Multifamily Performance Program
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Existing Buildings Standard Path
Simulation Guidelines
Version 6a

NYSERDA

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Simulation Guidelines

MPP EXISTING BUILDINGS STANDARD PATH

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1 SCOPE & OBJECTIVES

This document [1]contains methodologies for energy simulation and model calibration for buildings in NYSERDA's *Multifamily Performance Program – Existing Buildings Standard Path Component* ("Program"). This document is to be used by Multifamily Performance Partners ("Partners") to evaluate energy reduction measures and to calculate the projected savings and cost effectiveness of recommendations included in the Energy Reduction Plan ("ERP"). This document may be shared with the developer or property owner if requested.

1.1 Objectives

This document is a resource for Partners, the Program Implementer, and NYSERDA to ensure that:

- Savings projections are realistic.
- The number of model revisions is minimized because more guidance is provided from the beginning;
- Productivity is improved because Partners do not need to individually research the assumptions for various modeled parameters or develop external calculations;
- Consistent simulation methodology is used from Partner to Partner and from building to building based on peer-reviewed protocols;
- The best energy simulation and model calibration practices are followed; and
- Modeling assumptions are within reasonable ranges.

The guidelines outlined in this document may be periodically updated to cover additional topics.

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[1] This document version 6a removes references to tools exclusively available to NYSERDA Multifamily Performance Program Partners. Those Partners should use Version 6 of this document to comply with requirements of the NYSERDA Multifamily Performance Program.

2 GENERAL APPROACH

a) Savings from energy reduction measures shall be estimated using the *Whole Building Calibrated Simulation Approach,* as described in ASHRAE Guideline 14[2]. This approach involves modeling the existing building (creating a pre-retrofit simulation) with an approved whole building simulation software tool. The parameters for the pre-retrofit simulation are adjusted so that the projected annual energy consumption of each fuel is within the allowable margin from the annual utility bills, as described in the Model Calibration section of this document. Energy reduction measures are evaluated by making changes to the appropriate parameters of calibrated pre-retrofit simulation.

b) Pre-retrofit simulation inputs shall be based on results of field inspections, measurements, and as-built drawings. Where assumptions are made regarding building operating conditions, such as lighting runtime hours, interior temperature, hot water demand, etc., the assumed values shall be within the ranges provided in this document. If the Partner believes that there are special conditions that dictate the use of different assumptions or approaches for a particular project, these special conditions and appropriate references shall be documented in the ERP and are subject to Program review.

c) Inputs of pre- and post-retrofit simulations must be the same unless the related component is specifically addressed by proposed measures. *All* differences between the pre- and post-retrofit model inputs must be documented in the ERP, including key assumptions built into the simulation tool. For example, if U-values of the proposed windows or post-construction ACH are automatically set by the software, such as in EA QUIP, these defaults must be explicitly listed in the ERP.

d) The same operating condition assumptions shall be used in the energy reduction measure as in the existing building, unless a change in operating conditions is specifically included as part of the measure or unless directed otherwise in this document. For example, the lighting hours of operation must be the same in pre- and post-retrofit models unless one of the proposed measures includes installation of devices that affect fixture runtime, such as occupancy sensors, timers, or photocells.

e) Measures that are expected to increase energy consumption must be included in the post-retrofit model (i.e. higher proposed ventilation rates). The increase in energy usage must be offset by other measures to demonstrate achievement of the Program energy target.

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[2] *From ASHRAE Guideline 14*: The whole building calibrated simulation approach involves the use of a computer simulation tool to create a model of energy use and demand of the facility. This model, which is typically of pre-retrofit conditions, is calibrated or checked against actual measured energy use and demand data and possibly other operating data. The calibrated model is then used to predict energy use and demand of the post-retrofit conditions. Savings are derived by comparison of the modeled results under the two sets of conditions or by comparison of modeled and actual metered results.

3 MODEL CALIBRATION

3.1 General Approach

Projects may include several buildings that are individually metered for some or all fuels or have a common set of utility bills. Each building may have a single whole-building set of bills for each fuel or may include multiple sets of bills (i.e. electricity consumption in apartments is metered separately from the common space). This section provides guidelines for aggregating model results and utility bills for the purpose of model calibration.

a) When a single building has multiple sets of bills for a given fuel — for example, if electricity consumption in apartments is directly metered, or if there is a separate set of electric bills for the common space — all individual sets must be combined so that there is one set of bills representing the total whole building consumption of each fuel. Comparing the individual sets of bills to the modeled consumption of corresponding spaces — for example, comparing electricity usage of common spaces predicted by the model to the billing data for common spaces — may provide valuable additional insight into building operation, but it is not required.

b) When a project includes multiple buildings, the model calibration approach depends on the metering configurations and whether the buildings have similar envelope and mechanical systems.

   Buildings are considered to have *similar envelopes* if *all* of the following conditions are met:
   - Building geometries are similar:
     - Total conditioned building area differs by no more than 20%
     - Percentage of area taken by common spaces differs by no more than 20 percentage points.
     - Spaces in buildings are of a similar occupancy type
     - Areas of surfaces of each type (exterior and below grade walls, windows, roof, slab) differ by no more than 20%
   - Thermal properties of envelope components are similar
   - Infiltration rates are similar.

   Example: There are two 60,000 SF, 6-story buildings in the project. One building has 12,000 SF of corridors and common spaces (20% of total building area). The other building has the same corridor area, plus a community room, rental office and laundry on the first floor, with the total area of common spaces equal to 20,000 SF (33% of total building area). The percentage of common spaces in each of these buildings differ by 13 percentage points (33%-20%), and the buildings have spaces of different occupancy types; because of the different occupancy types, they may not be considered as having similar geometry.

   Buildings are considered to have *similar mechanical systems* if *all* of the following conditions are met:
   - HVAC or domestic hot water equipment in buildings is of similar type
   - Overall plant efficiency varies by no more than 5 percentage points.
   - Mechanical ventilation rates are similar (within 10% based on air changes per hour (ACH).

   Buildings are considered to have similar usage if the annual fuel usage per square foot of conditioned floor area differs by no more than 10%.

Calibration approaches for several typical configurations are described in Table 4.1. Other approaches may be allowed and are subject to Program review.

Table 4.1

	Similarity of Buildings and Systems	Type and Similarity of Heating Bills	Modeling Approach
Case A	Non-similar envelope or mechanical	Billing for heating fuel is either per apartment or per building.	Buildings must be explicitly modeled and individually calibrated to the corresponding set of utility bills.
Case B	Similar envelope and mechanical	Billing for heating fuel is either per apartment or per building; usage is similar between buildings.	Create single model representing *one* building; calibrate to area-weighted average annual usage.
Case C	Similar envelope and mechanical	The meter or billing data for heating fuel applies to multiple buildings.	Create single model representing *all* buildings that are served by a single heating-fuel meter; calibrate to the total annual usage shown for all fuels used at those buildings.
Case D	Non-similar mechanical systems	The meter or billing data for heating fuel applies to multiple buildings.	If simulation tool supports explicit modeling of non-identical HVAC systems in a single model file, the same approach as for Case C may be used. For tools that do not have this capability (such as TREAT), separate models must be created representing each building, and the total heating usage of these models must be calibrated to utility bills.

3.2 Calibration Requirements

a) If the simulation tool supports weather-normalized model-to-billing comparison by fuel and end use, such as in TREAT, the difference between the annual modeled use and the actual consumption for heating, cooling, and base load must differ by no more than 10%. Where variation exceeds 10%, review the billing data and model inputs for anomalies, data entry errors, misinterpretation of performance features, etc.

b) Users of approved modeling software tools that do not include billing analysis functionality are required to use a model calibration tool.

4 SIMULATION PROGRAM

a) Programs such as DOE-2, eQUEST, and TREAT have been approved for use in the Program. Additional ASHRAE 90.1-2007 compliant tools may be accepted upon NYSERDA review and approval of the software application.

b) The energy consumption of systems, equipment, and controls that are not directly supported by the software used for the project should be calculated outside of the simulation tool. External calculations may not be used to replace functions that are supported by the software tool. The results of external calculations may be used to inform modeling inputs or to adjust modeling results. The external calculation methodology must be documented and is subject to Program review. Original spreadsheets must be included in the submittals where applicable.

> *Example 1*: The proposed scope of work includes replacement of incandescent fixtures with fluorescent fixtures. Since any approved simulation tool will calculate savings from reduced lighting wattage, including interaction with space heating/cooling, the energy savings from this measure *must* be modeled in the simulation tool.
>
> *Example 2*: The proposed scope of work includes installation of daylighting controls. If the simulation tool used for the project does not support daylighting modeling, then the Partner may use external custom calculations or software tools to estimate the related energy savings or reduction in fixture runtime.

5 THERMAL ZONES

The thermal zones defined in the model impact the simulation accuracy. The following rules must be followed:

a) Each space or group of spaces that is served by non-identical HVAC systems, or that will be served by non-identical HVAC systems due to a proposed retrofit, must be modeled as a separate thermal zone served by an HVAC system of appropriate type and efficiency. For simulation tools such as TREAT that do not allow modeling multiple HVAC systems in one project, efficiency of the modeled HVAC system that represents the various actual systems found in the building must be based on the efficiencies of actual systems weighted by the heating load of thermal zones that they serve.

Example 1:
Site condition: Each apartment has a dedicated gas-fired furnace and a split system air conditioner. All in-unit systems are the same.

Modeling approach: Since all in-unit systems are identical, apartments may be combined into one thermal zone, provided that other conditions outlined in this section are met.

Example 2:
Site condition: Apartments in a building have hydronic baseboards and are served by a central boiler. Stairwells and utility areas have electric unit heaters.

Modeling approach: Stairwells and utility areas may be combined into one thermal zone because they are served by the same type of heating system (electric heaters). Apartments should be modeled as a separate zone served by central boiler. For TREAT projects, usage of electric unit heaters may be estimated using the heating load of the zone that includes stairwells and utility areas and modeled as a secondary heating system using fixed percentage of monthly energy or similar approach.

Example 3:
Site condition: All utility spaces in the building are served by electric heaters. The Energy Reduction Plan includes a recommendation to replace electric heaters in some of these spaces with gas unit heaters.

Modeling approach: Utility spaces for which the new heating system is proposed may only be combined with other utility spaces that would undergo the same improvement to correctly estimate the post-retrofit reduction in heating electric load and the increase in gas heating load.

Example 4:
Site condition: All apartments in the building are served by a central heating system. Some of the apartments also have room air conditioners.

Modeling approach: In order to correctly account for cooling energy usage, apartments *may* be modeled as two thermal zones — one combining all rooms that are cooled and another combining all rooms with no cooling.

b) If a space or group of spaces is determined to be overheated, and the overheating is being addressed in the ERP, overheated spaces *may* be modeled as a separate zone. Space temperature measurements or other means that were used to determine temperature and size of overheated zones must be included in the ERP. If overheated zones are not modeled explicitly, then the procedure used to calculate modeled pre- and post-retrofit temperature of aggregated zones must be documented in the ERP. An example calculation is included in Section 8.1.

c) Each space or group of spaces that have unique internal or solar heat gains or envelope loads *may* be modeled as separate thermal zones to improve the accuracy of the simulation. Combining apartments with different exposures or apartments adjacent to different surface types (roof, slab-on-grade, etc.) into one thermal zone may underestimate the cooling and heating loads.

Example 5:
Site condition: On a sunny day in April, south-facing apartments may get overheated due to solar gains, while north-facing apartments may need heat to maintain the thermostat setpoint.

Modeling approach: If all apartments are modeled as a single thermal zone, then solar gains through south-facing windows will offset heating load of north-facing apartments, which is not an accurate representation of site conditions. This will decrease the modeled heating usage and impact model-to-billing calibration. Modeling south-facing and north-facing apartments as two separate zones will improve the accuracy of simulation.

6 HEATING AND COOLING SYSTEMS

6.1 Heating Equipment

6.1.1 General

Several efficiency descriptors may be available for the existing heating equipment and the equipment considered as the retrofit.

Combustion Efficiency (E_c) accounts for stack losses and may be measured in the field by performing a combustion efficiency test.

Thermal Efficiency (E_t) accounts for the heat loss through the boiler jacket during boiler firing in addition to the stack losses; therefore, E_t is lower than E_c for the given equipment. It may be calculated as the ratio of the nameplate boiler output to the nameplate boiler input.

Annual Fuel Utilization Efficiency (AFUE) accounts for stack and jacket loss, as well as for equipment performance during the part load conditions in a "typical" installation. AFUE also accounts for the energy that is wasted when the boiler is "idling" to maintain internal temperature while the building is not calling for heat. AFUE cannot be measured in the field or calculated based on the parameters shown on the nameplate. It is determined through testing performed by the manufacturer. AFUE is also called "seasonal efficiency" and is typically only provided for equipment under 300,000 Btu/hr. The AFUE represents the part-load efficiency at the average outdoor temperature and load for a typical boiler installed in the United States. Although this value is useful for comparing different boiler models, it is not meant to represent actual efficiency of a specific installation [49]. With the exception of condensing boilers, part-load efficiency metrics are usually not provided for larger boilers.

A more complete explanation of each efficiency descriptor is available in Appendix D.

a) Energy consumption of fans and pumps associated with the heating system must be captured in both the pre- and post-retrofit models.

Example 1:
Site Conditions: Electric baseboards in apartments are replaced by a central hot water boiler.

Modeling Approach: Electricity consumption of pumps serving the new system must be included in the post-retrofit model to fully capture the tradeoffs between electric and hydronic heating. Ignoring the heating-related electricity consumption of the post-retrofit system will lead to overestimated electricity savings.

b) Performance of heating equipment may vary significantly depending on the overall HVAC system design and field conditions. The model inputs must be based on the performance of the existing and proposed heating systems for the conditions that exist at the given site. The relevant system design parameters must be described in the ERP for both existing and proposed conditions.

Example 2:
Site Conditions: The Energy Reduction Plan includes replacement of the existing boiler with a new condensing boiler. Marketing literature for the condensing boiler reports that the boiler has a thermal efficiency up to 98%.

Modeling Approach: The performance of condensing boilers depends strongly on the return water temperature and the variations in load, as shown on Figure 7.1 below, which is based on manufacture's literature for Benchmark 2.0 boiler. The operating conditions that are required to achieve the modeled efficiency must be documented in the ERP. The existing piping arrangement and a sample of radiators must be evaluated to ensure that the conditions required to achieve the modeled efficiency are feasible.

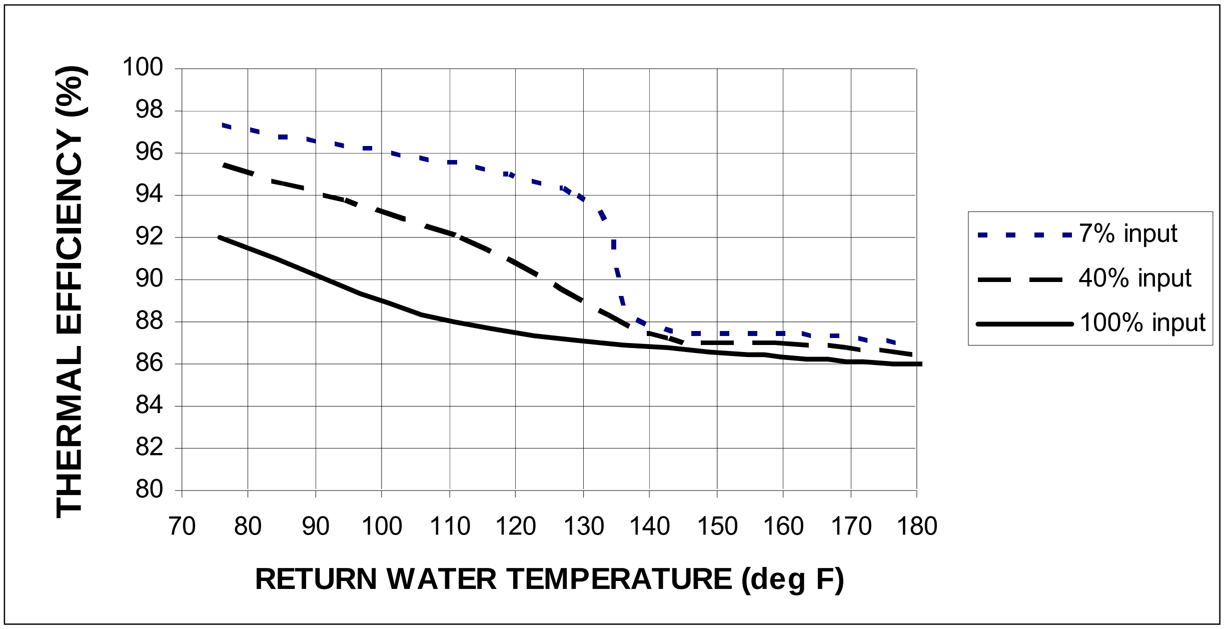

FIGURE 7.1
EXAMPLE CONDENSING BOILER THERMAL EFFICIENCY

Example 3:
Site Conditions: The Energy Reduction Plan includes replacement of the existing boiler with a boiler that is equipped with a burner that can fire at reduced inputs while modulating both fuel and air.

Modeling Approach: Projected savings should capture increased efficiency of modulating boiler at part load conditions. The performance curves entered in eQUEST or efficiency adjustment calculations for TREAT should be based on boiler part-load performance from manufacture, or typical performance of modulating boilers from ASHRAE Systems and Equipment Handbook shown below.

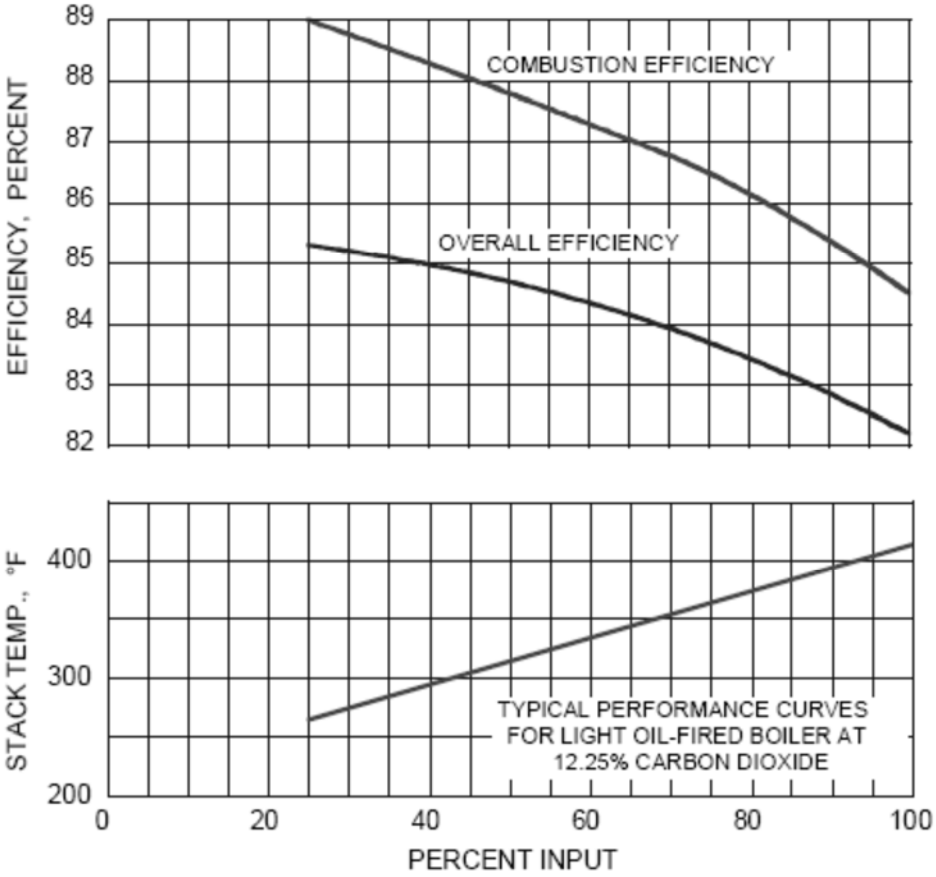

FIGURE 7.2
BOILER EFFICIENCY AS FUNCTION OF FUEL AND AIR INPUT [49]

Example 4:
Site Conditions: Energy modeling indicates that the existing boiler is significantly oversized. The energy reduction plan proposes to replace the existing boiler with a new higher efficiency unit of the appropriate size.

Modeling approach: In space heating applications, low part-loading for a boiler occurs over much of the heating season because of equipment oversizing and the fact that space heating boilers must be sized to meet the maximum load even though this load only occurs rarely. For example, one study found that multifamily boilers with on/off burners are typically only 21% loaded on a heating season average basis” [50].

The charts below show test data on efficiency for steam boiler and hot water boiler with and without reset control at different outdoor temperatures [51].

Steam boiler data in Figure 7.3 is for an actual two-pipe steam boiler with an input capacity of 1,420,000 Btu/h and stack efficiency of 73% serving a 36-unit multifamily building. The boiler was naturally vented with a louvered secondary opening, and draft *relief was provided by a barometric damper. The boiler was originally built to burn coal as the fuel, but has been converted to use natural gas.*

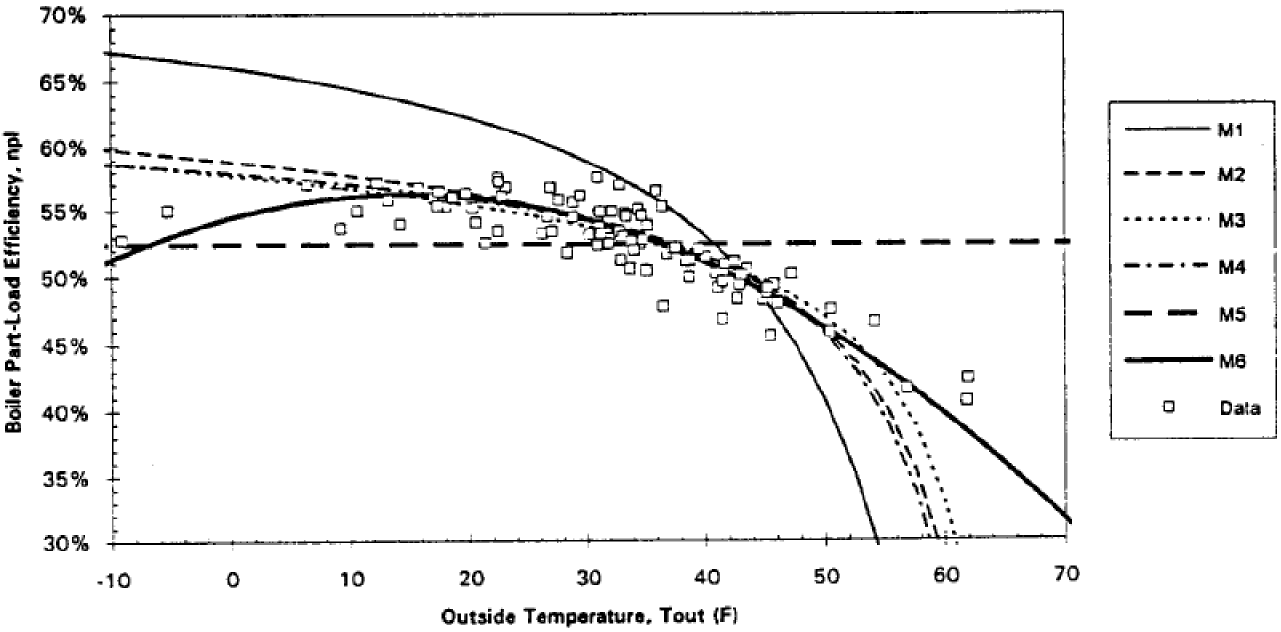

FIGURE 7.3
MODEL PREDICTIONS AND MEASURED DATA OF PART-LOAD EFFICIENCY FOR STEAM BOILER

Hot water boiler data in Figures 7.4-7.5 is for cast iron, gas fired, naturally vented, with a draft hood and a fixed secondary air opening, with the input capacity of 480,000 Btu/hr and 81.5% stack efficiency, and was serving a 17-unit, low-rise multifamily building.

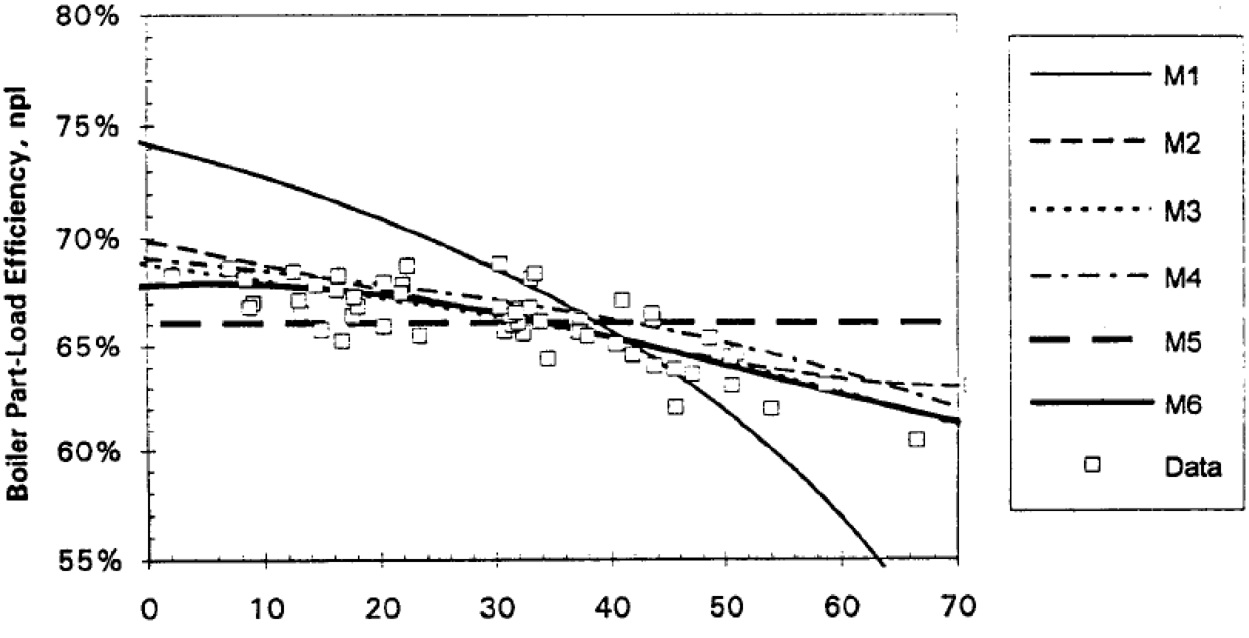

FIGURE 7.4

MODEL PREDICTIONS AND MEASURED DATA OF PART-LOAD EFFICIENCY FOR WATER BOILER IN CONSTANT TEMPERATURE MODE

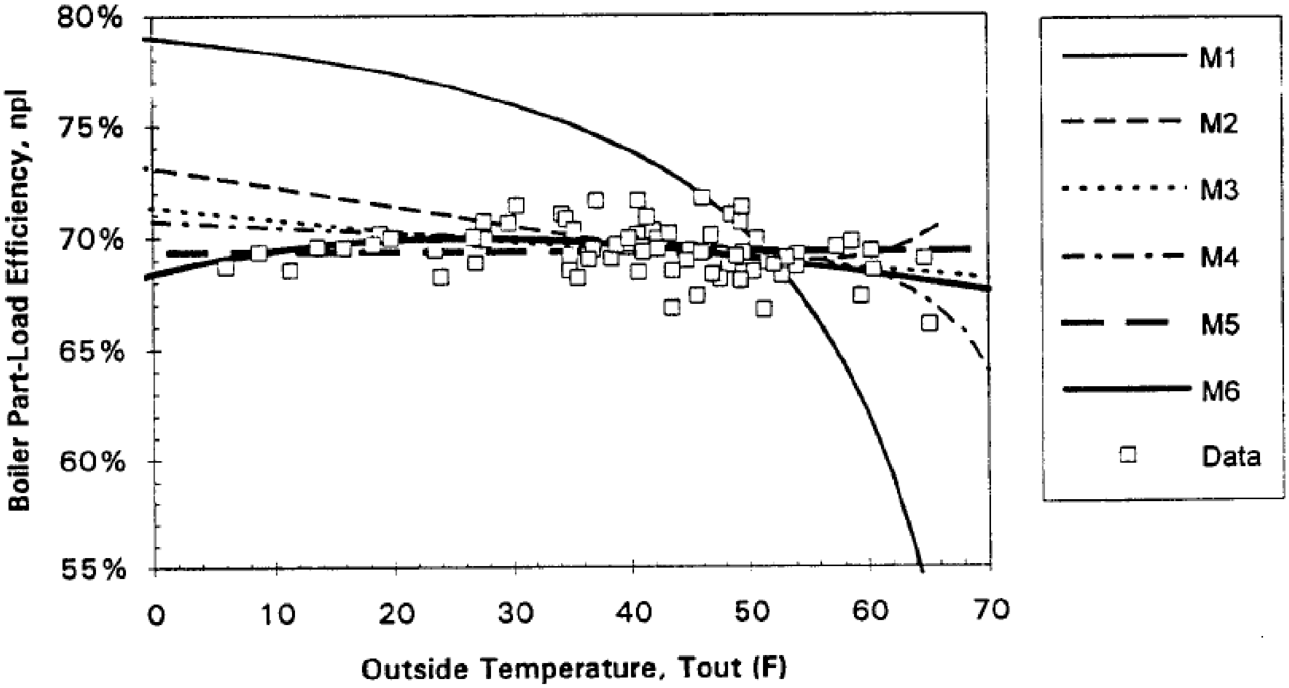

FIGURE 7.5
MODEL PREDICTIONS OF PART-LOAD EFFICIENCY AND MEASURED DATA FOR WATER BOILER IN RESET MODE

Run fraction at a given load condition may be estimated in the field by observing the burner operation. For example, if a boiler fires for 5 minutes, then remains off for 20 minutes before restarting, the run fraction is equal to 5 minutes / (5 minutes + 20 minutes)=0.2 or 20% [52].

In eQUEST, the boiler part-load performance penalty may be captured by specifying the size of the equipment in the Boiler Properties window of the Basic Specifications tab. In addition, specify the appropriate performance curves in f (part load ratio) input box of Performance Curves tab. The eQUEST library has default curves for atmospheric, forced draft, and condensing boilers. Alternatively, custom curves may be created using manufacture-specified or measured efficiency at part load conditions. eQUEST will combine part load equipment characteristics with hourly heating loads and use the appropriate efficiency for each hour of the year in the simulation.

In TREAT, part-load efficiency is handled as described in the User Manual: “The part-load adjustment is calculated for each month depending on equipment type and part-load ratio during the month and varies between 0.75 and 1. If part-load ratio for boilers is less than 0.1, then monthly usage is adjusted by 0.75 + 2.5 * PartLoadRatio. For forced air heating and cooling systems the monthly usage is adjusted by
0.75 + 0.25 * PartLoadRatio.”

6.1.2 Existing Conditions

a) For equipment with a heating capacity of 300,000 Btu/hr or less, if the listed AFUE is available from the equipment manufacturer for the existing equipment, $AFUE_{actual}$ shall be used in the pre-retrofit model. For equipment with a heating capacity of 300,000 Btu/hr or less with unknown listed AFUE, and for equipment with heating capacity greater than 300,000 Btu/hr, $E_{t,actual}$ shall be used. $AFUE_{actual}$ and $E_{t,actual}$ shall be calculated as described below.

Exception: If a heating retrofit is considered and AFUE is available for the existing equipment but *is not* available for the proposed equipment, $E_{t, actual}$ shall be used for the existing equipment.

$AFUE_{actual}$ and $E_{t,actual}$ for the existing equipment shall be calculated assuming that deterioration in annual or thermal efficiency is proportional to the deterioration in combustion efficiency as follows:

$$AFUE_{actual}=AFUE_{listed}*E_{c,actual}/E_{c,listed}$$

$$E_{t,actual}=E_{t,listed}*E_{c,actual}/E_{c,listed}$$

Where

$AFUE_{actual}$ = actual AFUE of existing equipment

$AFUE_{listed}$ = AFUE of existing equipment listed on the nameplate or in the manufacturer’s literature.

$E_{c,actual}$ = actual combustion efficiency of existing equipment measured during the audit.

$E_{c,listed}$ = combustion efficiency of existing equipment listed on the nameplate or in manufacturer’s literature.

$E_{t,actual}$ = actual thermal efficiency of existing equipment.

$E_{t,listed}$ = thermal efficiency of existing heating equipment listed on equipment nameplate or in manufacturer’s literature.

b) If either $E_{c,listed}$ or $E_{t,listed}$ is not available for the existing equipment, then Table 7.1 shall be used to estimate $E_{t,actual}$ based on the measured combustion efficiency $E_{c,actual}$. To compute $E_{t,actual}$, subtract the numbers in the table from the measured (actual) combustion efficiency percentage.

Table 7.1 Average Percentage Point Differences Between E_t & E_c [17]

Fluid	Heat Exchanger	300,000-2,500,000 Btu/hr		2,500,000 - 10,000,000 Btu/hr	
		Natural Gas	Oil #2	Natural Gas	Oil #2
Steam	Cast Iron	2.1	2.4	1.5	1.6
Water	Cast Iron	1.6	2.4	1.4	1.6
	Steel	2.2	3.4	NA	NA

For equipment below 300,000 Btu/hr, if $\text{AFUE}_{\text{actual}}$ cannot be calculated as described in the section above, and for air-source heat pumps, then Table 7.2 must be used to estimate efficiency based on the equipment age.

Table 7.2 Minimum Age-Based Efficiency

Mechanical Systems	Units	pre-1991	1992 to present
Gas Furnace	AFUE	0.76	0.78
Gas Boiler	AFUE	0.77	0.8
Oil Furnace or Boiler	AFUE	0.8	0.8
Air-Source Heat Pump	HSPF	6.8	6.8
Ground-Water Geothermal Heat Pump	COP	3.2	3.5
Ground-Coupled Geothermal Heat Pump	COP	2.7	3

c) The simulation model may account for lower summer efficiencies for the space heating boiler, in the case where this boiler heats domestic hot water. The assumptions and references must be documented in the ERP.

6.1.3 Improvements

a) System Replacement

AFUE shall be used to model the performance of equipment proposed as retrofit when the listed AFUE is available from the equipment manufacturer for both existing and proposed equipment. In all other cases, thermal efficiency (E_t) shall be used to model both pre- and post-retrofit equipment. Alternative methods may be used with appropriate references and documentation.

Rated efficiency of proposed HVAC equipment must be included in the ERP and must be based on the test procedure appropriate for the specified equipment type, as listed in Tables E803.2.2 of the Energy Conservation Construction Code of New York State. Equipment that does not have the standard rating, such as ARI rating, may be allowed as a measure, but is subject to Program Review.

b) Boiler Tune-up

The estimated useful life of boiler tune ups shall not exceed one year. The efficiency increase due to boiler tune-up depends on the boiler condition prior to the tune-up and the scope of work being performed. The longevity of such savings is difficult to determine, as factors such as water quality, fuel, and proper maintenance are all influential. For example, commercial boilers that use gas and light oil may only need to be cleaned once a year in comparison to boilers using heavy oil, which require several cleanings each year [43].

6.1.4 Cooling Equipment

a) Efficiency of Existing Equipment

If the efficiency of existing system cannot be determined based on the equipment nameplate, the following values must be used in the pre-retrofit model:

- central air conditioners: SEER 10 / EER 9,2 [53, p.41],
- heat pumps: SEER 10 / HSPF 6.8 [53, p.44].
- room air conditioners [53, p.73]
  <20,000 Btu.hr: SEER 9.7
  >=20,000 Btu/hr: SEER 8.5

b) Refrigerant charge correction

Refrigerant charge correction may be modeled as 10% improvement in pre-retrofit EER [53, p. 58].

6.2 Distribution System

6.2.1 Variable Frequency Drives (VFD)

Savings from the installation of variable speed drives shall be determined based on the fan/pump affinity laws using an exponent of 2.2 (to account for system effect) and no more than a 30% reduction in average flow. Savings can be attributed to water or air distribution.

Example 1:
Site condition: A central chiller plant in a high rise multifamily building using a primary / secondary pumping scheme feeds 300 gallons per minute (gpm) of water throughout the building to fan coil units. The pump is driven with a 10 hp motor with an operating bhp of 8.5. A VFD will be installed with an estimated average flow reduction of 20%. Existing motor revolutions per minute (RPM) is 1,800 (RPM is to be taken from design documents where available or from field gathered data).

Flow is directly proportional to rotational speed:

$$Q1/Q2 = N1/N2, 300/240 = 1800/N2, N2 = 1{,}440$$

Where:
Q = chilled water flow before and after VFD installation.
N = motor RPM before and after VFD installation.

Once the new RPM is found the reduction in kW can be determined as follows.

$$kW1/kW2 = (N1/N2)^{2.2}, \ kW2 = kW1/(N1/N2)^{2.2}$$

Where: $kW1 = 8.5(bhp) * 0.746/0.88$ (motor efficiency) = 6.34 kW
$kW2 = 7.2/(1800/1440)^{2.2}$
$kW2 = 7.2 / 1.75 = 4.11$

Pre and post kW should then be multiplied to the typical run hours for the unit based on location where applicable and the difference in kWh determined. The improvement can now be modeled as an appliance using the difference in kWh as the yearly consumption and removed as part of the improvement.

6.2.2 Steam Trap Replacements

Steam trap replacement savings shall be determined using Grashof's equation. Trap failure rate shall be estimated based on manufacturer's data when available or 10% / yr up to 40%. In no case shall the savings be more than 25% of the annual heating fuel consumption. The equation states:

$$\text{Lbs/hr (loss)} = C \times G \times 3{,}600 \times A \times p^{0.97}$$

Where:
C = Coefficient of discharge for hole, use 0.7
G = Grashof's constant = 0.0165
3,600 = # of seconds in (1) hour
A = Area of discharge of equivalent orifice diameter in square inches (use 75% of area to account for partially blocked openings)
P = pressure in steam line prior to trap, use 2.5 psia

Savings can then be calculated as:

MMBtu/yr = ((lb/hr loss(total) * 1,000 (Btu/lb steam) * hours of operation) / 1,000,000) / Boiler efficiency.

Example 1:
Site condition: A steam system feeding 100 radiators has not been maintained for 5 years. The equivalent trap orifice diameter is ¼". The heating system operates for 2,000 hours per year with a boiler efficiency of 78%.

$$\text{Lbs/hr (loss)} = C \times G \times 3{,}600 \times A \times p^{0.97}$$

C = 0.7
G = 0.0165
A = $(3.14 \times (0.25/2)^2)/2$ = 0.098sqin
P = 2.5

Lb/hr/trap = 9.91, # of failed traps = 100 x 0.4(max) = 40 traps
Total lbs/hr of steam lost = 9.91 x 40 396.4 lbs/hr
MMBtu / yr = (396.4 lbs/hr x 1,000 Btu/lb x 5,000) / 1,000,000 = 1,982/ .78 = 2,541 MMBtu/yr

After determining MMBtu savings, use standard fuel conversions to determine amount of fuel savings. Fuel savings can be modeled as an appliance with the same consumption and then removed for appropriate savings.

7 HEATING/COOLING TEMPERATURE SCHEDULE

7.1 Existing Conditions

a) Actual indoor temperatures during heating and cooling seasons must be modeled as thermostat setpoints. Heating and cooling setpoints used in the model must be documented in the Energy Reduction Plan.

b) If the total area-weighted building temperature of all modeled zones combined is outside a range of 69°F – 76°F for at least some of the time during the heating season, then the inputs must be supported by a record of indoor temperatures measured in multiple locations. [24, 25, 28].

> <u>*Example 1*</u>:
> *Site Conditions*: It is determined that 20% of apartments are overheated and that the average temperature for these apartments is 82°F. The average space temperature in the remaining apartments is 72°F.
>
> *Modeling Approach*: Overheated spaces may be modeled as a separate zone or aggregated with other apartments. If modeled as a separate zone, then the space temperature of the zone representing overheated apartments will be modeled as 82 °F, and the space temperature of the zone representing the rest of the apartments will be modeled as 72°F.
>
> If overheated areas are aggregated with other apartments into single zone, then the modeled temperature of this zone is calculated as 82°F * 20% + 72°F * 80% = 74°F.
>
> With either approach, the weighted average temperature in the model is 74°F, which falls within the range allowed by this Section 8.1(b).

7.2 Improvements

TEMPERATURE REDUCTION AT APARTMENT LEVEL		
Existing	**Proposed**	**Modeling Protocol**
Non-programmable thermostats; corresponding heating or cooling bills NOT paid by residents	Programmable thermostats in apartments or TRVs with no upper limit set	Not allowed in scope of work as an energy efficiency measure [25] – unlikely to generate energy savings
Non-programmable thermostats; corresponding heating or cooling bills paid by residents	Night setback via programmable thermostats in apartments	Heating: maximum 3°F setback for 8 hours per day [53, p. 55] Cooling: maximum 2°F increase for 6 hours per day [18]
Any resident-controlled thermostat, TRV, or other temperature control	Range-limited thermostats, TRVs, or other controls with a specific upper limit on indoor temperature	Must use interior space temperature no less than specified upper limit [24, 25]. Maximum 2°F temperature reduction.

Note that if modeled energy savings are based on the reduction of space temperature in apartments where occupants have unlimited apartment-level control over the heating setpoint, the post retrofit temperature during occupied periods should not be less than 74°F in buildings with owner-paid corresponding utilities, or 72°F in buildings with resident-paid corresponding utilities [25].

TEMPERATURE CONTROL AT BUILDING LEVEL – STEAM SYSTEMS		
Existing	**Proposed**	**Modeling Protocol - Steam**
On/off control only; no outdoor reset Note that outdoor reset for steam systems is defined as a control that adjusts the length of the steam cycle as the outdoor temperature changes.	Outdoor reset	Model as a temperature reduction. Do not model as “outdoor reset” as this option only applies to hot water system or vacuum steam systems. Must provide details of existing controls and evidence that outdoor reset is not currently being utilized. 1°F maximum temperature reduction
Outdoor reset; heating imbalances observed	EMS with indoor temperature sensors	Distribution imbalances *not* addressed : 2°F maximum temperature reduction Distribution imbalances addressed: 3°F maximum temperature reduction
Outdoor reset; no heating imbalances	EMS with indoor temperature sensors	3°F maximum temperature reduction

The temperature reductions in the table above are weighted average reductions, inclusive of night setback.

TEMPERATURE CONTROL AT BUILDING LEVEL – HOT WATER SYSTEMS		
Existing	**Proposed**	**Modeling Protocol – Hot Water**
On/off control only, no outdoor reset	Outdoor reset	Model as outdoor reset control on hot water loop. Must provide details of existing controls and evidence that outdoor reset is not currently being utilized. System must be able to operate with outdoor reset (condensing boilers and/or boilers separated from heating loop).
	Outdoor reset and EMS with indoor temperature sensors	Model as above for outdoor reset portion of savings. Additionally, model a temperature reduction of 1°F maximum if the outdoor reset curve (i.e. the hot water loop set point) will be adjusted based on feedback from apartment sensors.
Outdoor reset	EMS with indoor temperature sensors	Model as a temperature reduction if outdoor reset curve (hot water loop set point) will be adjusted based on feedback from apartment sensors. 1°F maximum temperature reduction

Steam boilers that supply a hot water loop are to be considered a hot water system.

The temperature reductions in the table above are weighted average reductions, inclusive of night setback.

For more information, see Appendix F

8 AIR INFILTRATION AND MECHANICAL VENTILATION

8.1 Mechanical Ventilation

a) Mechanical ventilation shall be modeled according to data collected during the site visit, including the fan runtime hours and flow rates. Fan flow rates may be measured, obtained from as-built drawings and specifications, estimated based on manufacturer’s data for the installed model and ductwork characteristics, or estimated based on the rated fan motor horsepower listed on the nameplate.

b) The electricity consumption of fan motors shall be included in the model based on the rated power consumption and the annual fan run time, as determined in the field. The following equations may be used to estimate fan motor energy:

$$kW_{fan} = CFM\left(\frac{FanStatic\,Pr\,essure}{8520 \cdot FanEfficiency}\right) \qquad [20]$$

$$kW_{fan} = bhp\left(\frac{0.746}{FanEfficiency}\right) \qquad [15]$$

where:

CFM = design flow rate

FanStaticPressure = pressure drop in ductwork, inch H_2O

FanEfficiency = fan motor efficiency fraction

8520 = conversion factor, $\left(\frac{ft3 * inches}{min\,utes * kW}\right)$

bhp = break horsepower of fan motor

c) If the proposed improvements include a change in mechanical ventilation rates, then the projected savings should reflect the impact of the change on heating and cooling loads and fan motor energy consumption.

8.2 Pre-retrofit Infiltration

a) Average air changes per hour (ACH) in the conditioned space caused by natural infiltration of outdoor air during the heating season must be below 1.0 ACH, or below 0.21 CFM per square foot[3] of gross vertical exterior wall area [2,4,6,7,8,9].[4] However, infiltration rates may be much lower than these maximum values in most multifamily buildings, and 0.6 ACH should be considered typical. Average heating season air changes that are higher than 1.0 ACH might occur when there are many intentional openings, such as a high occurrence of open windows. If present, these conditions must be documented in the ERP.

b) Blower door measurements may be converted to estimated annual infiltration rates using the equations below [21]:

$$ACH=ACH_{50}/K$$

$$ACH_{50}=CFM_{50}*L/\text{Building Volume [CF]}$$

Coefficients K and L may vary depending on the building and test conditions. In the absence of project-specific references, K=20 and L=60 should be used.

c) Non-apartment spaces with low area of exterior surfaces, such as corridors or basements, have much lower infiltration rates. For example, 0.2 ACH is considered typical for a basement. A notable exception to this rule are mechanical rooms, which often have much higher infiltration rates due to intentional combustion air openings.

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[3] This value of CFM/sq. ft. represents infiltration through all components of the building envelope, including the roof, normalized to CFM per square foot of gross vertical wall area above ground.

[4] These are approximations based on a review of reports by Gulay, et al., (1993); Palmiter, et al., (1995); Shaw et al., (1980, 1990, and 1991); and Sherman et al., (2004). Information on measured infiltration rates in multifamily buildings is extremely limited. Most of the available information cannot be directly correlated to New York State's building stock and climate conditions.

8.3 Interaction between Infiltration and Mechanical Ventilation

Outdoor air flow rates in pre- and post-retrofit models shall reflect the combined effect of natural and mechanical ventilation. If the simulation tool does not automatically account for the interaction between infiltration and ventilation, which is the case for most tools, including TREAT and eQUEST, then the combined flow rate must be calculated using equation (43) in Chapter 27 of the 2005 *ASHRAE Handbook–Fundamentals*, as quoted below:

$$Q_{comb} = Q_{bal} + \sqrt{Q_{unbal}^2 + Q_{infiltration}^2}$$

Q_{comb} [CFM] = combined rate of natural and mechanical ventilation.

Q_{bal} [CFM] = balanced mechanical ventilation in a space or group of connected spaces that have both exhaust and supply fans. This represents the portion of mechanical ventilation where the exhaust flow is equal to the supply flow. Q_{bal} = minimum($Q_{exhaust}$, Q_{supply})

Q_{unbal} [CFM] = unbalanced mechanical ventilation flow in a space of group of connected spaces. This is the portion of mechanical ventilation where either the exhaust or supply flow is greater than the other.

Q_{unbal} = maximum($Q_{exhaust}$, Q_{supply})- Q_{bal}. If the space has only supply or exhaust, all the flow is unbalanced.

$Q_{infiltration}$ [CFM] = natural (non-mechanical) infiltration rate.

Equivalent combined rate Q_{comb} may be modeled as either all mechanical or all natural ventilation, or as a combination of the two as appropriate for the simulation tool being used. See Section 9.5 Modeling Approach for calculation procedure.

8.4 Infiltration Reduction Improvements

Field research has shown that extensive air sealing measures can reduce a building's total infiltration rate by 18% to 38% [2, 9]. Consistent with that, the maximum percentage reduction in infiltration from all improvements combined is 38% source energy usage. This does not include the portion of infiltration that is attributable to occupant behavior, such as opened windows due to poor heating control.

9 LIGHTING

9.1 General

a) The modeled wattage of fixtures that have ballasts or transformers must include the consumption of all components and not just the nominal lamp wattage. Every effort should be made to look up the specifications for the particular ballast model number. Appendix A lists total wattages for the typical lamp/ballast combinations that may be used in the model if the fixture-specific information is not available. The model numbers of ballasts and lamps for the fixtures that are proposed to be replaced should be listed in the ERP.

b) If the hourly lighting load distribution must be entered into the modeling tool, then the software default schedules, or the schedules developed by NREL and made available at the Building America website at http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html (End-Use Profiles), may be used, provided that the load distribution does not exceed the total hours of operation required in this document.

c) Exterior lighting that is on the site utility meters (e.g., pole fixtures for walkways and parking, exterior lighting attached to the building, etc.) must be included in the energy simulation and considered for retrofit. Improvements to exterior lighting may involve replacement of existing fixtures with new fixtures having better efficacy, reducing the number of fixtures to eliminate overlighting, and installing lighting controls such as timers, occupancy sensors and photosensors.

d) The pre- and post-retrofit lighting power density of common spaces must be documented in the ERP. For example, corridor lighting usually offers a good opportunity for improvement and may be reduced below 0.9 W/SF per NYS Energy Code, 0.5 W/SF per ASHRAE 90.1 2004, or best practice, 0.3 W/SF. Parking garage lighting may also offer a good energy savings opportunity.

e) The same hours of operation must be used for pre- and post-retrofit fixtures unless the measure includes the installation of device(s) that affect the fixture runtime.

9.2 Existing Conditions

a) The modeled wattage of existing incandescent fixtures must be equal to the wattage of the installed bulbs, but no greater than the maximum rated fixture wattage.

b) Lighting inside apartment units for which no retrofit is proposed should be modeled as having an installed wattage of 2.0 W/SF [10] and operating 2.34 hr/day [23], or 2.0 * 2.34 = 4.68 [Wh/SF-day]. As part of the process to calibrate the model to utility bills, this energy consumption may be modified ± 30% by adjusting either the installed wattage or hours of operation.

c) Apartment lighting that is being retrofitted must be modeled with the operating hours from the table below based on the room type [10]. Alternatively, 3.2 hours/day runtime may be assumed for the existing incandescent fixtures retrofitted with screw-in CFLs [53, p.7] and 2.5 hours per day may be assumed for the existing fixtures that are replaced with new pin-base CFL fixtures [53, p.11]. Alternative assumptions may be used but must be accompanied by the proper references and are subject to Program review.

Table 10.1 In-Unit Lighting

Room Type	**Average Lighting Usage (hrs/day)**
Kitchen/Dining	3.5
Living Room	3.5
Hall	2.5
In-unit laundry/utility room	2.5
Bedroom	2.0
Bathroom	2.0

d) Existing or proposed lighting controls, including occupancy sensors and timers, may be modeled as a reduction in the hours of operation or as an equivalent adjustment to the installed lighting power from Table 10.2 [14, 15]. Alternative reductions in hours may be used but must be accompanied by the proper references and are subject to Program review.

Table 10.2 Common Area Lighting

Space Type	Power Adjustment Percentage Reduction in Operating Hours
Hallways/Corridors	25%
All other spaces intended for 24 hour use	10%

9.3 Improvements

a) If an improvement includes installation of fixtures that will use screw-in CFLs, then the modeled wattage of proposed fixtures must be equal to the maximum rated fixture wattage, regardless of the wattage of the proposed bulbs. For example, if a new fixture can use either incandescent bulbs or CFL, the wattage of the fixture's maximum allowable incandescent bulb must be used in the model.

b) When replacing incandescent lighting with fluorescent lights or CFLs, the lighting energy savings should be based on no more than 3.4:1 reduction in wattage [53, p.7,11]. For example, wattage of CFL that replaces 60W incandescent bulb should be modeled as no less than 60/3.4 = 18W. . This is different from what is suggested by CFL manufacturers' packaging, which often recommends a 4:1 reduction, or even more. In addition, care must be taken with special populations (such as seniors) to provide appropriate lighting levels.

10 ENVELOPE COMPONENTS

10.1 Surfaces

a) If different cross-sections through non steel-framed surfaces have different R-values, then the overall effective R-value for those surfaces must be calculated by first calculating the U-values of each cross-section and then pro-rating the U-value by the corresponding fraction of surface area Construction libraries of approved simulation tools may be used but must represent the combined thermal properties of the frame and cavity sections.

b) Effective R-values of metal frame constructions must be based on the tables in ASHRAE Standard 90.1-2004 reproduced in Appendix B of this document. If the pre-retrofit or post-retrofit conditions include insulation that has an intermediate R-value between those provided in the tables reproduced in Appendix B, then it is legitimate to interpolate between the framing/cavity R-values shown in the table. For example, if cavity insulation was determined to be R-20, but Appendix B only provides effective R-value for R-19 and R-21 cavity insulation for the given construction, then the average of these values may be used to model a surface with R-20 cavity insulation.

c) If gaps or other defects in the existing insulation are discovered, then its U-value must be de-rated. The de-rating procedure must be explained in the ERP.

d) For portions of envelope where construction cannot be determined, the following assumptions may be used [53, p.29]:

   - old, poorly insulated / un-insulated wall – R-7
   - existing wall with average insulation – R-11
   - old, poorly insulated roof – R-11
   - existing roof with average insulation – R-19

Libraries available in the simulation tools include many common constructions. If the exact match for the existing or proposed construction cannot be found (for example, if there is no matching entry in the TREAT library), then the effective R-value for the surface, including de-rating for insulation defects, should be calculated outside of the simulation tool. If software (such as TREAT) does not allow entering custom constructions, then the surface with the closest effective R-value must be selected from the library. An attempt should be made to select a surface assembly which also has a similar thermal mass. For example, if the actual wall has block construction, it is preferable that the surface assembly selected from the library to represent this wall includes a block layer.

10.2 Fenestration

10.2.1 Existing Condition

The following properties must be used to model existing windows unless building-specific information is available [53, p.33]:

- Single pane windows: solar heat gain coefficient of 0.87 and U-value of 1.2 Btu/hr-SF-deg F
- Double pane windows: solar heat gain coefficient of 0.77 and U-value of 0.87 Btu/hr-SF-deg F

10.2.2 Proposed windows

Where Energy Reduction Plan calls for Energy Star windows, but the window manufacturer and model number is not specified, windows with U-0.31 and SHGC of 0.35 must be remodeled, based on EPA minimum performance criteria for these products as of January 2010. If Energy Star windows are not available for the installation, then the actual properties of the specified window must be used.

11 DOMESTIC HOT WATER

11.1 Domestic Hot Water Heating Systems

11.1.1 Water Heating Equipment Categories

Residential Storage Water Heaters. This category includes electric heaters with input ≤ 12kW, gas heaters with input ≤ 75,000 BTU/h, and Oil heaters with input ≤ 105,000BTU/h, and storage capacity below 120 gal.

Residential Instantaneous Water Heaters. This category includes gas heaters with input ≤ 75,000 BTU/h and oil heaters with input ≤ 210,000BTU/h.

Larger storage and instantaneous heaters are categorized as *Non-residential*.

11.1.2 Water Heating Equipment Performance Characteristics

Efficiency of water heating equipment is described through one or more of the following parameters:

Recovery Efficiency (RE) – heat absorbed by the water divided by the heat input to the heating unit during the period that water temperature is raised from inlet temperature to final temperature.

Recovery Rate – the amount of hot water that a residential water heater can continually produce, usually reported as flow rate in gallons per hour, which can be maintained for a specified temperature rise through the water heater.

Energy Factor (EF) – a measure of water heater overall efficiency determined by comparing the energy supplied in heated water to the total daily energy consumption of the water heater determined following DOE test procedure (10 CFR Part 430). The energy factor represents the fraction of all heat that was used to heat the water and maintain the temperature of that water in the face of standby losses that is still present in the water when it flows into the distribution system. It can never be higher than the thermal efficiency (see below).

Standby loss (SL), as applied to a tank type water heater under test conditions with no water flow, is the average hourly energy consumption divided by the average hourly heat energy contained in the stored water expressed as percent per hour. This may be converted to the average Btu/hr energy consumption required to maintain any water-air temperature difference by multiplying the percent by the temperature difference, 8.25 Btu/gal*F (a nominal specific heat for water), the tank capacity, and then dividing by 100.

Thermal Efficiency (Et) is the heat in the water flowing from the heater outlet divided by the heat input over a specific period of steady-state conditions. E_t accounts for the flue losses and the loss through the heater (boiler) jacket when boiler is firing.

Residential water heaters (storage and instantaneous) have performance specified by the energy factor, EF. Non-residential water heaters with storage volume <10 gal usually have thermal efficiency E_t available. Water heaters with larger storage capacity have standby loss ratings in addition to thermal efficiency. For unfired storage tanks, R-value of tank insulation is usually specified.

11.1.3 Evaluating Performance of the Existing Water Heaters

If performance of the existing water heater is unknown, combustion efficiency E_c should be measured. This value should be reduced by 3 percentage points to estimate thermal efficiency E_t [39].

$$E_t=E_c-0.03$$

For all instantaneous water heaters, assume negligible standby losses SL=0 and $EF=E_t$.

For residential water heaters, the following relationship may be used to estimate EF [38]:

$$EF=0.62-0.0019*\text{Rated Storage Tank Volume}$$

For commercial storage water heaters, use the following relationship to estimate SL [38]:

$$SL=\frac{Q}{800}+\frac{110}{\sqrt{V}}$$

Q[Btu/hr] - rated input power
V[gallons] - rated storage tank volume

eQuest requires that user enters Heat Input Ratio (HIR), tank volume in gallons, and tank UA [38]. These shall be determined as follows:

$$HIR = 100/E_t$$

$$UA=SL*E_t/70$$

Part load performance degradation must be based on default DOE2 performance curves.

If simulation tool allows specifying water heater efficiency using different parameters, such as in TREAT, the same efficiency descriptors must be used for both baseline and proposed equipment where possible.

11.2 Existing DHW Demand

- Overall Hot Water Consumption

  The typical usage reported in the ASHRAE Applications Handbook is 14-54 gal/day/person. This is based on studies by Goldner and Price [46], which also demonstrate that a middle-range is 30 gal/day/person. This middle range is a good starting point for modeling. Demographic characteristics affecting hot water consumption are shown in Table 12.1.

- Consumption above 54 gal/day/person is possible and was observed in some field studies [46]; however, if the model is using a high water consumption to calibrate the model, then other possible factors affecting DHW usage must also be considered and justification must be included in the ERP. Examples of factors affecting DHW demand and/or DHW energy consumption could be the DHW temperature, equipment efficiency, standby and distribution losses, and water leaks.

Table 12.1
Demographic Characteristics Correlating to DHW Consumption [46]

Demographic Characteristics	**Average daily DHW usage (gallons/day per person)**
No occupants work Public assistance & low income (mix) Family & single parent households (mix) High % of Children Low income	54
Families Public assistance Singles Single-parent households	30
Couples Higher population density Middle income Seniors One person works, one stays home. All occupants work.	14

Note: These gallons are for DHW set at a temperature that will achieve 120ºF at the tap.

Example:
Site Conditions: A building has 15 apartments and is occupied mostly by low income families with children, with an average of three people per apartment.

Modeling Approach: Model hot water usage as being up to 54 gal/day-person*3 person/apt=162 gal/day/apartment. If proper calibration is still not achieved, then other factors affecting hot water heating energy consumption must be considered, including the DHW temperature, equipment efficiency, standby and distribution losses, water leaks, etc., before a further increase in hot water demand is modeled.

- Allocation of demand to the correct end uses.
    - If the ERP includes any measure that claims energy savings from reducing DHW consumption, then the base-building DHW consumption must be determined by calibrating the modeled DHW-related energy usage and by modeling all clothes washers and dishwashers on site. **Modeling of existing clothes washers and dishwashers is required for modeling the installation of faucet aerators or showerheads.** This will assist in validating the portion of total hot water consumption that is allocated to the non-appliance usage in the base-building model.

11.2.1 Clothes washers

The assumed hot water consumption of existing clothes washers shall be determined as follows:

Determination of annual loads per washer. Use actual measured annual loads per washer when available, such as from coin income receipts. Otherwise, use the typical loads per washer as defined below.

Common area washers. The number of annual wash cycles per each washer located in a common area shall be determined per the formula below, or as 2,738 cycles/year per washer, whichever is less:

$$L_{common} = \frac{(Number\ of\ occupants\ with\ no\ washer\ in\ apt.)}{(Number\ of\ common\ area\ washers)} \times 36.5$$

L_{common} = Annual number of loads per each washer located in a shared common area laundry room [47].

Number of occupants with no washer in apartment is equal to the total number of residents at the site multiplied by the percentage of apartments that do not have in-unit clothes washers.

Number of common area washers is equal to the total number of washers located in common areas, not just the washers intended for replacement.

The number of loads per washer shall be equally distributed among all common area washers.

In-apartment washers. The number of wash cycles for an in-apartment washing machine shall be modeled as being between 110 to 146 loads per occupant per year, multiplied by the number of occupants in that apartment [47] (the average number of occupants per apartment may be used). If the apartment has more than one washing machine, then the result should be divided by the number of washers to determine annual loads per washer.

Determination of hot water consumption per load. Hot water consumption per load shall be determined by multiplying the rated *total* gallons per load (hot and cold water combined) by the following percentages [48]:

- For non-EnergyStar® models, multiply the total rated water consumption per load by 29%.
- For EnergyStar® models, multiply the total rated water consumption per load by 21%.

Rated total gallons per load (hot and cold water combined) is equal to the rated water factor multiplied by the washer volume (cubic feet). If only the EPA rating for gallons per year is known, such as for residential models, then divide gallons per year by 392 to determine gallons per load (both hot and cold water).

11.2.2 Dishwashers

See discussion of dishwashers in Section 13.

11.3 DHW Improvements

11.3.1 Low flow devices

If the installation of low-flow faucet aerators or showerheads is included in the ERP, then:

- the flow rate of existing fixtures must be documented and based on measurements in a sample of apartments, and
- all existing dishwashers and clothes washers must also be modeled in the base-building model per these guidelines.

If the simulation tool allows for explicit modeling of water heating energy savings associated with low-flow device installation (such as TREAT), then the tool functionality must be used to calculate the savings. If the reduction in annual hot water consumption due to low flow fixture installation must be calculated externally (for example, when using eQUEST) the DHW Reduction must be calculated as described below, and applied to the existing modeled flow rate:

$$\text{DHW Reduction} = 100\% - \left[36\% + 54\%\left(\frac{LFS}{PS}\right) + 10\%\left(\frac{LFF}{PF}\right)\right]$$

DHW Reduction = % reduction in annual DHW usage
LFS [GPM] = average weighted flow rate of low-flow showerheads
PS [GPM] = average weighted flow rate of pre-retrofit showerhead
LFF [GPM] = average weighted flow rate of low-flow faucet
PF [GPM] = average weighted flow rate of pre-retrofit faucet

The calculation is based on the study by Hwang et al. http://enduse.lbl.gov/Info/LBNL-34046.pdf, that investigated volume-dominated (i.e., filling containers) versus flow-dominated water loads (i.e., showers, hand-washing). The flow rates of existing fixtures that are being replaced must be measured and included in the ERP.

11.3.2 EnergyStar® clothes washers.

Annual loads per washer shall be modeled as described in Section 12.2. Hot water consumption per load for new EnergyStar® models shall be determined by multiplying the rated *total* gallons per load (hot and cold water combined) by 21% [48].

11.3.3 EnergyStar® dishwashers.

Simulation guidelines for dishwasher DHW consumption and savings are shown in the Plug Loads section of this document.

12 PLUG LOADS

12.1 Existing Conditions

a) With the exception of refrigerators and dishwashers, kitchen appliances that *are not targeted for replacement* in the ERP may be modeled using the appropriate software defaults or as specified for pre-retrofit conditions in the Improvements section below. Usage of such appliances may be adjusted ±30% as part of model calibration.

b) The partner must sample a reasonable number of existing refrigerators, and must use data from the manufacturer, the appliance Energy Guide label, the Association of Home Appliance Manufacturers (AHAM) directory, or from the online databases such as http://www.kouba-cavallo.com/refrig1.html based on the actual models found in the building. If data on energy consumption based on the model numbers is not available in the sources listed above, the partner must monitor a reasonable sample of refrigerators.

c) Loads from miscellaneous small kitchen appliances, home entertainment equipment, computers, etc, *may* be combined into one category and modeled as 1.37 kWh/yr per square foot of finished floor area of living space [26]. This usage may be adjusted ±30% as part of the process of calibrating the model to utility bills. Alternatively, the actual equipment may be modeled as recorded during the audit and documented usage assumptions.

d) Miscellaneous electric loads in non-apartment spaces *may* either be based on Table 13.1 [27], or loads from actual equipment found during the audit and documented usage assumptions.

Table 13.1

Space Type	**Annual Electricity Usage**
Corridors, restrooms, stairs and support areas	0.7 kWh/SF
Offices	4.9 kWh/SF
All Other	1.0 kWh/SF

12.2 Improvements

a) If the ERP includes installation of EnergyStar® refrigerators, the post-retrofit usage must be based on data from http://www.energystar.gov/index.cfm?fuseaction=refrig.display_products_html.

b) If the ERP includes the installation of EnergyStar® dishwashers, then pre- and post-retrofit usage must be based on data for the existing and proposed models from the manufacturer, taken from the appliance Energy Guide label, or as published by Association of Home Appliance Manufacturers (AHAM). If the data for the pre- or post-retrofit dishwasher is unknown, then values from Table 13.2 may be used, based on the calculator accessible from http://www.energystar.gov/index.cfm?c=dishwash.pr_dishwashers. The usage is based on 215 cycles per year.

Table 13.2

Annual Fuel Usage per Unit	Energy Star Dishwasher	Existing Dishwasher
Electricity consumption	187 kWh	264 kWh
Water Heating Gas / Electric	6 therm /144 kWh	19 therm / 203 kWh

a) If the ERP includes the installation of EnergyStar® clothes washer, then information about the existing and proposed washer models must be provided, including manufacturer, model number, the rated total *motor* electricity consumption as listed by the manufacturer or current EnergyStar® publications, and documentation of the typical kWh consumed per cycle for each model. The associated water heating savings shall be modeled as described in Section 12.2.

APPENDIX A

The tables below are from the ASHRAE Standard 90.1 2004 User's Manual For a more comprehensive list of fixtures, refer to Tables NB-1 to NB-14 of Non-residential Alternative Calculation Method (ACM) Approval Manual [35]. For example, 44W may be used for a single-lamp F40T12 fixture with magnetic ballast if the exact lighting system power is unknown.

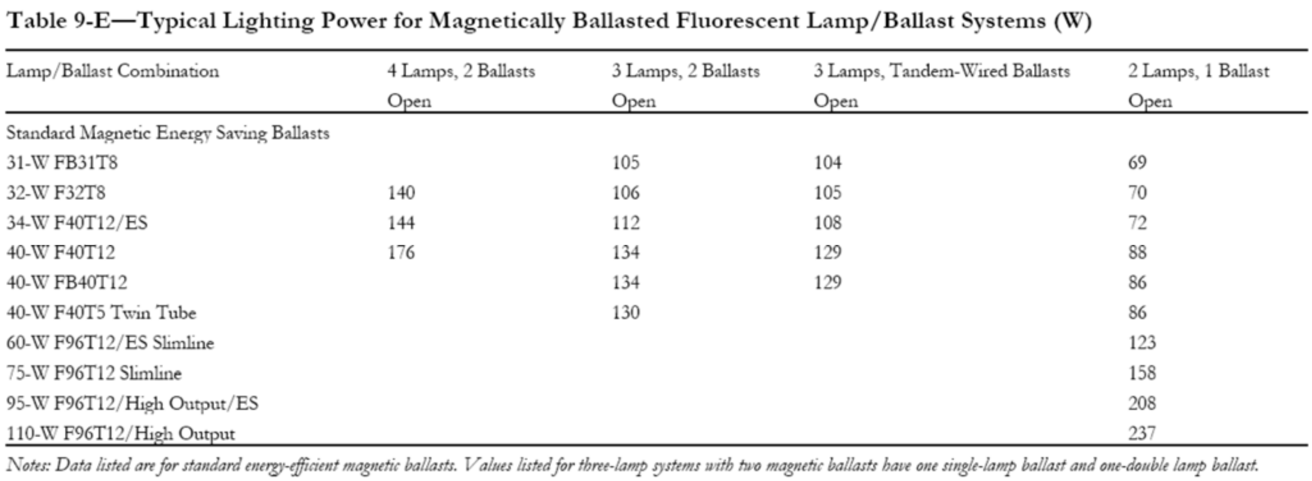

Table 9-E—Typical Lighting Power for Magnetically Ballasted Fluorescent Lamp/Ballast Systems (W)

Lamp/Ballast Combination	4 Lamps, 2 Ballasts Open	3 Lamps, 2 Ballasts Open	3 Lamps, Tandem-Wired Ballasts Open	2 Lamps, 1 Ballast Open
Standard Magnetic Energy Saving Ballasts				
31-W FB31T8		105	104	69
32-W F32T8	140	106	105	70
34-W F40T12/ES	144	112	108	72
40-W F40T12	176	134	129	88
40-W FB40T12		134	129	86
40-W F40T5 Twin Tube		130		86
60-W F96T12/ES Slimline				123
75-W F96T12 Slimline				158
95-W F96T12/High Output/ES				208
110-W F96T12/High Output				237

Notes: Data listed are for standard energy-efficient magnetic ballasts. Values listed for three-lamp systems with two magnetic ballasts have one single-lamp ballast and one-double lamp ballast.

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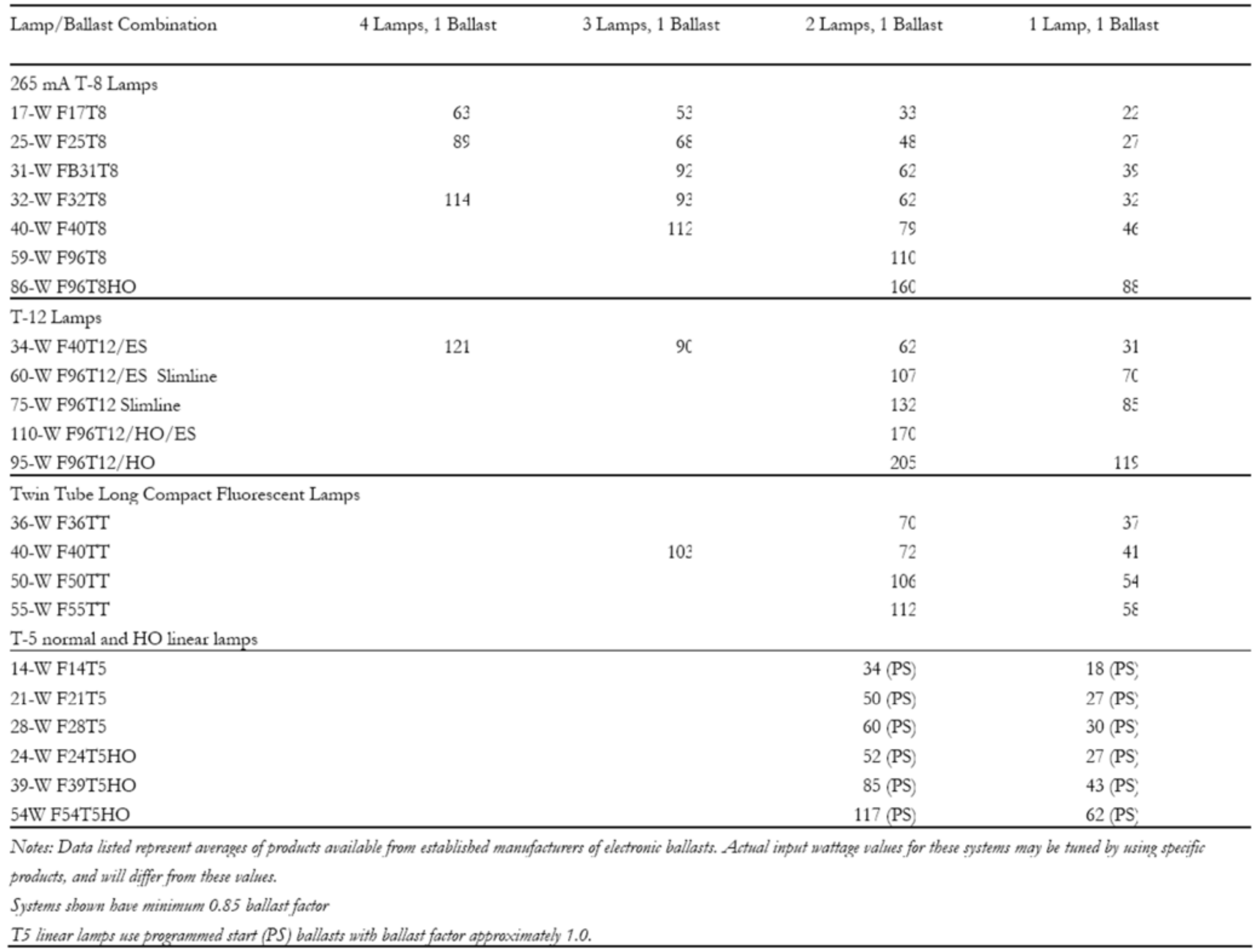
Table 9-F—Typical Lighting Power, Electronic Ballasted Fluorescent Lamp/Ballast Systems (W)



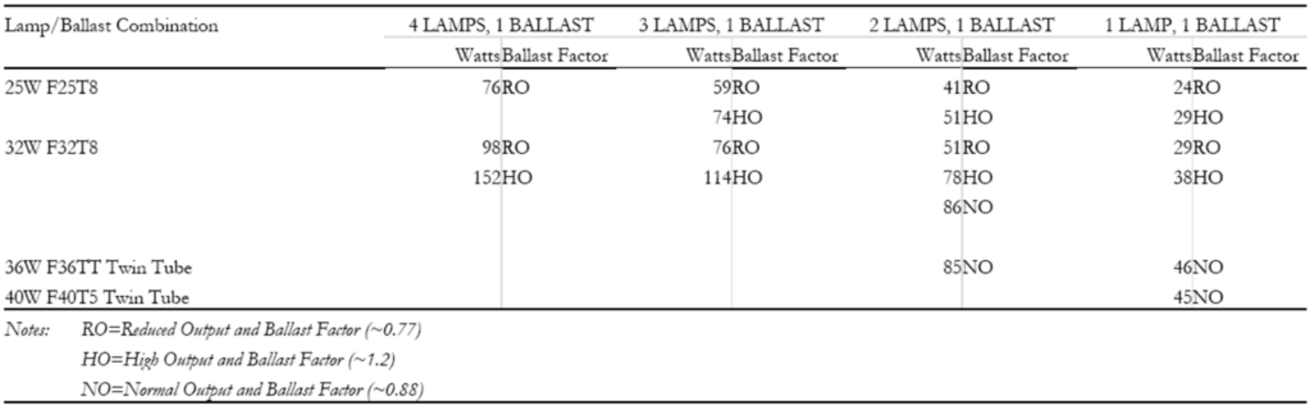
Lamp/Ballast Combination	4 Lamps, 1 Ballast	3 Lamps, 1 Ballast	2 Lamps, 1 Ballast	1 Lamp, 1 Ballast
265 mA T-8 Lamps				
17-W F17T8	63	53	33	22
25-W F25T8	89	68	48	27
31-W FB31T8		92	62	39
32-W F32T8	114	93	62	32
40-W F40T8		112	79	46
59-W F96T8			110	
86-W F96T8HO			160	88
T-12 Lamps				
34-W F40T12/ES	121	90	62	31
60-W F96T12/ES Slimline			107	70
75-W F96T12 Slimline			132	85
110-W F96T12/HO/ES			170	
95-W F96T12/HO			205	119
Twin Tube Long Compact Fluorescent Lamps				
36-W F36TT			70	37
40-W F40TT		103	72	41
50-W F50TT			106	54
55-W F55TT			112	58
T-5 normal and HO linear lamps				
14-W F14T5			34 (PS)	18 (PS)
21-W F21T5			50 (PS)	27 (PS)
28-W F28T5			60 (PS)	30 (PS)
24-W F24T5HO			52 (PS)	27 (PS)
39-W F39T5HO			85 (PS)	43 (PS)
54W F54T5HO			117 (PS)	62 (PS)

Notes: Data listed represent averages of products available from established manufacturers of electronic ballasts. Actual input wattage values for these systems may be tuned by using specific products, and will differ from these values.

Systems shown have minimum 0.85 ballast factor

T5 linear lamps use programmed start (PS) ballasts with ballast factor approximately 1.0.

Table 9-G—Electronically Ballasted High or Low-Wattage Fluorescent Lamp/Ballast Systems



Lamp/Ballast Combination	4 LAMPS, 1 BALLAST		3 LAMPS, 1 BALLAST		2 LAMPS, 1 BALLAST		1 LAMP, 1 BALLAST	
	Watts	Ballast Factor	Watts	Ballast Factor	Watts	Ballast Factor	Watts	Ballast Factor
25W F25T8	76	RO	59	RO	41	RO	24	RO
			74	HO	51	HO	29	HO
32W F32T8	98	RO	76	RO	51	RO	29	RO
	152	HO	114	HO	78	HO	38	HO
					86	NO		
36W F36TT Twin Tube					85	NO	46	NO
40W F40T5 Twin Tube							45	NO

Notes: *RO=Reduced Output and Ballast Factor (~0.77)*
HO=High Output and Ballast Factor (~1.2)
NO=Normal Output and Ballast Factor (~0.88)

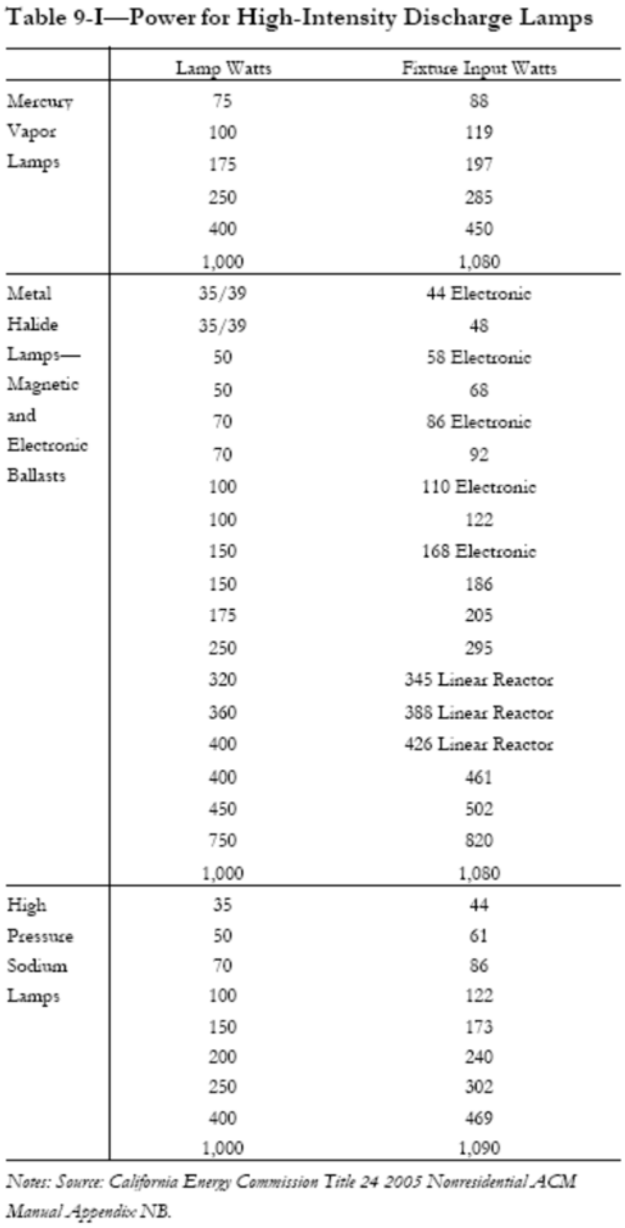


Table 9-I—Power for High-Intensity Discharge Lamps

	Lamp Watts	Fixture Input Watts
Mercury Vapor Lamps	75	88
	100	119
	175	197
	250	285
	400	450
	1,000	1,080
Metal Halide Lamps—Magnetic and Electronic Ballasts	35/39	44 Electronic
	35/39	48
	50	58 Electronic
	50	68
	70	86 Electronic
	70	92
	100	110 Electronic
	100	122
	150	168 Electronic
	150	186
	175	205
	250	295
	320	345 Linear Reactor
	360	388 Linear Reactor
	400	426 Linear Reactor
	400	461
	450	502
	750	820
	1,000	1,080
High Pressure Sodium Lamps	35	44
	50	61
	70	86
	100	122
	150	173
	200	240
	250	302
	400	469
	1,000	1,090

Notes: Source: California Energy Commission Title 24 2005 Nonresidential ACM Manual Appendix NB.

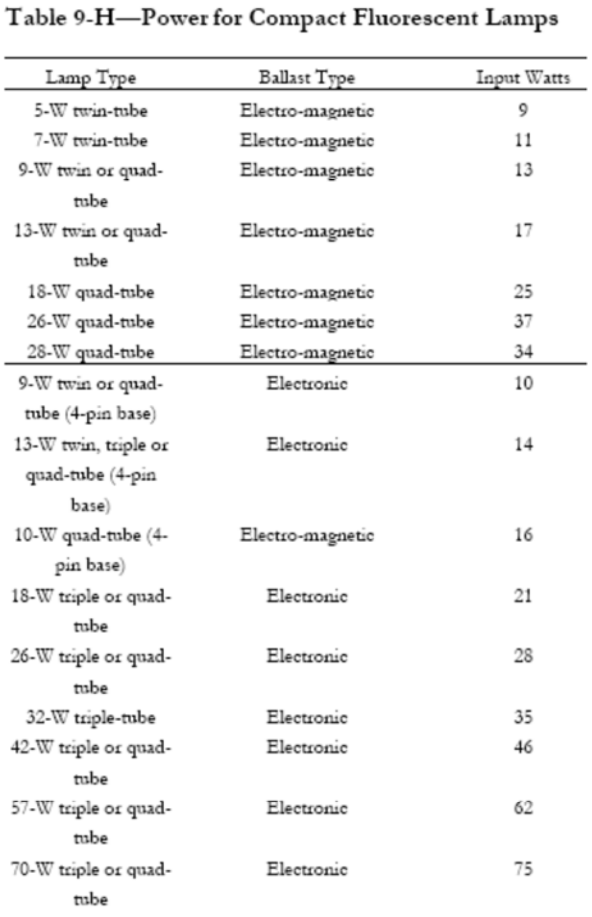


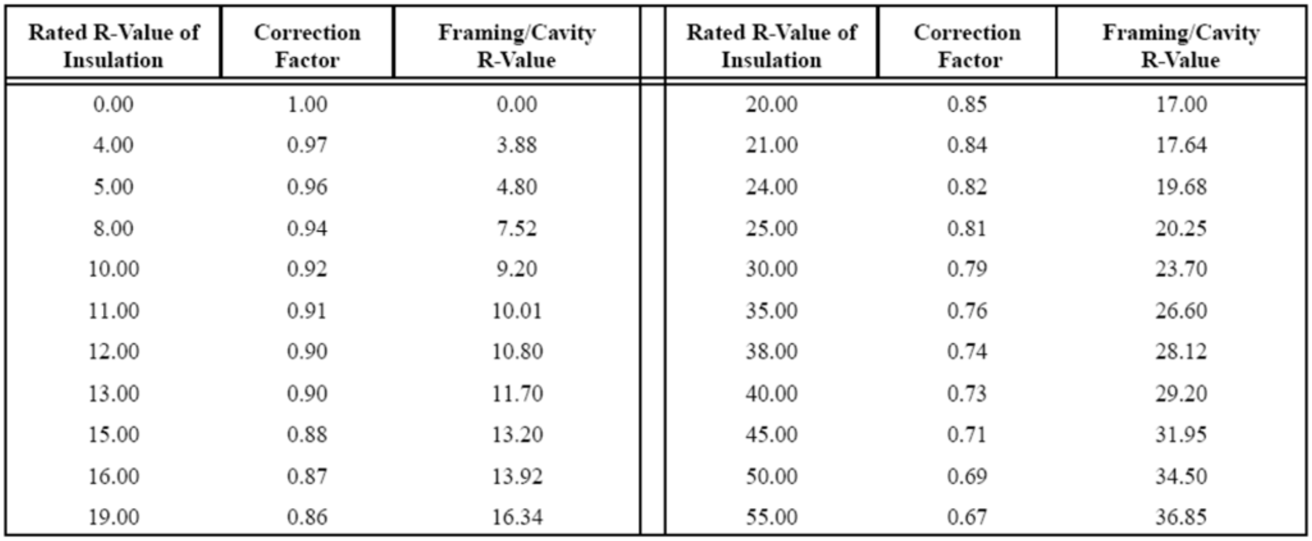
Table 9-H—Power for Compact Fluorescent Lamps

Lamp Type	Ballast Type	Input Watts
5-W twin-tube	Electro-magnetic	9
7-W twin-tube	Electro-magnetic	11
9-W twin or quad-tube	Electro-magnetic	13
13-W twin or quad-tube	Electro-magnetic	17
18-W quad-tube	Electro-magnetic	25
26-W quad-tube	Electro-magnetic	37
28-W quad-tube	Electro-magnetic	34
9-W twin or quad-tube (4-pin base)	Electronic	10
13-W twin, triple or quad-tube (4-pin base)	Electronic	14
10-W quad-tube (4-pin base)	Electro-magnetic	16
18-W triple or quad-tube	Electronic	21
26-W triple or quad-tube	Electronic	28
32-W triple-tube	Electronic	35
42-W triple or quad-tube	Electronic	46
57-W triple or quad-tube	Electronic	62
70-W triple or quad-tube	Electronic	75

APPENDIX B

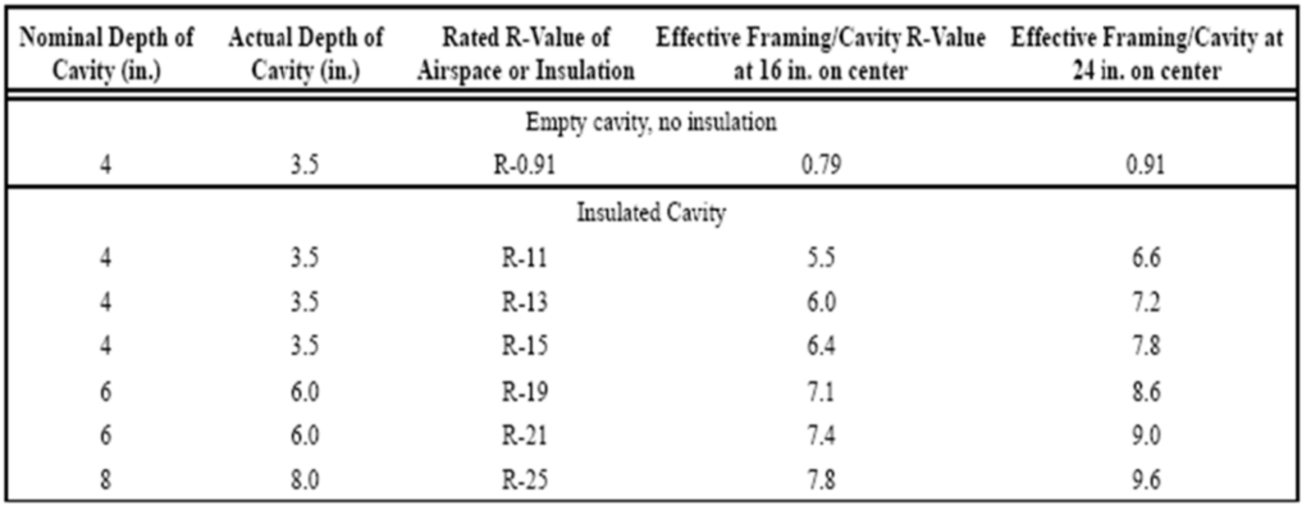
The tables below are from the ASHRAE Standard 90.1 2004 Appendix A and are reproduced with permission of ASHRAE. The permission is conveyed through Copyright Clearance Center, Inc.

TABLE A9.2A Effective Insulation/Framing Layer R-Values for Roof and Floor Insulation Installed Between Metal Framing (4 ft on center)



Rated R-Value of Insulation	Correction Factor	Framing/Cavity R-Value	Rated R-Value of Insulation	Correction Factor	Framing/Cavity R-Value
0.00	1.00	0.00	20.00	0.85	17.00
4.00	0.97	3.88	21.00	0.84	17.64
5.00	0.96	4.80	24.00	0.82	19.68
8.00	0.94	7.52	25.00	0.81	20.25
10.00	0.92	9.20	30.00	0.79	23.70
11.00	0.91	10.01	35.00	0.76	26.60
12.00	0.90	10.80	38.00	0.74	28.12
13.00	0.90	11.70	40.00	0.73	29.20
15.00	0.88	13.20	45.00	0.71	31.95
16.00	0.87	13.92	50.00	0.69	34.50
19.00	0.86	16.34	55.00	0.67	36.85

TABLE A9.2B Effective Insulation/Framing Layer R-Values for Wall Insulation Installed Between Steel Framing



Nominal Depth of Cavity (in.)	Actual Depth of Cavity (in.)	Rated R-Value of Airspace or Insulation	Effective Framing/Cavity R-Value at 16 in. on center	Effective Framing/Cavity at 24 in. on center
		Empty cavity, no insulation		
4	3.5	R-0.91	0.79	0.91
		Insulated Cavity		
4	3.5	R-11	5.5	6.6
4	3.5	R-13	6.0	7.2
4	3.5	R-15	6.4	7.8
6	6.0	R-19	7.1	8.6
6	6.0	R-21	7.4	9.0
8	8.0	R-25	7.8	9.6

APPENDIX C

		ELA, SqIn/unit	Unit	
Ceiling/ Ceiling Penetrations	General Ceiling (well-sealed)	0.011	ft^2	2001 ASHRAE Fundamentals
	General Ceiling (average)	0.026	ft^2	2001 ASHRAE Fundamentals
	General Ceiling (very-leaky)	0.04	ft^2	2001 ASHRAE Fundamentals
	Ceiling/ Flue vents (well-sealed)	4.3	each	2001 ASHRAE Fundamentals
	Ceiling/ Flue vents (average to very leaky)	4.8	each	2001 ASHRAE Fundamentals
	Lights, Recessed (well-sealed)	0.23	each	2001 ASHRAE Fundamentals
	Lights, Recessed (average)	1.6	each	2001 ASHRAE Fundamentals
	Lights, Recessed (very leaky)	3.3	each	2001 ASHRAE Fundamentals
	Lights, Surface Mounted (average)	0.13	each	2001 ASHRAE Fundamentals
Crawl Space	Crawl Space/ Open chase (well-sealed)	0.1	ft^2	2001 ASHRAE Fundamentals
	Crawl Space/ Open chase (average)	0.144	ft^2	2001 ASHRAE Fundamentals
	Crawl Space/ Open chase (very leaky)	0.24	ft^2	2001 ASHRAE Fundamentals
Doors	Framing- General (well-sealed)	0.37	each	2001 ASHRAE Fundamentals
	Framing- General (average)	1.9	each	2001 ASHRAE Fundamentals
	Framing- General (very leaky)	3.9	each	2001 ASHRAE Fundamentals
	Framing- Masonry, caulked	0.014	ft^2	2001 ASHRAE Fundamentals
	Framing- Masonry, not caulked	0.024	ft^2	2001 ASHRAE Fundamentals
	Framing- Wood, caulked	0.004	ft^2	2001 ASHRAE Fundamentals
	Framing- Wood, not caulked	0.024	ft^2	2001 ASHRAE Fundamentals
	Attic/ Crawl Space, weatherstripped	2.8	each	2001 ASHRAE Fundamentals
	Attic/ Crawl Space, not weatherstripped	4.6	each	2001 ASHRAE Fundamentals

		ELA, SqIn/unit	Unit	
	Attic Hatch, not weatherstripped	6.8	each	2001 ASHRAE Fundamentals
	Attic Hatch, weatherstripped	3.4	each	2001 ASHRAE Fundamentals
	Attic Hatch, weatherstripped, insulated	0.6	each	2001 ASHRAE Fundamentals
	Elevator (well-sealed)	0.022	each	2001 ASHRAE Fundamentals
	Elevator (average)	0.04	each	2001 ASHRAE Fundamentals
	Double, weatherstripped	0.12	ft^2	2001 ASHRAE Fundamentals
	Double, not weatherstripped	0.16	ft^2	2001 ASHRAE Fundamentals
	Interior Stairs (well-sealed)	0.012	ft (crack)	2001 ASHRAE Fundamentals
	Interior Stairs (average)	0.04	ft (crack)	2001 ASHRAE Fundamentals
	Interior Stairs (leaky)	0.07	ft (crack)	2001 ASHRAE Fundamentals
	Replacement Doors, cfm/ft known (enter cfm/ft in Additional Info)	-	ft	2001 ASHRAE Fundamentals
	Replacement Doors, cfm/sq ft known (enter cfm/sq ft in Additional Info)	-	sq ft	2001 ASHRAE Fundamentals
	Single, weatherstripped	1.9	each	2001 ASHRAE Fundamentals
	Single, not weatherstripped	3.3	each	2001 ASHRAE Fundamentals
	Sliding Exterior Glass Patio (well-sealed)	0.46	each	2001 ASHRAE Fundamentals
	Sliding Exterior Glass Patio (average)	3.4	each	2001 ASHRAE Fundamentals
	Sliding Exterior Glass Patio (very leaky)	9.3	each	2001 ASHRAE Fundamentals
	Storm (select in addition to other doors)	-0.9	each	2001 ASHRAE Fundamentals
	Vestibule (select in addition to other door)	-1.6	each	2001 ASHRAE Fundamentals
Electrical Outlets	Elec outlets/ switches w/ gaskets	0.023	each	2001 ASHRAE Fundamentals

		ELA, SqIn/unit	Unit	
	Elec outlets/switches w/o gaskets	0.38	each	2001 ASHRAE Fundamentals
Exterior Wall	Clay brick Cavity Wall	0.0098	ft^2	2001 ASHRAE Fundamentals
	Continuous Air Infiltration Barrier	0.0022	ft^2	2001 ASHRAE Fundamentals
	Heavyweight concrete block	0.0036	ft^2	2001 ASHRAE Fundamentals
	Lightweight concrete block, unfinished	0.05	ft^2	2001 ASHRAE Fundamentals
	Lightweight concrete block, painted or stucco	0.016	ft^2	2001 ASHRAE Fundamentals
	Rigid Sheathing	0.005	ft^2	2001 ASHRAE Fundamentals
	Wood frame w/ dense packed or wet cellulose	0.004	ft^2	Estimated [2]
	Wood-frame w/o Air Barrier System (average)	0.0071	ft^2	Estimated [2]
	Wood-frame w/o Air Barrier System (leaky)	0.01	ft^2	Estimated [2]
Fireplace	With open damper	5.04	ft^2	2001 ASHRAE Fundamentals
	With closed damper	0.62	ft^2	2001 ASHRAE Fundamentals
	With glass door	0.58	ft^2	2001 ASHRAE Fundamentals
Floor Over Crawl Space	Floor over Crawl Space (well-sealed)	0.006	ft^2	2001 ASHRAE Fundamentals
	Floor over Crawl Space (average)	0.032	ft^2	2001 ASHRAE Fundamentals
	Floor over Crawl Space (very leaky)	0.071	ft^2	2001 ASHRAE Fundamentals
Joints	Joint- Floor/Wall caulked	0.04	ft (crack)	2001 ASHRAE Fundamentals
	Joint- Floor/Wall uncaulked	0.2	ft (crack)	2001 ASHRAE Fundamentals
	Joint- Ceiling/Wall (well-sealed)	0.0075	ft (crack)	2001 ASHRAE Fundamentals
	Joint- Ceiling/Wall (average)	0.07	ft (crack)	2001 ASHRAE Fundamentals
	Joint- Ceiling/Wall (very leaky)	0.12	ft (crack)	2001 ASHRAE Fundamentals
Penetrations	Penetrations- Pipes/Wiring, caulked (any size)	0.3	each	2001 ASHRAE Fundamentals

		ELA, SqIn/unit	Unit	
	Penetrations- Pipes/Wiring, uncaulked	0.9	each	2001 ASHRAE Fundamentals
	Penetrations- Pipes/Wiring, uncaulked (large)	3.7	each	2001 ASHRAE Fundamentals
	Air-conditioner Sleeve, caulked	1.9	each	Estimated [3]
	Air-conditioner Sleeve, uncaulked	3.9	each	Estimated [3]
Windows	Framing- masonry, caulked	0.019	ft^2	2001 ASHRAE Fundamentals
	Framing- masonry, uncaulked	0.094	ft^2	2001 ASHRAE Fundamentals
	Framing- wood, caulked	0.004	ft^2	2001 ASHRAE Fundamentals
	Framing- wood, uncaulked	0.025	ft^2	2001 ASHRAE Fundamentals
	Awning/ Hopper, weatherstripped	0.012	ft^2	2001 ASHRAE Fundamentals
	Awning/ Hopper, not weatherstripped	0.023	ft^2	2001 ASHRAE Fundamentals
	Casement, weatherstripped	0.011	ft (crack)	2001 ASHRAE Fundamentals
	Casement, not weatherstripped	0.013	ft (crack)	2001 ASHRAE Fundamentals
	Double hung, with storm, weatherstripped	0.031	ft (crack)	2001 ASHRAE Fundamentals [1]
	Double hung, with storm, not weatherstripped	0.046	ft (crack)	2001 ASHRAE Fundamentals
	Double hung, weatherstripped	0.037	ft (crack)	2001 ASHRAE Fundamentals [1]
	Double hung, not weatherstripped	0.12	ft (crack)	2001 ASHRAE Fundamentals
	Double horizontal slider, wood, weatherstripped	0.026	ft (crack)	2001 ASHRAE Fundamentals
	Double horizontal slider, aluminum, weatherstripped	0.034	ft (crack)	2001 ASHRAE Fundamentals
	Double horizontal slider, not weatherstripped	0.052	ft (crack)	2001 ASHRAE Fundamentals
	Replacement Windows (enter NFRC AL under Additional Info)	-	ft^2	2001 ASHRAE Fundamentals
	Sill (well-sealed)	0.0065	ft (crack)	2001 ASHRAE Fundamentals
	Sill (average)	0.0099	ft (crack)	2001 ASHRAE Fundamentals

		ELA, SqIn/unit	Unit	
	Sill (very leaky)	0.01	ft (crack)	2001 ASHRAE Fundamentals
	Single hung, weatherstripped	0.041	ft (sash)	2001 ASHRAE Fundamentals
	Single horizontal slider, aluminum	0.04	ft (sash)	2001 ASHRAE Fundamentals
	Single horizontal slider, wood	0.021	ft (sash)	2001 ASHRAE Fundamentals
	Storm Inside, flexible sheet with a mechanical seal	0.0072	ft (sash)	2001 ASHRAE Fundamentals
	Storm Inside, rigid sheet with magnetic seal	0.0056	ft (sash)	2001 ASHRAE Fundamentals
	Storm Inside, rigid sheet with mechanical seal	0.019	ft (sash)	2001 ASHRAE Fundamentals
	Storm Outside, pressurized track	0.025	ft (sash)	2001 ASHRAE Fundamentals
Vent	Bathroom with damper closed	1.6	each	2001 ASHRAE Fundamentals
	Bathroom with damper open	3.1	each	2001 ASHRAE Fundamentals
	Ceiling/ Flue vents (well-sealed)	4.3	each	2001 ASHRAE Fundamentals
	Ceiling/ Flue vents (average to very leaky)	4.8	each	2001 ASHRAE Fundamentals
	Dryer with damper	0.46	each	2001 ASHRAE Fundamentals
	Dryer without damper	2.3	each	2001 ASHRAE Fundamentals
	Kitchen with tight gasket	0.16	each	2001 ASHRAE Fundamentals
	Kitchen with damper closed	0.8	each	2001 ASHRAE Fundamentals
	Kitchen with damper open	6.2	each	2001 ASHRAE Fundamentals

[1] In ASHRAE table, double hung with storm is leakier than double hung without storm. Flipped the values for consistency.

[2] Estimated based on the following references:

2001 ASHRAE Handbook- Fundamentals. Atlanta: American Society of heating, Refrigerating and Air-Conditioning Engineers, Inc.

TenWolde, Anton, Charles Carll, Vyto Malinauskas. 1998. Air Pressures in Wood Frame Walls. Thermal Performance of the Exterior Envelopes of Buildings VII. Clearwater beach, FL.

Canada Mortgage and Housing Corporation. Research and Highlight Developments- Wet sprayed cellulose insulation in Wood frame construction. Technical Series 90-240

[3] Estimated assuming that leakage through caulked/un-caulked AC sleeve is similar to leakage through average/very leaky general door framing

APPENDIX E – TECHNICAL TOPIC – BOILER EFFICIENCY DEFINITIONS

BOILER EFFICIENCY DEFINITIONS

April 17, 2008 (updated October 29, 2010)

There are many different terms to describe heating system efficiency, and some of those terms have more than one definition. "Combustion efficiency," "thermal efficiency," and "boiler efficiency" can all have different meanings, and it is important to understand what definition is intended.

For the purpose of NYSERDA's Multifamily Performance Program, the critical distinction is between descriptions of steady state efficiency and descriptions of seasonal or annual efficiency.

Combustion efficiency and thermal efficiency describe steady state efficiency. Annual Fuel Utilization Efficiency (AFUE) and other measures of seasonal or annual efficiency are non-steady state measures that include a boiler's performance when it is operating at part load and idling between calls for heat.

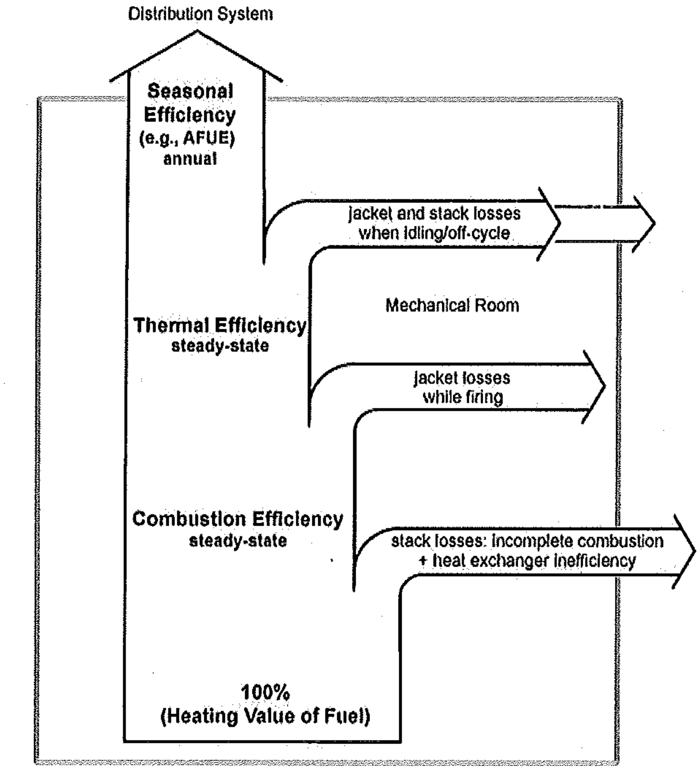


Fig. 1 Boiler Efficiency Losses

WORKING WITH EFFICIENCY RATINGS

ASHRAE Standard 90.1-2007 describes the minimum acceptable ratings for new boilers:

Boiler Btu/hour	Standard Used for Minimum Rating
<300,000	AFUE
300,000—2,500,000	Thermal Efficiency (E_t)
>2,500,000	Combustion Efficiency (E_c)

The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) publishes Certified Product Directories for commercial and residential boilers.

COMBUSTION EFFICIENCY

$$\text{Combustion Efficiency } \% = \frac{\text{Fuel Input} - \text{Stack Losses}}{\text{Fuel Input}} \times 100$$

Combustion efficiency describes the results of a combustion efficiency field test on an existing combustion appliance. The test estimates the heat lost up the stack once the combustion appliance has been firing long enough to reach equilibrium. Combustion efficiency does not account for jacket losses or off-cycle losses.

BOILER EFFICIENCY DEFINITIONS

Stack heat loss is assessed by measuring:

- Net stack temperature, the difference between the temperature in the flue and the temperature in the mechanical room
- Carbon dioxide concentration or oxygen concentration in the flue gas (%)

Carbon monoxide is also often measured as an indication of unburned flue gases.

Combustion efficiency measurements account for inefficiency of the heat exchanger due to soot, scale, or poor maintenance because heat that fails to transfer through the heat exchanger goes up the stack.

The Hydronics Institute *Testing Standard BTS-2000* provides a test procedure for rating the combustion efficiency of new boilers. The *BTS-2000* combustion efficiency test is a more precise version of the combustion efficiency field test. Values for combustion efficiency measured using this standard are given in the AHRI boiler directories referenced above.

Fig. 2 Cast Iron Sectional Boilers

The Building Performance Institute's *Technical Standards for Multifamily Building Analysts* also address combustion efficiency testing as part of the building analysis process. Section 4.2 requires that "combustion efficiency tests shall be completed at steady-state conditions and interpreted based on observed operating conditions to establish overall boiler efficiency."

> "Combustion efficiency does not account for jacket losses or off-cycle losses."

THERMAL EFFICIENCY

$$\text{Thermal Efficiency } \% = \frac{\text{Output}}{\text{Input}} \times 100$$

Thermal efficiency is the ratio of boiler input and output. These values are found on the boiler nameplate or manufacturer's data. The definition of thermal efficiency shown above is also from *BTS-2000*.

Thermal efficiency cannot be tested in the field; it requires metering the fuel input and measuring the pounds of steam, rate of hot water production, and condensate produced (for steam boilers or condensing boilers). The biggest difference between combustion efficiency and thermal efficiency is that thermal efficiency accounts for the heat lost through the boiler jacket during boiler firing.

ANNUAL OR SEASONAL EFFICIENCY

Seasonal efficiency cannot be tested in the field or described with a simple equation. In addition to stack losses and jacket losses, seasonal efficiency accounts for heat loss during periods that the boiler is "idling" to maintain its internal temperature while the building is not calling for heat.

The AFUE rating system applies to boilers up to 300,000 Btu per hour input. ASHRAE is working on Standard 155P, a similar rating system for larger boilers and boiler systems. The AHRI *Certified Product Directories* provide AFUE values for larger boilers and boiler systems.

ASHRAE/ANSI Standard 103-1997 describes the procedure used to calculate AFUE, which includes assumptions such as:

- Varying outdoor temperatures in order to simulate a "typical" winter. While this is a typical winter for the entire United States (not NYS), it does model boiler performance at part load
- An oversizing factor, which means the boiler does not run at full capacity, even on the coldest day.

Seasonal efficiency is the closest approximation of the boiler's actual performance in a particular building. The AFUE rating system makes simplifying assumptions that may not apply to a particular installation. However, as a single number to represent seasonal efficiency, it comes closer than any other rating system currently available.

Fig. 3 New condensing boiler

BOILER EFFICIENCY DEFINITIONS

SOURCES AND STANDARDS

ASHRAE 90.1-2007 Energy Standard for Buildings except Low-rise Residential Buildings. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2007.

ASHRAE/ANSI 103-1997 Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1997.

BTS-2000 Efficiency of Commercial Space Heating Boilers. Berkeley Heights, NJ: Hydronics Institute Division of AHRI, 2007.

Certified Product Directory: Boilers, Baseboard Radiation, Finned Tube (Commercial) Radiation, Indirect-fired Water heaters. Berkeley Heights, NJ: Air-Conditioning, Heating, and Refrigeration Institute, April 2009.

Technical Standards for the Multifamily Building Analyst Professional. Malta, NY: Building Performance Institute, 2008.

WEB RESOURCES

www.ahrinet.org

www.ashrae.org

www.bpi.org

APPENDIX F – TECHNICAL TOPIC – ENERGY MANAGEMENT SYSTEMS

Energy Management Systems

nyserda
Energy. Innovation. Solutions.

Introduction

In an effort to cost-effectively reduce building-wide overheating, some multifamily building owners choose to install an energy management system (EMS) to control the boiler. The primary function of an EMS in multifamily buildings is to monitor indoor temperatures using a network of temperature sensors and then to use that information to control the heating system. This tech tip focuses on how to use an EMS to better control the run time of the boiler or the temperature of the water circulated through the building.

Background

Many multifamily buildings across New York State are overheated in the winter. In general, the most severe overheating is found in buildings heated by steam and hot water. Frequent causes of overheating are:

- degraded heating distribution systems
- inadequate or improperly calibrated heating system controls
- the complicated reality of heating multifamily buildings

Both New York State Code and New York City Code require a minimum indoor temperature of 68°F during the winter for multifamily buildings. For the purpose of this discussion, we define "overheated" as anything above code minimum, but many building owners aim for a minimum of 70°F to ensure tenant comfort. A range of temperatures is expected, but temperatures more than 72°F are widely considered overheated.

There are many boiler control strategies used to maintain this minimum temperature, and they vary widely in their ability to do so while conserving energy and keeping fuel costs low. Many centralized boiler controls operate without any feedback from indoor temperature sensors, which limits their ability to achieve all three goals. Controls that allow the tenants to adjust the amount of heat coming from a radiator, such as thermostatic radiator valves (TRVs) or thermostats, can reduce both overheating and tenant complaints, but they can be expensive to install. They also typically rely on tenant cooperation to achieve savings. This can make them unappealing for energy conservation retrofits because savings may be unreliable.

NYS and NYC Code Requirements

New York State *– Heat supply. Every owner and operator of any building who rents, leases or lets one or more dwelling unit, rooming unit, dormitory or guestroom on terms, either expressed or implied, to furnish heat to the occupants thereof shall supply heat during the period from September 15th to May 31st to maintain a temperature of not less than 68°F (20°C) in all habitable rooms, bathrooms and toilet rooms. (Section 602.3)*

New York City *– Heat must be supplied from October 1 through May 31 to tenants in multiple dwellings. If the outdoor temperature falls below 55°F between the hours of six a.m. and ten p.m., each apartment must be heated to a temperature of at least 68°F. If the outdoor temperature falls below 40°F between the hours of ten p.m. and six a.m., each apartment must be heated to a temperature of at least 55°F. (Multiple Dwelling Law § 79; Multiple Residence Law § 173; NYC Admin. Code § 27-2029.)*

Figure 1: Central computers of Energy Management Systems installed in the field and manufactured (from left to right) by Heat-Timer, U.S. Energy, EnTech, and Intech 21. Photo credits: Far left and left by Taitem Engineering; right and far right by the Association for Energy Affordability.

Description of Energy Management Systems

Energy management systems have two main functions that differentiate them from other types of boiler controls:

First, many EMSs can **monitor a wide array of data** types and display the data in a computer program or on a website. Depending on the model, data points that can be monitored include domestic hot water temperature, fuel consumption, fuel oil tank level, boiler stack temperature, boiler water usage, and more. Although these monitoring capabilities are often emphasized in marketing materials and can be a useful tool for some boiler operators, they do not produce any energy savings by themselves. Action by the boiler operator is required to turn any of the information listed above into potential energy savings.

Second, EMSs use **a network of temperature sensors** to better control the run time of the boiler or the temperature of the water circulated through the building. One temperature sensor monitors outdoor air temperature. It determines whether the building should be heated at any given time, where on the outdoor reset curve the boiler should operate, or which curve should be used. Additionally a series of sensors is installed in a sample of apartments to monitor the temperature inside the building.

Multiple temperature sensors are recommended to get an accurate picture of what is going on in the building. Measuring temperatures in several apartments reduces the impact of anomalies caused by open windows, electric heaters, and tenants who shut off their radiators. **Best practice:** Install sensors in a representative sample of no fewer than 10% of the apartments; this provides adequate redundancy while keeping costs reasonable. **Best practice:** Install the sensors in apartments on different floors and lines to take into account differences in temperature between upper and lower floors, sunny and shaded sides, and windward and leeward sides of the building. Many EMS manufacturers offer wireless sensors which can reduce installation costs.

The indoor sensors are used to calculate an approximate average building temperature, which the EMS uses to control the boiler. **In steam systems,** this average temperature is used to prevent unnecessary firing when the building's target temperature is already met. That is, the apartment sensors "vote." If enough sensors indicate apartments are warm enough, the EMS keeps the boiler off, and if enough indicate apartments are too cool, the EMS allows the boiler to fire.

In hot water systems, instead of turning the boiler on and off, the EMS uses the apartment temperature data to adjust the outdoor reset curve. For example, if the outdoor reset curve calls for a supply water temperature of 160°F , but the average indoor temperature is close to the setpoint, the outdoor reset curve might be adjusted to provide supply water at 150°F.

Most EMSs can be programmed to lower the indoor temperature at night, which can result in additional savings. We recommend implementing night setback, if permitted by code.

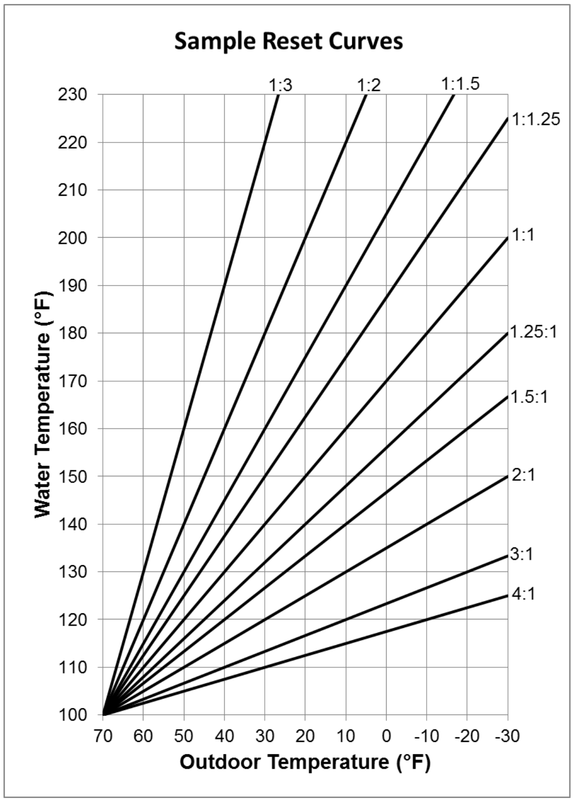
For both steam and hot water systems, the primary result of implementing an EMS is to reduce the average indoor temperature. Keep in mind that the EMS alone cannot supply more heat to specific cold apartments nor reduce the heat supplied to specific hot apartments.

Outdoor Reset Control

*In buildings heated with **hot water,** the use of outdoor reset curves can reduce overheating and save energy by varying the temperature of the water circulating through the building. In general, as the outdoor temperature decreases, warmer water is circulated. Actual water temperatures required are building-specific.*

***Example:** A building might require 140°F circulating water when it is 55°F outside, but 180°F water when it is 20°F outside.*

The outdoor reset ratio defines how much the water temperature is increased per degree of outdoor temperature decrease. For example, with a 1:1 ratio, the water temperature is increased 1°F when the outdoor temperature falls 1°F. With a 1:1.25 ratio, the water temperature is increased 1.25°F for every 1°F the outdoor temperature falls.


Sample Reset Curves

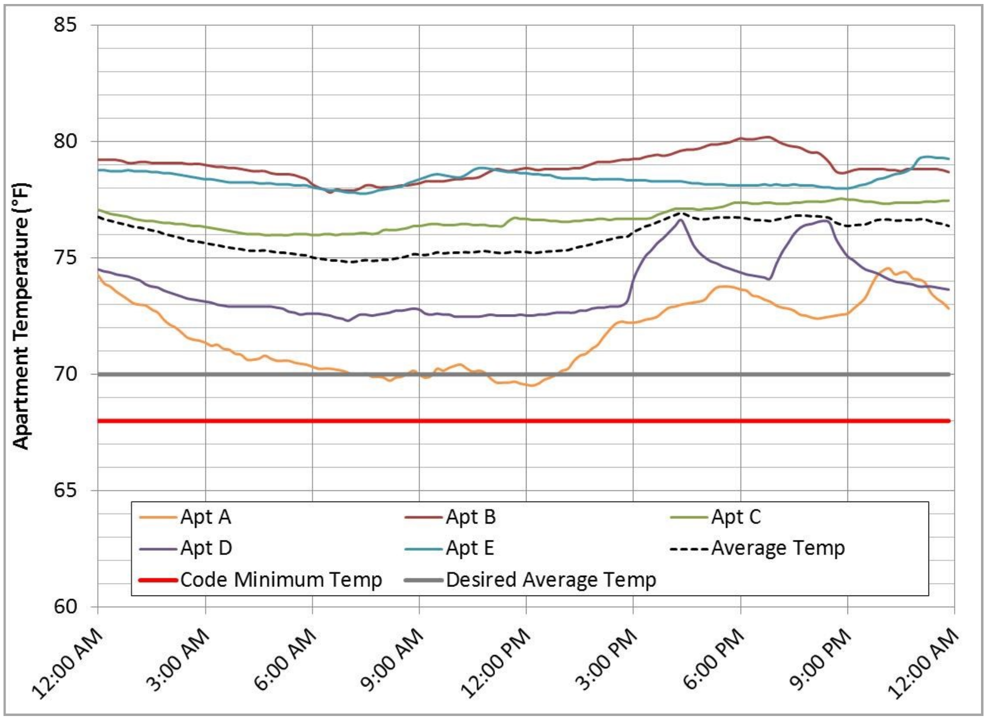


Figure 2: Sample apartment temperatures in a building with no EMS.

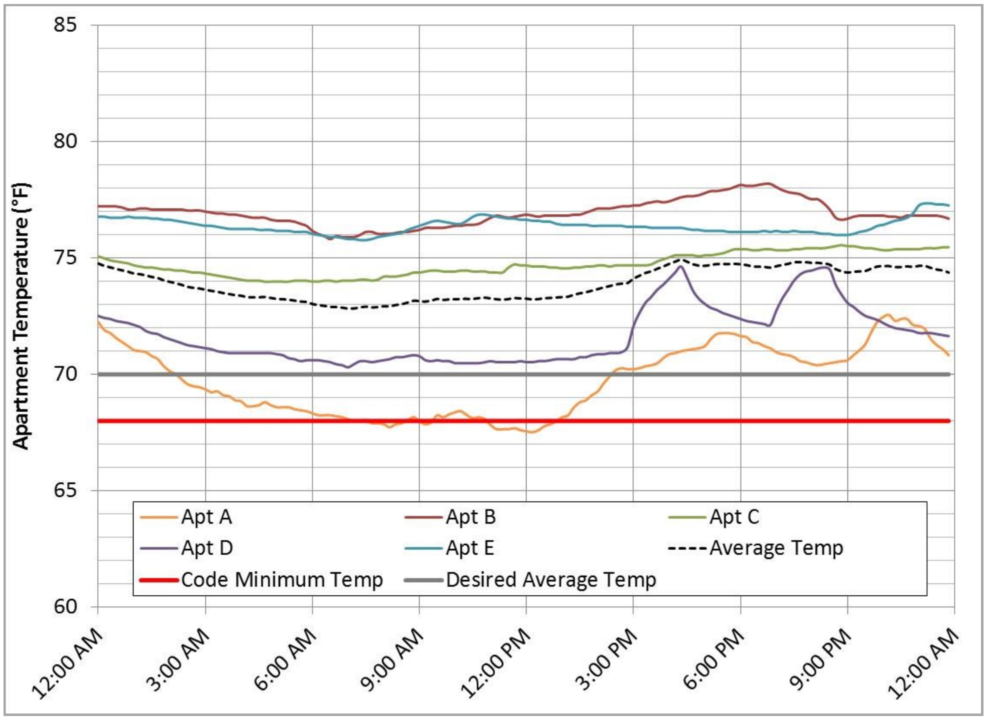


Figure 3: Temperatures in the sample apartments, altered to show the effect of installing an EMS on the boiler.

Main Drawback of EMS

Figure 2 shows the temperature in five apartments for a typical 24-hour period in a building without an EMS. Note that at a few points during the day there is a difference of almost 10°F between the hottest and coldest apartments.

Figure 3 shows the temperatures for the same five apartments, altered to show what the temperature profile might look like in the same building on the same day if an EMS was controlling the boiler. Note that all of the apartment temperatures have decreased by approximately 2°F and the average building temperature has also decreased. The difference between the hottest and coldest apartment is still nearly 10°F at some points. Also, the coolest apartment occasionally dips below the code-minimum 68°F. If the EMS were to decrease the indoor temperature further, the temperature in Apartment A would no longer meet code.

Figures 2 and 3 illustrate the **main drawback** of EMSs: Because they are not able to direct more or less heat to specific apartments, some apartments will continue to be overheated and some savings will be unrealized. Balancing the distribution system so that the apartments are heated more evenly is therefore critical to maximizing savings. Most heating systems were designed to supply heat to all apartments at approximately the same time. Over the years, however, systems may be altered and key components may degrade or fail. The result is that heat may now reach some apartments more slowly than others. These heating imbalances can have many causes, including failed or clogged air vents, failed steam traps, sediment build-up in distribution pipes, removed radiation, removal of vacuum pumps, and others.

Figure 4 shows what might happen to apartment temperatures in our sample building if an EMS were installed and the distribution system were balanced. Note the much smaller range of temperatures between the hottest and coldest apartments (4°F maximum), and no significantly overheated apartments. Achieving maximum savings with an EMS can only be realized in conjunction with balancing the distribution system.

Predicting Energy Savings

To calculate potential energy savings, you must first estimate and enter the reduction in average building temperature into the building energy model. In a recent study of mid-rise steam and hot water heated buildings, energy management systems were successful in reducing average building temperatures in twelve out of fifteen buildings.[1] The average reduction in building temperature was 2.5°F for steam-heated buildings and 0.6°F for hot water heated buildings (Table 1). However, even when the boilers were controlled by EMSs, between 67% and 100% of the apartments in each building were found to be overheated. As expected, there was a strong positive correlation between how overheated a building was without the EMS operating and how much the average temperature was reduced by turning on the EMS. That is, buildings with the highest average temperature when the EMS was deactivated had the largest reduction in average building temperature when the EMS was reactivated.

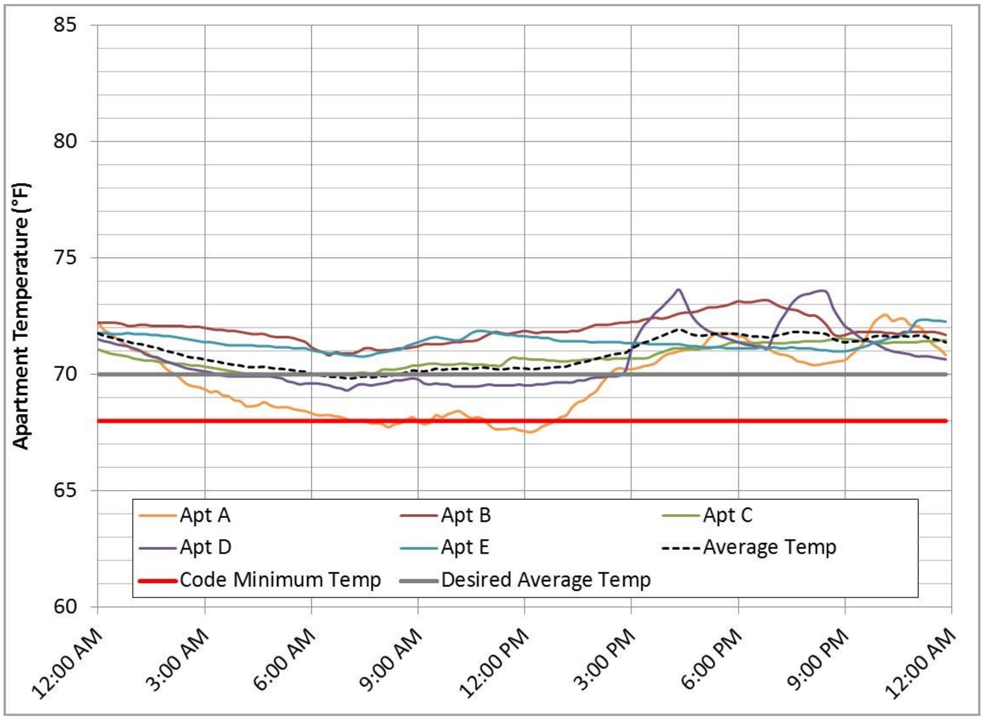


*Figure 4: Temperatures in our sample building adjusted to show what is likely to happen when an EMS is installed **and** the distribution system is balanced.*

	Average Reductions in Building Temperature			Number of Buildings
	Average	Minimum	Maximum	
1-Pipe Steam	2.5°F	-0.5°F	5.9°F	12
Hot Water	0.6°F	-1.6°F	2.6°F	3

Table 1: Reductions in building temperature achieved when the EMSs were activated.

The study did not track fuel consumption, so heating fuel and cost savings results must be extrapolated. A U.S. Department of Energy publication from 2013[2] stated that overheating increases annual heating energy consumption by approximately 3% per degree Fahrenheit per day. Using this DOE estimate and the average temperature reductions found by Dentz, et al., 7% heating energy savings for steam buildings and 2% savings for hot water buildings are likely when an EMS is installed in a building. EMS manufacturers predict at least 10% heating energy savings, which they claim is conservative, from upgrading boiler controls from an outdoor reset to an EMS. Compared to the temperature reductions achieved by Dentz, et al., 10% heating energy savings should not be considered a conservative estimate but it may be useful instead as an upper limit for achievable savings.

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Modeling Protocols for Implementing EMS on Heating Systems in Multifamily Buildings

The following modeling protocols are intended to help energy modelers accurately and conservatively calculate potential savings from implementing Energy Management Systems on steam and hot water systems.

STEAM SYSTEMS

Existing	Proposed	Modeling Protocol - Steam
On/off control only; no outdoor reset Note that outdoor reset for steam systems is defined as a control that adjusts the length of the steam cycle as the outdoor temperature changes.	Outdoor reset	Model as a temperature reduction. Do not model “outdoor reset” as this option only applies to hot water system or vacuum steam systems. Must provide details of existing controls and evidence that outdoor reset is not currently being utilized. 1°F maximum temperature reduction
Outdoor reset; heating imbalances observed	EMS with indoor temperature sensors; distribution imbalances not addressed	2°F maximum temperature reduction
Outdoor reset; heating imbalances observed	EMS with indoor temperature sensors; distribution balanced	3°F maximum temperature reduction
Outdoor reset; no heating imbalances	EMS with indoor temperature sensors	3°F maximum temperature reduction

HOT WATER SYSTEMS

Existing	Proposed	Modeling Protocol – Hot Water
On/off control only, no outdoor reset	Outdoor reset and EMS with indoor temperature sensors	Model as outdoor reset control on hot water loop. Must provide details of existing controls and evidence that outdoor reset is not currently being utilized. System must be able to operate with outdoor reset (condensing boilers and/or boilers separated from heating loop). Additionally, model a temperature reduction of 1°F maximum if the outdoor reset curve (i.e. the hot water loop set point) will be adjusted based on feedback from apartment sensors.
Outdoor reset	EMS with indoor temperature sensors	Model as a temperature reduction if outdoor reset curve (hot water loop set point) will be adjusted based on feedback from apartment sensors. 1°F maximum temperature reduction

Note: Steam boilers that supply a hot water loop are to be considered a hot water system.

Best Practices to Achieve Savings

Energy management systems can reduce heating energy use in multifamily buildings. Taking the following steps will help maximize savings.

1. Identify pre-existing temperature control problems. Measure and record building temperatures in a variety of apartments during the heating season. Interview the superintendent, manager, owner, and residents to gain an understanding of heating issues in the building.
2. Evaluate loads on the building. Determine whether there are other factors causing the apartments to be over- or under-heated such as solar loads, wind loads, removed or oversized radiators, etc.
3. Gain a general understanding of the distribution system layout. Then look for patterns in heating imbalances.
4. Consider implementing comprehensive rebalancing if heating imbalances are observed. Savings will be limited without rebalancing.
5. Identify all components of the existing boiler control system. Make sure that the existing controls are unable to provide indoor temperature feedback. Determine whether night setback and outdoor reset controls are in place.
6. Model predicted savings using the modeling protocols above.
7. Review the plan for the new controls, including a careful examination of sensor locations, set points, and zones. Ensure that the proposed EMS provides a significantly different control strategy than the old control system; otherwise, savings will not be achieved. In 2-pipe and hot water systems, sensors should be installed in no fewer than 10% of apartments and on a variety of floors and in a variety of apartment lines. In 1-pipe steam systems, sensors should be installed in no fewer than 25% of apartments and on a variety of floors, and there must be a sensor in the apartment at the end of each steam line.
8. Inspect the installation. Ensure that the sensors are located in apartments that represent average building temperatures and that they are installed on interior walls, out of direct sunlight, and away from sources of drafts or heat.
9. Review the EMS settings; make sure they have been adjusted to reflect the needs of the building. Note that in general, the target setpoint for the EMS will need to be several degrees warmer than the minimum temperature required by code to ensure that the coldest apartments meet code. If you are working in a building where tenants are likely to resist a temperature change, consider reducing the temperature slowly, across several months. Also consider adjusting the temperatures seasonally, to be warmer in deep winter and cooler in the fall and spring.
10. If balancing work was performed, create a plan for continued maintenance. Train building staff on how to maintain the distribution system.
11. Train staff thoroughly on how to properly operate the new EMS, or consider restricting their access to the controls. If the building does not currently have a protocol for addressing tenant heating complaints, develop one that involves correcting all other potential reasons for low temperatures before turning up the EMS setpoints. Emphasize that staff should not override the system or increase the temperature in the whole building just because of a single tenant complaint.

Conclusion

Energy management systems can be an effective tool for reducing the high average temperatures often found in multifamily buildings and they can lead to substantial energy and cost savings. It is important, however, to understand the capabilities and limitations of EMS controls. EMSs cannot correct temperature differences in apartments that are caused by heating system imbalances; as a result, the overall temperature reduction possible in a given building is limited by the temperature of the coldest apartments. In order to maximize savings, comprehensive balancing work must be performed in conjunction with an EMS installation.

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