non-residential Measures (Section 8.2.2)
- General Guidelines for Custom Measure Analysis (Section 8.2.3)
- In Appendix Section 8 titled Refrigeration Calculator Assumptions, there is a new section called Interactive Factor Calculation
- In Appendix Section 8.2.8 Reviewing and Developing a Measurement (MFS) Plan Elements, subsections were added for Proposed Energy savings Calculation Methodology, Plan for Capturing Operational Diversity and, Data Adequacy Review

11 LPC WEATHER FILES

There are five weather locations identified as representative for the Valley, Huntsville, Chattanooga, Nashville, Memphis, and Knoxville. The following table lists the weather files used for each LPC.

Table 26. LPC Weather File Locations

Weather File Location	LPC Name	TVA District	State
Huntsville	Albertville Municipal Utilities Board	Alabama	Alabama
Huntsville	Arab Electric Cooperative, Inc.	Alabama	Alabama
Huntsville	Athens Electric Department, City of (AL)	Alabama	Alabama
Huntsville	Bessemer Electric Service	Alabama	Alabama
Huntsville	Cherokee Electric Cooperative	Alabama	Alabama
Huntsville	Courtland Electric Department	Alabama	Alabama
Huntsville	Cullman Electric Cooperative (AL Coop)	Alabama	Alabama
Huntsville	Cullman Power Board (AL Muni)	Alabama	Alabama
Huntsville	Decatur Utilities	Alabama	Alabama
Huntsville	Florence Electricity Department, City of	Alabama	Alabama
Huntsville	Fort Payne Improvement Authority	Alabama	Alabama
Huntsville	Franklin Electric Cooperative (AL)	Alabama	Alabama
Huntsville	Guntersville Electric Board	Alabama	Alabama
Huntsville	Hartselle Utilities	Alabama	Alabama
Huntsville	Huntsville Utilities	Alabama	Alabama
Huntsville	Joe Wheeler Electric Membership Corporation	Alabama	Alabama
Huntsville	Marshall-DeKalb Electric Cooperative	Alabama	Alabama
Huntsville	Muscle Shoals Electric Board	Alabama	Alabama
Huntsville	North Alabama Electric Cooperative	Alabama	Alabama
Huntsville	Russellville Electric Board (AL)	Alabama	Alabama
Huntsville	Sand Mountain Electric Cooperative	Alabama	Alabama
Huntsville	Scottsboro Electric Power Board	Alabama	Alabama
Huntsville	Sheffield Utilities	Alabama	Alabama
Huntsville	Tarrant Electric Department	Alabama	Alabama
Huntsville	Tuscumbia Electricity Department	Alabama	Alabama
Chattanooga	Athens Utilities Board (TN)	Southeast	Tennessee
Chattanooga	Blue Ridge Mountain Electric Membership Corporation	Southeast	Tennessee
Chattanooga	Chickamauga Electric System	Southeast	Georgia
Chattanooga	Cleveland Utilities	Southeast	Tennessee
Chattanooga	Dayton Electric Department, City of	Southeast	Tennessee

Weather File Location	LPC Name	TVA District	State
Chattanooga	Electric Power Board of Chattanooga (EPB)	Southeast	Tennessee
Chattanooga	Etowah Utilities	Southeast	Tennessee
Chattanooga	Fort Loudoun Electric Cooperative	Southeast	North Carolina
Chattanooga	Loudon Utilities	Southeast	Tennessee
Chattanooga	Murphy Power Board	Southeast	Tennessee
Chattanooga	North Georgia Electric Membership Corporation	Southeast	Georgia
Chattanooga	Rockwood Electric Utility	Southeast	Tennessee
Chattanooga	Sequachee Valley Electric Cooperative	Southeast	Georgia
Chattanooga	Sweetwater Utilities Board	Southeast	Tennessee
Chattanooga	Tri-State Electric Membership Corporation	Southeast	Tennessee
Chattanooga	Volunteer Energy Cooperative	Southeast	Tennessee
Knoxville	Alcoa Electric Department, City of	Northeast	Tennessee
Knoxville	Appalachian Electric Cooperative	Northeast	Tennessee
Knoxville	Bristol Tennessee Essential Services	Northeast	Virginia
Knoxville	Bristol Virginia Utilities	Northeast	Tennessee
Knoxville	Clinton Utilities Board	Northeast	Tennessee
Knoxville	Elizabethton Electric Department, City of	Northeast	Tennessee
Knoxville	Erwin Utilities	Northeast	Tennessee
Knoxville	Greeneville Light & Power System	Northeast	Tennessee
Knoxville	Harriman Utility Board	Northeast	Tennessee
Knoxville	Holston Electric Cooperative	Northeast	Tennessee
Knoxville	Jellico Electric and Water Systems	Northeast	Tennessee
Knoxville	Johnson City Power Board	Northeast	Tennessee
Knoxville	Knoxville Utilities Board (KUB)	Northeast	Tennessee
Knoxville	LaFollette Utilities Board	Northeast	Tennessee
Knoxville	Lenoir City Utilities Board	Northeast	Tennessee
Knoxville	Maryville Electric Department, City of	Northeast	Tennessee
Knoxville	Morristown Utilities Systems	Northeast	Tennessee
Knoxville	Mountain Electric Cooperative, Inc.	Northeast	Tennessee
Knoxville	Newport Utilities	Northeast	Tennessee
Knoxville	Oak Ridge Electric Department	Northeast	Tennessee
Knoxville	Plateau Electric Cooperative	Northeast	Tennessee
Knoxville	Powell Valley Electric Cooperative	Northeast	Tennessee
Knoxville	Sevier County Electric System	Northeast	Tennessee
Nashville	Benton Electric System (KY)	Kentucky	Kentucky
Nashville	Bowling Green Municipal Utilities	Kentucky	Kentucky

Weather File Location	LPC Name	TVA District	State
Nashville	Franklin Electric Plant Board (KY)	Kentucky	Kentucky
Nashville	Fulton Electric System	Kentucky	Kentucky
Nashville	Glasgow Electric Plant Board	Kentucky	Kentucky
Nashville	Hickman Electric Plant Board	Kentucky	Kentucky
Nashville	Hickman-Fulton Co. Rural Electric Cooperative Corp.	Kentucky	Kentucky
Nashville	Hopkinsville Electric System	Kentucky	Kentucky
Nashville	Mayfield Electric & Water System	Kentucky	Kentucky
Nashville	Murray Electric System	Kentucky	Kentucky
Nashville	Pennyrile Rural Electric Cooperative Corporation	Kentucky	Kentucky
Nashville	Russellville Electric Plant Board (KY)	Kentucky	Kentucky
Nashville	Tri-County Electric Membership Corporation	Kentucky	Tennessee
Nashville	Warren Rural Electric Cooperative Corporation	Kentucky	Kentucky
Nashville	West Kentucky Rural Electric Cooperative Corporation	Kentucky	Kentucky
Nashville	Caney Fork Electric Cooperative, Inc.	Middle TN	Tennessee
Nashville	Clarksville (CDE Lightband)	Middle TN	Tennessee
Nashville	Columbia Power & Water Systems	Middle TN	Tennessee
Nashville	Cookeville Electric Department	Middle TN	Tennessee
Nashville	Cumberland Electric Membership Corporation	Middle TN	Tennessee
Nashville	Dickson Electric Department	Middle TN	Tennessee
Nashville	Duck River Electric Membership Corporation	Middle TN	Tennessee
Nashville	Fayetteville Public Utilities	Middle TN	Tennessee
Nashville	Gallatin Department of Electricity	Middle TN	Tennessee
Nashville	Lawrenceburg Utility Systems	Middle TN	Tennessee
Nashville	Lewisburg Electric System	Middle TN	Tennessee
Nashville	McMinnville Electric System	Middle TN	Tennessee
Nashville	Meriwether Lewis Electric Cooperative	Middle TN	Tennessee
Nashville	Middle Tennessee Electric Membership Corporation (MTEMC)	Middle TN	Tennessee
Nashville	Mount Pleasant Power System	Middle TN	Tennessee
Nashville	Murfreesboro Electric Department	Middle TN	Tennessee
Nashville	Nashville Electric Service (NES)	Middle TN	Tennessee
Nashville	Pulaski (PES Energize)	Middle TN	Tennessee
Nashville	Shelbyville Power System	Middle TN	Tennessee
Nashville	Smithville Electric System	Middle TN	Tennessee
Nashville	Sparta Electric & Public Works	Middle TN	Tennessee
Nashville	Springfield Department of Electricity	Middle TN	Tennessee

Weather File Location	LPC Name	TVA District	State
Nashville	Tennessee Valley Electric Cooperative	Middle TN	Tennessee
Nashville	Tullahoma Board of Public Utilities	Middle TN	Tennessee
Nashville	Upper Cumberland Electric Membership Corporation	Middle TN	Tennessee
Nashville	Winchester Utilities	Middle TN	Tennessee
Memphis	4-County Electric Power Association	Mississippi	Mississippi
Memphis	Aberdeen Electric Department	Mississippi	Mississippi
Memphis	Alcorn County Electric Power Association	Mississippi	Mississippi
Memphis	Amory Water & Electric	Mississippi	Mississippi
Memphis	Central Electric Power Association	Mississippi	Mississippi
Memphis	Columbus Light & Water	Mississippi	Mississippi
Memphis	East Mississippi Electric Power Association	Mississippi	Mississippi
Memphis	Holly Springs Electric Department	Mississippi	Mississippi
Memphis	Louisville Utilities	Mississippi	Mississippi
Memphis	Macon Electric Department, City of	Mississippi	Mississippi
Memphis	Monroe County Electric Power Association	Mississippi	Mississippi
Memphis	Natchez Trace Electric Power Association	Mississippi	Mississippi
Memphis	New Albany Light, Gas & Water	Mississippi	Mississippi
Memphis	North East Mississippi Electric Power Association	Mississippi	Mississippi
Memphis	Northcentral Mississippi Electric Power Association	Mississippi	Mississippi
Memphis	Okolona Electric Department, City of	Mississippi	Mississippi
Memphis	Oxford Electric Department, City of	Mississippi	Mississippi
Memphis	Philadelphia Utilities	Mississippi	Mississippi
Memphis	Pontotoc Electric Power Association	Mississippi	Mississippi
Memphis	Prentiss County Electric Power Association	Mississippi	Mississippi
Memphis	Starkville Electric System	Mississippi	Mississippi
Memphis	Tallahatchie Valley Electric Power Association	Mississippi	Mississippi
Memphis	Tippah Electric Power Association	Mississippi	Mississippi
Memphis	Tishomingo County Electric Power Association	Mississippi	Mississippi
Memphis	Tombigbee Electric Power Association	Mississippi	Mississippi
Memphis	Tupelo Water & Light Department, City of	Mississippi	Mississippi
Memphis	Water Valley Electric Department, City of	Mississippi	Mississippi
Memphis	West Point Electric System, City of	Mississippi	Mississippi
Memphis	Benton County Electric System (TN)	West	Tennessee
Memphis	Bolivar Energy Authority	West	Tennessee
Memphis	Brownsville Utility Department	West	Tennessee
Memphis	Carroll County Electric Department	West	Tennessee

Weather File Location	LPC Name	TVA District	State
Memphis	Chickasaw Electric Cooperative	West	Tennessee
Memphis	Covington Electric System	West	Tennessee
Memphis	Dyersburg Electric System	West	Tennessee
Memphis	Forked Deer Electric Cooperative	West	Tennessee
Memphis	Gibson Electric Membership Corporation	West	Tennessee
Memphis	Humboldt Utilities	West	Tennessee
Memphis	Jackson Energy Authority	West	Tennessee
Memphis	Lexington Electric System	West	Tennessee
Memphis	Memphis Light, Gas & Water Division	West	Tennessee
Memphis	Milan Department of Public Utilities	West	Tennessee
Memphis	Newbern Electric Water & Gas	West	Tennessee
Memphis	Paris Board of Public Utilities	West	Tennessee
Memphis	Pickwick Electric Cooperative	West	Tennessee
Memphis	Ripley Power and Light	West	Tennessee
Memphis	Southwest Tennessee Electric Membership Corporation	West	Tennessee
Memphis	Trenton Light & Water Department	West	Tennessee
Memphis	Union City Electric System	West	Tennessee
Memphis	Weakley County Municipal Electric System	West	Tennessee

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.