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$MMBTU_{ECM}$ = increased heating fuel consumption in MMBtu to compensate for reduced fan motor waste heat (**applies to furnaces with ECM fan motors only**)[16].

$$= (0.019)(CAP)(EFLH_{heat})\left(\frac{\eta_{base}}{\eta_{ee}}\right)$$

The 2011 TRM defines prescriptive savings based on three efficiency strata. The values in the 2011 are shown in Table 26 below.

Table 26: 2011 TRM Prescriptive Furnace Savings

Furnace Efficiency	ΔMMBTU/Unit/yr
Furnace AFUE =>92%	21.1
Furnace AFUE =>92% w/ECM	19.6
Furnace AFUE =>94% w/ECM	23.6

KEMA followed the documentation trail for these prescriptive savings to the sources referenced in the TRM, a potential study report[17] and a deemed savings database.[18] Table 27 provides the sources and values in the documentation referenced by the TRM.

Table 27: Condensing Furnace TRM Sources

Market Category	Baseline Efficiency (value)	Savings Factor (value)	Annual Savings (MMBtu)
Market Driven	Energy Star Furnace Savings Calculator (78% AFUE)	GDS Calculation based on 92% AFUE (15.2%)	NYSERDA Deemed Savings Database, Rev 09-082006 adjusted to Boston, measure efficiency difference,92% vs. 90% and size 120,00 Btu vs. 80,000 Btu with base usage = 266.2 MMBtu (40.46 MMBtu)
Retrofit	Summit Blue Estimate (78% AFUE)	GDS Calculation based on 92% AFUE (18.5%)	NYSERDA Deemed Savings Database, Rev 09-082006 adjusted to Boston, measure efficiency difference,92% vs. 90% and size 120,00 Btu vs. 80,000 Btu with base usage = 276.9 MMBtu (51.17 MMBtu)

The GDS does not provide sufficient information to allow the methodology to be replicated. KEMA acquired and reviewed the deemed savings database, which did not include the

[16] Adapted from "Electricity Use by New Furnaces: A Wisconsin Field Study," Energy Center of Wisconsin, 10/2003.
[17] GDS Associates, Inc. (2009). *Natural Gas Energy Efficiency Potential in Massachusetts*. Prepared for Gas Networks.
[18] "NYSERDA Deemed Savings Database, Rev 09-082006"

underlying calculation methodology. Thus our analysis could only compare our calculated savings to the values listed in the TRM.

The baseline efficiency is defined as shown in Table 28 below, in both the 2010 and 2011 TRM.

Table 28: TRM Furnace Baseline

Equipment Type	Size Category (Input)	Subcategory or Rating Condition	Minimum Efficiency
Warm air furnace, gas fired	<225,000 Btu/h	-	78% AFUE or 80% E_t
	>=225,000 Btu/h	Maximum capacity	80% E_t
Warm air duct furnace	All capacities	Maximum capacity	80% E_t

KEMA used these baseline efficiencies for the analysis.

8.2 Condensing Furnace Methodology

Onset Hobo Microstation time-of-use loggers were installed that measured the current of the combustion blower and the temperature of the supply and return air at the furnace at five minute intervals, and where the conditioned space was accessible, the temperature at the controlling thermostat. The loggers were in place for between 26 and 67 days, with an average monitoring period of 54 days.

After logger retrieval the data was checked for consistency and completeness, the following steps were applied to the data for each measure:

1. The Logger data were trimmed to remove any pre- and post-installation data that does not represent actual operating conditions.

2. The remaining data set was examined for anomalies, such as readings outside the expected range. For example, the current draw by the combustion blower was recorded in a small number of 5-minute intervals during the start-up phase. In these cases, which occurred for less than a fraction of one percent of the readings, the recorded data point exceeds the average by a factor of approximately five. Since this was an instantaneous reading, and not representative of the 5-minute interval, using this data point in subsequent analyses would skew the results. Consequently, these data points were replaced with the average of the data set absent the outliers.

Two other data sets were required for the analysis, and both weather related. These were the average hourly temperature for the study period and the TMY data was for four weather stations

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in Massachusetts, at Boston, Worchester, Chicopee Falls, and Pittsfield. This process resulted in clean and consistent sets of measured data incorporating the variables shown in Table 29 below.

Table 29: Measured Furnace Variables

Measured Variables (Study Period)		
Name	Measurement Interval	Source
Combustion Blower Current (amperage)	5-minute	Data logger
Supply Air Temperature (° F)	5-minute	Data logger
Return Air Temperature(° F)	5-minute	Data logger
Temperature at Thermostat (° F)	5-minute	Data logger
Study Period Outdoor Dry Bulb Air Temperature(° F)	Hourly	NOAA
Typical Meteorological Year Outdoor Dry Bulb Temperature(° F)	Hourly	TMY2

The analysis process began with the cleaned data sets.

Analysis Process Steps

In this section we provide a high-level overview of the steps in the analysis. While this accurately represents the logic of the analysis, in practice this is an iterative process that is not conducive to strict sequential presentation.

Step 1. The cleaned 5-minute interval data set is processed to develop average hourly combustion blower current draw and the average hourly supply and return air temperatures.

Step 2. The hourly data set is differentiated into two periods, weekdays (WD) and weekend/holiday (WEH) to accommodate typical control strategies.

Step 3. A furnace power output fraction is calculated for each hour in the sample. This factor is based on the current draw of each hour as compared to the average current draw of all time periods when the burner is operating.

The next series of steps expands the sample time frame measurements to the full year (8760 hours) and develops the factors necessary to calculate the usage difference between the installed and baseline equipment.

Step 4. Through an iterative series of regression analysis, coefficients are developed to calculate the burner run time fraction, the furnace output fraction, the supply temperature, and the return temperature for each hour based on the outdoor dry bulb (ODB) temperature from typical meteorological year weather data. The objective of this analysis is to develop an equation that produces values for these factors as close as possible to the observed measurements. These factors will vary for each site.

Step 5. A factor for heat added from air circulation, including the blower motor waste heat is calculated for each system.

Step 6. Using the equations developed in Step 4, the following are calculated for each hour of the year:

a. Furnace Run Time Fraction

b. Furnace Output Fraction

c. Supply Air Temperature

d. Return Air Temperature

Step 7. Furnace performance coefficients are calculated based on secondary data. In the absence of specific data for the furnace installed at the monitored site, we used coefficients developed from representative furnace performance curves.

Step 8. The following hourly boiler operating variables are calculated based on the above:

a. Furnace Output – This is the calculated Btu output for the hour as a product of the steady-state output and the furnace power output fraction.

b. Furnace Efficiency - Hourly furnace operating efficiency is calculated as a factor of supply air temperature, furnace run time fraction, and furnace output fraction using the coefficients developed in Step 4 above.

c. Furnace Gas Input – A function of the installed gas input and the baseline boiler efficiency incorporating an adjustment for Btu added by circulation.

d. Baseline Supply Air Temperature – A function of the calculated hourly return air temperature of the operating unit.

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e. Baseline Furnace Efficiency – A function of the calculated run time and output fractions of the measured unit, the baseline efficiency contained in the TRM, and the baseline supply air temperature.

f. Baseline Gas Input – A function of the baseline efficiency for the equipment under consideration per the TRM, the weighted average annual efficiency calculated for the sample point, and the calculated boiler gas input.

At this phase in the analysis hourly factors for the full 8760 hours of the year have been developed. Our analysis also develop equivalent full load hours and average efficiency (in AFUE) for each unit, but, in the absence of a documented methodology and set of assumptions underlying the development of the TRM values, we did not compare our findings to a deemed calculation.

Step 9. The installed furnace gas input and baseline furnace gas input each are summed to develop the respective annual inputs. The difference between the two is ΔMMBtu, or the evaluated savings.

8.3 Furnace Site Descriptions

Site #321-35 – Store front: 80,000 Btu/hr input

Furnace provides all of the space heat for a store front in a brick commercial building with interior walls on both sides and other tenants above. The furnace supplies heat for this unit only. The temperature schedule was 72ºF when open and 60ºF when closed. Furnace operation was monitored for 49 days.

Site #342-63 – Light industrial: 72,000 Btu/hr input

The retrofit furnace provides space heat for half of a basement factory space in a brick industrial building. Three other furnaces heat the other half of the basement and part of the first floor. There are pieces of machinery in the conditioned space which lower the heating load on the furnaces. The space is maintained at a constant 70ºF. Operation was monitored for 26 days.

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Site #355-51 – Multifamily: 80,000 Btu/hr input

The retrofit furnace provides all of the space heat for one detached unit in a multifamily complex. Temperature is maintained at a constant 70ºF with a thermostat located in an interior hallway. Operation was monitored for 50 days.

Site #365 – Church office and support

#365 -25: 60,000 Btu/hr input

#365 -27: 75,000 Btu/hr input

The furnaces provide space heat to a church facility with intermittent use and reported low usage during the monitoring period. The heated space is attached to building on both sides. The smaller furnace temperature schedule is 71ºF when open, 66ºF when closed. The larger furnace is set to 66ºF when open and turned off when the building is closed. The operation of both units was monitored for 62 days.

Site #368-7 & -99 – Warehouse, 2 Story: Two 90,000 Btu/hr input

This facility is a freestanding two-story building used as a garage, warehouse, and offices. One furnace provides space heat for the first floor. The temperature schedule is 70ºF when operating, 60ºF when closed. The second furnace was installed on the second floor and is not connected to a thermostat. The operator reports that it has never run. Both units were retrofit. Operation was monitored on both units for 67 days and some usage was detected on the second unit.

Site #376-6 – Retail: 120,000 Btu/hr input

This retrofit furnace provides all of the space heat for a single-story freestanding building housing a retail sales floor, storage and offices. This is a small building approximately 1,500 square feet. The temperature is set at a constant 70ºF. Operation was monitored for 55 days.

Site #463-48 – Warehouse: 69,000 Btu/hr input

This freestanding commercial building houses a supply company that operates roughly 25 hours per week. The temperate schedule was not determined. The furnace provides all of the space heat for the building. Operation was monitored for 57 days.

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Site #467-2 &-67 – Church offices: Two 130,000 Btu/hr input

This facility is a freestanding, single-story, converted barn that houses church offices. The full space heat load is served by the two retrofit furnaces. The temperature schedule is 72ºF when open, about 50 hours per week, 58ºF when closed. Operation of both was monitored for 54 days.

Site #474-66 – Professional offices: Two 80,000 Btu/hr and one 40,000 Btu/hr input

This new construction two-story building houses a medical practice. Three furnaces provide all of the space heat requirements. The temperature schedule is 74ºF when open (approximately 50 hours per week) and 65ºF when closed. Loggers were in place for 50 days, but due to logger failure data was collect only for one of the larger furnaces.

9. Appendix C - Infrared Heaters

9.1 Infrared Heaters Measure Description

This project evaluated the performance of gas-fired low intensity infrared heating systems in place of unit heater, furnace, or other standard efficiency equipment. Low-intensity heaters have an enclosed flame. When heat is required, the burner control box ignites a gas/air mixture and hot gases are pushed through steel radiant tubing by an internal fan. As these gases pass through the assembly, the tubing is heated and emits infrared energy, which is then directed toward the floor by highly polished reflectors. This energy is absorbed by objects in its path, such as the floor, machinery, and people. Objects in the path of the infrared energy in turn re-radiate this heat to create a comfort zone at the floor level.

Infrared-heating accounts for 37 projects with a total of 72,912 therms of savings in the Prescriptive Gas Tracking Data. Measurement and verification analyses will be performed on 6 of these projects. These 6 projects have total annual savings of 13,392 therms. This is 18.4% of the total tracking savings for this measure.

Both the 2010 and 2011 versions of the Massachusetts TRMs have a fixed savings per installed unit. The value shown for the 2010 TRM is 77.4 MMBtu/year while the value shown in the 2011 TRM is 74.4 MMBtu/year. Both TRMs reference modeled data from 62 low-intensity infrared heaters installed by the predecessor of Columbia Gas of MA. The data is contained in a spreadsheet with the name “Infrared Samples - Bay State Gas.xls.” This file contains nine records with savings that average to 74.4 MMBtu/year. These savings are listed as “Estimated” but the estimation methodology is not documented. It appears that the intended value for savings from this source is consequently 74.4 MMBtu/year.

KEMA reviewed the material provided by the program sponsors and was not able to document the equations used to determine the savings beyond a simple average of the projects listed in the spreadsheet referenced above. We reviewed the literature on IR savings[19] and developed the equation below to calculate savings for each project.

[19] http://www.spaceray.com/pdf/infrared-heating_engineering-manual_0305.pdf

$$\Delta MMBtu = (CAP)(EFLH)\left(\frac{CF_{base}}{\eta_{base}} - \frac{CF_{ee}}{\eta_{ee}}\right)$$

Where:

$\Delta MMBtu$	= gross annual MMBtu savings
CAP	= Heating load requirement (MBtu/hr)
EFLH	= equivalent full load hours
CF_{base}	= Compensating factor for baseline equipment
η_{base}	= Thermal efficiency of baseline equipment
CF_{ee}	= Compensating factor for efficient equipment
η_{ee}	= Thermal efficiency of efficient equipment

The compensating factors and thermal efficiency values are discussed in the following section.

9.2 Methodology

Time-of-use loggers were installed to measure the flow of current to the infrared heaters installed through the program. Data loggers to measure space temperature were installed if not precluded by the nature of operations and/or the facility. The loggers were in place for between 52 and 64 days, with an average monitoring period of 57 days.

After logger retrieval the data was checked for consistency and completeness. The data set then was examined for anomalies, such as readings outside the expected range, and corrected. For example if the space temperature reading exceeded the reasonable range or the current inrush was captured by the logger, these data points are corrected to fall within a reasonable range.

In addition to the site-collected data, the analysis required the measured hourly temperatures and typical meteorological year data for weather stations in Massachusetts, at Boston, Worchester, Chicopee Falls, and Pittsfield. The variables for the analysis are shown in Table 30.

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Table 30: Infrared Heater Variables

Variables (Study Period)		
Name	Measurement / Input Interval	Source
Combustion Blower Current (amperage)	5-minute	Data logger
Indoor Temperature (° F)	5-minute	Data logger
Study Period Outdoor Dry Bulb Air Temperature(° F)	Hourly	NOAA
Typical Meteorological Year Outdoor Dry Bulb Temperature(° F)	Hourly	TMY

Analysis Process Steps

In this section we provide a high-level overview of the steps in the analysis. While this accurately represents the logic of the analysis, in practice this is an iterative process that does not require a strict sequential order.

Step 1. Additional variables were required to calculate energy usage and saving relative to the baseline in the absence of a defined equation-based methodology for calculating savings. These include:

a. IR Compensating Factor – Manufacturers' sizing recommendations incorporate a compensating factor for IR heating equipment based on the difference in heat output required to heat objects by radiation as compared heating the ambient air and the objects within the envelope by convection.[20] This factor is directly related to the mounting height of heater.

Table 31: IR Compensating Factors

Mounting Height	IR Compensating Factor
12	0.78
16	0.80
20	0.82
24	0.84
28	0.86
32	0.88
36	0.90
40	0.92

[20] Ibid.

b. Thermal efficiency of the IR heater – The thermal efficiency of the IR heater was calculated by an engineering analysis of the physical properties of atmospheric natural gas combustion, the theoretical minimum and maximum temperatures at which a low intensity heater fire tube would radiate heat, and other factors. Based on this analysis we determined to use 82% thermal efficiency in our calculations.

c. The baseline equipment for all analyses was modeled as a suspended unit heater with thermal efficiency of 80% serving the equivalent area as the site IR heaters. The output of the unit heater is sufficient to meet the same building heat requirement as the IR heater(s) monitored.

Table 32 below illustrates the comparison of these factors, and how they relate to building heat requirements.

Table 32: Sample Calculation of IR vs. Unit Heater Sizing

Sample Calculation		
	IR Htr	Unit Htr
ASHRAE building heat load	100,000	100,000
Compensation factor	0.850	1.000
Output heat Required	85,000	100,000
Thermal Efficiency	82.0%	80.0%
Input heat Required	103,659	125,000

Step 2. The following factors are developed for the cleaned 5-minute interval data set:

a. Maximum Current Draw

b. Heat Output Fraction – The 5-minute interval current divided by the maximum current draw.

c. IR Btu/hr Input – The total input capacity of the unit(s) monitored multiplied by the heat output fraction.

d. IR Btu/hr Output – The IR Btu/hr input times the IR thermal efficiency.

e. Unit Heater Btu/hr Output – The IR Btu/hr output divided by the IR compensating factor.

f. Unit Heater Btu/hr Input – The unit heater output divided by the unit heater efficiency.

g. Savings – The difference between IR heater and unit heater inputs

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10. Appendix D - Indirect Water Heaters

10.1 Indirect Water Heaters Measure Description

Indirect water heaters use an insulated storage tank containing a heat exchanger energized by a closed recirculation loop off the space heating boiler. This system design can contribute to reduced standby heat loss, increased efficiency from burner operation at or near steady-state efficiency and reduce cycling losses during the heating season.

Indirect water heating accounts for 24 projects with a total of 69,616 therms of savings in the Prescriptive Gas Tracking Data. Measurement and verification analyses were performed on 10 of these projects. These 10 projects have total annual savings of 7,296 therms. This is 10.5% of the total tracking savings for this measure.

Both the 2010 and 2011 versions of the TRM assign a fixed quantity of prescriptive savings, 30.4 annual MMBtu[21], to each unit installed.

In order to adequately analyze the TRM values it was necessary to determine, to the extent possible, the calculations underlying the prescriptive savings value. The source referenced in both TRMs was a GDS report. The sources listed in this report are shown in Table 33 below:

Table 33: Indirect Water Heater Sources for TRM Values

Market Category	Baseline Efficiency (value)	Savings Factor (value)	Annual Savings (MMBtu)
Market Driven	US DOE Federal Energy Management Program (Storage tank water heater at 0.59 EF)	GDS Calculation (28.1%)	ESource – Gas Fired Water Heater Screening Tool - Assumptions of .85 thermal efficiency and 250 gallons per day. Base use = 108.3 MMBtu (30.38 savings)
Retrofit	Federal Code FR66/11/Jan. 17,2001, p 4497 ((Storage tank water heater at 0.55 EF)	GDS Calculation (32.9%)	ESource – Gas Fired Water Heater Screening Tool - Assumptions of .85 thermal efficiency and 250 gallons per day. Base use = 111.5 MMBtu (36.72 savings)

KEMA used the current version of the screening tool[22] populated with the values in listed in the GDS report and was not able to replicate the values listed in the report. The values calculated

[21] Natural Gas Energy Efficiency Potential in Massachusetts, Appendix B-2, p.2, GDS, 2009.

[22] http://www.esource.com/BEA/demo/Shared/PA_41_calc.html, accessed 5/10/12