White Paper

Savings Calculations for Residential Ground Source Heat Pumps

The Basis for Equivalent Full Load Hours (EFLH) and Seasonal Efficiency Factors

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Revised

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Overview

This white paper is intended to provide the background and basis for energy savings calculations for a revised TRM savings calculation method for Ground Source Heat Pumps (GSHPs) in residential applications. It focuses on the determination of the total heating load using an equivalent full load hours approach. It then recommends a basis for determining seasonal efficiency for a GSHP system, starting from published AHRI certified rating data and factoring in the impact of fan and pumping power.

Determining Total Annual Heating Load

The purpose of EFLH

The purpose of Equivalent Full Load Hours (EFLH) is to provide an approximate method to predict the annual or seasonal load from a simple, known quantity–such as the capacity or output of a heating appliance. EFLH methods allow annual space heating (or cooling) loads to be quickly estimated for a range of buildings and climates. Once annual load has been established, this in turn allows energy savings to be quantified. ELFH methods to predict annual load are widely used in Technical Resource Manuals (TRMs) as well as in other similar guides meant to predict energy savings from applying more energy efficient equipment. Published values of EFLH often depend on the climate, HVAC system type, and the building application.

An important aspect is the known quantity that is used in the EFLH calculations. Each set of published EFLH values depend on whether known quantity is: 1.) the peak load on the building, 2.) the actual heating capacity of the installed equipment, or 3.) the nominal size or rating of a machine. In all cases the EFLH is defined as shown below and has units of hours.

$$\text{EFLH (hours)} = \frac{\text{Annual Load (Btu)}}{\text{Equipment Capacity or Building Peak Load (Btu/h)}}$$

A Theoretical Basis: Determining Equivalent Full Load Hours (EFLH) from Weather Data

Typical meteorological year data (TMY-3) was used to make temperature bin data that is used in this analysis. The number of hours in each 2˚F bin is determined for various NY cities. The plot below shows the heating load line for LaGuardia Airport, NY. The load fraction equals 1 (or 100%) at the 1% design temperature of 15˚F for New York. The heating load is assumed to go to zero at a balance point temperature of 57.5˚F for an "Average" home. Using this load line with the number of hours in each 2˚F temperature bin at non-summer conditions (i.e., excluding June through September), the result is 1,634 EFLH for the heating season. Appendix A provides more detail on the weather data, the heating load line, and the bin calculations.

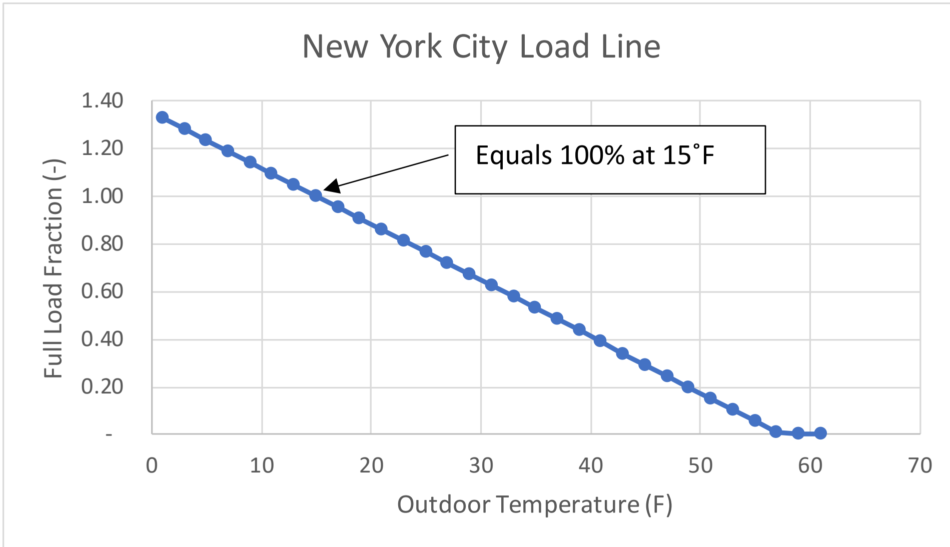

Figure 1. Heating Load Line Plot for LaGuardia Airport. Full Load Fraction = 1.0 at 1% design (15˚F), equals zero at 57.5˚F

Similarly, using the temperature bin data and the 1% design temperature we can do this calculation for other upstate cities. The result is 1,939 EFLH for Albany (-2˚F), 2,147 EFLH for Buffalo (5˚F), and 2,068 EFLH for Massena (-10˚F). Table 1 summarizes the theoretical EFLH for balance points of 55˚F, 57.5 ˚F and 60˚F for all the NY cities. Modern code compliant homes with typical amounts of internal gain would be expected to have a balance point temperature closer to 55˚F, while older homes might have a balance point closer to 60˚F. We have selected the mid-point of 57.5˚F as representative of Average vintage homes.

Table 1. Theoretical EFLH Values Determined Using Peak Load at 1% Design Temperature

	1% Design Temp (˚F)	**Balance Point 60˚F**	**Balance Point 57.5˚F**	**Balance Point 55˚F**
Albany	-2	2,066	1,939	1,808
Binghamton	2	2,266	2,128	1,984
Buffalo	5	2,288	2,147	2,001
Massena	-10	2,184	2,068	1,949
New York (LGA)	15	1,800	1,634	1,462
Poughkeepsie	5	2,248	2,104	1,954
Syracuse	2	2,156	2,026	1,892

System Sizing Adjustments

The EFLH values defined so far are for "perfectly sized" equipment that runs 100% of the time at the 1% design temperature. This EFLH value is not the same as the EFLH that would be used with equipment capacity or "size". Equipment heating capacity would generally be larger because it includes some amount of "up sizing" as part of normal design practice. In addition, the nominal size of a ground source heat pump is often larger than its actual rated heating capacity. In contrast, the nominal "size" of furnaces and boilers are typically better aligned with their actual heating output. The table below highlights these points.

Table 2. Accounting for the Differences Between Peak Load, Heating Capacity, and Nominal Equipment Size

Load or Equipment Capacity	**Description**	**Relative Value**
Perfectly sized Equipment/Loads	The heating load at the 1% temperature design condition.	Basis
Manual J Design Load (heating)	The design loads determined from the Manual J calculations from ACCA include various safety factors. One example is that no internal gains are assumed with the heating load with these calculations[1]. The Manual J design load is estimated to be 10% greater.	~10% higher than perfectly sized
Manual S Equipment Capacity (heating)	Then, per NYS code, contractors must use ACCA Manual S to find the required equipment heating capacity to satisfy the Manual J heating load. By using the NYSERDA GSHP Program data (205 entries for New Construction) and data from the AHRI database, we found that the heating capacity is about the same as the Manual J Loads (actually 3% lower according to Appendix B analysis).	About the same as Manual J Load
Nominal Equipment Size	The nominal size of a ground source heat pump – usually expressed as "cooling tons" – is typically bigger than the actual "GLHP" AHRI heating capacity. From the analysis of the AHRI data (Appendix C), the nominal cooling capacity is very close to the GLHP cooling capacity certified by AHRI. Further, we find that the GLHP cooling capacity is about 133% of the heating capacity (i.e., Manual S heating capacity). Similarly, from the NYSERDA GSHP Program database (Appendix B) we find that the nominal cooling capacity is 129% of the Manual J heating load. Therefore, we use an average value of 130%	Unit Size ~30% higher than equipment heating capacity

Table Note: The "GLHP" heating capacity is from ASHRAE/ISO 13256-1. The heating capacity corresponds to a ground loop temperature of 32˚F.

[1] Manual J ignores internal gains for heating load calculations. Electric loads in a single-family home are typically 10,000 kWh per year, or 3,800 Btu/h. This is approximately 10% of heating Load. Therefore, the Manual J design heating load should be approximately 10% bigger than the theoretical load at the 1% design condition.

EFLH values must be modified depending on whether they are being used with: 1) peak loads, 2) Manual J heating loads, 3) Manual S heating capacities, or 4) nominal equipment sizes. For instance, the EFLH values provided in the TRM are meant to be used with the nominal size for HVAC equipment. By contrast, in the GSHP measure section of the TRM, the approach has changed to using EFLH values based on the Manual J design heating loads instead. As a result, the current TRM now includes an adjustment factor (F_{EFLH}) of 1.25 to account for this change. The sections below assess different EFLH values may be more appropriate for use with Manual J heating loads.

EFLH Appropriate for Use with Manual J Heating Loads

The EFLH values must be modified to account for which input data is being used in the calculations. As shown in Table 2 above, the Manual J load is 10% greater than the theoretical peak load. Accordingly, the EFLH based on the 1% design conditions from weather bin analysis (Table 1) need to be divided by (110%). This yields the $EFLH_{MJ}$ values listed in the table below. **For clarity we refer to these values as the Building EFLH, or BEFLH, in the remainder of this document.**

Table 3. Values of EFLH for Use with Manual J Design Heating Loads for Each City and Vintage

	$EFLH_{MJ}$ or BELFH Based on 1% Design & Adjusted for Manual J Heating Load		
	Old Balance Point 60°F	**Average Balance Point 57.5°F**	**New Balance Point 55°F**
Albany	1,878	1,763	1,643
Binghamton	2,060	1,935	1,804
Buffalo	2,080	1,952	1,819
Massena	1,986	1,880	1,772
New York (LGA)	1,636	1,485	1,329
Poughkeepsie	2,044	1,912	1,776
Syracuse	1,960	1,842	1,720

Note: The EFLH values from Table 1 are divided by 110% to find EFLH values for use with Manual J heating load.

Then: Annual Heating Load, MMBtu = BEFLH x [Manual J Load, Btu/h] / 10^6

Since these BEFLH values were based on the Manual J heating load—and have nothing to do with equipment size or type—they can be used to the find the annual heating load for any type of HVAC system. The Manual J heating load only depends on the characteristics of the building. It does not depend on the HVAC system. As noted, this approach is currently applied in the TRM only with respect to GSHP.

EFLH Values from the TRM for use with nominal equipment sizes

Appendix G of the New York TRM includes EFLHs for various climates, building types and equipment ages. These values were originally developed using the DOE-2.2 building simulation model. The DOE-2 models use different assumptions between the different cities due to construction differences, indoor set points, etc. This may explain the greater variation between the downstate and upstate cities in the EFLH values from the TRM (Table 4) compared to EFLH values in Table 1. The EFLH values from the TRM are generally multiplied by the furnace heating capacity (or, in the TRM: "$kBTUh_{out}$") to determine the total seasonal annual space heating load.

Table 4. Values for EFLH from the NY TRM (Appendix G) for Single Family Detached Dwelling

SINGLE-FAMILY DETACHED HEATING EFLH BY VINTAGE AND CITY

City	Old	Average	New
Albany	1,042	978	925
Binghamton	1,086	1,029	963
Buffalo	1,072	1,032	957
Massena	1,125	1,061	1,009
NYC	867	786	725
Poughkeepsie	931	862	807
Syracuse	1,098	1,042	972

For Ground Source Heat Pumps in the TRM, The EFLH from the table above are adjusted by a factor of 1.25 (F_{EFLH}). Then the modified EFLH value is multiplied by the Actual Heating Load (AHL), which in the GSHP Measure section in the TRM, is the Manual J design heating load. According to the April 2019 version of the TRM:

> *"Note, the EFLH data in Appendix G are based on system nameplate capacity, while the equations in this section are based on actual building load. The F_{EFLH} factor is introduced to account for the equipment oversizing assumption embedded in the Appendix G data. The oversizing assumption embedded in the Appendix G data are appropriate for equipment sized to meet the peak-cooling load, such as central air conditioners and air source heat pumps. However, GSHPs are typically sized to meet the heating load; and the oversizing assumptions embedded in the Appendix G data are not appropriate"*

Table 5 compares the BEFLH from Table 3 to the EFLH from Appendix G of the TRM ($EFLH_{AppG}$). After the correction factor (F_{EFLH}=1.25) is applied to the TRM value, the adjusted EFLH is still only 70% of the BEFLH for use with Manual J. A correction factor of approximately F_{EFLH}=1.8 to 2.0 would be needed to make **$EFLH_{AppG}$** match **BEFLH**.

Table 5. Comparing EFLH Values for Average Single Family, Detached Dwelling After Applying the GSHP Adjustment Factor

	BEFLH	**$EFLH_{AppG}$**	**$EFLH_{AppG}$ x 1.25**
	EFLH Based on 1% Design & Adjusted for Manual J Heating Load	**Appendix G TRM EFLH (average column from Table 3)**	**TRM EFLH Adjusted by 1.25 for GSHPs**
Albany	1,763	978	1,223
Binghamton	1,935	1,029	1,286
Buffalo	1,952	1,032	1,290
Massena	1,880	1,061	1,326
New York (LGA)	1,485	786	983
Poughkeepsie (Newburgh)	1,912	862	1,078
Syracuse	1,842	1,042	1,303

Instead of applying a correction factor, we propose to publish the **BEFLH values for each city and construction vintage from Table 3** in the TRM measure section[2].

EFLH for Use with Nominal GSHP Size

While, as noted, the TRM bases annual heating load calculations for GSHP on the Manual J design load, EFLH values appropriate for finding the annual heating load from the nominal equipment size for GSHPs might also be useful for some types of savings analysis. These values of $EFLH_{tons}$ can be determined using the information from Table 2. In order to find $EFLH_{tons}$, a further modification of 30% needs to be applied to reflect the difference between nominal GSHP (cooling) capacity and Manual J heating load (which is shown to be similar to the rated heating capacity in Table 2). Dividing the values from Table 3 for Average vintage by this additional factor of 130% results in:

$EFLH_{tons}$ = 1,142 for New York
= 1,356 for Albany
= 1,502 for Buffalo

[2] Based on feedback from the TRM Management Committee and TRC.

Then: Annual Heating Load, MMBtu = $EFLH_{tons}$ x [nominal GLHP cooling capacity, tons] x 12 / 1000

These values were used in the policy analysis work by NYSERDA to predict statewide utility impacts since that work was based on nominal size of the heat pump.

Determining Total Annual Cooling Load

Appendix G of the New York TRM also includes cooling EFLHs for various climates, building types and equipment ages. The table below shows the values for a single-family home for various cities and construction vintages. These values were developed using the DOE-2.2 building simulation model using different assumptions between the different cities due to construction differences, indoor set points, etc. Unlike the heating EFLH values in the current TRM, these values have not been adjusted by the 2014 evaluation study (see Appendix D). Instead, they are still consistent with the DOE-2 analysis discussed in Appendix A of the TRM.

Table 6. Values for Cooling EFLH from the NY TRM (Appendix G) for Single Family Detached Dwelling

SINGLE-FAMILY DETACHED COOLING EFLH BY VINTAGE AND CITY

City	Old	Average	New
Albany	322	310	279
Binghamton	199	197	158
Buffalo	334	322	276
Massena	258	250	210
NYC	670	649	630
Poughkeepsie	496	470	464
Syracuse	310	296	268

The cooling EFLH values from Appendix G of the TRM are generally meant to be multiplied by the nominal air conditioner cooling capacity to determine the total seasonal space cooling load (see the "Air Conditioner -Central (CAC)" measure on page 116 of the Version 7 TRM). In the current version of the GSHP measure in the TRM, the EFLH values from Appendix G of the TRM are multiplied by a factor of (F_{EFLH} = 1.25) account for the difference between the nominal cooling capacity and the Manual J cooling load. This factor is consistent with the stated "20% oversizing" described in Appendix A[3] of the TRM (on page 504 in Version 7).

Therefore, we propose to retain the calculation method in the current TRM and determine annual cooling load from the EFLH values from Appendix G with the current factor $F_{EFLH,c}$ = 1.25. These $BEFLH_c$ values are summarized in Table 7 below.

[3] Actually the math in the GSHP measure is consistent with slightly modified definition: design load = 80% of air conditioner size. Then the inverse of 1 divided by 0.8 equals 1.25.

Table 7. Recommended Values for Cooling $BEFLH_c$ for Single Family Detached Dwelling by City and Vintage

City	Old	Average	New
Albany	403	388	349
Binghamton	249	246	198
Buffalo	418	403	345
Massena	323	313	263
New York	838	811	788
Poughkeepsie	620	588	580
Syracuse	388	370	335

We also considered using the temperature-based bin analysis described above for heating to find the cooling BEFLH values. However, while temperature-based bin analysis is realistic for heating loads, they are not appropriate for residential cooling systems. The heating load depends on the indoor-to-outdoor temperature difference with simple envelope "UA" calculation procedure. Cooling depends on the temperature difference as well as the solar load imposed on the home (roof, windows, etc). Therefore, the more complicated calculation procedures imbedded in software packages such as DOE-2.2 are more appropriate for cooling. Cooling calculation procedures use transfer function methods or other similar approaches that take into account the thermal mass of the building envelope and resulting time lag for summer time heat transfer into the space. Therefore, we determined it was best to retain the DOE-2.2 calculations for cooling.

Determining Seasonal Efficiency Factor

<u>ASHRAE/ISO Rating Standard</u>

The rating standard for ground source heat pump equipment is ASHRAE/ISO 13256-1. AHRI uses this standard for its product certification program. The standard provides the rated capacity and efficiency in both heating and cooling for open-loop, ground water heat pumps (the "GWHP" rating) as well as closed loop, ground source heat pumps (the "GLHP" rating). The ISO standard also provides efficiency ratings at part load conditions for staged equipment (dual capacity or variable speed). All testing is done with a brine solution.

Table 8. Test Conditions and Certified Data from ASHRAE/ISO 13256-1 Standard

GLHP Rating	Entering Air Conditions DB/WB	Entering Brine Temperature	Certified AHRI Data
Cooling – Std/Full Load	80.6°F / 66.2°F	77°F	$EER_{GLHP\text{-}full}$, $QC_{GLHP\text{-}full}$
Cooling – Part Load		68°F	$EER_{GLHP\text{-}part}$, $QC_{GLHP\text{-}part}$
Heating – Std/Full Load	68°F	32°F	$COP_{GLHP\text{-}full}$, $QH_{GLHP\text{-}full}$
Heating – Part Load		41°F	$COP_{GLHP\text{-}part}$, $QH_{GLHP\text{-}part}$

GWHP Rating	Entering Air Conditions DB/WB	Entering Brine Temperature	Certified AHRI Data

Cooling – Std/Full Load	80.6°F / 66.2°F	59°F	$EER_{GWHP\text{-}full}$, $QC_{GWHP\text{-}full}$
Cooling – Part Load		59°F	$EER_{GWHP\text{-}part}$, $QC_{GWHP\text{-}part}$
Heating - Std/Full Load	68°F	50°F	$COP_{GWHP\text{-}full}$, $QH_{GWHP\text{-}full}$
Heating – Part Load		50°F	$COP_{GWHP\text{-}part}$, $QH_{GWHP\text{-}part}$

Note: DB is Dry Bulb Temperature, WB is Wet Bulb Temperature

The full load test conditions are more reflective of operation at peak or full load. The part load test conditions for staged equipment are more reflective of lightly loaded conditions. The ASHRAE/ISO standard also includes modest corrections for the impact of pumping power based on the water pressure drop through the unit (about 5-10 Watts per nominal ton). Unlike other AHRI standards that require a minimum external static pressure that varies with unit size, the fan power in this standard are corrected to zero external static pressure (assuming 30% efficient fan-motor). Therefore, the amount of fan power in the rated efficiency values are even lower than the already-modest fan power values included in AHRI Standard 210/240 for conventional heat pumps and air conditioner.

Determining Seasonal Efficiency

The average seasonal efficiency for the heating mode (COP_{season}) and the cooling mode (EER_{season}) can be determined from the certified AHRI data listed in Table 8 for both GLHP-rated closed loop systems and GWHP-rated open loop systems. However, correction factors are required to compensate for several issues:

- The differences in entering fluid temperatures between rated conditions and the averages observed in NY field testing. The 50-site study (NYSERDA 2017) observed average loop temperatures of 40°F for heating and about 68°F for cooling for closed loop sites in Upstate NY, compared to the GLHP-rated entering fluid temperatures of 41°F and 68°F shown in Table 8 for part load conditions. Open loop systems had entering fluid temperatures near 50°F for both heating and cooling compared to rated entering conditions of 50°F for heating and 59°F for cooling.
- The ASHRAE/ISO efficiency values do not include enough fan (or distribution) power to represent true performance in an actual application with ductwork (since the standard corrects to zero external static pressure).
- The rated efficiency values do not fully account for pumping power. Factors must be applied that vary based on pump power and how the pump is controlled on a staged system
- Dual capacity and variable speed systems spend considerable amount of time at part conditions. The full and part load efficiency values must be appropriately weighted to find the seasonal average efficiency.

The average seasonal heating efficiency for staged equipment in closed loop applications is calculated as:

$$COP_{season} = (F_{full} \times COP_{GLHP\text{-}full} \times 1.08 \times F_{pump\text{-}full} + F_{part} \times COP_{GLHP\text{-}part} \times F_{pump\text{-}part}) \times F_{dist\text{-}h}$$

For Single stage units the equation simplifies to:

$$COP_{season} = COP_{GLHP,full} \times 1.08 \times F_{pump\text{-}full} \times F_{dist\text{-}h}$$

The average seasonal cooling efficiency for staged equipment in closed loop applications is calculated as:

$$EER_{season} = (F_{full} \times EER_{GLHP\text{-}full} \times 1.09 \times F_{pump\text{-}full} + F_{part} \times EER_{GLHP\text{-}part} \times F_{pump\text{-}part}) \times F_{dist\text{-}c}$$

For Single stage units the equation simplifies to:

$$EER_{season} = EER_{GLHP\text{-}full} \times 1.09 \times F_{pump\text{-}full} \times F_{dist\text{-}c}$$

For open loop applications, the GWHP-rated COP and EER are used to calculate seasonal heating and cooling efficiency using:

$$COP_{season} = (F_{full} \times COP_{GWHP\text{-}full} \times F_{pump\text{-}full} + F_{part} \times COP_{GWHP\text{-}part} \times F_{pump\text{-}part}) \times F_{dist\text{-}h}$$

$$EER_{season} = (F_{full} \times EER_{GWHP\text{-}full} \times F_{pump\text{-}full} + F_{part} \times EER_{GWHP\text{-}part} \times F_{pump\text{-}part}) \times 1.09 \times F_{dist\text{-}c}$$

where:

$COP_{GLHP\text{-}full}$ -	The rated COP of the unit at GLHP full load (or standard) heating conditions from ASHRAE/ISO 13256-1. This value is certified by AHRI and is available in the product directory. It corresponds to an entering loop temperature of 32°F. See Table 8.
$COP_{GLHP\text{-}part}$ -	The rated COP of the unit at GLHP part load heating conditions from ASHRAE/ISO 13256-1. This value is certified by AHRI and is available in the product directory. It corresponds to an entering loop temperature of 41°F. See Table 8.
$EER_{GLHP\text{-}full}$ -	The rated EER of the unit at GLHP full load (or standard) cooling conditions from ASHRAE/ISO 13256-1. This value is certified by AHRI and is available in the product directory. It corresponds to an entering loop temperature of 77°F. See Table 8.
$EER_{GLHP\text{-}part}$ -	The rated EER of the unit at GLHP part load cooling conditions from ASHRAE/ISO 13256-1. This value is certified by AHRI and is available in the product directory. It corresponds to an entering loop temperature of 68°F. See Table 8.
$COP_{GWHP\text{-}full}$ -	The rated COP of the unit at GWHP full load (or standard) heating conditions from ASHRAE/ISO 13256-1. This value is certified by AHRI and is available in the product directory. It corresponds to an entering loop temperature of 50°F. See Table 8.
$COP_{GWHP\text{-}part}$ -	The rated COP of the unit at GWHP part load heating conditions from ASHRAE/ISO 13256-1. This value is certified by AHRI and is available in the product directory. It corresponds to an entering loop temperature of 50°F. See Table 8.
$EER_{GWHP\text{-}full}$ -	The rated EER of the unit at GWHP full load (or standard) cooling conditions from ASHRAE/ISO 13256-1. This value is certified by AHRI and is available in the product directory. It corresponds to an entering loop temperature of 59°F. See Table 8.
$EER_{GWHP\text{-}part}$ -	The rated EER of the unit at GWHP part load cooling conditions from ASHRAE/ISO 13256-1. This value is certified by AHRI and is available in the product directory. It corresponds to an entering loop temperature of 59°F. See Table 8.
1.08 -	Correction for 8% change in COP as the entering fluid temperature increases from 32°F to 40°F. The 1% per °F was observed from published performance data as well as in the IGSHPA Design Manual (IGSHPA 2011, Table 2.18, page 2-46).
1.09 -	Correction for 9% change in EER as the entering fluid temperature decreases from 77°F to 68°F. The 1% per °F was observed from published performance data as well as in the IGSHPA Design Manual (IGSHPA 2011, Table 2.19, page 2-47). This factor is also used to correct the GWHP-rated EERs from 59°F to 50°F.

F_{full}	Seasonal weighting factor for full load efficiency = 0.25. Approximate factors based in part on observed mix of low and high stage operation from field testing (NYSERDA 2017)
F_{part}	Seasonal weighting factor for part load efficiency = 0.75. Approximate factors based in part on observed mix of low and high stage operation from field testing (NYSERDA 2017)
$F_{pump\text{-}full}$	Factor to adjust the full load efficiency to account for additional pumping power used by the system. Choose the appropriate factor from Table 10 based on the mode (Heating or Cooling) and pumping power (Watts/ton).
$F_{pump\text{-}part}$	Factor to adjust the part load efficiency to account for additional pumping power used by the system. Choose the appropriate factor from Table 10 based on the mode (Heating or Cooling) and pumping power (Watts/ton). The pumping control method and the part-to-full load capacity ratio (CR) are also be considered.
$F_{dist\text{-}h}$, $F_{dist\text{-}c}$	Factor to adjust the heating and cooling efficiency to account additional distribution power (fan or boiler pump) that would be required, beyond the fan power corresponding to zero static in rated COP.

Pumping Power Correction Factor (F_{pump})

A correction factor for Pumps (F_{pump}) is required because the rated efficiency values only include the pumping energy associated with the water-side pressure drop through the heat pump unit (typically about 5-10 Watts per nominal ton, according to Pane and Domanski, 2012). Actual pumping power is much higher. The ASHRAE GSHP Design Guide (Kavanaugh and Rafferty 2015) developed a grading system for commercial systems that assigned scores based on the amount of pumping power per installed ton (which has been adapted for residential applications here). For instance, they give a grade of “A” to system that uses 45 Watts per nominal ton and a grade of “B” to system that uses 60 Watts per nominal ton. Table 9 shows the impact of incrementally adding pump power to find a new corrected COP for heating and EER for cooling. It also includes pumping power at 75 and 90 Watts per nominal ton since we have observed levels that high in the field. The rated GLHP COP and EER used as the starting point is for a dual stage heating pump with typical performance. The Ratio at the bottom of the table is the value of F_{pump} than be applied in each case.

Table 9. The Impact of Pumping Power on Heating and Cooling Efficiency (45 to 90 Watts per ton)

GSHP Pump Factor - Heating	FULL	PART	PART	PART	PART	PART	FULL	PART	PART	PART	PART	PART	FULL	PART	PART	PART	PART	PART	FULL	PART	PART	PART	PART	PART
		Constant Speed Pump		Staged Pumping		Variable		Constant Speed Pump		Staged Pumping		Variable		Constant Speed Pump		Staged Pumping		Variable		Constant Speed Pump		Staged Pumping		Variable
Capacity Fraction (CR)	1	0.75	0.4	0.75	0.4	0.4	1	0.75	0.4	0.75	0.4	0.4	1	0.75	0.4	0.75	0.4	0.4	1	0.75	0.4	0.75	0.4	0.4
Pumping Fraction	1	1	1	0.7	0.35	0.3	1	1	1	0.75	0.4	0.3	1	1	1	0.75	0.4	0.3	1	1	1	0.75	0.4	0.3
GLHP COP (-)	3.7	4.2	4.2	4.2	4.2	4.2	3.7	4.2	4.2	4.2	4.2	4.2	3.7	4.2	4.2	4.2	4.2	4.2	3.7	4.2	4.2	4.2	4.2	4.2
Rated power (kW per ton)	0.71	0.47	0.25	0.47	0.25	0.25	0.71	0.47	0.25	0.47	0.25	0.25	0.71	0.47	0.25	0.47	0.25	0.25	0.71	0.47	0.25	0.47	0.25	0.25
Additional pump power (W per to	45	45	45	45	45	45	60	60	60	60	60	60	75	75	75	75	75	75	90	90	90	90	90	90
Corrected power (kW per ton)	0.76	0.52	0.30	0.50	0.27	0.26	0.77	0.53	0.31	0.52	0.28	0.27	0.79	0.55	0.33	0.53	0.28	0.27	0.80	0.56	0.34	0.54	0.29	0.28
Htg capacity (MBtu/h)	9.00	6.75	3.60	6.75	3.60	3.60	9.00	6.75	3.60	6.75	3.60	3.60	9.00	6.75	3.60	6.75	3.60	3.60	9.00	6.75	3.60	6.75	3.60	3.60
Corrected COP (-)	3.48	3.83	3.56	3.94	3.95	3.99	3.41	3.73	3.39	3.83	3.83	3.92	3.35	3.62	3.23	3.75	3.75	3.85	3.29	3.53	3.09	3.67	3.67	3.79
Ratio	*0.94*	*0.91*	*0.85*	*0.94*	*0.94*	*0.95*	*0.92*	*0.89*	*0.81*	*0.91*	*0.91*	*0.93*	*0.90*	*0.86*	*0.77*	*0.89*	*0.89*	*0.92*	*0.89*	*0.84*	*0.74*	*0.87*	*0.87*	*0.90*

GSHP Pump Factor - Cooling	FULL	PART	PART	PART	PART	PART	FULL	PART	PART	PART	PART	PART	FULL	PART	PART	PART	PART	PART	FULL	PART	PART	PART	PART	PART
		Constant Speed Pump		Staged Pumping		Variable		Constant Speed Pump		Staged Pumping		Variable		Constant Speed Pump		Staged Pumping		Variable		Constant Speed Pump		Staged Pumping		Variable
Capacity Fraction (CR)	1	0.75	0.4	0.75	0.4	0.4	1	0.75	0.4	0.75	0.4	0.4	1	0.75	0.4	0.75	0.4	0.4	1	0.75	0.4	0.75	0.4	0.4
Pumping Power Fraction	1	1	1	0.75	0.4	0.3	1	1	1	0.75	0.4	0.3	1	1	1	0.75	0.4	0.3	1	1	1	0.75	0.4	0.3
GLHP Full Load EER (Btu/Wh)	16.0	24.5	24.5	24.5	24.5	24.5	16.0	24.5	24.5	24.5	24.5	24.5	16.0	24.5	24.5	24.5	24.5	24.5	16.0	24.5	24.5	24.5	24.5	24.5
Rated power (kW per ton)	0.75	0.37	0.20	0.37	0.20	0.20	0.75	0.37	0.20	0.37	0.20	0.20	0.75	0.37	0.20	0.37	0.20	0.20	0.75	0.37	0.20	0.37	0.20	0.20
Additional pump power (W per to	45	45	45	45	45	45	60	60	60	60	60	60	75	75	75	75	75	75	90	90	90	90	90	90
Corrected power (kW per ton)	0.80	0.41	0.24	0.40	0.21	0.21	0.81	0.43	0.26	0.41	0.22	0.21	0.83	0.44	0.27	0.42	0.23	0.22	0.84	0.46	0.29	0.43	0.23	0.22
Cooling capacity (MBtu/h)	12.00	9.00	4.80	9.00	4.80	4.80	12.00	9.00	4.80	9.00	4.80	4.80	12.00	9.00	4.80	9.00	4.80	4.80	12.00	9.00	4.80	9.00	4.80	4.80
Corrected EER (Btu/Wh)	15.09	21.83	19.92	22.44	22.44	22.92	14.81	21.06	18.76	21.83	21.83	22.44	14.55	20.35	17.72	21.25	21.25	21.98	14.29	19.68	16.79	20.70	20.70	21.53
Ratio	*0.94*	*0.89*	*0.81*	*0.92*	*0.92*	*0.94*	*0.93*	*0.86*	*0.77*	*0.89*	*0.89*	*0.92*	*0.91*	*0.83*	*0.72*	*0.87*	*0.87*	*0.90*	*0.89*	*0.80*	*0.69*	*0.84*	*0.84*	*0.88*

Note: Starting (rated) values for full and part load COPs are 3.7 and 4.2 at GLHP conditions. Full and part load cooling EERs are 16 and 24.5 Btu/Wh at GLHP conditions. H-C-ratio is 0.75 for heating analysis.

For part load performance there are multiple ways to control the pump at low stage:

- the pump can maintain constant flow regardless of heat pump stage
- the pump can stage flow in proportion to the capacity
- the pump can be variable speed and modulate with the variable speed compressor.

A constant speed pump results in poor performance since the pump power becomes relatively larger portion of total power at low stage. Variable speed pumping with a variable speed compressor results in the best performance. The last consideration is the part-to-full capacity ratio (CR), which can be calculated as follows:

$$CR = QC_{GLHP\text{-}part} / QC_{GLHP\text{-}full}$$

The values of QC are the rated AHRI data defined in Table 8. Dual stage units typically have a value of CR near 0.75. Heat pumps with variable speed compressors have a CR closer to 0.4. The penalty of constant speed pumping is highest for units that have a lower value of CR.

Table 10 summarizes the values of $F_{pump-full}$ and $F_{pump-part}$ that can be determined for each pump arrangement. In this table the pumping power is expanded to include even higher values of 120 Watts per ton. The full load pumping factors are typically 0.94 to 0.86. Part load factors can range from 0.62 to 0.95 depending on the pump power, the pump control method, and the capacity ratio of the heat pump. The pumping factor from the table that is closest to the actual situation should be used.

Table 10. Values of $F_{pump-full}$ and $F_{pump-part}$ for Various Situations (data from Table 9, but expanded up 120 Watts per ton)

		45 Watts/ton		60 Watts/ton		75 Watts/ton		90 Watts/ton		105 Watts/ton		120 Watts/ton	
	Capacity Ratio (CR)	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating
Full Load		0.94	0.94	0.93	0.92	0.91	0.90	0.89	0.89	0.88	0.87	0.86	0.86
Part Load - Constant Flow	0.75	0.89	0.91	0.86	0.89	0.83	0.86	0.80	0.84	0.78	0.82	0.75	0.80
Part Load - Constant Flow	0.4	0.81	0.85	0.77	0.81	0.72	0.77	0.69	0.74	0.65	0.71	0.62	0.68
Part Load - Staged Pumping	0.75	0.92	0.94	0.89	0.91	0.87	0.89	0.84	0.87	0.82	0.86	0.80	0.84
Part Load - Staged Pumping	0.4	0.92	0.94	0.89	0.91	0.87	0.89	0.84	0.87	0.82	0.86	0.80	0.84
Part Load - Variable Pumping	0.4	0.94	0.95	0.92	0.93	0.90	0.92	0.88	0.90	0.86	0.89	0.84	0.87

Distribution (Fan) Power Correction

The fan power included in with the rated efficiencies corresponds to zero external static pressure and therefore is smaller than would be expected for an actual application. ASHRAE Research Project RP-1449 (Rudd et al 2013) compared rated SEER values to catalog data published by manufacturers for several units. For this comparison they inferred that the indoor fan power included in the test conditions for AHRI Standard 210/240 was about 0.25 Watts/cfm for PSC motors and 0.18 Watt/cfm for ECM motors[4]. Field test results from various climates, show that actual fan power levels are about twice these levels (Sachs et al 2007), or 0.5 Watts/cfm for PSC motors and 0.35 Watts/cfm for ECM motors. While these values are from conventional air conditioners and heat pumps, it expected that these trends and values also apply to the indoor fans for ground source heat pumps units.

Under the ASHRAE/ISO standard, the fan power included into the efficiency rating would even be lower because of the zero static pressure rating. We estimate that the included fan power under the ASHRAE/ISO standard would be about 60% of the values from Rudd et al (2013), or 0.15 Watts/cfm for PSC and 0.11 Watts/cfm for ECM.

Table 11 uses the assumed fan power values for the ASHRAE/ISO standard and expected fan power values for an actual installation for both a PSC fan and ECM fan. The table includes various starting efficiency levels for both heating and cooling (but these factors only have a slight impact). Overall, we recommend using fan or distribution factors (F_{dist}) of 0.91 for heating COP and 0.85 for cooling EER.

[4] PSC is Phase Split Capacitor, ECM is Electronically Commutated Motor (also Brushless Permanent Magnet Motor)

Table 11. Corrections to Seasonal Efficiency for ACTUAL Fan Power

Heating Compared to Actual

H-C Ratio	0.75	0.75	0.75
GSHP -Heating	**COP=3 PSC Fan**	**COP=3.5 ECM Fan**	**COP=4 ECM Fan**
GLHP Full Load COP	3.0	3.5	4.0
Rated fan power (W/cfm)	0.15	0.11	0.11
Actual fan power (W/cfm)	0.50	0.35	0.35
Rated airflow (cfm per ton)	390	390	390
Rated power (kW per ton)	0.88	0.75	0.66
Additional fan power (W per ton)	136.50	93.60	93.60
Actual power (kW per ton)	1.02	0.85	0.75
Actual Htg capacity (MBtu/h)	9.47	9.32	9.32
Corrected COP	**2.73**	**3.22**	**3.63**
Ratio	***0.91***	***0.92***	***0.91***

Cooling Compared to Actual AC

GSHP -Cooling	**EER=14 PSC Fan**	**EER=16 ECM Fan**	**EER=18 ECM Fan**
GLHP Full Load EER	14.0	16.0	18.0
Rated fan power (W/cfm)	0.15	0.11	0.11
Actual fan power (W/cfm)	0.50	0.35	0.35
Rated airflow (cfm per ton)	390	390	390
Rated power (kW per ton)	0.86	0.75	0.67
Additional fan power (W per ton)	136.50	93.60	93.60
Actual power (kW per ton)	0.99	0.84	0.76
Actual Clg capacity (MBtu/h)	11.53	11.68	11.68
Corrected EER	**11.61**	**13.85**	**15.36**
Ratio	***0.83***	***0.87***	***0.85***

Instead of developing distribution factors to account for actual fan power for the GSHP system, the TRM requires a factor to get to the amount of distribution power relative to the baseline, code compliant system, whether it be a fuel-fired furnace, a fuel-fired boiler, or a conventional air source heat pump. This approach is appropriate for the TRM calculations, since the base case (or code compliant case) fuel-fired system does not account for the electrical consumption of the furnace fan or boiler. Therefore, only the differential electrical power between the GSHP and the base case equipment would be considered.

Rudd et al (2013) also simulated fan power for a furnace. They used a furnace airflow rate (and fan power consumption) that was 70% lower than the cooling airflow. Table 12 shows the ratios or factors that would be appropriate in the TRM when the goal is to match the fan power of the base furnace fan power. The assumed baseline furnace power is 137 Watts (we have assumed that boiler pump power would be equivalent). In the cooling mode, the difference between the base case (or compliance case) fan power and GSHP case would correspond to the difference in fan power required for GSHPs under the ASHRAE/ISO standard and fan power required by the AHRI 210/240 standard for a conventional air conditioner.

Table 12. Corrections to Seasonal Heating Efficiency for Fan/Distribution Power

Heating Compared to Furnace (actual furnace airflow is 70% of GSHP)

H-C Ratio	0.75	0.75	0.75
GSHP -Heating	**COP=3 PSC Fan**	**COP=3.5 ECM Fan**	**COP=4 ECM Fan**
GLHP Full Load COP	3.0	3.5	4.0
ISO Rated fan power (W/cfm)	0.15	0.11	0.11
FURNACE fan power (W/cfm)	0.50	0.35	0.35
Rated airflow (cfm per ton)	390	390	390
Rated power (kW per ton)	0.88	0.75	0.66
Additional fan power (W per ton)	78.00	52.65	52.65
Actual power (kW per ton)	0.96	0.81	0.71
Actual Htg capacity (MBtu/h)	9.27	9.18	9.18
Corrected COP	2.84	3.34	3.78
Ratio	***0.95***	***0.95***	***0.94***

Heating Compared to ASHP (correct to Rated Fan Power)

H-C Ratio	0.75	0.75	0.75
GSHP -Heating	**COP=3 PSC Fan**	**COP=3.5 ECM Fan**	**COP=4 ECM Fan**
GLHP Full Load COP	3.0	3.5	4.0
ISO Rated fan power (W/cfm)	0.15	0.11	0.11
AHRI Heat Pump fan power (W/cfm)	0.25	0.18	0.18
Rated airflow (cfm per ton)	390	390	390
Rated power (kW per ton)	0.88	0.75	0.66
Additional fan power (W per ton)	39.00	27.30	27.30
Actual power (kW per ton)	0.92	0.78	0.69
Actual Htg capacity (MBtu/h)	9.13	9.09	9.09
Corrected COP	2.92	3.41	3.88
Ratio	***0.97***	***0.98***	***0.97***

Cooling Compared to Conv AC (corrrect to Rated Fan Power)

GSHP -Cooling	EER=14 PSC Fan	EER=16 ECM Fan	EER=18 ECM Fan
GLHP Full Load EER	14.0	16.0	18.0
ISO Rated fan power (W/cfm)	0.15	0.11	0.11
AHRI fan power (W/cfm)	0.25	0.18	0.18
Rated airflow (cfm per ton)	390	390	390
Rated power (kW per ton)	0.86	0.75	0.67
Additional fan power (W per ton)	39.00	27.30	27.30
Actual power (kW per ton)	0.90	0.78	0.69
Actual Clg capacity (MBtu/h)	11.87	11.91	11.91
Corrected EER	13.24	15.32	17.16
Ratio	***0.95***	***0.96***	***0.95***

Cooling Compared to Conv AC (corrrect to Rated Fan Power)

GSHP -Cooling	EER=14 PSC Fan	EER=16 ECM Fan	EER=18 ECM Fan
GLHP Full Load EER	14.0	16.0	18.0
ISO Rated fan power (W/cfm)	0.15	0.11	0.11
AHRI fan power (W/cfm)	0.25	0.18	0.18
Rated airflow (cfm per ton)	390	390	390
Rated power (kW per ton)	0.86	0.75	0.67
Additional fan power (W per ton)	39.00	27.30	27.30
Actual power (kW per ton)	0.90	0.78	0.69
Actual Clg capacity (MBtu/h)	11.87	11.91	11.91
Corrected EER	13.24	15.32	17.16
Ratio	***0.95***	***0.96***	***0.95***

The distribution factors to use in each case summarized in the table below.

Table 13. Values of Distribution Factor (F_{dist}) to Correct to ACTUAL Conditions or DIFFERENTIAL from baseline

	Fan Factors to correct Seasonal Efficiency for ACTUAL Fan Power (from Table 11)	**Distribution Factors to correct Seasonal Efficiency for Baseline (or DIFFERENTIAL) Fan/Pump Power (from Table 12)**		
		Furnace Fan	**Boiler Pumps**	**Air-Source HP**
Heating	0.91	0.95	0.95	0.97
Cooling	0.85	0.95		

An Example Calculation

This example uses data for a Water Furnace ND038, dual stage, 3 ton unit

AHRI Data: $COP_{GLHP\text{-}full}$ = 4.1, $COP_{GLHP\text{-}part}$ = 4.8

$QC_{GLHP\text{-}part}$ = 30100 Btu/h, $QC_{GLHP\text{-}full}$ = 40200 Btu/h → CR = 0.75

The unit has staged pumps, the pumping power is 45 W/ton.

$F_{pump\text{-}full}$ = 0.94, $F_{pump\text{-}part}$ = 0.94 (from Table 10, with CR=0.75)

We are calculating the seasonal COP based on actual fan power:

$F_{dist\text{-}h}$ =0.91 for heating (from Table 13, actual fan power)

Therefore:

$$\text{Actual Seasonal COP} = (\,4.1 \times 1.08 \times 0.94 \times 0.25 \;+\; 4.8 \times 0.94 \times 0.75\,) \times 0.91 = 4.0$$

Conclusions

Determining Annual Loads with EFLH

To properly use published Equivalent Full Load Hour (EFLH) values, the basis for developing the values must be understood. The EFLH values in Appendix G of the NY TRM have been developed by the traditional method of dividing the annual heating load by the heating equipment size. The heating capacity of furnaces and boilers is fixed and is clearly represented by the equipment nameplate rating or size.

Heat pumps have heating capacities that vary with ambient temperature. Furthermore, the nameplate ratings are based on the rated cooling capacity, which are often quite different from the rated heating capacity, which is again are different from the actual heating capacity at design conditions. Therefore, EFLH values can vary based on:

- Equipment type (furnaces, ground source heat pumps, air source heat pumps as displacement or whole house solution)
- Whether the EFLH values are being used with equipment size or design heating load

For the GSHP measure in current TRM, the Appendix G EFLH values for heating are multiplied by a factor a 1.25 before being multiplied by the actual heating load (AHL) determined by ACCA Manual J. Based on the analysis presented here, we propose that the BEFLH heating values from Table 3 and the $BEFLH_c$ cooling values from Table 7 be published in the TRM measure section for each appropriate technology.

Determining Seasonal Efficiency Factor

The average seasonal efficiency factor can be determined from the AHRI certified data. Several corrections must be applied to account for: differences in entering fluid temperatures, actual pumping power, additional fan power, and weighting between full load and part load conditions.

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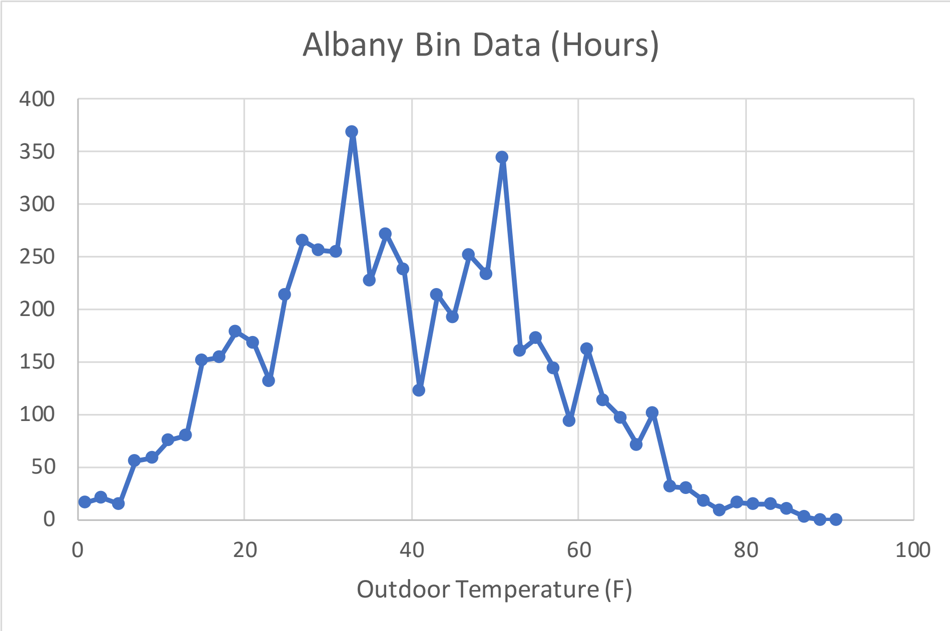
Appendix A - Calculations for Theoretical Equivalent Full Load Hours (EFLH)

The number of hours in each temperature bin for the New York locations are listed in Table A-1. Figure A-1 plots the binned temperature data for Albany and NY LaGuardia.

Table A-1. Binned Temperature Data for Various New York Locations Derived from TMY-3 Data. Bins are in 2°F increments, the temperature listed in the table (Temp Bin) is the center of each bin.

	Albany	Binghamton	Buffalo	Massena	New_York	Poughkeepsie	Syracuse
1% design> . Temp Bin	**-2**	**2**	**5**	**-10**	**15**	**10**	**2**
-23	0	0	0	2	0	0	0
-21	0	0	0	7	0	0	0
-19	0	0	0	3	0	0	0
-17	0	0	0	6	0	0	0
-15	0	0	0	3	0	1	0
-13	0	0	0	2	0	2	0
-11	0	0	0	15	0	7	0
-9	0	0	0	24	0	6	0
-7	0	2	0	21	0	9	1
-5	0	4	0	25	0	5	2
-3	5	5	1	58	0	14	7
-1	10	14	0	49	0	19	10
1	16	22	4	42	0	38	7
3	20	17	12	69	0	36	14
5	14	11	15	47	3	30	10
7	55	42	23	101	7	42	20
9	58	71	41	99	1	41	38
11	76	76	75	119	9	47	47
13	80	66	86	122	9	48	73
15	152	157	207	199	26	83	166
17	154	167	140	154	40	67	145
19	179	129	177	190	39	96	157
21	168	158	151	185	44	140	182
23	132	87	75	96	36	77	152
25	214	215	180	186	87	138	191
27	265	215	181	189	114	186	190
29	256	243	191	207	133	170	228
31	255	382	218	230	171	183	310
33	369	459	423	388	303	354	483
35	227	271	346	316	263	233	331
37	271	250	303	290	326	239	238
39	238	246	292	240	267	289	236
41	122	114	182	108	121	177	130
43	213	264	300	212	275	275	223
45	192	233	276	215	313	304	223
47	251	266	226	180	276	274	215
49	234	244	251	171	331	256	215
51	344	328	323	219	558	420	263
53	161	191	219	186	294	216	159
55	172	190	136	159	279	230	162
57	144	170	162	141	261	210	179
59	93	62	81	75	103	94	75
61	162	109	153	107	202	134	131

Note: The hours during June through September are excluded from each bin



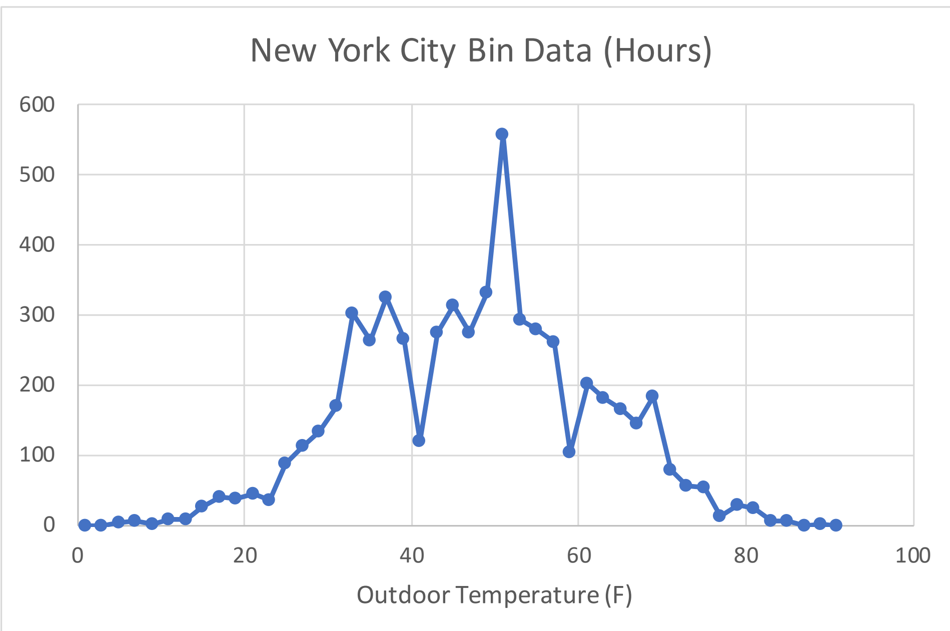


Figure A-1. Number of Hours in Each Temperature Bin for Albany and New York City based on TMY-2 Data (excluding June through September)

Figure A-2 shows the heating load line for New York (same as Figure 1 in main report). The load fraction equals 100% at the 1% design temperature for NY (15°F). The load fraction goes to zero at the assumed balance point temperature of 57.5°F. The heating load line is linear with outdoor temperature because building heat loss is proportional to the indoor-outdoor temperature difference. The indoor temperature is generally constant, so heat loss (or load) varies linearly with outdoor temperature.

Table A-2 shows the bin calculations to find the EFLH for New York and Albany. The number of hours in each bin (NH) is multiplied by load fraction (LF) in each bin. Then all those values are summed to find the seasonal EFLH. The sum is 1633.6 for New York and 1938.9 for Albany. These EFLH values correspond to the rounded values in Table 1 in the main document (1634 and 1939).

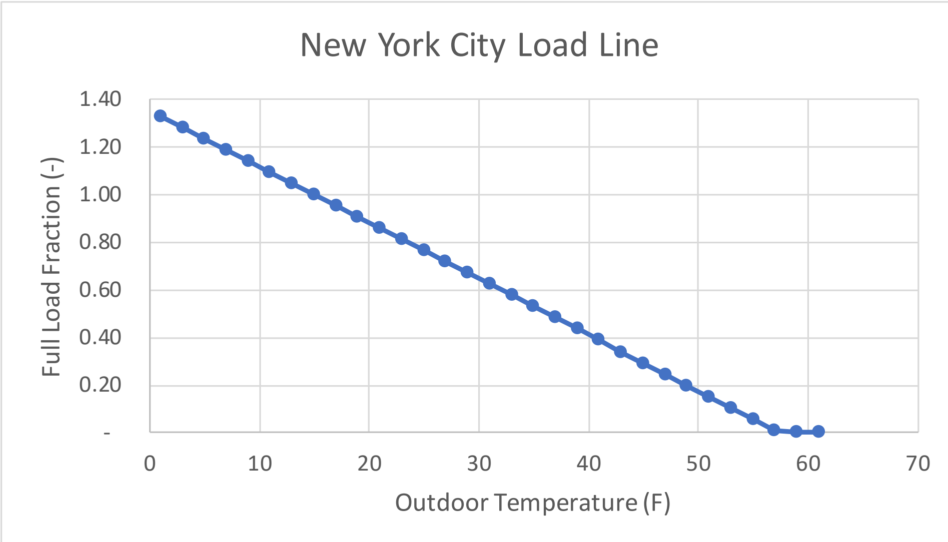


Figure A-2. Heating Load Line for New York (same as Figure 1)

Table A-2. The Bin Calculations to Find EFLH for Albany and New York

Bin calculations for Albany

Outdoor Temp (F)	Hours (NH)	Load Fraction (LF)	NH x LF
-3	5	1.02	5.08
-1	10	0.98	9.83
1	16	0.95	15.19
3	20	0.92	18.32
5	14	0.88	12.35
7	55	0.85	46.68
9	58	0.82	47.28
11	76	0.78	59.39
13	80	0.75	59.83
15	152	0.71	108.57
17	154	0.68	104.82
19	179	0.65	115.82
21	168	0.61	103.06
23	132	0.58	76.54
25	214	0.55	116.89
27	265	0.51	135.84
29	256	0.48	122.62
31	255	0.45	113.57
33	369	0.41	151.94
35	227	0.38	85.84
37	271	0.34	93.37
39	238	0.31	74.00
41	122	0.28	33.83
43	213	0.24	51.91
45	192	0.21	40.34
47	251	0.18	44.29
49	234	0.14	33.43
51	344	0.11	37.58
53	161	0.08	12.18
55	172	0.04	7.23
57	144	0.01	1.21
59	93	-	-
61	162	-	-
63	114	-	-
65	97	-	-
	5047		**1,938.85**

Bin calculations for NY Laguardia

Outdoor Temp (F)	Hours (NH)	Load Fraction (LF)	NH x LF
-3	0	1.42	-
-1	0	1.38	-
1	0	1.33	-
3	0	1.28	-
5	3	1.24	3.71
7	7	1.19	8.32
9	1	1.14	1.14
11	9	1.09	9.85
13	9	1.05	9.42
15	26	1.00	26.00
17	40	0.95	38.12
19	39	0.91	35.33
21	44	0.86	37.79
23	36	0.81	29.22
25	87	0.76	66.53
27	114	0.72	81.81
29	133	0.67	89.19
31	171	0.62	106.62
33	303	0.58	174.67
35	263	0.53	139.24
37	326	0.48	157.25
39	267	0.44	116.22
41	121	0.39	46.98
43	275	0.34	93.82
45	313	0.29	92.06
47	276	0.25	68.19
49	331	0.20	66.20
51	558	0.15	85.34
53	294	0.11	31.13
55	279	0.06	16.41
57	261	0.01	3.07
59	103	-	-
61	202	-	-
63	182	-	-
65	165	-	-
	4586		**1,633.62**

The previous version of the GSHP White Paper from May 27, 2019 used TMY-2 weather data for the calculations of Equivalent Full Load Hours (EFLH). In this version of the Paper we made the following changes:

- Changed from using TMY-2 to TMY-3 Data
- Changed from 5°F bins to 2°F bins for greater resolution in the bin calculations
- Excluded data from June through September from the heating analysis (per the TRM approach)
- Changed the Balance Point Temperature for an "Average" home from 55°F to 57.5°F.

The resulting impact is shown in Table A-3 below for Average vintage construction. The new $EFLH_{MJ}$ (or BEFLH) for Buffalo is now 6% higher and the value for New York decreased by more than 6%. The overall average change for all cities combined was less than 1%.

Table A-3. The Impact of Changing Weather Data Source for $EFLH_{MJ}$ (or BEFLH) Calculation (OLD=TMY-2, NEW=TMY-3)

	OLD WP $EFLH_{MJ}$	**NEW WP $EFLH_{MJ}$**	**Change**
Albany	1,748	1,763	0.9%
Binghamton	1,994	1,935	-3.0%
Buffalo	1,840	1,952	6.1%
Massena	1,910	1,880	-1.6%
New_York	1,588	1,485	-6.5%
Poughkeepsie	1,868	1,912	2.4%
Syracuse	1,835	1,842	0.4%
			-0.2%

To distinguish between Old, Average and New construction vintages, as defined in the TRM, we changed the balance points in the bin calculations for EFLH. We represented the range between Old and New by the balance point range of 60°F to 55°F. Average vintage is in the middle at 57.5°F. Table A-4 shows that Old and New are, on average, ±7% around Average vintage. This spread is in line with the ranges expressed in Appendix G of the TRM, which are also shown below in Table A-5. The differences between the vintages for the EFLH values from Appendix G are ±6% around Average vintage.

Table A-4. The Impact of Construction Vintage (or balance point) on $EFLH_{MJ}$ or BEFLH Values

	Old	**Average**	**New**	**Compared to Average**	
	60F	**57.5F**	**55F**	**Old/60F**	**New/55F**
Albany	1,878	1,763	1,643	6.5%	-6.8%
Binghamton	2,060	1,935	1,804	6.5%	-6.7%
Buffalo	2,080	1,952	1,819	6.6%	-6.8%
Massena	1,986	1,880	1,772	5.6%	-5.8%
New_York	1,636	1,485	1,329	10.2%	-10.5%
Poughkeepsie	2,044	1,912	1,776	6.9%	-7.1%
Syracuse	1,960	1,842	1,720	6.4%	-6.6%
				7.0%	-7.2%

Table A-5. The Differences in EFLH Based on Construction Vintage from Appendix G of the TRM

	TRM Appendix G			**Compared to Average**	
	Old	**Average**	**New**	**Old**	**New**
Albany	1042	978	925	6.5%	-5.4%
Binghamton	1086	1029	963	5.5%	-6.4%
Buffalo	1072	1032	957	3.9%	-7.3%
Massena	1125	1061	1009	6.0%	-4.9%
New_York	867	786	725	10.3%	-7.8%
Poughkeepsie	931	862	807	8.0%	-6.4%
Syracuse	1098	1042	972	5.4%	-6.7%
				6.5%	-6.4%

Appendix B - Analysis of Data from NYSERDA GSHP Rebate Program

The NYSERDA GSHP Rebate Program gathers data on GSHP unit size (i.e., the ASHRAE/ISO 13256-1 GLHP Rated Cooling Capacity) as well as the Manual J design heating load calculated for the building. As of March 2019, there were more than 770 GSHP Small System entries in the database. The data provided the means to assess the relationship between equipment size and design load for a range of systems. The program has provided incentives for "New Construction", retrofits in "Existing" homes, and heat pump unit "Replacements".

This analysis focuses on the 200 New Construction entries, which are listed in Table B-1. We focus on new homes since it is likely that the contractor was better able to complete an accurate Manual J calculation as the basis for equipment sizing. Note that this sample also includes some "From the Groundup" homes from Western NY, where larger, variable-speed equipment was allowed to be installed by the NYSERDA program.

For each entry we calculated:

$$\text{Size-Load Ratio} = \frac{[\text{GLHP Cooling Capacity, tons}] \times [12000\ \text{Btu/ton-h}]}{[\text{Manual J Heating Load, Btu/h}]}$$

The average Size-Load Ratio for the 200 homes is 129% (the average for the entire sample was 120%).

From the analysis of the AHRI data in Appendix C we also know that the GLHP heating capacity averages about 75% of the cooling capacity. Combining these two ratios we can further conclude the rated GLHP Heating Capacity is about the same as the Manual J Heating Load.

$$\text{GLHP Heating Capacity} = \left[1.29\ \frac{\text{GLHP Cooling}}{\text{Manual J Heating}}\right] \times \left[0.75\ \frac{\text{GLHP Heating}}{\text{GLHP Cooling}}\right]$$

GLHP Heating Capacity = 97% of Manual J Heating Load

Table B-1. Program Data for GSHP Incentive Program (New Construction, sorted by ratio)

City	Primary Heating Fuel	Primary Heating System	LoopField Subtype	Total System Size - GLHP Cooling (tons)	Manual J Heat load (Btu/hr)	Size-Load Ratio
Scarsdale			DX	2.25	92,998	29%
Ossining			DX	5	117,224	51%
Boonville			horizontal	2	43,291	55%
Canisteo	Propane	Furnace	horizontal	5.36	113,599	57%
Stanfordville			DX	4	80,600	60%
Valley	Oil	Boiler	Vertical	4	70,336	68%
Moravia	Other	Other	horizontal	2.55	41,903	73%
Red Hook	Oil	Furnace	Vertical	3.12	51,103	73%
Mecklenburg	Propane	Boiler	horizontal	4.29	67,984	76%
Waverly			horizontal	3.83	59,579	77%
Trumansburg	Propane	Furnace	Vertical	3.83	58,279	79%
Penn Yan			Vertical	6.11	88,397	83%
Williamson			horizontal	5.1	69,410	88%
Clayton			horizontal	4.67	63,368	88%
Sloansville			Pond	3	40,385	89%
Burdett	Natural gas	Other	Vertical	3.83	50,405	91%
Hemlock			horizontal	4.67	61,389	91%
Pound Ridge	Propane	Other	Vertical	5.12	66,657	92%
Clayton			Vertical	4.67	60,462	93%
Catskill	Other	Other	Vertical	3.18	41,095	93%
Clarence			horizontal	4.67	60,242	93%
Lockport			horizontal	4.67	60,242	93%
Accord			Vertical	2	25,773	93%
Manlius	Oil	Furnace	Vertical	3	38,412	94%
Corners			horizontal	3.18	39,828	96%
Addison	Other	Other	horizontal	4.83	60,245	96%
Ballston Spa	Other	Other	Vertical	4.67	57,990	97%
Bergen			horizontal	13.09	161,602	97%
Amsterdam			Pond	2.2	27,132	97%
Rhinebeck			DX	5	61,555	97%
Bainbridge			horizontal	4	48,143	100%
Rush			horizontal	3.83	45,563	101%
Ithaca			horizontal	3.71	43,993	101%
Eden			Pond	5.11	60,561	101%
Fly Creek	Oil	Boiler	horizontal	4.83	56,507	103%
Johnsburg			horizontal	4.67	54,590	103%
Corners	Other	Other	Vertical	9.33	108,653	103%
Kingston			horizontal	4.23	48,429	105%
Skaneateles			horizontal	4.71	53,564	106%
Akron			horizontal	3	34,116	106%
Katonah			Vertical	6	68,038	106%
Schodack			Vertical	3.18	36,018	106%
Lockport			horizontal	4.67	52,679	106%
Interlaken				5.21	58,522	107%
Penn Yan			Vertical	8.07	90,438	107%
Somers			DX	3	33,585	107%
Hurley			Vertical	4.67	52,224	107%
Auburn			horizontal	4.23	46,850	108%
Pittsford			horizontal	6.72	74,272	109%
Horseheads				4.23	46,433	109%
Groveland			horizontal	4.67	51,090	110%
Fayetteville	Other	Other	Vertical	10.41	113,802	110%
Castorland	Other	Other	horizontal	4	43,353	111%
Montour Falls			horizontal	5.58	60,324	111%
Highland			horizontal	5	53,838	111%
Springs	Other	Other	Vertical	8.92	95,940	112%
Avon	Propane	Furnace	horizontal	4.44	47,639	112%
H			Vertical	1.92	20,581	112%
Manor	Other	Other	horizontal	6.04	64,743	112%
Clarence			Vertical	4.67	50,024	112%
Marcellus	Oil	Boiler	Vertical	4.08	43,686	112%
Baldwinsville			horizontal	3.83	41,001	112%
Pulteney			Vertical	8.5	90,333	113%
Rushville			horizontal	6.15	65,107	113%
Moravia			Vertical	4.5	47,479	114%
Sterling	Oil	Other	horizontal	5.12	53,983	114%
Middlesex			Vertical	5.36	56,456	114%
Clinton			horizontal	2.92	30,746	114%
Parma			horizontal	3.18	33,353	114%
Marietta	Propane	Furnace	Vertical	4.15	43,303	115%
Batavia			horizontal	4.67	48,685	115%
Williamson			horizontal	8.5	88,149	116%
Clinton			Pond	4.85	49,626	117%
Orchard Park			horizontal	4.67	47,519	118%
Somers			DX	4	40,576	118%
Ithaca			horizontal	3.83	38,761	119%
Stafford	Other	Other	Pond	8.58	86,444	119%
Dansville			horizontal	4.44	44,534	120%
Ontario			horizontal	4.99	50,001	120%
Star Lake	Other	Other	Vertical	4.12	41,263	120%
Vernon Center	Oil	Furnace	horizontal	6.15	61,124	121%
Katonah	Other	Other	Vertical	7	69,550	121%
Hamburg			horizontal	3.18	31,568	121%
East Amherst			Vertical	3.18	31,568	121%
Rye			Vertical	9	88,486	122%
Livonia			horizontal	4.44	43,392	123%
Rochester			Pond	9.5	92,685	123%
Livonia			horizontal	6.89	67,000	123%
Somers			DX	4	38,499	125%
East Amherst	Other	Other	Vertical	6.72	64,418	125%
Webster			Vertical	4.83	46,194	125%
Amherst			horizontal	3	28,666	126%
Newfield	Other	Other	horizontal	6.72	64,196	126%
Queensbury			horizontal	4.08	38,879	126%
Homer			Pond	4.29	40,711	126%
Ballston Spa	Other	Furnace	horizontal	4.15	39,332	127%
Holland Patent	Propane	Boiler	horizontal	8.33	78,900	127%
Norwich	Other	Other	horizontal	8.01	75,864	127%
Gasport			horizontal	3.83	36,174	127%

City	Primary Heating Fuel	Primary Heating System	LoopField Subtype	Total System Size - GLHP Cooling (tons)	Manual J Heat load (Btu/hr)	Size-Load Ratio
Utica	Propane	Furnace	horizontal	6.15	57,841	128%
Copake			Vertical	5.89	55,358	128%
Big Flats			Vertical	4.23	39,489	129%
Newfane			horizontal	3.18	29,680	129%
Keesville	Other	Other	horizontal	4.33	40,383	129%
Forestville			horizontal	2.26	20,960	129%
Farmington			horizontal	4.08	37,803	130%
Fultonham			horizontal	3.05	28,209	130%
Clarence			Vertical	3.83	35,423	130%
Boston			horizontal	4.67	43,151	130%
New Paltz	Oil	Furnace	Vertical	3.18	29,300	130%
Preble	Oil	Furnace	Vertical	4.67	42,977	130%
Owego	Oil	Furnace	horizontal	5.12	46,876	131%
Cazenovia			horizontal	3.35	30,610	131%
New Hartford	Other	Furnace	Vertical	4.29	39,066	132%
Canandaigua			horizontal	6.29	57,155	132%
Campbell			horizontal	5.46	49,507	132%
Lagrangeville			DX	9	81,449	133%
Jackson			Vertical	3.18	28,763	133%
East Amherst			Vertical	3.83	34,596	133%
East Amherst			Vertical	3.83	34,596	133%
Hamburg			Vertical	10	90,015	133%
East Amherst			Vertical	3.18	28,500	134%
Corning			Vertical	9.17	81,826	134%
Skaneateles			horizontal	6.56	58,529	134%
West Winfield	Oil	Furnace	horizontal	4.23	37,581	135%
Palmyra			horizontal	6.72	59,507	136%
Hilton			horizontal	5.46	48,207	136%
Cowlesville			horizontal	6.71	59,165	136%
Canandaigua			Vertical	4.67	41,173	136%
New Berlin	Other		Pond	8.68	76,295	137%
Palmyra	Propane	Other	horizontal	4.29	37,623	137%
Lockport			horizontal	4.67	40,850	137%
Penn Yan			Vertical	11.12	96,757	138%
Boston			horizontal	3.43	29,684	139%
Wales Center			Vertical	5.06	43,689	139%
Clarence			Vertical	5.46	46,739	140%
East Amherst			Vertical	4.23	36,115	141%
Deansboro	Other		horizontal	5.46	46,556	141%
Canandaigua	Other	Other	Vertical	4.67	39,808	141%
Canandaigua	Other	Other	Vertical	4.67	39,808	141%
Canandaigua			Vertical	4.67	39,808	141%
Corners			DX	9	76,657	141%
Fly Creek	Oil	Furnace	horizontal	5.12	43,580	141%
Palmyra			horizontal	4.23	35,803	142%
Bergen			horizontal	5.46	46,078	142%
Honeoye Falls			Vertical	5.13	42,849	144%
Wilson			horizontal	4.67	38,707	145%
Groton	Propane	Furnace	Vertical	6.72	55,639	145%
Amherst			Vertical	2.92	23,963	146%
East Amherst			Vertical	4.23	34,596	147%
East Amherst			Vertical	4.23	34,596	147%
East Amherst			Vertical	4.23	34,596	147%
East Amherst	Other	Other	Vertical	4.23	34,596	147%
Skaneateles	Propane	Furnace	Vertical	6.72	54,057	149%
Mexico			horizontal	4.67	37,311	150%
Scottsville	Other	Other	Vertical	6.89	55,007	150%
Lake George	Other	Other	Vertical	4.23	33,533	151%
Lagrangeville			DX	2	15,766	152%
East Amherst			Vertical	4.23	33,334	152%
t			Vertical	13.83	108,935	152%
Dundee	Propane	Other	Vertical	3.14	24,668	153%
Center	Other	Other	Vertical	4.67	36,641	153%
Goldens Bridge	Other	Other	DX	8	62,721	153%
Holland Patent	Propane	Furnace	horizontal	6.53	51,026	154%
East Amherst			Vertical	3	23,405	154%
Schaghticoke			horizontal	2.2	17,083	155%
Ithaca	Propane	Furnace	horizontal	5.89	45,676	155%
Lake Luzerne			Vertical	3.18	24,498	156%
Copake			Vertical	6.29	48,420	156%
East Amherst			Vertical	5.46	41,994	156%
Ellicottville			horizontal	9.96	75,573	158%
Germantown			Vertical	7.12	53,833	159%
Rochester			horizontal	9.5	71,709	159%
Churchville	Other	Other	horizontal	6.72	50,233	161%
Lima	Other		horizontal	6.72	49,769	162%
Brooktondale	Oil	Furnace	horizontal	5.58	41,196	163%
Lewiston			Vertical	4.23	31,150	163%
t	Other	Other	Vertical	6.72	49,438	163%
Branchport			Vertical	6.72	49,308	164%
Rochester			horizontal	9.5	68,244	167%
Brooktondale	Oil	Furnace	horizontal	6.72	48,043	168%
t			Pond	5.95	42,278	169%
Manlius			Vertical	6.72	47,335	170%
Lansing	Propane	Furnace	Vertical	6.72	47,088	171%
Naples			horizontal	7.52	52,545	172%
Oswego			horizontal	11.64	80,442	174%
Greenwich	Other	Other	Vertical	3.14	21,694	174%
Penn Yan			Vertical	6.72	46,416	174%
Honeoye Falls			horizontal	6.72	45,768	176%
Mendon			horizontal	4.23	28,591	178%
Wayne	Other	Other	Vertical	6.72	45,263	178%
Manlius			Vertical	6.72	45,213	178%
Canandaigua			Vertical	5.95	39,151	182%
Mayfield		Other	horizontal	8.33	54,758	183%
Keuka Park			Pond	6.72	43,652	185%
Attica			horizontal	6.72	43,284	186%
Grand Island			horizontal	6.72	43,134	187%
Penn Yan			Vertical	6.72	42,029	192%
Boston	Other	Other	horizontal	6.72	41,427	195%
Lockport			horizontal	4.23	26,005	195%

Appendix C - Analysis of AHRI Certified Capacity Data for GSHP Equipment

The AHRI directory (www.ahridirectory.org) lists the capacity and efficiency data for all the products in its certification program. For this analysis we focused on Water Furnace Series 3, 5 & 7 products that are rated under ASHRAE/ISO 13256-1 (type code WBAHP). Table C-1 lists the capacities for 63 products. The table includes:

- The nominal size (from the model number)
- The WSHP Rated Cooling Capacity (Btu/h)
- The GLHP Rated Cooling Capacity (Btu/h)
- The GLHP Rated Heating Capacity (Btu/h)

The WSHP rating corresponds to conditions to performance in a traditional water loop system with a cooling tower. The GLHP ratings correspond to performance in closed loop geothermal system. The data are also shown in percentage terms in the table. The table also show the ratio of the GLHP rated heating and cooling capacity (H-C Ratio). Figure C-1 plots this ratio vs. nominal size. The top of the table shows the average percentages for the sample of products. From this data we can infer the following trends:

- Rated GLHP Cooling Capacity is typically the same as nominal size (at least for this manufacturer)
- GLHP Heating Capacity is about 75% of GLHP Cooling Capacity. Stated the other way, the Cooling Capacity is 133% of heating capacity (i.e., 1/0.75)

We also looked at larger sample of 250 units for various manufacturers with type code WBAHP and found that the average H-C ratio was very similar at 76%.

Table C-1. Certified Capacity Data from the AHRI Directory (for Waterfurnace Products)

							94%	99%	74%	75%
Brand Name	Model Number	Staging	Nominal Size (Model No)	Ratings - Full Load WLHP Cooling Capacity (Btuh)	Certified Ratings - Full Load GLHP Cooling	Certified Ratings - Full Load GLHP Heating	Percent of Nominal			H-C Ratio
5 SERIES	NSV/NSH012G1*0		12000	11280	12000	9500	94%	100%	79%	79%
5 SERIES	NSV/NSH018G1*0		18000	18000	18500	14700	100%	103%	82%	79%
5 SERIES	NSV/NSH060G1*0		60000	61300	65500	43200	102%	109%	72%	66%
5 SERIES	NSV/NSH070G1*0		70000	67000	70600	52000	96%	101%	74%	74%
7 SERIES	NVV/NVH048A1*1	Multistage	48000	41000	46000	43000	85%	96%	90%	93%
7 SERIES	NVV/NVH060A1*1	Multistage	60000	50000	56000	51000	83%	93%	85%	91%
7 SERIES	NVV/NVH036A1*(1,2)	Multistage	36000	32000	36000	32000	89%	100%	89%	89%
5 SERIES	NDV/NDH026G1*(1,4)	Multistage	26000	26000	27700	19500	100%	107%	75%	70%
5 SERIES	NDV/NDH038G1*(1,2,4)	Multistage	38000	39000	40200	26700	103%	106%	70%	66%
5 SERIES	NDV/NDH049G1*(1,2,4)	Multistage	49000	50300	52000	37400	103%	106%	76%	72%
5 SERIES	NDV/NDH064G1*(1,4)	Multistage	64000	62000	65100	47100	97%	102%	74%	72%
5 SERIES	NDV/NDH072G1*(1,4)	Multistage	72000	69000	71600	54200	96%	99%	75%	76%
5 SERIES	NSV/NSH018G1*(1,4)		18000	18000	18500	14700	100%	103%	82%	79%
5 SERIES	NSV/NSH022G1*(0,3)		22000	21000	21500	14200	95%	98%	65%	66%
5 SERIES	NSV/NSH022G1*(1,4)		22000	21900	23000	14200	100%	105%	65%	62%
5 SERIES	NSV/NSH030G1*(0,3)		30000	27000	29200	19800	90%	97%	66%	68%
5 SERIES	NSV/NSH030G1*(1,4)		30000	27800	29400	20000	93%	98%	67%	68%
5 SERIES	NSV/NSH036G1*(0,3)		36000	34100	34600	24100	95%	96%	67%	70%
5 SERIES	NSV/NSH036G1*(1,2,4)		36000	34900	35400	24100	97%	98%	67%	68%
5 SERIES	NSV/NSH042G1*(0,3)		42000	40100	41600	27500	95%	99%	65%	66%
5 SERIES	NSV/NSH042G1*(1,2,4)		42000	40800	42000	27500	97%	100%	65%	65%
5 SERIES	NSV/NSH048G1*(0,3)		48000	46400	48900	35000	97%	102%	73%	72%
5 SERIES	NSV/NSH048G1*(1,2,4)		48000	47300	49300	35000	99%	103%	73%	71%
5 SERIES	NSV/NSH060G1*(1,4)		60000	61300	66500	45000	102%	111%	75%	68%
5 SERIES	NSV/NSH070G1*(1,4)		70000	67000	70600	52500	96%	101%	75%	74%
5 SERIES	NSV/NSH012H1*0		12000	11300	12000	9500	94%	100%	79%	79%
5 SERIES	NSV/NSH018H1*0		18000	17400	18500	14500	97%	103%	81%	78%
5 SERIES	NSV/NSH022H1*(0,3)		22000	17200	17700	15000	78%	80%	68%	85%
5 SERIES	NSV/NSH030H1*(0,3)		30000	26800	27900	20300	89%	93%	68%	73%
5 SERIES	NSV/NSH036H1*(0,3)		36000	31500	32900	24400	88%	91%	68%	74%
5 SERIES	NSV/NSH042H1*(0,3)		42000	38300	40300	28900	91%	96%	69%	72%
5 SERIES	NSV/NSH048H1*(0,3)		48000	43200	45500	36400	90%	95%	76%	80%
5 SERIES	NSV/NSH060H1*0		60000	61000	62300	46100	102%	104%	77%	74%
5 SERIES	NSV/NSH070H1*0		70000	66200	69100	53500	95%	99%	76%	77%
5 SERIES	NSV/NSH018H1*(1,4)		18000	17400	18500	14500	97%	103%	81%	78%
5 SERIES	NSV/NSH022H1*(1,4)		22000	18100	19200	15500	82%	87%	70%	81%
5 SERIES	NSV/NSH030H1*(1,4)		30000	27000	28100	20500	90%	94%	68%	73%
5 SERIES	NSV/NSH036H1*(1,2,4)		36000	32300	33700	24400	90%	94%	68%	72%
5 SERIES	NSV/NSH042H1*(1,2,4)		42000	39000	40700	28900	93%	97%	69%	71%
5 SERIES	NSV/NSH048H1*(1,2,4)		48000	44100	45900	36400	92%	96%	76%	79%
5 SERIES	NSV/NSH060H1*(1,4)		60000	61100	62200	47900	102%	104%	80%	77%
5 SERIES	NSV/NSH070H1*(1,4)		70000	66200	69100	54000	95%	99%	77%	78%
5 SERIES	NDV/NDH038H1*(1,2,4)	Multistage	38000	36500	38200	28500	96%	101%	75%	75%
5 SERIES	NDV/NDH049H1*(1,2,4)	Multistage	49000	49100	50800	38200	100%	104%	78%	75%
5 SERIES	NDV/NDH064H1*(1,4)	Multistage	64000	62300	65500	47300	97%	102%	74%	72%
5 SERIES	NDV/NDH072H1*(1,4)	Multistage	72000	70100	73800	55400	97%	103%	77%	75%
5 SERIES	NDV/NDH026H1*(1,4)	Multistage	26000	24900	26400	19500	96%	102%	75%	74%
5 SERIES	NDP026H1*1	Multistage	26000	23500	24800	19300	90%	95%	74%	78%
5 SERIES	NDP038H1*(1,2)	Multistage	38000	36500	38200	28300	96%	101%	74%	74%
5 SERIES	NDP049H1*1	Multistage	49000	48800	50400	38000	100%	103%	78%	75%
5 SERIES	NDP064H1*1	Multistage	64000	60000	62500	46300	94%	98%	72%	74%
5 SERIES	NDP072H1*1	Multistage	72000	67400	71700	55400	94%	100%	77%	77%
5 SERIES	NSV/NSH036J1*(0,3)		36000	31500	32900	24400	88%	91%	68%	74%
5 SERIES	NSV/NSH042J1*(0,3)		42000	38300	40300	28900	91%	96%	69%	72%
5 SERIES	NSV/NSH036J1*(1,2,4)		36000	32300	33700	24400	90%	94%	68%	72%
5 SERIES	NSV/NSH042J1*(1,2,4)		42000	39000	40700	28900	93%	97%	69%	71%
5 SERIES	NDV/NDH038J1*(1,2,4)	Multistage	38000	36500	38200	28500	96%	101%	75%	75%
3 SERIES	LD(V,H)024A	Multistage	24000	22000	23100	18900	92%	96%	79%	82%
3 SERIES	LD(V,H)036A	Multistage	36000	33700	35100	26000	94%	98%	72%	74%
3 SERIES	LD(V,H)048A	Multistage	48000	46500	49000	36000	97%	102%	75%	73%
3 SERIES	LD(V,H)060A	Multistage	60000	57200	59900	45300	95%	100%	76%	76%
3 SERIES	LD(V,H)072A	Multistage	72000	64400	67000	52000	89%	93%	72%	78%
3 SERIES	LD(V,H)060B	Multistage	60000	57200	59900	45300	95%	100%	76%	76%

Figure C-1 shows the range of H-C Ratios. The Series 7 variable capacity units are the three outliers near 90%. The dual stage and single stage units show a more consistent pattern.

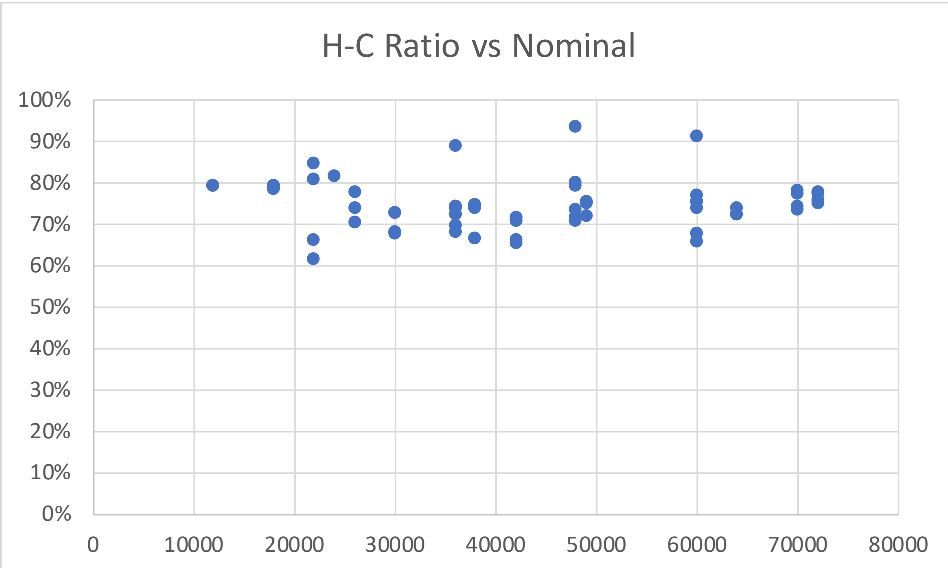


Figure C-1. The Ratio of Heating and Cooling Capacity (H-C Ratio) vs. Nominal Unit Size

Appendix D - The Change in EFLH Values Based on 2014 Evaluation Report for High Efficiency Heating Equipment for 2009-2011

Background

The 2014 evaluation report by Opinion Dynamics independently calculated the Full Load Hours (FLH) and found that these values were, on average, 29% lower than the FLH values in the TRM at the time. Therefore, the revised FLH values in the current TRM (version 7) for 5 of the 7 NY cities were taken directly from the evaluation report (excluding Binghamton and Massena, which may have had a slightly different adjustment).

FLH Values from the Evaluation Report

These recommended FLH values from the evaluation report were calculated by the following method, as described on page 20-21 of report:

- Finding the space heating gas use by determining the temperature-dependent portion of the total gas heating load for each home in the post-retrofit period using an HDD-65 method
- Using program data for the nominal size of the newly installed equipment (furnace or boiler)
- Then for each home: $FLH = \frac{\text{[annual space heating gas use, Btu-fuel]}}{\text{[equipment input rating, Btu-fuel/h]}}$

Using these corrected FLH values in the TRM is appropriate for gas-fired furnaces and boilers, but would not apply to EFLH values determined for use with other data, such as Manual J building design loads. Since the new factors are totally empirical, they depend on the relative sizing of the furnaces and boilers in the sample. While NYS code now requires that equipment be sized using ACCA Manual J and Manual S to be within 10% of the load, the sample of systems in this study were mostly installed before this requirement. Historically furnaces have been sized larger than the heating loads. Anecdotally, boiler oversizing has been observed to be even greater.

The Original FLH Values from DOE-2 Simulations

The FLH values developed from original DOE-2 analysis is based on the houses described in Appendix A of the TRM. The furnace sizing keyword in DOE-2 was set to be 20%, meaning the size of the furnace was set to be 20% larger than the equipment size determined by DOE-2's auto-sizing feature. The auto sizing function in DOE-2 was developed in the 1980s, and it is unlikely that the equipment size from that process in DOE-2 is the same as a result from newest version of Manual J and Manual S. Therefore, it is unclear what the sizing of the furnace is relative to Manual J.

Summary

The evaluation report found definitive differences between the FLH values it calculated and the FLH values determined from DOE-2 simulations (that were originally in the TRM). However, it is not clear if the change was caused by differences in gas use (i.e., heating load) or if it was caused by different equipment sizing conventions between actual practice in the field and the DOE-2 sizing assumptions. The FLH values in the evaluation report are based on actual sizing practice in the field. We believe those equipment sizes were larger than what DOE-2 originally assumed, so this made the FLH values smaller in the evaluation report.

As result of all this, the 29% adjustment factor only applies to furnaces and boilers given sizing practices in place in the 2009-2011 timeframe. This adjustment factor cannot be applied to the EFLH values developed with weather data for use with Manual J design heating loads.

Appendix E – GSHP Desuperheater Savings: Comparing Various Calculations of Desuperheater Energy Impact

Desuperheater Operation is Complicated

A desuperheater is a heat exchanger on a GSHP that transfers heat from the hot refrigerant leaving the compressor to domestic hot water (DHW). The desuperheater pump in the unit pulls water from the bottom of a DHW tank, heats it, and returns it to the tank. The desuperheater pump controls only operate when the compressor is running and the DHW water pulled from the bottom of the tank is cool enough to pick up heat from the refrigerant. The heat provided by the desuperheater is "free" during cooling operation but is provided at the space heating COP of the GSHP unit during the heating season. Desuperheater piping losses, pump cycling controls, and the piping connections to the tank all affect desuperheater performance.

Illinois TRM

The Illinois TRM assumes the desuperheater meets 67% of the domestic water heating (DHW) load for 8 months. So 0.67%*8/12 = 44%. The reference was Doug Dougherty, Geothermal Exchange Organization. This assumption appears to be more appropriate for a cooling climate than for NY.

Illinois uses 17.6 gallons per day (GPD) per person, comparted to 17.2 GPD in the NY TRM.

Single family house is assumed to have 2.56 people per household by default

GeoLink Report from WaterFurnace

WaterFurnace provided a GeoLink report for Albany, NY. The 4-ton unit served an annual space heating load of 57.3 million Btu. The annual water heating load was assumed be 12.2 million Btu (which implies ~54 GPD). The desuperheater meets 50% of the annual DHW load with series 7 variable speed unit and 55% with a series 5 dual stage. Table E-1 below shows the seasonal space heating COPs for each case as well as the average annual COP for water heating for these two units.

Table E-1. Results from GeoLink for Desuperheater Performance

	Seasonal COP for Space Heating COP_{SH}	Average Water Heating COP_{DHW}	Fraction of Annual Load Served by Desup
Series 7	4.33	5.46 (126.0%)	50%
Series 5	3.69	4.67 (126.5%)	55%

The annual average COP for water heating is defined below. We assume that in the heating mode, water heating is provided at the space heating efficiency (COP_{SH}). In the cooling, the water heating is provided for free. The equation below shows that the relationship between COP_{SH} and COP_{DHW} is related to the fraction of the annual desuperheater load that occurs during the heating mode (F_{htg}).

$$COP_{DHW} = \frac{Heat}{(Power_{htg} + Power_{clg})} = \frac{Q_{DHW}}{(Q_{DHW} \times F_{htg}/COP_{SH} + 0)} = \frac{COP_{SH}}{F_{htg}}$$

In this case for Albany, NY with this house, the implied value for F_{htg} from the GeoLink report is 0.79.

Measured Performance for Wisconsin Homes (Carlson 1997)

CDH Energy measured desuperheater performance for a GSHP system in a Wisconsin home in the mid-1990s. Carlson (1997) measured performance at a house with 4-ton unit that had an annual space heating load 104 million Btu. He developed the following regression model to predict the impact of desuperheater operation on daily energy use of the electric tank:

$$\text{kWh/day} = 1.683 + \text{GPD} \times 0.141 - 0.459 \times \text{CH}$$

where: GPD - gallons per day of hot water use
CH - compressor runtime, operating hours per day

Each hour of compressor operation reduced daily electric use by 0.459 kWh. For the house in Carlson (1997) the maximum observed compressor runtime was 19 hrs per day. We assumed that the GSHP also reaches 19 hrs per day at the 99% design condition of -2F for Albany, to develop the linear model shown below. We assumed the same runtime hours per delivered capacity in the cooling mode.

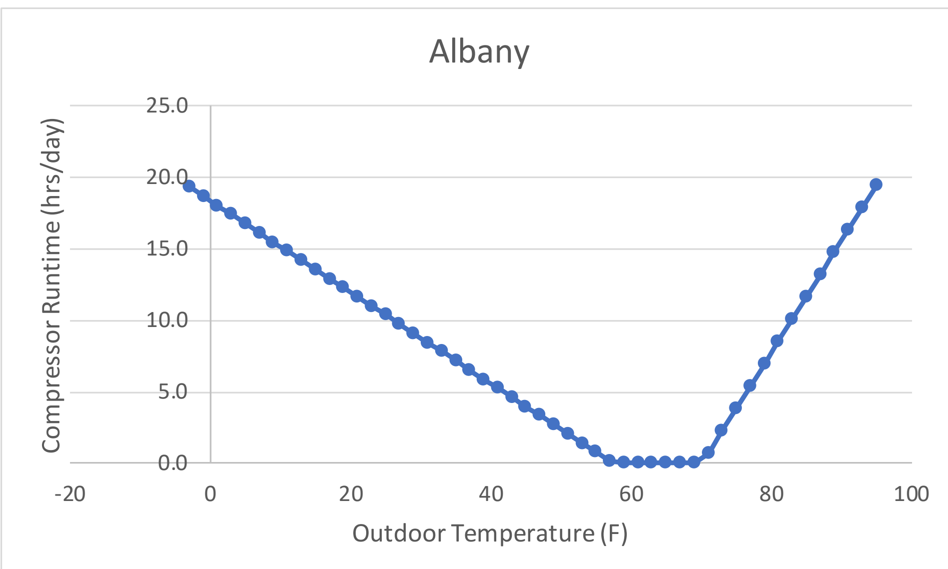


Figure E-1. Relationship Showing Compressor Runtime as a Function of Outdoor Temperature

Using the relationship above in Figure E-1 with the regression model from Carlson (1997) we could also determine the fraction of the DHW load that could be met by the desuperheater at each outdoor temperature at any level of GPD, with the following equation:

$$\text{Fraction of Load Met} = 1 - \frac{1.683 + \text{GPD} \times 0.141 - 0.459 \times \text{CH}}{1.683 + \text{GPD} \times 0.141}$$

Figure E-2 shows the resulting fraction at each outdoor temperature assuming GPD = 35 gal/day. We used the TMY-3 temperature bin data for Albany with the model in Figure E-2 to find the weighted average fraction of load met by the desuperheater. For data shown in Figure E-2, the annual average desuperheater fraction was 35% for Albany. We repeated this analysis for other weather NY cities and the annual averages varied from 34 to 37%. The average for all the NY cities was 36% at 35 gal/day, implying the result did not change significantly between climates. However, we found that the GPD did impact the results as shown in the Table E-2 below.

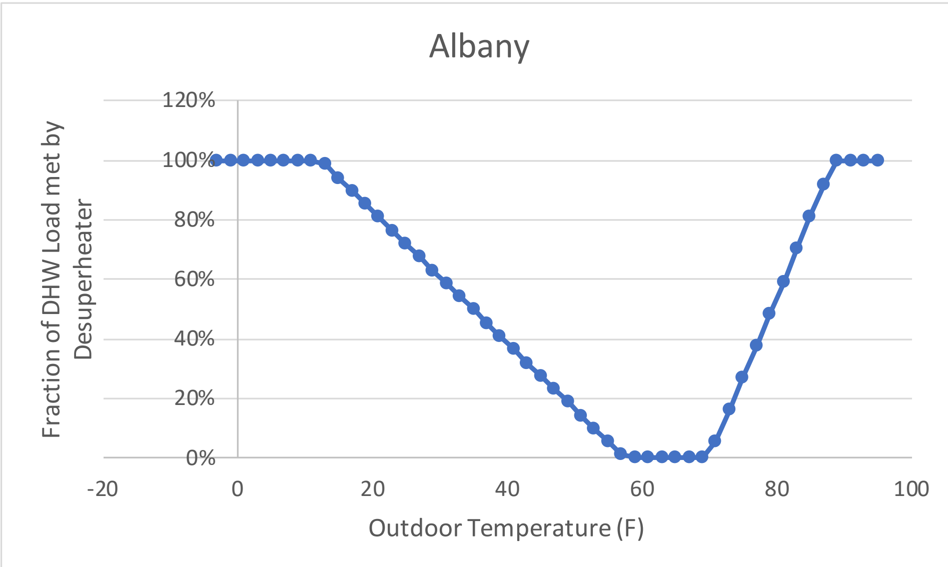


Figure E-2. Fraction DHW Load Met by the Desuperheater as a Function of Outdoor Temperature (at 35 GPD)

Table E-2. Resulting Fraction of Load Met by the Desuperheater as a Function of Hot Water Use

GPD	Fraction of DHW Load met by Desuperheater
35	36%
45	30%
55	26%
65	22%

Note: The results were not found to be strongly dependent on NY climate

Using the bin analysis we also could determine the fraction of desuperheater load that was delivered during heating operation (F_{htg}). For the upstate cities the fraction ranged from 84 to 87%, with an average of 86%. For New York, 72% of the desuperheating load occurred during heating operation. These values are in reasonable alignment with the 79% fraction found by GeoLink.

<u>Comparing Results</u>

The analysis by GeoLink appears to determine the amount of heat leaving the desuperheater in the GSHP unit assuming a relatively cool entering water temperature. The desuperheater piping pulls water from the bottom of the tank and returns it to the tank, in some cases via a co-axial fitting installed at the tank drain. In contrast, the results from Carlson (1997) show the net reduction in tank element electric use. This explains why the Geolink analysis predicts an annual load fraction of 50-55% for the desuperheater at 53 GPD while the corresponding value is 26% at 55 GPD in Table 2 above. The distribution losses in the piping, mixing/de-stratifying of the tank volume from pump operation, and differences in the water temperatures entering the desuperheater all serve to reduce the overall effect on tank energy use.

<u>References</u>

Carlson, S. 1997. “Geothermal Heat Pump Performance in Heating Dominated Climates.” Presented at Heat Pumps in Cold Climates, 3rd International Technical Conference. August 11-12. Wolfville, Nova Scotia.

CDH Energy. 1997. “Enhanced Heat Pump Case Study Demonstration Results. Final Report for Energy Center of Wisconsin. Madison. May.

Appendix F - Using PNNL's IECC Low-Rise Multi-Family Simulation Results to Develop BEFLH Values for the NY TRM

Overview

The simulation results from the EnergyPlus runs that PNNL completed as part of its IECC code evaluation were used to develop appropriate values of building equivalent full load hours (BEFLH) for NY TRM. The equivalent full load hours from EnergyPlus ($EFLH_{EP}$) for the three simulated NY cities (Albany, Binghamton, New York) where compared to Low-Rise Multi-family values from Appendix G of the TRM for the corresponding cities. A single multiplication factor was found that minimized the error or difference between the Appendix G values and the PNNL EnergyPlus values. The resulting factor was used to find the BEFLH values for all seven NY cities:

$$BEFLH = EFLH_{APP\,G} \times Factor$$

PNNL Simulation Results

The low-rise multi-family energy models from PNNL were for a 21,600 sq ft, 3-story apartment building with 18 apartments (zones). Simulation results for compliant low-rise multi-family buildings are available for IECC 2006, 2009 and 2012 at https://www.energycodes.gov/development/residential/iecc_models. Results were available for three NY locations (Albany, Binghamton, New York) and with four different building foundation types (crawlspace, heatedbsmt, slab, unheatedbsmt).

In order to determine equivalent BEFLH/EFLH values from the PNNL simulation results, the data needs to be considered on the same basis, i.e. as the ratio of annual heating load delivered divided by the Manual J design load:

- The PNNL simulation results are mainly provided as input energy. In order to ensure a like-for-like comparison, only the results for the system with resistance heating was used since the input energy and output energy are the same in this case.
- The sizing criteria of the electric heat "coil" in for the simulation results with EnergyPlus uses the 99.6% design condition, while Manual J uses the 99% condition but excludes the house internal gains from the calculation to get a bigger result. Therefore, we believe that the EnergyPlus sizing approach in the PNNL results for the electric resistance heat case yields a sufficiently close result to Manual J to allow a like-for-like comparison.

We parsed the results to pull data from the PNNL HTML files. The key data from the EnergyPlus results were the annual electricity input for (space) heating and the nominal capacity of the heating coil, which, as discussed above, can be used in this case to calculate the equivalent full load hours from EnergyPlus ($EFLH_{EP}$) that is equivalent to BEFLH. The example below uses the simulation data for IECC 2006 in New York with a crawlspace:

$$EFLH_{EP} = \frac{[\text{Annual Heating Electricity, kBtu}] \times 1000}{[\text{Nominal Htr Capacity, All zones, Btu/h}]} = \frac{365{,}591 \times 1000}{256{,}561} = 1425$$

The tables below repeat this process for all the other cities. The building foundation type had very little impact, so we only show crawlspace results.

	$EFLH_{EP}$		
	Albany	Binghamton	New York
IECC 2006	1,664	1,673	1,425
IECC 2009	1,644	1,657	1,395
IECC 2012	1,490	1,497	1,245

The actual annual heating loads from the PNNL results and the nominal heating capacity from the PNNL HTML files are are summarized in the table below for reference.

	Annual Heating Load (MBtu)		
	Albany	Binghamton	New York
IECC 2006	451,520	448,340	365,591
IECC 2009	426,524	423,413	333,670
IECC 2012	310,123	296,656	218,802

	Nominal Heater Capacity (Btu/h)		
	Albany	Binghamton	New York
IECC 2006	271,428	267,918	256,561
IECC 2009	259,453	255,503	239,191
IECC 2012	208,153	198,186	175,812

Proposed BEFLH Values (Appendix G x Factor)

The "Factor" that provided the smallest difference – or best agreement – was a value of 1.7. In the table below the proposed TRM values of BEFLH using 1.7 are compared for two vintages: 1) the newest vintage in the proposed TRM (2007+) are in reasonable agreement with the IECC 2012 values of $EFLH_{EP}$ and 2) the average vintage BEFLH values (1979 to 2006) are close to the $EFLH_{EP}$ values for IECC 2006. The differences between BEFLH and $EFLH_{EP}$ range from +26% to -31% with an average absolute difference of 15.6%.

Multi-Family Low Rise	Albany	Binghamton	New York
BEFLH - Proposed TRM (1979 TO 2006)	1,720	2,117	1,229
$EFLH_{EP}$ - IECC 2006	1,664	1,673	1,425
Ratio	103%	126%	86%
BEFLH - Proposed TRM (2007+)	1,239	1,528	855
$EFLH_{EP}$ - IECC 2012	1,490	1,497	1,245
	83%	102%	69%

The Proposed TRM values for low-rise multi-family are based on multiplying the Appendix G values by a factor of 1.7. The table below shows the impact of using different factors. The average absolute difference was the lowest with a factor of 1.7. The impact of using a different factors on the absolute difference are shown in the table below.

Factor	**Average Absolute Difference**
1.5	20.0%
1.6	16.9%
1.7	**15.6%**
1.8	16.6%
1.9	17.5%

Proposed BEFLH Values for NY Cities

The values in Appendix G of the TRM were multiplied by a factor of 1.7 to develop these final BEFLH values.

	Pre-war	Prior 1979	1979 to 2006	2007 to present
Albany	1889	1751	1720	1239
Binghamton	2375	2244	2117	1528
Buffalo	2178	2072	2066	1501
Massena	2436	2220	2254	1639
New York	1698	1287	1229	855
Poughkeepsie	1457	1520	1476	1047
Syracuse	2372	1998	2050	1437