Closing the Gap: Getting Full Performance from Residential Central Air Conditioners

Task 4 - Develop New Climate-Sensitive Air Conditioner

Simulation Results and Cost Benefit Analysis

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Executive Summary

This simulation study integrated detailed models of conventional and advanced cooling and dehumidification equipment into a TRNSYS-based building simulation model. Building models were developed for a standard HERS Reference house, meant to represent current construction practice, and a High-Efficiency house that would likely qualify for a federal tax credit.

The different houses were simulated in seven southeastern U.S. cities and with various ventilation/infiltration scenarios including: 1) variable or natural infiltration alone, and 2) mechanical ventilation that complied with ASHRAE Standard 62.2-2004. The simulations accurately considered several key factors that affect dehumidification performance and space humidity levels, including: 1) duct air leakage and thermal losses, 2) the impact of part load latent capacity degradation with various supply air fan control and ventilation strategies, and 3) the impact of space overcooling and other novel dehumidification control strategies.

The simulation results for the standard HERS Reference house with natural infiltration were consistent with recent field experience: a conventional air conditioner can maintain adequate humidity control for all but a few hundred hours a year in the most humid climates. However, as houses become more energy efficient – i.e., with better windows, more insulation, tighter construction, and less duct air leakage – the number of hours that the space humidity exceeds 60% RH will increase substantially. The reduction in sensible cooling loads decreases air conditioner runtime and causes space humidity levels to increase.

Implementing the continuous outdoor ventilation rates required under ASHRAE Standard 62.2-2004 also increases space humidity levels, further increasing the need for explicit dehumidification. Continuous ventilation provides more outdoor air at times when natural infiltration is normally modest. While the impact of continuous ventilation on the total cooling load is small during these moderate outdoor air conditions, the moisture introduced at these times can have a big impact on space humidity levels since air conditioner runtimes are low.

Care must be taken to minimize the impact of providing continuous ventilation to the house. Operating the air conditioner supply fan continuously to provide ventilation not only increases fan energy use but increases the number of high humidity hours by a factor of two to four compared to separately providing ventilation with an exhaust fan. Fan cycling controllers that limit supply fan operation to a fraction of the time (and control a ventilation air damper) can significantly reduce humidity and energy impacts of the central fan integrated ventilation approach.

Standalone dehumidifiers were found to be a cost-effective approach to providing humidity control on a life-cycle basis. Even a very small dehumidifier (37 pint per day) could provide good humidity control in a 2000 sq ft residence. When combined with fan cycling controls and a ventilation damper, the simple dehumidifier was one of the most promising approaches to providing good whole-house air distribution combined with dehumidification and ventilation. Condenser reheat systems also show promise.

Energy-efficient, properly-ventilated homes in humid climates need equipment that can cost-effectively provide modest amounts of dehumidification while also providing cooling and ventilation.

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1. Introduction

Current air conditioners and heat pumps are generally compromise designs that meet equipment rating conditions (ARI Standard 210/240) cost-effectively and work adequately in a variety of climates. However, greater comfort and energy savings can be realized if units are designed for specific regional climates. In particular, a unit optimized for hot-dry conditions can improve efficiency by sacrificing dehumidification ability. And a unit optimized for hot-humid conditions can increase dehumidification and comfort without "over-cooling" a space.

The California Energy Commission (CEC), through its Public Interest Energy Research (PIER) program, is currently co-funding the development of a residential air conditioner optimized for hot-dry climates.[1] In addition, the New York State Energy Research and Development Authority (NYSERDA) is sponsoring a project to develop an air conditioner optimized for northern climates (short duration cooling season with relatively high peak loads that strain utilities and electrical distribution systems). Task 4 of this NASEO/STAC project is intended to complement the CEC and NYSERDA efforts by developing a residential air conditioner optimized for hot-humid climates.

The steps for developing the hot-humid air conditioner will include the following activities: (1) identify possible system configurations, (2) computer modeling of systems with and without various air conditioner component options to determine their effectiveness and potentials for efficiency and dehumidification performance, (3) cost-benefit analysis of the various options, (4) design and construction of a prototype unit, (5) testing the prototype in the laboratory and modifying the unit as needed, and (6) field test the prototype unit. This document describes the computer simulation modeling and cost-benefit analysis that were performed as part (2) and part (3) of this development task.

[1] http://www.hdac-des-pier.com

2. Simulation Approach and Assumptions

Cities

The geographical target areas for the hot-humid climate air conditioner are climate zones 1A, 2A and 3A as defined by the 2004 International Energy Conservation Code (IECC), with particular emphasis on the warm-humid region below the white line as shown in Figure 1. The weather data used for the computer simulations were the typical meteorological year data sets (TMY2)[2] for the following southeastern U.S. cities:

TMY2 City	Climate Zone
Miami, FL	1A
Jacksonville, FL	2A
Atlanta, GA	3A
Sterling, VA[3]	4
Houston, TX	2A
Fort Worth, TX	3A
Wilmington, NC	3A

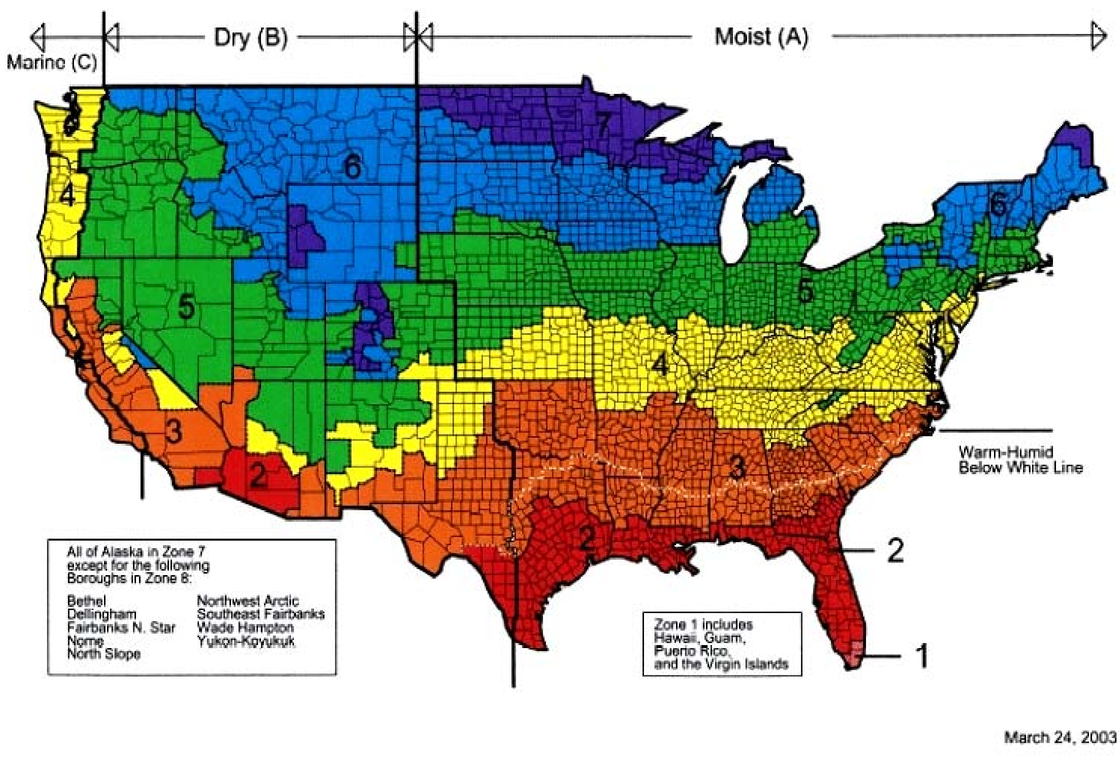


Figure 1. Climate Zones for United States Locations

[2] User's Manual for TMY2s, NREL/SP-463-7668, 1995, http://rredc.nrel.gov/solar/pubs/tmy2/
[3] While Sterling, VA is not in the warm humid zone defined in Figure 1, it was included to investigate impacts for this zone which is adjacent to the primary geographical region. Sterling is also included in the broader definition of a hot and humid region as defined in Task 1 of the overall project.

Building Characteristics

Two residential buildings were simulated for each city representing both standard and high-efficiency home construction in the southeastern United States:

1. A HERS Reference house, as per the 2006 RESNET Standards, that is meant to represent typical new construction,
2. A "High-Efficiency" house that has combined heating and cooling loads that are 33-53% lower than the HERS Reference house. This design is representative of a "best practice" house that may qualify for a Federal Tax Credit (Energy Policy Act of 2005).

Both homes have 2,000 ft^2 of conditioned floor area, but the building characteristics varied based on climate zone as per the RESNET Standards. The details of the building envelope used in each region for the reference and high-efficiency houses are given in Table 1 and Table 2 below.

The variations in construction efficiency level and simulation weather data will define the expected range of cooling and dehumidification loads on air-conditioning (AC) equipment used in single-family homes located in this climate region.

Standard (HERS Reference) House

The characteristics for the standard house were based on the 2006 RESNET Standards, Section 303.4 (HERS Reference Home)[4]. The 2006 RESNET building characteristics vary with climate zone and are largely consistent with the 2006 IECC minimum efficiency standards for residential construction (with a few differences). For the geographical area of interest to this project, the predominant foundation types are slab-on-grade and crawlspace. For this simulation study, slab-on-grade foundations were assumed for all homes (standard and high-efficiency) and for all locations.

Several computer programs are accredited by RESNET to provide the calculations necessary to produce a home energy rating, including the automatic generation of a HERS Reference to establish the baseline of comparison. EnergyGauge[5] is one such computer program that is widely used by HERS raters. In many instances, the inputs for the HERS Reference house generated by EnergyGauge were used to define the building characteristics for the standard home that was simulated as part of this study.

High-Efficiency House

The high-efficiency house was similar to the standard house but with higher wall and ceiling insulation levels, improved windows, and forced air distribution system improvements (i.e., no duct air leakage and ducts located in the conditioned space). Internal loads were assumed to be the same for both the standard and high-efficiency houses. The annual cooling and heating loads for the high-efficiency house are approximately 33% to 53% lower than those for the standard house.

[4] 2006 Mortgage Industry HERS Standards, http://www.resnet.us/standards/mortgage/RESNET_Standards-2006.pdf
[5] EnergyGauge, http://www.energygauge.com/

Table 1. Insulation Level for HERS Reference and High-Efficiency Building Envelope

			HERS Reference	High-Efficiency House
	Climate Zone		R-Value (h-ft^2-F/Btu)	R-Value (h-ft^2-F/Btu)
Wall	1		11.2	19.4
	2		11.2	19.4
	3		11.2	19.4
	4		11.2	19.4
Ceiling	1		24.9	38.5
	2		24.9	38.5
	3		24.9	38.5
	4		30.5	38.5
Floor	1	no ins	13.0	13.0
	2	no ins	13.0	13.0
	3	no ins	13.0	13.0
	4	R10, 2 ft	20.8	20.8

Note: R-value for the slab-on-grade floor is "effective R-value" as described in "Underground Surfaces" by Fred Winkelmann in DOE User News, Vol. 19, No. 1, 1998

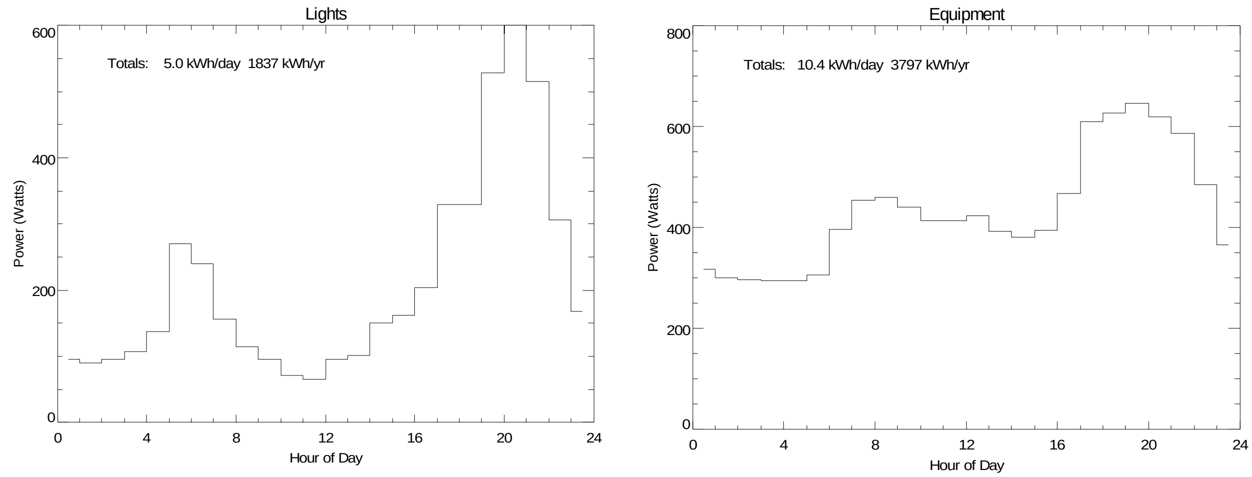
Table 2. Window Characteristics for HERS Reference and High-Efficiency House

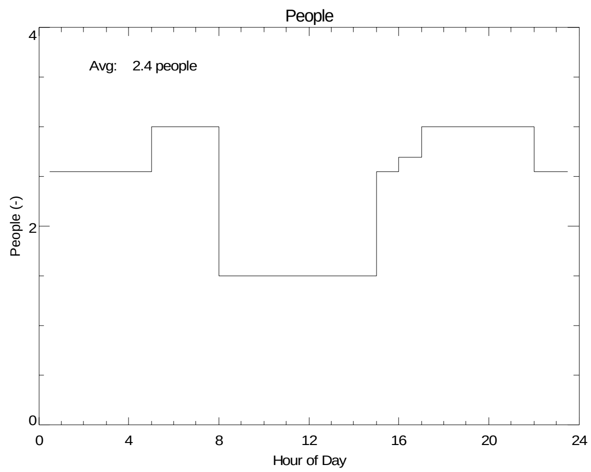
	HERS Reference		High-Efficiency House	
Climate Zone	Window U-Value (Btu/h-ft^2-F)	Window SHGC (-)	Window U-Value (Btu/h-ft^2-F)	Window SHGC (-)
1	1.2	0.40	0.75	0.20
2	0.75	0.40	0.65	0.20
3	0.65	0.40	0.40	0.35
4	0.40	0.55	0.30	0.45

Internal Loads

The internal loads in the conditioned space were taken from the HERS Reference house as generated by EnergyGauge. The schedule for lights, equipment and people are shown in Figure 2 below. The same internal loads and schedules were used for the HERS Reference and High-Efficiency houses (total annual electric load of 5,635 kWh per year). All energy use for lighting and equipment is assumed to become sensible gains to the space. The peak occupancy is 3 people. The people are assumed to be seated, performing light activity, which adds 420 Btu/h per person to the space (as per ISO Standard 7720). The total internal moisture gain on a daily basis becomes 10.3 lb/day (4.7 kg/day) for the average of 2.4 people. No additional internal moisture load is added to the space beyond that generated by the occupants themselves. This internal moisture gain is 24% lower than the net moisture gain of 13.6 lb/day (6.2 kg/day) recommended for this average occupancy level under ASHRAE Standard 160P[6].

[6] http://www.ashrae.org/





Lights: 1,837.4 kWh/yr
Equipment: 3,797.7 kWh/yr
Total: 5,635.1 kWh/yr

People: 230 Btu/h-p Sensible
190 Btu/h-p Latent
(10.3 lb/day moisture gain)

Figure 2. Schedules for Lights, Equipment and People

Infiltration and Ventilation

Infiltration for the HERS Reference house is defined by specifying envelope leakage area and using the Sherman-Grimsrud calculation method. HERS specifies the specific leakage area (SLA) per floor area as per the Sherman-Grimsrud method given in the ASHRAE Handbook of Fundamentals and used by the DOE-2 and EnergyGauge building energy simulation programs. The specified SLA translates to an equivalent leakage area (ELA) of 138.2 in^2 for this house, or 3.9 in^2 of leakage area per 100 ft^2 of building envelope area (not counting the slab-on-grade floor). The High-Efficiency house is assumed to have an ELA of 88.6 in^2, or 2.5 in^2 of leakage area per 100 ft^2 of building envelope area.

Table 3. Infiltration Parameters for HERS Reference and High-Efficiency House

	HERS Reference	**High Efficiency**
Equivalent leakage area (ELA) (in^2)	138.2	88.6
ELA per 100 sq ft of envelope area (in^2 per 100 ft^2)	3.9	2.5
Specific Leakage Area (SLA) or ELA per Floor Area (ft^2 per ft^2)	0.00048	0.000307

Note: The ELA is used in the Sherman Grimsrud calculations for temperature and wind-driven infiltration

For both of these slab-on-grade houses, the Sherman-Grimsrud model was evaluated using heavy shielding terrain parameters (A, B, C = 0.67, 0.25, 0.19), as described by Sherman (1998)[7]. The building height (H) is 8 ft, the difference in ceiling-floor fractional leakage area (X) is taken as 0, and the fraction of total leakage area in the floor and ceiling (R) is 0.5. These parameters were selected to correspond to the inputs to the EnergyGauge building energy simulation program, which automatically calculates these values for a HERS Reference house based on a user-supplied ELA.

Figure 3 and Figure 4 below show the resulting range of air change (ACH) values that the Sherman-Grimsrud method calculates for each house using the outdoor temperatures and windspeeds from the TMY2 weather data for Miami and Atlanta. The indoor temperature ranged between the heating and cooling set points (i.e., 70-75°F) for each hour for these calculations. As expected, the different ELAs for the HERS Reference and High-Efficiency homes result in different infiltration rates. This calculation includes temperature and wind-driven infiltration and excludes additional ventilation induced by duct leakage (duct leakage is discussed in the section below).

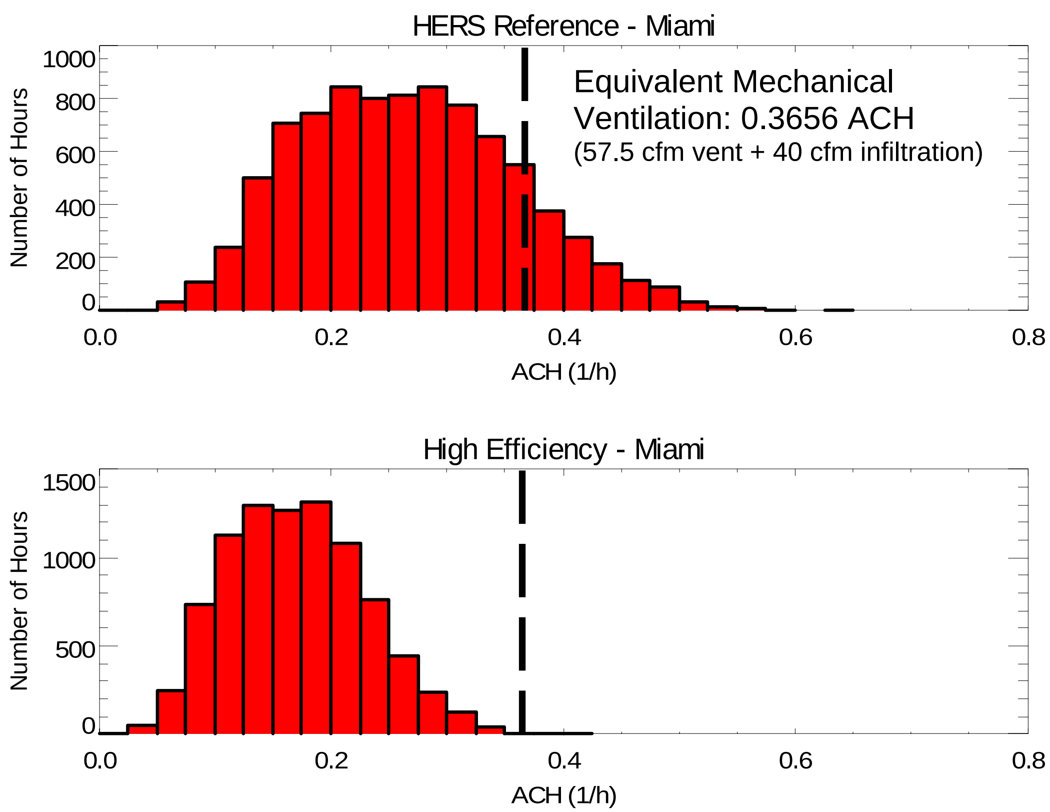


Figure 3. Distribution of Air Change Rates for Miami

[7] "The Use of Blower Door Data", Max Sherman, Energy Performance of Buildings Group, Lawrence Berkeley Laboratory, Berkeley, CA. March 1998. LBL #35173

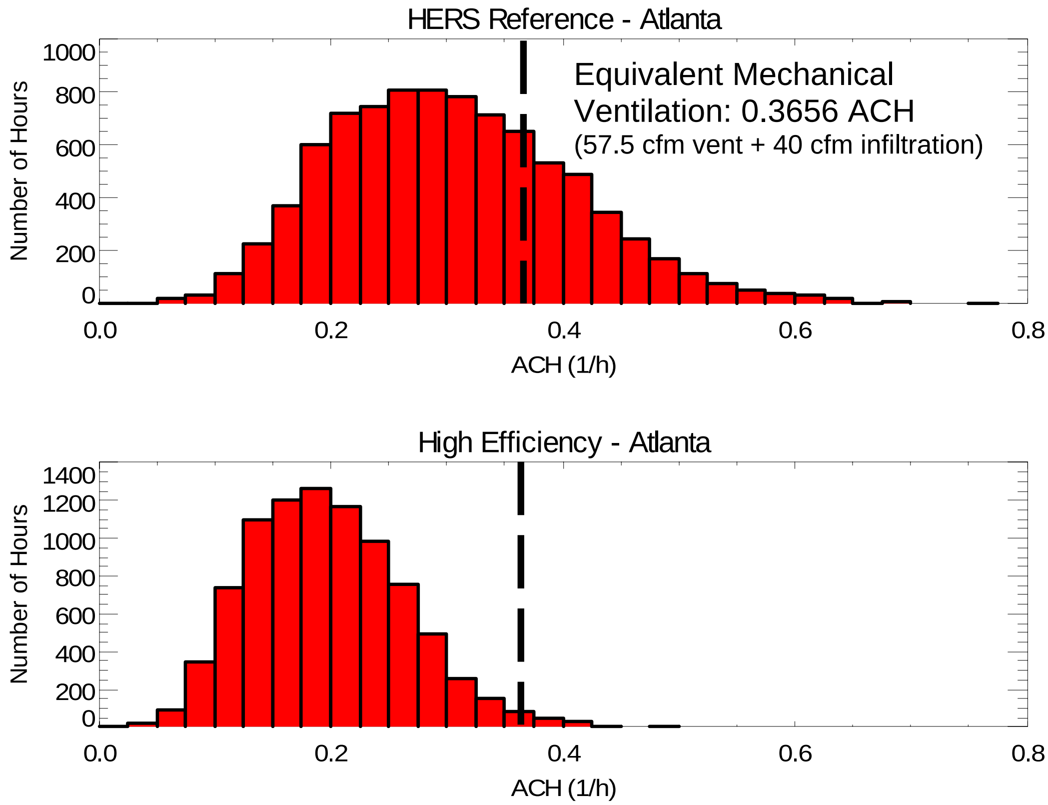


Figure 4. Distribution of Air Change Rates for Atlanta

ASHRAE Standard 62.2-2004[8] specifies mechanical ventilation of 57.5 cfm for this 4 bedroom, 2000 ft^2 house. The mechanical ventilation requirement in ASHRAE Standard 62.2 assumes that an infiltration credit equivalent to 2% of the floor area (or 40 cfm) is also provided as background (Section 4.1.3 of ASHRAE 62.2). Therefore the combined effective infiltration or ventilation rate for this house according to ASHRAE Standard 62.2 is 97.5 cfm, or 0.3656 ACH. For the cases with mechanical ventilation in this study, it was arbitrarily assumed that this background infiltration of 40 cfm (or 0.15 ACH) was constant for each hour of the year.

Table 4. Mechanical Ventilation and Infiltration Credit from ASHRAE 62.2-2004

	Ventilation (cfm)	**Equivalent ACH (h^{-1})**
Mechanical Ventilation cfm = 0.01 x Floor Area + 7.5 x (N_{br} + 1)	57.5	0.2156
Assumed Infiltration Credit cfm = 0.02 x Floor Area	40	0.15
Combined Ventilation and Infiltration	97.5	0.3656

[8] http://resourcecenter.ashrae.org/store/ashrae/

Duct Leakage

The HERS Reference house specifies that the thermal distribution system have a Distribution System Efficiency (DSE) of 0.80. To achieve this performance, a duct leakage model, as shown in Figure 5, was implemented and assumes the ducts are located in the attic. Appendix A provides a detailed summary of the equations used in the model. The duct leakage model accounts for conduction losses from the ducts to the attic, leakage of attic air into the return duct, and exfiltration of conditioned air from the supply duct into the attic. Attic conditions are tracked by the building model for each hour assuming an outdoor air infiltration rate that is 10 times the air change rate (ACH) used in the house zone (i.e., either 10 times the Sherman-Grimsrud infiltration value, or 10 times the specified constant infiltration).

Any additional airflows induced by duct leakage in the attic or in the main zone of the house are assumed to be small compared to the normal infiltration and therefore occur independently between each zone and outdoors. It is also assumed that duct leakage does not affect the normal infiltration values and does not induce any zone-to-zone interactions – such as leakage from the house to the attic. This assumption that infiltration and duct leakage do not interact is reasonable as long as the supply and return leaks are reasonably balanced and the leaks are small compared to the attic infiltration rate.

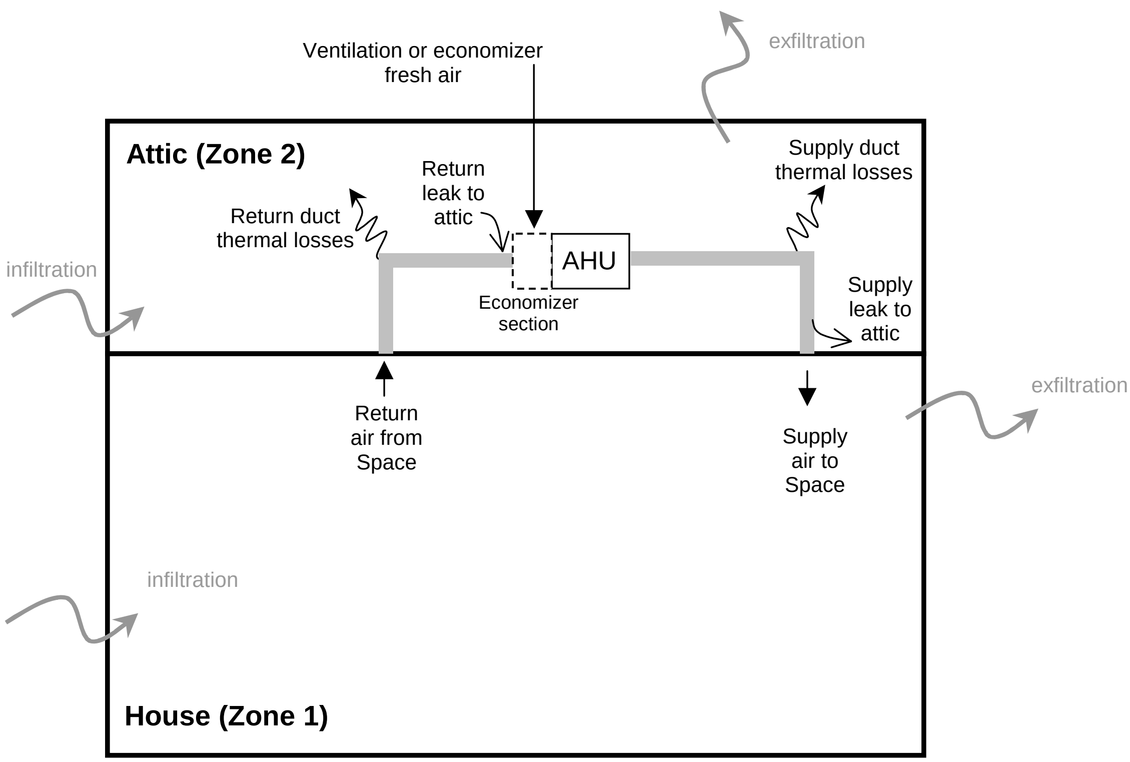


Figure 5. Schematic of Duct Leakage Model

Based on assumptions used for the HERS Reference house from the EnergyGauge building energy simulation program, supply and return air duct leakage rates of 3% and 4%, supply and return duct surface areas of 300 ft^2 and 100 ft^2 for a 1200 cfm system, and a duct insulation level of R6 were selected. Table 5 shows the impact of progressively implementing these duct leakage parameters for the HERS Reference house in Miami. The ratio of the AC runtime is a good surrogate for the distribution system efficiency. These nominal duct leakage parameters result in a combined impact equivalent to a distribution system efficiency of 80.5%. Therefore, these parameters were implemented in the duct leakage model to represent the HERS Reference house. For the high-efficiency house, the distribution system efficiency was assumed to be 1.0 (which assumes leak-free ductwork located in the conditioned zone).

Table 5. Summary of Duct Leakage Impacts for the Miami HERS Reference House

	AC Runtime (hrs)	Ratio
No duct losses	1,481.9	-
Only Thermal losses (R6 insulation)	1,730.4	85.6%
Only Thermal losses (R99 insulation)	1,500.0	98.8%
Only Return Air Leak (4%)	1,551.8	95.5%
Only Supply Air Leak (3%)	1,531.3	96.8%
Only Return & Supply Air Leaks (4% & 3%)	1,593.8	93.0%
Thermal Losses & Air Leakage Combined	1,842.0	80.5%

Note: Supply and return duct areas are 300 ft^2 and 100 ft^2 when the air flow is 1200 cfm at the AC unit

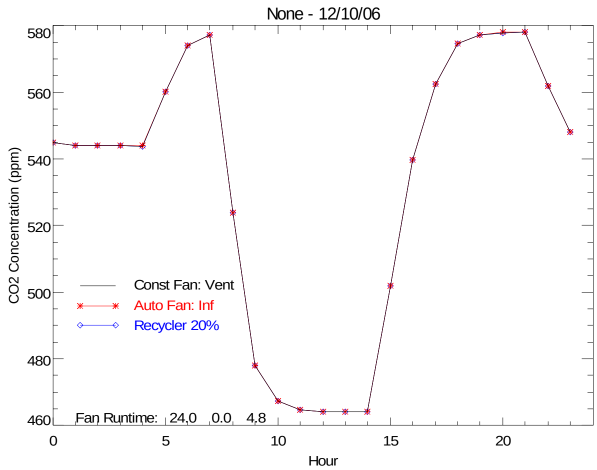
CO_2 Balance

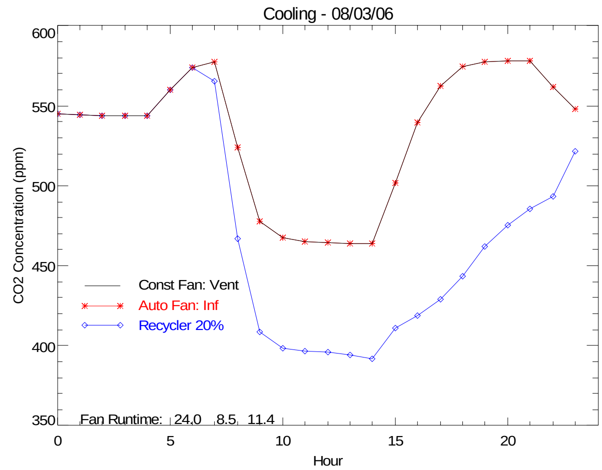
In order to track the combined impact of ventilation, infiltration, duct air leakage and supply air fan overrun strategies on the amount of outdoor air entering the house, a CO_2 volume balance was implemented on the house and attic zones. The balance assumes no zone-to-zone air exchange and assumes both the house zone and the attic zone are well mixed. The model assumes each person adds 0.3 liters/min of CO_2 at an activity level of 1.2 MET.

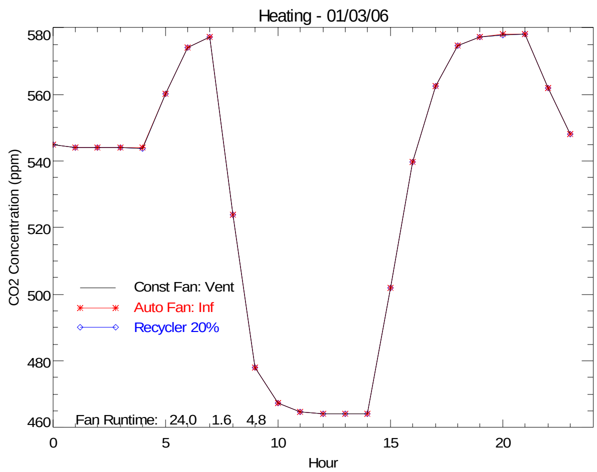
Since the HVAC system can provide an indeterminate amount of outdoor air depending on its control state, the amount of duct air leakage, and other factors, the equivalent amount of outdoor air brought into the zone (Qv) is determined using:

$$Qv = Qs \cdot \frac{(Cs-C)}{(Co-C)}$$

where Qs is the supply air flow, Cs is the concentration of CO_2 in the supply air, C is the space CO_2 concentration, and Co is the outdoor CO_2 level (assumed to be constant at 350 ppm). To demonstrate the validity of this model, the plots in Figure 6 were generated to show the impact of different ventilation strategies on CO_2 levels in the house zone. The first case in each plot is to operate the supply air fan continuously to provide ventilation of 57.5 cfm and assume 40 cfm of infiltration. The second strategy assumes a constant 97.5 cfm (or 0.3656 ACH) provided by infiltration. The third strategy uses a fan recycler that assumes that a ventilation rate of 287.5 cfm (5 times the required ventilation) is provided only when the supply air fan runs to meet the heating or cooling load. The fan recycler controls ensure that the supply air fan runs for at least 20% of the hour if no call for heating and cooling has caused the hourly fan runtime to exceed that threshold.





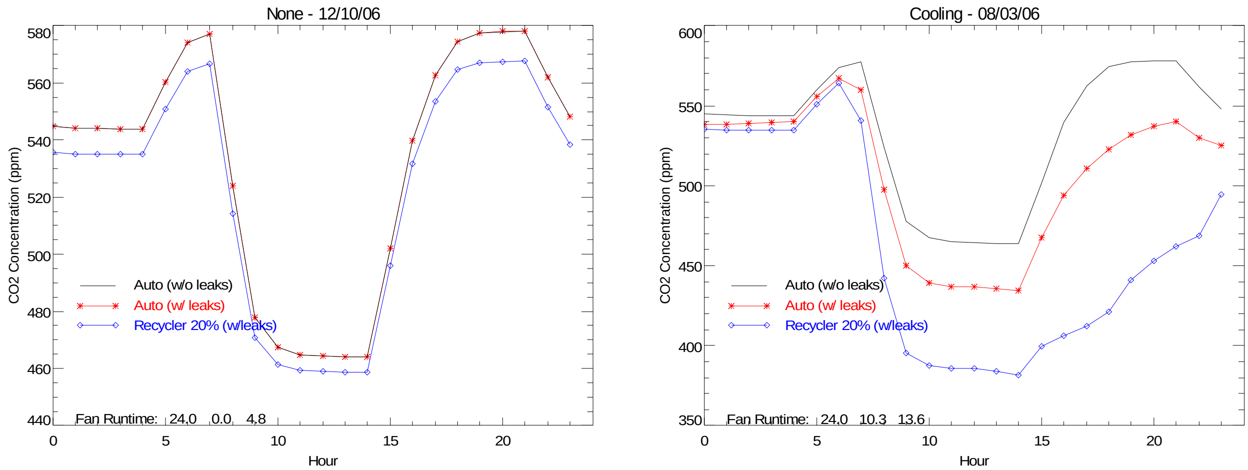


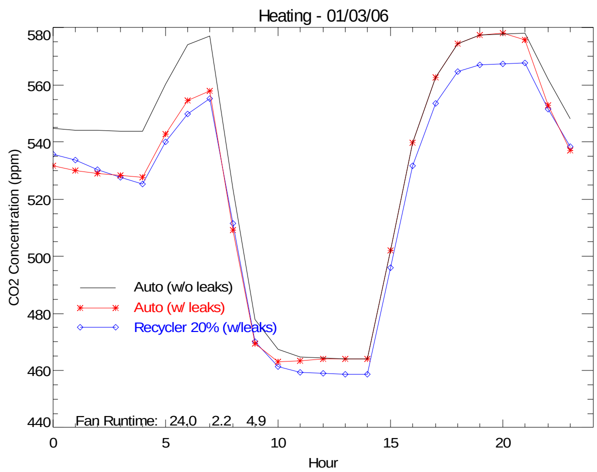
- Constant Fan with Ventilation
  (57.5 cfm vent + 40 cfm infiltration)
- Auto Fan with Infiltration Only
  (97.5 cfm infiltration)
- Auto Fan + Recycler at 20%
  (287.5 cfm of vent + 40 cfm infiltration; fan runs at least 20% of hour, or when heating and cooling is required)

Figure 6. Comparing the Impact of Different Ventilation Strategies on CO_2 Levels

The plots in Figure 6 confirm that identical amounts of ventilation – and therefore identical CO_2 levels – are provided by all three strategies on days when no heating and cooling are required (plot marked "None"). On a heating day, the CO_2 levels are nearly identical for all three strategies because the heating runtime never exceeded 20% in any hour. In the summer, the fan recycler strategy (without its optional ventilation damper controls) provides "excess" ventilation, because the cooling runtime exceeds 20% starting around 8 am on this summer day. Therefore the supply air fan runs more than 20% of the time and, as a result, the CO_2 levels are lower for this cooling day. The simple ventilation and infiltration strategies provide identical CO_2 levels for this day, as would be expected.

Figure 7 shows the impact that duct air leakage has on CO_2 levels in the house. Duct leakage (red *s) has no impact on CO_2 levels on the day with no cooling or heating operation for the case of AUTO fan with infiltration only. The fan recycler control, however, lowers CO_2 levels (provides more ventilation) when duct leakage is considered during this day without heating or cooling. When heating or cooling is required, duct air leakage provides additional ventilation to the space, as indicated by the lower CO_2 levels.





- Base: Auto Fan w/ Inf. (no duct leakage) (97.5 cfm infiltration)
- Auto Fan w/ Inf. and Duct Leakage (97.5 cfm infiltration + leakage)
- Auto Fan + Recycler at 20% & Duct Leaks (287.5 cfm of vent + 40 cfm infiltration; fan runs at least 20% of hour, or when heating and cooling is required; duct leakage when fans are on)

Figure 7. Comparing the Impact of Different Ventilation Strategies on CO_2 Levels with Duct Leakage

Latent Capacity Degradation

Recent work by Shirey and Henderson (2006)[9] demonstrated that latent degradation even has a modest impact on the latent performance of air conditioners that cycle the supply air fan with the compressor (i.e., the AUTO Fan mode). An engineering model was developed that assumes a very modest air flow across the wet cooling coil during the off cycle. For this simulation study the off-cycle airflow was assumed to be 250 times less than the operating airflow. Figure 8 below shows laboratory data measurements from the recent study, the level of latent degradation predicted by the model (solid black line), and the model parameters used to predict latent degradation.

Of course a more significant amount of latent degradation occurs when the supply air fan runs continuously. For configurations with constant supply fan operation, latent degradation parameters similar to those used for the AUTO fan cases were used. The degradation curve for the constant fan mode is shown in Figure 9 for nominal coil entering conditions of 80°F dry bulb, 67°F wet bulb.[10]

[9] http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1537-05.pdf
[10] For both fan modes, the steady state SHR is determined based on actual coil operating conditions. The steady state SHR values shown on Figures 8 and 9 are only meant to illustrate degradation at one representative condition.

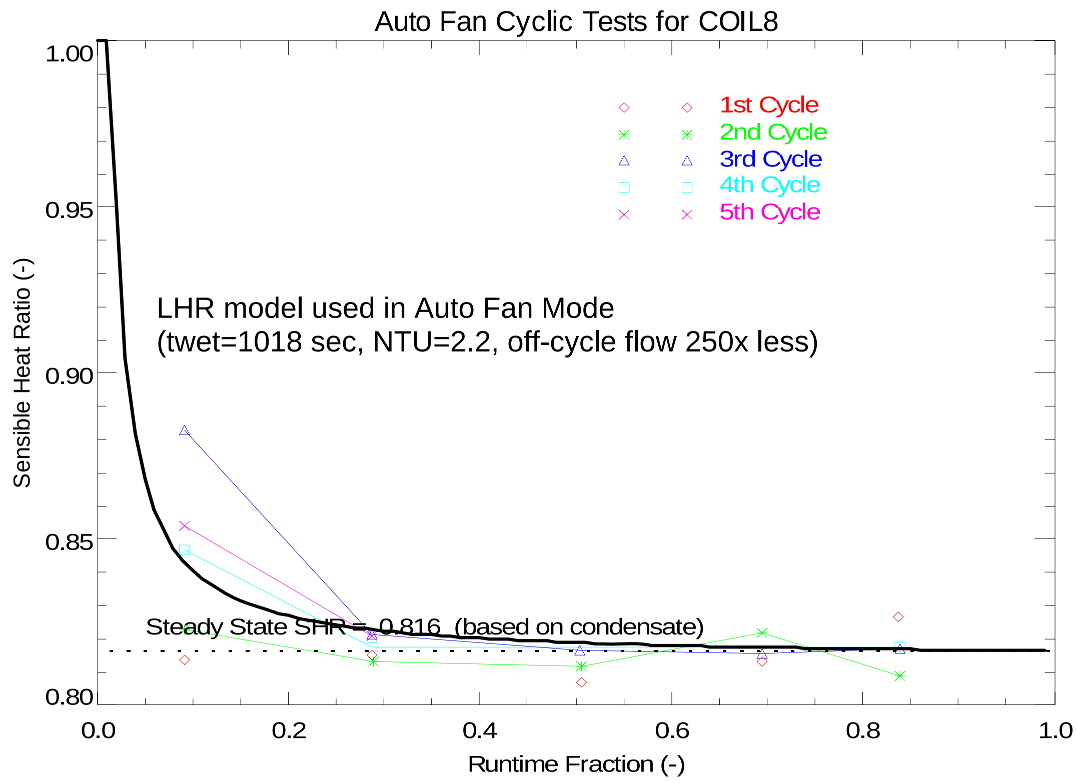


Figure 8. Latent Degradation Model and Laboratory Data in AUTO Fan Mode (from Shirey and Henderson 2006, Figure 5-48)

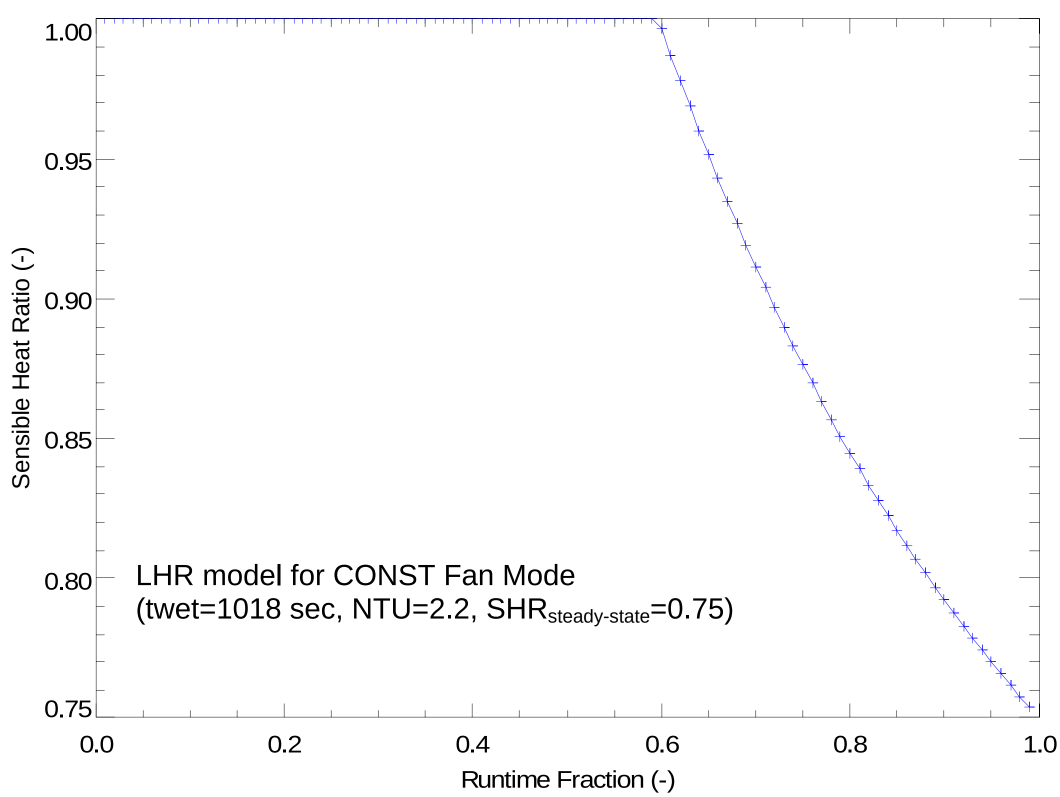


Figure 9. Latent Degradation Model for CONSTANT Fan Mode

Simulation Tool

TRN-ResDH[11], a TRNSYS-based hour-by-hour building energy simulation tool, was used to simulate the baseline and advanced HVAC technologies in these residential applications. TRN-ResDH includes component models for the various dehumidification systems of interest in this study, including conventional dehumidifiers, Santa Fe dehumidifiers, and the Munters HCU. It also includes robust models for conventional AC components that accurately predict performance at part-load conditions. The impact of moisture capacitance in building materials and furnishings, moisture evaporation from the cooling coil when the system is off, and other impacts of fan performance are all considered in this simulation tool. As a result, this tool properly considers all of the factors that are critical to predicting energy consumption and resulting indoor humidity conditions.

[11] http://www.cdhenergy.com/trn-resdh2/trn-resdh2.php

3. Ideal Cooling and Heating Load Analysis

Annual simulations of the standard (HERS Reference) and high-efficiency homes were completed for each city to determine the hourly heating, cooling and dehumidification loads that need to be met by the HVAC system. The simulations were performed using the four sets of temperature and humidity set points shown below. In all simulations a heating set point of 70°F was used.

Cooling and Dehumidification
Set Points:

75°F & 50% RH
78°F & 50% RH
75°F & 60% RH
78°F & 60% RH

The simulations were performed for seven different climate locations with appropriate building construction for each location (see description in Section 2 above). Infiltration and ventilation were modeled using two different scenarios:

1) infiltration varies with ambient temperature and wind speed using the Sherman-Grimsrud method described above (with no additional mechanical ventilation), and
2) infiltration/ventilation is constant at 0.3656 ACH or 97.5 cfm for each hour of the year, per ASHRAE Standard 62.2-2004, to represent mechanical ventilation.

The air-conditioning system was arbitrarily set at 3 tons and 1200 cfm for all of these simulation runs for ideal loads. The supply air fan power was assumed to be 0.35 Watt per cfm of airflow. This fixed unit size was in some cases slightly larger than required for the HERS Reference house. This modest equipment over sizing affected the loads in the HERS Reference house because duct air leakage was considered. Sizing was not an issue for the High Efficiency house since no duct leakage was assumed in this case. An arbitrarily large standard dehumidifier was used to meet the latent load (maintain the dehumidification set point).

The tables below summarize the building load results. Table 6 compares the total cooling and heating loads for the standard and high-efficiency homes. The high-efficiency house has combined heating/cooling loads that are 43 to 53% lower than the HERS Reference house for the variable infiltration scenario and 33% to 47% lower with the assumption of constant infiltration/ventilation. About half of the difference is due to locating the air ducts inside the conditioned space.

Table 7 compares sensible and latent cooling loads for the two buildings. Sensible load reductions range from 23% to 49% and latent load reductions range from 30% to 44% for the variable infiltration scenario. For the constant infiltration/ventilation scenario, the range of load reduction becomes 24% to 48% for the sensible cooling load and 10% to 24% for the latent cooling load. Since the sensible load decreases more than the latent load for the constant infiltration/ventilation case, the average annual SHR (sensible heat ratio) decreases for the high-efficiency house compared to the standard house. The change in average annual SHR is greater for the most humid climates.

Table 8 indicates the amount of time that the cooling loads occur below various SHR levels. It also gives the percentage of the total cooling hours that occur below each SHR level. For instance, for the HERS Reference house located in Miami with set points of 75°F and 50% RH, there are 2,214 cooling hours when the load SHR is below 0.6. This is 30% of the total annual cooling hours for the variable infiltration scenario.

Table 8 also includes the same data for the case of constant infiltration/ventilation. For the same Miami HERS Reference house with set points of 75°F and 50% RH, but with constant infiltration/ventilation, the time with an SHR below 0.6 increases to 3,804 hours, or 50% of the total annual cooling hours. Figure 10 shows the histograms of SHR for each hour of the cooling season for Miami with set points of 75°F and 50% RH, which correspond to the first row in each table. Similar histograms are provided in Appendix B for the other locations.

Table 6. Comparing Total Annual Heating and Cooling Loads for the Standard and High-Efficiency Homes

Variable Infiltration (Sherman-Grimsrud)

		Total Cooling Load (ton-hr)			Total Heating Load (MBtu)			
		HERS Ref	High Eff	Change	HERS Ref	High Eff	Change	Combined Change
	Miami-FL	5,717	3,120	45%	2,414	625	74%	46%
	Jacksonville-FL	3,759	2,270	40%	19,541	9,328	52%	43%
	Atlanta-GA	2,111	1,506	29%	45,417	17,047	62%	50%
75 F & 50%	Sterling-VA	1,959	1,353	31%	55,475	21,806	61%	52%
	Houston-TX	4,008	2,440	39%	21,259	10,203	52%	43%
	Fort_Worth-TX	3,614	2,475	32%	31,238	10,234	67%	46%
	Wilmington-NC	2,778	1,933	30%	36,327	12,607	65%	49%
	Miami-FL	4,127	2,270	45%	2,063	559	73%	46%
	Jacksonville-FL	2,823	1,709	39%	19,101	9,205	52%	44%
	Atlanta-GA	1,492	1,110	26%	45,114	16,979	62%	52%
78 F & 50%	Sterling-VA	1,453	1,043	28%	54,772	21,631	61%	53%
	Houston-TX	3,042	1,864	39%	20,736	10,020	52%	43%
	Fort_Worth-TX	2,759	1,947	29%	30,782	10,126	67%	48%
	Wilmington-NC	2,069	1,476	29%	35,936	12,462	65%	50%
	Miami-FL	5,597	2,994	47%	2,470	625	75%	48%
	Jacksonville-FL	3,652	2,170	41%	19,750	9,332	53%	44%
	Atlanta-GA	2,066	1,481	28%	45,538	17,050	63%	50%
75 F & 60%	Sterling-VA	1,933	1,338	31%	55,490	21,806	61%	52%
	Houston-TX	3,896	2,339	40%	21,312	10,210	52%	44%
	Fort_Worth-TX	3,566	2,451	31%	31,267	10,234	67%	46%
	Wilmington-NC	2,681	1,868	30%	36,408	12,610	65%	49%
	Miami-FL	3,950	2,107	47%	2,089	560	73%	48%
	Jacksonville-FL	2,673	1,585	41%	19,293	9,213	52%	45%
	Atlanta-GA	1,427	1,073	25%	45,221	16,982	62%	52%
78 F& 60%	Sterling-VA	1,415	1,023	28%	54,757	21,629	61%	53%
	Houston-TX	2,897	1,745	40%	20,813	10,022	52%	44%
	Fort_Worth-TX	2,692	1,912	29%	30,817	10,127	67%	48%
	Wilmington-NC	1,936	1,390	28%	36,021	12,462	65%	51%

Constant Infiltration/Ventilation (0.3656 ACH or 97.5 cfm)

		Total Cooling Load (ton-hr)			Total Heating Load (MBtu)			
		HERS Ref	High Eff	Change	HERS Ref	High Eff	Change	Combined Change
	Miami-FL	6,180	4,053	34%	2,531	855	66%	35%
	Jacksonville-FL	4,142	2,947	29%	19,874	11,159	44%	33%
	Atlanta-GA	2,260	1,749	23%	44,470	19,597	56%	43%
75 F & 50%	Sterling-VA	2,066	1,522	26%	53,007	25,175	53%	44%
	Houston-TX	4,348	3,111	28%	21,196	11,896	44%	33%
	Fort_Worth-TX	3,734	2,773	26%	30,689	12,201	60%	40%
	Wilmington-NC	3,047	2,409	21%	36,090	14,962	59%	40%
	Miami-FL	4,539	3,061	33%	2,175	760	65%	34%
	Jacksonville-FL	3,135	2,266	28%	19,379	11,000	43%	33%
	Atlanta-GA	1,599	1,274	20%	44,152	19,457	56%	45%
78 F & 50%	Sterling-VA	1,528	1,147	25%	52,283	24,971	52%	45%
	Houston-TX	3,334	2,424	27%	20,701	11,704	43%	33%
	Fort_Worth-TX	2,855	2,163	24%	30,249	12,064	60%	41%
	Wilmington-NC	2,292	1,869	18%	35,661	14,816	58%	41%
	Miami-FL	5,957	3,609	39%	2,592	855	67%	40%
	Jacksonville-FL	3,925	2,603	34%	20,160	11,167	45%	37%
	Atlanta-GA	2,169	1,634	25%	44,598	19,604	56%	44%
75 F & 60%	Sterling-VA	1,996	1,419	29%	53,020	25,176	53%	45%
	Houston-TX	4,153	2,790	33%	21,302	11,897	44%	36%
	Fort_Worth-TX	3,669	2,681	27%	30,784	12,199	60%	41%
	Wilmington-NC	2,863	2,157	25%	36,223	14,957	59%	42%
	Miami-FL	4,240	2,571	39%	2,223	760	66%	40%
	Jacksonville-FL	2,863	1,892	34%	19,637	11,011	44%	38%
	Atlanta-GA	1,477	1,142	23%	44,312	19,469	56%	47%
78 F& 60%	Sterling-VA	1,442	1,041	28%	52,288	24,973	52%	46%
	Houston-TX	3,091	2,075	33%	20,798	11,702	44%	37%
	Fort_Worth-TX	2,764	2,062	25%	30,316	12,067	60%	42%
	Wilmington-NC	2,071	1,595	23%	35,790	14,812	59%	44%

Notes: HERS Ref – HERS Reference House, High Eff – High Efficiency House

Table 7. Comparing Sensible and Latent Cooling Loads for the Standard and High-Efficiency Homes

Variable Infiltration (Sherman-Grimsrud)

		Annual Cooling Load (ton-hr)							
		Sensible Cooling			Latent Cooling			Average SHR	
		HERS Ref	High Eff	Change	HERS Ref	High Eff	Change	HERS Ref	High Eff
75 F & 50%	Miami-FL	4,100	2,182	47%	1,617	938	42%	0.72	0.70
	Jacksonville-FL	2,711	1,638	40%	1,048	632	40%	0.72	0.72
	Atlanta-GA	1,648	1,206	27%	463	300	35%	0.78	0.80
	Sterling-VA	1,551	1,092	30%	407	261	36%	0.79	0.81
	Houston-TX	2,874	1,762	39%	1,134	679	40%	0.72	0.72
	Fort_Worth-TX	2,901	2,041	30%	713	434	39%	0.80	0.82
	Wilmington-NC	1,936	1,424	26%	843	509	40%	0.70	0.74
78 F & 50%	Miami-FL	2,793	1,449	48%	1,334	821	38%	0.68	0.64
	Jacksonville-FL	1,913	1,131	41%	909	578	36%	0.68	0.66
	Atlanta-GA	1,102	849	23%	390	261	33%	0.74	0.76
	Sterling-VA	1,113	819	26%	341	225	34%	0.77	0.78
	Houston-TX	2,069	1,251	40%	973	613	37%	0.68	0.67
	Fort_Worth-TX	2,170	1,576	27%	588	371	37%	0.79	0.81
	Wilmington-NC	1,343	1,023	24%	727	453	38%	0.65	0.69
75 F & 60%	Miami-FL	4,147	2,185	47%	1,450	809	44%	0.74	0.73
	Jacksonville-FL	2,744	1,638	40%	907	532	41%	0.75	0.75
	Atlanta-GA	1,654	1,207	27%	412	274	33%	0.80	0.81
	Sterling-VA	1,561	1,091	30%	372	246	34%	0.81	0.82
	Houston-TX	2,907	1,762	39%	988	577	42%	0.75	0.75
	Fort_Worth-TX	2,910	2,042	30%	656	409	38%	0.82	0.83
	Wilmington-NC	1,968	1,425	28%	712	442	38%	0.73	0.76
78 F& 60%	Miami-FL	2,822	1,449	49%	1,127	658	42%	0.71	0.69
	Jacksonville-FL	1,940	1,132	42%	733	453	38%	0.73	0.71
	Atlanta-GA	1,109	849	23%	318	224	30%	0.78	0.79
	Sterling-VA	1,123	819	27%	292	204	30%	0.79	0.80
	Houston-TX	2,093	1,251	40%	804	494	39%	0.72	0.72
	Fort_Worth-TX	2,179	1,576	28%	513	336	34%	0.81	0.82
	Wilmington-NC	1,366	1,024	25%	570	366	36%	0.71	0.74

Constant Infiltration/Ventilation (0.3656 ACH or 97.5 cfm)

		Annual Cooling Load (ton-hr)							
		Sensible Cooling			Latent Cooling			Average SHR	
		HERS Ref	High Eff	Change	HERS Ref	High Eff	Change	HERS Ref	High Eff
75 F & 50%	Miami-FL	4,073	2,249	45%	2,107	1,803	14%	0.66	0.56
	Jacksonville-FL	2,658	1,656	38%	1,483	1,291	13%	0.64	0.56
	Atlanta-GA	1,621	1,188	27%	639	561	12%	0.72	0.68
	Sterling-VA	1,503	1,038	31%	564	485	14%	0.73	0.68
	Houston-TX	2,833	1,797	37%	1,514	1,315	13%	0.65	0.58
	Fort_Worth-TX	2,883	2,059	29%	851	714	16%	0.77	0.74
	Wilmington-NC	1,896	1,406	26%	1,151	1,003	13%	0.62	0.58
78 F & 50%	Miami-FL	2,745	1,463	47%	1,794	1,598	11%	0.60	0.48
	Jacksonville-FL	1,854	1,116	40%	1,281	1,150	10%	0.59	0.49
	Atlanta-GA	1,067	805	25%	532	469	12%	0.67	0.63
	Sterling-VA	1,064	747	30%	464	400	14%	0.70	0.65
	Houston-TX	2,023	1,250	38%	1,310	1,174	10%	0.61	0.52
	Fort_Worth-TX	2,150	1,565	27%	705	597	15%	0.75	0.72
	Wilmington-NC	1,294	986	24%	998	883	12%	0.56	0.53
75 F & 60%	Miami-FL	4,168	2,254	46%	1,789	1,355	24%	0.70	0.62
	Jacksonville-FL	2,732	1,661	39%	1,193	942	21%	0.70	0.64
	Atlanta-GA	1,636	1,189	27%	533	445	17%	0.75	0.73
	Sterling-VA	1,526	1,040	32%	471	380	19%	0.76	0.73
	Houston-TX	2,906	1,802	38%	1,248	987	21%	0.70	0.65
	Fort_Worth-TX	2,905	2,061	29%	764	620	19%	0.79	0.77
	Wilmington-NC	1,950	1,409	28%	913	747	18%	0.68	0.65
78 F& 60%	Miami-FL	2,813	1,464	48%	1,427	1,106	22%	0.66	0.57
	Jacksonville-FL	1,905	1,119	41%	958	773	19%	0.67	0.59
	Atlanta-GA	1,078	806	25%	399	337	16%	0.73	0.71
	Sterling-VA	1,082	749	31%	360	291	19%	0.75	0.72
	Houston-TX	2,073	1,253	40%	1,018	822	19%	0.67	0.60
	Fort_Worth-TX	2,164	1,567	28%	600	496	17%	0.78	0.76
	Wilmington-NC	1,335	989	26%	736	606	18%	0.64	0.62

Notes: HERS Ref – HERS Reference House, High Eff – High Efficiency House

Table 8. Cumulative Occurrences of Time-Weighted SHR

Variable Infiltration (Sherman-Grimsrud)

		HERS Reference with SHR below:						High Efficiency with SHR below:					
		0.6		0.5		0.4		0.6		0.5		0.4	
		Cooling Hours	% of All Cooling Hrs	Cooling Hours	% of All Cooling Hrs	Cooling Hours	% of All Cooling Hrs	Cooling Hours	% of All Cooling Hrs	Cooling Hours	% of All Cooling Hrs	Cooling Hours	% of All Cooling Hrs
	Miami-FL	2,214	30%	1,839	25%	1,653	22%	2,047	28%	1,705	23%	1,511	20%
	Jacksonville-FL	2,122	37%	1,919	34%	1,789	31%	1,796	32%	1,676	30%	1,586	28%
	Atlanta-GA	709	22%	701	22%	697	22%	400	12%	398	12%	394	12%
75 F & 50%	Sterling-VA	578	22%	567	21%	560	21%	280	10%	269	10%	264	10%
	Houston-TX	2,009	35%	1,745	31%	1,631	29%	1,668	30%	1,518	27%	1,433	26%
	Fort_Worth-TX	735	17%	698	16%	674	16%	405	9%	388	9%	383	9%
	Wilmington-NC	1,856	42%	1,649	38%	1,513	34%	1,067	25%	933	22%	864	20%
	Miami-FL	2,874	41%	2,614	38%	2,473	36%	2,739	40%	2,428	36%	2,246	33%
	Jacksonville-FL	2,495	48%	2,412	46%	2,357	45%	2,184	43%	2,111	41%	2,053	40%
	Atlanta-GA	925	35%	925	35%	921	35%	523	20%	520	19%	520	19%
78 F & 50%	Sterling-VA	674	30%	670	30%	667	30%	323	15%	318	15%	317	15%
	Houston-TX	2,323	45%	2,203	42%	2,103	41%	1,944	38%	1,859	37%	1,794	36%
	Fort_Worth-TX	863	23%	848	22%	838	22%	461	12%	456	12%	454	12%
	Wilmington-NC	2,093	52%	2,019	50%	1,937	48%	1,263	33%	1,217	32%	1,165	31%
	Miami-FL	318	5%	309	5%	308	5%	440	7%	435	7%	433	7%
	Jacksonville-FL	291	7%	279	6%	279	6%	315	7%	315	7%	315	7%
	Atlanta-GA	104	4%	95	4%	95	4%	29	1%	29	1%	29	1%
75 F & 60%	Sterling-VA	32	1%	22	1%	22	1%	-	0%	-	0%	-	0%
	Houston-TX	455	10%	437	9%	430	9%	445	10%	436	9%	429	9%
	Fort_Worth-TX	85	2%	70	2%	70	2%	16	0%	16	0%	16	0%
	Wilmington-NC	250	8%	244	7%	241	7%	100	3%	100	3%	100	3%
	Miami-FL	683	13%	664	12%	664	12%	728	13%	727	13%	726	13%
	Jacksonville-FL	509	14%	459	13%	459	13%	500	13%	500	13%	499	13%
	Atlanta-GA	163	8%	159	8%	159	8%	51	2%	51	2%	51	2%
78 F& 60%	Sterling-VA	68	4%	58	4%	58	4%	4	0%	4	0%	4	0%
	Houston-TX	682	17%	644	16%	641	16%	667	17%	665	16%	657	16%
	Fort_Worth-TX	160	5%	146	5%	146	5%	28	1%	28	1%	28	1%
	Wilmington-NC	434	16%	406	15%	406	15%	163	6%	163	6%	163	6%

Constant Infiltration/Ventilation (0.3656 ACH or 97.5 cfm)

		HERS Reference with SHR below:						High Efficiency with SHR below:					
		0.6		0.5		0.4		0.6		0.5		0.4	
		Cooling Hours	% of All Cooling Hrs	Cooling Hours	% of All Cooling Hrs	Cooling Hours	% of All Cooling Hrs	Cooling Hours	% of All Cooling Hrs	Cooling Hours	% of All Cooling Hrs	Cooling Hours	% of All Cooling Hrs
	Miami-FL	3,804	50%	2,840	37%	2,255	29%	5,019	65%	3,617	47%	2,641	34%
	Jacksonville-FL	3,525	58%	3,040	50%	2,684	44%	4,035	67%	3,356	55%	2,892	48%
	Atlanta-GA	1,397	39%	1,353	37%	1,325	37%	1,460	39%	1,378	36%	1,305	35%
75 F & 50%	Sterling-VA	1,228	40%	1,171	39%	1,120	37%	1,274	41%	1,171	38%	1,084	35%
	Houston-TX	3,302	55%	2,785	47%	2,373	40%	3,774	63%	3,118	52%	2,581	43%
	Fort_Worth-TX	1,101	25%	1,011	23%	908	21%	1,134	26%	978	22%	816	18%
	Wilmington-NC	2,819	60%	2,400	51%	2,099	45%	2,873	61%	2,339	50%	1,977	42%
	Miami-FL	4,392	60%	3,849	53%	3,381	46%	5,490	75%	4,590	63%	3,863	53%
	Jacksonville-FL	3,769	66%	3,473	61%	3,275	57%	4,246	74%	3,805	66%	3,470	60%
	Atlanta-GA	1,531	48%	1,520	48%	1,515	48%	1,468	44%	1,442	44%	1,415	43%
78 F & 50%	Sterling-VA	1,220	47%	1,196	46%	1,178	45%	1,190	45%	1,139	43%	1,114	42%
	Houston-TX	3,513	62%	3,225	57%	3,009	53%	3,975	70%	3,564	63%	3,220	57%
	Fort_Worth-TX	1,163	30%	1,119	29%	1,093	28%	1,114	28%	1,028	26%	960	24%
	Wilmington-NC	3,024	68%	2,755	62%	2,579	58%	2,938	67%	2,586	59%	2,348	54%
	Miami-FL	754	11%	689	10%	652	10%	1,754	26%	1,462	21%	1,198	18%
	Jacksonville-FL	777	17%	660	14%	629	14%	1,296	28%	1,149	24%	1,031	22%
	Atlanta-GA	207	8%	176	7%	176	7%	163	6%	158	5%	155	5%
75 F & 60%	Sterling-VA	151	7%	119	5%	117	5%	167	7%	157	7%	147	6%
	Houston-TX	774	16%	715	15%	689	14%	1,219	25%	1,097	22%	1,002	20%
	Fort_Worth-TX	130	3%	113	3%	113	3%	98	2%	93	2%	89	2%
	Wilmington-NC	694	20%	614	18%	583	17%	804	22%	719	19%	629	17%
	Miami-FL	1,229	21%	1,114	19%	1,097	19%	2,089	35%	1,885	31%	1,731	29%
	Jacksonville-FL	1,066	28%	905	24%	890	23%	1,462	36%	1,374	34%	1,303	32%
	Atlanta-GA	259	13%	240	12%	240	12%	217	10%	202	9%	202	9%
78 F& 60%	Sterling-VA	176	11%	145	9%	145	9%	153	9%	148	8%	147	8%
	Houston-TX	1,050	26%	932	23%	921	23%	1,394	32%	1,320	31%	1,266	29%
	Fort_Worth-TX	219	7%	188	6%	188	6%	140	4%	131	4%	130	4%
	Wilmington-NC	914	30%	816	27%	803	27%	847	27%	787	25%	740	24%

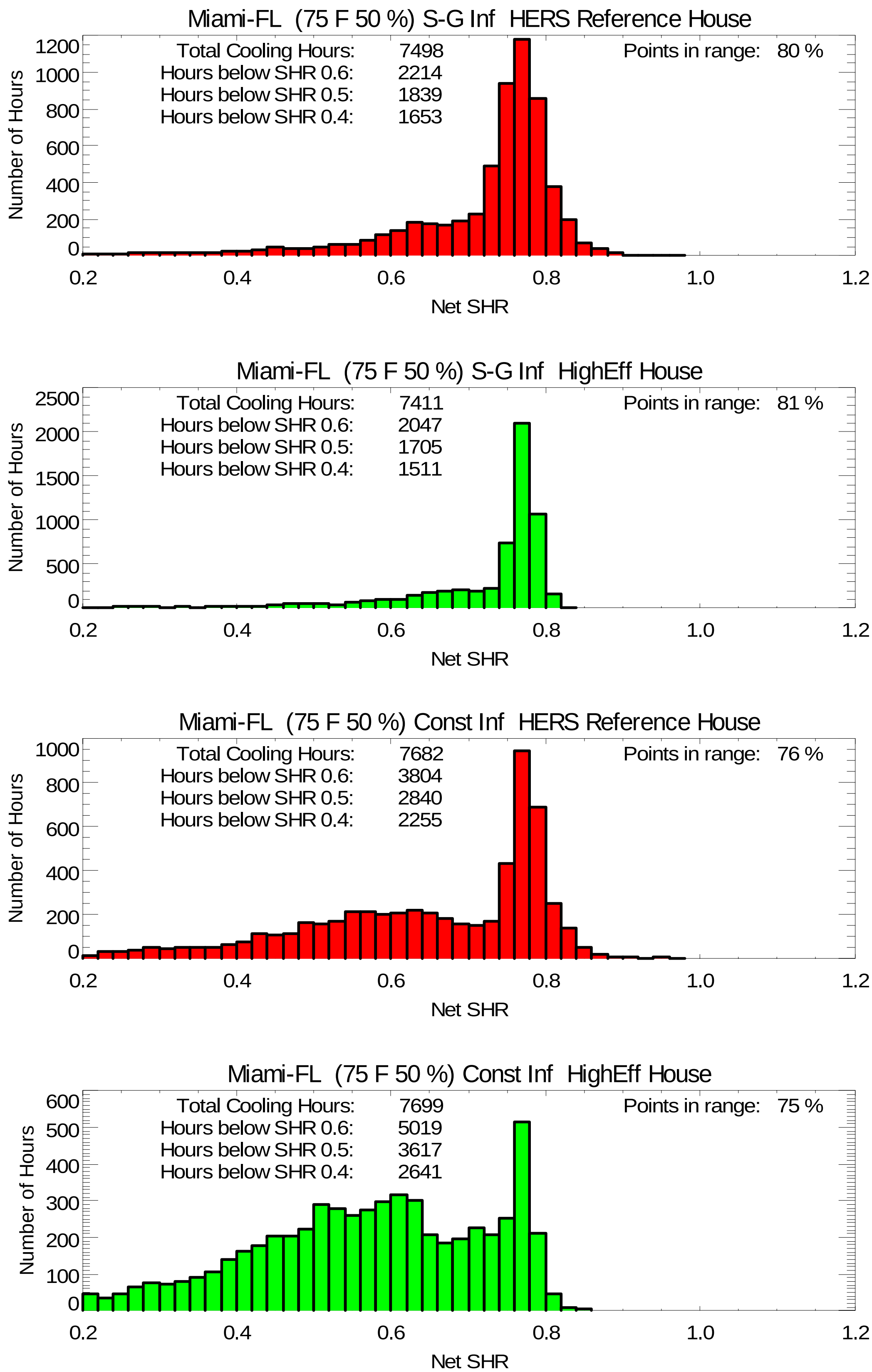


Figure 10. Histograms of Building Load SHR for Miami at 75°F & 50% RH (see Appendix B for similar graphs at other conditions)

Table 9 provides an analogous summary that shows the amount of annual cooling load that occurs below each SHR level. It also gives the result on a percentage basis. For the HERS Reference house with variable infiltration in Miami at 75°F and 50% RH, the amount of total cooling load that occurs with the SHR below 0.6 is 6.35 million Btus, which is 9.3% of the total annual cooling load. So while the SHR is below 0.6 for 30% of time (Table 8), the load at these conditions only represents 9.3% of the annual cooling load. Similarly, for this same case but with constant infiltration/ventilation, the SHR is lower than 0.6 for 50% of the time (Table 8), but these periods only represent 24.8% of the annual cooling load.

Appendix B provides SHR histograms for each case listed in Table 8 and Table 9. Histograms are given for the time-weighted SHR (corresponds to Table 8) that show the number of hours that the building needs cooling at various SHRs. Histograms are also given for the load-weighted SHR (corresponds to Table 9); these plots show the amount of cooling load occurring at each SHR.

Table 9. Cumulative Occurrences of Load-Weighted SHR

Variable Infiltration (Sherman-Grimsrud)

		HERS Reference with SHR below:						High Efficiency with SHR below:					
		0.6		0.5		0.4		0.6		0.5		0.4	
		Total Cooling (MMBTU)	% of Total Cooling Load	Total Cooling (MMBTU)	% of Total Cooling Load	Total Cooling (MMBTU)	% of Total Cooling Load	Total Cooling (MMBTU)	% of Total Cooling Load	Total Cooling (MMBTU)	% of Total Cooling Load	Total Cooling (MMBTU)	% of Total Cooling Load
75 F & 50%	Miami-FL	6.35	9.3%	4.07	5.9%	3.26	4.8%	4.22	11.3%	2.97	7.9%	2.41	6.4%
	Jacksonville-FL	4.46	9.9%	3.41	7.6%	2.90	6.4%	2.62	9.6%	2.21	8.1%	1.96	7.2%
	Atlanta-GA	1.10	4.3%	1.06	4.2%	1.05	4.2%	0.47	2.6%	0.46	2.6%	0.46	2.5%
	Sterling-VA	0.94	4.0%	0.89	3.8%	0.86	3.7%	0.36	2.2%	0.33	2.0%	0.32	2.0%
	Houston-TX	5.36	11.1%	3.68	7.6%	3.12	6.5%	3.02	10.3%	2.41	8.2%	2.13	7.3%
	Fort_Worth-TX	1.52	3.5%	1.29	3.0%	1.18	2.7%	0.56	1.9%	0.50	1.7%	0.48	1.6%
	Wilmington-NC	4.66	14.0%	3.36	10.1%	2.72	8.2%	2.00	8.6%	1.49	6.4%	1.26	5.4%
78 F & 50%	Miami-FL	7.11	14.4%	5.68	11.5%	5.08	10.3%	5.30	19.4%	4.23	15.5%	3.74	13.7%
	Jacksonville-FL	4.78	14.1%	4.38	12.9%	4.16	12.3%	3.21	15.6%	2.96	14.4%	2.82	13.7%
	Atlanta-GA	1.51	8.5%	1.51	8.5%	1.50	8.4%	0.65	4.9%	0.64	4.8%	0.64	4.8%
	Sterling-VA	1.09	6.2%	1.08	6.2%	1.07	6.1%	0.43	3.5%	0.42	3.3%	0.41	3.3%
	Houston-TX	5.32	14.6%	4.64	12.7%	4.15	11.4%	3.37	15.1%	3.07	13.7%	2.86	12.8%
	Fort_Worth-TX	1.64	5.0%	1.55	4.7%	1.52	4.6%	0.64	2.8%	0.63	2.7%	0.62	2.7%
	Wilmington-NC	4.62	18.6%	4.14	16.7%	3.75	15.1%	2.09	11.8%	1.94	11.0%	1.80	10.1%
75 F & 60%	Miami-FL	0.57	0.9%	0.56	0.8%	0.56	0.8%	0.64	1.8%	0.63	1.7%	0.63	1.7%
	Jacksonville-FL	0.42	1.0%	0.41	0.9%	0.41	0.9%	0.38	1.5%	0.38	1.5%	0.38	1.5%
	Atlanta-GA	0.15	0.6%	0.13	0.5%	0.13	0.5%	0.03	0.2%	0.03	0.2%	0.03	0.2%
	Sterling-VA	0.05	0.2%	0.04	0.2%	0.04	0.2%	0.00	0.0%	0.00	0.0%	0.00	0.0%
	Houston-TX	0.89	1.9%	0.85	1.8%	0.82	1.8%	0.68	2.4%	0.65	2.3%	0.63	2.2%
	Fort_Worth-TX	0.13	0.3%	0.12	0.3%	0.12	0.3%	0.02	0.1%	0.02	0.1%	0.02	0.1%
	Wilmington-NC	0.47	1.5%	0.47	1.4%	0.45	1.4%	0.12	0.5%	0.12	0.5%	0.12	0.5%
78 F& 60%	Miami-FL	1.41	3.0%	1.39	2.9%	1.39	2.9%	1.24	4.9%	1.24	4.9%	1.24	4.9%
	Jacksonville-FL	0.84	2.6%	0.78	2.4%	0.78	2.4%	0.71	3.7%	0.71	3.7%	0.70	3.7%
	Atlanta-GA	0.27	1.6%	0.26	1.5%	0.26	1.5%	0.05	0.4%	0.05	0.4%	0.05	0.4%
	Sterling-VA	0.11	0.6%	0.10	0.6%	0.10	0.6%	0.00	0.0%	0.00	0.0%	0.00	0.0%
	Houston-TX	1.38	4.0%	1.32	3.8%	1.31	3.8%	1.04	5.0%	1.03	4.9%	1.01	4.8%
	Fort_Worth-TX	0.28	0.9%	0.26	0.8%	0.26	0.8%	0.03	0.1%	0.03	0.1%	0.03	0.1%
	Wilmington-NC	0.83	3.6%	0.80	3.4%	0.80	3.4%	0.23	1.4%	0.23	1.4%	0.23	1.4%

Constant Infiltration/Ventilation (0.3656 ACH or 97.5 cfm)

		HERS Reference with SHR below:						High Efficiency with SHR below:					
		0.6		0.5		0.4		0.6		0.5		0.4	
		Total Cooling (MMBTU)	% of Total Cooling Load	Total Cooling (MMBTU)	% of Total Cooling Load	Total Cooling (MMBTU)	% of Total Cooling Load	Total Cooling (MMBTU)	% of Total Cooling Load	Total Cooling (MMBTU)	% of Total Cooling Load	Total Cooling (MMBTU)	% of Total Cooling Load
75 F & 50%	Miami-FL	18.37	24.8%	9.41	12.7%	5.70	7.7%	24.48	50.3%	12.76	26.2%	7.00	14.4%
	Jacksonville-FL	13.12	26.4%	8.46	17.0%	6.17	12.4%	15.27	43.2%	9.49	26.8%	6.72	19.0%
	Atlanta-GA	3.06	11.3%	2.75	10.1%	2.61	9.6%	3.39	16.1%	2.93	14.0%	2.61	12.4%
	Sterling-VA	3.09	12.5%	2.58	10.4%	2.28	9.2%	3.47	19.0%	2.76	15.1%	2.29	12.6%
	Houston-TX	13.44	25.8%	8.47	16.2%	5.80	11.1%	15.27	40.9%	9.66	25.9%	6.44	17.3%
	Fort_Worth-TX	3.28	7.3%	2.58	5.8%	1.97	4.4%	3.69	11.1%	2.73	8.2%	1.87	5.6%
	Wilmington-NC	10.82	29.6%	6.73	18.4%	4.80	13.1%	11.67	40.4%	6.95	24.0%	4.79	16.6%
78 F & 50%	Miami-FL	17.22	31.6%	11.91	21.9%	8.83	16.2%	22.47	61.2%	14.98	40.8%	10.50	28.6%
	Jacksonville-FL	11.84	31.5%	8.86	23.5%	7.51	20.0%	14.03	51.6%	10.14	37.3%	8.03	29.5%
	Atlanta-GA	3.03	15.8%	2.93	15.3%	2.91	15.2%	2.83	18.5%	2.71	17.8%	2.61	17.1%
	Sterling-VA	2.61	14.2%	2.44	13.3%	2.34	12.7%	2.67	19.4%	2.36	17.2%	2.24	16.3%
	Houston-TX	11.90	29.7%	8.91	22.3%	7.42	18.6%	13.86	47.6%	10.17	35.0%	7.99	27.5%
	Fort_Worth-TX	2.74	8.0%	2.45	7.2%	2.30	6.7%	2.83	10.9%	2.38	9.2%	2.06	8.0%
	Wilmington-NC	10.08	36.7%	7.30	26.5%	6.10	22.2%	10.24	45.6%	7.18	32.0%	5.69	25.4%
75 F & 60%	Miami-FL	2.10	2.9%	1.74	2.4%	1.53	2.1%	6.36	14.7%	4.54	10.5%	3.13	7.2%
	Jacksonville-FL	1.83	3.9%	1.44	3.1%	1.27	2.7%	3.77	12.1%	2.85	9.1%	2.27	7.3%
	Atlanta-GA	0.35	1.4%	0.30	1.2%	0.30	1.2%	0.23	1.2%	0.21	1.1%	0.21	1.0%
	Sterling-VA	0.30	1.2%	0.24	1.0%	0.23	1.0%	0.32	1.9%	0.28	1.6%	0.24	1.4%
	Houston-TX	1.85	3.7%	1.66	3.3%	1.52	3.1%	3.38	10.1%	2.62	7.8%	2.13	6.4%
	Fort_Worth-TX	0.23	0.5%	0.21	0.5%	0.21	0.5%	0.17	0.5%	0.15	0.5%	0.13	0.4%
	Wilmington-NC	1.79	5.2%	1.52	4.4%	1.34	3.9%	2.51	9.7%	1.96	7.6%	1.51	5.8%
78 F& 60%	Miami-FL	3.02	5.9%	2.72	5.4%	2.62	5.2%	6.07	19.7%	4.96	16.1%	4.26	13.8%
	Jacksonville-FL	2.26	6.6%	1.89	5.5%	1.82	5.3%	3.49	15.4%	2.98	13.1%	2.64	11.6%
	Atlanta-GA	0.49	2.8%	0.45	2.5%	0.45	2.5%	0.31	2.3%	0.27	1.9%	0.27	1.9%
	Sterling-VA	0.34	2.0%	0.29	1.7%	0.29	1.7%	0.25	2.0%	0.24	1.9%	0.23	1.9%
	Houston-TX	2.39	6.4%	2.12	5.7%	2.06	5.6%	3.34	13.4%	2.89	11.6%	2.63	10.6%
	Fort_Worth-TX	0.42	1.3%	0.37	1.1%	0.37	1.1%	0.21	0.9%	0.19	0.7%	0.18	0.7%
	Wilmington-NC	2.09	8.4%	1.85	7.4%	1.79	7.2%	2.13	11.1%	1.80	9.4%	1.59	8.3%

4. Conventional AC Performance

The previous section of this report summarized the calculation of space conditioning loads to perfectly maintain the desired temperature and relative humidity set points. In reality, conventional air conditioners only control the space temperature, and the space humidity varies depending on the characteristics of the AC equipment and cooling/dehumidification load. Because of duct air leakage (for the HERS Reference house) and other factors, the sizing of the AC system relative to the building load is also important.

The air conditioner used in this analysis was assumed to have an EER of 13.3 Btu/Wh at the nominal rating point[12] based on gross coil capacity and without considering the supply fan power. The SHR of the cooling coil at the nominal rating point is 0.77. The unit has performance characteristics typical of a system that uses a TXV refrigerant expansion device[13]. Using a supply fan power of 0.35 Watts per cfm, the "as-installed" SEER for this unit is 11.7 Btu/Wh. The SEER rating procedure in reality has a low static pressure requirement that results in much lower supply air fan power than is typically measured in field applications. If a lower supply fan power of 0.15-0.20 Watts per cfm is assumed – or 180-240 Watts for the 1200 cfm supply airflow – then the "nominal" SEER for this AC system would be 12.7-13.1 Btu/Wh.

AC Equipment Sizing

All AC systems were sized based on a 75°F dry-bulb temperature set point. A separate unit size was determined for the HERS Reference and High-Efficiency houses. The AC equipment was sized to the nearest 0.1 tons with air flow maintained at 400 cfm per nominal ton. The duct air leakage fractions remained constant while the duct insulation surface area was scaled with air flow. The AC size was determined for the constant infiltration/ventilation scenario, but this same size was also used for simulations with the variable infiltration (Sherman-Grimsrud) scenario. The size was selected so that the temperature set point was never exceeded by more than 0.1-0.2°F. Table 10 lists the resulting air conditioner capacity (or unit size) for each house in each climate. Table 11 indicates how well the AC unit size matches the load (based on 75°F set point) by listing the number of hours the AC operated at each runtime fraction (RTF). The table also shows the maximum deviation of the indoor dry-bulb temperature over the set point. The high-efficiency house is 4% to 15% oversized for the case of variable infiltration since the load at peak conditions is much less than when constant infiltration/ventilation is provided.

[12] Nominal rating point: 95°F outdoors, 80°F/67°F entering coil and 450 cfm per ton supply air flow.
[13] The model also includes generic AC performance curves for AC units with a "fixed orifice" expansion device that were developed using the Heat Pump Design Model (HPDM) from ORNL. The orifice unit demonstrates different performance variations with outdoor temperature and supply air flow.

Table 10. AC Equipment Sizes Selected for Each House and Climate

	HERS Reference House (tons)	High-Efficiency House (tons)	AC Size Reduction
Miami-FL	2.8	1.7	39%
Jacksonville-FL	3.0	2.0	33%
Atlanta-GA	2.8	1.9	32%
Sterling-VA	3.1	2.1	32%
Houston-TX	3.0	2.0	33%
Fort_Worth-TX	3.1	2.2	29%
Wilmington-NC	2.8	2.0	29%

Note: These AC sizes were used for each climate regardless of infiltration/ventilation scenario or dry-bulb set point temperature

Table 11. Cumulative Hours at Various Air Conditioner Loading Levels

Variable Infiltration

		Hours at or Above Run Time Fraction (RTF):									
		0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	Peak RTF	Max Dev from Setpt (F)
Miami-FL	HERS Reference	5	15	61	153	312	502	694	934	1.00	0.12
Jacksonville-FL	HERS Reference	2	7	22	50	99	187	362	539	0.96	0.00
Atlanta-GA	HERS Reference	3	6	8	14	32	54	109	206	0.99	0.00
Sterling-VA	HERS Reference	3	7	9	17	31	66	126	216	1.00	0.01
Houston-TX	HERS Reference	1	7	40	92	180	274	408	591	0.96	0.00
Fort_Worth-TX	HERS Reference	7	35	85	152	254	375	494	641	1.00	0.00
Wilmington-NC	HERS Reference	4	14	28	62	116	185	278	391	0.97	0.00
Miami-FL	High Efficiency	0	0	4	11	49	165	323	558	0.90	0.00
Jacksonville-FL	High Efficiency	0	0	1	11	33	74	152	311	0.89	0.00
Atlanta-GA	High Efficiency	1	2	5	9	18	46	88	199	0.96	0.00
Sterling-VA	High Efficiency	0	1	3	8	15	35	87	177	0.91	0.00
Houston-TX	High Efficiency	0	0	1	21	80	145	241	391	0.85	0.00
Fort_Worth-TX	High Efficiency	0	0	14	56	113	223	349	485	0.89	0.00
Wilmington-NC	High Efficiency	0	0	1	13	32	77	167	286	0.86	0.00

Constant Infiltration/Ventilation

		Hours at or Above Run Time Fraction (RTF):									
		0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	Peak RTF	Max Dev from Setpt (F)
Miami-FL	HERS Reference	8	47	102	253	445	621	830	1081	1.00	0.16
Jacksonville-FL	HERS Reference	5	17	46	91	182	325	514	680	1.00	0.03
Atlanta-GA	HERS Reference	3	7	13	25	51	93	173	298	1.00	0.01
Sterling-VA	HERS Reference	4	7	14	25	55	95	186	278	1.00	0.03
Houston-TX	HERS Reference	5	25	63	143	240	357	533	723	1.00	0.01
Fort_Worth-TX	HERS Reference	7	45	94	181	293	411	541	697	1.00	0.01
Wilmington-NC	HERS Reference	9	22	49	100	172	257	364	490	1.00	0.01
Miami-FL	High Efficiency	6	20	67	172	344	543	773	1013	1.00	0.05
Jacksonville-FL	High Efficiency	6	22	49	98	187	342	519	675	1.00	0.02
Atlanta-GA	High Efficiency	7	11	22	50	87	165	290	438	1.00	0.13
Sterling-VA	High Efficiency	3	7	13	38	71	152	238	346	1.00	0.04
Houston-TX	High Efficiency	7	36	92	164	255	390	567	755	1.00	0.00
Fort_Worth-TX	High Efficiency	4	39	89	177	288	413	541	722	0.97	0.00
Wilmington-NC	High Efficiency	3	17	40	96	174	269	402	540	0.99	0.00

Note: Results for 75°F set point temperature

Indoor Humidity Results from Annual Simulations

Figure 11, Figure 12, and Figure 13 show the resulting indoor humidity levels for Miami, Houston and Atlanta when a conventional AC is used to meet the cooling and dehumidification loads (with AUTO supply air fan operation and conventional thermostat control). Results for other locations are shown in Appendix B. The key metric selected for this study is the number of hours in the year when the indoor humidity level exceeds 60% RH. These values are listed for all climates and houses in Table 12. Figure 14, Figure 15, and Figure 16 are shade plots that show when the high humidity periods occur for the best case (HERS Reference house, variable infiltration) and worst case (High-Efficiency house, constant infiltration) scenarios that were modeled. The hours for each day are shown as a vertical stripe on the plot. The different shades indicate how far above 60% RH the humidity was in each hour. For light gray periods, the humidity was below 60%. The next darker shades of gray progressively indicate the humidity was between 60-65% RH, 65-70% RH, or greater than 70% RH.

The simulation results for the HERS Reference house with variable (or natural) infiltration and 75ºF set point temperature are consistent with field experience[14]: the indoor humidity is above 60% RH for less than 1000 hrs per year in all climates but Houston. Miami, Houston, Jacksonville, and Wilmington spent the most time over 60% RH (i.e., 724, 1017, 622 and 588 hours, respectively). The other locations (Atlanta, Sterling, Fort Worth) are much less humid.

The high-efficiency house consistently has more hours above 60% RH in the humid climates, even with the smaller effective leakage area and lower infiltration (see Figure 3 and Figure 4). There is little difference in hours above 60% RH for the houses located in less humid climates (Atlanta, Sterling, Fort Worth). Both houses (standard and high-efficiency) have more hours above 60% RH when the ventilation specified by ASHRAE Standard 62.2-2004 is supplied (i.e., the constant infiltration/ventilation scenario). Ventilation has an especially large impact on indoor humidity levels at times when there is little or no sensible cooling load. Because outdoor humidity levels are frequently high when the cooling load is very small, increasing the set point from 75ºF to 78ºF actually increases the number of hours that indoor humidity exceeds 60% RH. Similarly, lowering the set point to 72ºF decreases the number of hours exceeding 60% RH (see the next section of this report for further discussion of the 72°F set point).

The text on the shade plots (Figure 14, Figure 15, and Figure 16) show that most of the hours over 60% RH occur when there is no cooling load (i.e., no air conditioner operation). These periods typically occur when the space temperature is between the cooling and heating set points. Figure 14 shows that of the 724 hours over 60% RH in Miami for the HERS Reference house with variable (Sherman-Grimsrud) infiltration, only 100 hours occurred when the air conditioner was operating. For the same house and infiltration scenario in Houston, only 159 of the 1017 hours over 60% RH were associated with cooling operation. For the High-Efficiency house with constant infiltration/ventilation, a much larger percentage of the hours over 60% RH are associated with cooling operation: 2,476 of 3,909 hours in Miami (63%) and 1,036 of 2,623 in Houston (39%).

[14] Rudd, A. and H. Henderson. 2007. "Monitored Indoor Moisture and Temperature Conditions in Humid Climate U.S. Residences." ASHRAE Transactions, DA-07-046, January

Table 12. Hours Above 60% RH with Conventional AC System

Variable Infiltration (Sherman-Grimsrud)

		Hours above 60 % RH	
		HERS Ref	**High Eff**
75 F	Miami-FL	724	1,641
	Jacksonville-FL	622	976
	Atlanta-GA	193	73
	Sterling-VA	46	-
	Houston-TX	1017	1,400
	Fort_Worth-TX	131	29
	Wilmington-NC	588	253
78 F	Miami-FL	1667	2,699
	Jacksonville-FL	1153	1,768
	Atlanta-GA	385	118
	Sterling-VA	119	5
	Houston-TX	1535	2,040
	Fort_Worth-TX	305	51
	Wilmington-NC	974	468

Constant Infiltration/Ventilation (0.3656 ACH or 97.5 cfm)

		Hours above 60 % RH	
		HERS Ref	**High Eff**
75 F	Miami-FL	1,583	3,909
	Jacksonville-FL	1,391	2,833
	Atlanta-GA	384	355
	Sterling-VA	268	342
	Houston-TX	1,557	2,623
	Fort_Worth-TX	216	191
	Wilmington-NC	1,384	1,750
78 F	Miami-FL	2,473	4,592
	Jacksonville-FL	1,954	3,297
	Atlanta-GA	563	449
	Sterling-VA	318	299
	Houston-TX	1,991	2,955
	Fort_Worth-TX	385	263
	Wilmington-NC	1,772	1,841

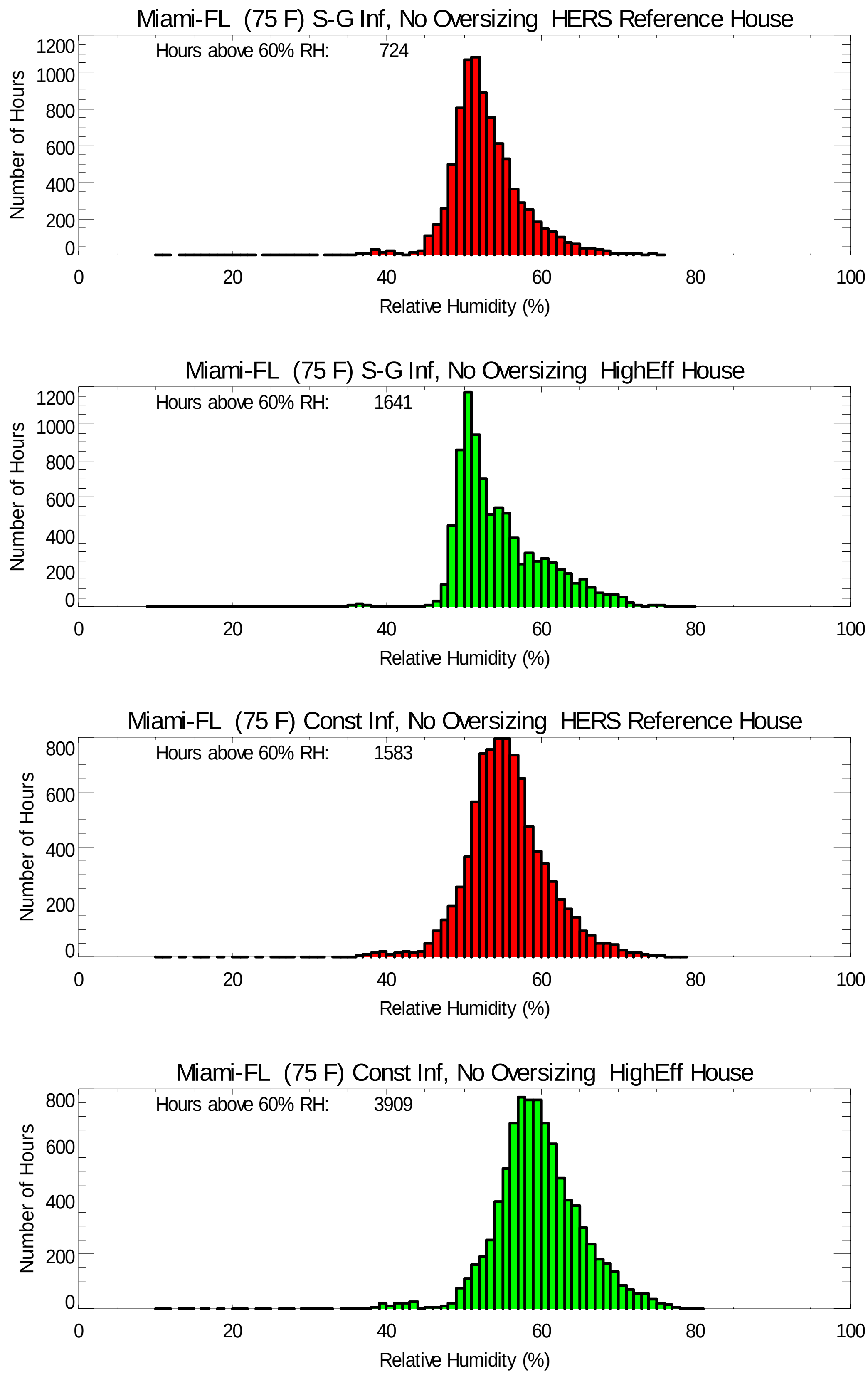


Figure 11. Comparison of Relative Humidity Distributions for Miami with 75°F Set Point

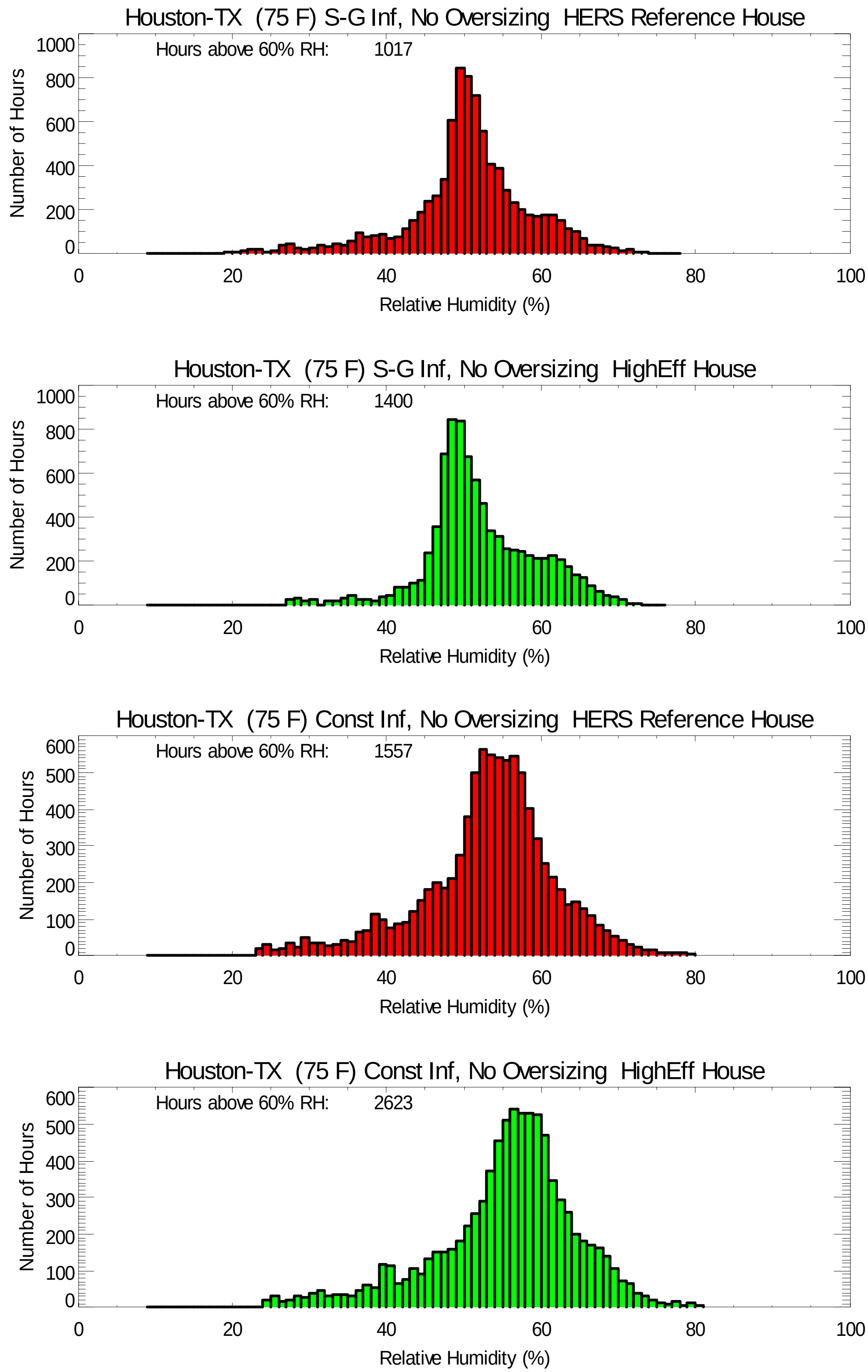


Figure 12. Comparison of Relative Humidity Distributions for Houston with 75°F Set Point

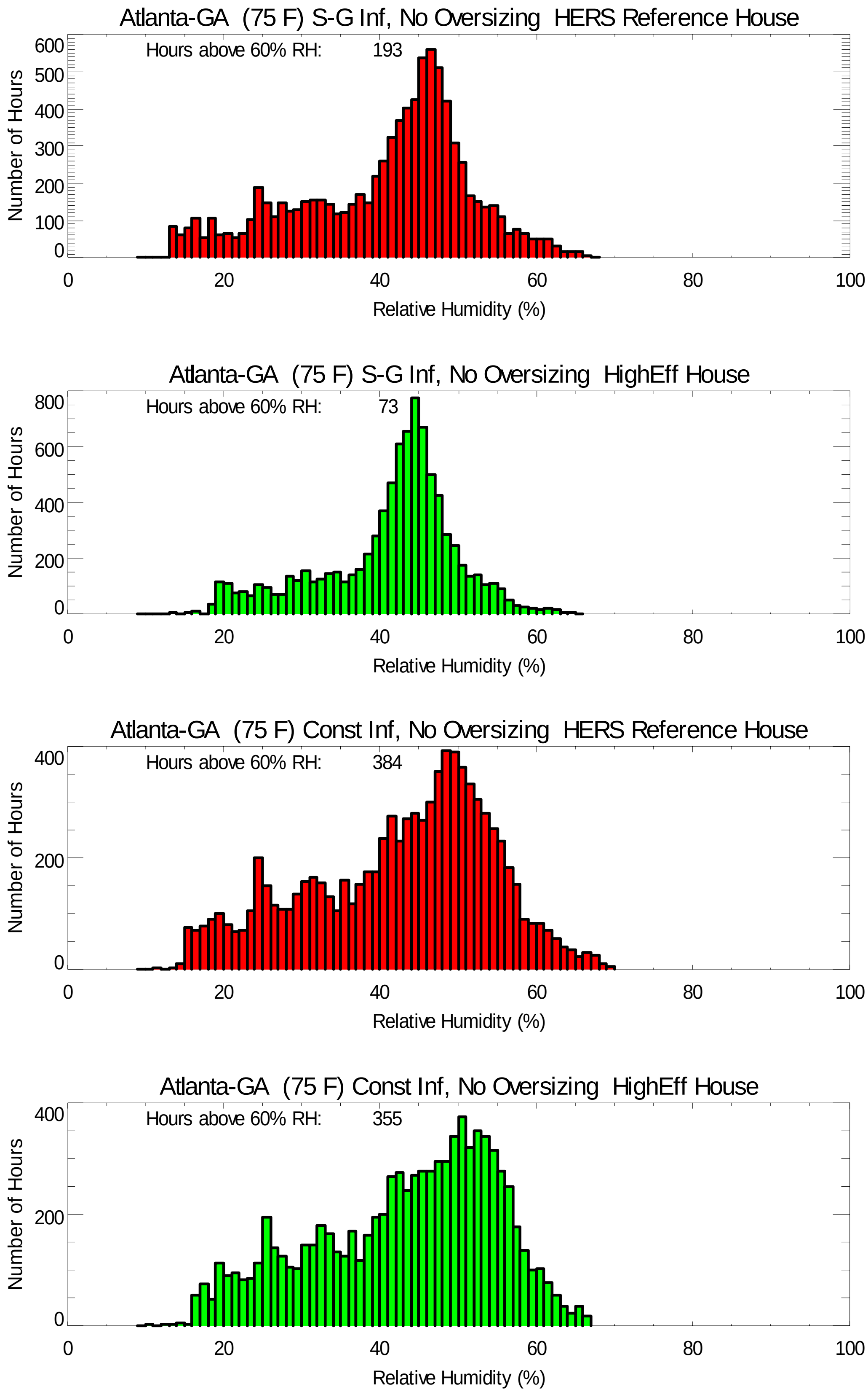
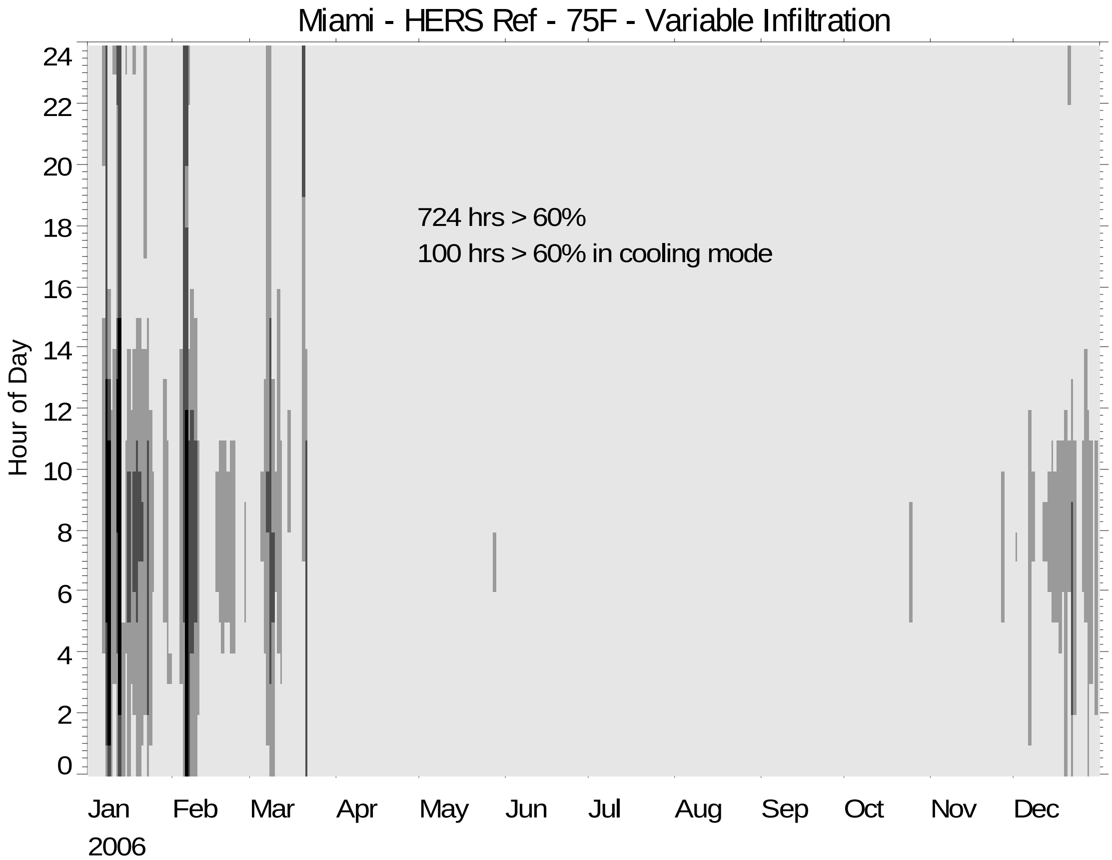


Figure 13. Comparison of Relative Humidity Distributions for Atlanta with 75°F Set Point



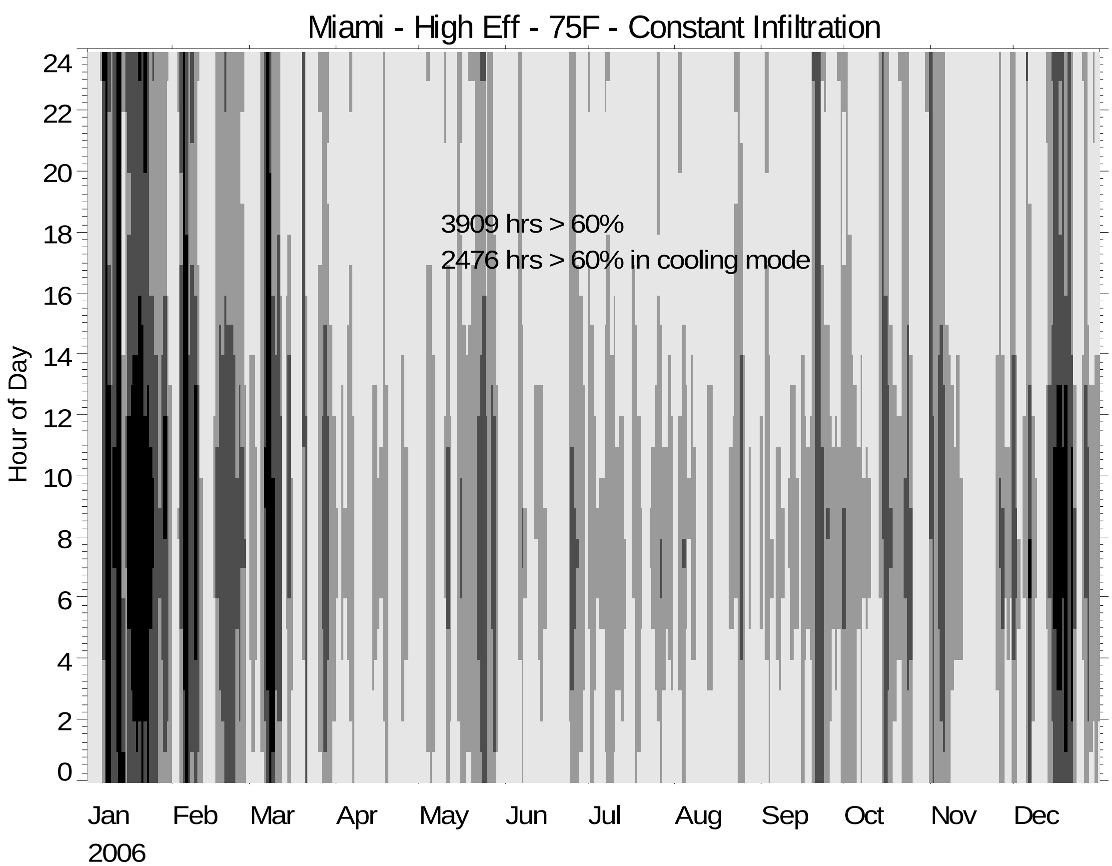


Figure 14. Shade Plots showing Humid Periods for HERS Reference and High Efficiency Houses in Miami

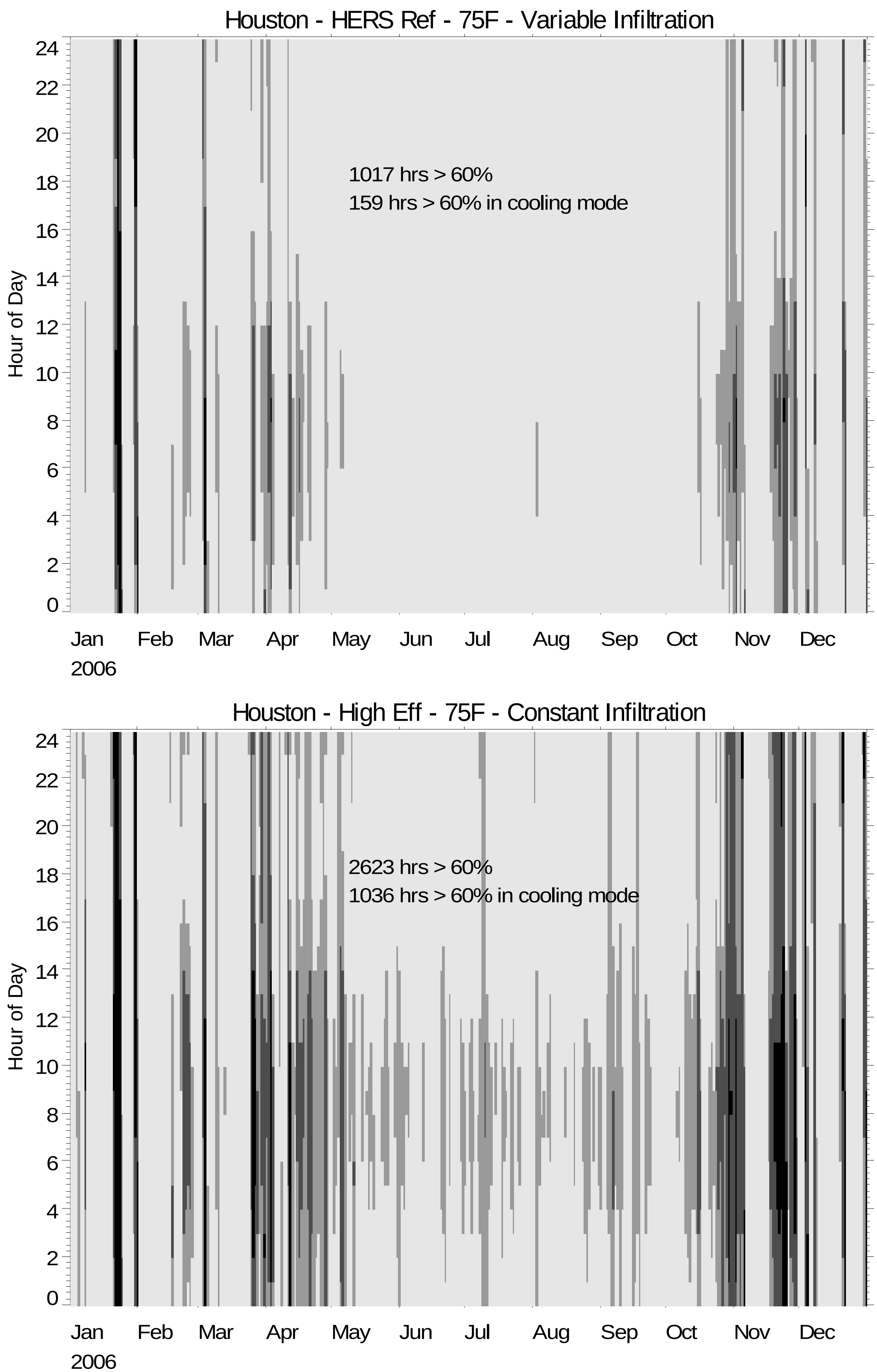
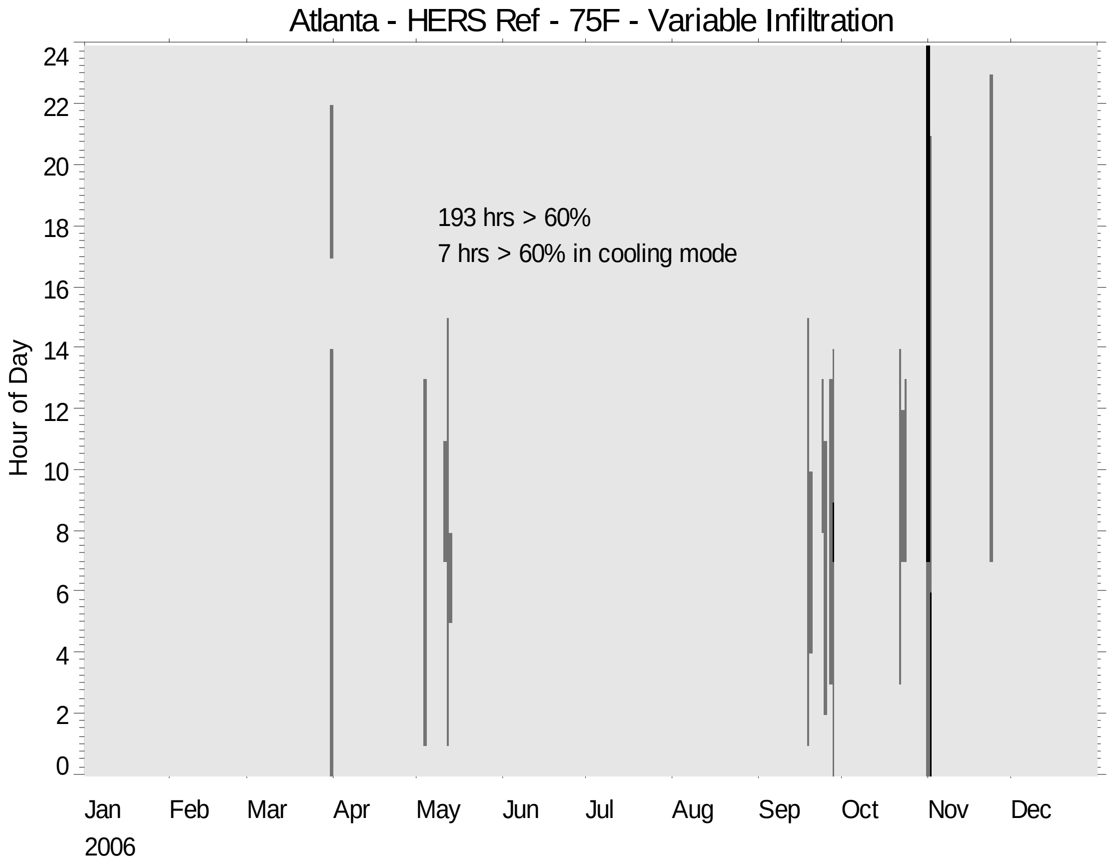


Figure 15. Shade Plots showing Humid Periods for HERS Reference and High Efficiency Houses in Houston



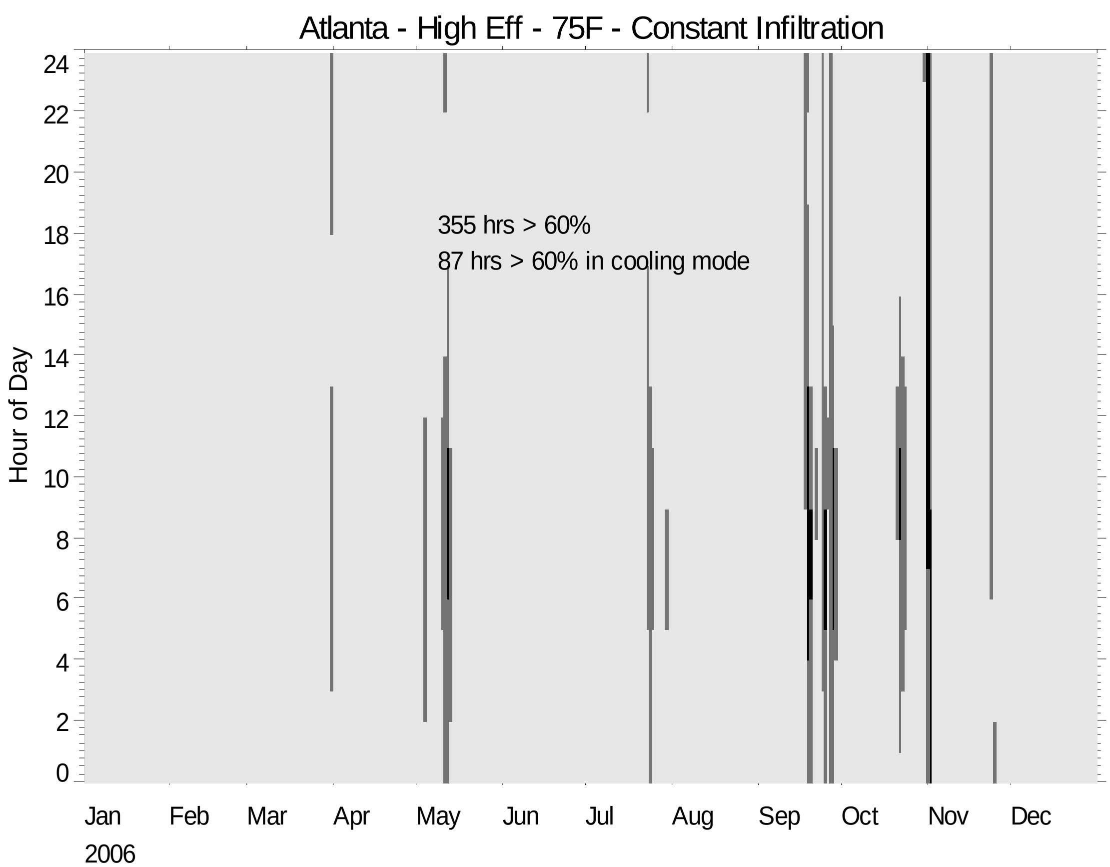


Figure 16. Shade Plots showing Humid Periods for HERS Reference and High Efficiency Houses in Atlanta

Sensitivity Analysis of Conventional AC Configurations

The hours with indoor humidity over 60% RH are clearly affected by the high-efficiency building envelope design as well as continuous ventilation rates specified by ASHRAE Standard 62.2-2004. The cooling set point temperature also has a strong impact. Table 13 compares the impact of various cooling set point temperatures (78ºF, 75ºF, and 72ºF) on indoor humidity levels. Again, since many of the high humidity hours occur when little or no sensible cooling is required, lowering the cooling set point eliminates many of the high humidity hours (by increasing air conditioner operation at part-load conditions). This impact counteracts the expected tendency of lower cooling set point temperatures to increase the indoor RH (because a similar indoor dew point temperature is maintained with lower indoor temperature).

Table 13. Impact of Cooling Set Point Temperature on High Humidity Hours

Miami	Hours Above 60% RH					
	HERS Reference			High Efficiency House		
	78°F	75°F	72°F	78°F	75°F	72°F
S-G Infiltration	1,667	724	218	2,699	1,641	391
Constant Inf	2,473	1,583	859	4,592	3,909	3,245

Houston	Hours Above 60% RH					
	HERS Reference			High Efficiency House		
	78°F	75°F	72°F	78°F	75°F	72°F
S-G Infiltration	1,535	1,017	438	2,040	1,400	423
Constant Inf	1,991	1,557	1,029	2,955	2,623	2,165

Atlanta	Hours Above 60% RH					
	HERS Reference			High Efficiency House		
	78°F	75°F	72°F	78°F	75°F	72°F
S-G Infiltration	385	193	58	118	73	40
Constant Inf	563	384	203	449	355	236

Notes: The air conditioner is sized for 75ºF set point temperature and constant ventilation/infiltration for each house and city.

Air conditioner oversizing had a somewhat unexpected impact on humidity control. The results in Table 14 for the High-Efficiency house – with airtight ducts located in the conditioned space – show the expected result of slightly more hours above 60% RH as unit size increases (due to latent capacity degradation from Figure 8). For the HERS Reference house with duct leakage, the oversized AC units actually reduce the number of hours over 60% RH. In this case, duct leakage is impacted by the reduced operating hours of the oversized unit which decreases the latent load on the house (i.e., lower supply air fan runtime due to larger equipment size actually reduces duct air leakage which reduces the latent load on the AC system). The load reduction associated with duct leakage and AC oversizing counteracts the expected impact of more latent degradation at part-load conditions. This result is supported by the Florida AC sizing field tests conducted as part of this STAC project (Task 3.2)[15].

[15] Sonne, J., D.Parker, and D. Shirey. 2006. Measured Impacts of Proper Air Conditioning Sizing in Four Florida Case Study Homes. Contract Report FSEC-CR-1641-06. Cocoa: Florida Solar Energy Center. http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1641-06.pdf

Oversizing does have a modest impact on energy use, increasing energy use by 2-3% for a 30% oversized case in the HERS Reference house and decreasing the energy use by 1% with 30% oversizing in the High-Efficiency case. The part-load parameters chosen for this study assume a system startup time constant of 45 seconds and a maximum cycling rate of 3 cycles/hour, which roughly corresponds to a degradation coefficient (Cd) of 0.1.

Table 14. Impact of Air Conditioner Oversizing on High Indoor Humidity and AC Energy Use

Miami		HERS Reference House			High Efficiency House		
		Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)	Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)
Variable Infiltration (S-G)	No Oversizing	724	2075.9	100%	1,641	1911.0	100%
	10% Oversizing	714	1889.0	101%	1,645	1719.2	100%
	30% Oversizing	692	1607.0	102%	1,649	1430.8	99%
Constant Infiltration	No Oversizing	1,583	2166.2	100%	3,909	2170.4	100%
	10% Oversizing	1,544	1969.2	101%	3,951	1954.7	100%
	30% Oversizing	1,489	1674.2	102%	4,015	1624.4	99%

Houston		HERS Reference House			High Efficiency House		
		Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)	Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)
Variable Infiltration (S-G)	No Oversizing	1,017	1355.0	100%	1,400	1273.6	100%
	10% Oversizing	1,002	1234.3	101%	1,405	1146.5	100%
	30% Oversizing	976	1052.0	103%	1,411	954.7	99%
Constant Infiltration	No Oversizing	1,557	1411.0	100%	2,623	1433.6	100%
	10% Oversizing	1,537	1283.7	101%	2,643	1290.5	100%
	30% Oversizing	1,498	1092.1	102%	2,680	1069.8	99%

Atlanta		HERS Reference House			High Efficiency House		
		Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)	Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)
Variable Infiltration (S-G)	No Oversizing	193	779.0	100%	73	867.5	100%
	10% Oversizing	192	710.4	101%	74	781.4	100%
	30% Oversizing	184	606.9	103%	75	651.0	99%
Constant Infiltration	No Oversizing	384	802.5	100%	355	930.2	100%
	10% Oversizing	378	731.4	101%	358	837.3	100%
	30% Oversizing	372	623.4	103%	364	695.6	99%

Notes: Supply air flow increases with AC equipment size to maintain 400 cfm per ton. Duct surface area changes proportionally with airflow. Duct air leakage is held as a constant percentage of supply air flow in each case. Fan power is maintained at 0.35 W/cfm. Cooling set point temperature is 75ºF.

Lowering the supply airflow rate has a beneficial impact on high indoor humidity levels. Table 15 shows the impact of decreasing the air flow to 300 cfm/ton, instead of the baseline 400 cfm/ton assumed in the simulations previously described. The number of hours over 60% RH typically drops by 20-30% if this lower air flow rate is used. The annual energy use increases by only 1-2% for the 300 cfm per ton case. Energy use increases slightly because the compressor efficiency is lower. However, the drop in fan power somewhat mitigates this impact.

Table 15. Impact of Lower Supply Air Flow on High Indoor Humidity and AC Energy Use

Miami		HERS Reference House			High Efficiency House		
		Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)	Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)
Variable Infiltration (S-G)	400 cfm/ton	724	2075.9	100%	1,641	1911.0	100%
	300 cfm/ton	533	2015.2	100%	1,306	1876.1	101%
Constant Infiltration	400 cfm/ton	1,583	2166.2	100%	3,909	2170.4	100%
	300 cfm/ton	1,116	2104.6	100%	2,861	2128.7	101%

Houston		HERS Reference House			High Efficiency House		
		Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)	Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)
Variable Infiltration (S-G)	400 cfm/ton	1,017	1355.0	100%	1,400	1273.6	100%
	300 cfm/ton	859	1317.2	100%	1,196	1252.7	101%
Constant Infiltration	400 cfm/ton	1,557	1411.0	100%	2,623	1433.6	100%
	300 cfm/ton	1,294	1370.6	100%	2,064	1411.3	101%

Atlanta		HERS Reference House			High Efficiency House		
		Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)	Hours above 60% RH (hrs)	AC Runtime (hrs)	Relative Energy Use (%)
Variable Infiltration (S-G)	400 cfm/ton	193	779.0	100%	73	867.5	100%
	300 cfm/ton	165	764.3	100%	66	863.6	102%
Constant Infiltration	400 cfm/ton	384	802.5	100%	355	930.2	100%
	300 cfm/ton	342	788.3	101%	285	926.1	102%

Notes: Supply air flow and fan power decrease proportionally at 300 cfm/ton. Unit size remains the same. Duct surface area changes proportionally with airflow. Duct air leakage is held as a constant percentage of supply air flow in each case. Fan power is maintained at 0.35 W/cfm. Cooling set point temperature is 75ºF.

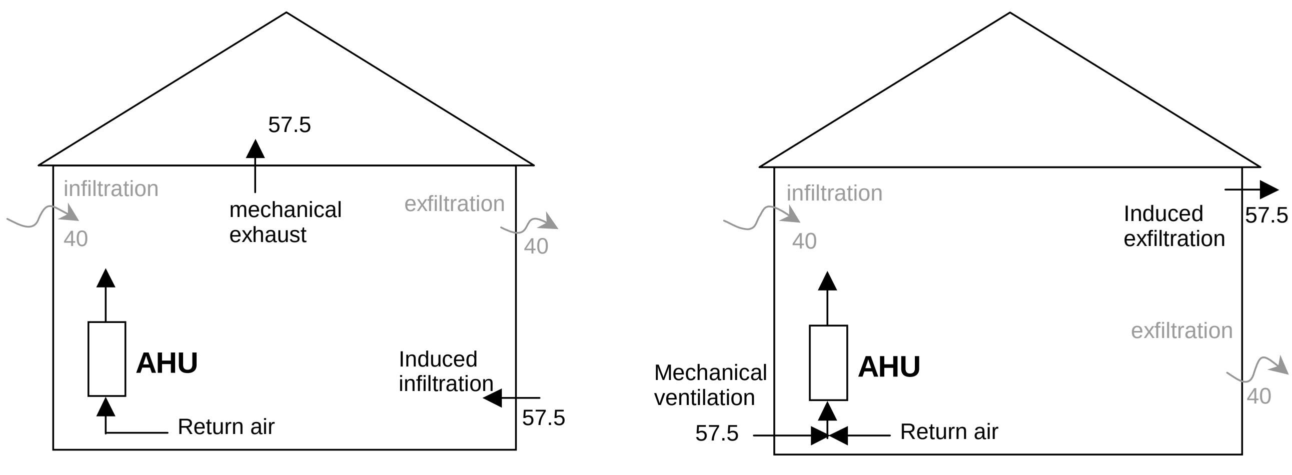
In reality, the normalized fan power (W per cfm) increases slightly when the supply airflow rate is decreased from 400 to 300 cfm per ton. The example above assumed that the supply fan power decreased in proportion with the air flow at 300 cfm/ton (i.e., the normalized fan power remained constant at 0.35 W/cfm). If the fan power is assumed to be 0.4 W/cfm at 300 cfm/ton, this is more representative of "riding the fan curve" with a forward-curve centrifugal fan. With this assumption the hours above 60% RH do not change significantly from those shown in Table 15 above; however, the relative energy use for the 300 cfm/ton scenario increases to 102-103% for Miami and Houston and 103-104% for Atlanta.

5. AC Control Enhancements & Other Dehumidification Options

This section evaluates the relative performance of various AC control options to provide ventilation while adequately controlling space humidity levels. It also evaluates various standard and high-efficiency dehumidification systems, and their impact on indoor humidity levels and energy use.

Impact of Various AC Control Approaches

In previous sections of this report, the simulations for the constant infiltration/ventilation case assumed that the outdoor air enters and leaves the house independent of the AC unit (e.g., induced by a mechanical exhaust fan as shown in Figure 17a). Another approach is to use the central fan in the AC air handler unit (AHU) to bring ventilation air into the house (Figure 17b). This is typically accomplished by adding an outdoor air intake at the air handler to provide 57.5 cfm of outdoor air (with 40 cfm of constant infiltration supplied independently of the AHU). Providing outdoor air directly into the AHU increases the capacity and efficiency of the cooling coil by providing a higher entering air wet-bulb temperature. However, it also requires continuous or constant supply air fan operation, which increases fan energy use and causes more latent capacity degradation at part-load conditions (Figure 9).



a) Mechanical Exhaust ***b) Mechanical ventilation at AHU (central fan integrated)***

Figure 17. Schematic of Mechanical Ventilation Options

For the remainder of Section 5, the base case or conventional AC always operates in the AUTO fan mode with ventilation provided by a separate exhaust fan (i.e., Figure 17a). The thermostat cooling set point is 75°F, unless stated otherwise. Total HVAC energy use includes cooling and year-round supply air fan power (but does not include heating fuel consumption).

All scenarios with the AUTO fan mode include an additional 40 Watts of power use for the mechanical exhaust fan (0.7 Watts/cfm). This fan operates continuously year round and adds 350 kWh per year to the total HVAC energy use values given in each table below.

Table 16 compares the simulation results for the traditional AUTO fan approach (with a separate ventilation system) to using the air handler to continuously provide outdoor ventilation air (Figure 17b configuration). In the Miami HERS Reference house, energy use is 34% higher with the constant fan mode (CONST) and the hours when indoor humidity exceeds 60% RH increases more than 4 fold. The increased indoor humidity levels primarily result from latent capacity degradation due to continuous supply air fan operation while the cooling coil cycles on/off to meet the thermostat set point temperature (Figure 9).[16] Separate sensitivity runs demonstrated that constant fan operation combined with duct leakage also has a modest secondary impact (increasing the time above 60% RH by about 200 hours per year for simulation runs when latent degradation is ignored). Similar impacts occur in the other climates and for the High-Efficiency house.

Table 16. Impact of Using AC Supply Fan to Provide Mechanical Ventilation

HERS Reference House		Hours above 60% RH (hrs)	AC Runtime (hrs)	AC Electric Use (kWh)	Supply Fan Electric Use (kWh)	Total HVAC Electric Use[1] (kWh)	Relative Energy Use (%)
Miami	AUTO Fan	1,583	2,166	5,201	859	6,411	100%
	CONST Fan	7,283	2,089	5,165	3,434	8,598	134%
Jacksonville	AUTO Fan	1,391	1,333	3,460	641	4,451	100%
	CONST Fan	5,579	1,298	3,476	3,679	7,155	161%
Atlanta	AUTO Fan	384	803	1,908	490	2,748	100%
	CONST Fan	585	747	1,809	3,434	5,243	191%
Sterling	AUTO Fan	268	672	1,755	506	2,610	100%
	CONST Fan	1,641	641	1,714	3,802	5,516	211%
Houston	AUTO Fan	1,557	1,411	3,670	678	4,697	100%
	CONST Fan	5,411	1,351	3,630	3,679	7,309	156%
Fort Worth	AUTO Fan	216	1,278	3,402	679	4,430	100%
	CONST Fan	1,229	1,206	3,299	3,802	7,101	160%
Wilmington	AUTO Fan	1,384	1,023	2,458	543	3,351	100%
	CONST Fan	4,303	997	2,466	3,434	5,899	176%

High Efficiency House		Hours above 60% RH (hrs)	AC Runtime (hrs)	AC Electric Use (kWh)	Supply Fan Electric Use (kWh)	Total HVAC Electric Use[1] (kWh)	Relative Energy Use (%)
Miami	AUTO Fan	3,909	2,170	3,187	520	4,057	100%
	CONST Fan	7,971	2,102	3,180	2,085	5,265	130%
Jacksonville	AUTO Fan	2,833	1,333	2,310	418	3,078	100%
	CONST Fan	5,903	1,315	2,350	2,453	4,803	156%
Atlanta	AUTO Fan	355	930	1,485	326	2,161	100%
	CONST Fan	648	872	1,420	2,330	3,751	174%
Sterling	AUTO Fan	342	726	1,277	314	1,941	100%
	CONST Fan	1,626	720	1,295	2,575	3,870	199%
Houston	AUTO Fan	2,623	1,434	2,485	449	3,284	100%
	CONST Fan	5,656	1,393	2,492	2,453	4,944	151%
Fort Worth	AUTO Fan	191	1,356	2,544	466	3,360	100%
	CONST Fan	1,211	1,298	2,504	2,698	5,202	155%
Wilmington	AUTO Fan	1,750	1,111	1,897	371	2,618	100%
	CONST Fan	4,201	1,104	1,937	2,453	4,390	168%

Notes: 1 - AUTO Fan case includes additional 40 Watts of power for mechanical exhaust fan that runs continuously year-round to exhaust 57.5 cfm (350 kWh/yr)
Cooling set point temperature is 75ºF.

Many manufacturers include controls in their units that keep the indoor fan on for a short time at the end of each cooling cycle (in AUTO mode). This control approach is used because it results

[16] http://www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1537-05.pdf

in a lower Cd as determined in the SEER test procedure and provides a slightly higher SEER rating. Adding this time delay has a significant impact on the hours above 60% RH. Table 17 shows that adding an off-cycle fan delay of 90 seconds increases the number of hours over 60% RH from 1,583 to 2,854 hours per year for the Miami HERS Reference house. The higher humidity levels are primarily due to latent degradation effects (Figure 8 and Figure 9). Similarly, the 90-second delay increases the time above 60% RH from 1,557 to 2,517 hours in Houston. AC runtime decreases slightly because more sensible capacity is provided at the expense of latent capacity with fan overrun, so the thermostat is satisfied sooner.

Table 17. Impact of Fan Delays on Dehumidification Performance

Miami		Hours above 60% RH (hrs)	AC Runtime (hrs)	AC Electric Use (kWh)	Supply Fan Electric Use (kWh)	Total HVAC Electric Use[1] (kWh)	Relative Energy Use (%)
Base Case	AUTO Fan	1,583	2,166	5,201	859	6,411	100%
57.5 cfm Vent at AC	CONST Fan	7,283	2,089	5,165	3,434	8,598	134%
Fan Overrun (1s)	AUTO Fan	1,587	2,165	5,199	860	6,409	100%
Fan Overrun (30 s)	AUTO Fan	1,894	2,143	5,159	890	6,398	100%
Fan Overrun (90 s)	AUTO Fan	2,854	2,096	5,075	948	6,373	99%

Houston		Hours above 60% RH (hrs)	AC Runtime (hrs)	AC Electric Use (kWh)	Supply Fan Electric Use (kWh)	Total HVAC Electric Use[1] (kWh)	Relative Energy Use (%)
Base Case	AUTO Fan	1,557	1,411	3,670	678	4,697	100%
57.5 cfm Vent at AC	CONST Fan	5,411	1,351	3,630	3,679	7,309	156%
Fan Overrun (1s)	AUTO Fan	1,564	1,410	3,667	678	4,696	100%
Fan Overrun (30 s)	AUTO Fan	1,780	1,395	3,639	704	4,693	100%
Fan Overrun (90 s)	AUTO Fan	2,517	1,363	3,576	756	4,682	100%

Notes: 1 - AUTO Fan case includes additional 350 kWh for mechanical exhaust fan.
HERS Reference house with 75°F cooling set point.

One way to mitigate the negative impact of constant fan operation is to run the supply air fan only part of the time to provide ventilation. Fan cycling controllers (CYCLER) are available to operate the supply air fan during hours when no cooling or heating is required. This controller helps keep the house air mixed and at more uniform conditions. If ventilation air is introduced at the AC fan (as shown in Figure 17b), then the controller can also help to provide continuous ventilation. This approach is also known as central fan integrated (CFI) ventilation.[17] The controller operates the supply air fan to ensure a minimum fan-operating fraction in each hour. For instance, a 20% minimum fraction operates the supply fan for at least 12 minutes of each hour. If 6 minutes of cooling or heating have been provided in the hour, then the controller will only operate the fan an additional 6 minutes to provide the necessary 12 minutes of total fan operation. The controller can optionally control a fresh air damper, closing it once the desired amount of ventilation (i.e., fan runtime) has been provided for the hour. This option prevents over-ventilation when supply air fan runtimes exceed the minimum due to cooling or heating demand, since the outdoor ventilation air flow rate is typically set to 3 to 5 times the rate required if outdoor ventilation were to be provided continuously.

[17] Rudd, A., J. Lstiburek and K. Ueno 2005. Residential Dehumidification Systems Research for Hot-Humid Climates. Building Science Corporation. NREL/SR-550-36643. February.

Table 18 shows the impact of fan cycling controls in Miami and Houston for the HERS Reference house. The third entry in each section of the table shows results for the case where the fan cycling controls are set to operate a minimum of 10% of the time to mix the space air during periods when there is little or no call for cooling or heating. For this case, it is assumed that a separate ventilation system is being used to provide the required outdoor ventilation air (same as the base case in Table 18). Mixing is provided while only increasing total annual HVAC electric use by 1-3% (compared to 34% and 56% for constant fan operation in Miami and Houston, respectively). The extra fan operation provides a modest amount of additional latent capacity degradation and duct leakage, increasing the time above 60% RH from 1,583 to 1,834 hours per year in Miami and 1,557 and 1,785 hours per year in Houston.

If the fan cycling controls are set for a minimum runtime of 20% of the hour, and the supply fan is set to provide 287.5 cfm of outdoor ventilation air, then the minimum outdoor air supplied to the house is equivalent to 57.5 cfm, on average. With this scenario (CYCLER-Vent Only [20%]), the hours over 60% RH increase to 2,513 hours per year in Miami and 2,389 hours per year in Houston. The energy use is 20-23% over the base case since a substantial amount of additional ventilation air is provided. If a damper is installed and controlled to shut off the outdoor air inlet once the 20% runtime (and 57.5 cfm of ventilation) has been reached for each hour (CYCLER-Vent w/Dmpr [20%]), then this reduces the time over 60% RH to 1,712 and 1,759 hours in the two locations and reduces the energy penalty to 5% and 8% over the base case.

Providing ventilation at the AHU with fan cycling controls and damper shutoff resulted in even fewer high humidity hours than the mixing only case with a 10% minimum fan runtime. To understand this somewhat surprising result, a simulation with mixing only at a 20% minimum fan runtime was also completed for Miami. Mixing only at 20% runtime in Miami resulted in more than 2,300 hours over 60% RH (compared to 1,712 hours for the ventilation with damper case). This implies that the dehumidification performance benefit of mixing a large fraction of outdoor air at the coil helps to mitigate a significant portion of the latent degradation and duct air leakage penalties due to keeping the supply air fan operating longer.

Table 18. Impact of Fan Cycling Controls (CYCLER) on Dehumidification Performance

Miami		**Hours above 60% RH (hrs)**	**AC Runtime (hrs)**	**AC Electric Use (kWh)**	**Supply Fan Electric Use (kWh)**	**Total HVAC Electric Use[1] (kWh)**	**Relative Energy Use (%)**
Base Case	AUTO Fan	1,583	2,166	5,201	859	6,411	100%
Continuous Ventilation	CONST Fan	7,283	2,089	5,165	3,434	8,598	134%
CYCLER - Mixing Only (10%)	AUTO Fan	1,834	2,153	5,173	983	6,506	101%
CYCLER - Vent Only (20%)	AUTO Fan	2,513	2,485	6,063	1,284	7,697	120%
CYCLER - Vent w/ Dmpr (20%)	AUTO Fan	1,712	2,155	5,220	1,161	6,731	105%

Houston		**Hours above 60% RH (hrs)**	**AC Runtime (hrs)**	**AC Electric Use (kWh)**	**Supply Fan Electric Use (kWh)**	**Total HVAC Electric Use[1] (kWh)**	**Relative Energy Use (%)**
Base Case	AUTO Fan	1,557	1,411	3,670	678	4,697	100%
Continuous Ventilation	CONST Fan	5,411	1,351	3,630	3,679	7,309	156%
CYCLER - Mixing Only (10%)	AUTO Fan	1,785	1,396	3,635	836	4,821	103%
CYCLER - Vent Only (20%)	AUTO Fan	2,389	1,608	4,260	1,152	5,762	123%
CYCLER - Vent w/ Dmpr (20%)	AUTO Fan	1,759	1,393	3,660	1,062	5,072	108%

Notes: 1 - AUTO Fan case includes additional 350 kWh for mechanical exhaust fan.
HERS Reference house with 75ºF cooling set point.

Several enhanced AC control approaches have the potential to improve dehumidification performance. One such procedure is lowering the cooling set point (or overcooling) in response to high humidity levels. One manufacturer allows up to a 3ºF space temperature decrease as the space humidity increases above a dehumidification set point. The data in Figure 18 and Figure 19 show the implementation of this approach in the simulation model. The temperature set point is lowered or reset by 3ºF as the space humidity increases from 55% to 60% RH.[18] Figure 19 shows simulation results for a two day period in May for Miami where a high humidity period pushes down the space temperature. Table 19 shows the results for this control scenario in Miami and Houston. Many of the high humidity hours occur when cooling is just barely required. As a result, pushing the cooling set point down at these times forces more cooling and dehumidification and lowers the total hours above 60% RH from 1,583 to 1,070 in Miami and 1,557 to 1,156 hours in Houston. The energy penalty is about 6% for this scenario. Overcooling the space may also result in occupant comfort issues.

[18] The manufacturer's literature actually states that the RH set point is reset upward by 2% RH for each degree of space overcooling. However, this subtle difference is negligible when simulating performance on an hourly basis. Also the manufacturer reports a maximum 6% RH change with a 3°F decrease in space temperature (instead of 5% RH with 3°F, which was used here).

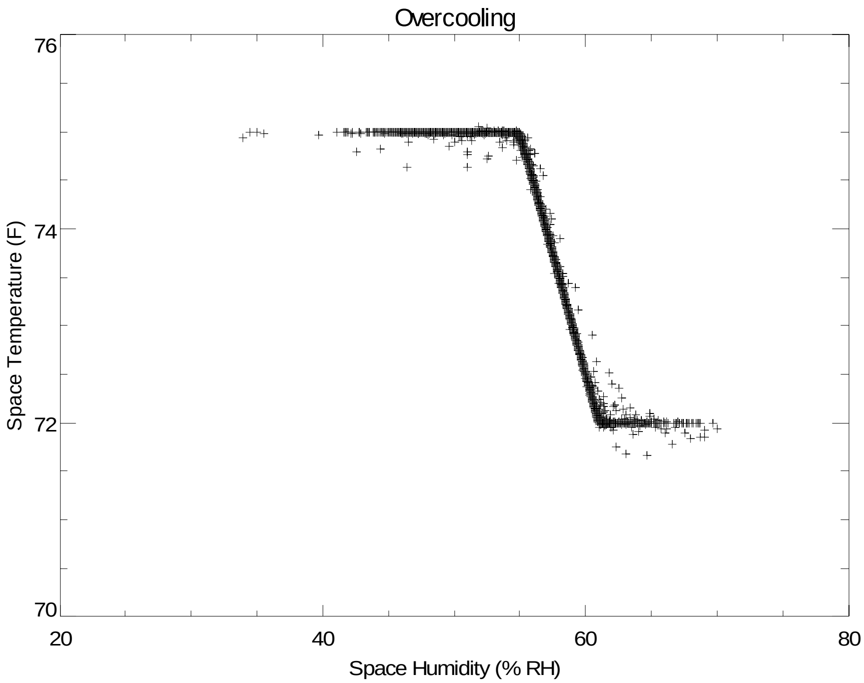


Figure 18. Variation of Space Temperature Setpoint with Space Humidity: 3ºF Overcooling Controls

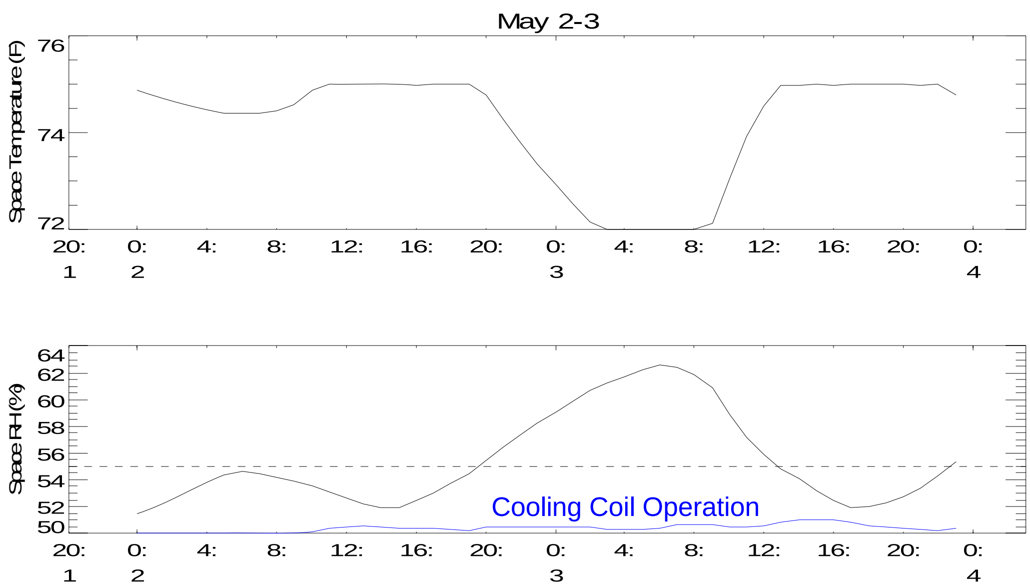


Figure 19. Example of Space Temperature Setpoint Variations with Space Humidity

Another common dehumidification enhancement listed in Table 19 is to lower the supply air fan speed when indoor humidity exceeds a set point. This more passive dehumidification approach lowers the SHR of the cooling coil but does not directly prolong cooling coil operation. Lowering the fan speed to 80% when the RH is above 55% provides a more modest dehumidification improvement: decreasing the time over 60% RH from 1,583 to 1,251 hours in Miami and 1,557 to 1,383 in Houston. The more modest impact of this control approach underscores the fact that most high humidity periods occur when cooling loads are low.

Changing the reduced fan speed activation set point from 55% RH to 25% RH slightly improves indoor humidity control, decreasing the hours above 60% RH from 1,251 to 1,131 in Miami. The activation point of 25% RH effectively keeps the fan at 80% speed (or 320 cfm/ton) all the time in Miami and provides similar performance to the 300 cfm/ton case listed above in Table 15 (1,116 hours above 60% RH for the Miami case with constant infiltration).

Table 19. Impact of Enhanced AC Controls

Miami	Hours above 60% RH (hrs)	AC Runtime (hrs)	AC Electric Use (kWh)	Supply Fan Electric Use (kWh)	Total HVAC Electric Use[1] (kWh)	Relative Energy Use (%)
Base Case	1,583	2,166	5,201	859	6,411	100%
Over Cooling by 3F	1,070	2,314	5,533	918	6,801	106%
80% Supply Airflow	1,251	2,223	5,281	821	6,451	101%

Houston	Hours above 60% RH (hrs)	AC Runtime (hrs)	AC Electric Use (kWh)	Supply Fan Electric Use (kWh)	Total HVAC Electric Use[1] (kWh)	Relative Energy Use (%)
Base Case	1,557	1,411	3,670	678	4,697	100%
Over Cooling by 3F	1,156	1,510	3,901	721	4,972	106%
80% Supply Airflow	1,383	1,446	3,722	651	4,723	101%

Notes: Overcooling proportional to how much RH exceeds 55% set point
Lower supply air flow activated when humidity exceeds 55% set point
HERS Reference House with 75°F cooling set point
1 – Includes additional 350 kWh for mechanical exhaust fan

Standard Dehumidification Enhancements

Standalone dehumidifiers (DH) can directly meet dehumidification loads, but also add sensible heat to the space that increases cooling operation. Table 20 summarizes the results for using various sizes of a standard DH unit (nominal efficiency: 2.6 pint/kWh) in Miami and Houston for the HERS Reference house. Table 21 shows similar results for the High-Efficiency house. Even a smaller DH unit (e.g., 37 pint/day) is capable of meeting nearly all the dehumidification loads. The overall energy penalty is 22-24% in Miami and 26-27% in Houston compared to the conventional or base case AC in the HERS Reference house. For the High-Efficiency house the energy penalty for dehumidification becomes 56% in Miami and 47-48% in Houston.

In practical terms, it is often difficult for a non-ducted, standalone dehumidifier to adequately dry an entire house. To ensure dehumidification is adequately distributed through the house, a fan cycling controller can be used to periodically run the supply air fan in order to mix the air in the house zone. The 4th row in each section of Table 20 and Table 21 shows the performance of a standalone DH with fan cycling controls operating to provide a minimum fan runtime of 10% to mix the zone. Roughly the same level of dehumidification is provided with slightly larger energy penalty (i.e., 3% larger penalty in Miami and 4-6% larger penalty in Houston).

Table 20. Impact of Stand Alone Dehumidification: HERS Reference House

Miami	Hours above 60% RH	AC Runtime	Dehumid Runtime	AC Electric Use	Supply Fan Electric Use	Mech. Exh. Fan Use	DH Unit Electric Use	DH FAN Electric Use	Total Electric Use	Relative Energy Use
	(hrs)	(hrs)	(hrs)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(%)
Conventional AC	1,583	2,166	-	5,201	859	350	-	-	6,411	100%
Standalone Dehum (37 pint)	18	2,283	2,062	5,454	904	350	1,131	-	7,838	122%
Standalone Dehum (75 pint)	-	2,294	1,083	5,480	908	350	1,189	-	7,927	124%
Standalone Dehum (75 pint) MIXED	-	2,303	1,173	5,502	1,018	350	1,288	-	8,158	127%
AC with Ventilation (57.5 cfm)	7,283	2,089	-	5,165	3,434	-	-	-	8,598	134%
AC w/ Vent (37 pint)	3,440	2,663	7,068	6,417	3,434	-	3,950	-	13,801	215%
AC w/ Vent (75 pint)	183	2,954	5,124	7,051	3,434	-	5,678	-	16,164	252%
AC w/ Vent (150 pint)	-	3,019	2,724	7,192	3,434	-	6,020	-	16,645	260%
Std Dehum (75 pt) 20% CYC/DMP	-	2,279	972	5,500	1,168	-	1,066	-	7,734	121%

Houston	Hours above 60% RH	AC Runtime	Dehumid Runtime	AC Electric Use	Supply Fan Electric Use	Mech. Exh. Fan Use	DH Unit Electric Use	DH FAN Electric Use	Total Electric Use	Relative Energy Use
	(hrs)	(hrs)	(hrs)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(%)
Conventional AC	1,557	1,411	-	3,670	678	350	-	-	4,697	100%
Standalone Dehum (37 pint)	7	1,492	1,834	3,856	708	350	1,000	-	5,914	126%
Standalone Dehum (75 pint)	-	1,496	969	3,868	710	350	1,057	-	5,985	127%
Standalone Dehum (75 pint) MIXED	-	1,503	1,051	3,885	860	350	1,148	-	6,243	133%
AC with Ventilation (57.5 cfm)	5,411	1,351	-	3,630	3,679	-	-	-	7,309	156%
AC w/ Vent (37 pint)	2,236	1,730	5,292	4,515	3,679	-	2,950	-	11,144	237%
AC w/ Vent (75 pint)	91	1,922	3,865	4,957	3,679	-	4,280	-	12,916	275%
AC w/ Vent (150 pint)	-	1,954	1,968	5,029	3,679	-	4,347	-	13,055	278%
Std Dehum (75 pt) 20% CYC/DMP	-	1,494	954	3,906	1,073	-	1,041	-	6,019	128%

Notes: Dehumidifier set point is 55% RH. Standard DH unit performance map with nominal efficiency of 2.6 pint/kWh.

Table 21. Impact of Stand Alone Dehumidification: High-Efficiency House

Miami	Hours above 60% RH	AC Runtime	Dehumid Runtime	AC Electric Use	Supply Fan Electric Use	Mech. Exh. Fan Use	DH Unit Electric Use	DH FAN Electric Use	Total Electric Use	Relative Energy Use
	(hrs)	(hrs)	(hrs)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(%)
Conventional AC	3,909	2,170	-	3,187	520	350	-	-	4,057	100%
Standalone Dehum (37 pint)	-	2,585	2,951	3,729	618	350	1,629	-	6,325	156%
Standalone Dehum (75 pint)	-	2,592	1,486	3,738	620	350	1,640	-	6,348	156%
Standalone Dehum (75 pint) MIXED	-	2,597	1,523	3,745	676	350	1,681	-	6,452	159%
AC with Ventilation (57.5 cfm)	7,971	2,102	-	3,180	2,085	-	-	-	5,265	130%
AC w/ Vent (37 pint)	973	3,111	6,527	4,497	2,085	-	3,629	-	10,211	252%
AC w/ Vent (75 pint)	-	3,315	4,033	4,756	2,085	-	4,461	-	11,301	279%
AC w/ Vent (150 pint)	-	3,325	2,043	4,772	2,085	-	4,517	-	11,374	280%
Std Dehum (75 pt) 20% CYC/DMP	-	2,534	1,101	3,736	757	-	1,215	-	5,707	141%

Houston	Hours above 60% RH	AC Runtime	Dehumid Runtime	AC Electric Use	Supply Fan Electric Use	Mech. Exh. Fan Use	DH Unit Electric Use	DH FAN Electric Use	Total Electric Use	Relative Energy Use
	(hrs)	(hrs)	(hrs)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(%)
Conventional AC	2,623	1,434	-	2,485	449	350	-	-	3,284	100%
Standalone Dehum (37 pint)	-	1,639	2,137	2,802	503	350	1,172	-	4,827	147%
Standalone Dehum (75 pint)	-	1,643	1,080	2,810	505	350	1,185	-	4,850	148%
Standalone Dehum (75 pint) MIXED	-	1,646	1,111	2,814	601	350	1,220	-	4,985	152%
AC with Ventilation (57.5 cfm)	5,656	1,393	-	2,492	2,453	-	-	-	4,944	151%
AC w/ Vent (37 pint)	674	1,945	4,865	3,341	2,453	-	2,702	-	8,495	259%
AC w/ Vent (75 pint)	-	2,055	2,794	3,505	2,453	-	3,087	-	9,045	275%
AC w/ Vent (150 pint)	-	2,078	1,490	3,540	2,453	-	3,293	-	9,285	283%
Std Dehum (75 pt) 20% CYC/DMP	-	1,620	900	2,823	738	-	986	-	4,548	138%

Notes: Dehumidifier set point is 55% RH. Standard DH unit performance map with nominal efficiency of 2.6 pint/kWh.

Using a dehumidifier with the AC supply air fan operating continuously to provide ventilation air greatly increases dehumidifier operation. For the case of the conventional AC (without a dehumidifier), there are 7,283 hours over 60% RH in Miami and 5,411 hours in Houston with the AC supply air fan providing continuous ventilation in the HERS Reference house (the time over

60% RH becomes 7,971 hours and 5,656 hours in Miami and Houston for the High-Efficiency house). A larger dehumidifier is needed in this case since almost none of the latent load is met with the cooling coil. For the HERS Reference house (Table 20), the dehumidifier must run 3-5 times longer in Miami and 3-4 times longer in Houston under this scenario compared to normal AUTO fan operation (e.g., AC w/Vent [37 pint] versus Standalone Dehum [37 pint]). For the High-Efficiency house, the dehumidifier runs 2-3 times longer when the supply air fan runs continuously. In all cases the energy penalty due to dehumidifier operation is much larger when the AC supply fan operates continuously.

Finally, the last row in Table 20 and Table 21 shows the impact of combining fan cycling controls and a ventilation damper with a standard 75 pint per day dehumidifier. This option provides the same degree of ventilation as the other options. However, providing fresh air at the cooling coil inlet increases the latent capacity of the AC cooling coil and reduces the dehumidification load on the dehumidifier. The net result is good humidity control and low energy use relative to the other options.

Advanced Dehumidification Enhancements

Several other dehumidification options were also evaluated including:

- Santa Fe high efficiency dehumidifier from Therma-Stor. This 105 pint/day unit has a nominal efficiency of 5.4 pints/kWh, which is twice the dehumidification efficiency of a standard DH unit. This higher efficiency unit adds less sensible heat to the space (so less AC operation is required). Like the standard DH, this standalone unit was also assumed to control to a set point of 55% RH.
- Mini MAU. A very small makeup air unit (MAU) could be used to provide continuous treatment of ventilation air. The MAU is assumed to have its own fan and pretreated air is provided into the supply duct after (or in parallel with) the cooling coil. Only a 0.2 or 0.3 ton unit would be required to dehumidify 57.5 cfm of outdoor air. The condenser coil is located in the cold supply air. The unit was assumed to have 1 stage of cooling capacity and require separate fan power equivalent to 0.7 W/cfm (40 Watts).
- Residential Munters HCU. Munters makes a commercial desiccant unit that regenerates the desiccant wheel with condenser heat. We have assumed that a unit 20% the size of the HCU-1004 could be applied in a house as a ducted dehumidifier (separate ductwork from that used by the conventional AC unit). The 200 cfm HCU unit would be mounted outdoors. It would treat recirculated air from the house and provide no outdoor ventilation air.
- Enthalpy Wheel/ERV. A small energy recovery ventilator (ERV) is assumed to treat 57.5 cfm of incoming outdoor air while exhausting the same amount of air. The ERV runs continuously and is decoupled from the AC supply air fan (which is in the AUTO mode). The assumed effectiveness is 75% and the fan power for both the exhaust and return fans is assumed to be 0.5 W/cfm (on each side).
- Conventional AC with Heat Pipe HX. A heat pipe heat exchanger can be used to enhance the dehumidification performance of a conventional DX cooling coil. The heat pipe is assumed to be a 2-row, 11 fpi plate fin coil with a face area of 3 ft^2 on each side of the cooling coil (heat exchanger effectiveness ~ 0.32). The fan power is increased to 0.4 W/cfm (from 0.35 W/cfm for the conventional AC) to account for the extra air-side pressure drop.

- Condenser Reheat. A condenser reheat coil is installed downstream of the cooling coil to provide free air reheat. The cooling coil operates to hold either the cooling or dehumidification set point. The reheat coil modulates its heat output to maintain the space temperature at set point 0.5ºF below the cooling set point (if cooling coil operation driven by dehumidification overcools the space). The maximum heating capacity of the condenser reheat coil is assumed to be 75% of the nominal cooling coil capacity, or roughly half of the total condenser heat rejection. As a result the compressor discharge pressure is still driven by outdoor conditions since at least half of the condenser heat must be rejected to ambient.

Table 22 and Table 23 show the simulation results for these options in the HERS Reference and High-Efficiency houses, respectively. The high-efficiency Santa Fe DH unit provides good dehumidification with about half the energy penalty of the standard dehumidifier in all cases. The small scale MAU also provides good dehumidification with a slightly lower energy penalty than the standard dehumidifier (in reality the condenser sees air from the cooling coil outlet instead of the space which was assumed for these simulations, so the actual efficiency for this case would probably be even higher than was predicted here). The Munters HCU provides good dehumidification with a very low energy penalty. One major issue with this unit, however, is the need to be installed outside to reject heat to ambient.

Table 22. Impact of Other Dehumidification Equipment Options: HERS Reference House

Miami	Hours above 60% RH (hrs)	AC Runtime (hrs)	Dehumid Runtime (hrs)	AC Electric Use (kWh)	Supply Fan Electric Use (kWh)	Mech. Exh. Fan Use (kWh)	DH Unit Electric Use (kWh)	DH FAN Electric Use (kWh)	Total Electric Use (kWh)	Relative Energy Use (%)
Conventional AC	1,583	2,166	-	5,201	859	350	-	-	6,411	100%
Standalone Dehum (75 pint)	-	2,294	1,083	5,480	908	350	1,189	-	7,927	124%
Santa Fe High Efficiency DH	-	2,248	859	5,374	890	350	628	-	7,243	113%
Mini MAU (0.2 tons, 288 cfm/ton)	77	2,269	2,410	5,418	898	-	449	353	7,471	117%
Mini MAU (0.3 tons, 192 cfm/ton)	34	2,271	1,905	5,421	898	-	502	353	7,527	117%
Munters HCU	-	2,046	897	4,898	813	350	777	69	6,976	109%
Conv AC (AUTO) w/ ERV (CONST)	1,201	1,563	7,135	3,830	621	-	205	252	5,161	80%
AC with HP HX	675	2,478	-	5,644	1,122	350	-	-	7,116	111%
Condenser Reheat System	-	2,635	-	6,212	1,042	350	-	-	7,603	119%

Houston	Hours above 60% RH (hrs)	AC Runtime (hrs)	Dehumid Runtime (hrs)	AC Electric Use (kWh)	Supply Fan Electric Use (kWh)	Mech. Exh. Fan Use (kWh)	DH Unit Electric Use (kWh)	DH FAN Electric Use (kWh)	Total Electric Use (kWh)	Relative Energy Use (%)
Conventional AC	1,557	1,411	-	3,670	678	350	-	-	4,697	100%
Standalone Dehum (75 pint)	-	1,496	969	3,868	710	350	1,057	-	5,985	127%
Santa Fe High Efficiency DH	-	1,467	760	3,796	699	350	553	-	5,398	115%
Mini MAU (0.2 tons, 288 cfm/ton)	81	1,482	2,180	3,830	697	-	376	353	5,608	119%
Mini MAU (0.3 tons, 192 cfm/ton)	23	1,483	1,792	3,834	698	-	435	353	5,672	121%
Munters HCU	-	1,333	769	3,457	646	350	659	59	5,230	111%
Conv AC (AUTO) w/ ERV (CONST)	1,241	1,021	6,157	2,716	502	-	177	252	3,899	83%
AC with HP HX	1,047	1,607	-	3,969	869	350	-	-	5,187	110%
Condenser Reheat System	-	1,756	-	4,458	817	350	-	-	5,626	120%

Table 23. Impact of Other Dehumidification Equipment Options: High-Efficiency House

Miami	Hours above 60% RH (hrs)	AC Runtime (hrs)	Dehumid Runtime (hrs)	AC Electric Use (kWh)	Supply Fan Electric Use (kWh)	Mech. Exh. Fan Use (kWh)	DH Unit Electric Use (kWh)	DH FAN Electric Use (kWh)	Total Electric Use (kWh)	Relative Energy Use (%)
Conventional AC	3,909	2,170	-	3,187	520	350	-	-	4,057	100%
Standalone Dehum (75 pint)	-	2,592	1,486	3,738	620	350	1,640	-	6,348	156%
Santa Fe High Efficiency DH	-	2,476	1,206	3,581	592	350	888	-	5,411	133%
Mini MAU (0.2 tons, 288 cfm/ton)	6	2,551	3,508	3,680	610	-	673	353	5,667	140%
Mini MAU (0.3 tons, 192 cfm/ton)	5	2,559	2,604	3,692	612	-	708	353	5,718	141%
Munters HCU	-	1,859	1,425	2,713	446	350	1,240	110	4,968	122%
Conv AC (AUTO) w/ ERV (CONST)	1,726	1,445	6,984	2,152	347	-	201	252	3,203	79%
AC with HP HX	1,583	2,596	-	3,571	710	350	-	-	4,631	114%
Condenser Reheat System	-	3,344	-	4,664	799	350	-	-	5,813	143%

Houston	Hours above 60% RH (hrs)	AC Runtime (hrs)	Dehumid Runtime (hrs)	AC Electric Use (kWh)	Supply Fan Electric Use (kWh)	Mech. Exh. Fan Use (kWh)	DH Unit Electric Use (kWh)	DH FAN Electric Use (kWh)	Total Electric Use (kWh)	Relative Energy Use (%)
Conventional AC	2,623	1,434	-	2,485	449	350	-	-	3,284	100%
Standalone Dehum (75 pint)	-	1,643	1,080	2,810	505	350	1,185	-	4,850	148%
Santa Fe High Efficiency DH	-	1,584	870	2,713	488	350	638	-	4,189	128%
Mini MAU (0.2 tons, 288 cfm/ton)	20	1,632	2,611	2,790	502	-	459	353	4,457	136%
Mini MAU (0.3 tons, 192 cfm/ton)	7	1,637	2,065	2,799	504	-	509	353	4,518	138%
Munters HCU	-	1,281	999	2,209	407	350	861	77	3,981	121%
Conv AC (AUTO) w/ ERV (CONST)	1,323	981	6,153	1,722	318	-	177	252	2,721	83%
AC with HP HX	1,572	1,690	-	2,750	595	350	-	-	3,695	113%
Condenser Reheat System	-	2,078	-	3,441	627	350	-	-	4,418	135%

As expected, the ERV is more energy efficient than any of the other options simulated; however, the ERV option still results in a large number of hours with elevated space humidity levels. The ERV has a modest humidity impact since it can not provide dehumidification when the indoor-to-outdoor humidity differential is small. The simple condenser reheat system provides good humidity control with an energy penalty that is slightly lower than the standalone dehumidifier.

6. What Dehumidification Options are Most Cost Effective?

The simulations in the sections above evaluated the dehumidification performance of various conventional and advanced space-conditioning options. The results show that two factors are likely to increase the need for explicit dehumidification:

- High-efficiency houses in humid climates (Miami, Houston, Jacksonville and Wilmington) spend more hours over 60% RH compared to a standard (HERS Reference) house due to significantly lower sensible cooling loads, and

- Adding continuous ventilation, as required under ASHRAE Standard 62.2-2004, increases the number of hours over 60% RH compared to a house with only natural infiltration.

As a result, many houses need explicit dehumidification to maintain good humidity control. Of the various dehumidification options evaluated in this study, many were able to eliminate the hours with high indoor humidity (i.e., hours when space humidity is greater than 60% RH).

A basic life-cycle cost analysis was performed to determine which of these options would be the most cost effective. The incremental first costs, relative to a conventional AC system, were estimated using R.S. Means, vendor websites, and other data sources (the equipment costing details are summarized in Appendix C). The energy operating cost premiums were determined using the annual energy data from Tables 20 through 23 along with assumed energy costs of $0.10/kWh for both Miami and Houston. The net present value of the operating cost premium and the incremental capital cost was determined assuming a 10-year life and a discount rate of 3% per year. The results of the life-cycle analysis are shown in Table 24.

Table 24. Comparison of Incremental Equipment, Operating and Life-Cycle Cost Savings

				Operating Cost Premium				Net Present Cost			
				HERS Reference		High Efficiency		HERS Reference		High Efficiency	
Dehumidification Options	Incremental Equip Cost Premium	Additional Controls & Installation	Total Cost Premium	Miami	Houston	Miami	Houston	Miami	Houston	Miami	Houston
Standalone Dehum (37 pint)	$210	$40	$250	$143	$122	$227	$154	$1,468	$1,288	$2,185	$1,566
Standalone Dehum (75 pint)	$269	$40	$309	$152	$129	$229	$157	$1,603	$1,407	$2,263	$1,644
Santa Fe High Efficiency DH	$1,139	$40	$1,179	$83	$70	$135	$91	$1,889	$1,777	$2,334	$1,951
Standalone Dehum (75 pint) MIXED	$330	$40	$370	$175	$155	$240	$170	$1,861	$1,688	$2,413	$1,821
Standalone Dehum (75 pint) CYC/DMP	$508	$69	$577	$132	$132	$165	$126	$1,706	$1,705	$1,985	$1,655
Mini MAU (0.2 tons, 288 cfm/ton)	$805	$258	$1,063	$106	$91	$161	$117	$1,967	$1,840	$2,437	$2,063
Mini MAU (0.3 tons, 192 cfm/ton)	$890	$258	$1,147	$112	$97	$166	$123	$2,100	$1,978	$2,564	$2,199
Munters HCU	$1,650	$749	$2,399	$57	$53	$91	$70	$2,881	$2,853	$3,176	$2,993
Conv AC (AUTO) w/ ERV (CONST)	$1,010	$621	$1,631	($125)	($80)	($85)	($56)	$564	$950	$903	$1,151
AC with HP HX	$625		$625	$71	$49	$57	$41	$1,226	$1,043	$1,115	$975
Condenser Reheat System	$352	$320	$672	$119	$93	$176	$113	$1,689	$1,463	$2,170	$1,639

Notes: Gray shaded rows indicate systems that provide good humidity control (i.e., only a few hours above 60% RH)
Operating cost premium based on incremental energy use compared to conventional AC unit and assumes $0.10/kWh.
Life-cycle costs determined for 10 yr equipment life with 3% annual discount rate.

The conventional standalone dehumidifier and the condenser reheat system are the lowest cost options that also provide good humidity control[19]. The high-efficiency (Santa Fe) standalone

[19] The ERV and heat pipe assisted AC both have lower life-cycle costs but do not always maintain the space below 60% RH.

dehumidifier has slightly higher life-cycle costs, implying its much better dehumidification efficiency and large capacity are not fully utilized because dehumidification loads are small.

Field studies conducted by the Building America program (Rudd et al. 2005) have demonstrated that some means of zone air mixing is required to dehumidify an entire house with a simple standalone unit. To provide adequate zone air mixing, the dehumidifier unit must be ducted, or the central air handler can be used to distribute the dehumidified air. Alternatively, fan cycling controls on the main air handler unit can be used to keep the house zone well mixed. Of the options that provide good mixing to ensure uniform dehumidification, the condenser reheat system and standalone dehumidifier with fan cycling controls (and outdoor air damper) have the lowest life-cycle costs. If the fan cycling controls do not provide ventilation, but only operate the AC supply air fan 10% of the time to provide zone mixing, the life-cycle cost is slightly higher. The Mini MAU also has the potential to provide good mixing and humidity control with a slightly higher life-cycle cost. Figure 20 below graphically compares the life-cycle cost premium for these options (cost premium over the baseline conventional AC).

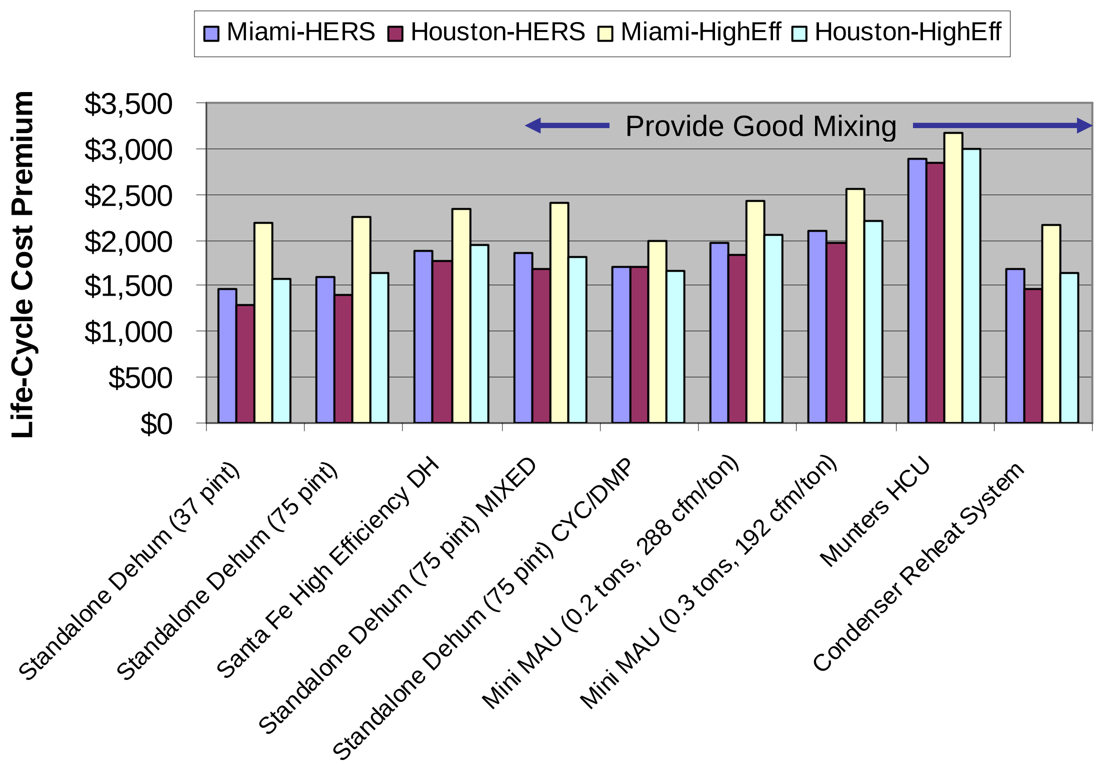


Figure 20. Comparing Life-Cycle Cost Premiums for the Most Promising Dehumidification Options

7. Summary and Conclusions

This study integrated detailed models of conventional and advanced cooling and dehumidification equipment into a TRNSYS-based building simulation model. Building models were developed for a standard HERS Reference house, meant to represent current construction practice, and a High-Efficiency house that would likely qualify for a federal tax credit. The combined heating and cooling loads were 33% to 53% lower for the High-Efficiency house, depending on climate, set point and other factors. The size of the air conditioner was 29% to 39% smaller in the High-Efficiency house compared to the standard house.

The different houses were simulated in seven southeastern U.S. cities and with various ventilation/infiltration scenarios including: 1) variable or natural infiltration alone, and 2) mechanical ventilation that complied with ASHRAE Standard 62.2-2004. The simulations accurately considered several key factors that affect dehumidification performance and space humidity levels, including: 1) duct air leakage and thermal losses, 2) the impact of part load latent capacity degradation with various supply air fan control and ventilation strategies, and 3) the impact of space overcooling and other novel dehumidification control strategies.

Summary of Findings

The first step was to evaluate the sensible and latent cooling loads in the buildings, independent of HVAC equipment used. Some of the major findings from this “ideal” load analysis included:

- The humid locations of Miami, Houston, Jacksonville, and Wilmington all yielded similar cooling and dehumidification load requirements. Atlanta, Sterling and Fort Worth were consistently found to require much less dehumidification than the other locations.
- An evaluation of hourly sensible heat ratios (SHRs) showed that the humid locations can have many hours when the SHR of the cooling load is low. However, the cooling load associated with these periods is small. For instance, the standard HERS Reference house in Miami with variable infiltration and set points of 75°F and 50% RH spends 30% of the cooling season with the SHR below 0.6. However, these hours represent only 9.3% of the total annual cooling load.
- If the same house uses constant ventilation (per ASHRAE Standard 62.2-2004), then the number of hours and load with a low SHR increase substantially. The same HERS Reference house in Miami with continuous ventilation spends 50% of the annual cooling hours with an SHR below 0.6. The cooling load associated with these hours becomes about 25% of the total annual cooling load.

When a conventional 13 SEER air conditioner is used to condition the houses, the periods of low SHR for the most part result in periods of high indoor humidity. The metric used in this study to assess the degree of humidity control was the number of hours in the year when the space humidity exceeded 60% RH. The main findings for this part of the study included:

- The simulation results for the standard HERS Reference house with variable infiltration (and a 75°F cooling set point) were generally consistent with field experience: a conventional AC provides adequate dehumidification to hold the space below 60% RH for all but a few hundred hours of the year in most climates. The annual time above 60% RH ranged from 588 to 1017 hours in the four most humid climates and 46 to 193 hours in the three less humid climates.
- Indoor humidity levels were typically higher for the High-Efficiency house compared to the standard house, in spite of the fact that infiltration rates were lower. The reduction in sensible cooling loads due to better walls and windows reduces air conditioner runtimes and results in less dehumidification provided by the air conditioner coil.
- Adding continuous ventilation, as required by ASHRAE Standard 62.2-2004, significantly increases the number of hours over 60% RH in all scenarios. The main reason is that more ventilation is provided at moderate outdoor conditions, when the driving potential for natural infiltration is small. While the impact of continuous ventilation on the total cooling load is small at these outdoor conditions, the moisture introduced at these times can have a big impact on space humidity levels since air conditioner runtimes are low.
- Because high humidity conditions occur at times when cooling loads are small, lowering the cooling set point temperature can have a big impact on space humidity levels. Decreasing the cooling set point to 72°F substantially decreased the hours above 60% RH.
- Reducing the AC supply air flow to 300 cfm per ton (instead of 400 cfm per ton) had the expected impact of significantly lowering space humidity levels.
- The impact of air conditioner sizing was found to be somewhat at odds with conventional wisdom: for the standard HERS Reference house, which included duct air leakage and thermal losses, oversizing the air conditioner actually resulted in slightly lower indoor humidity levels. Oversizing decreased the supply fan runtime, which in turn decreased the amount of outdoor air introduced to the space from duct leakage. The High-Efficiency house, which assumed no duct air leakage, showed a modest increase in indoor humidity levels due to oversizing, as might normally be expected.
- In most cases, it was assumed that the AC unit's supply air fan operated in AUTO fan mode, with the supply fan cycling on and off with the cooling coil. Continuous ventilation was assumed to be provided by a separate exhaust fan. Another method to provide continuous ventilation is to introduce outdoor air through the air handler unit. The simulations showed that continuous or CONSTANT supply air fan operation with ventilation not only increased energy use significantly, but also increased the number of hours over 60% RH by a factor of two to four.
- Another ventilation strategy is to use a fan cycling controller to periodically operate the supply air fan to guarantee a minimum runtime fraction for each hour to provide outdoor air to the space. This central fan integrated strategy requires a ventilation air intake on the air handler unit. In some cases the fan cycling controller will also open and close a ventilation air damper to ensure that only the proper amount of ventilation air is provided. The fan cycling controller with a ventilation damper provides the exact amount of ventilation to the air handler (over the course of an hour) with only a modest impact on indoor humidity levels. The energy penalty for this strategy is very modest compared to operating the supply air fan continuously to provide ventilation.

Several advanced cooling and dehumidification systems, working in tandem with the conventional air conditioner, were also evaluated. These systems explicitly provided dehumidification that generally eliminated the number of hours above 60% RH. The major findings for this part of the study included:

- A conventional standalone dehumidifier provided good humidity control with a fairly modest energy cost premium. Even a small dehumidifier (i.e., 37 pint per day) was able to satisfy the modest dehumidification loads that the conventional AC was unable to meet.
- A standalone dehumidifier used with a fan cycling controller and ventilation air damper provides dehumidification along with some level of periodic supply fan operation to ensure ventilation and dehumidification are adequately distributed throughout the house.
- Many of the advanced dehumidification options – such as high efficiency dehumidifiers, a small Munters HCU unit, and a mini makeup air unit – provided good humidity control but are generally less cost effective than the conventional standalone dehumidifier options.
- Condenser reheat systems are potentially a cost-effective humidity control option.

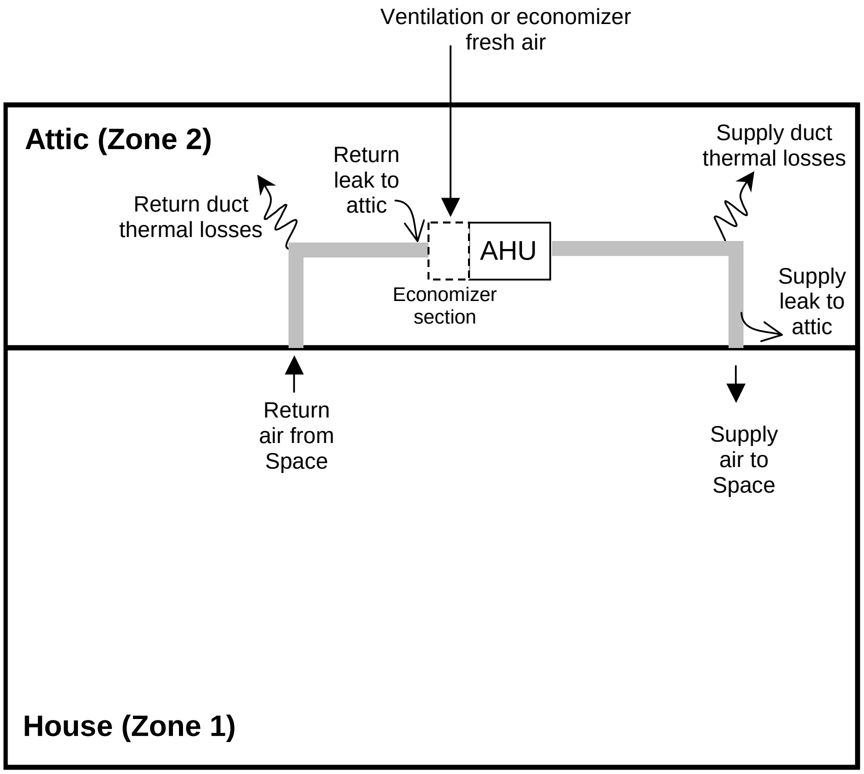
Implications for the Future

The results of this study imply that as houses located in humid climates become more energy efficient, and provide the continuous ventilation required by ASHRAE Standard 62.2-2004, they will have a greater need for explicit dehumidification. The amount of additional dehumidification required can be modest – even the smallest dehumidifier on the market today can satisfy the unmet moisture loads in a 2,000 sq ft house. Because the moisture loads are modest, dehumidifier efficiency is in some cases a secondary issue. Finding efficient ways to work with existing equipment and systems in the home can often be more important.

Therefore, equipment options or configurations that can provide modest dehumidification capacity while coordinating their operation with conventional cooling and ventilation systems in a cost effective manner appear to be promising for future energy-efficient homes. Several of the advanced dehumidification systems evaluated as part of this study provided improved energy performance while maintaining proper indoor humidity levels, but high first cost yielded relatively high life-cycle costs. The research team believes that alternative designs for some of these options can be developed to reduce first cost, and these designs will be further investigated and refined during the next stage of this project.

Appendix A
Duct Leakage and Thermal Loss Model

The duct leakage model in TRN-RESDH assumes all losses are to and from zone 2 (the attic).



Return Duct

Air from the house zone (zone 1) enters the return duct. These are average conditions for the time step. According to evaluations of ASHRAE Standard 152 by Palmiter et al, the temperature change of air in a duct that passes through an unconditioned space at a uniform temperate (T_o) is defined as:

$$\frac{(T_{out} - T_o)}{(T_{in} - T_o)} = e^{-UA/m \cdot cp}$$

Applying this to our case, the thermal losses from the return duct are given by:

$$TAR = T_{z2} + (T_{z1} - T_{z2})e^{-A_R / M'_R \cdot cp \cdot (R_{duct} + 1)}$$

WAR = w_{z1}

where:

T_{z1}, T_{z2} - Temperature of zone 1 and 2 (°F)
w_{z1}, w_{z2} - humidity ratio of zone 1 and 2 (lb/lb)
A_R - Area of Return Duct (ft^2)
M_R - Return Airflow into economizer section of AHU (lb/h)
F_R - fraction of total return airflow (M_R) from zone 2
M'_R - Airflow into Return Duct after accounting for leakage (lb/h)
i.e. $M'_R = M_{R*} (1-F_R)$
cp - specific heat of air (Btu/lb-°F)
R_{duct} - R-Value of duct insulation (ft^2-°F/Btu)
(the value of 1 accounts for the film coefficient)

Then the impact of the return leak is added in after the thermal losses:

$TAR' = TAR \cdot (1-F_R) + T_{z2} \cdot F_R$
$WAR' = WAR \cdot (1-F_R) + w_{z2} \cdot F_R$

Where TAR' and WAR' are the conditions entering the economizer section (however the economizer and enthalpy wheel control calculations are still based on space conditions)

The heat gain to zone 2 from thermal conduction is the same as the heat loss of the return air as it travel through the duct, which is defined as

$Q_r = M_R \cdot (1-F_R) \cdot 0.241 \cdot (T_{z1} - TAR)$

Supply Duct

Supply air from the AHU unit (i.e., the average for the time step) enters the supply duct. The impact of thermal conduction losses are given by

$$TAS = T_{z2} + (T_{ACout} - T_{z2})e^{-A_S / M_S \cdot cp \cdot R_{duct}}$$
$WAS = w_{ACout}$

where:
T_{ACout} - Average Temperature leaving AHU (°F)
w_{ACout} - average humidity ratio leaving AHU (lb/lb)
A_S - Area of Supply Duct (ft^2)
M_S - Supply Airflow from AHU (lb/h)

A portion of the supply air flow goes to the space (zone 1), while the balance goes into the attic (zone 2)

To Space (zone 1): $M_{S\text{-}space} = M_S \cdot (1- F_S)$
To zone 2: $M_{S\text{-}z2} = M_S \cdot F_S$

where:
F_S - fraction of total Supply airflow (M_S) into zone 2

The heat gain to zone 2 from thermal conduction is the same as the heat loss of the supply air as it travel through the duct, which is defined as

$$Q_s = M_S \cdot 0.241 \cdot (T_{ACout} - TAS)$$

Impact on Attic

Zone 2 has two impacts from the duct losses:

1. Supply air (airflow of $M_{S\text{-}z2}$ at TAS and WAS) enters the zone to condition it,
2. Conduction losses from the return duct (Q_r) and the supply duct (Q_s) are added to the zone as a thermal gain.

We make the following assumptions that should be valid for modest leakage rates:

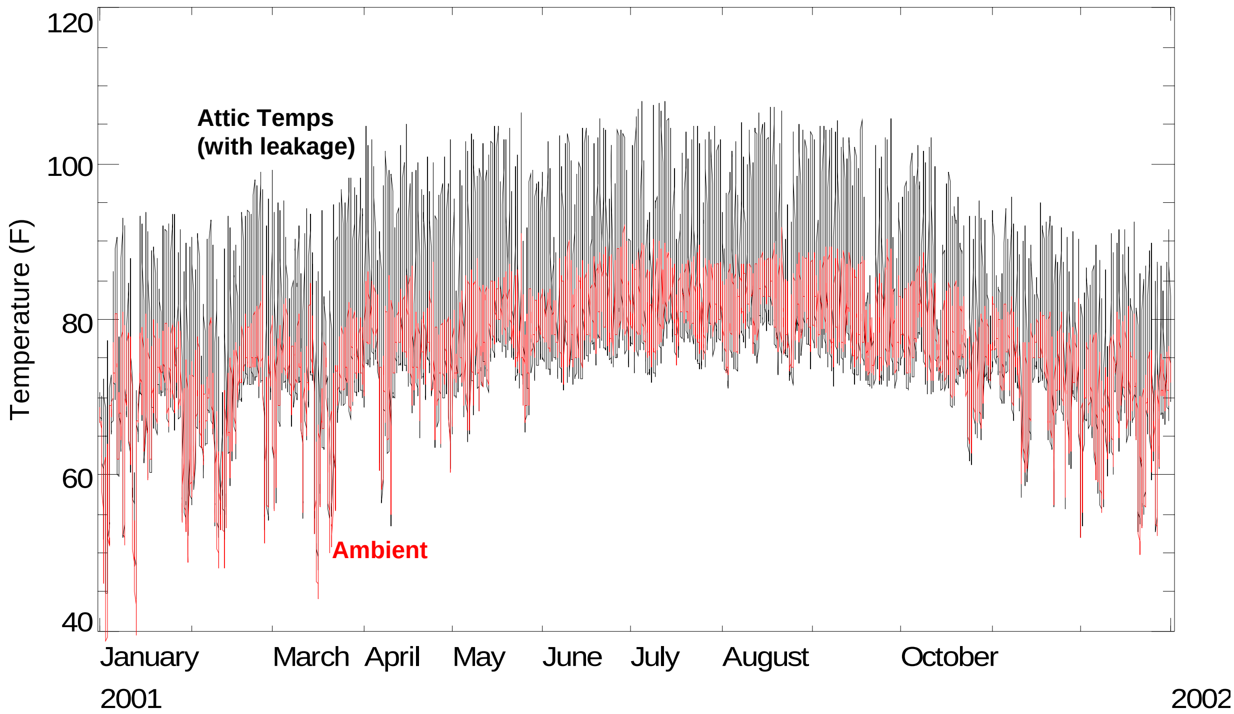
- Any mismatch of flow from zone 2 (return leaks) and into zone 2 (supply leaks) is neglected,
- Duct leaks have no impact on infiltration rates in either zone,
- Infiltration rates from zone 1 do not affect zone 2 and vice versa.

Duct Leakage Impact

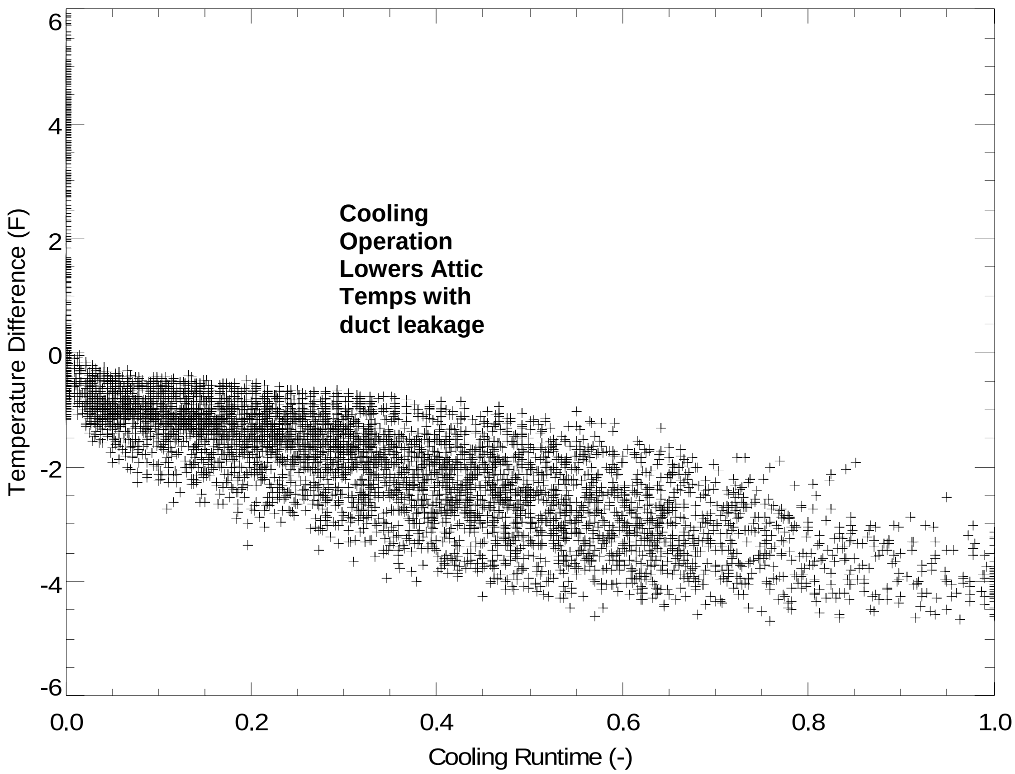
Here is the impact of duct leakage for the HERs reference house in Miami. The ratio of the runtime is a good surrogate for the distribution efficiency. The nominal values provide an 80% distribution system efficiency.

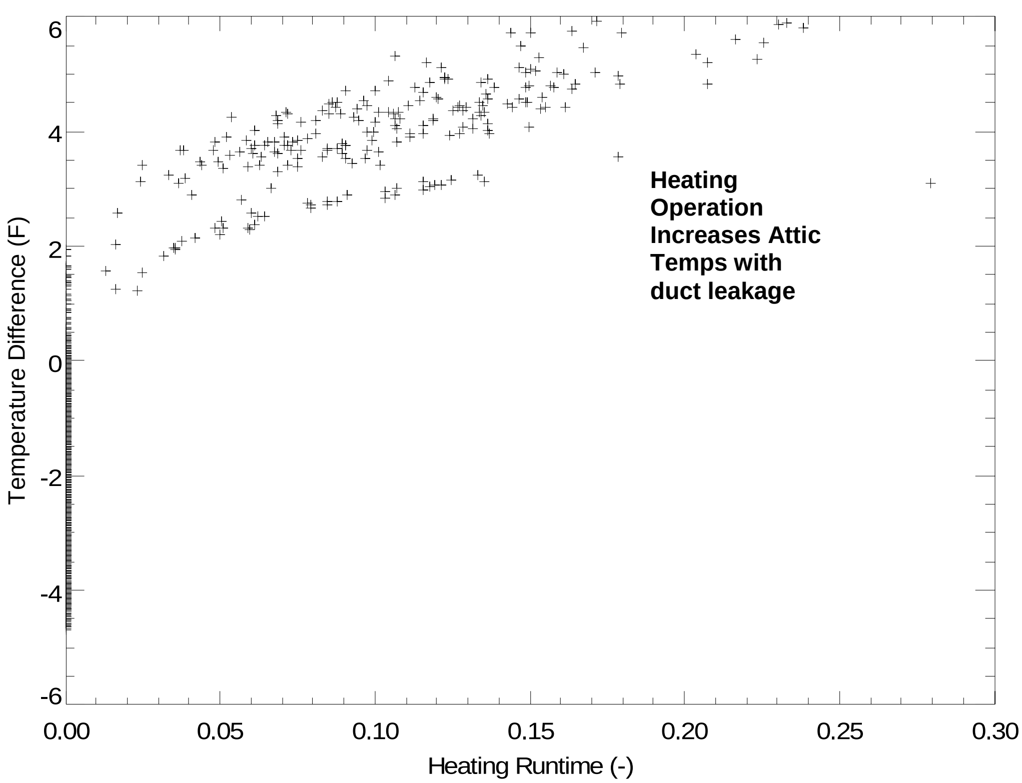
	AC Runtime (hrs)	**Ratio**
No duct losses	1,481.9	-
Only Thermal losses (R6 insulation)	1,730.4	85.6%
Only Thermal losses (R99 insulation)	1,500.0	98.8%
Only Return Leak (4%)	1,551.8	95.5%
Only Supply Leak (3%)	1,531.3	96.8%
Only Return & Supply Leaks (4% & 3%)	1,593.8	93.0%
Thermal Losses & Leakage Combined	1,842.0	80.5%

Notes: Supply and return duct areas are 300 ft2 and 100 ft2. Air flow is 1200 cfm for supply and return at the AC unit.

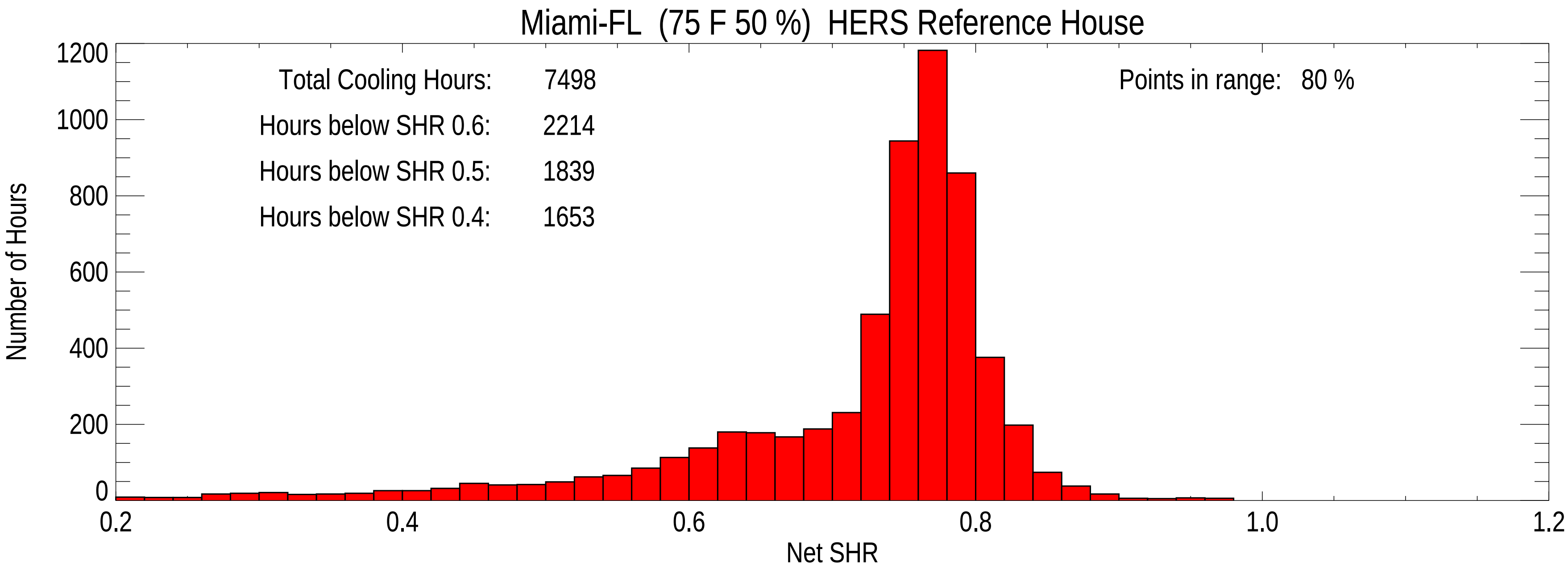


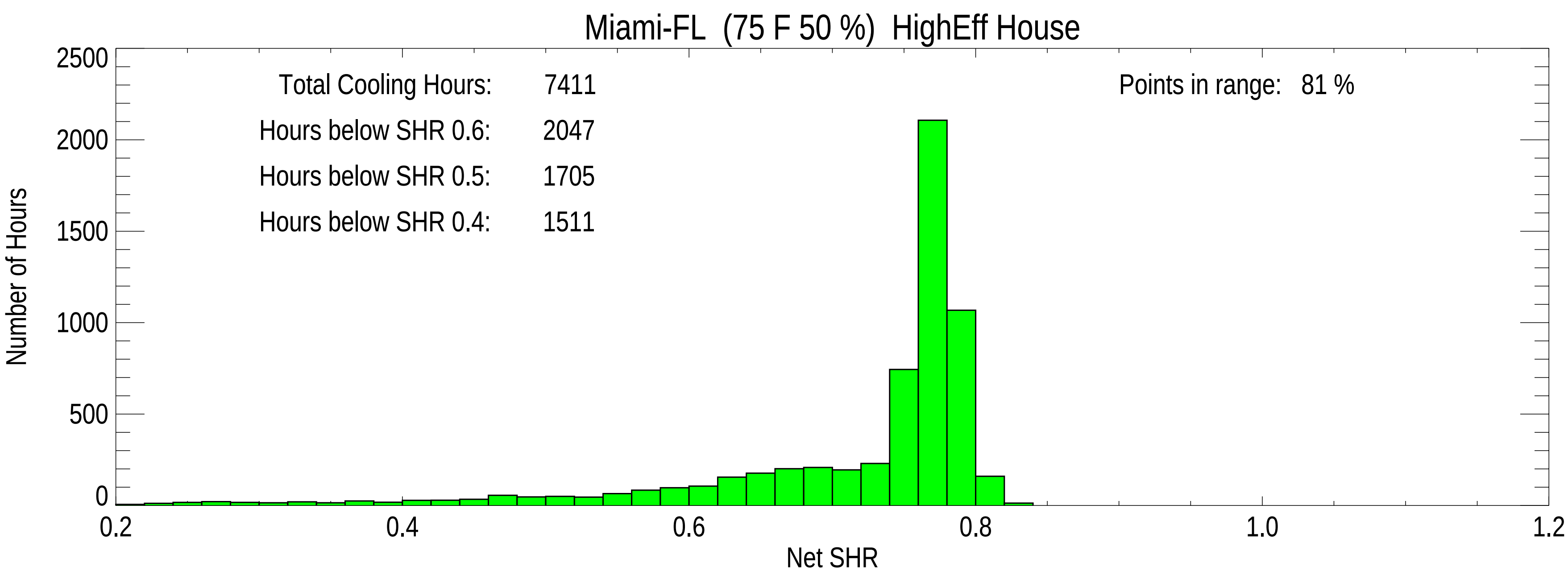
The next plots show the difference in attic temperatures with and without duct leakage. Duct leakage cools the attic in the summer and heats it in the winter.

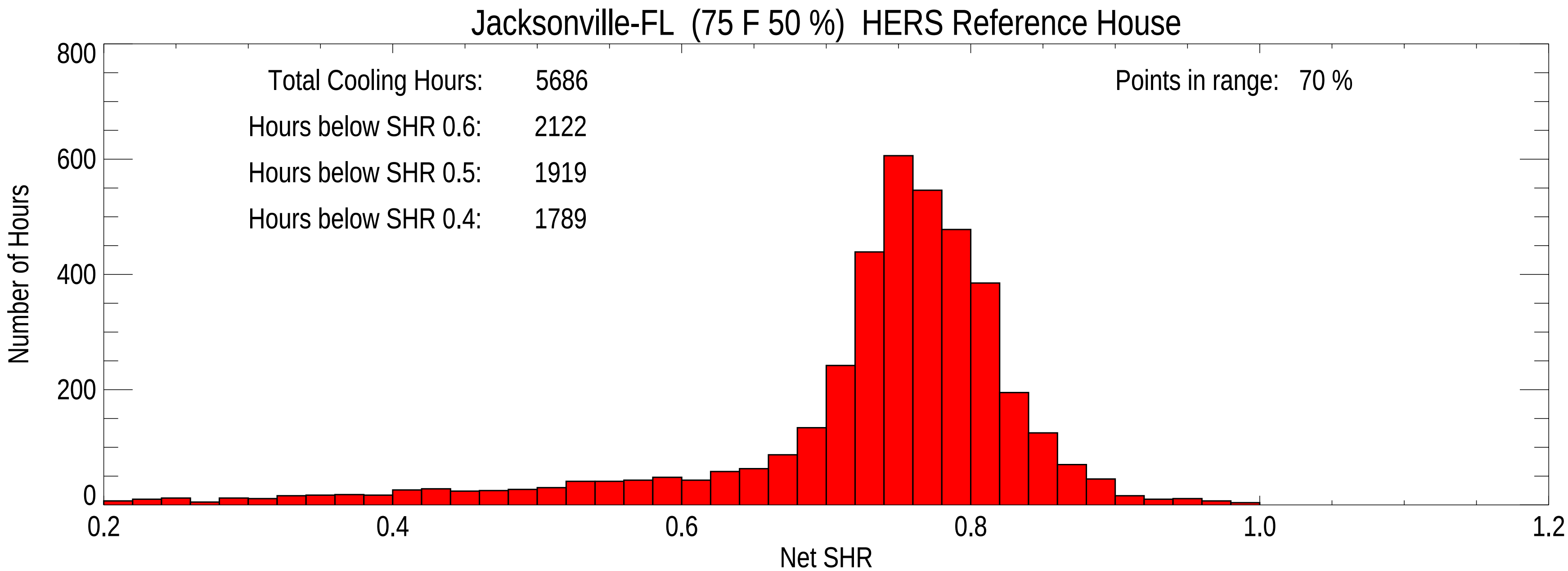

Cooling
Operation
Lowers Attic
Temps with
duct leakage
Temperature Difference (F)
Cooling Runtime (-)
6
4
2
0
-2
-4
-6
0.0
0.2
0.4
0.6
0.8
1.0

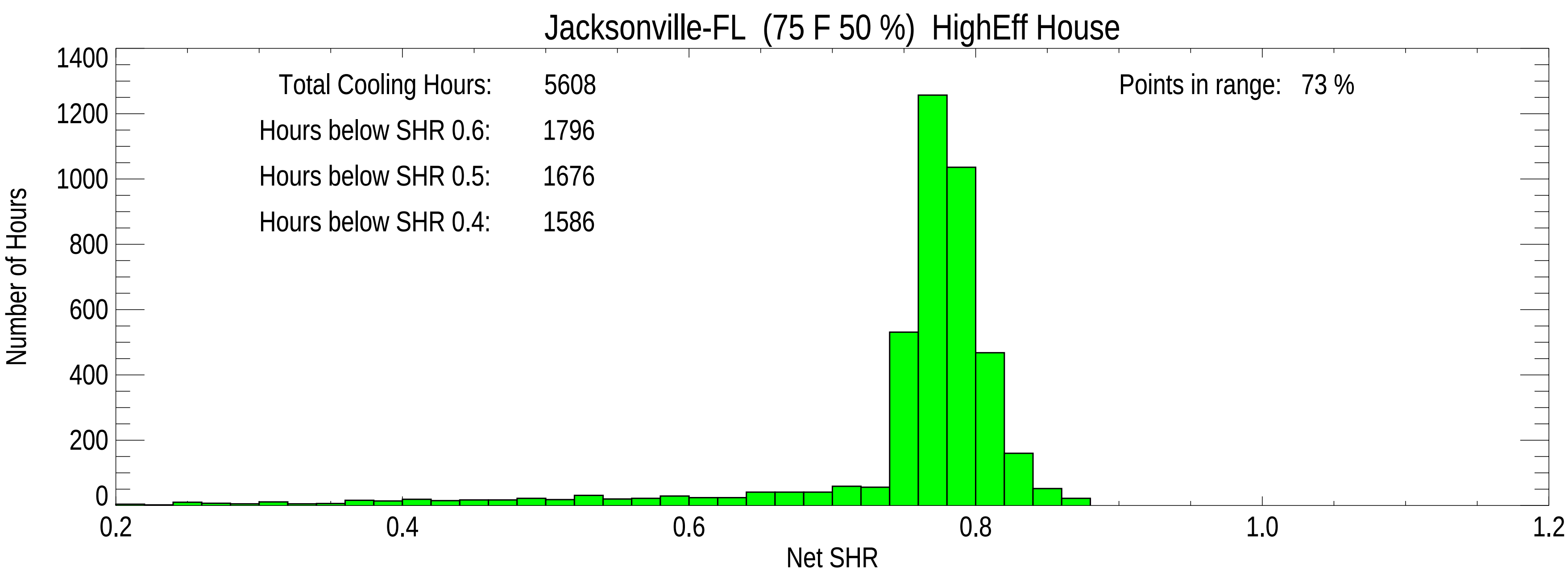

Heating
Operation
Increases Attic
Temps with
duct leakage
Temperature Difference (F)
Heating Runtime (-)
6
4
2
0
-2
-4
-6
0.00
0.05
0.10
0.15
0.20
0.25
0.30

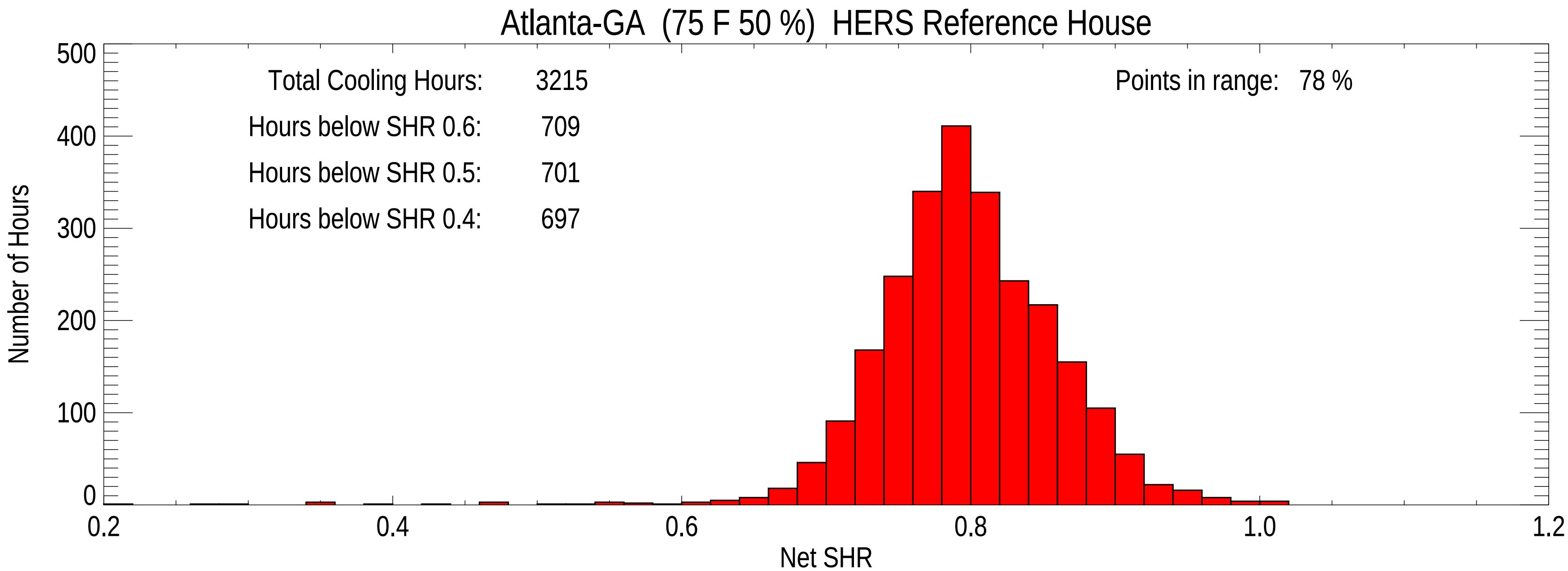
Appendix B
Plots of Time and Load Weighted SHR and RH

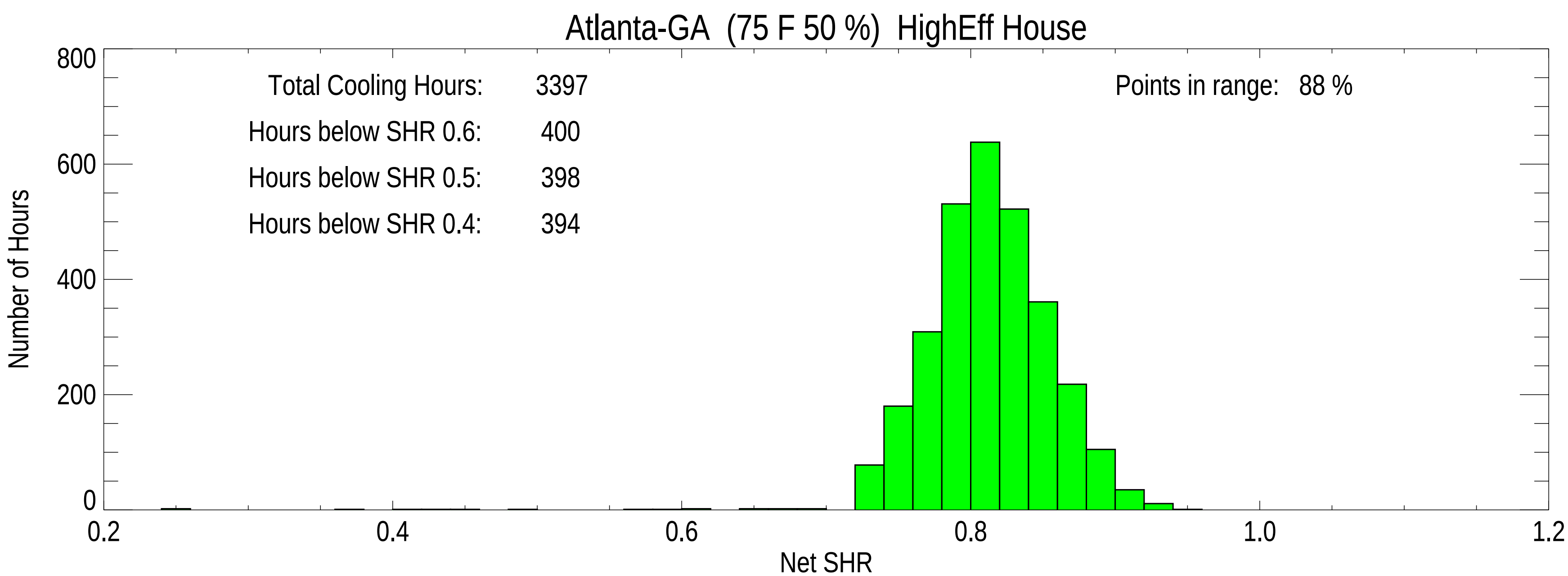

Miami-FL (75 F 50 %) HERS Reference House
Total Cooling Hours: 7498
Hours below SHR 0.6: 2214
Hours below SHR 0.5: 1839
Hours below SHR 0.4: 1653
Points in range: 80 %
Number of Hours
0
200
400
600
800
1000
1200
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

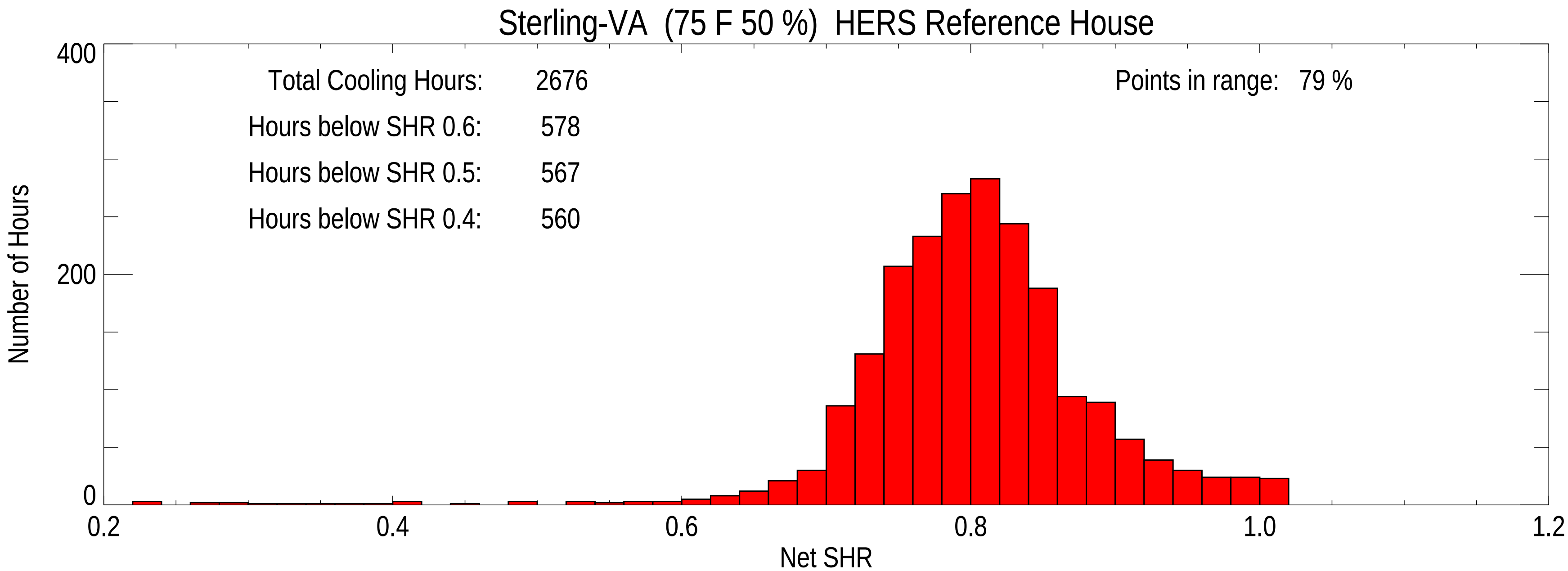

Miami-FL (75 F 50 %) HighEff House
Total Cooling Hours: 7411
Hours below SHR 0.6: 2047
Hours below SHR 0.5: 1705
Hours below SHR 0.4: 1511
Points in range: 81 %
Number of Hours
0
500
1000
1500
2000
2500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

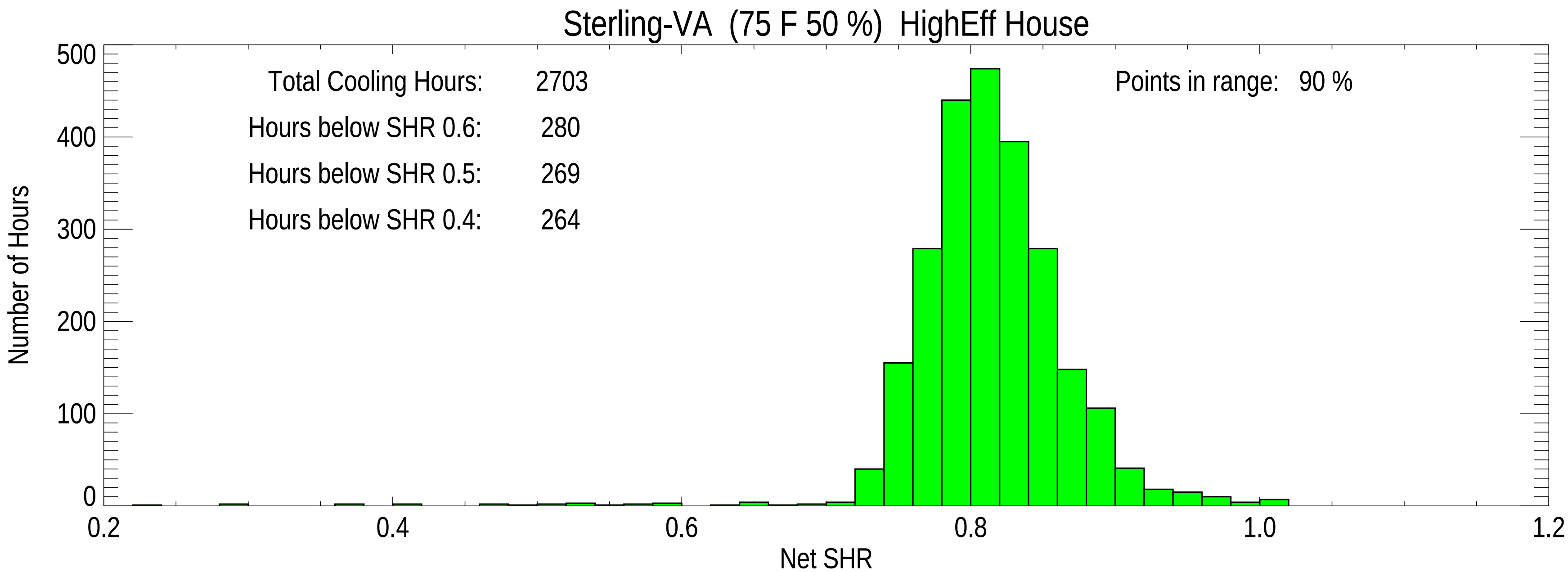

Jacksonville-FL (75 F 50 %) HERS Reference House
Total Cooling Hours: 5686
Hours below SHR 0.6: 2122
Hours below SHR 0.5: 1919
Hours below SHR 0.4: 1789
Points in range: 70 %
Number of Hours
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

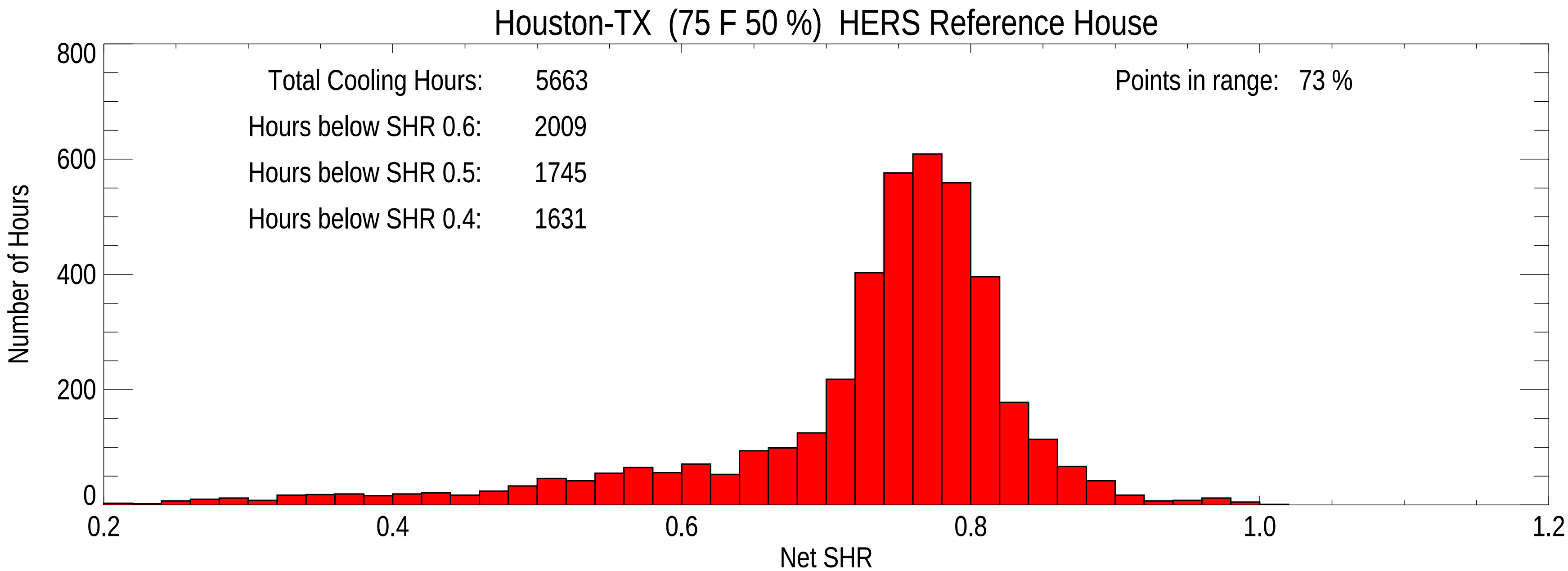

Jacksonville-FL (75 F 50 %) HighEff House
Total Cooling Hours: 5608
Hours below SHR 0.6: 1796
Hours below SHR 0.5: 1676
Hours below SHR 0.4: 1586
Points in range: 73 %
Number of Hours
0
200
400
600
800
1000
1200
1400
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

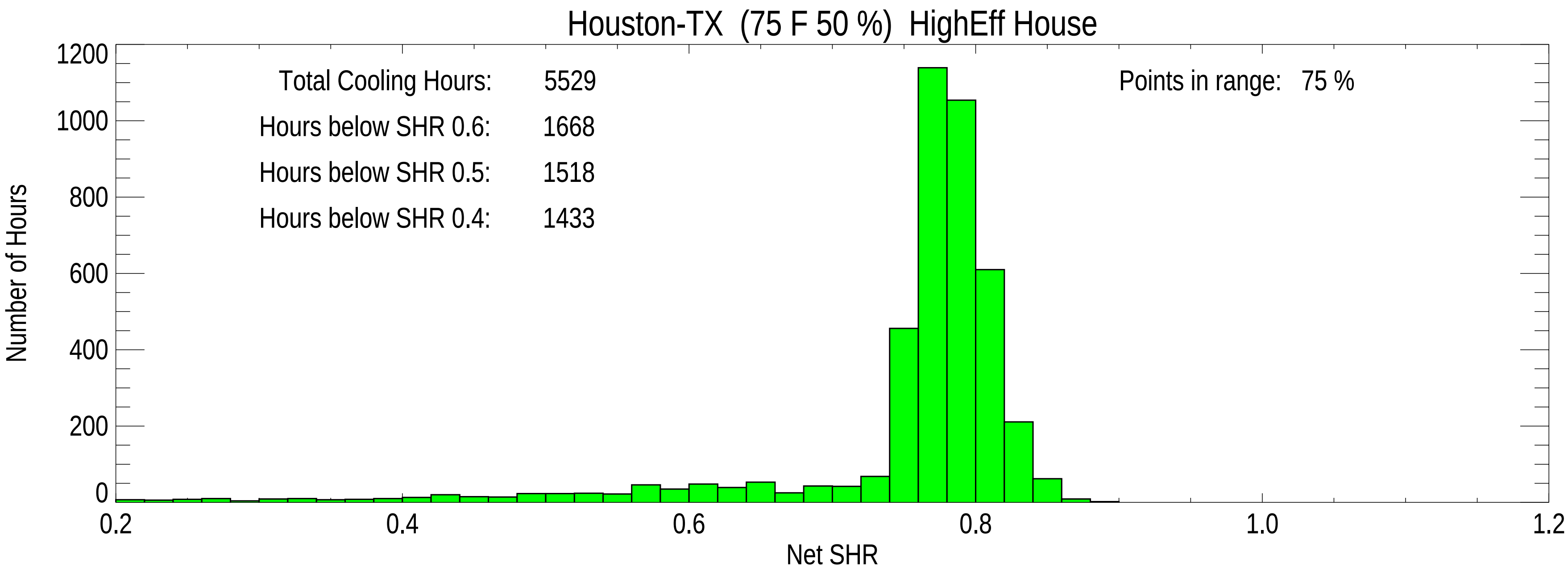

Atlanta-GA (75 F 50 %) HERS Reference House
Total Cooling Hours: 3215
Hours below SHR 0.6: 709
Hours below SHR 0.5: 701
Hours below SHR 0.4: 697
Points in range: 78 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

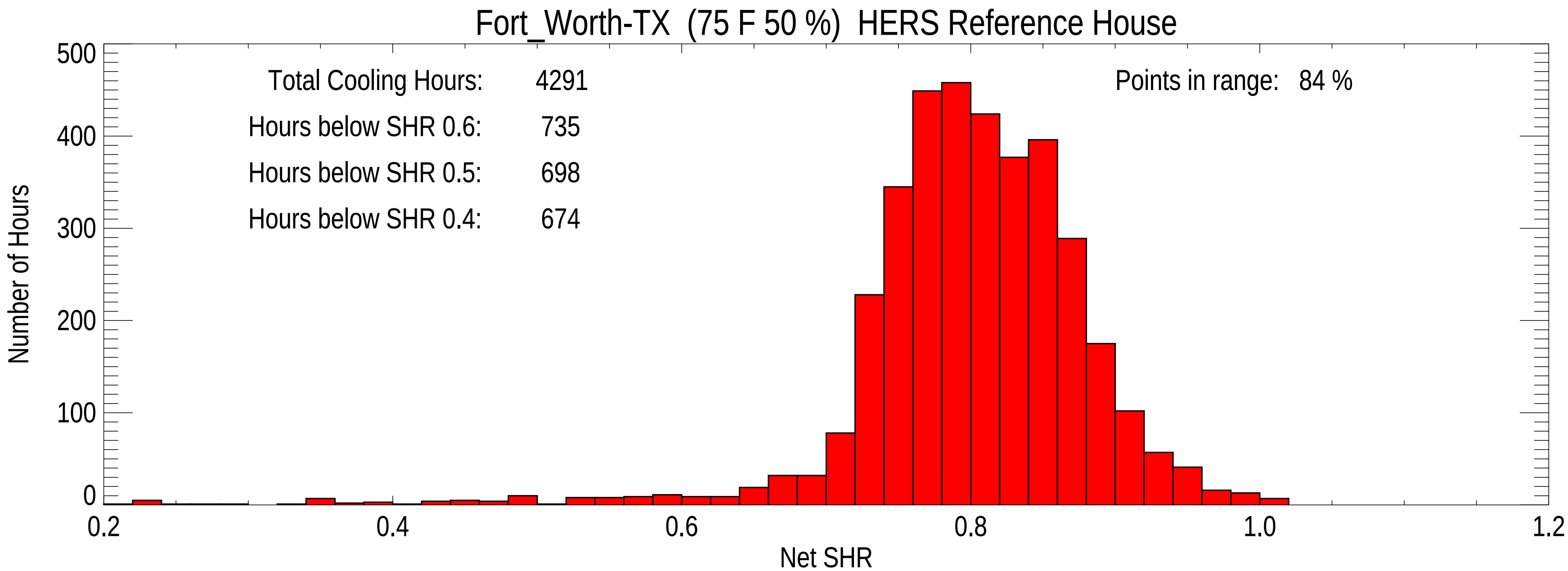

Atlanta-GA (75 F 50 %) HighEff House
Total Cooling Hours: 3397
Hours below SHR 0.6: 400
Hours below SHR 0.5: 398
Hours below SHR 0.4: 394
Points in range: 88 %
Number of Hours
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

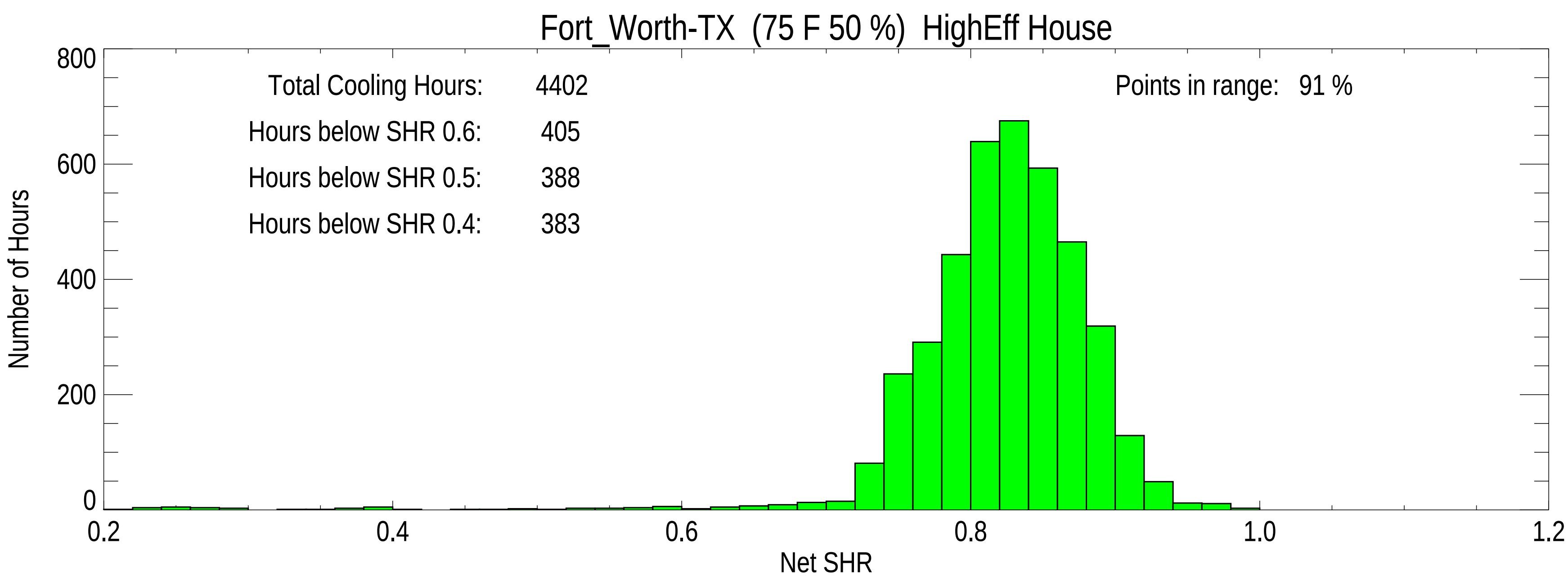

Sterling-VA (75 F 50 %) HERS Reference House
Total Cooling Hours: 2676
Hours below SHR 0.6: 578
Hours below SHR 0.5: 567
Hours below SHR 0.4: 560
Points in range: 79 %
Number of Hours
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

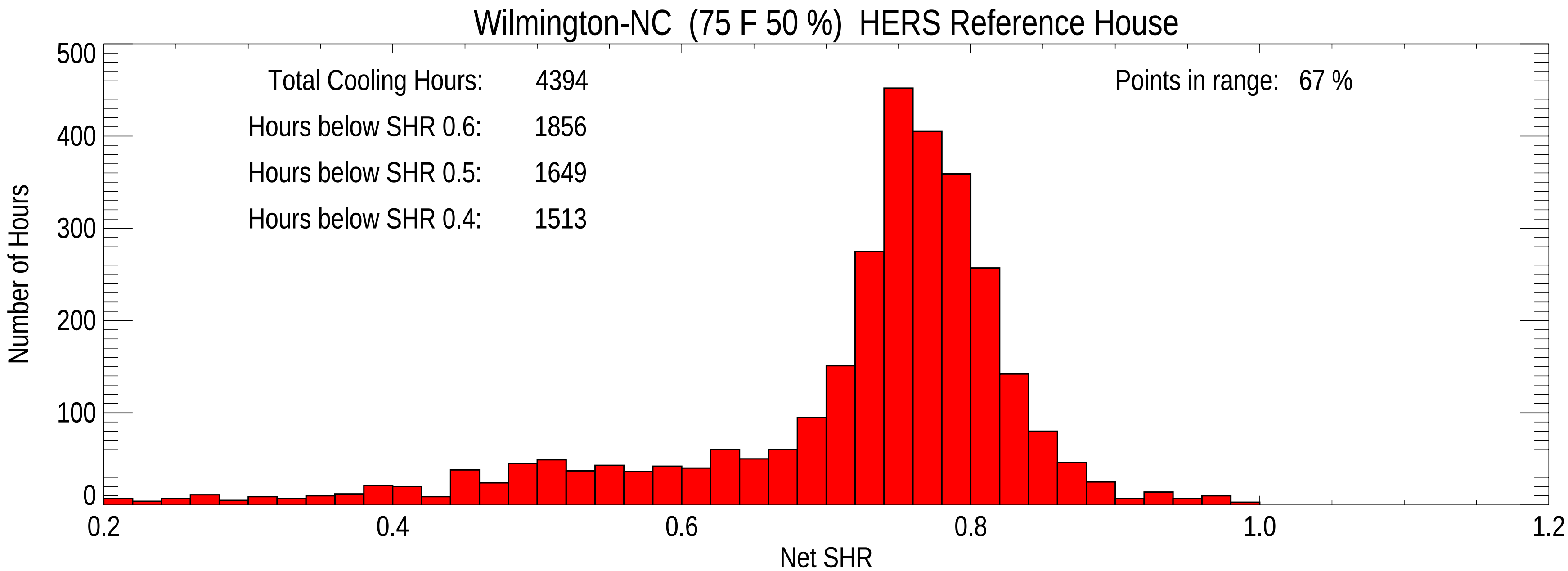

Sterling-VA (75 F 50 %) HighEff House
Total Cooling Hours: 2703
Hours below SHR 0.6: 280
Hours below SHR 0.5: 269
Hours below SHR 0.4: 264
Points in range: 90 %
Number of Hours
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

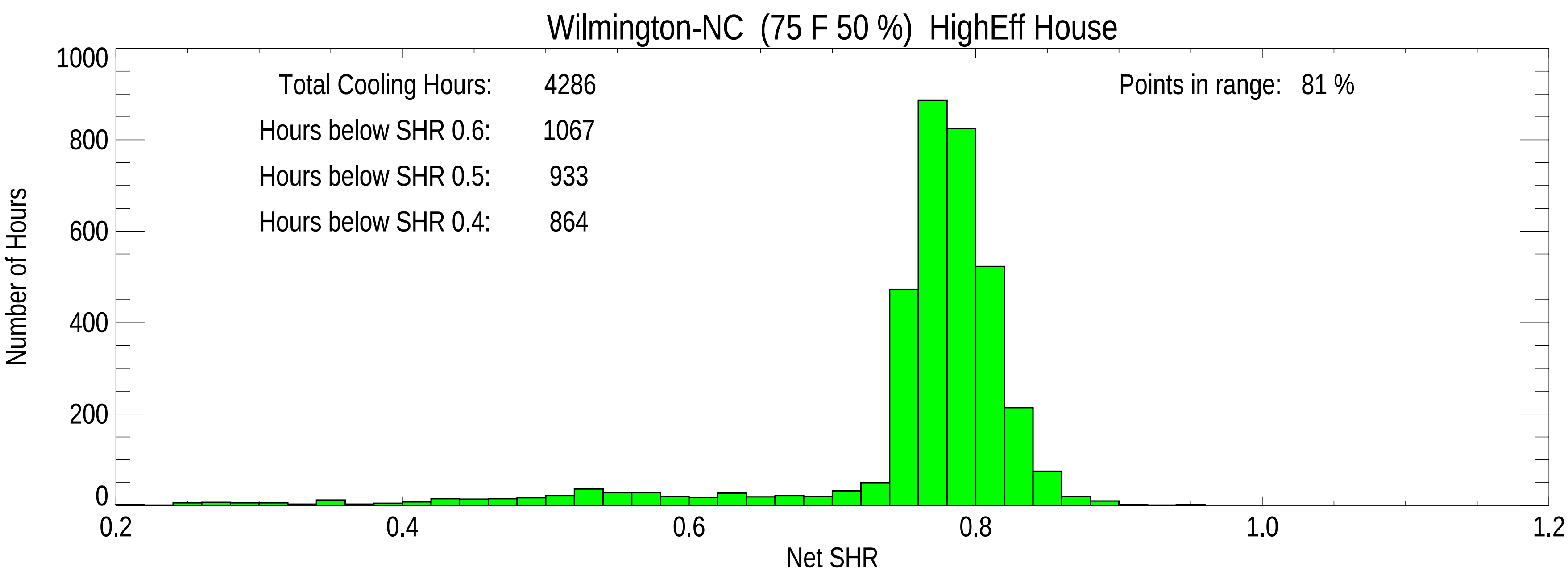

Houston-TX (75 F 50 %) HERS Reference House
Total Cooling Hours: 5663
Hours below SHR 0.6: 2009
Hours below SHR 0.5: 1745
Hours below SHR 0.4: 1631
Points in range: 73 %
Number of Hours
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

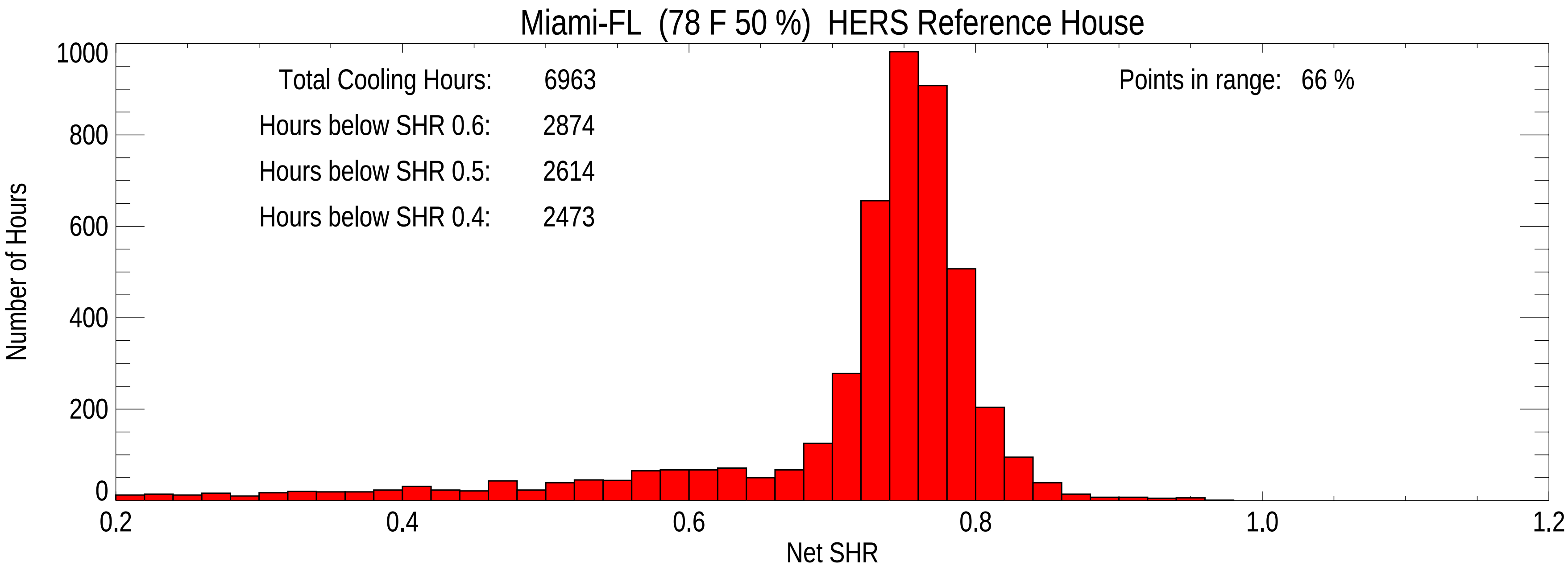

Houston-TX (75 F 50 %) HighEff House
Total Cooling Hours: 5529
Hours below SHR 0.6: 1668
Hours below SHR 0.5: 1518
Hours below SHR 0.4: 1433
Points in range: 75 %
Number of Hours
0
200
400
600
800
1000
1200
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

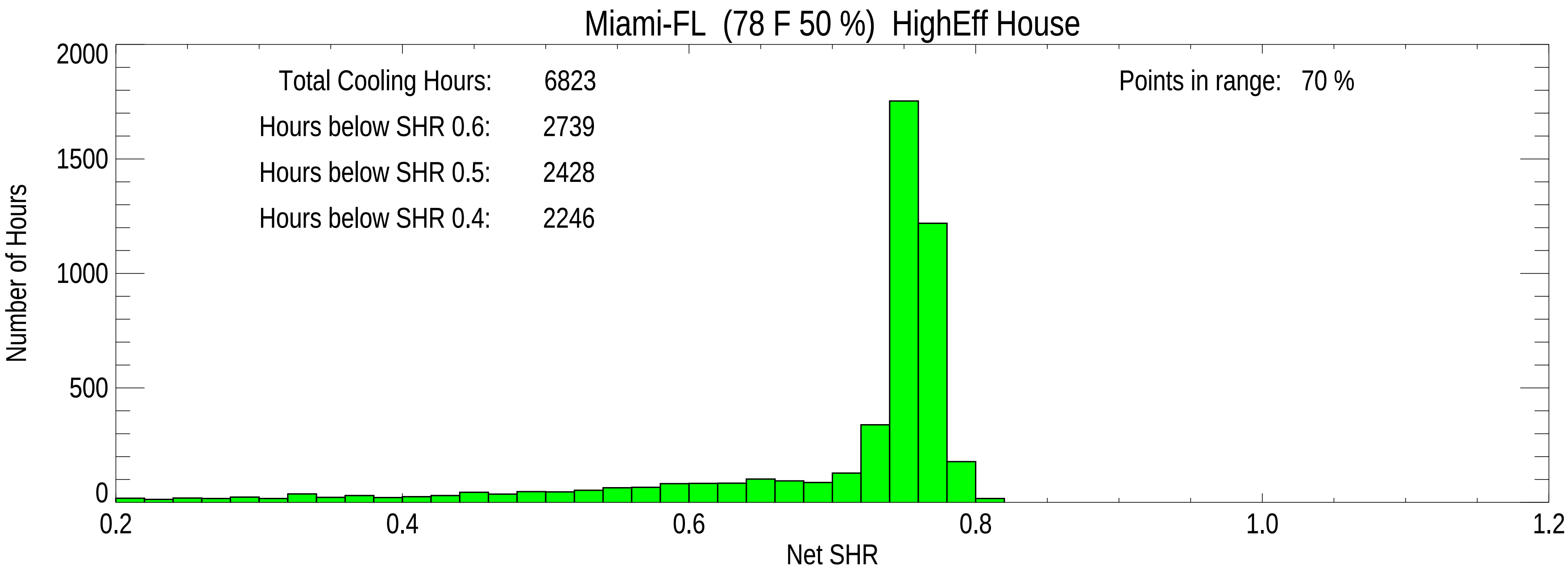

Fort_Worth-TX (75 F 50 %) HERS Reference House
Total Cooling Hours: 4291
Hours below SHR 0.6: 735
Hours below SHR 0.5: 698
Hours below SHR 0.4: 674
Points in range: 84 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

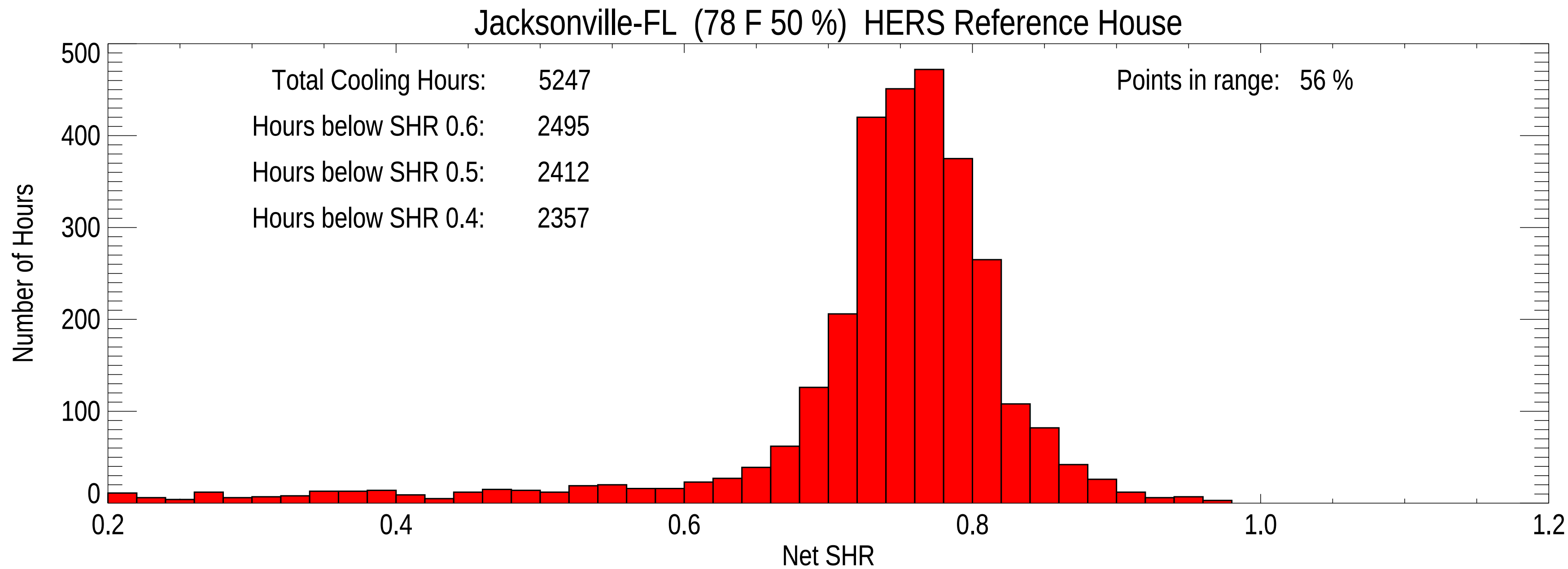

Fort_Worth-TX (75 F 50 %) HighEff House
Total Cooling Hours: 4402
Hours below SHR 0.6: 405
Hours below SHR 0.5: 388
Hours below SHR 0.4: 383
Points in range: 91 %
Number of Hours
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

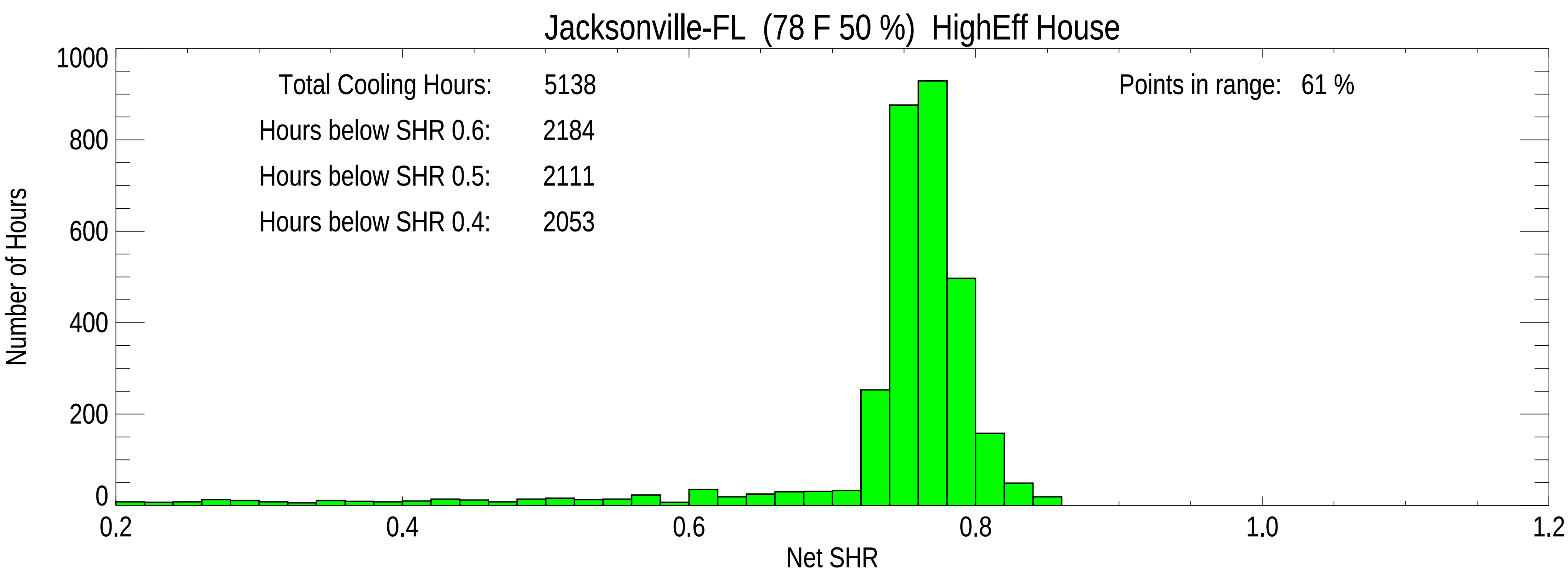

Wilmington-NC (75 F 50 %) HERS Reference House
Total Cooling Hours: 4394
Hours below SHR 0.6: 1856
Hours below SHR 0.5: 1649
Hours below SHR 0.4: 1513
Points in range: 67 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

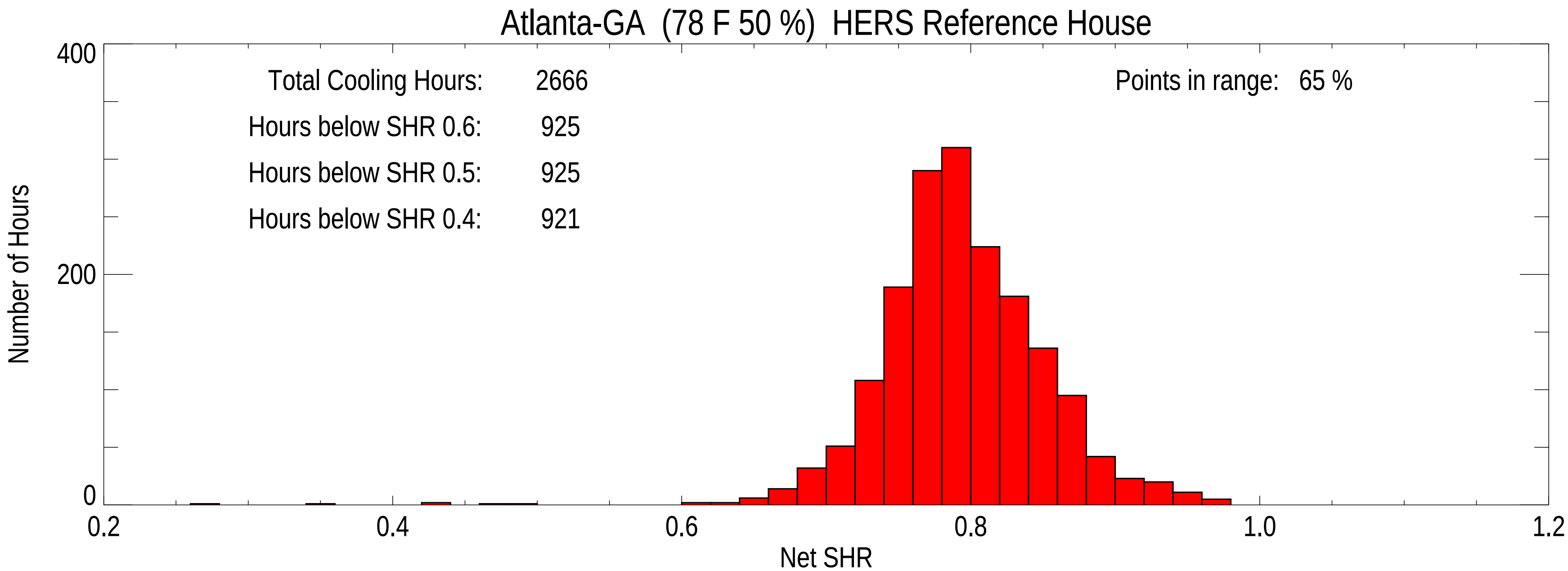

Wilmington-NC (75 F 50 %) HighEff House
Total Cooling Hours: 4286
Hours below SHR 0.6: 1067
Hours below SHR 0.5: 933
Hours below SHR 0.4: 864
Points in range: 81 %
Number of Hours
0
200
400
600
800
1000
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

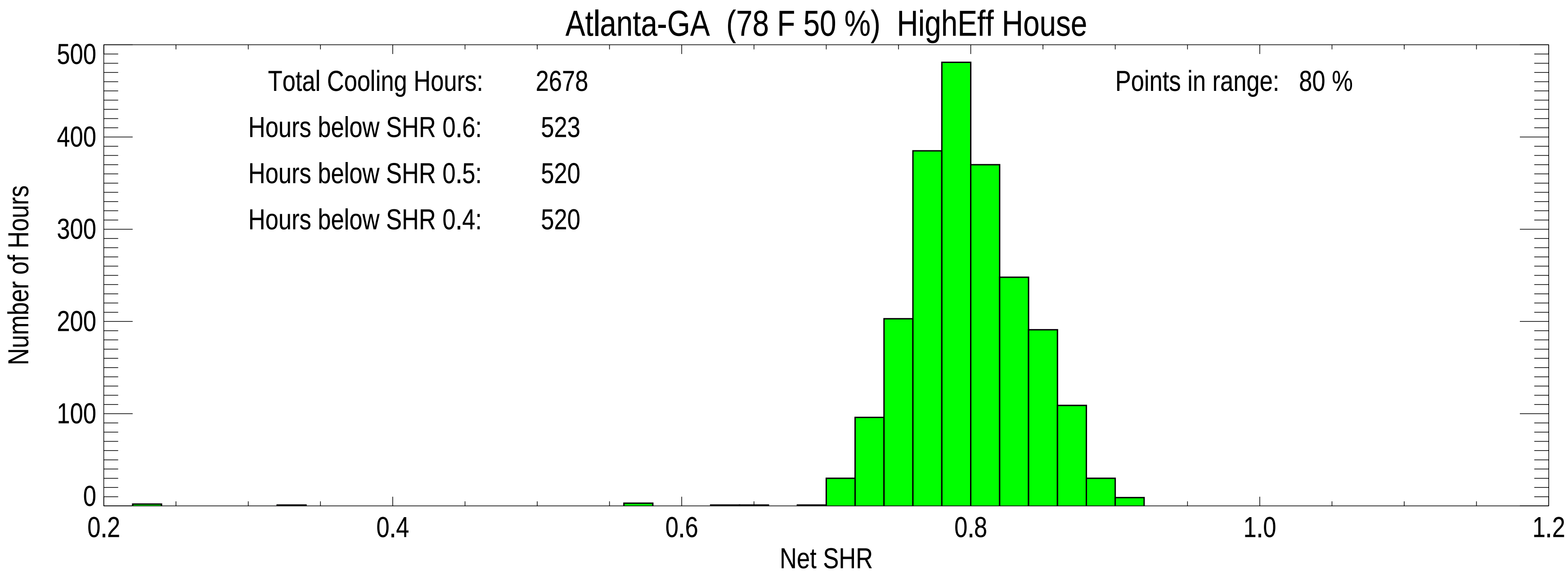

Miami-FL (78 F 50 %) HERS Reference House
Total Cooling Hours: 6963
Hours below SHR 0.6: 2874
Hours below SHR 0.5: 2614
Hours below SHR 0.4: 2473
Points in range: 66 %
Number of Hours
0
200
400
600
800
1000
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

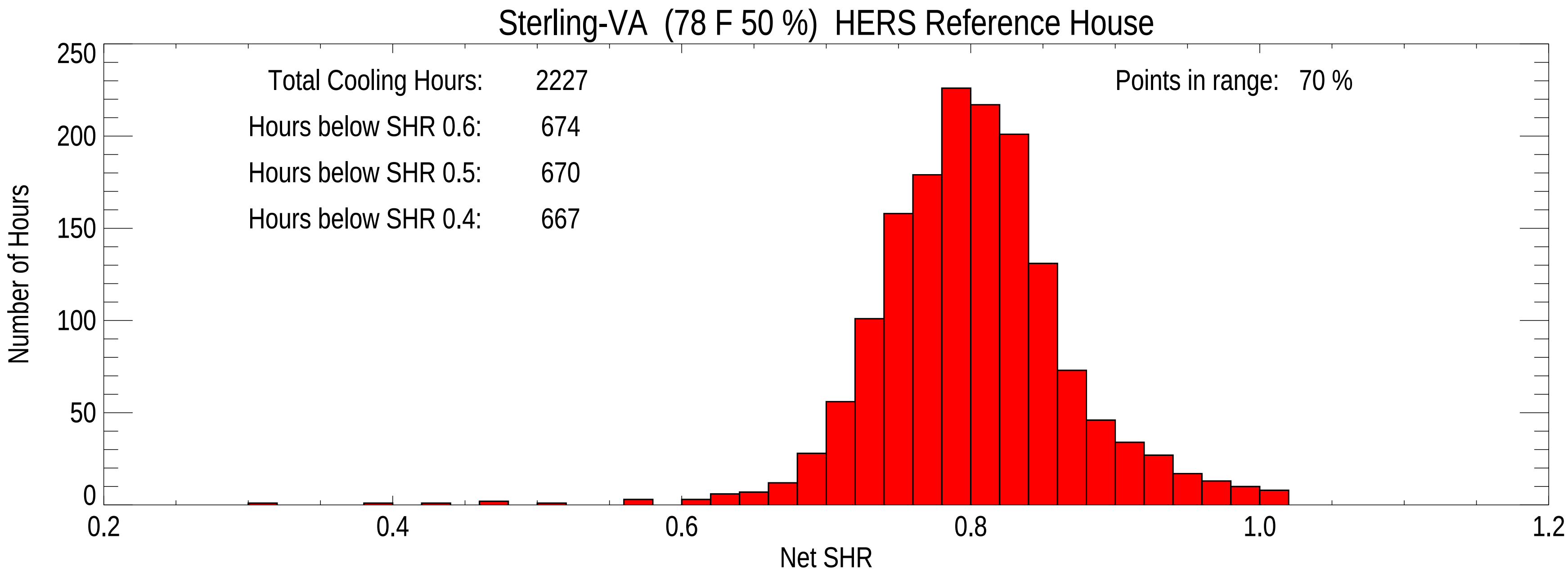

Miami-FL (78 F 50 %) HighEff House
Total Cooling Hours: 6823
Hours below SHR 0.6: 2739
Hours below SHR 0.5: 2428
Hours below SHR 0.4: 2246
Points in range: 70 %
Number of Hours
0
500
1000
1500
2000
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

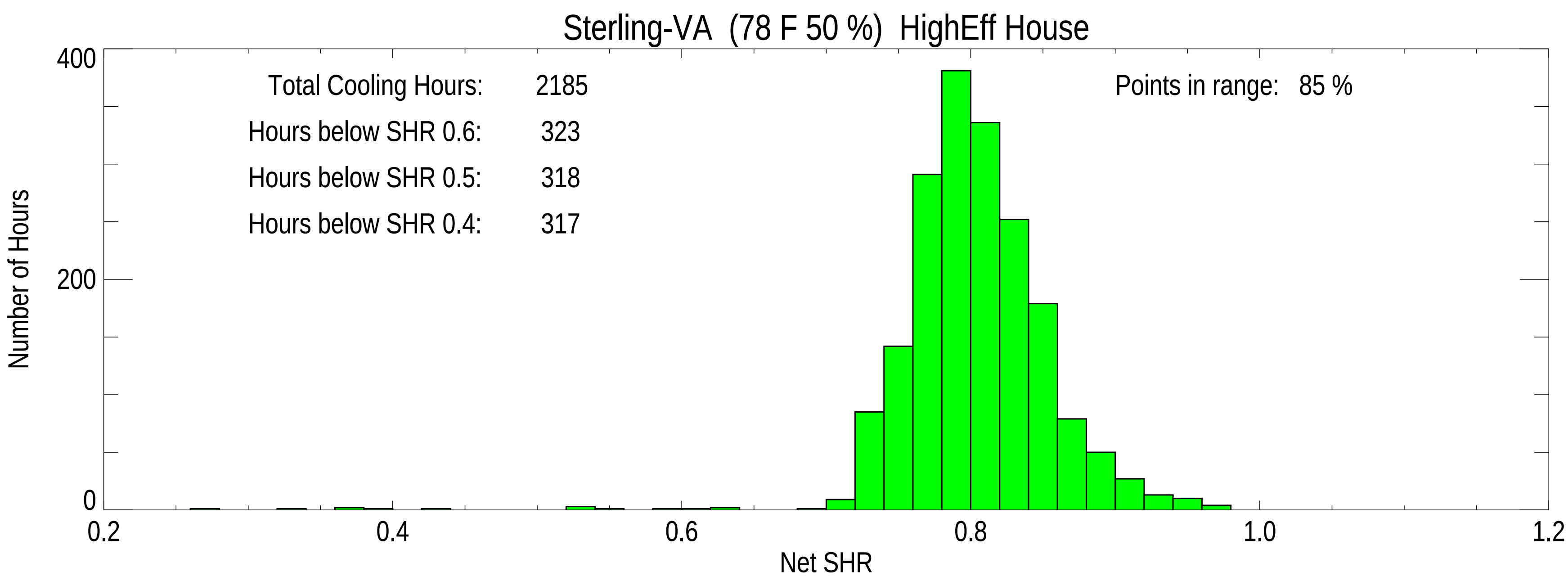

Jacksonville-FL (78 F 50 %) HERS Reference House
Total Cooling Hours: 5247
Hours below SHR 0.6: 2495
Hours below SHR 0.5: 2412
Hours below SHR 0.4: 2357
Points in range: 56 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

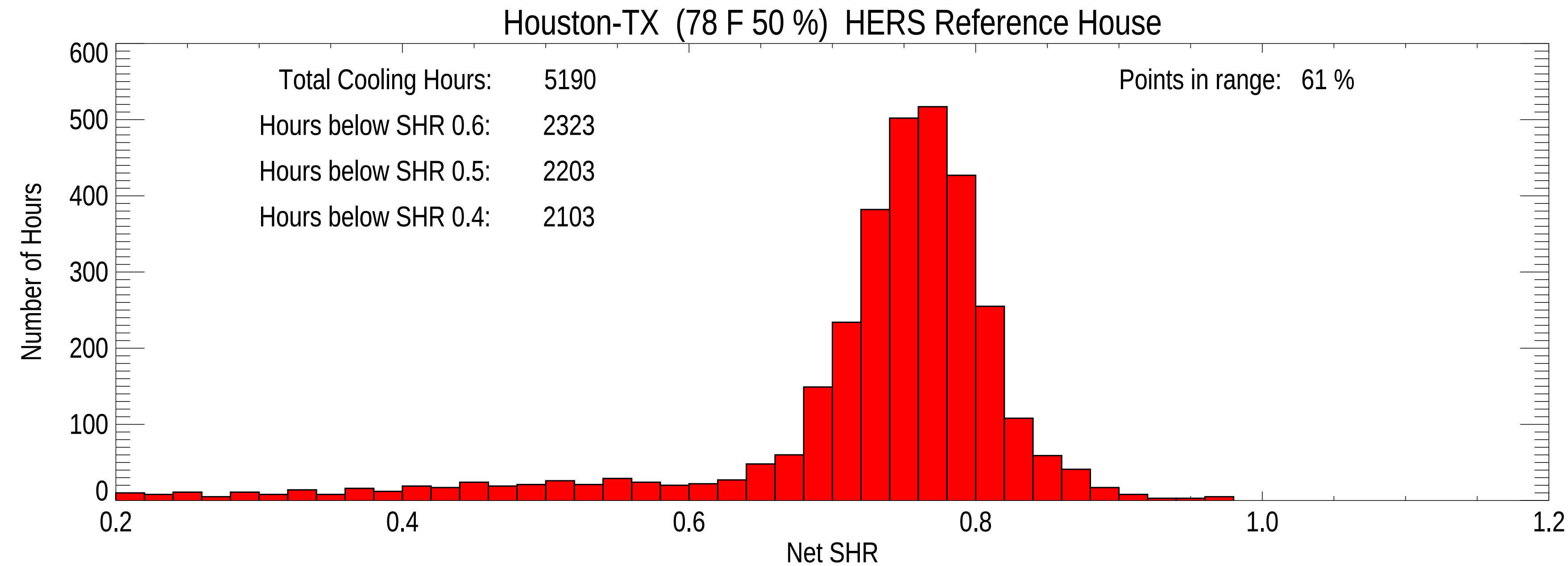

Jacksonville-FL (78 F 50 %) HighEff House
Total Cooling Hours: 5138
Hours below SHR 0.6: 2184
Hours below SHR 0.5: 2111
Hours below SHR 0.4: 2053
Points in range: 61 %
Number of Hours
0
200
400
600
800
1000
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

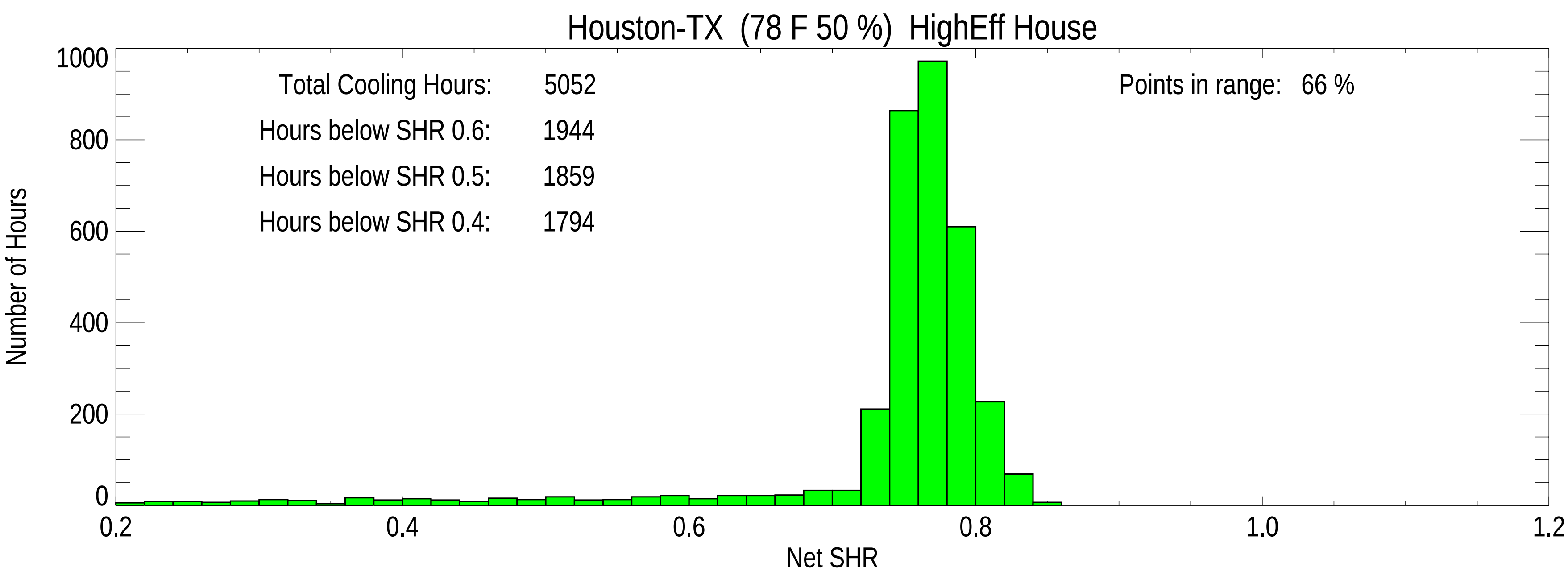

Atlanta-GA (78 F 50 %) HERS Reference House
Total Cooling Hours: 2666
Hours below SHR 0.6: 925
Hours below SHR 0.5: 925
Hours below SHR 0.4: 921
Points in range: 65 %
Number of Hours
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

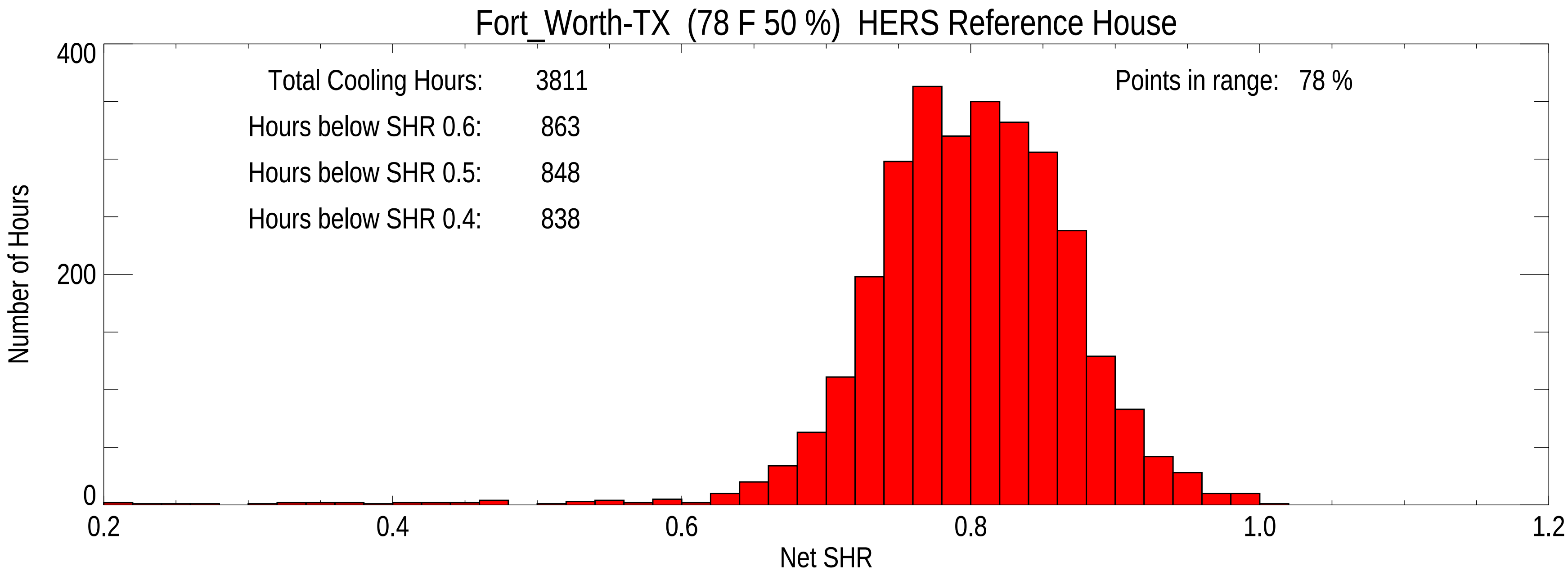

Atlanta-GA (78 F 50 %) HighEff House
Total Cooling Hours: 2678
Hours below SHR 0.6: 523
Hours below SHR 0.5: 520
Hours below SHR 0.4: 520
Points in range: 80 %
Number of Hours
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

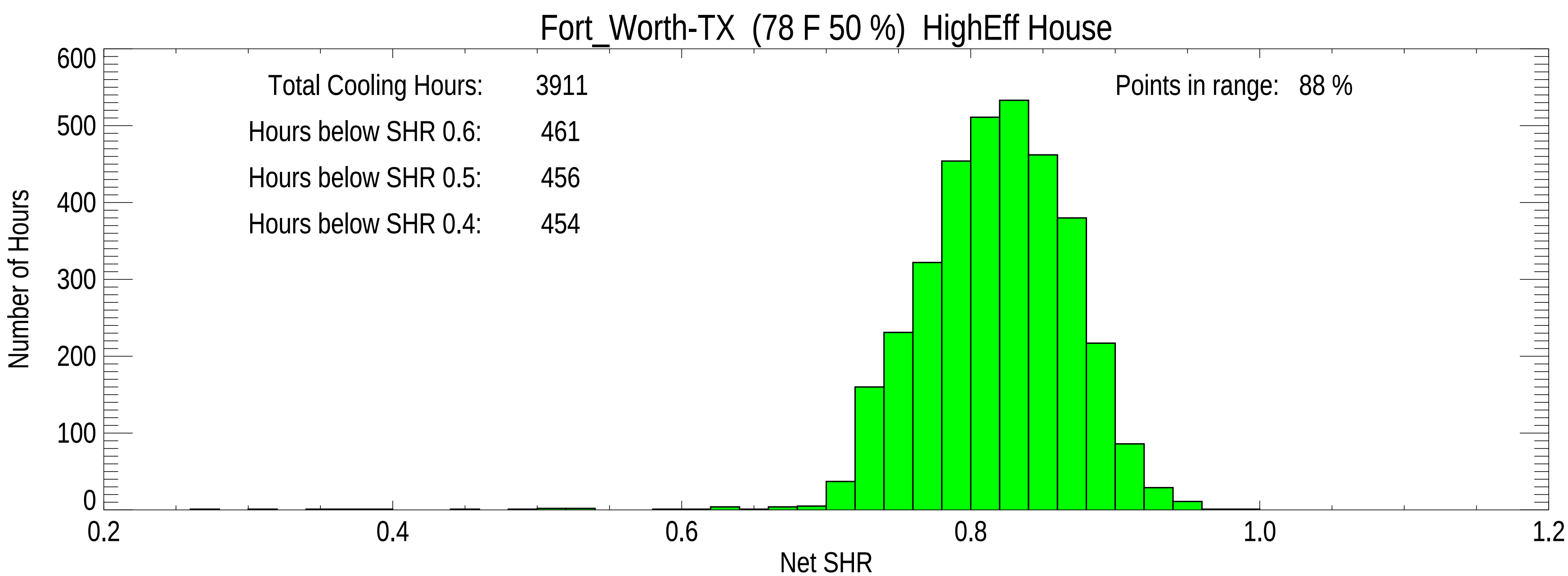

Sterling-VA (78 F 50 %) HERS Reference House
Total Cooling Hours: 2227
Hours below SHR 0.6: 674
Hours below SHR 0.5: 670
Hours below SHR 0.4: 667
Points in range: 70 %
Number of Hours
0
50
100
150
200
250
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

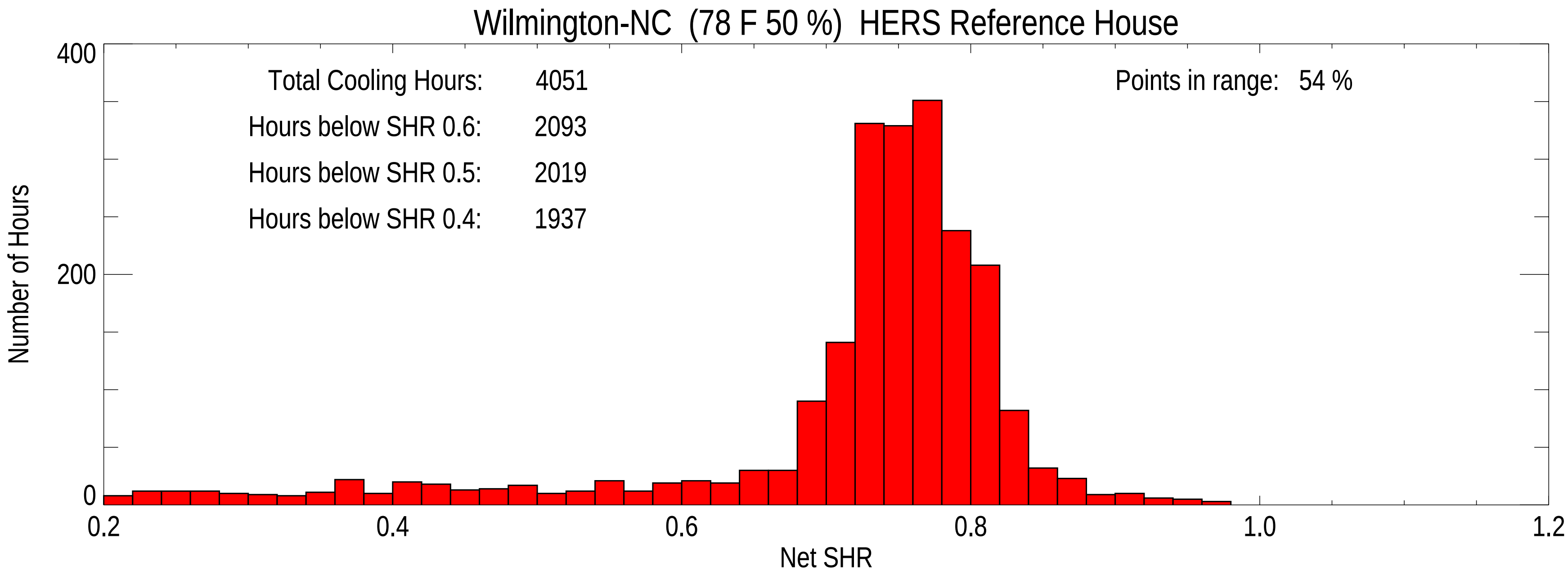

Sterling-VA (78 F 50 %) HighEff House
Total Cooling Hours: 2185
Hours below SHR 0.6: 323
Hours below SHR 0.5: 318
Hours below SHR 0.4: 317
Points in range: 85 %
Number of Hours
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

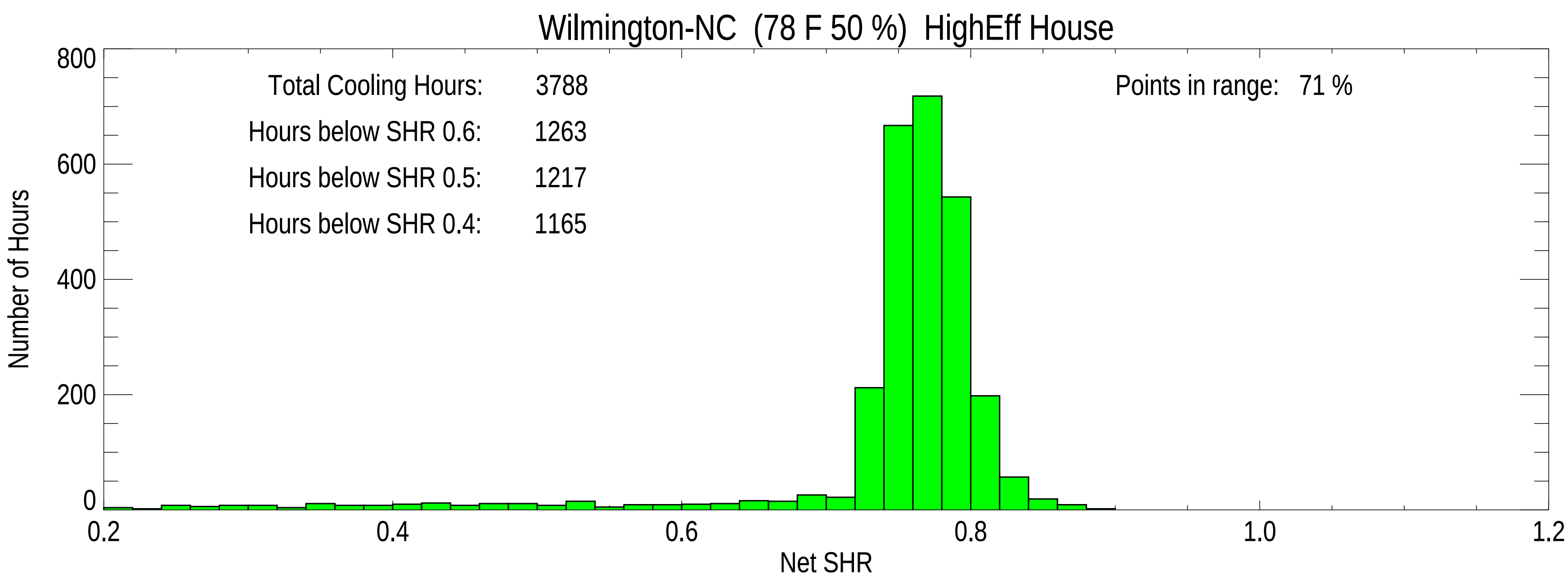

Houston-TX (78 F 50 %) HERS Reference House
Total Cooling Hours: 5190
Hours below SHR 0.6: 2323
Hours below SHR 0.5: 2203
Hours below SHR 0.4: 2103
Points in range: 61 %
Number of Hours
600
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

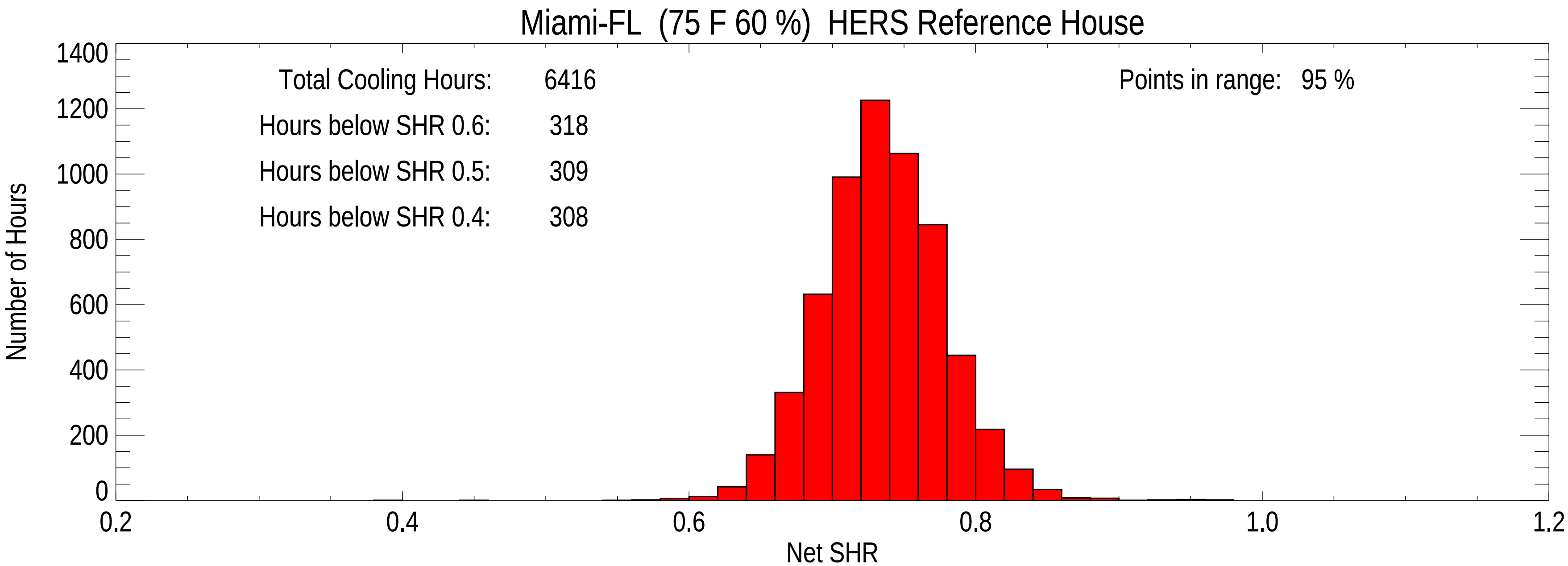

Houston-TX (78 F 50 %) HighEff House
Total Cooling Hours: 5052
Hours below SHR 0.6: 1944
Hours below SHR 0.5: 1859
Hours below SHR 0.4: 1794
Points in range: 66 %
Number of Hours
1000
800
600
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

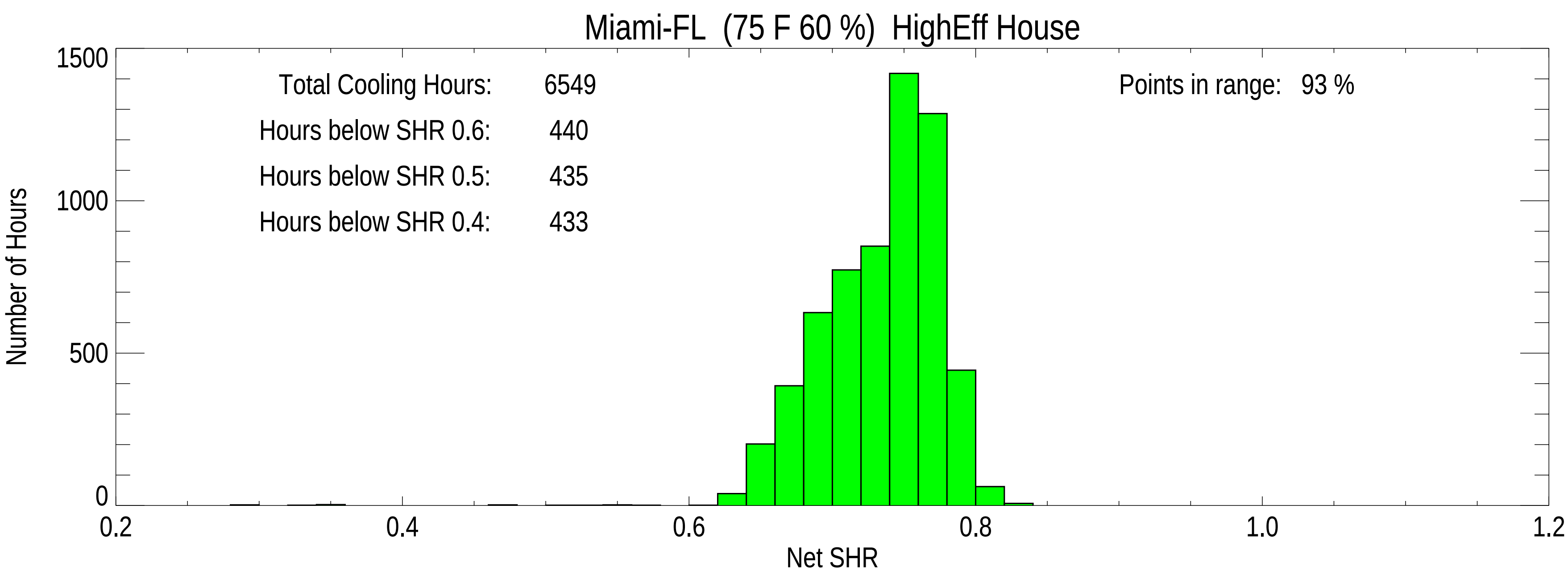

Fort_Worth-TX (78 F 50 %) HERS Reference House
Total Cooling Hours: 3811
Hours below SHR 0.6: 863
Hours below SHR 0.5: 848
Hours below SHR 0.4: 838
Points in range: 78 %
Number of Hours
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

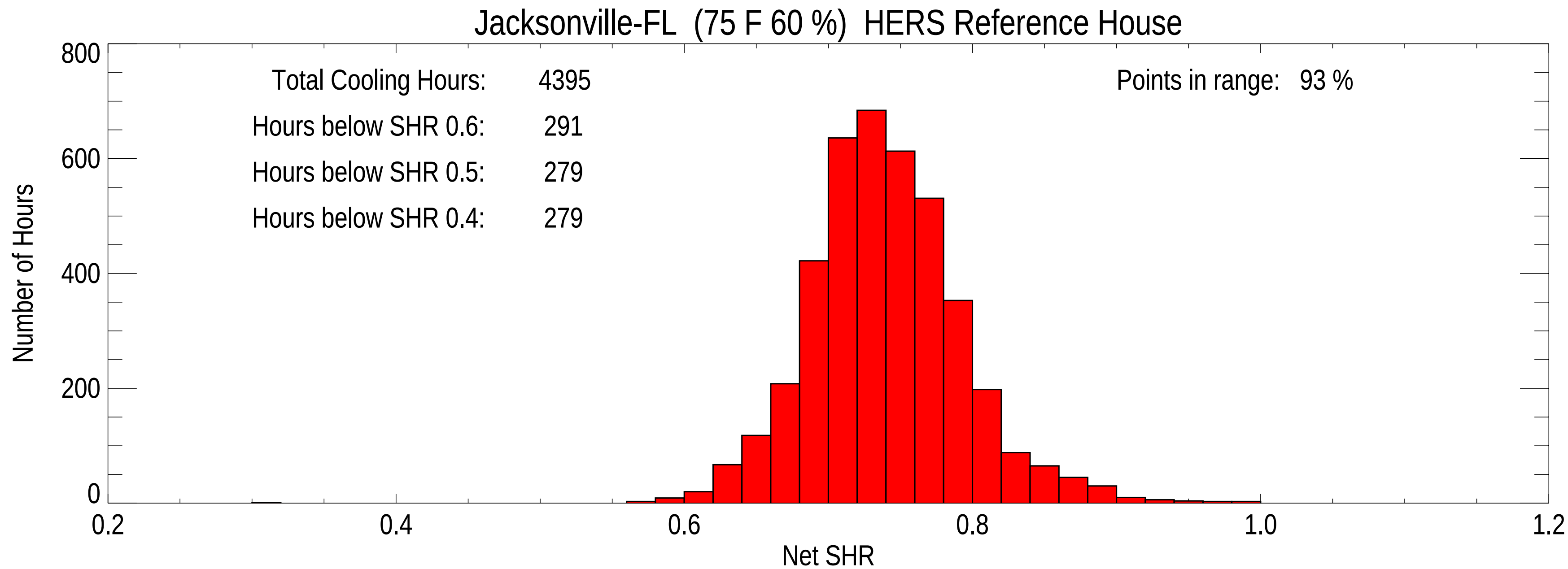

Fort_Worth-TX (78 F 50 %) HighEff House
Total Cooling Hours: 3911
Hours below SHR 0.6: 461
Hours below SHR 0.5: 456
Hours below SHR 0.4: 454
Points in range: 88 %
Number of Hours
0
100
200
300
400
500
600
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

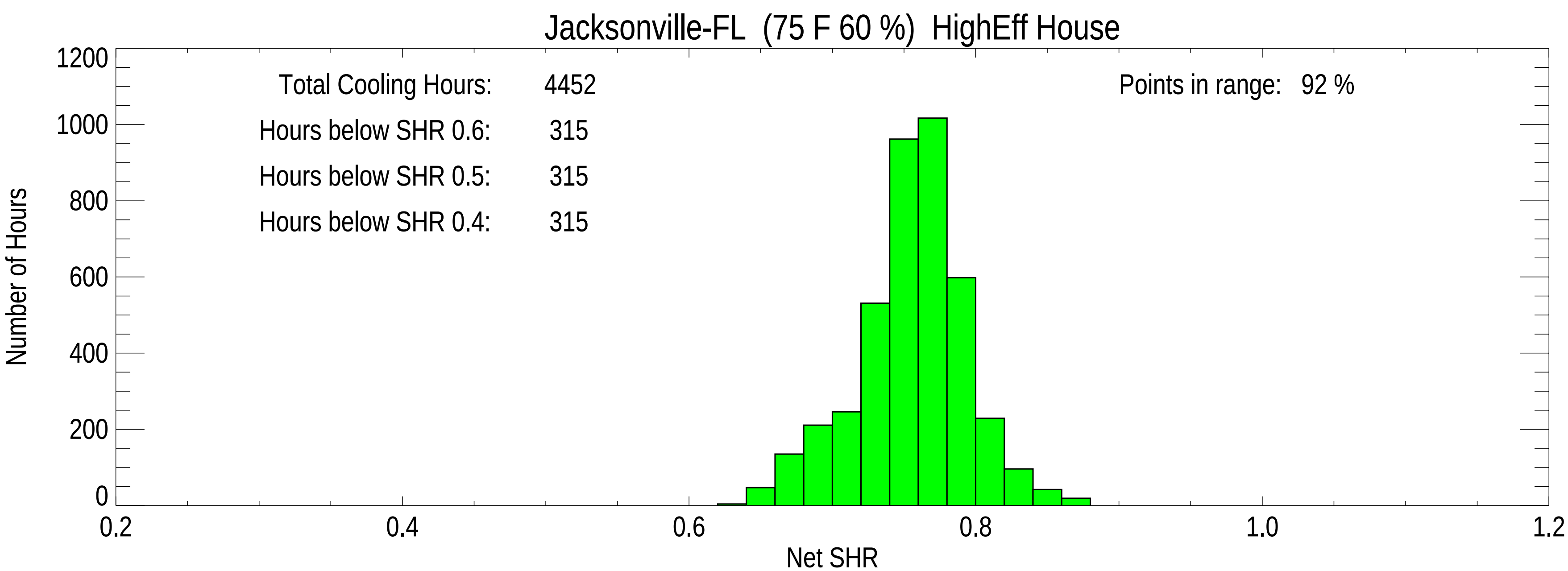

Wilmington-NC (78 F 50 %) HERS Reference House
Total Cooling Hours: 4051
Hours below SHR 0.6: 2093
Hours below SHR 0.5: 2019
Hours below SHR 0.4: 1937
Points in range: 54 %
Number of Hours
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

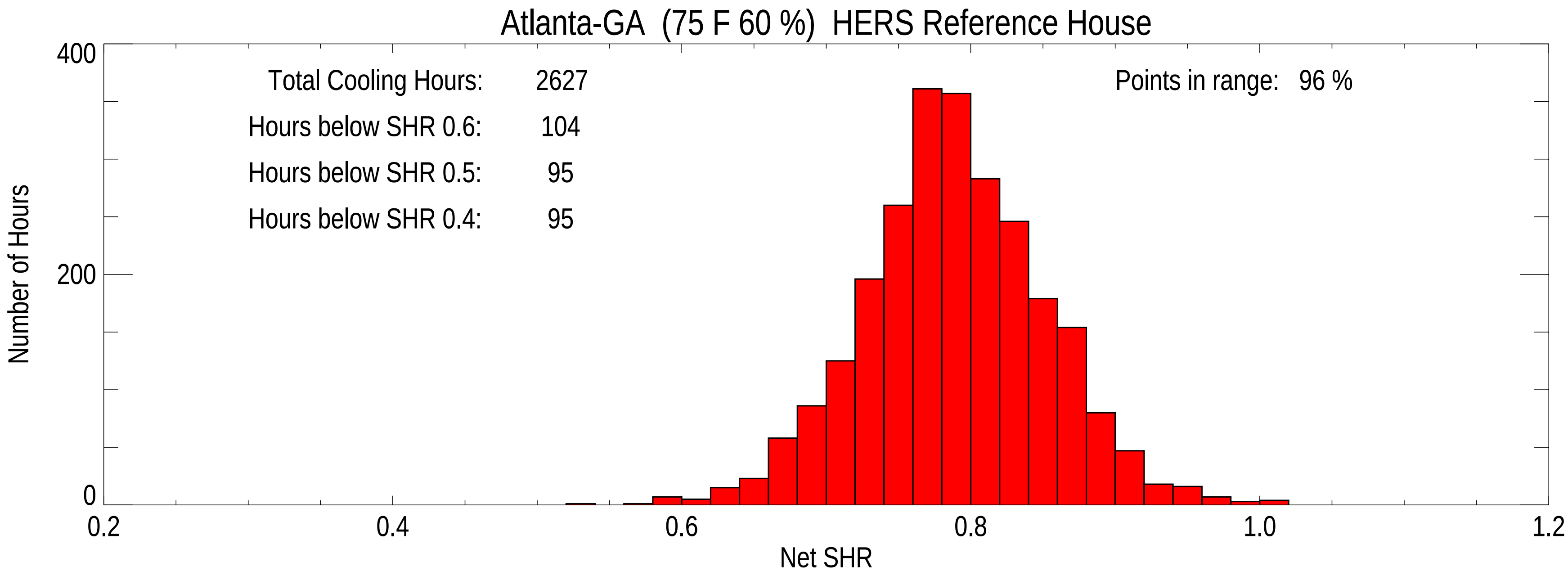

Wilmington-NC (78 F 50 %) HighEff House
Total Cooling Hours: 3788
Hours below SHR 0.6: 1263
Hours below SHR 0.5: 1217
Hours below SHR 0.4: 1165
Points in range: 71 %
Number of Hours
800
600
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

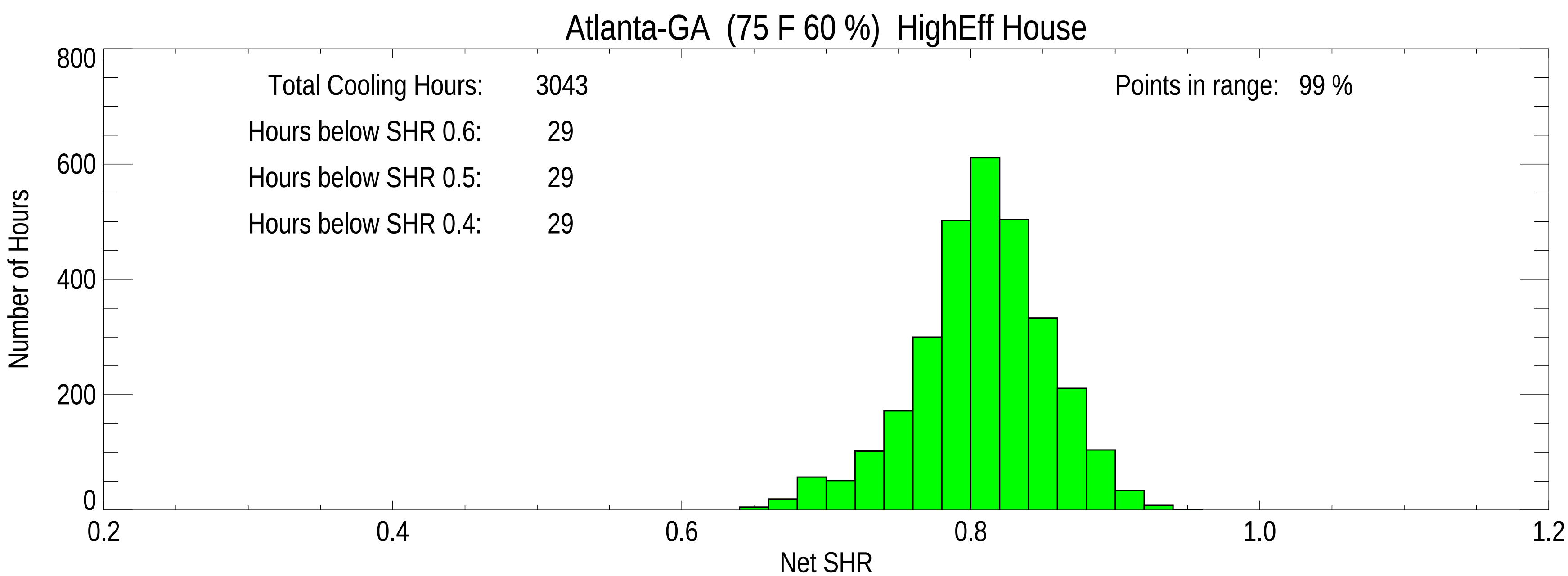

Miami-FL (75 F 60 %) HERS Reference House
Total Cooling Hours: 6416
Hours below SHR 0.6: 318
Hours below SHR 0.5: 309
Hours below SHR 0.4: 308
Points in range: 95 %
Number of Hours
0
200
400
600
800
1000
1200
1400
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

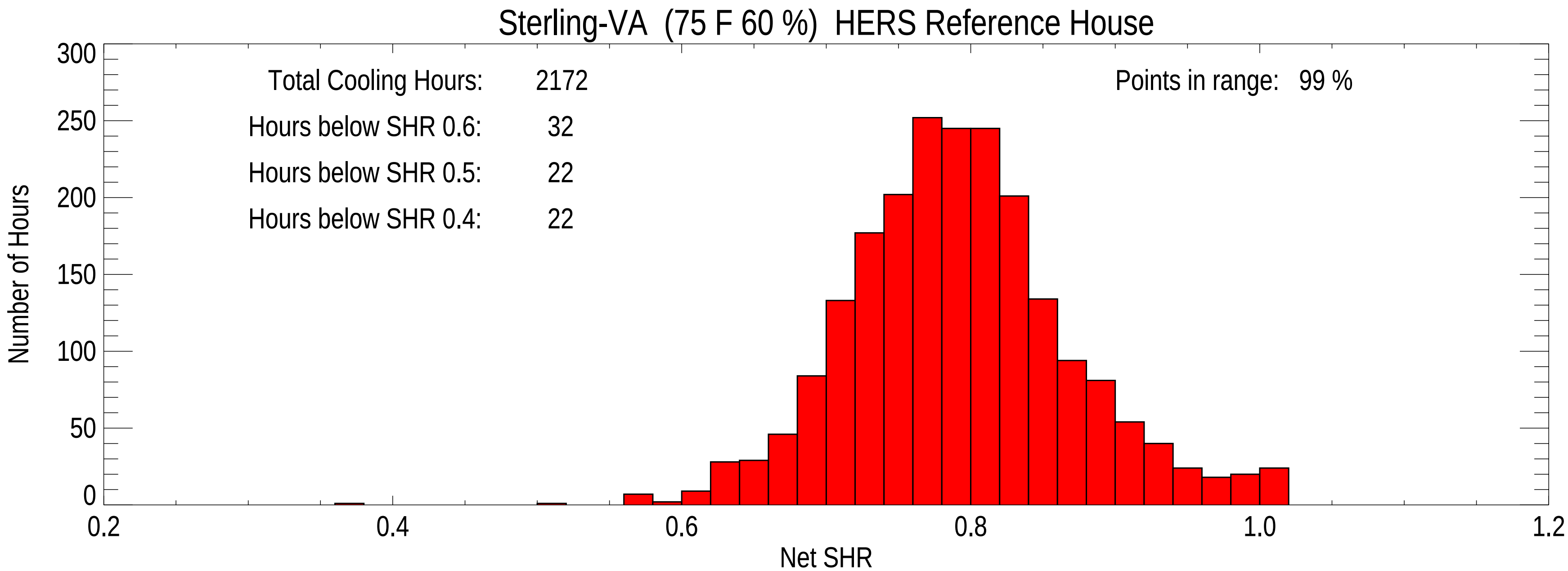

Miami-FL (75 F 60 %) HighEff House
Total Cooling Hours: 6549
Hours below SHR 0.6: 440
Hours below SHR 0.5: 435
Hours below SHR 0.4: 433
Points in range: 93 %
Number of Hours
0
500
1000
1500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

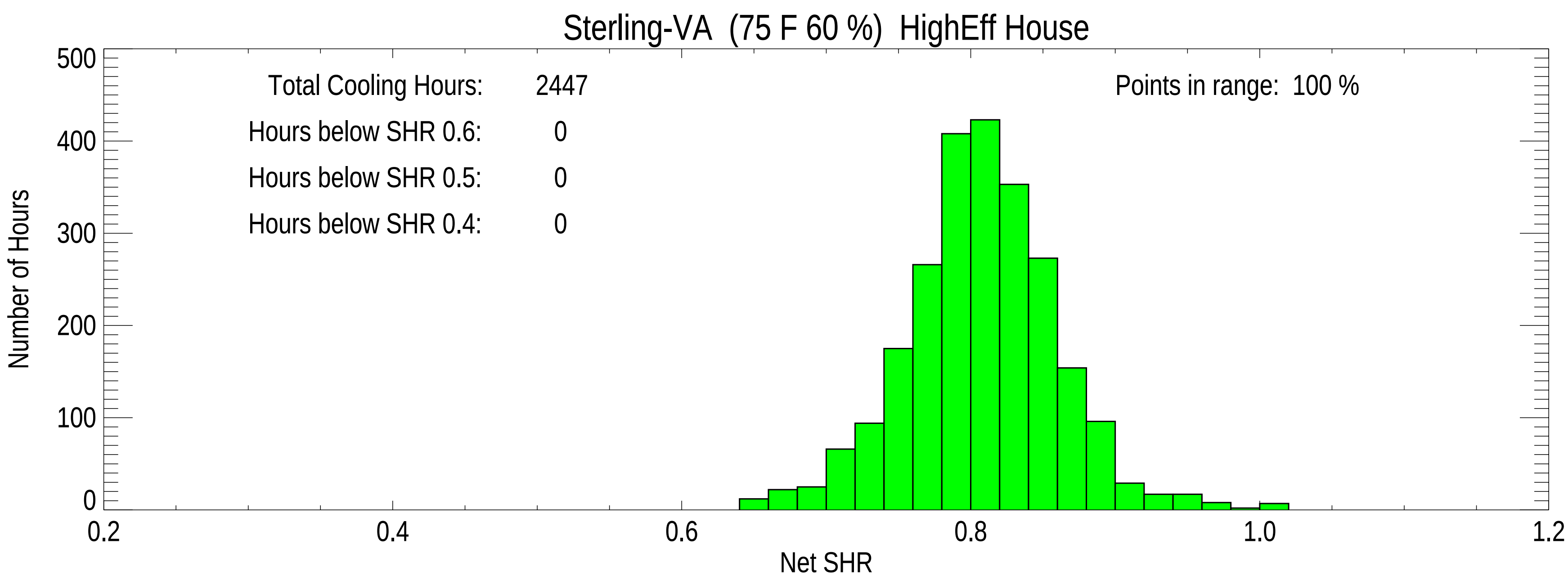

Jacksonville-FL (75 F 60 %) HERS Reference House
Total Cooling Hours: 4395
Hours below SHR 0.6: 291
Hours below SHR 0.5: 279
Hours below SHR 0.4: 279
Points in range: 93 %
Number of Hours
800
600
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

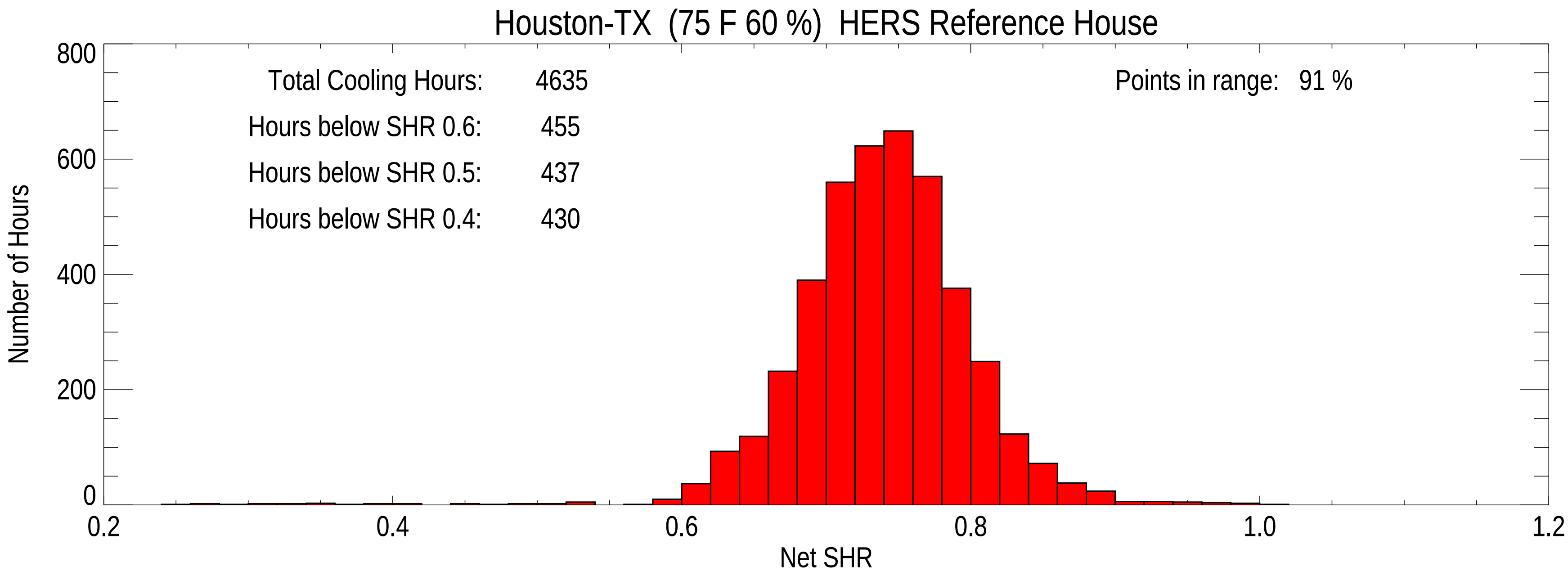

Jacksonville-FL (75 F 60 %) HighEff House
Total Cooling Hours: 4452
Hours below SHR 0.6: 315
Hours below SHR 0.5: 315
Hours below SHR 0.4: 315
Points in range: 92 %
Number of Hours
1200
1000
800
600
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

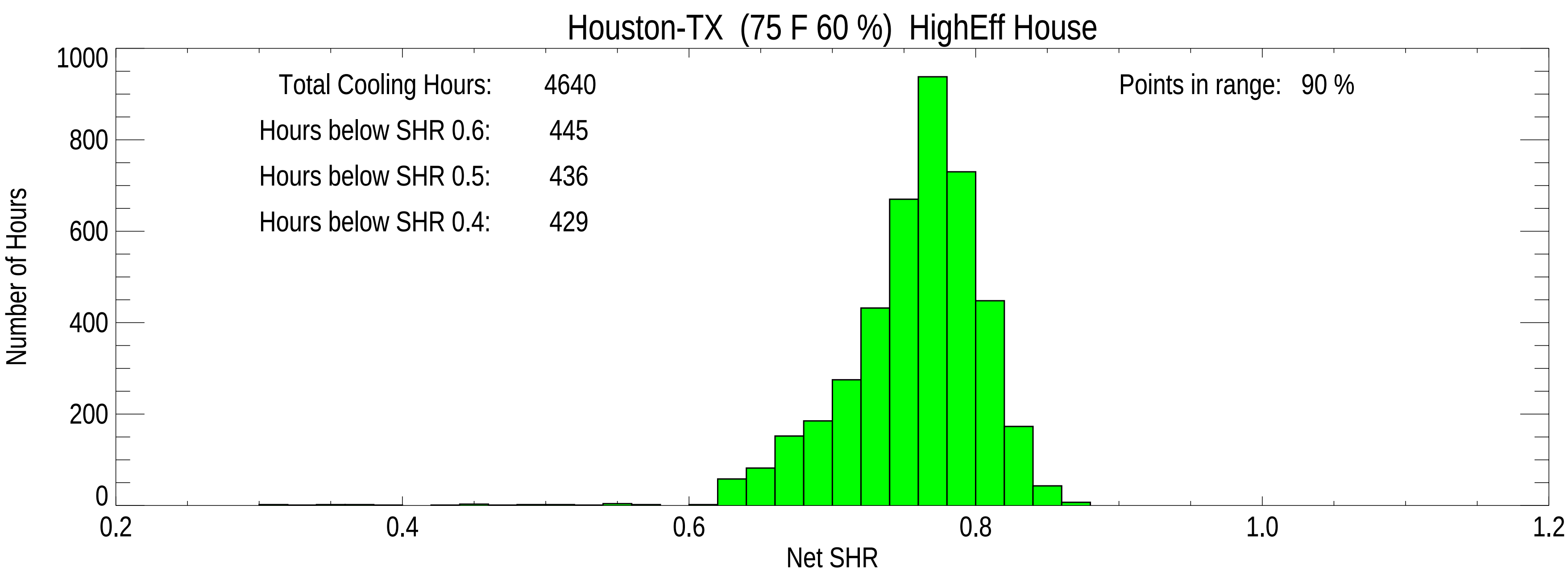

Atlanta-GA (75 F 60 %) HERS Reference House
Total Cooling Hours: 2627
Hours below SHR 0.6: 104
Hours below SHR 0.5: 95
Hours below SHR 0.4: 95
Points in range: 96 %
Number of Hours
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

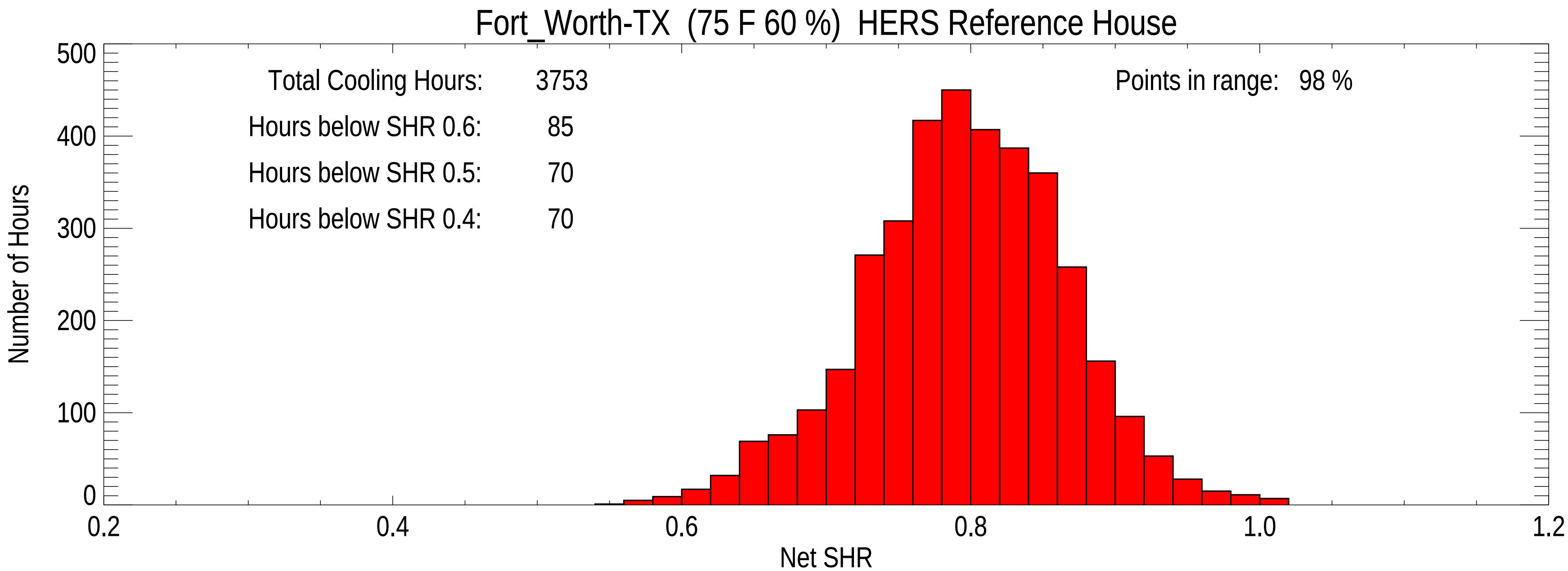

Atlanta-GA (75 F 60 %) HighEff House
Total Cooling Hours: 3043
Hours below SHR 0.6: 29
Hours below SHR 0.5: 29
Hours below SHR 0.4: 29
Points in range: 99 %
Number of Hours
800
600
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

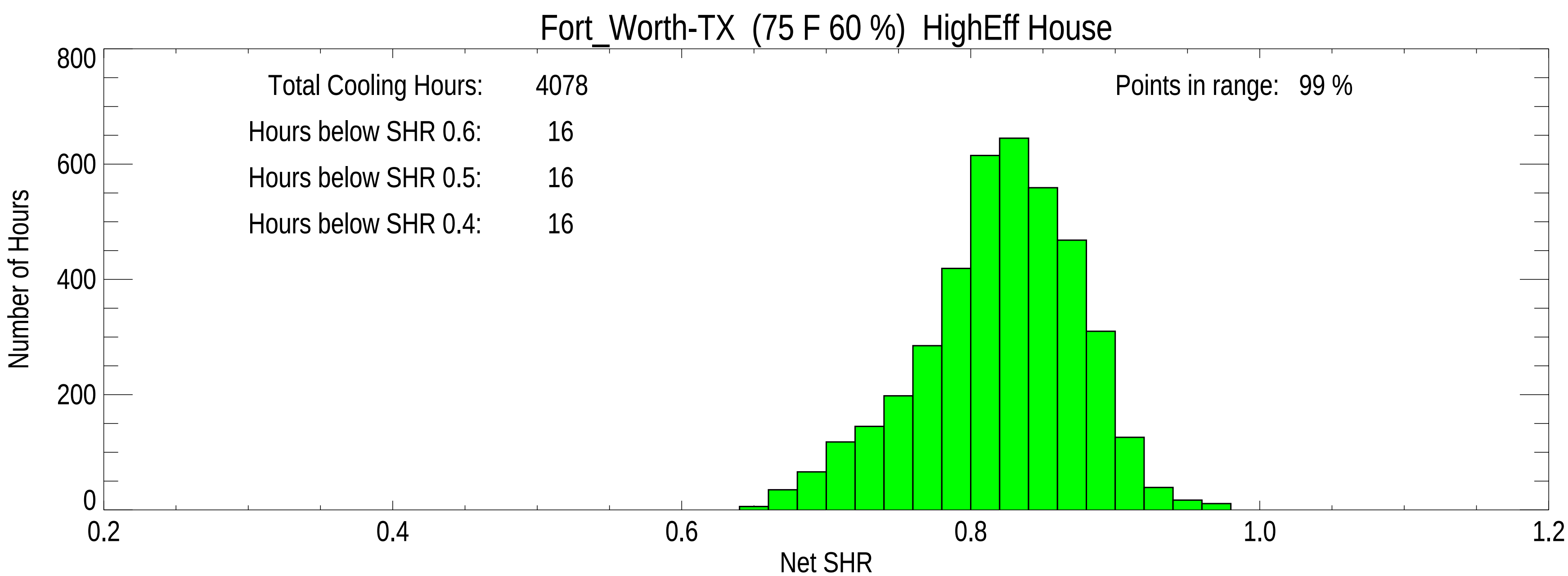

Sterling-VA (75 F 60 %) HERS Reference House
Total Cooling Hours: 2172
Hours below SHR 0.6: 32
Hours below SHR 0.5: 22
Hours below SHR 0.4: 22
Points in range: 99 %
Number of Hours
0
50
100
150
200
250
300
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

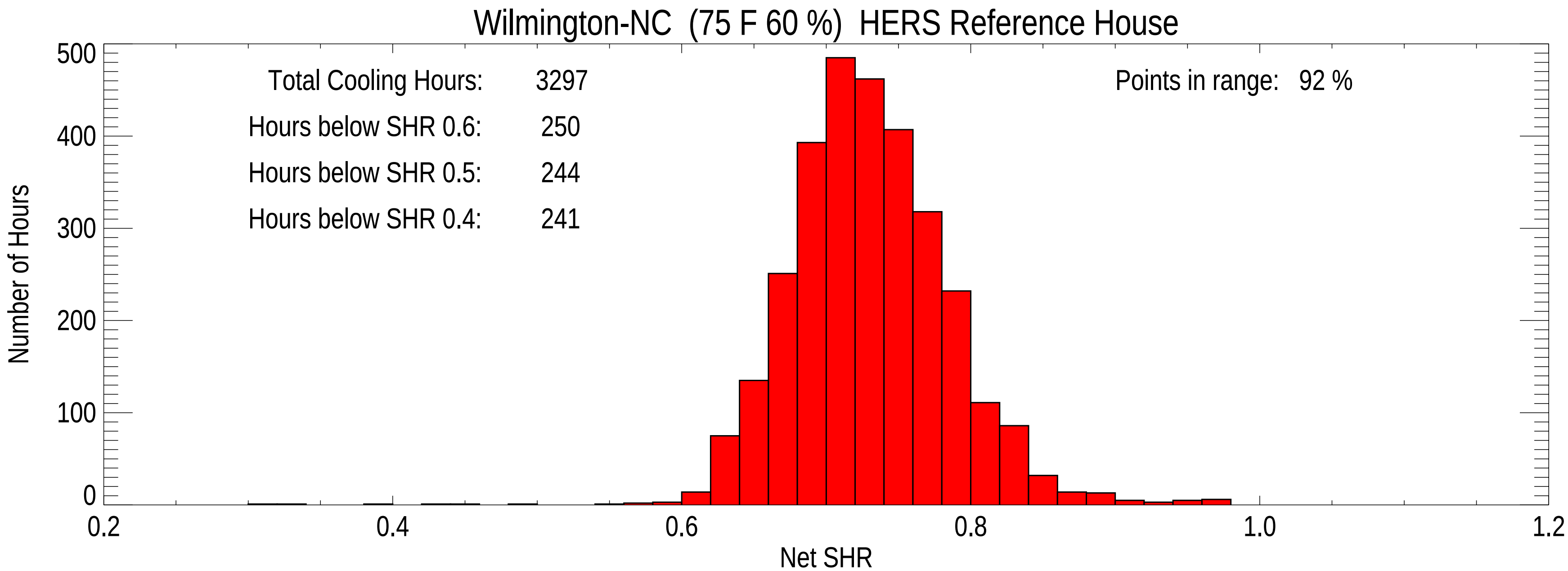

Sterling-VA (75 F 60 %) HighEff House
Total Cooling Hours: 2447
Hours below SHR 0.6: 0
Hours below SHR 0.5: 0
Hours below SHR 0.4: 0
Points in range: 100 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

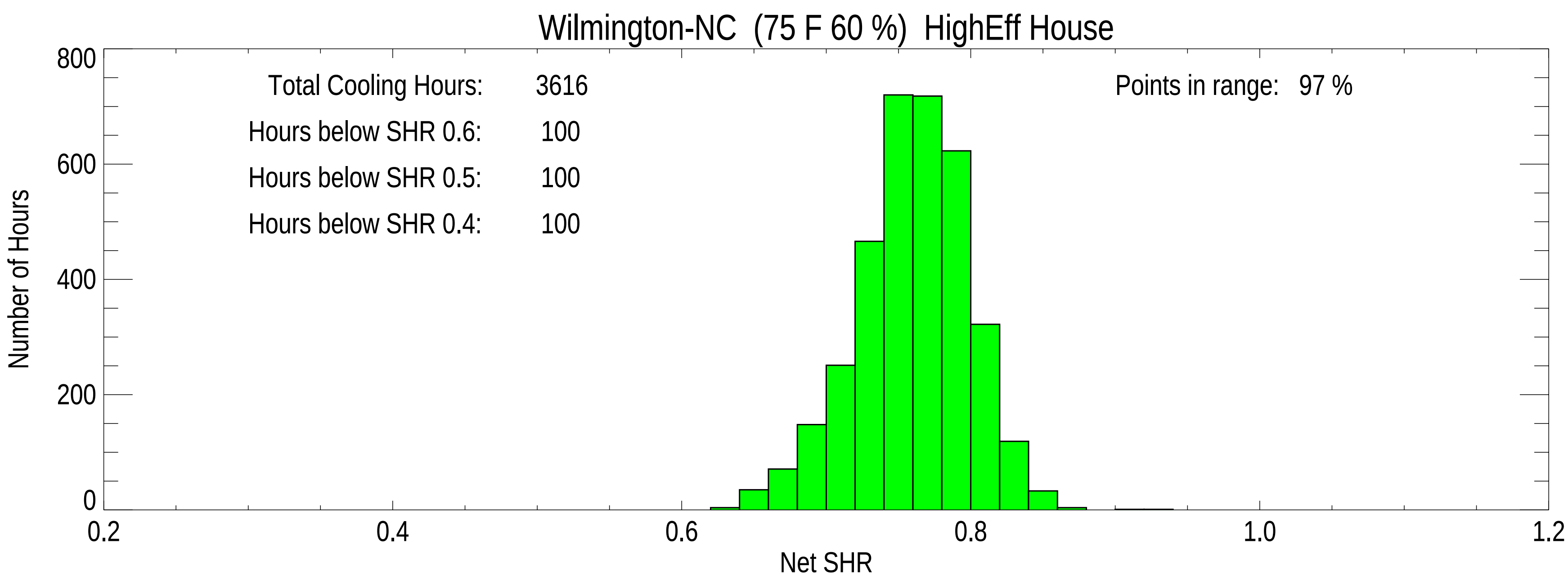

Houston-TX (75 F 60 %) HERS Reference House
Total Cooling Hours: 4635
Hours below SHR 0.6: 455
Hours below SHR 0.5: 437
Hours below SHR 0.4: 430
Points in range: 91 %
Number of Hours
Net SHR
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
1.2

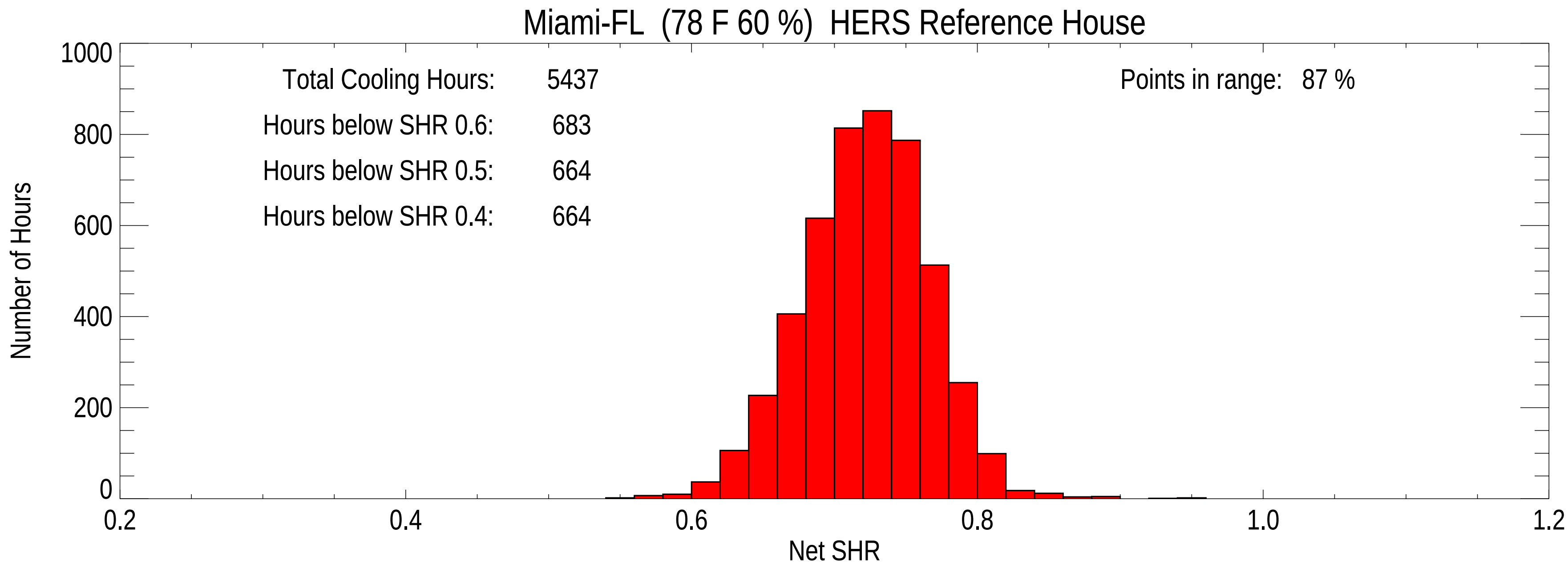

Houston-TX (75 F 60 %) HighEff House
Total Cooling Hours: 4640
Hours below SHR 0.6: 445
Hours below SHR 0.5: 436
Hours below SHR 0.4: 429
Points in range: 90 %
Number of Hours
Net SHR
0
200
400
600
800
1000
0.2
0.4
0.6
0.8
1.0
1.2

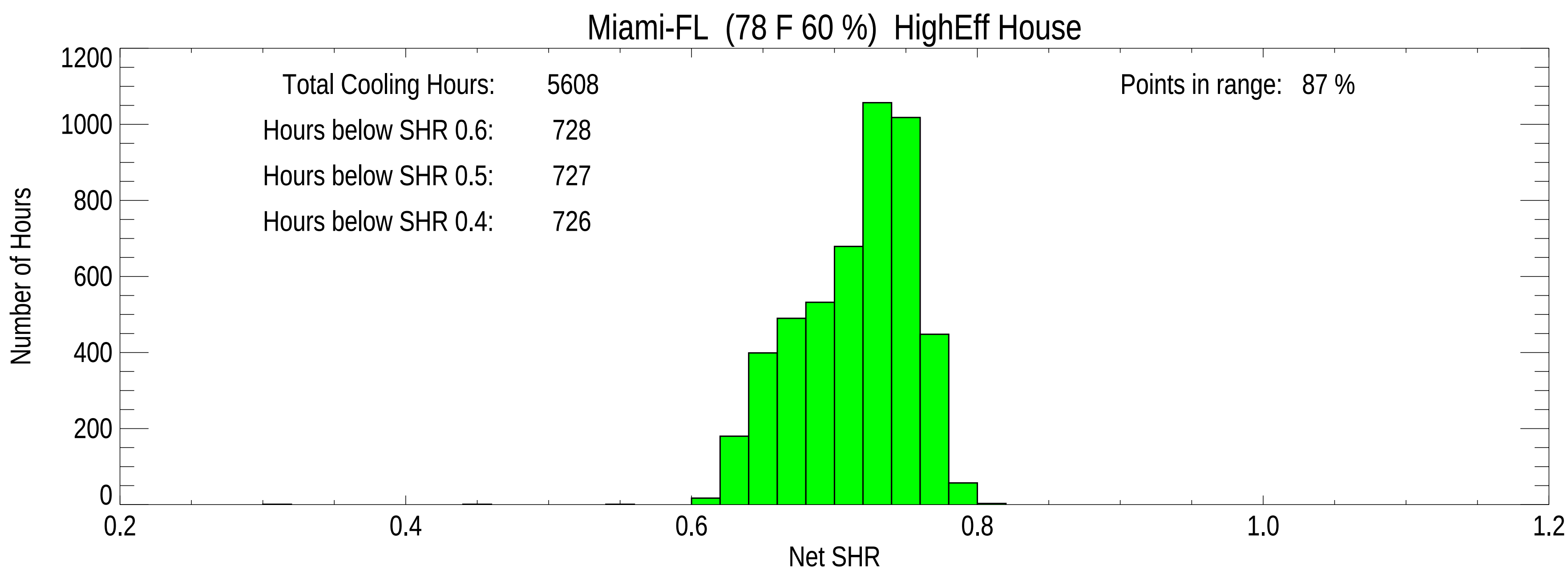

Fort_Worth-TX (75 F 60 %) HERS Reference House
Total Cooling Hours: 3753
Hours below SHR 0.6: 85
Hours below SHR 0.5: 70
Hours below SHR 0.4: 70
Points in range: 98 %
Number of Hours
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

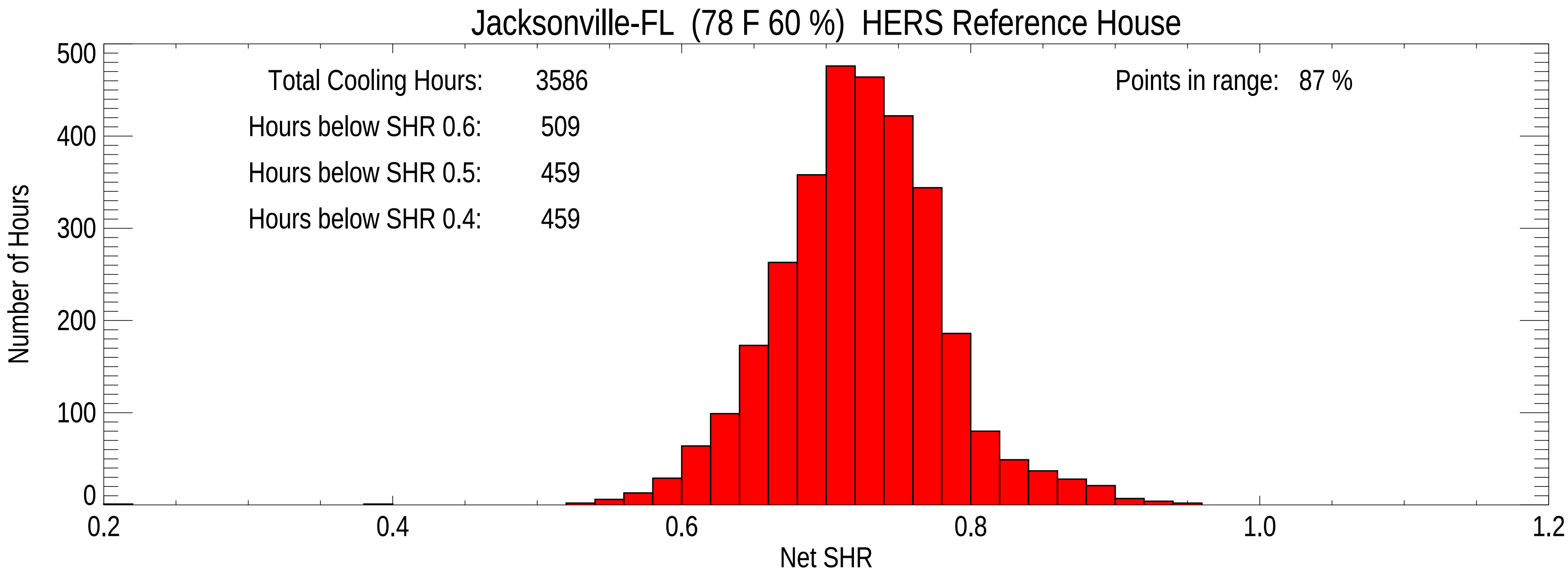

Fort_Worth-TX (75 F 60 %) HighEff House
Total Cooling Hours: 4078
Hours below SHR 0.6: 16
Hours below SHR 0.5: 16
Hours below SHR 0.4: 16
Points in range: 99 %
Number of Hours
800
600
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

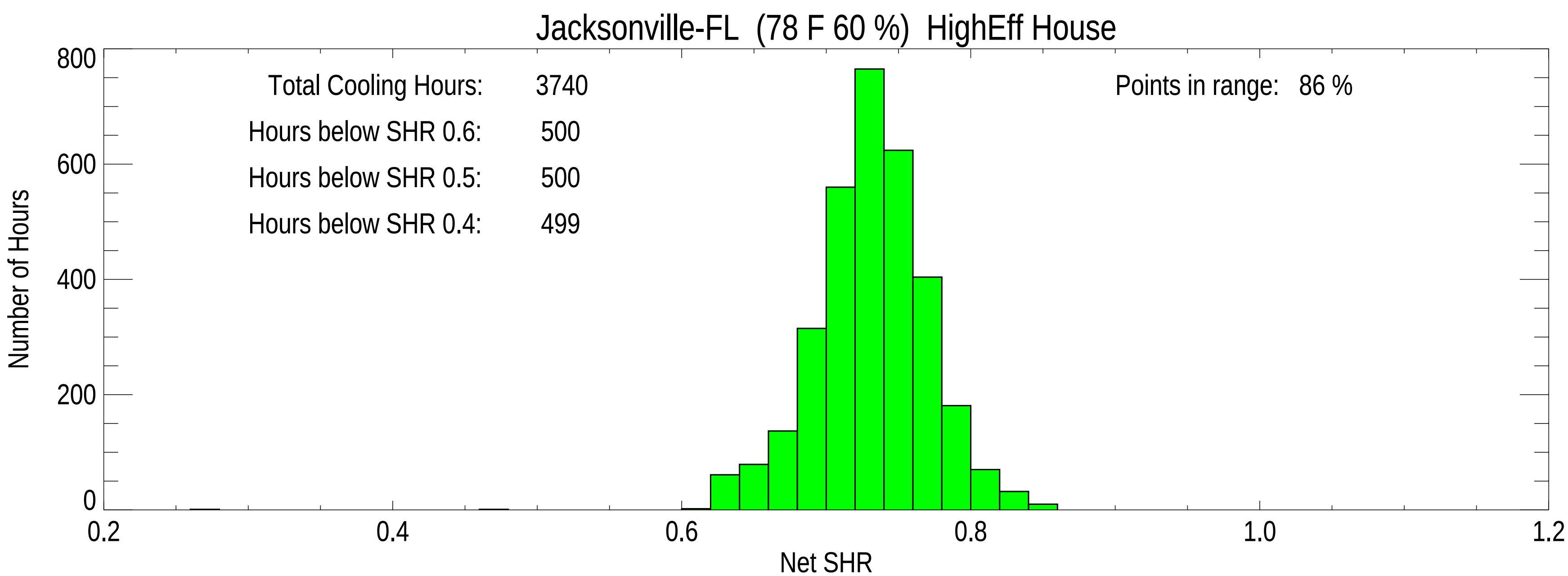

Wilmington-NC (75 F 60 %) HERS Reference House
Total Cooling Hours: 3297
Hours below SHR 0.6: 250
Hours below SHR 0.5: 244
Hours below SHR 0.4: 241
Points in range: 92 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

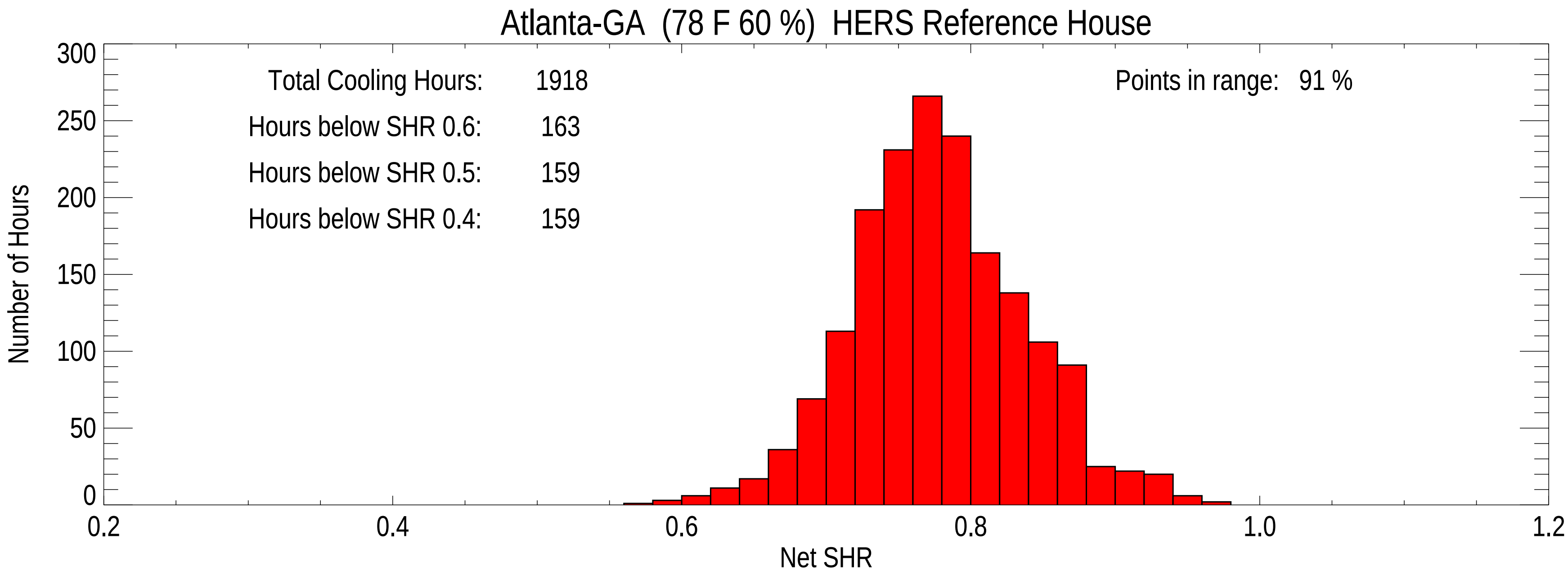

Wilmington-NC (75 F 60 %) HighEff House
Total Cooling Hours: 3616
Hours below SHR 0.6: 100
Hours below SHR 0.5: 100
Hours below SHR 0.4: 100
Points in range: 97 %
Number of Hours
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

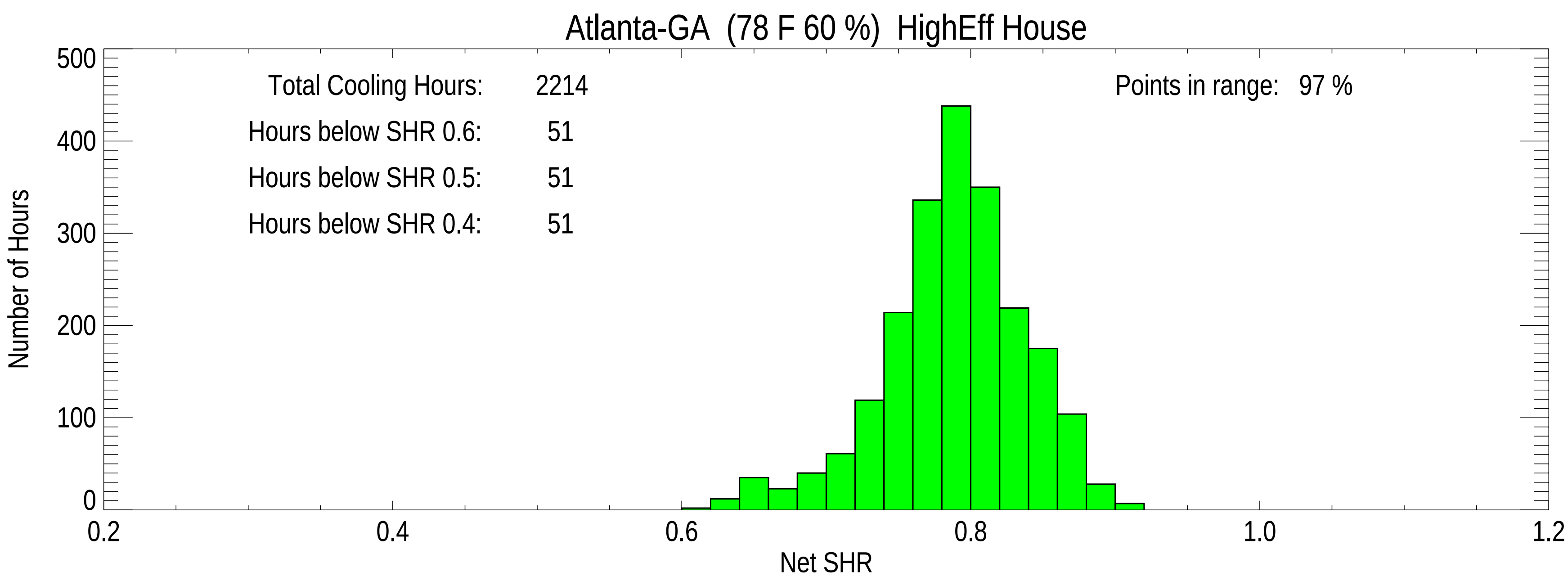

Miami-FL (78 F 60 %) HERS Reference House
Total Cooling Hours: 5437
Hours below SHR 0.6: 683
Hours below SHR 0.5: 664
Hours below SHR 0.4: 664
Points in range: 87 %
Number of Hours
0
200
400
600
800
1000
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

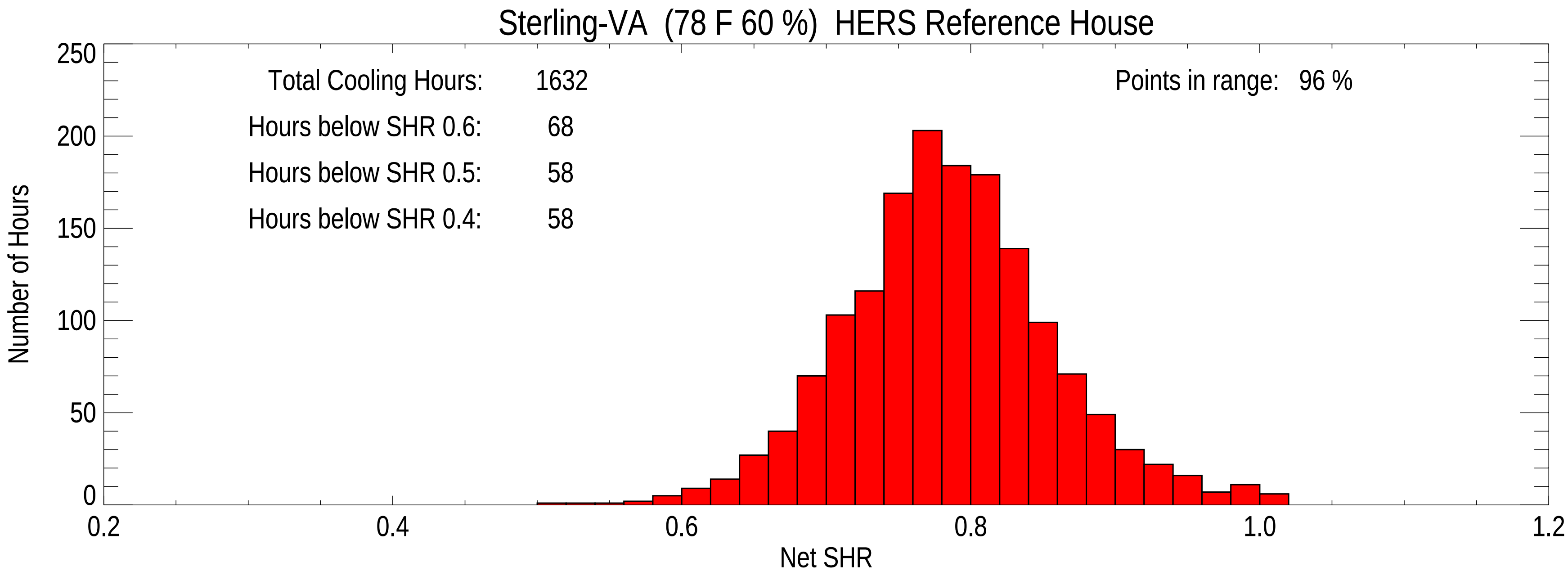

Miami-FL (78 F 60 %) HighEff House
Total Cooling Hours: 5608
Hours below SHR 0.6: 728
Hours below SHR 0.5: 727
Hours below SHR 0.4: 726
Points in range: 87 %
Number of Hours
0
200
400
600
800
1000
1200
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

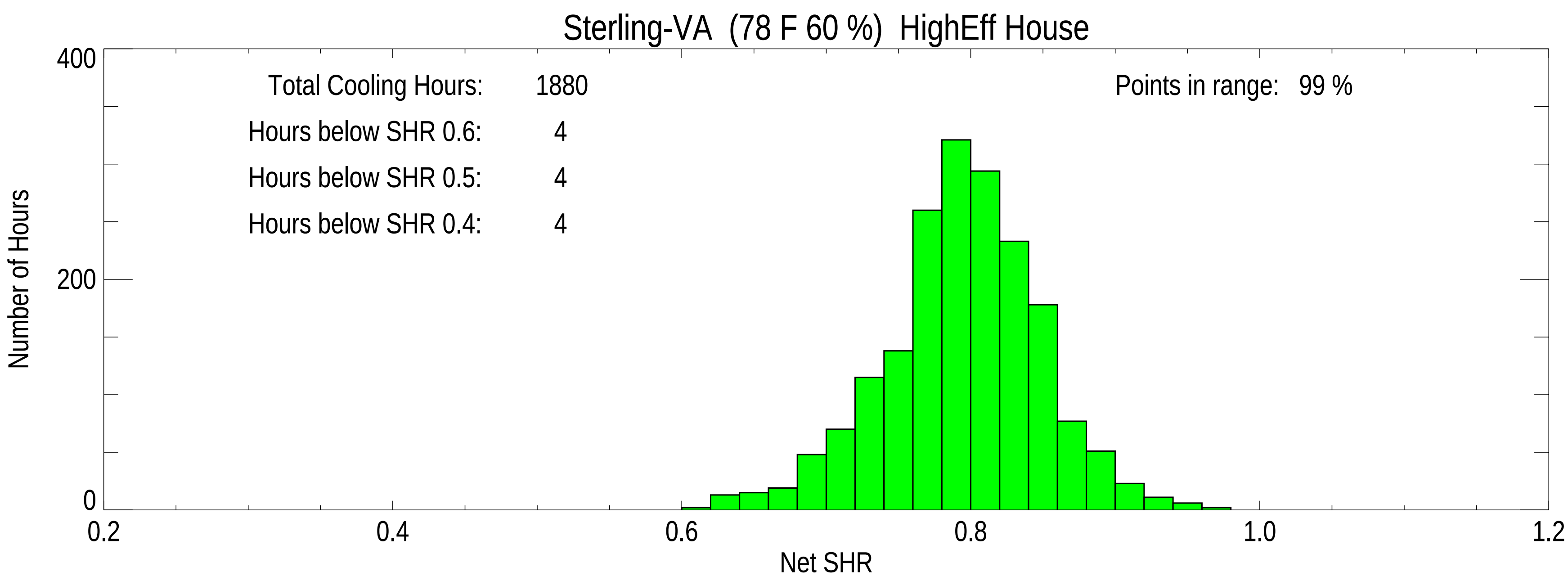

Jacksonville-FL (78 F 60 %) HERS Reference House
Total Cooling Hours: 3586
Hours below SHR 0.6: 509
Hours below SHR 0.5: 459
Hours below SHR 0.4: 459
Points in range: 87 %
Number of Hours
Net SHR
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2

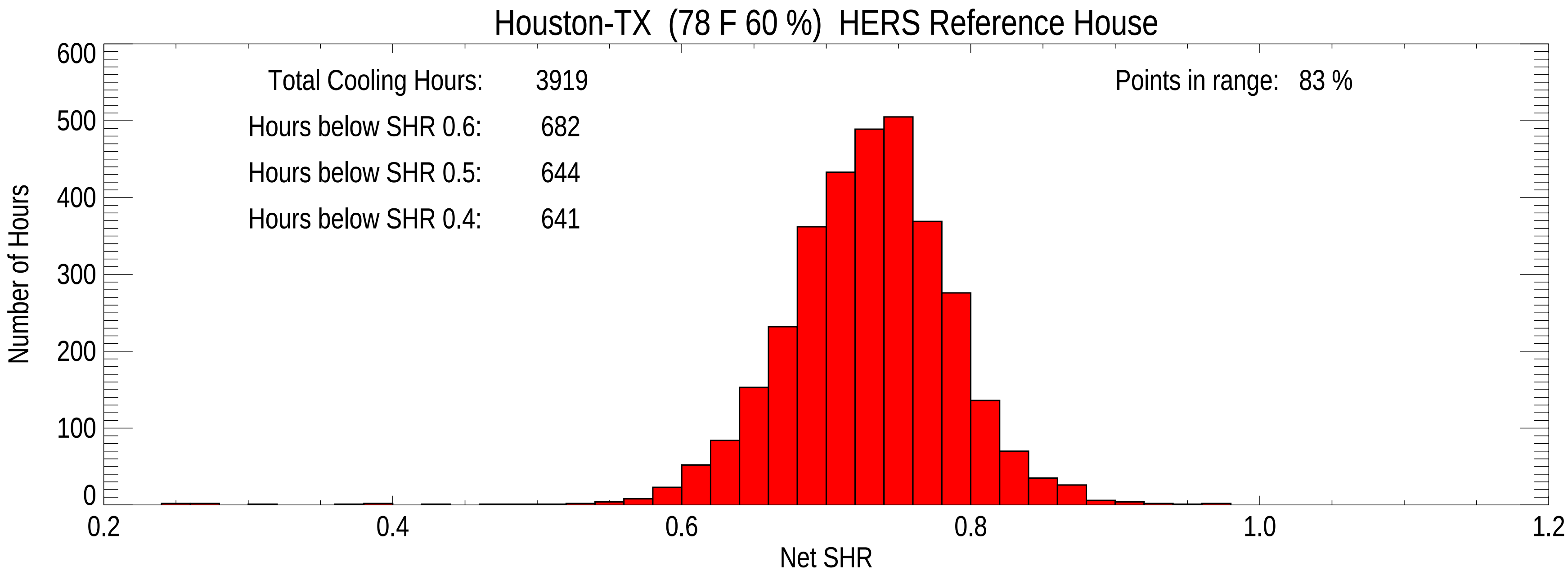

Jacksonville-FL (78 F 60 %) HighEff House
Total Cooling Hours: 3740
Hours below SHR 0.6: 500
Hours below SHR 0.5: 500
Hours below SHR 0.4: 499
Points in range: 86 %
Number of Hours
Net SHR
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
1.2

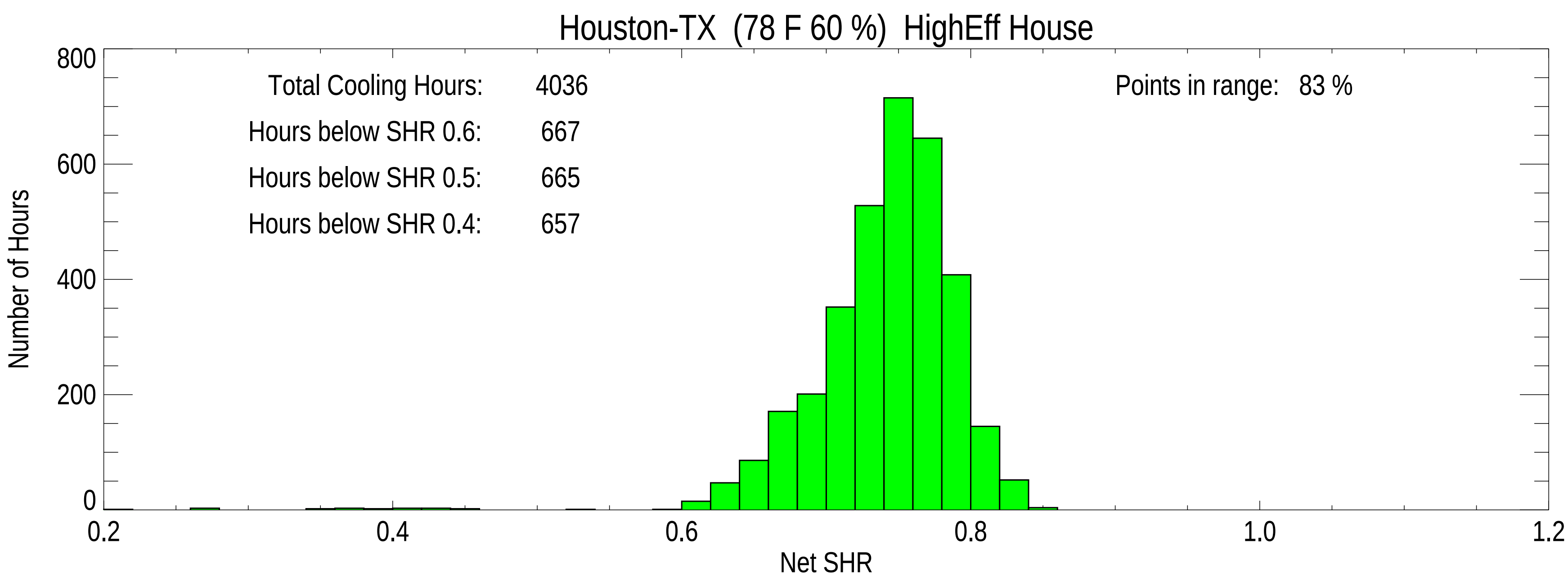

Atlanta-GA (78 F 60 %) HERS Reference House
Total Cooling Hours: 1918
Hours below SHR 0.6: 163
Hours below SHR 0.5: 159
Hours below SHR 0.4: 159
Points in range: 91 %
Number of Hours
0
50
100
150
200
250
300
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

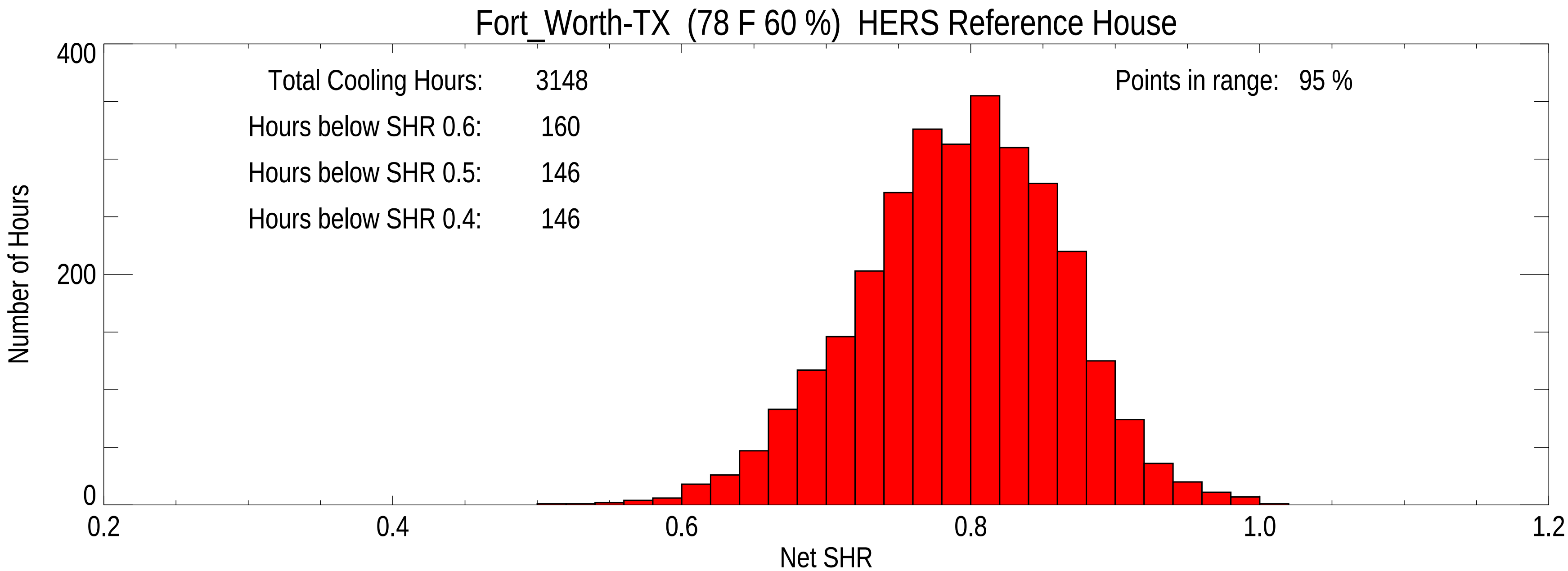

Atlanta-GA (78 F 60 %) HighEff House
Total Cooling Hours: 2214
Hours below SHR 0.6: 51
Hours below SHR 0.5: 51
Hours below SHR 0.4: 51
Points in range: 97 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

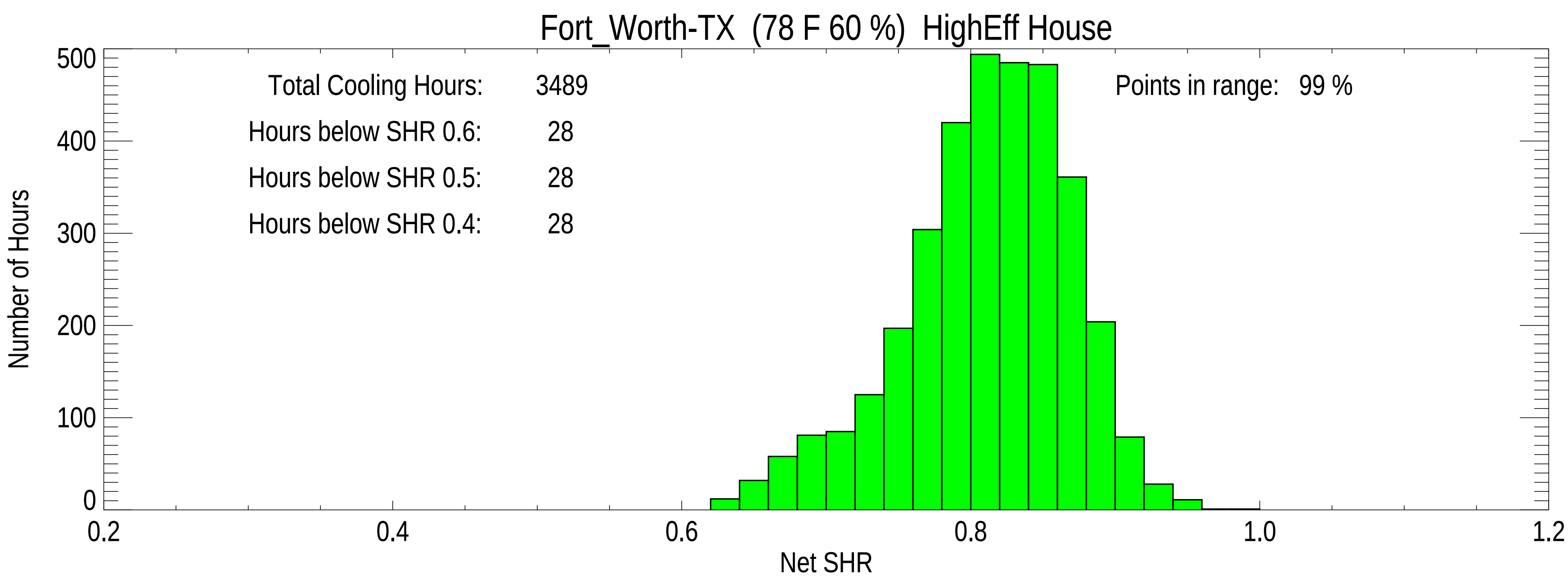

Sterling-VA (78 F 60 %) HERS Reference House
Total Cooling Hours: 1632
Hours below SHR 0.6: 68
Hours below SHR 0.5: 58
Hours below SHR 0.4: 58
Points in range: 96 %
Number of Hours
Net SHR
0
50
100
150
200
250
0.2
0.4
0.6
0.8
1.0
1.2

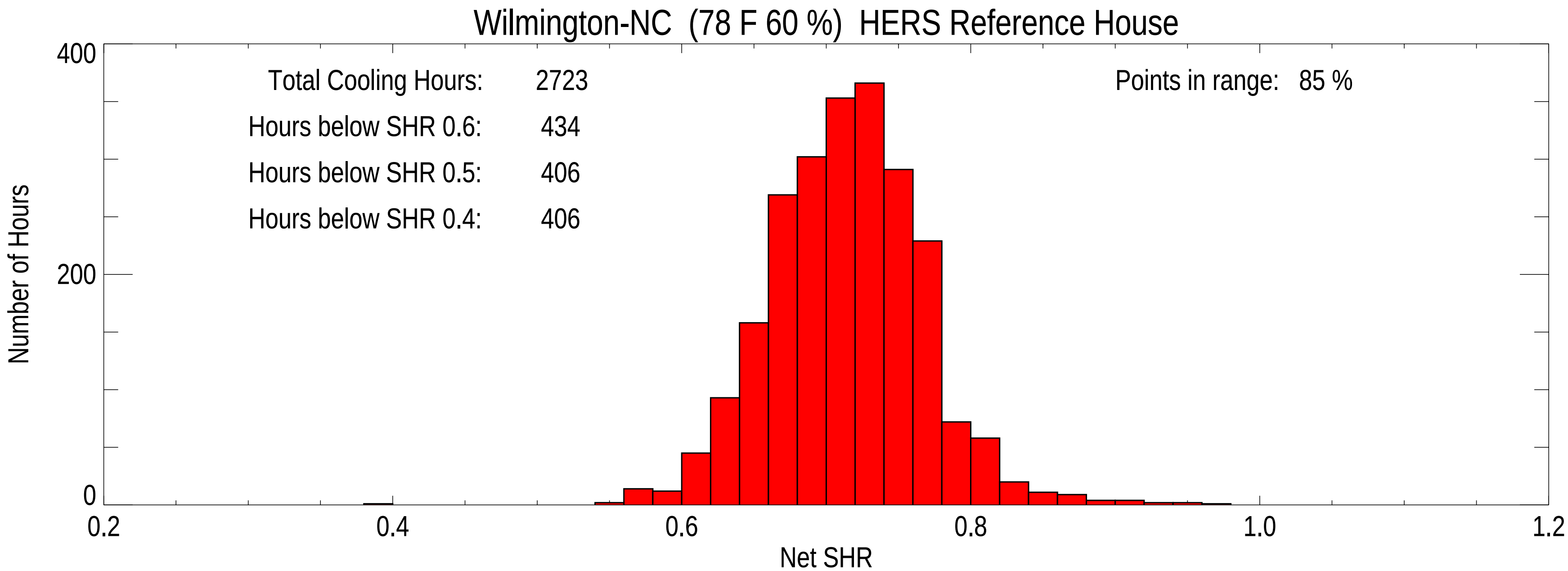

Sterling-VA (78 F 60 %) HighEff House
Total Cooling Hours: 1880
Hours below SHR 0.6: 4
Hours below SHR 0.5: 4
Hours below SHR 0.4: 4
Points in range: 99 %
Number of Hours
Net SHR
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2

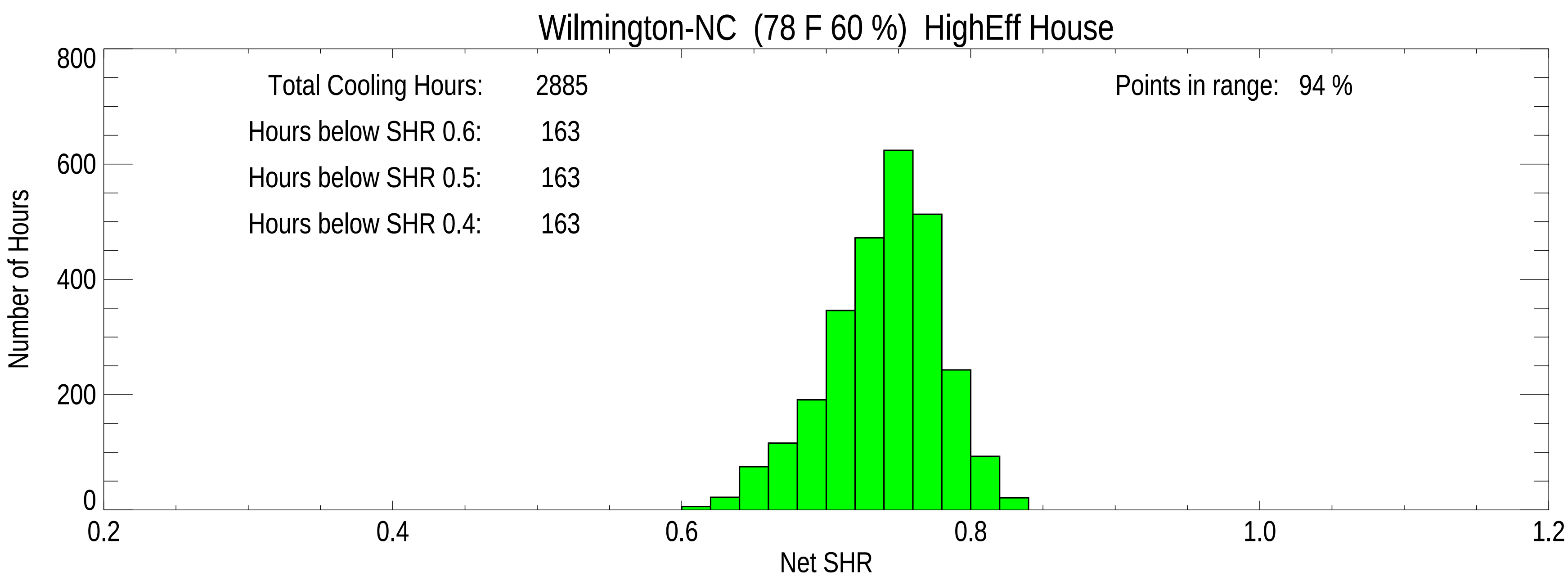

Houston-TX (78 F 60 %) HERS Reference House
Total Cooling Hours: 3919
Hours below SHR 0.6: 682
Hours below SHR 0.5: 644
Hours below SHR 0.4: 641
Points in range: 83 %
Number of Hours
0
100
200
300
400
500
600
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

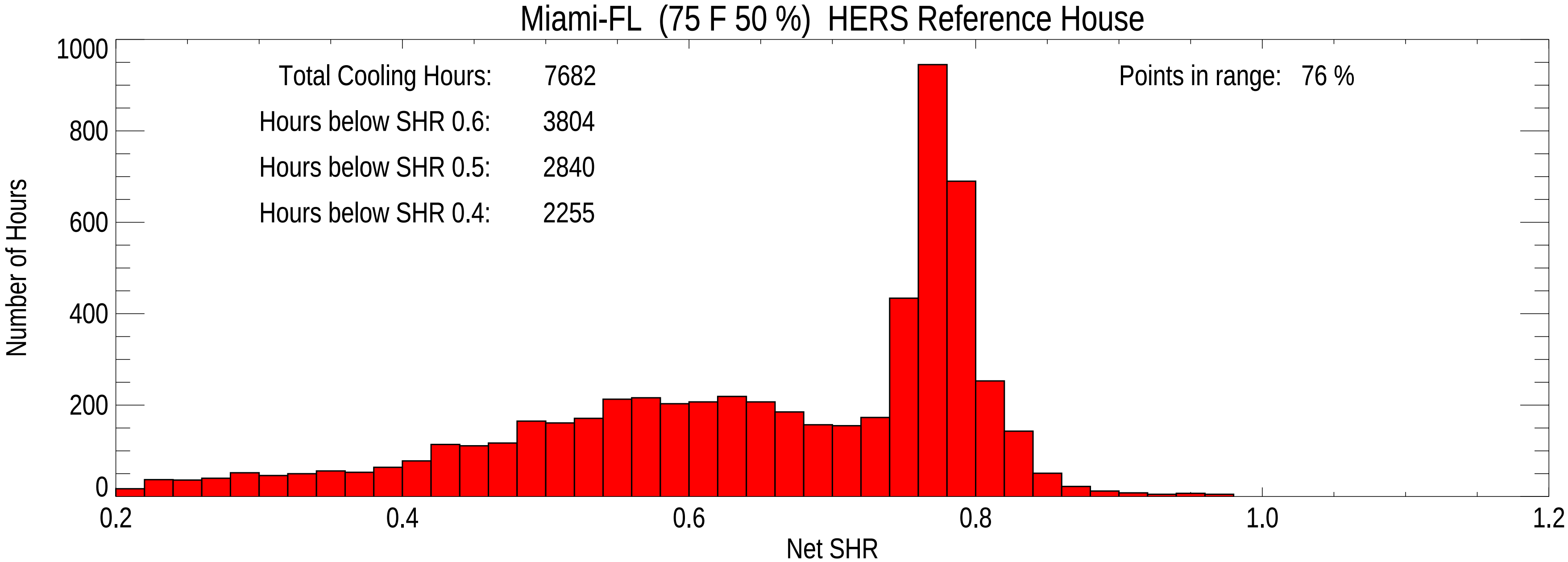

Houston-TX (78 F 60 %) HighEff House
Total Cooling Hours: 4036
Hours below SHR 0.6: 667
Hours below SHR 0.5: 665
Hours below SHR 0.4: 657
Points in range: 83 %
Number of Hours
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

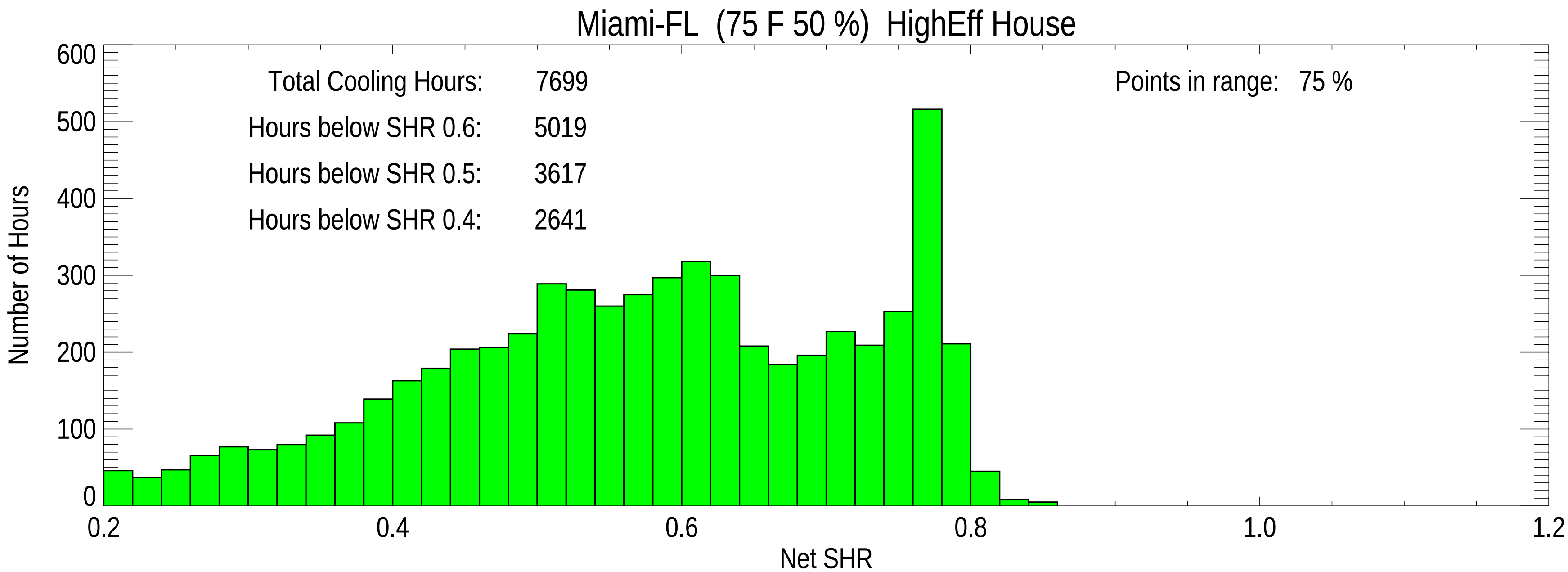

Fort_Worth-TX (78 F 60 %) HERS Reference House
Total Cooling Hours: 3148
Hours below SHR 0.6: 160
Hours below SHR 0.5: 146
Hours below SHR 0.4: 146
Points in range: 95 %
Number of Hours
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

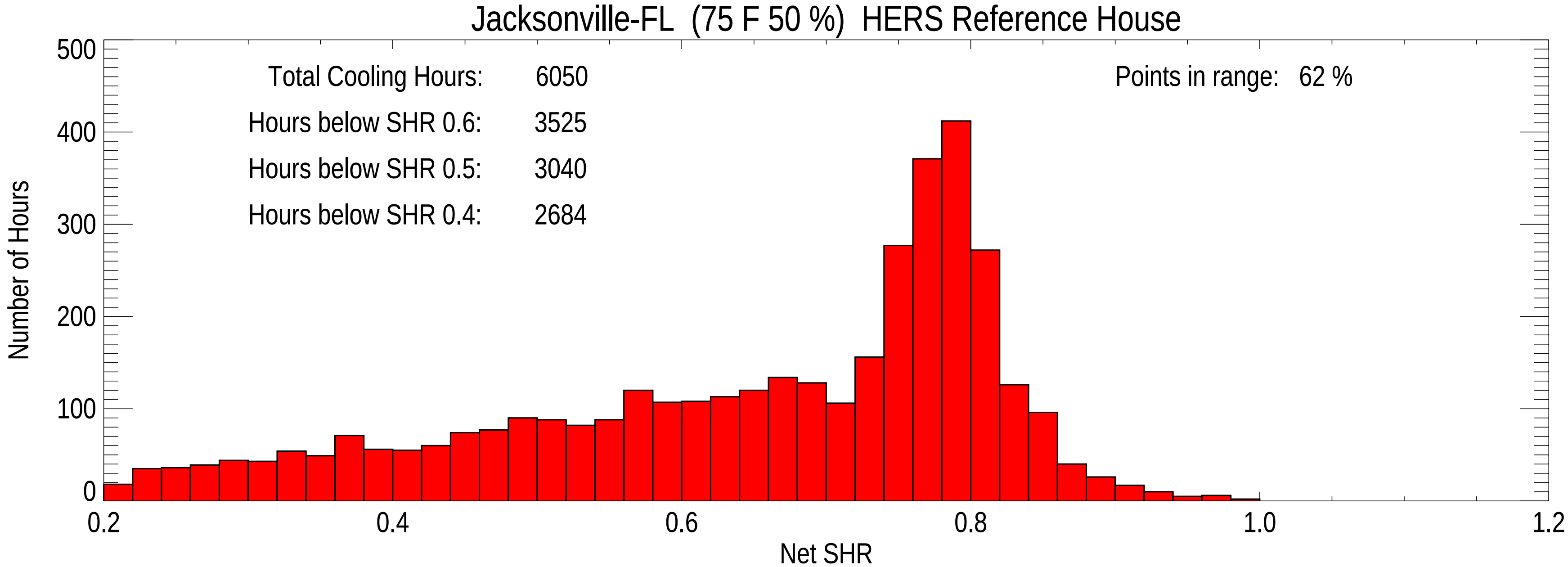

Fort_Worth-TX (78 F 60 %) HighEff House
Total Cooling Hours: 3489
Hours below SHR 0.6: 28
Hours below SHR 0.5: 28
Hours below SHR 0.4: 28
Points in range: 99 %
Number of Hours
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

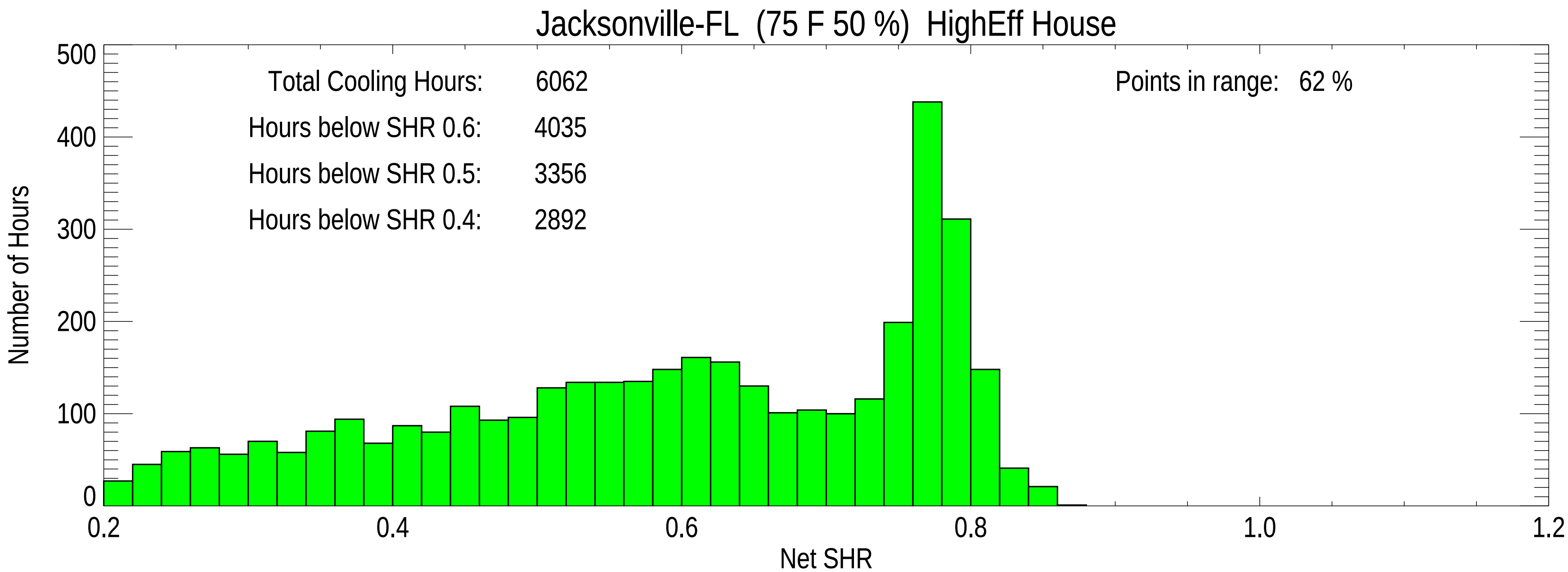

Wilmington-NC (78 F 60 %) HERS Reference House
Total Cooling Hours: 2723
Hours below SHR 0.6: 434
Hours below SHR 0.5: 406
Hours below SHR 0.4: 406
Points in range: 85 %
Number of Hours
Net SHR
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2

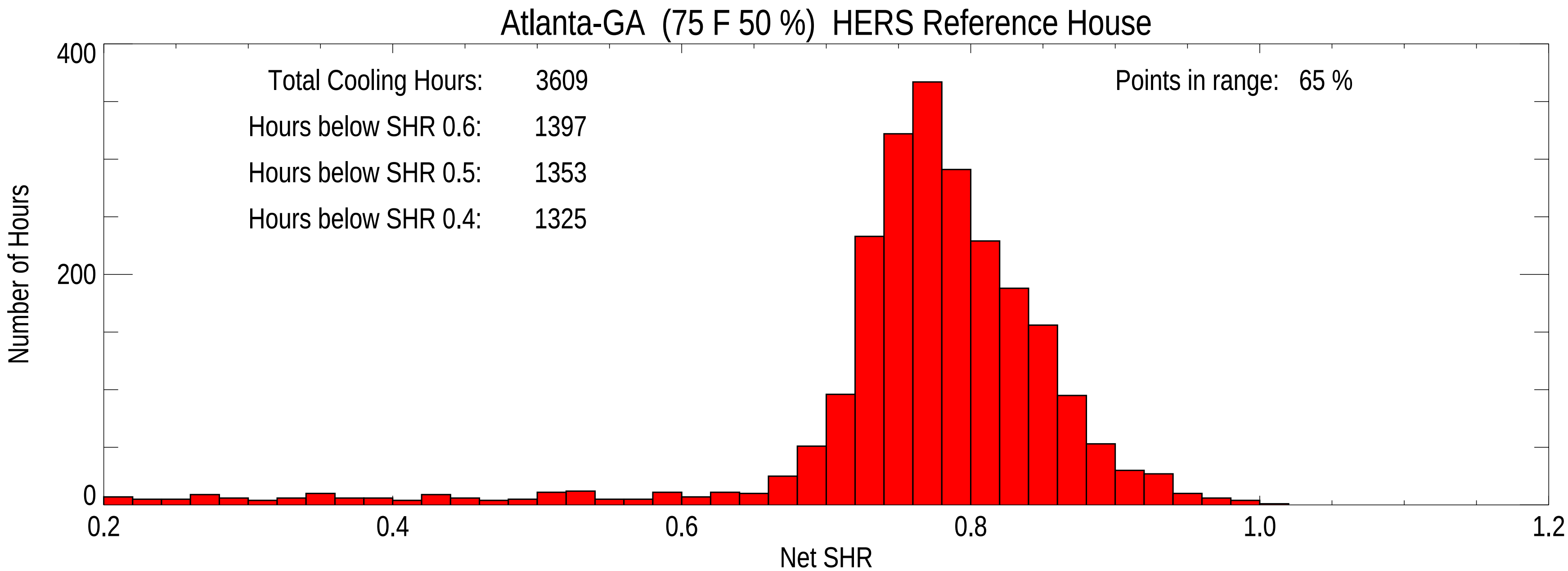

Wilmington-NC (78 F 60 %) HighEff House
Total Cooling Hours: 2885
Hours below SHR 0.6: 163
Hours below SHR 0.5: 163
Hours below SHR 0.4: 163
Points in range: 94 %
Number of Hours
Net SHR
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
1.2

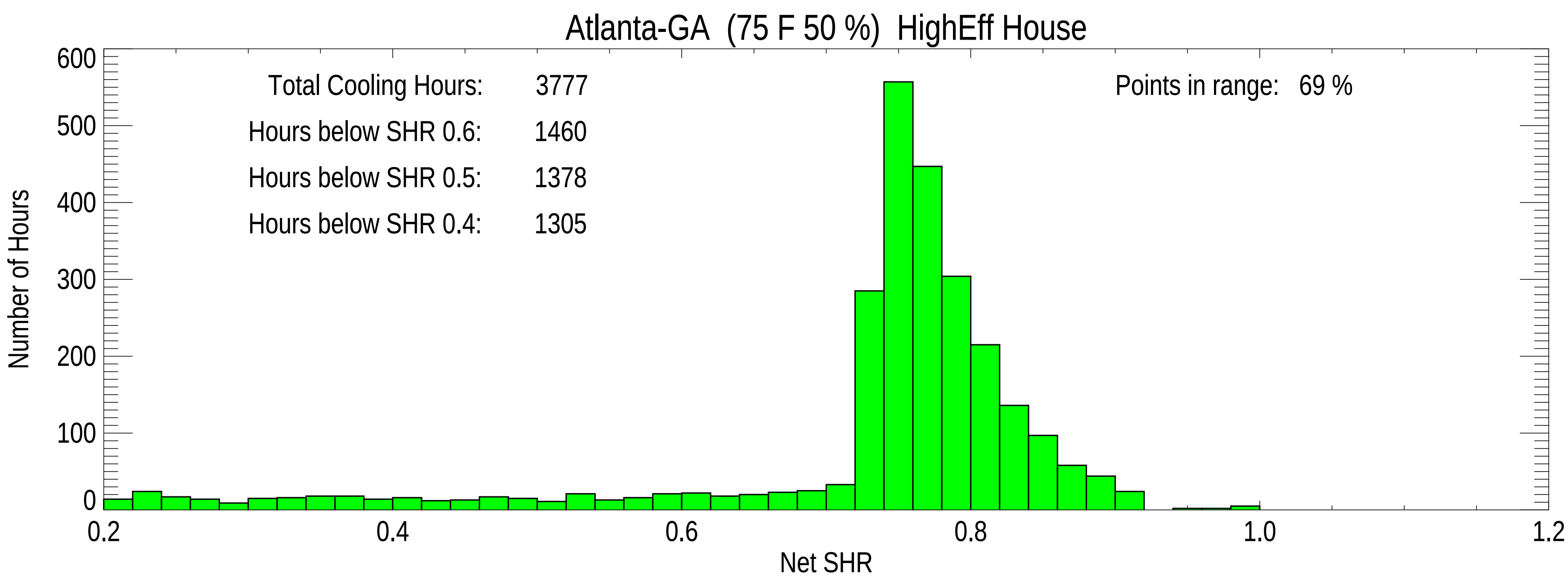

Miami-FL (75 F 50 %) HERS Reference House
Total Cooling Hours: 7682
Hours below SHR 0.6: 3804
Hours below SHR 0.5: 2840
Hours below SHR 0.4: 2255
Points in range: 76 %
Number of Hours
1000
800
600
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

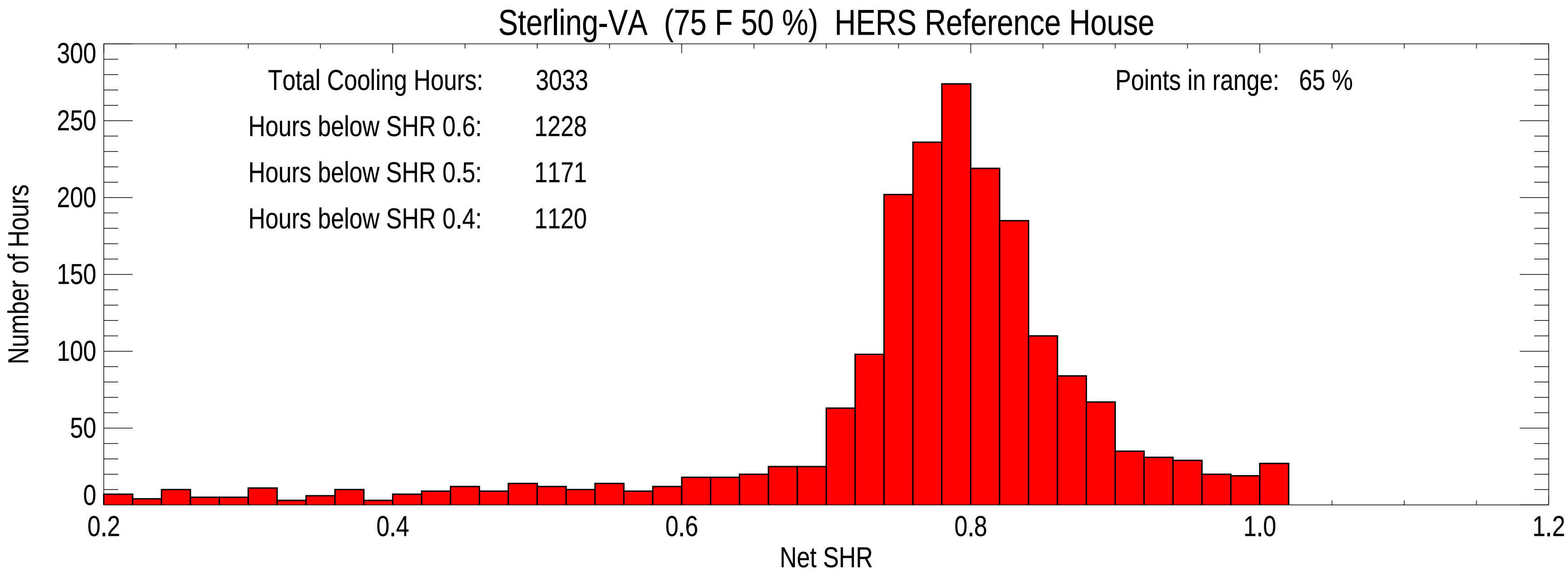

Miami-FL (75 F 50 %) HighEff House
Total Cooling Hours: 7699
Hours below SHR 0.6: 5019
Hours below SHR 0.5: 3617
Hours below SHR 0.4: 2641
Points in range: 75 %
Number of Hours
600
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

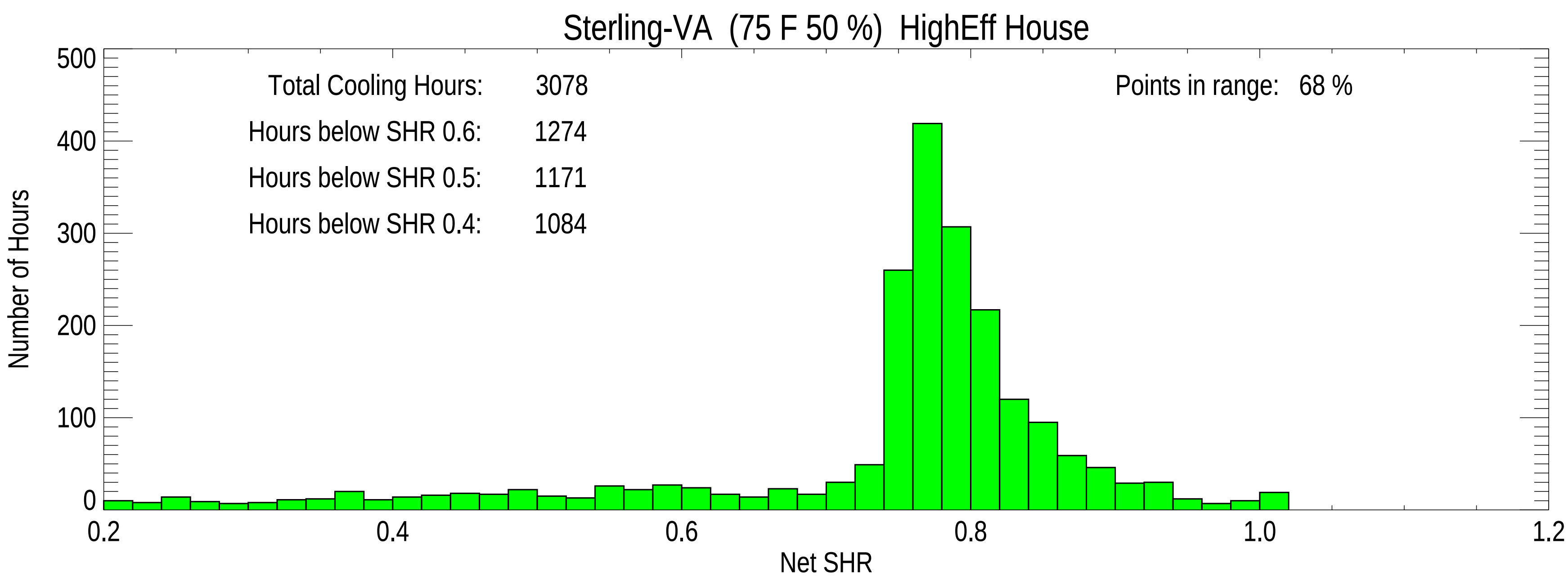

Jacksonville-FL (75 F 50 %) HERS Reference House
Total Cooling Hours: 6050
Hours below SHR 0.6: 3525
Hours below SHR 0.5: 3040
Hours below SHR 0.4: 2684
Points in range: 62 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

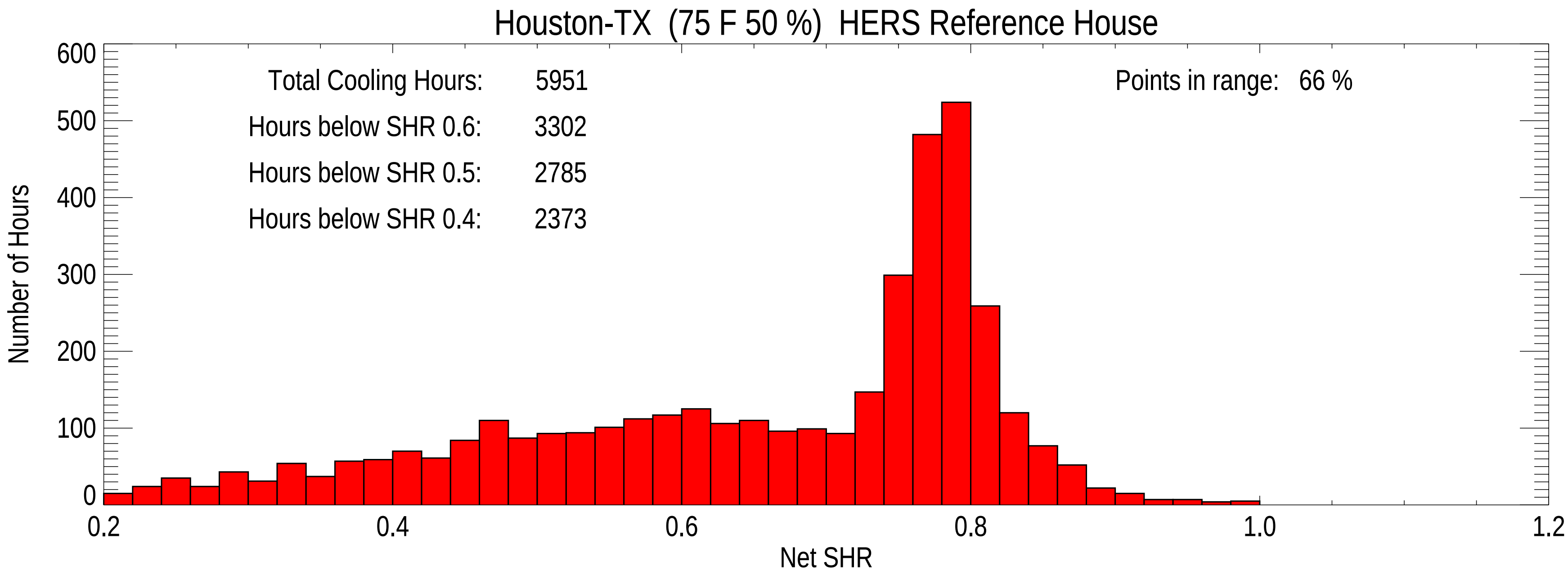

Jacksonville-FL (75 F 50 %) HighEff House
Total Cooling Hours: 6062
Hours below SHR 0.6: 4035
Hours below SHR 0.5: 3356
Hours below SHR 0.4: 2892
Points in range: 62 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

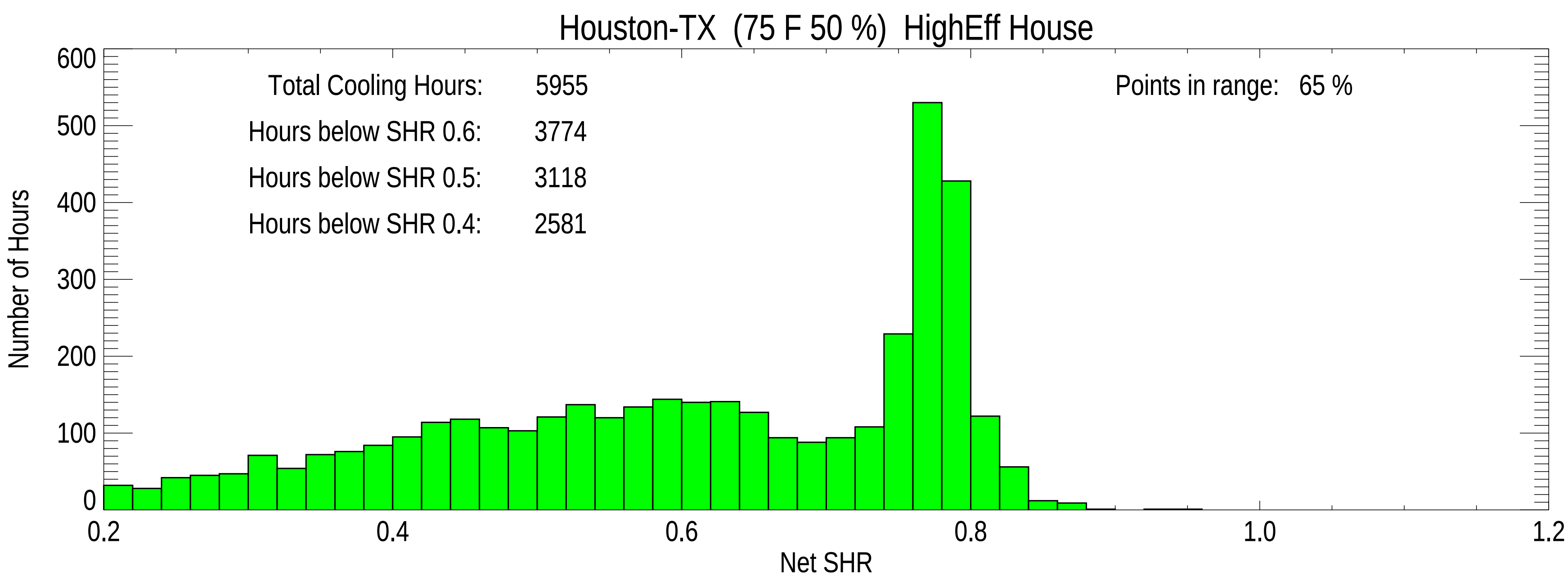

Atlanta-GA (75 F 50 %) HERS Reference House
Total Cooling Hours: 3609
Hours below SHR 0.6: 1397
Hours below SHR 0.5: 1353
Hours below SHR 0.4: 1325
Points in range: 65 %
Number of Hours
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

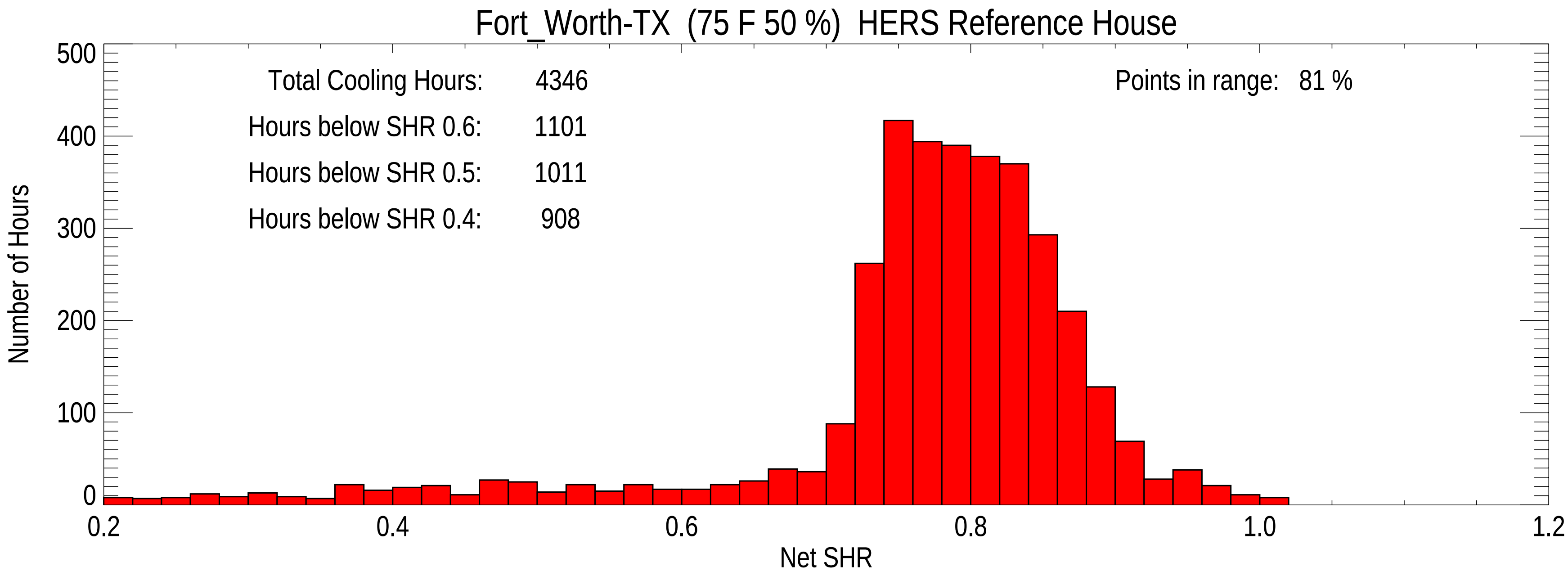

Atlanta-GA (75 F 50 %) HighEff House
Total Cooling Hours: 3777
Hours below SHR 0.6: 1460
Hours below SHR 0.5: 1378
Hours below SHR 0.4: 1305
Points in range: 69 %
Number of Hours
0
100
200
300
400
500
600
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

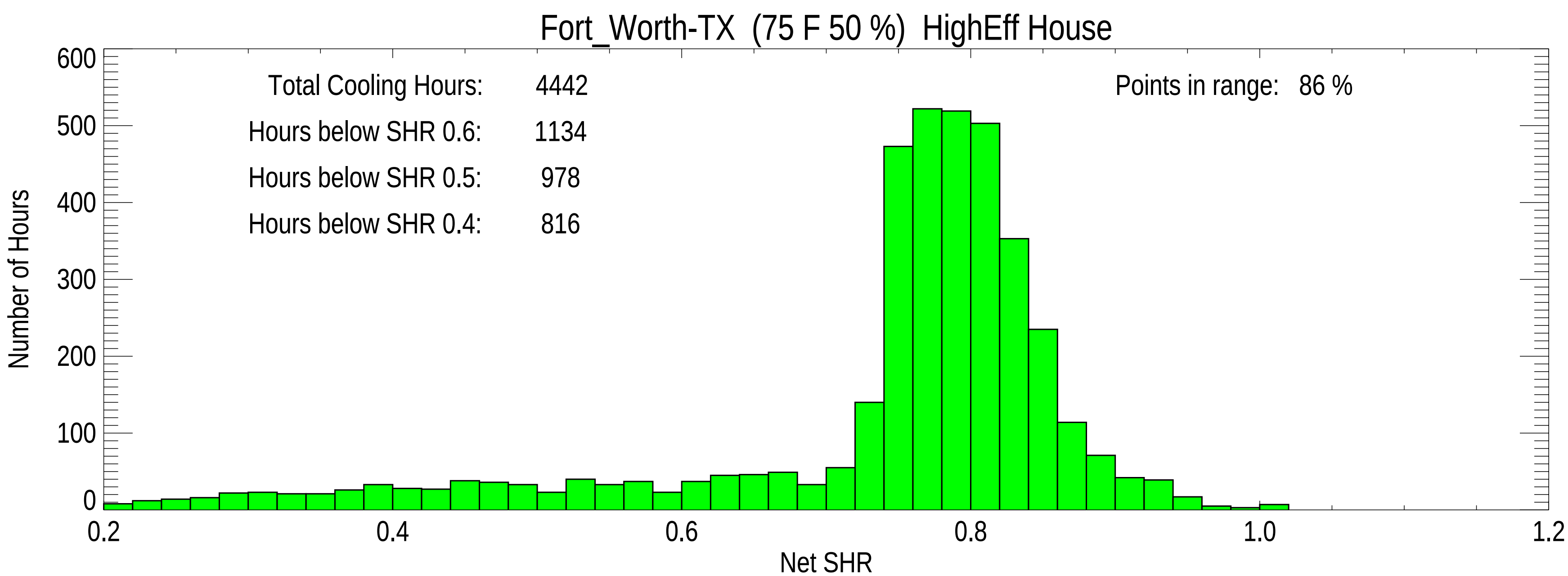

Sterling-VA (75 F 50 %) HERS Reference House
Total Cooling Hours: 3033
Hours below SHR 0.6: 1228
Hours below SHR 0.5: 1171
Hours below SHR 0.4: 1120
Points in range: 65 %
Number of Hours
Net SHR
0
50
100
150
200
250
300
0.2
0.4
0.6
0.8
1.0
1.2

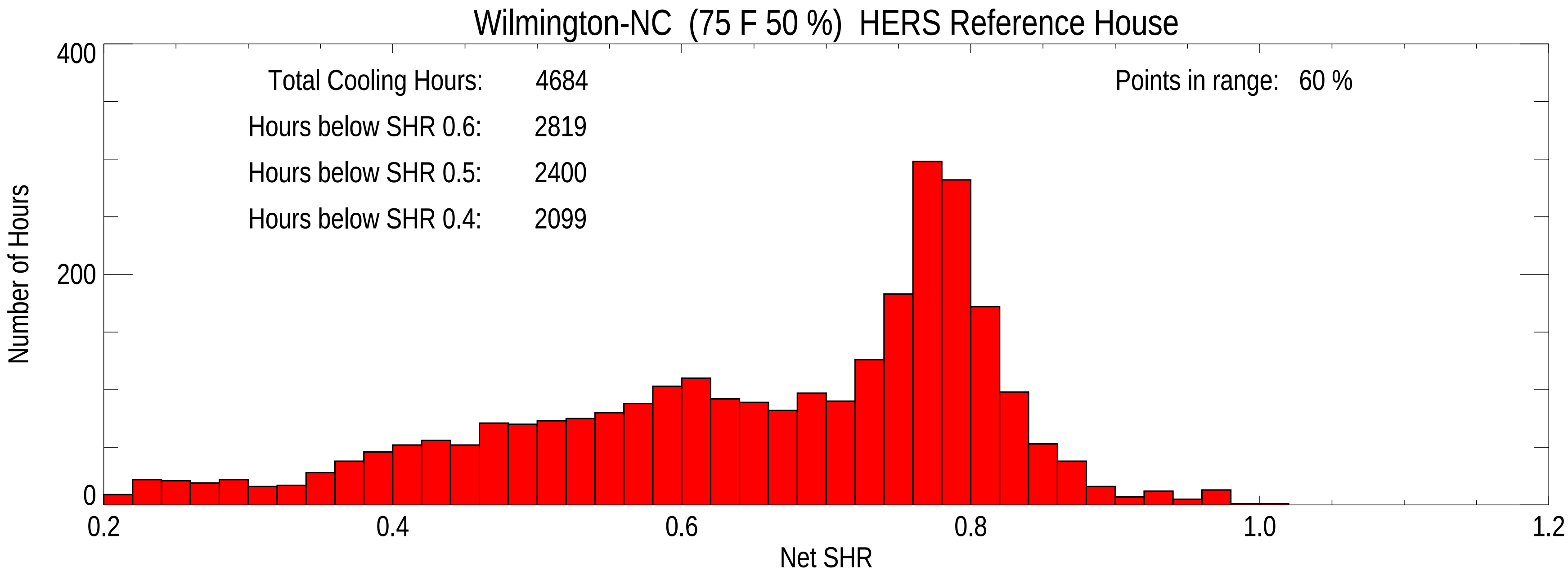

Sterling-VA (75 F 50 %) HighEff House
Total Cooling Hours: 3078
Hours below SHR 0.6: 1274
Hours below SHR 0.5: 1171
Hours below SHR 0.4: 1084
Points in range: 68 %
Number of Hours
Net SHR
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2

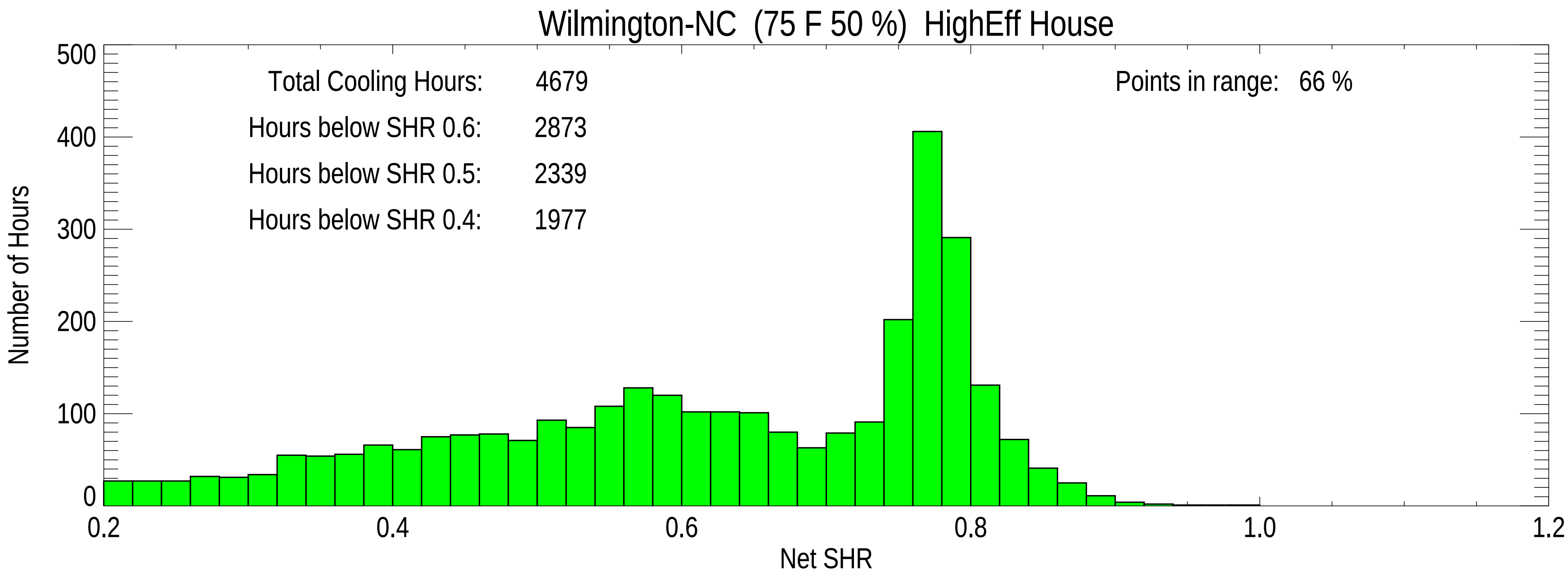

Houston-TX (75 F 50 %) HERS Reference House
Total Cooling Hours: 5951
Hours below SHR 0.6: 3302
Hours below SHR 0.5: 2785
Hours below SHR 0.4: 2373
Points in range: 66 %
Number of Hours
Net SHR
0
100
200
300
400
500
600
0.2
0.4
0.6
0.8
1.0
1.2


Houston-TX (75 F 50 %) HighEff House
Total Cooling Hours: 5955
Hours below SHR 0.6: 3774
Hours below SHR 0.5: 3118
Hours below SHR 0.4: 2581
Points in range: 65 %
Number of Hours
Net SHR
0
100
200
300
400
500
600
0.2
0.4
0.6
0.8
1.0
1.2

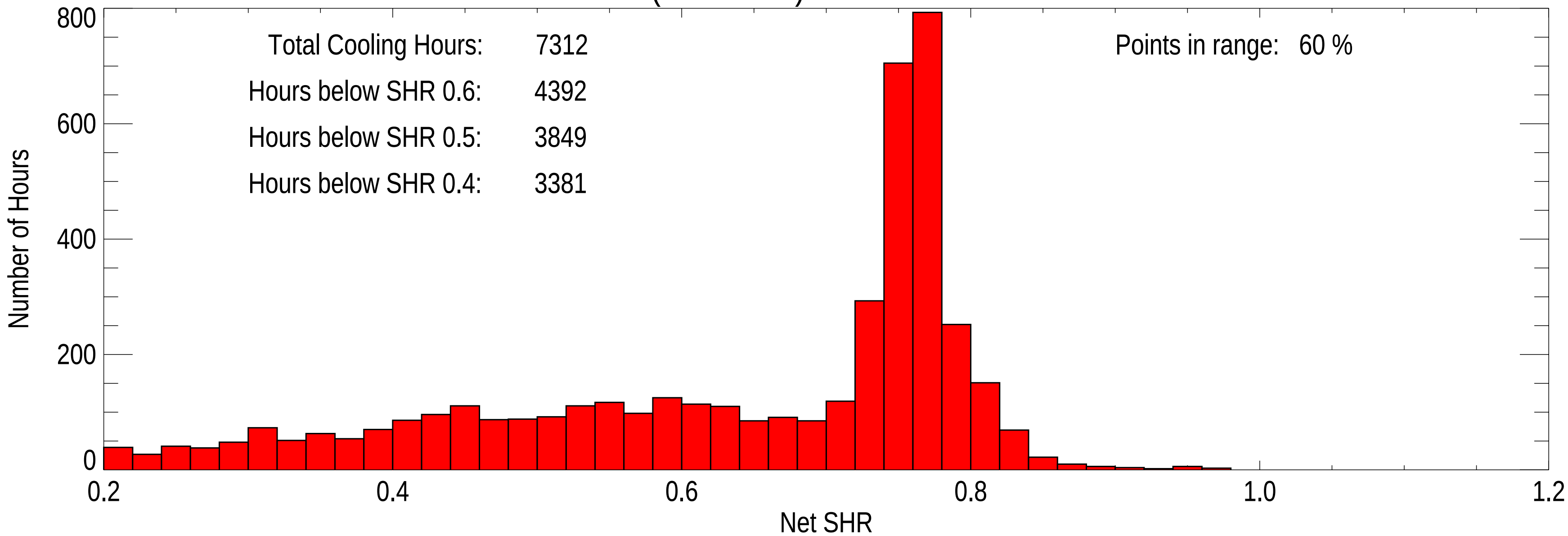

Fort_Worth-TX (75 F 50 %) HERS Reference House
Total Cooling Hours: 4346
Hours below SHR 0.6: 1101
Hours below SHR 0.5: 1011
Hours below SHR 0.4: 908
Points in range: 81 %
Number of Hours
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR


Fort_Worth-TX (75 F 50 %) HighEff House
Total Cooling Hours: 4442
Hours below SHR 0.6: 1134
Hours below SHR 0.5: 978
Hours below SHR 0.4: 816
Points in range: 86 %
Number of Hours
600
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

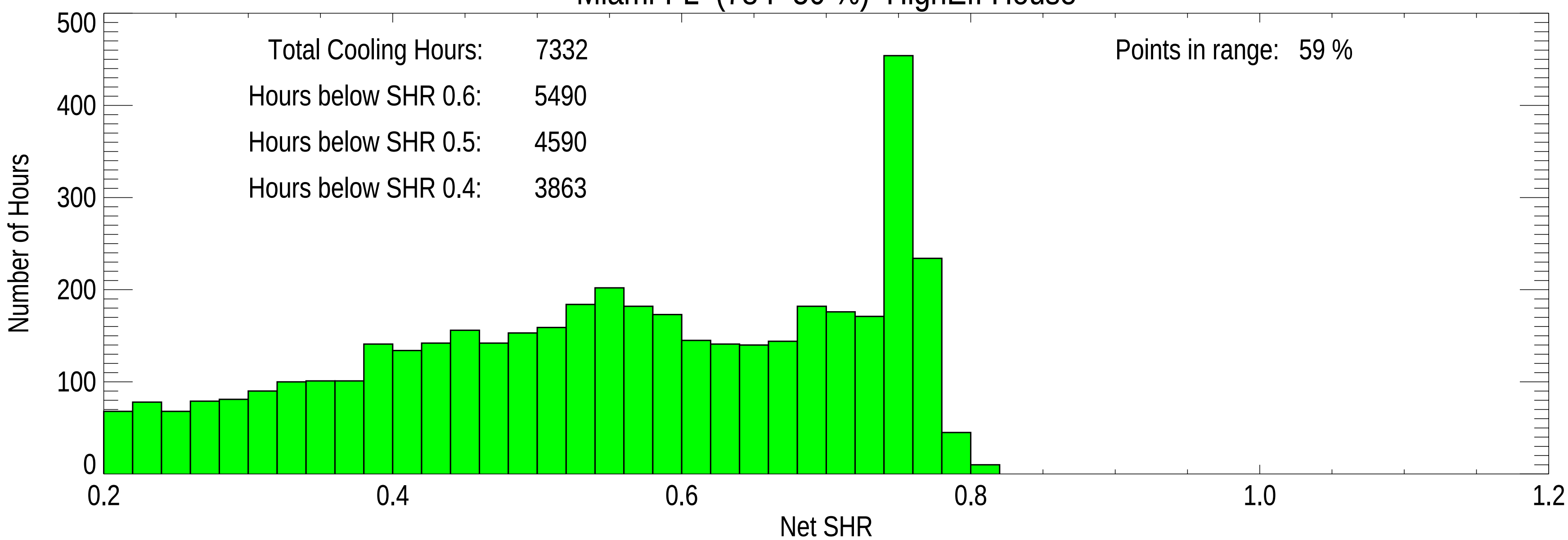

Wilmington-NC (75 F 50 %) HERS Reference House
Total Cooling Hours: 4684
Hours below SHR 0.6: 2819
Hours below SHR 0.5: 2400
Hours below SHR 0.4: 2099
Points in range: 60 %
Number of Hours
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

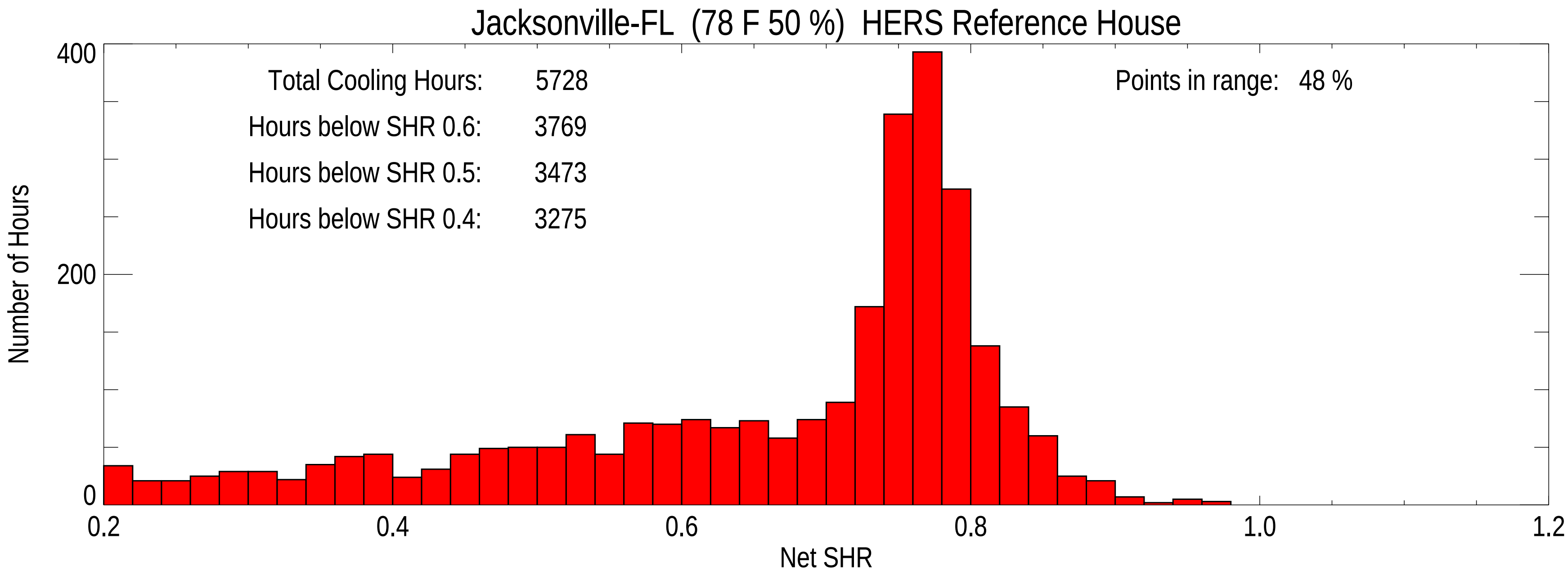

Wilmington-NC (75 F 50 %) HighEff House
Total Cooling Hours: 4679
Hours below SHR 0.6: 2873
Hours below SHR 0.5: 2339
Hours below SHR 0.4: 1977
Points in range: 66 %
Number of Hours
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

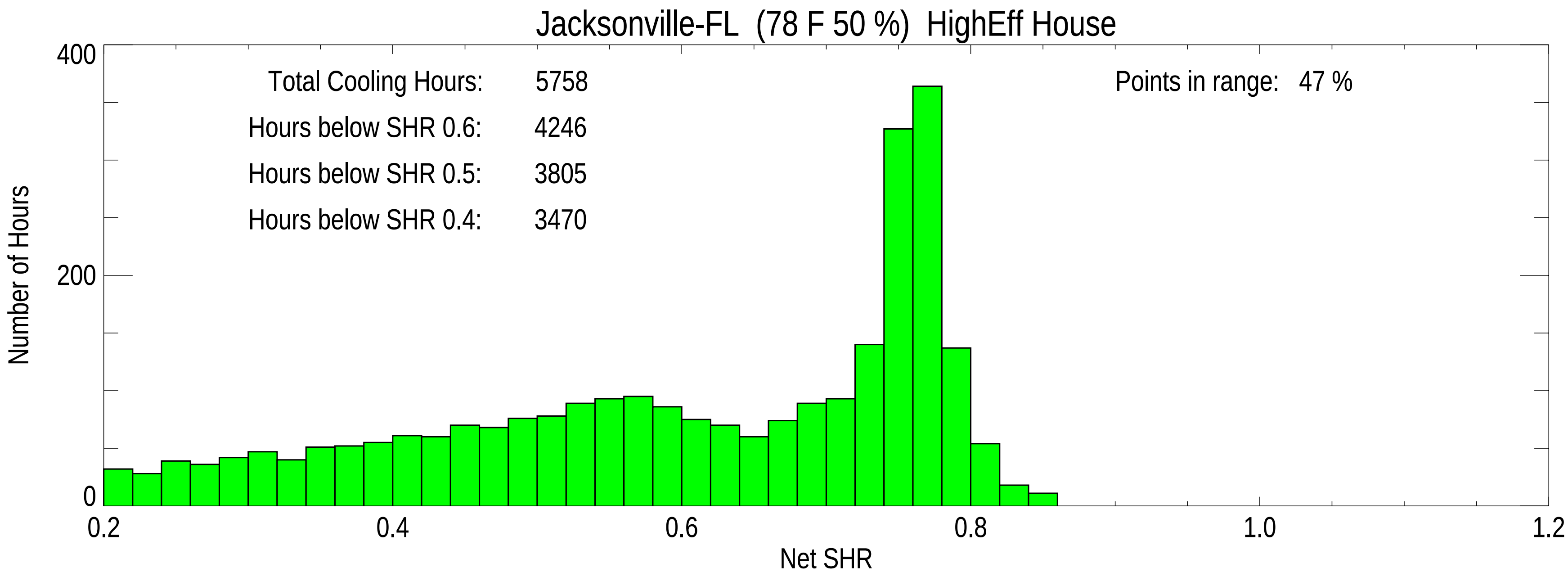
Miami-FL (78 F 50 %) HERS Reference House

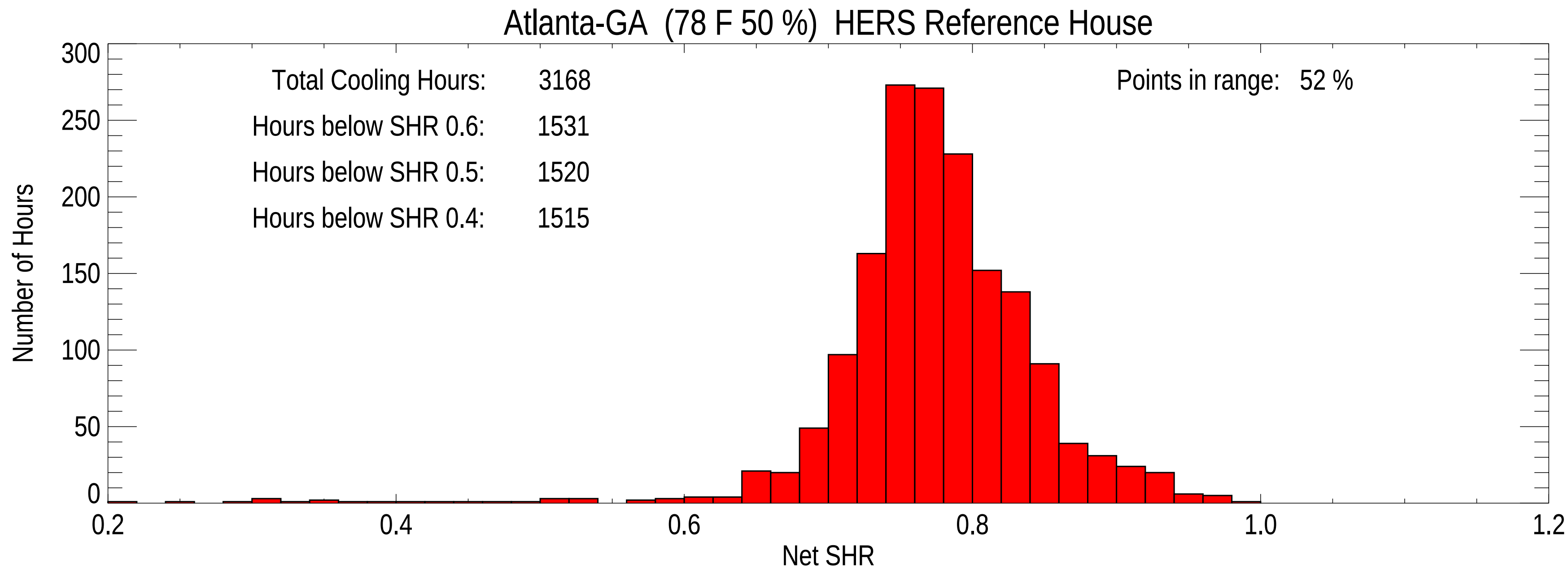


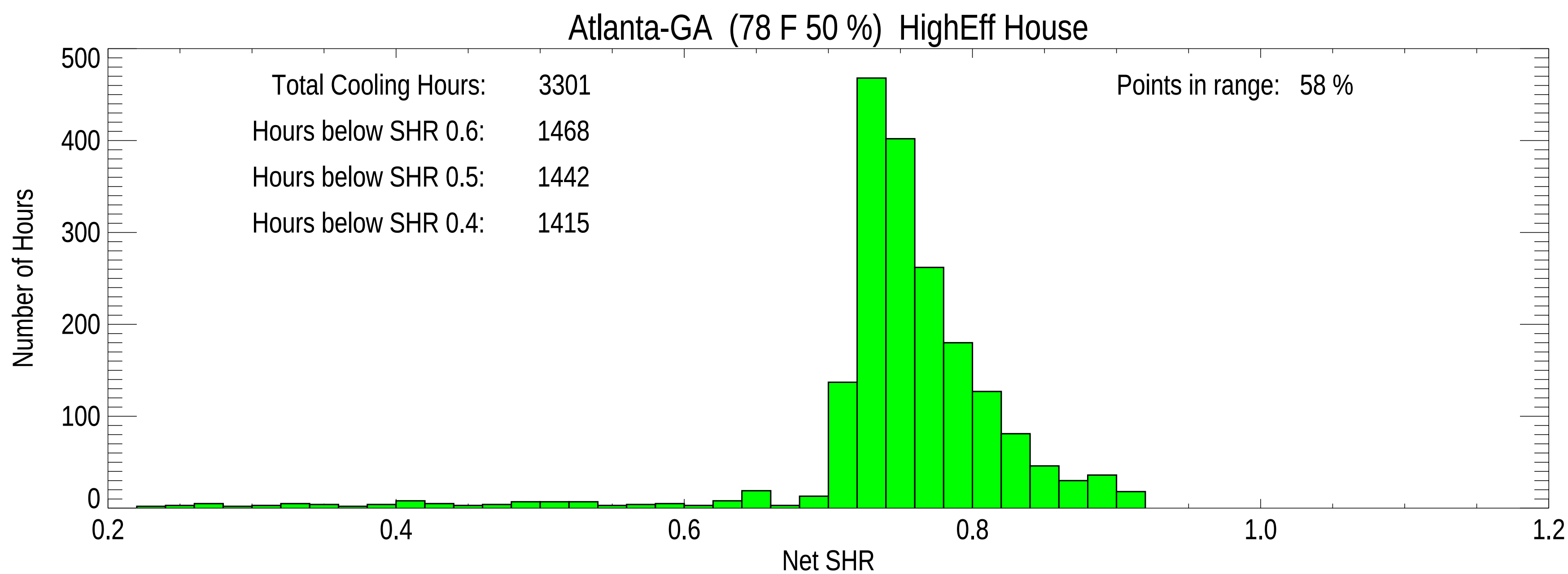
Miami-FL (78 F 50 %) HighEff House

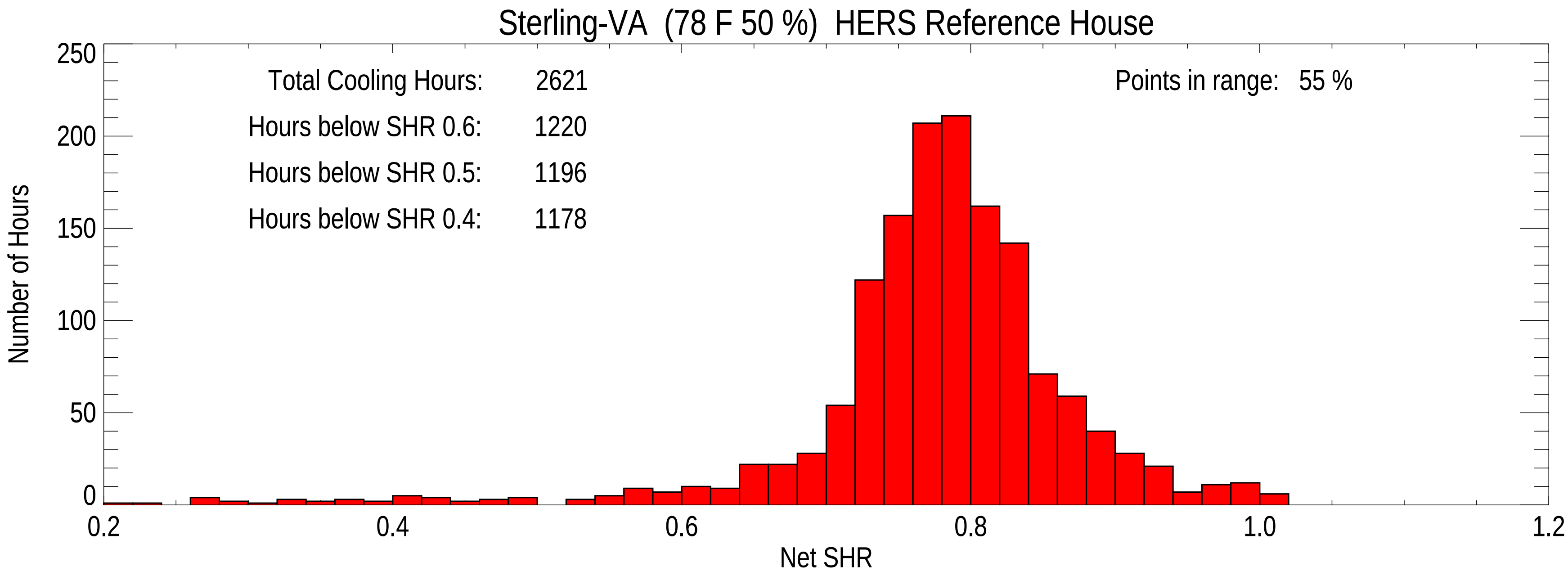


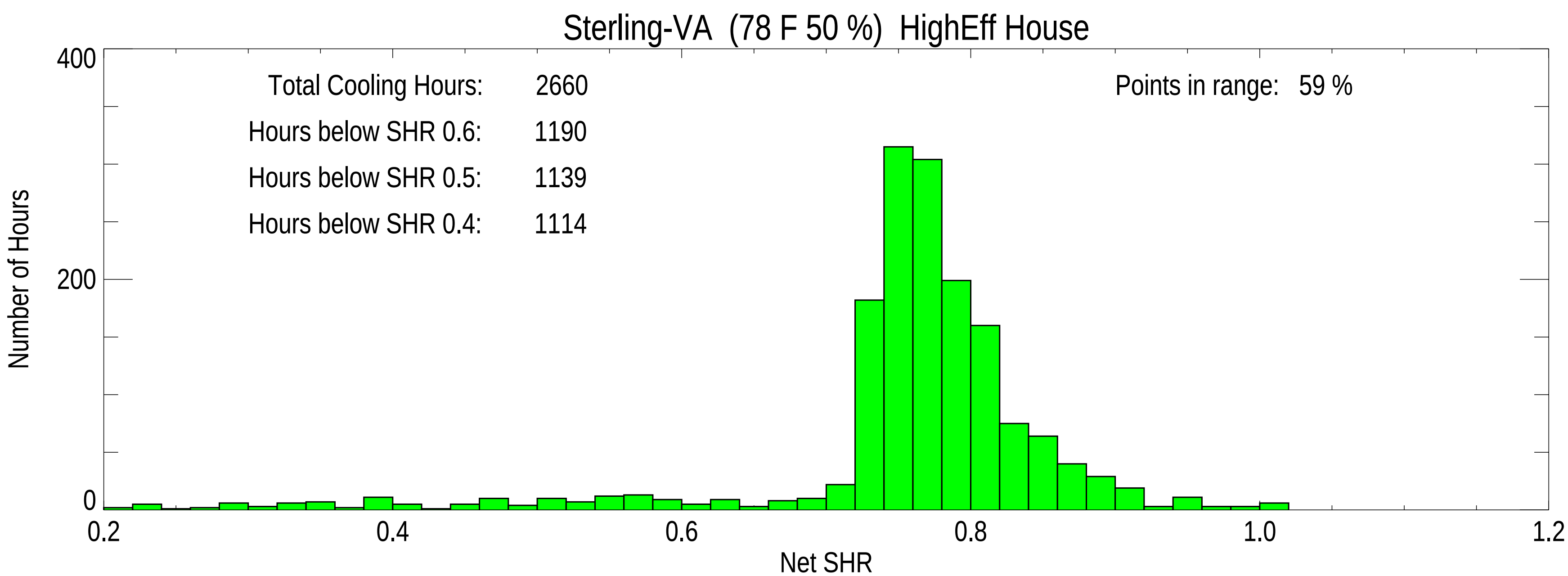

Jacksonville-FL (78 F 50 %) HERS Reference House
Total Cooling Hours: 5728
Hours below SHR 0.6: 3769
Hours below SHR 0.5: 3473
Hours below SHR 0.4: 3275
Points in range: 48 %
Number of Hours
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

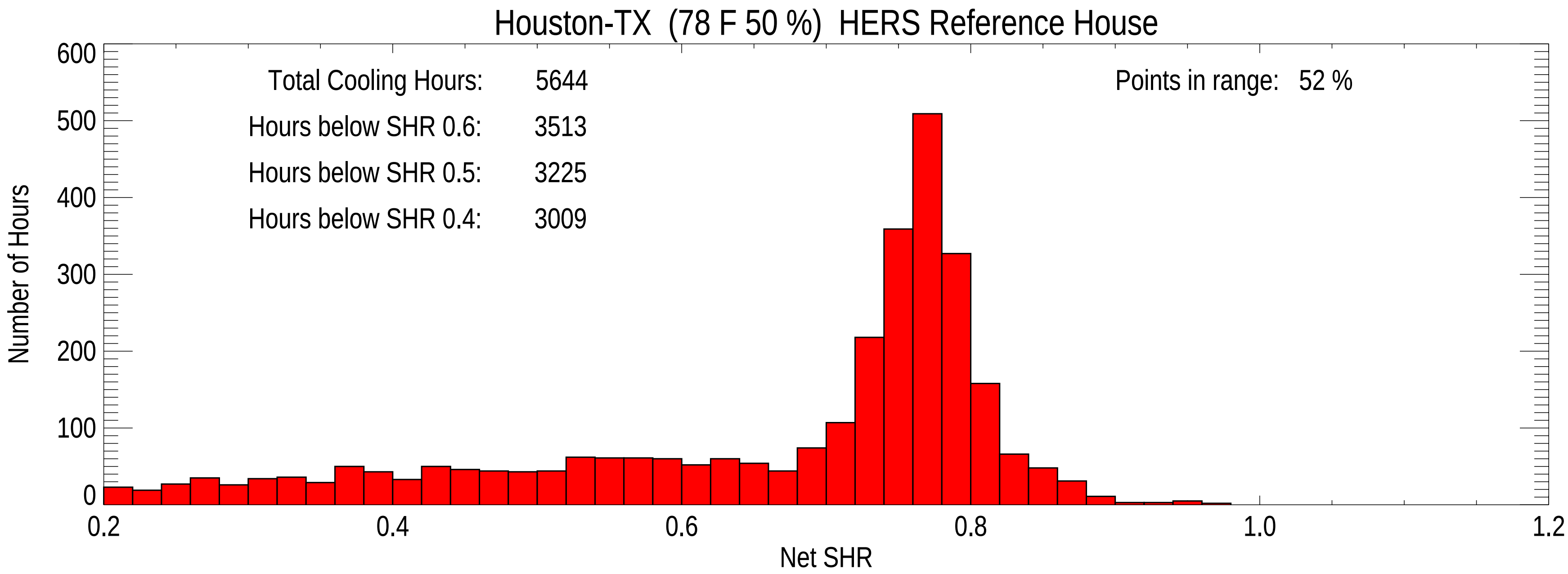

Jacksonville-FL (78 F 50 %) HighEff House
Total Cooling Hours: 5758
Hours below SHR 0.6: 4246
Hours below SHR 0.5: 3805
Hours below SHR 0.4: 3470
Points in range: 47 %
Number of Hours
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

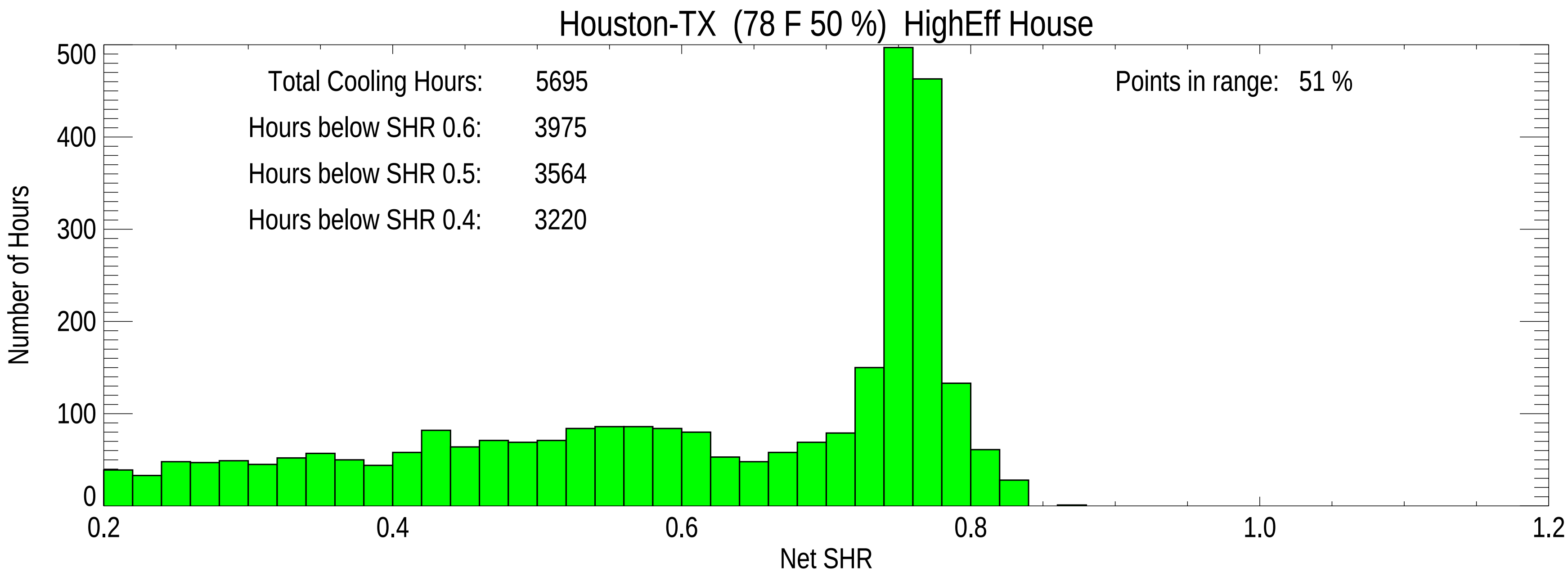

Atlanta-GA (78 F 50 %) HERS Reference House
Total Cooling Hours: 3168
Hours below SHR 0.6: 1531
Hours below SHR 0.5: 1520
Hours below SHR 0.4: 1515
Points in range: 52 %
Number of Hours
0
50
100
150
200
250
300
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

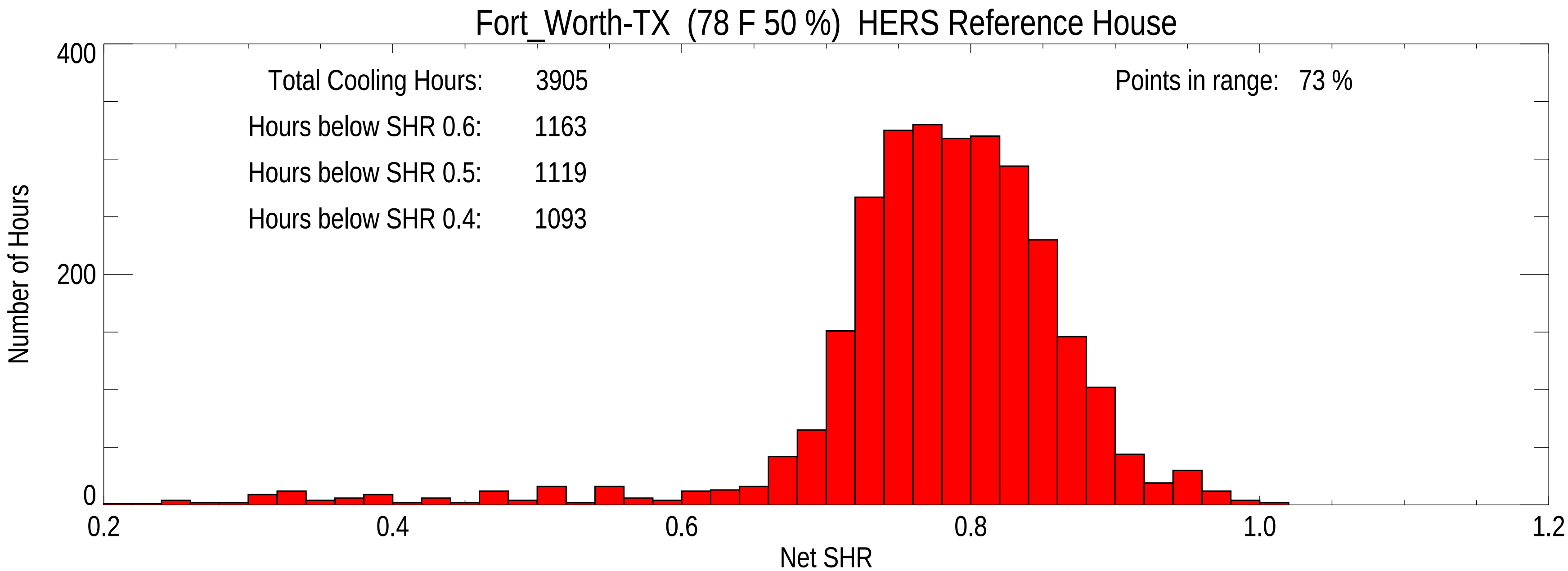

Atlanta-GA (78 F 50 %) HighEff House
Total Cooling Hours: 3301
Hours below SHR 0.6: 1468
Hours below SHR 0.5: 1442
Hours below SHR 0.4: 1415
Points in range: 58 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

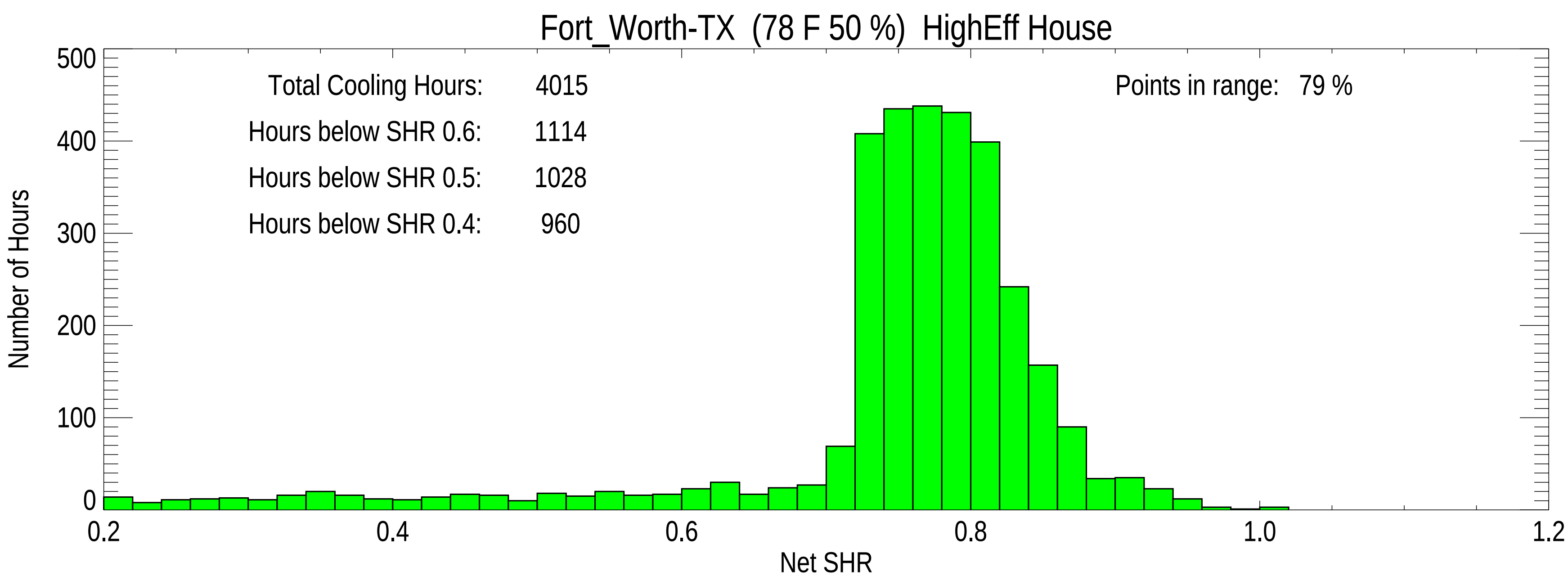

Sterling-VA (78 F 50 %) HERS Reference House
Total Cooling Hours: 2621
Hours below SHR 0.6: 1220
Hours below SHR 0.5: 1196
Hours below SHR 0.4: 1178
Points in range: 55 %
Number of Hours
250
200
150
100
50
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

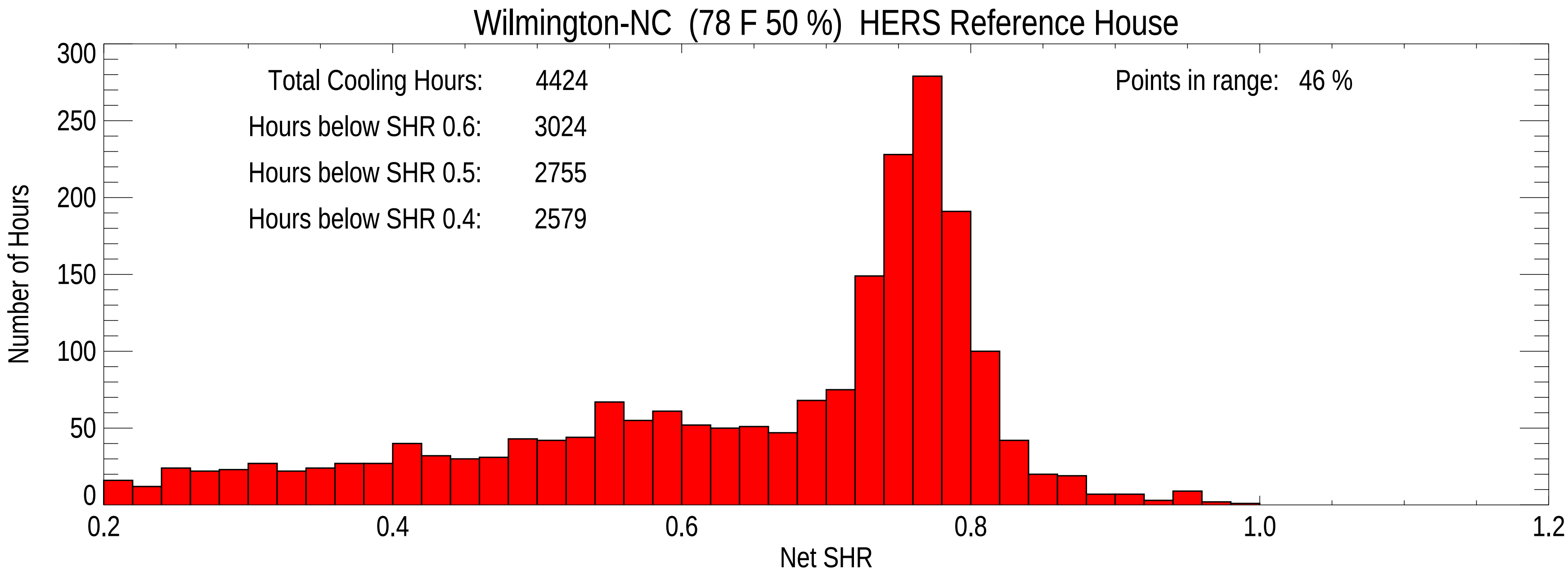

Sterling-VA (78 F 50 %) HighEff House
Total Cooling Hours: 2660
Hours below SHR 0.6: 1190
Hours below SHR 0.5: 1139
Hours below SHR 0.4: 1114
Points in range: 59 %
Number of Hours
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

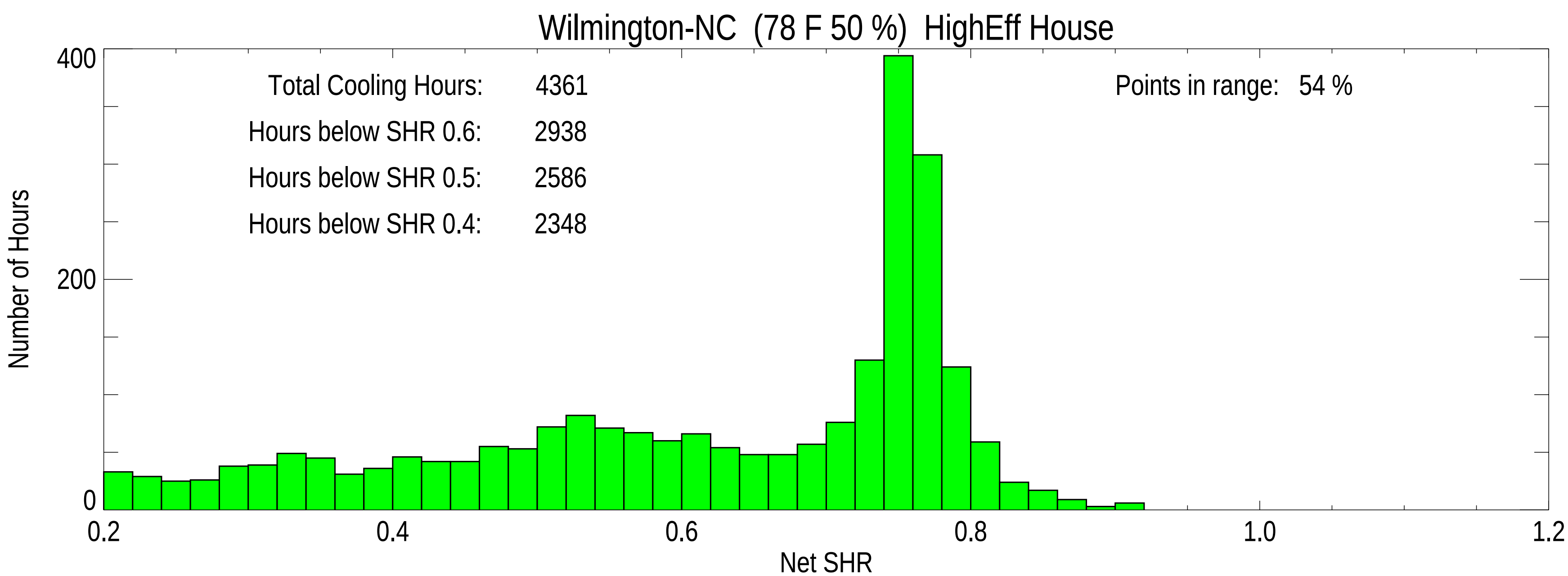

Houston-TX (78 F 50 %) HERS Reference House
Total Cooling Hours: 5644
Hours below SHR 0.6: 3513
Hours below SHR 0.5: 3225
Hours below SHR 0.4: 3009
Points in range: 52 %
Number of Hours
0
100
200
300
400
500
600
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

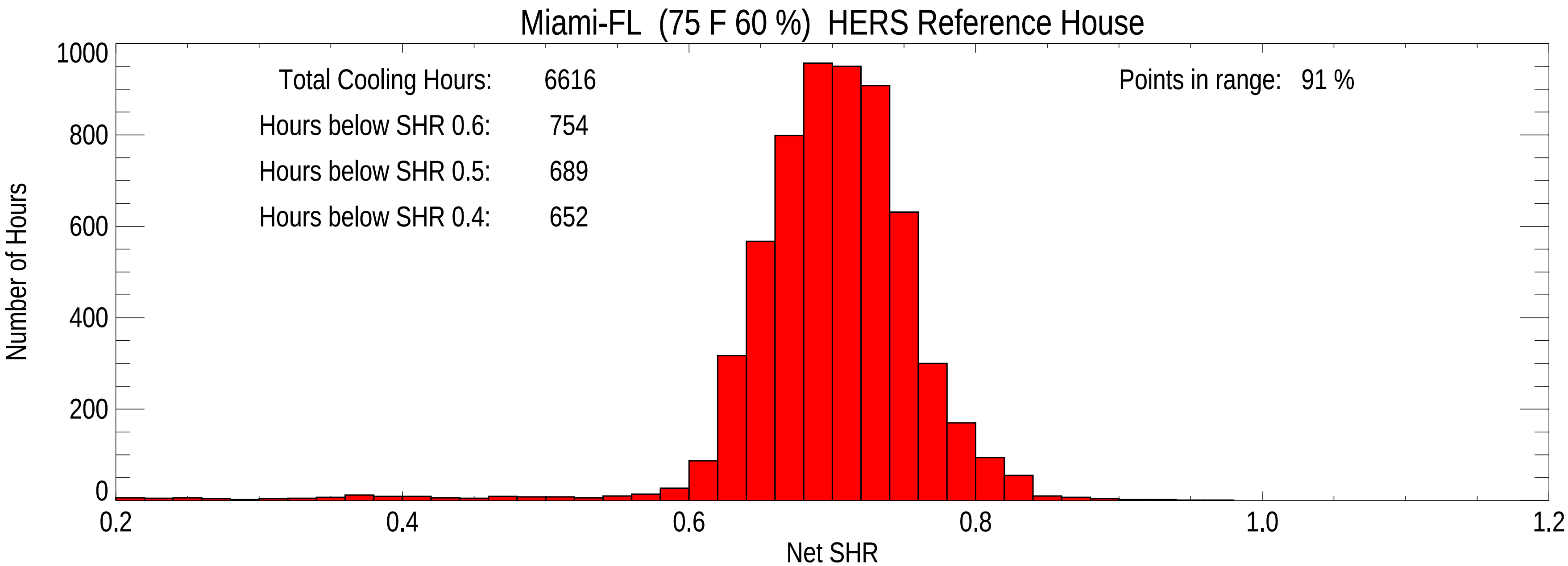

Houston-TX (78 F 50 %) HighEff House
Total Cooling Hours: 5695
Hours below SHR 0.6: 3975
Hours below SHR 0.5: 3564
Hours below SHR 0.4: 3220
Points in range: 51 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

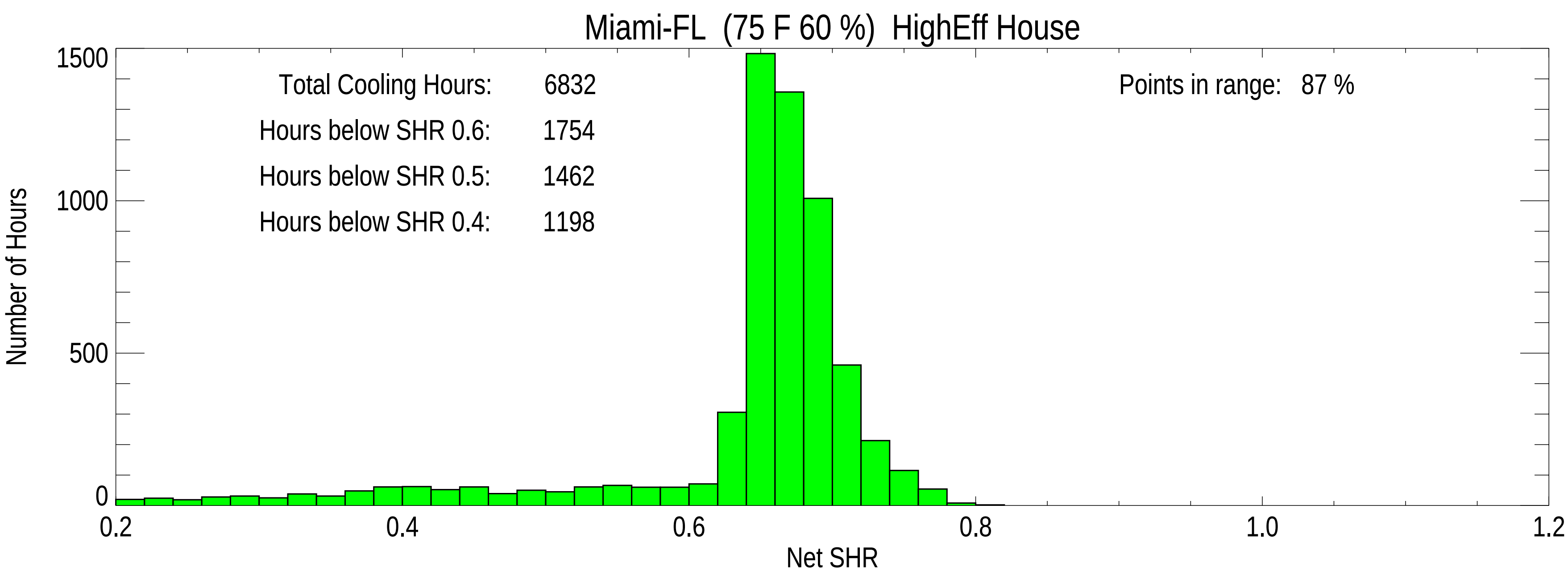

Fort_Worth-TX (78 F 50 %) HERS Reference House
Total Cooling Hours: 3905
Hours below SHR 0.6: 1163
Hours below SHR 0.5: 1119
Hours below SHR 0.4: 1093
Points in range: 73 %
Number of Hours
Net SHR

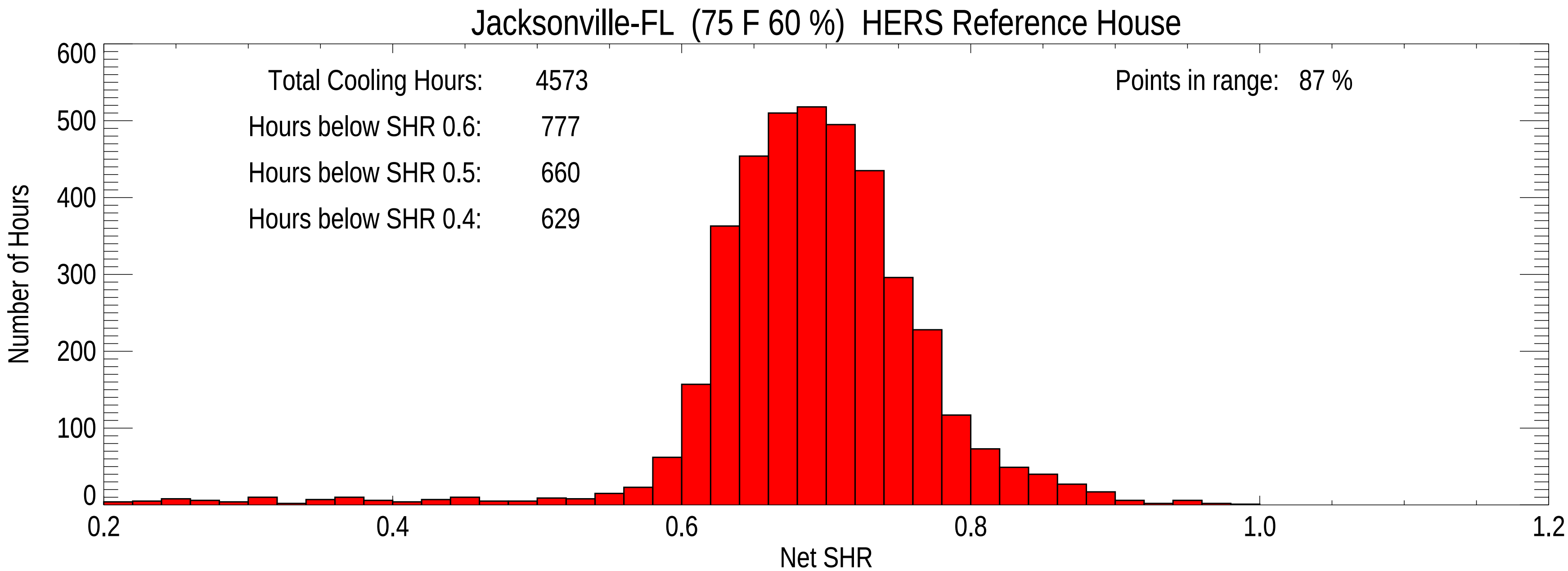

Fort_Worth-TX (78 F 50 %) HighEff House
Total Cooling Hours: 4015
Hours below SHR 0.6: 1114
Hours below SHR 0.5: 1028
Hours below SHR 0.4: 960
Points in range: 79 %
Number of Hours
Net SHR

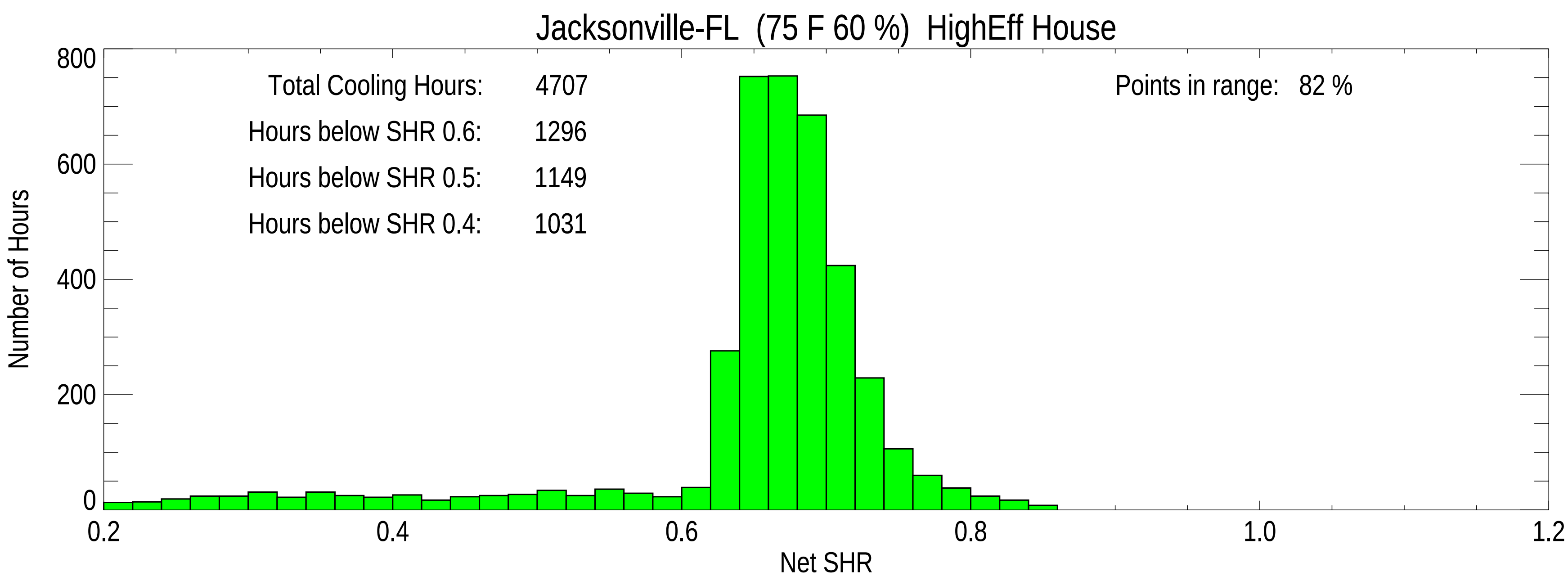

Wilmington-NC (78 F 50 %) HERS Reference House
Total Cooling Hours: 4424
Hours below SHR 0.6: 3024
Hours below SHR 0.5: 2755
Hours below SHR 0.4: 2579
Points in range: 46 %
Number of Hours
300
250
200
150
100
50
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

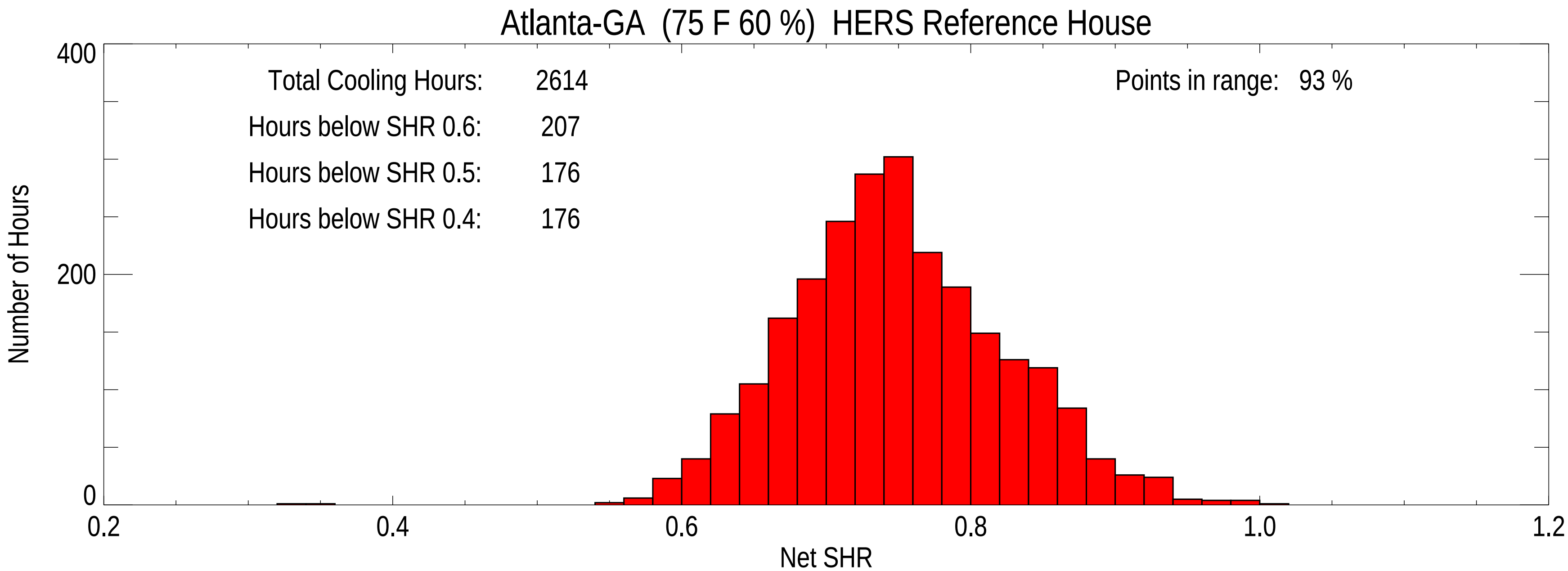

Wilmington-NC (78 F 50 %) HighEff House
Total Cooling Hours: 4361
Hours below SHR 0.6: 2938
Hours below SHR 0.5: 2586
Hours below SHR 0.4: 2348
Points in range: 54 %
Number of Hours
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

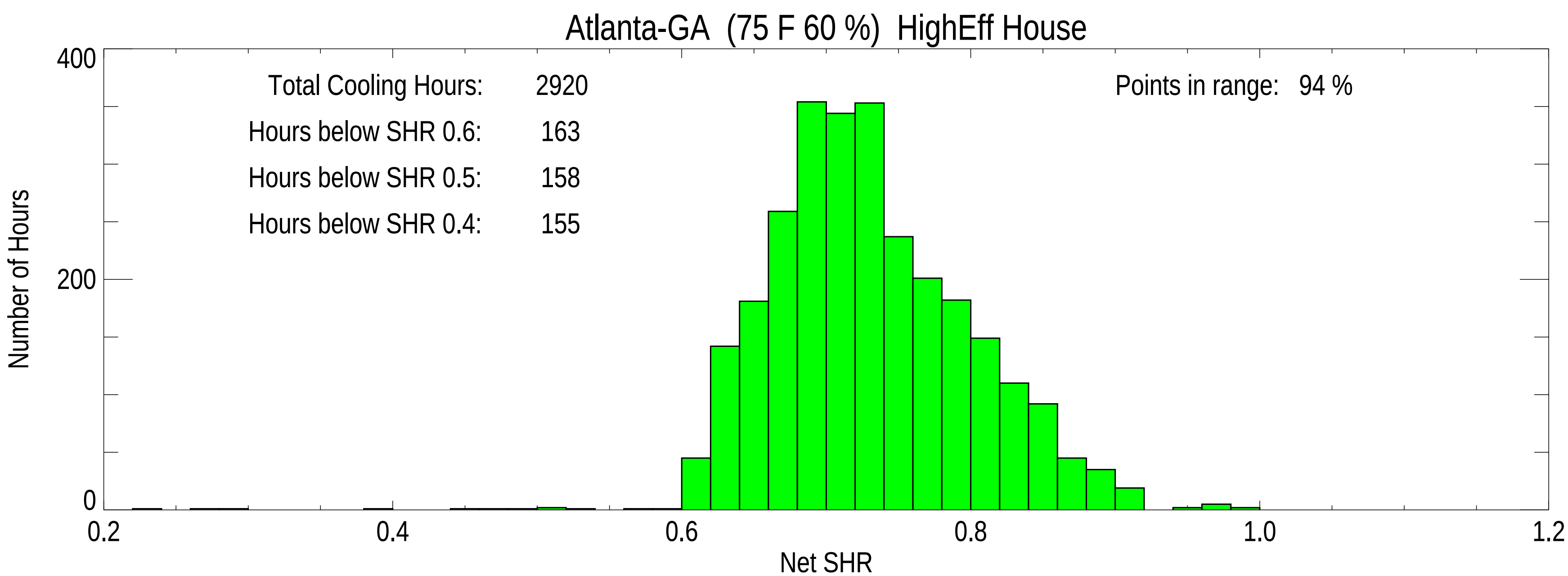

Miami-FL (75 F 60 %) HERS Reference House
Total Cooling Hours: 6616
Hours below SHR 0.6: 754
Hours below SHR 0.5: 689
Hours below SHR 0.4: 652
Points in range: 91 %
Number of Hours
1000
800
600
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

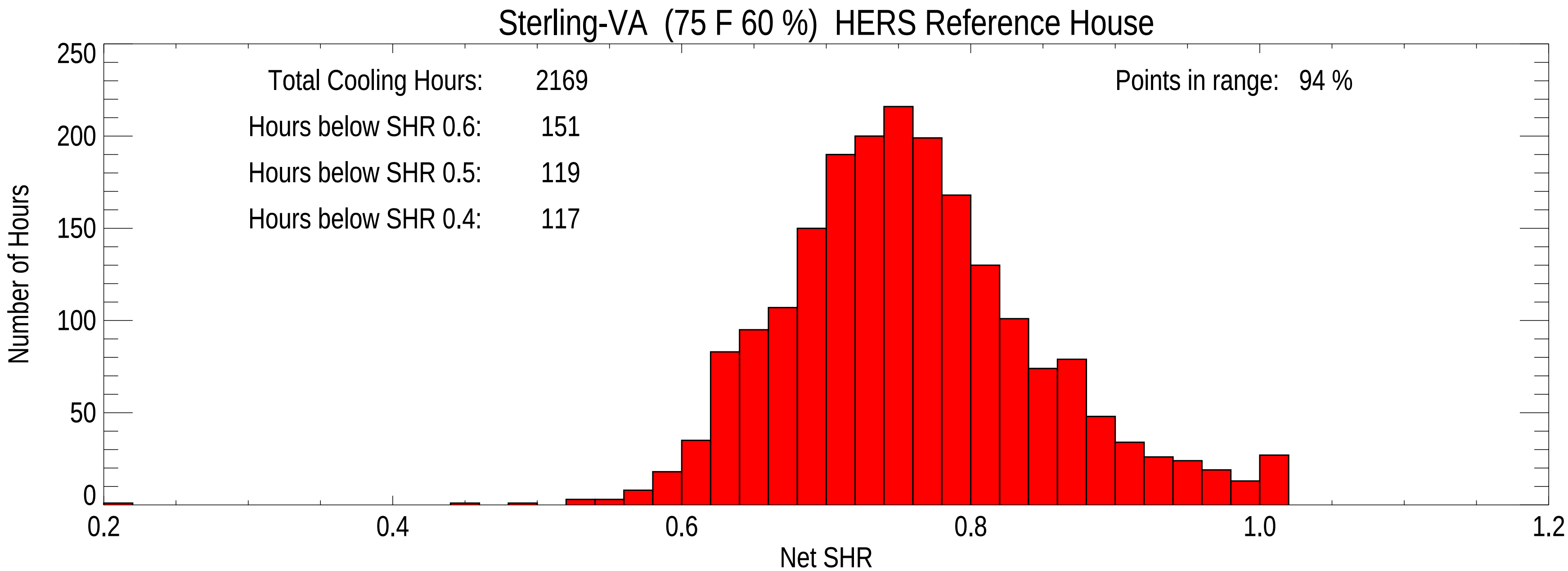

Miami-FL (75 F 60 %) HighEff House
Total Cooling Hours: 6832
Hours below SHR 0.6: 1754
Hours below SHR 0.5: 1462
Hours below SHR 0.4: 1198
Points in range: 87 %
Number of Hours
1500
1000
500
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

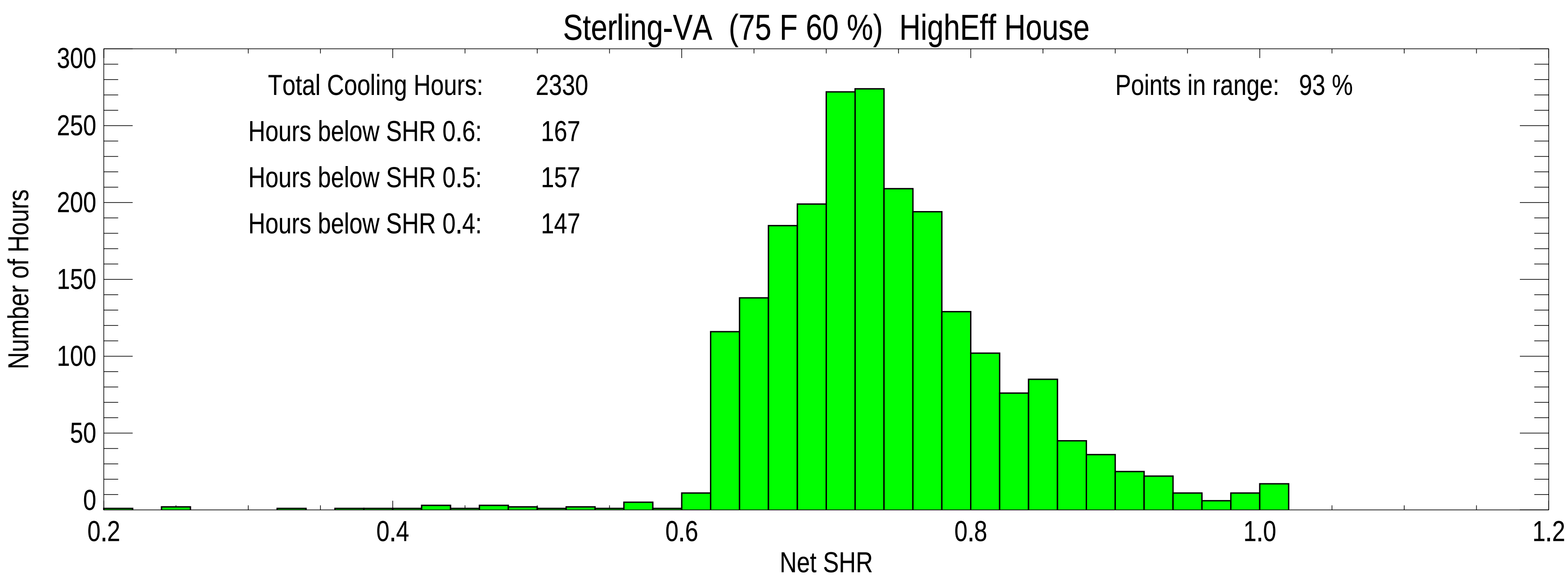

Jacksonville-FL (75 F 60 %) HERS Reference House
Total Cooling Hours: 4573
Hours below SHR 0.6: 777
Hours below SHR 0.5: 660
Hours below SHR 0.4: 629
Points in range: 87 %
Number of Hours
0
100
200
300
400
500
600
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

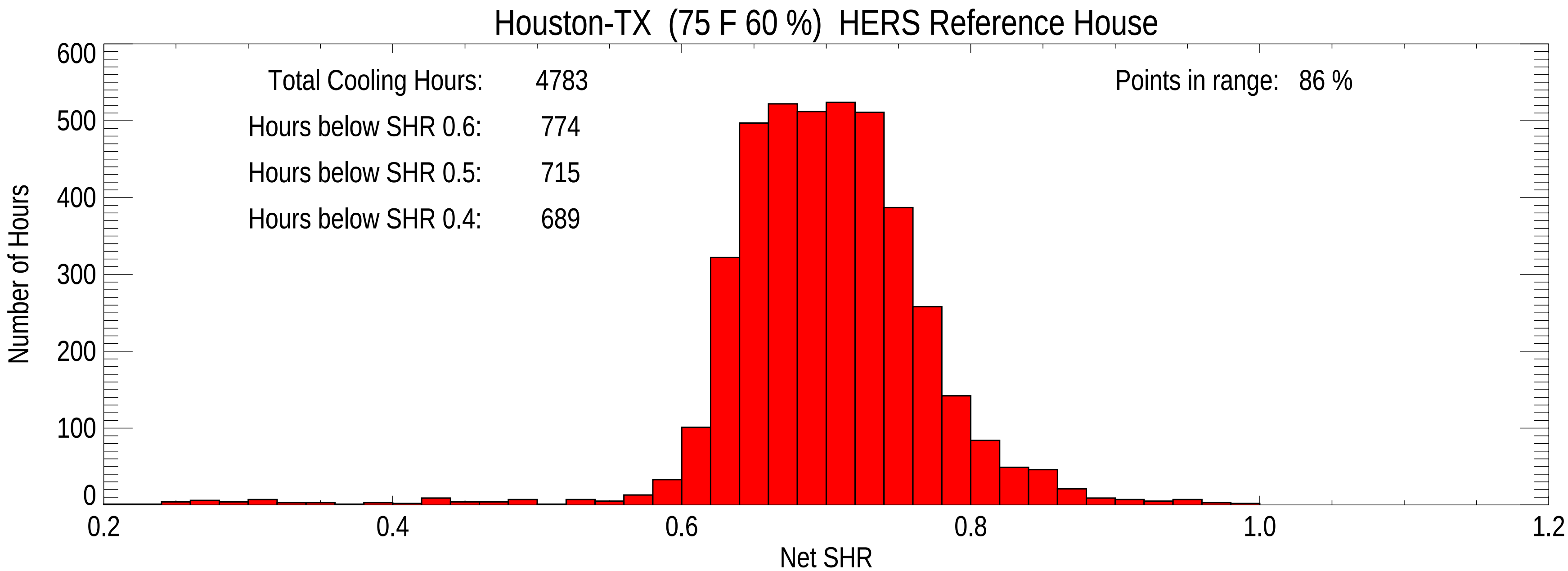

Jacksonville-FL (75 F 60 %) HighEff House
Total Cooling Hours: 4707
Hours below SHR 0.6: 1296
Hours below SHR 0.5: 1149
Hours below SHR 0.4: 1031
Points in range: 82 %
Number of Hours
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

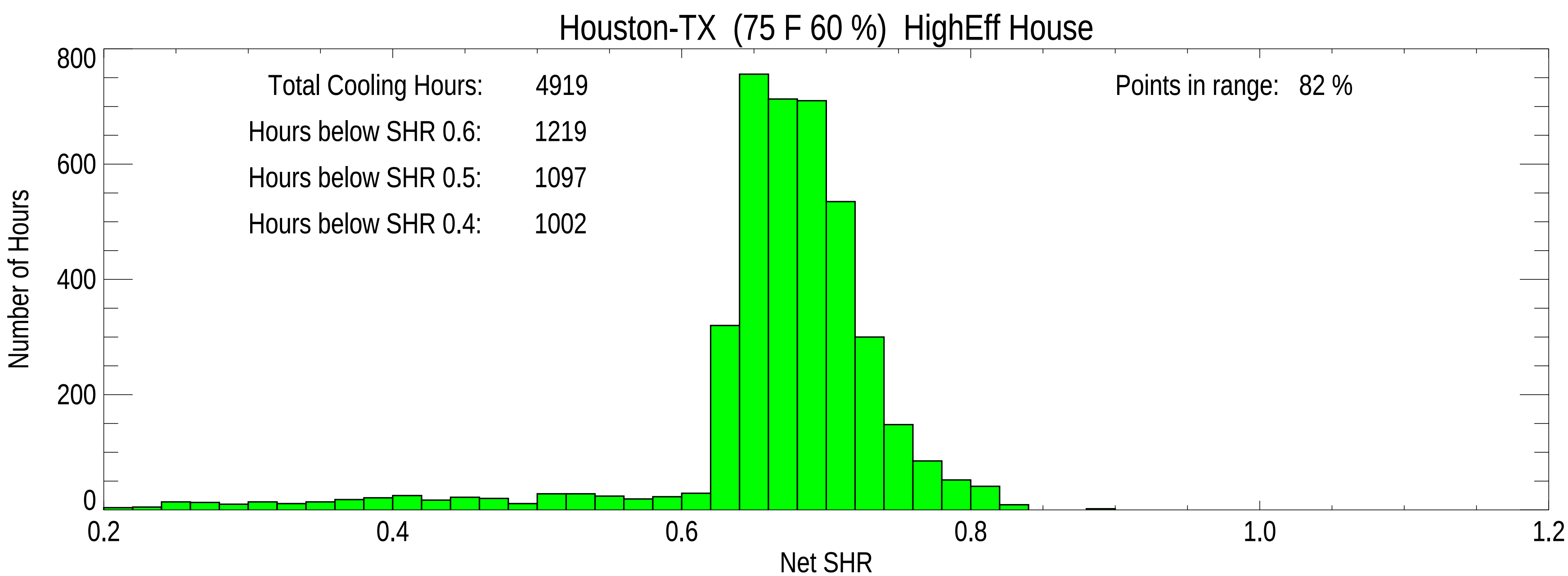

Atlanta-GA (75 F 60 %) HERS Reference House
Total Cooling Hours: 2614
Hours below SHR 0.6: 207
Hours below SHR 0.5: 176
Hours below SHR 0.4: 176
Points in range: 93 %
Number of Hours
Net SHR
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2

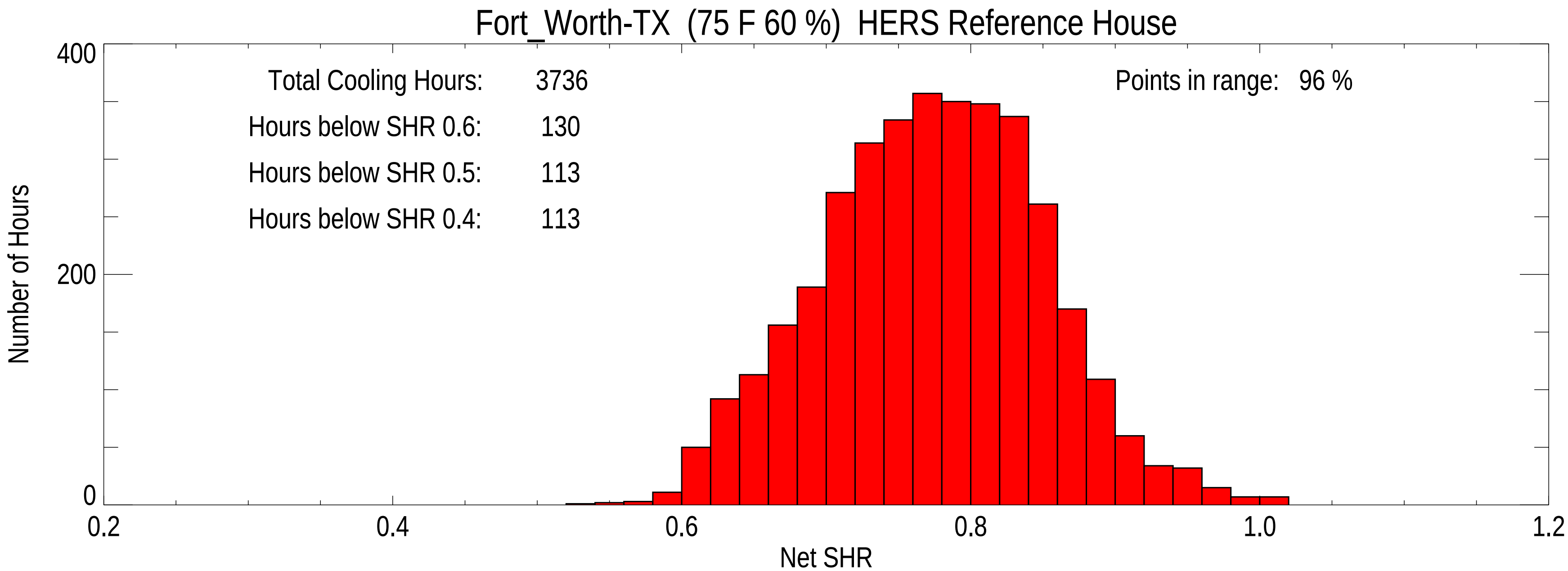

Atlanta-GA (75 F 60 %) HighEff House
Total Cooling Hours: 2920
Hours below SHR 0.6: 163
Hours below SHR 0.5: 158
Hours below SHR 0.4: 155
Points in range: 94 %
Number of Hours
Net SHR
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2

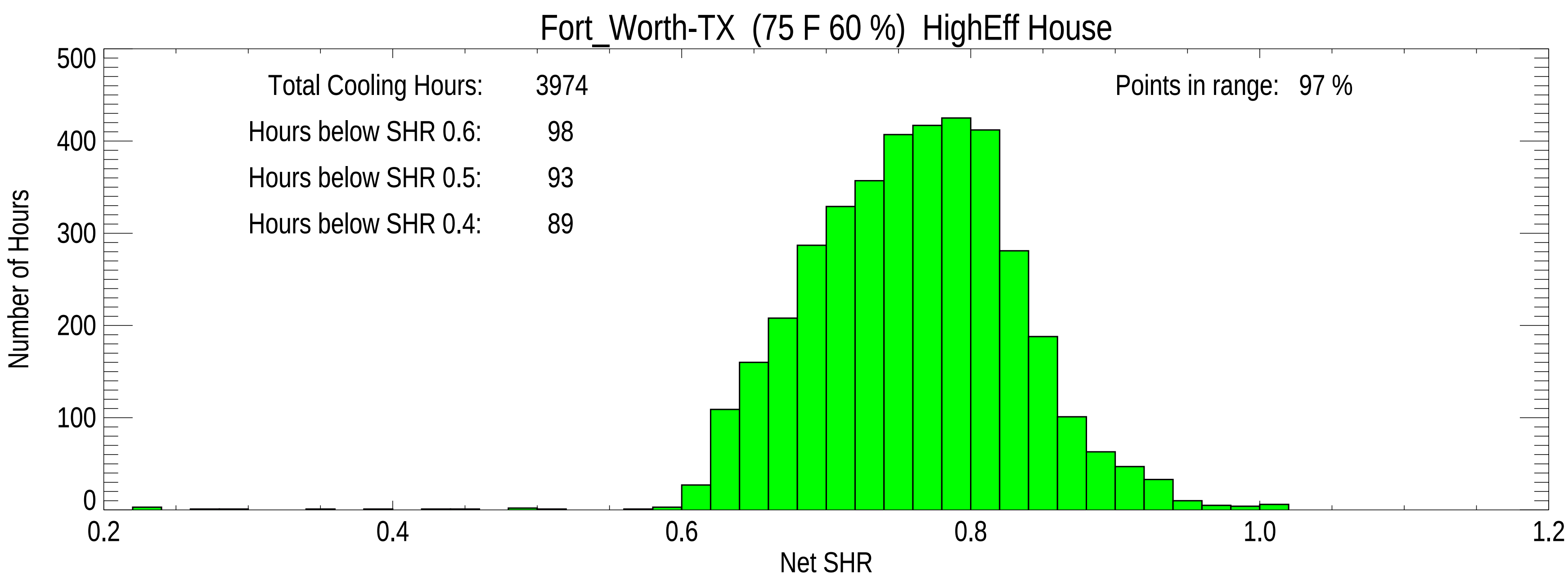

Sterling-VA (75 F 60 %) HERS Reference House
Total Cooling Hours: 2169
Hours below SHR 0.6: 151
Hours below SHR 0.5: 119
Hours below SHR 0.4: 117
Points in range: 94 %
Number of Hours
250
200
150
100
50
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

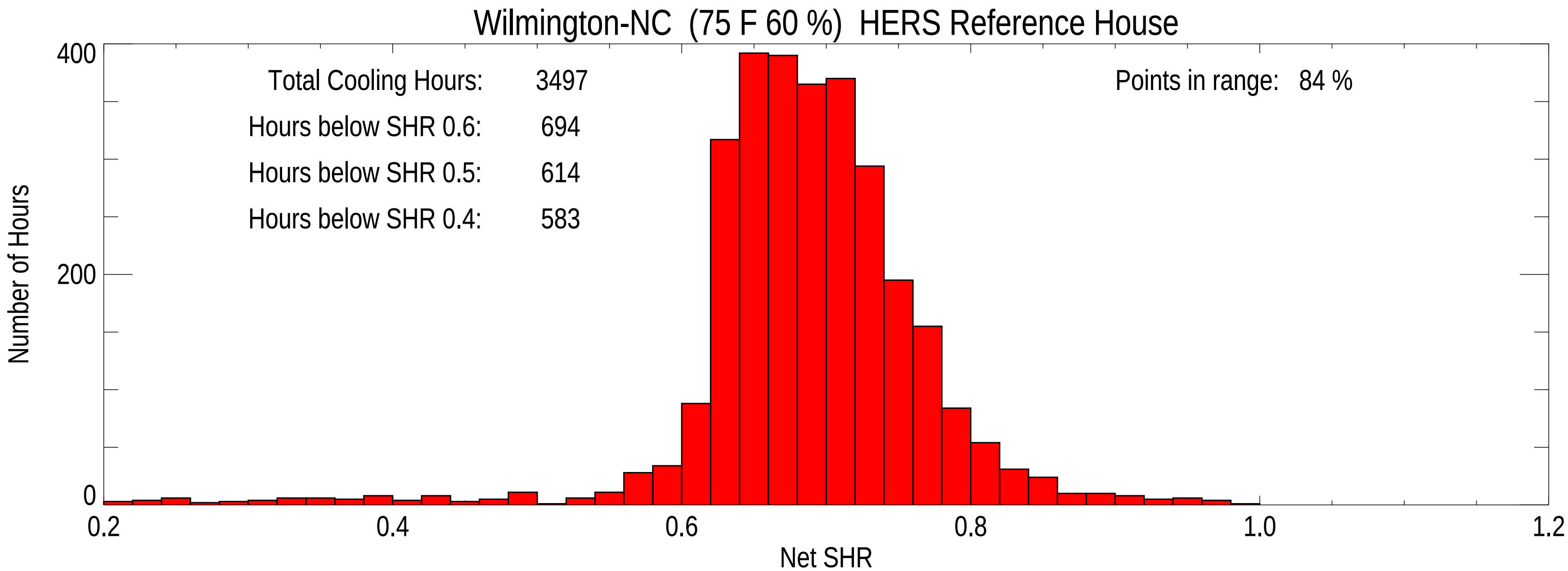

Sterling-VA (75 F 60 %) HighEff House
Total Cooling Hours: 2330
Hours below SHR 0.6: 167
Hours below SHR 0.5: 157
Hours below SHR 0.4: 147
Points in range: 93 %
Number of Hours
300
250
200
150
100
50
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

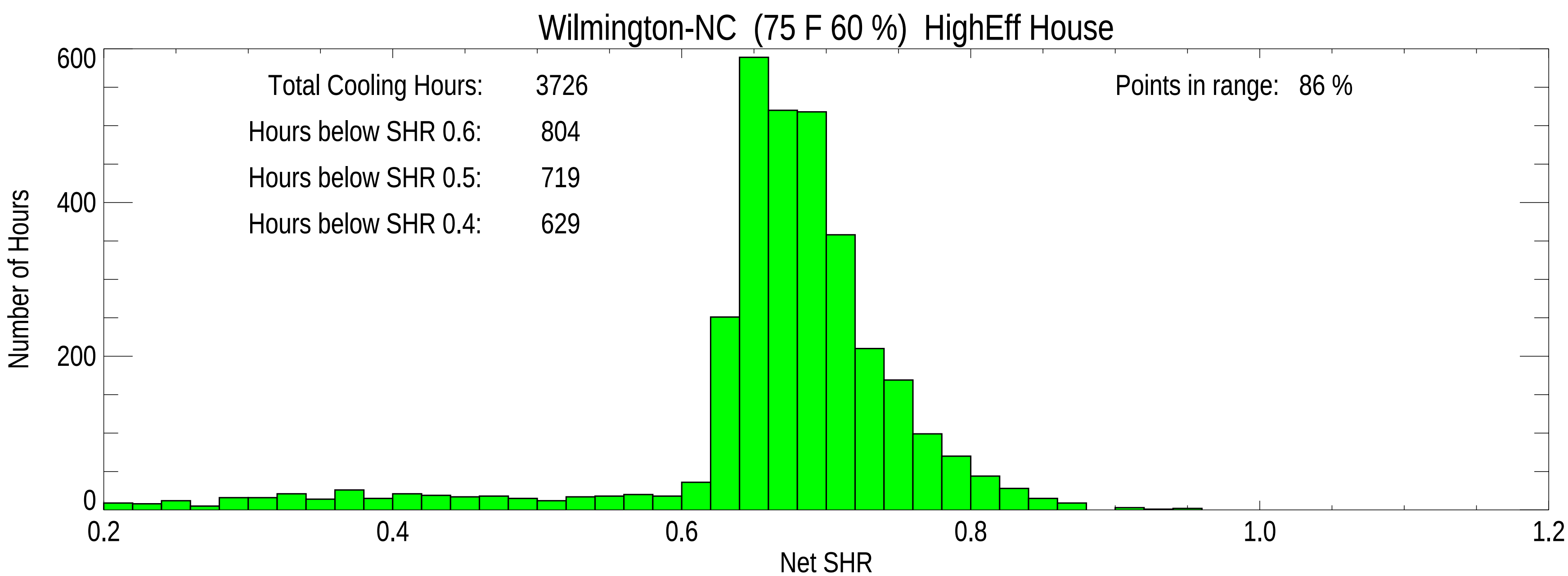

Houston-TX (75 F 60 %) HERS Reference House
Total Cooling Hours: 4783
Hours below SHR 0.6: 774
Hours below SHR 0.5: 715
Hours below SHR 0.4: 689
Points in range: 86 %
Number of Hours
Net SHR
0
100
200
300
400
500
600
0.2
0.4
0.6
0.8
1.0
1.2

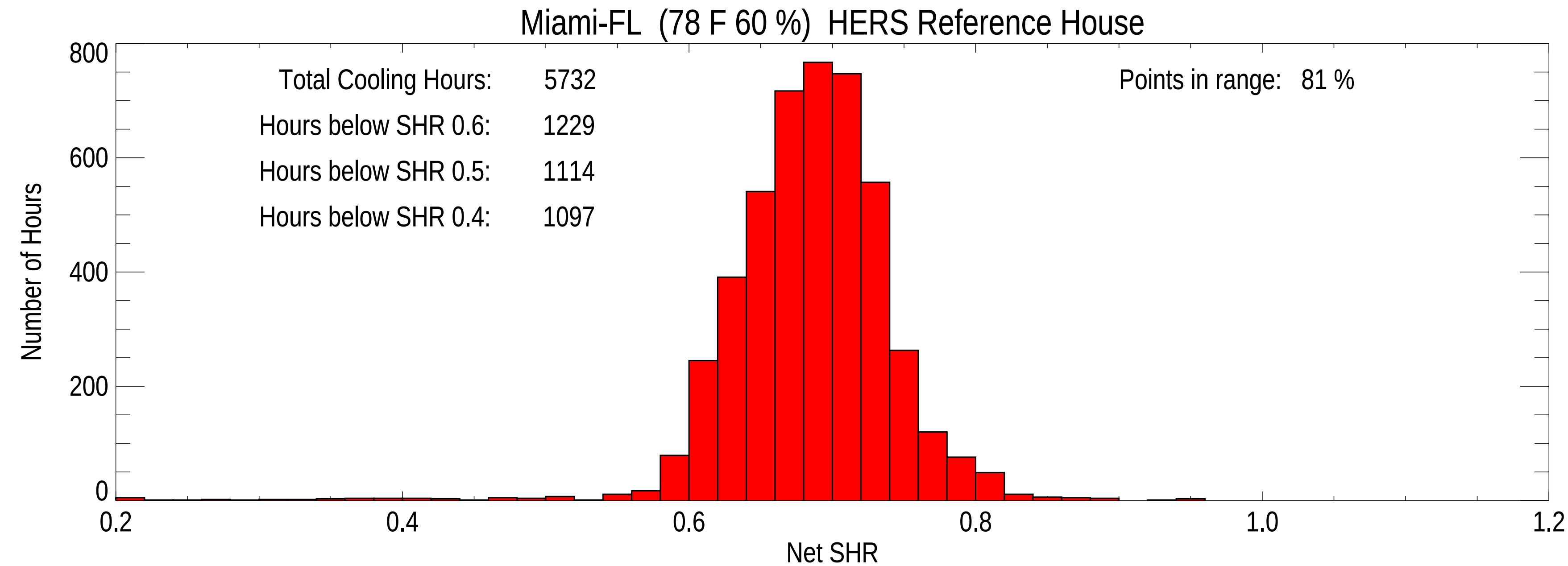

Houston-TX (75 F 60 %) HighEff House
Total Cooling Hours: 4919
Hours below SHR 0.6: 1219
Hours below SHR 0.5: 1097
Hours below SHR 0.4: 1002
Points in range: 82 %
Number of Hours
Net SHR
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
1.2

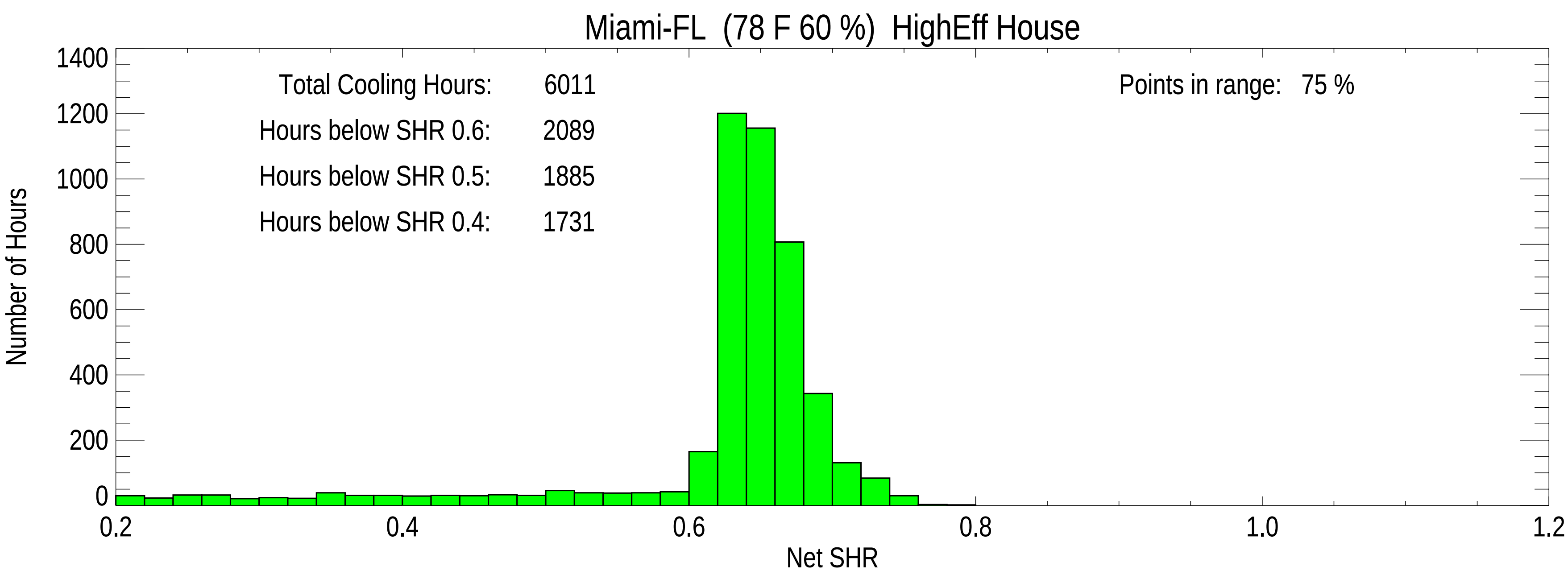

Fort_Worth-TX (75 F 60 %) HERS Reference House
Total Cooling Hours: 3736
Hours below SHR 0.6: 130
Hours below SHR 0.5: 113
Hours below SHR 0.4: 113
Points in range: 96 %
Number of Hours
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

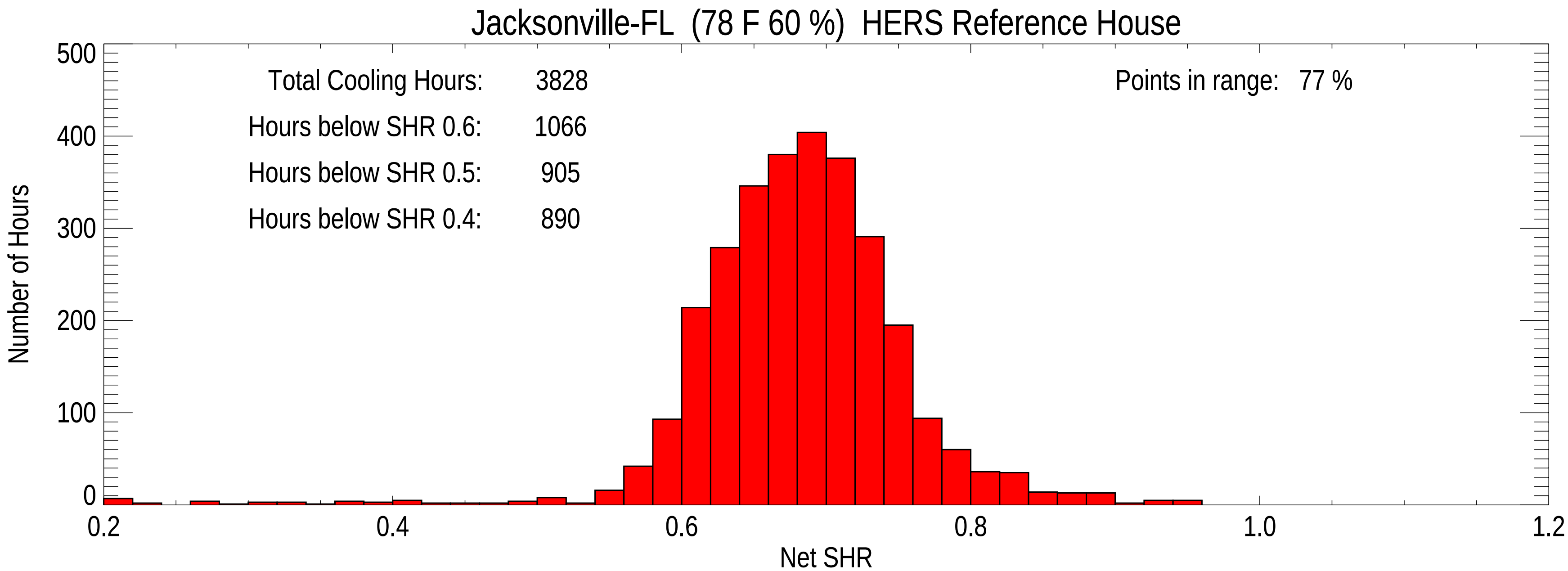

Fort_Worth-TX (75 F 60 %) HighEff House
Total Cooling Hours: 3974
Hours below SHR 0.6: 98
Hours below SHR 0.5: 93
Hours below SHR 0.4: 89
Points in range: 97 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

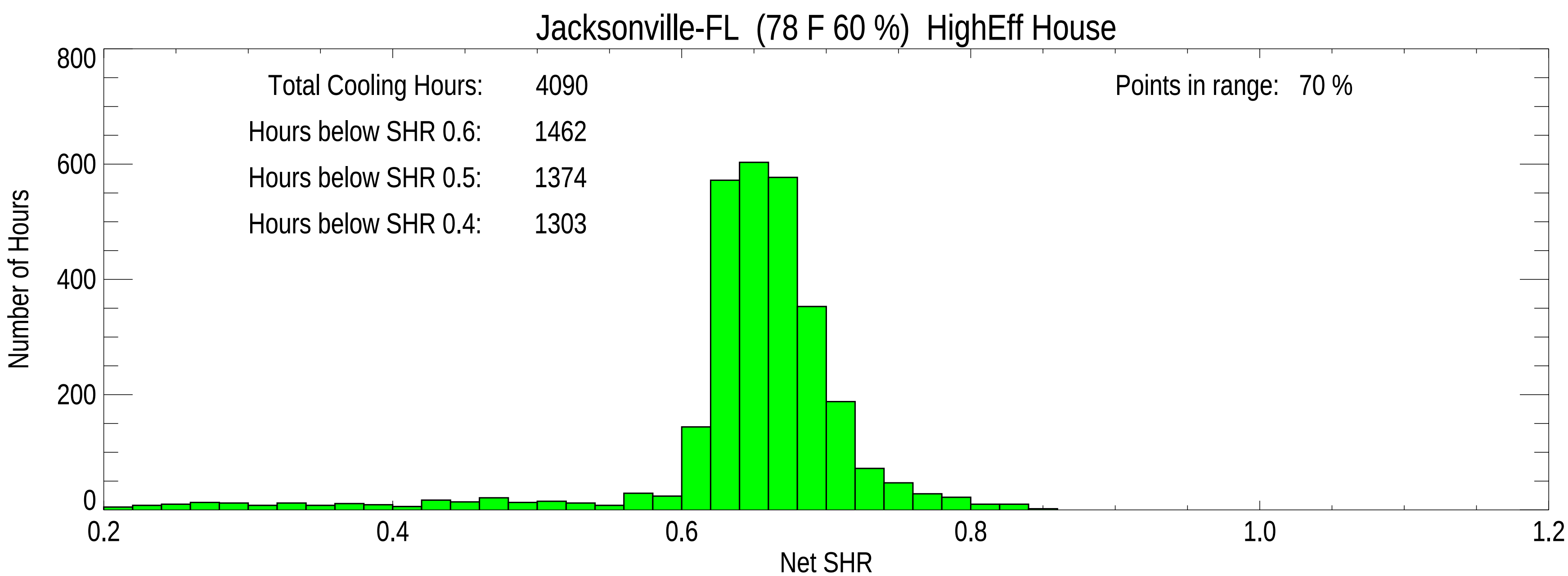

Wilmington-NC (75 F 60 %) HERS Reference House
Total Cooling Hours: 3497
Hours below SHR 0.6: 694
Hours below SHR 0.5: 614
Hours below SHR 0.4: 583
Points in range: 84 %
Number of Hours
Net SHR
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2

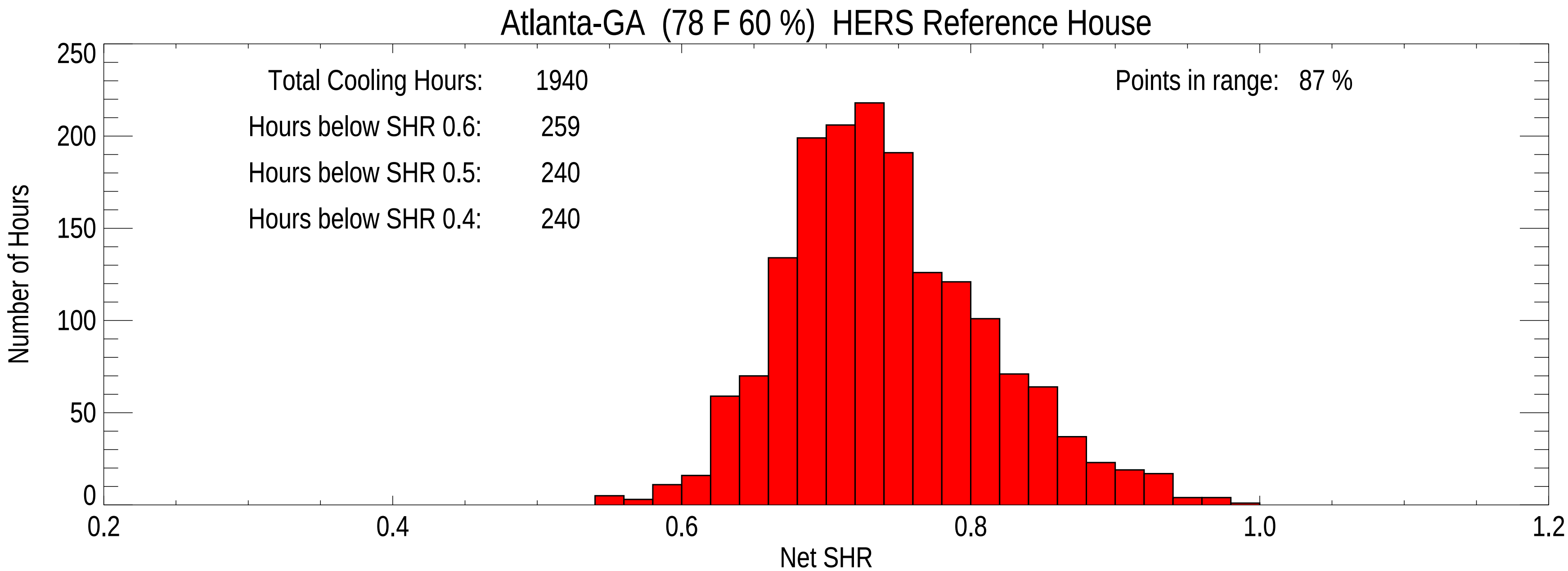

Wilmington-NC (75 F 60 %) HighEff House
Total Cooling Hours: 3726
Hours below SHR 0.6: 804
Hours below SHR 0.5: 719
Hours below SHR 0.4: 629
Points in range: 86 %
Number of Hours
Net SHR
0
200
400
600
0.2
0.4
0.6
0.8
1.0
1.2

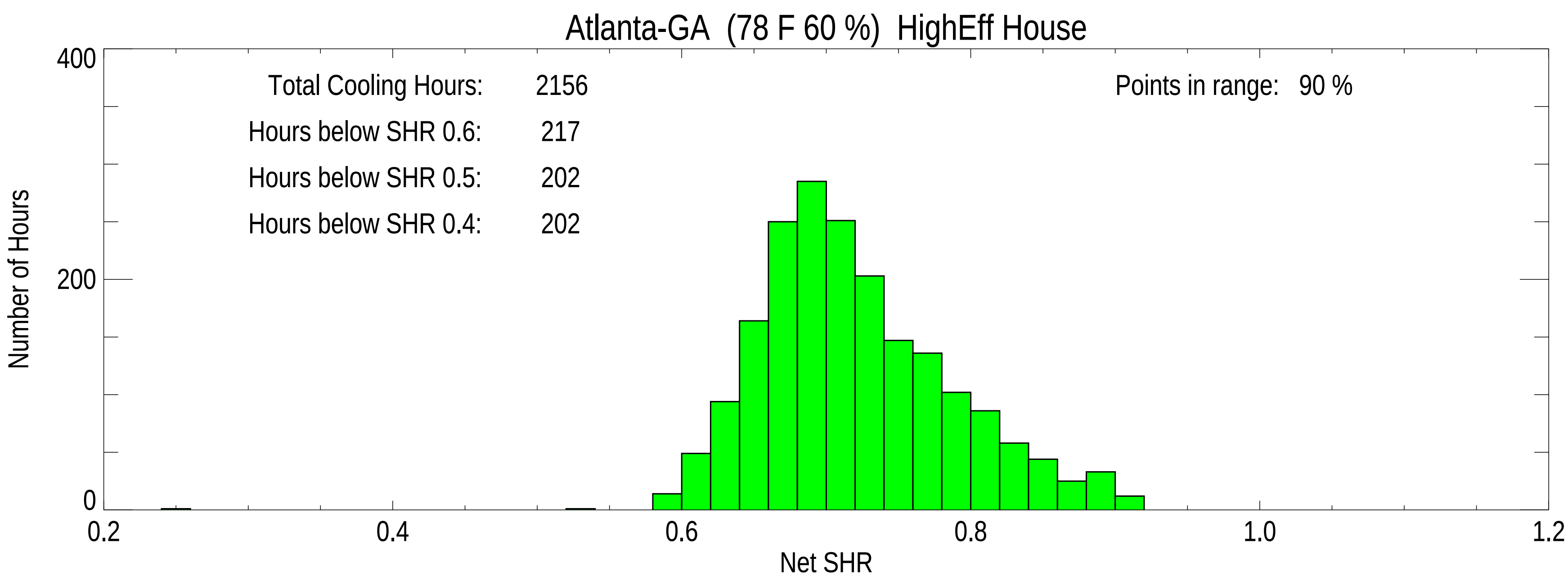

Miami-FL (78 F 60 %) HERS Reference House
Total Cooling Hours: 5732
Hours below SHR 0.6: 1229
Hours below SHR 0.5: 1114
Hours below SHR 0.4: 1097
Points in range: 81 %
Number of Hours
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

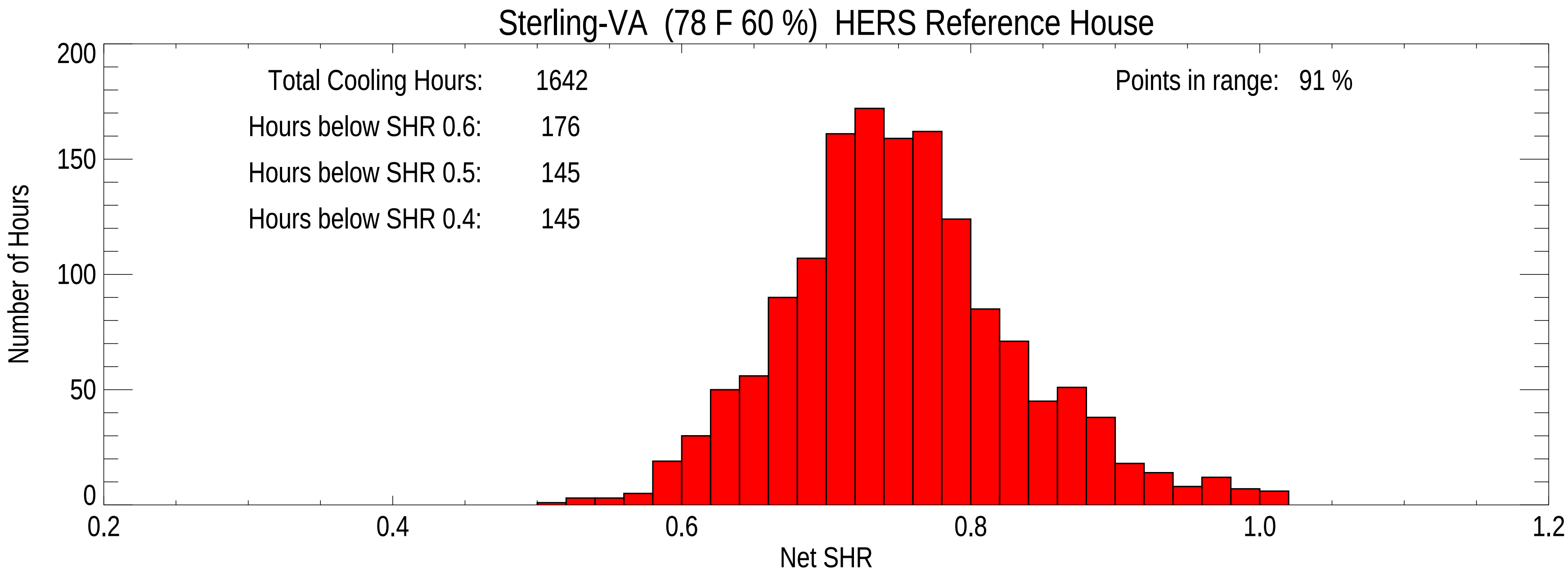

Miami-FL (78 F 60 %) HighEff House
Total Cooling Hours: 6011
Hours below SHR 0.6: 2089
Hours below SHR 0.5: 1885
Hours below SHR 0.4: 1731
Points in range: 75 %
Number of Hours
0
200
400
600
800
1000
1200
1400
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

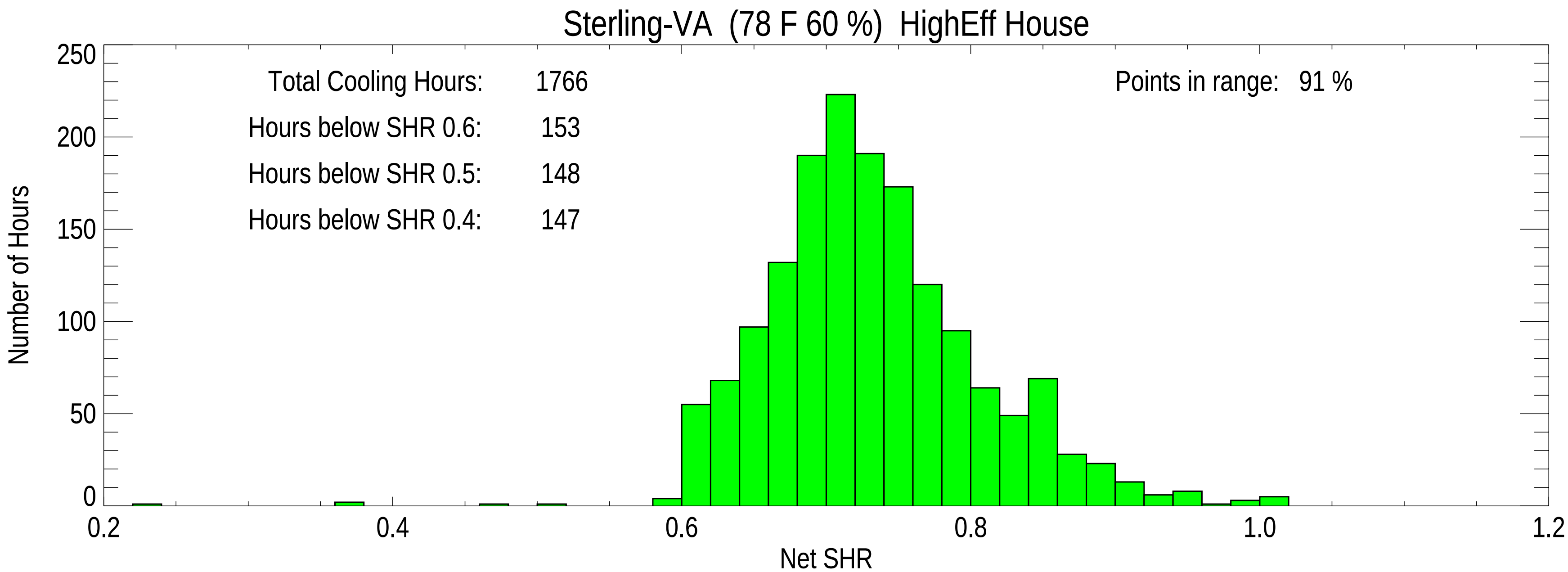

Jacksonville-FL (78 F 60 %) HERS Reference House
Total Cooling Hours: 3828
Hours below SHR 0.6: 1066
Hours below SHR 0.5: 905
Hours below SHR 0.4: 890
Points in range: 77 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

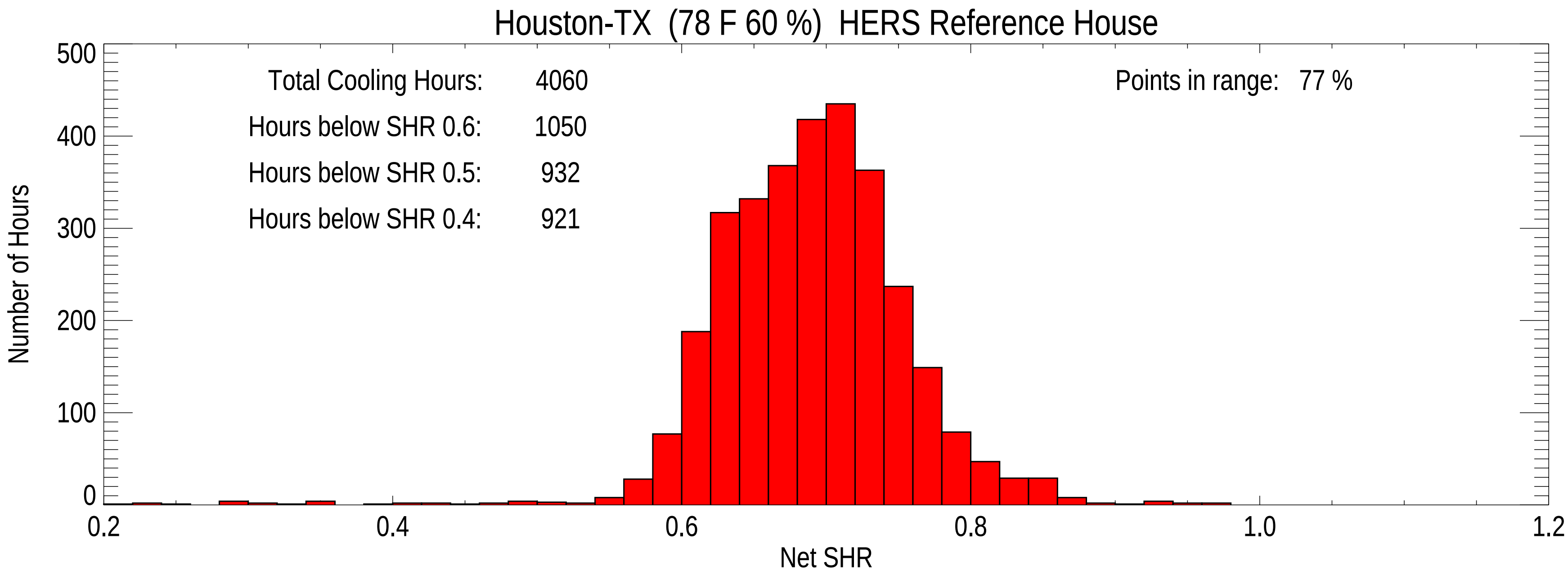

Jacksonville-FL (78 F 60 %) HighEff House
Total Cooling Hours: 4090
Hours below SHR 0.6: 1462
Hours below SHR 0.5: 1374
Hours below SHR 0.4: 1303
Points in range: 70 %
Number of Hours
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

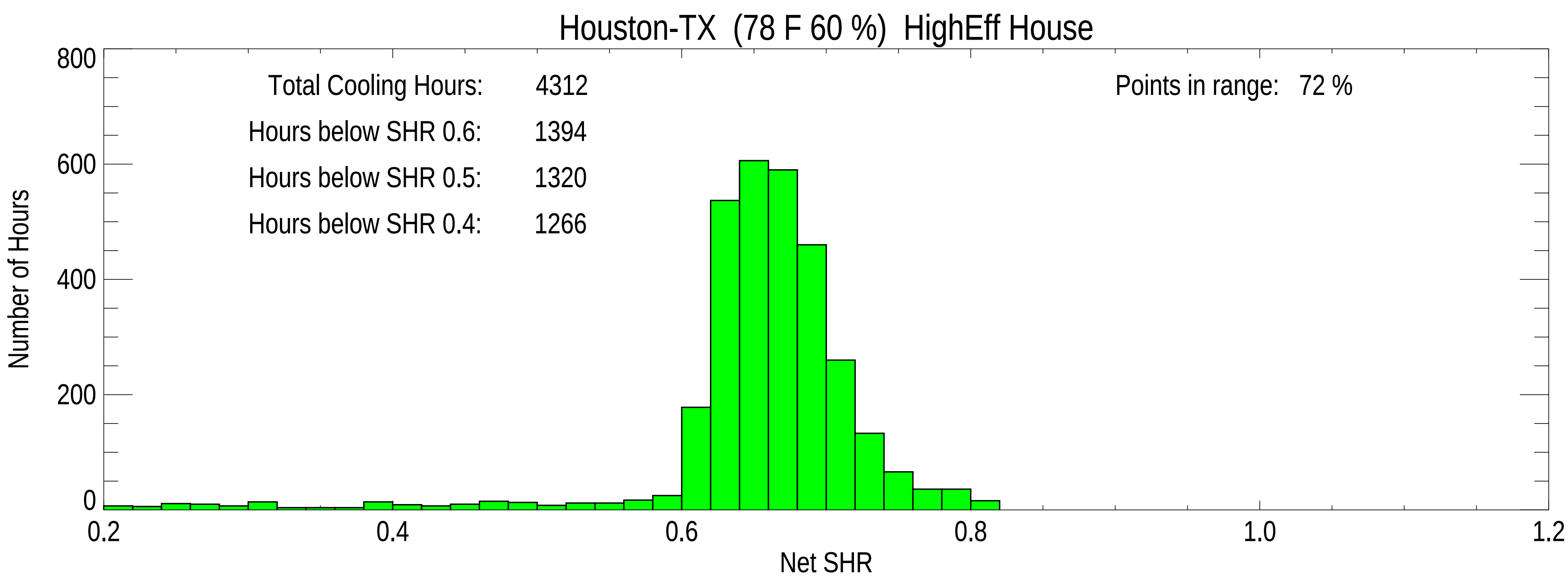

Atlanta-GA (78 F 60 %) HERS Reference House
Total Cooling Hours: 1940
Hours below SHR 0.6: 259
Hours below SHR 0.5: 240
Hours below SHR 0.4: 240
Points in range: 87 %
Number of Hours
250
200
150
100
50
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

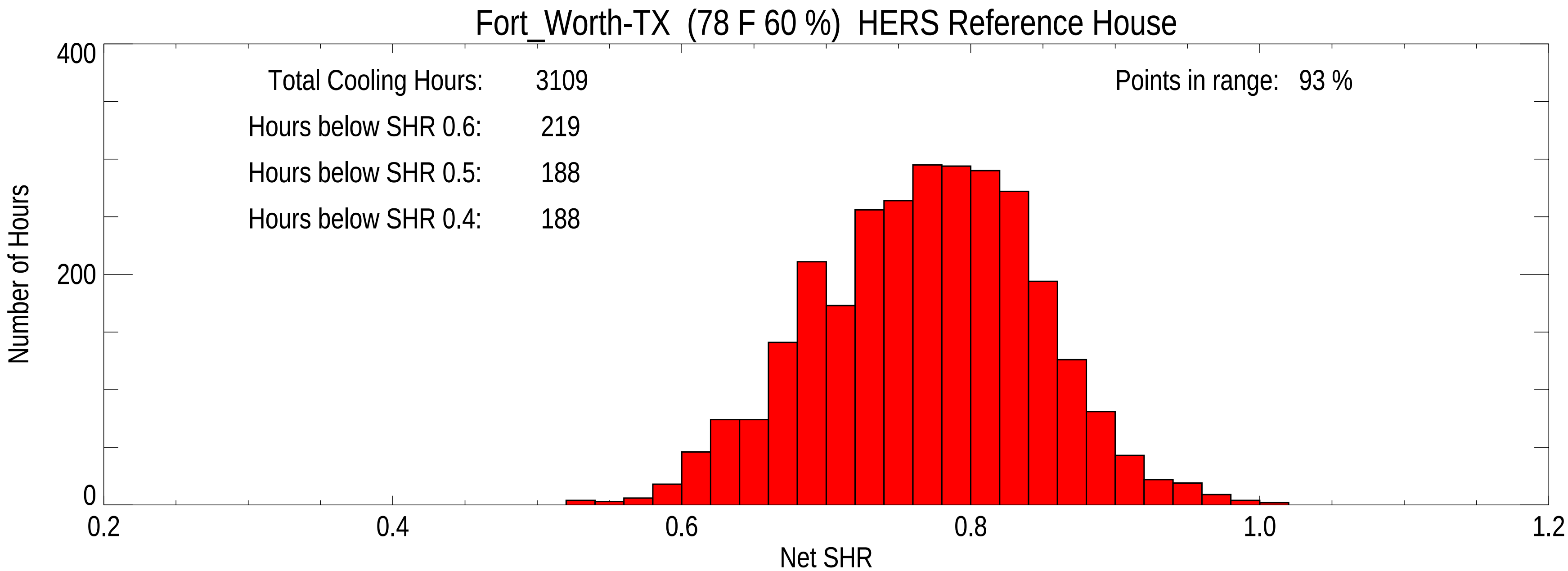

Atlanta-GA (78 F 60 %) HighEff House
Total Cooling Hours: 2156
Hours below SHR 0.6: 217
Hours below SHR 0.5: 202
Hours below SHR 0.4: 202
Points in range: 90 %
Number of Hours
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

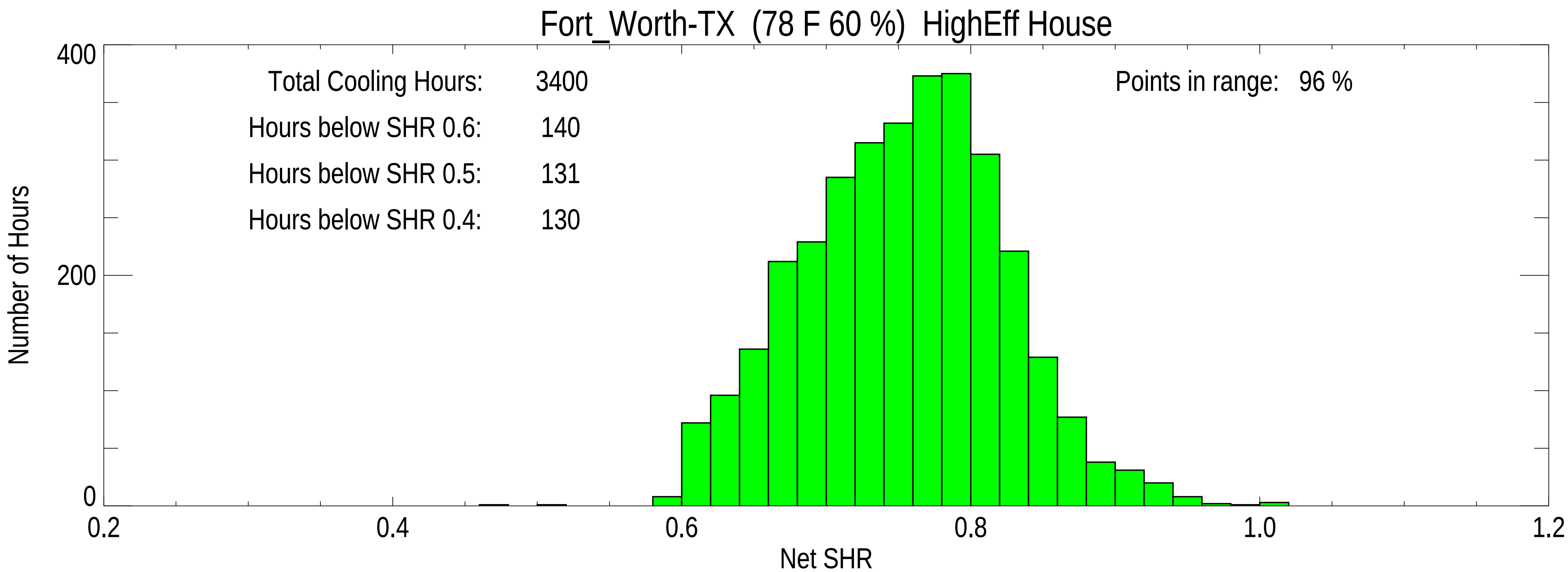

Sterling-VA (78 F 60 %) HERS Reference House
Total Cooling Hours: 1642
Hours below SHR 0.6: 176
Hours below SHR 0.5: 145
Hours below SHR 0.4: 145
Points in range: 91 %
Number of Hours
0
50
100
150
200
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

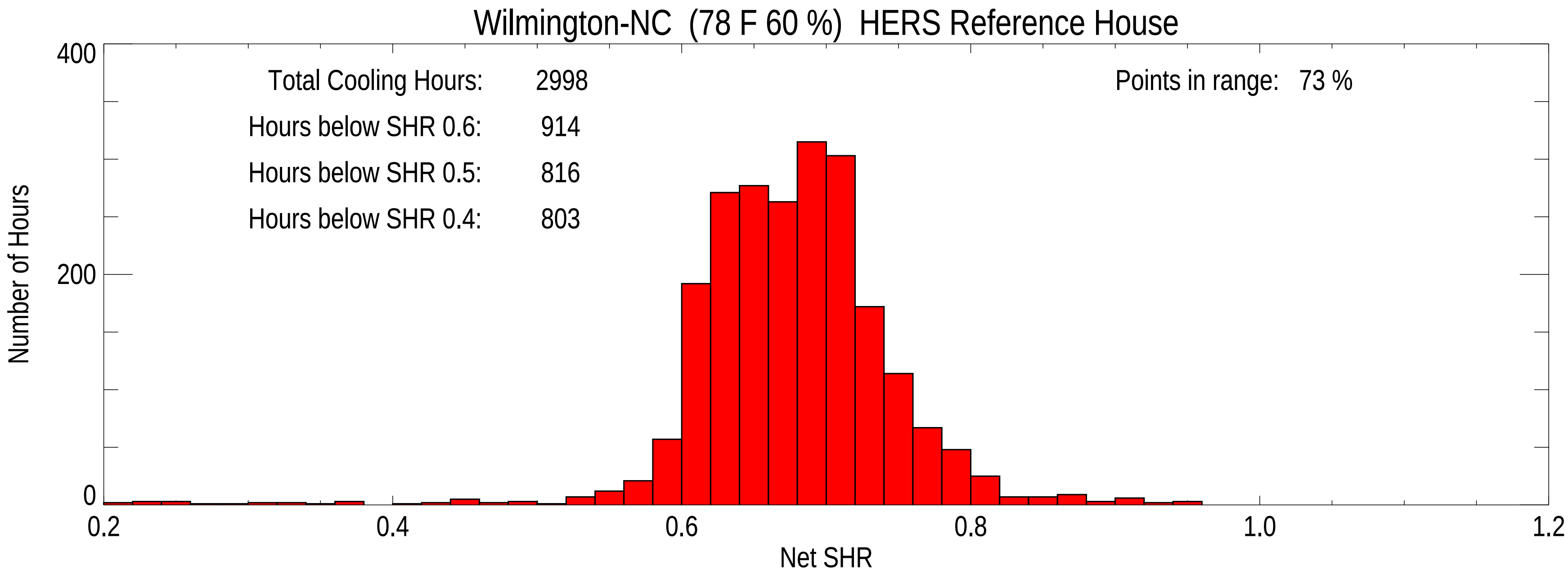

Sterling-VA (78 F 60 %) HighEff House
Total Cooling Hours: 1766
Hours below SHR 0.6: 153
Hours below SHR 0.5: 148
Hours below SHR 0.4: 147
Points in range: 91 %
Number of Hours
0
50
100
150
200
250
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

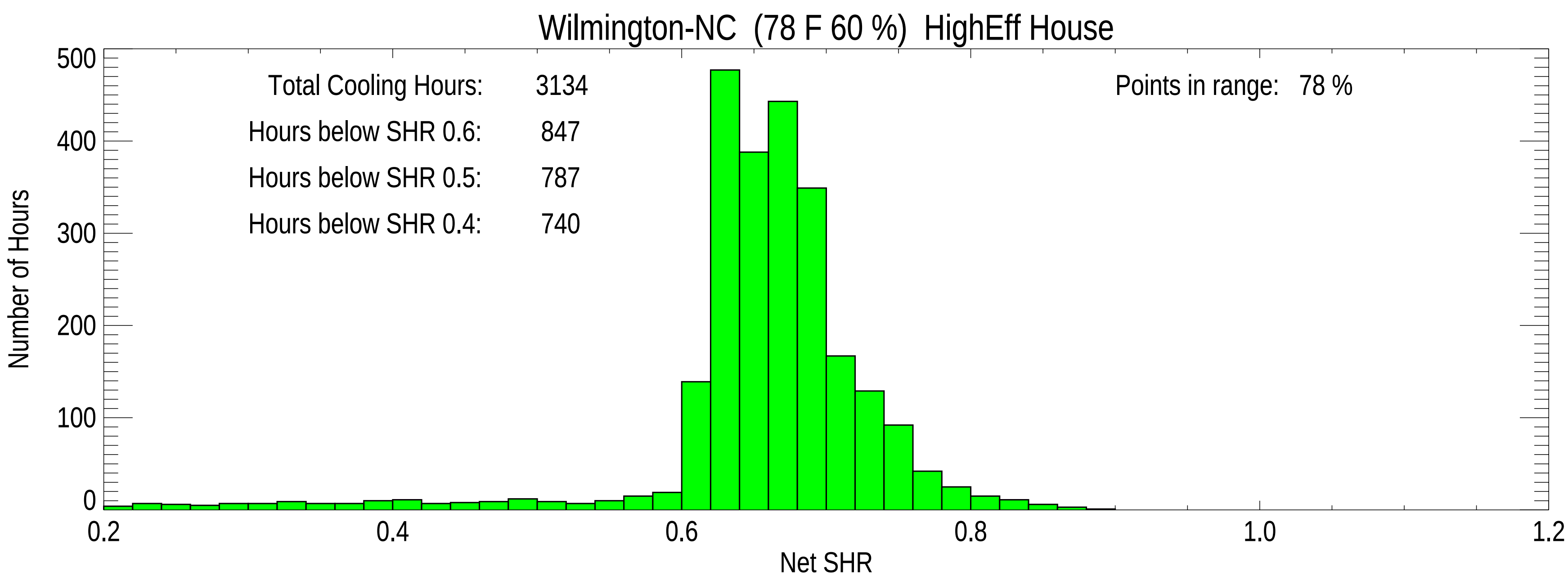

Houston-TX (78 F 60 %) HERS Reference House
Total Cooling Hours: 4060
Hours below SHR 0.6: 1050
Hours below SHR 0.5: 932
Hours below SHR 0.4: 921
Points in range: 77 %
Number of Hours
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

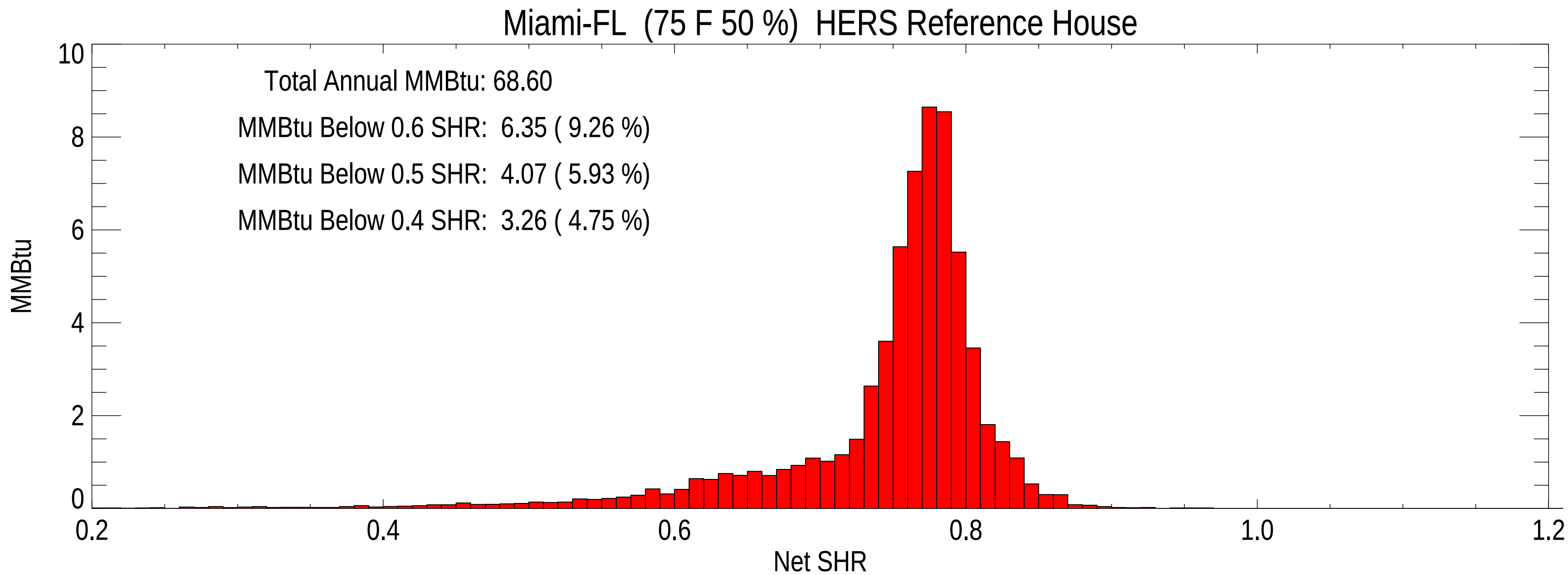

Houston-TX (78 F 60 %) HighEff House
Total Cooling Hours: 4312
Hours below SHR 0.6: 1394
Hours below SHR 0.5: 1320
Hours below SHR 0.4: 1266
Points in range: 72 %
Number of Hours
800
600
400
200
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

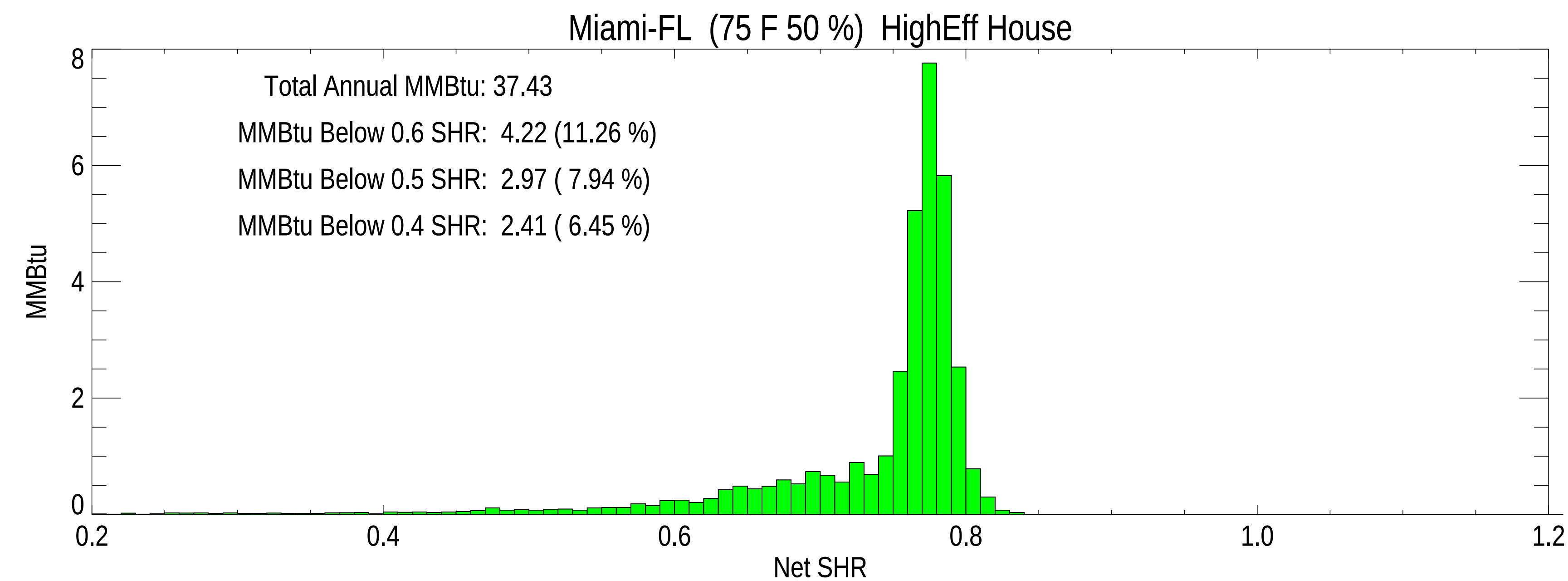

Fort_Worth-TX (78 F 60 %) HERS Reference House
Total Cooling Hours: 3109
Hours below SHR 0.6: 219
Hours below SHR 0.5: 188
Hours below SHR 0.4: 188
Points in range: 93 %
Number of Hours
Net SHR
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2

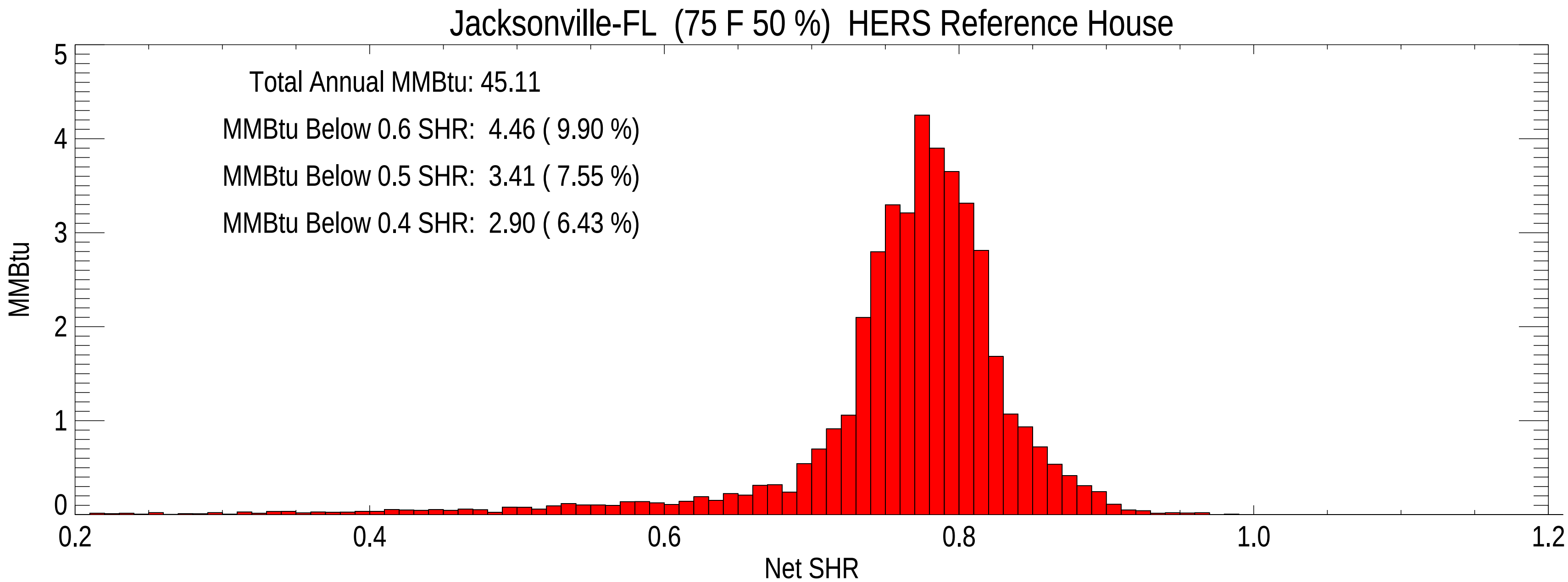

Fort_Worth-TX (78 F 60 %) HighEff House
Total Cooling Hours: 3400
Hours below SHR 0.6: 140
Hours below SHR 0.5: 131
Hours below SHR 0.4: 130
Points in range: 96 %
Number of Hours
Net SHR
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2

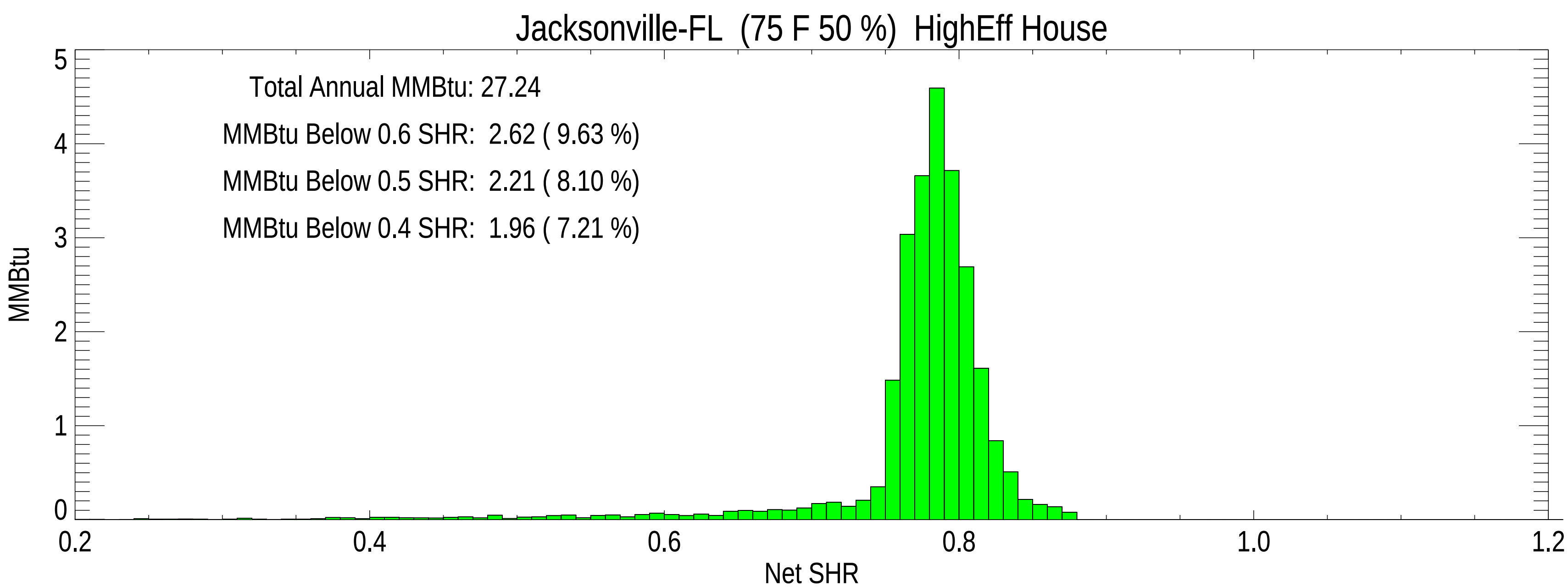

Wilmington-NC (78 F 60 %) HERS Reference House
Total Cooling Hours: 2998
Hours below SHR 0.6: 914
Hours below SHR 0.5: 816
Hours below SHR 0.4: 803
Points in range: 73 %
Number of Hours
0
200
400
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

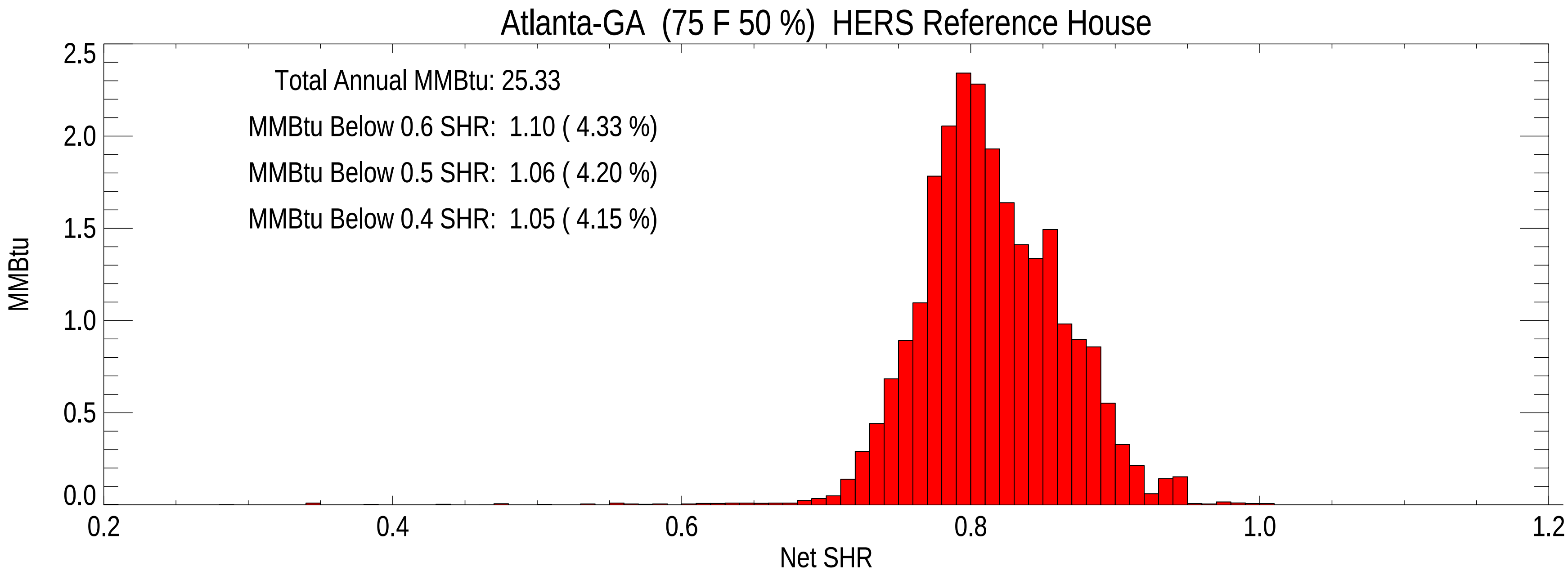

Wilmington-NC (78 F 60 %) HighEff House
Total Cooling Hours: 3134
Hours below SHR 0.6: 847
Hours below SHR 0.5: 787
Hours below SHR 0.4: 740
Points in range: 78 %
Number of Hours
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

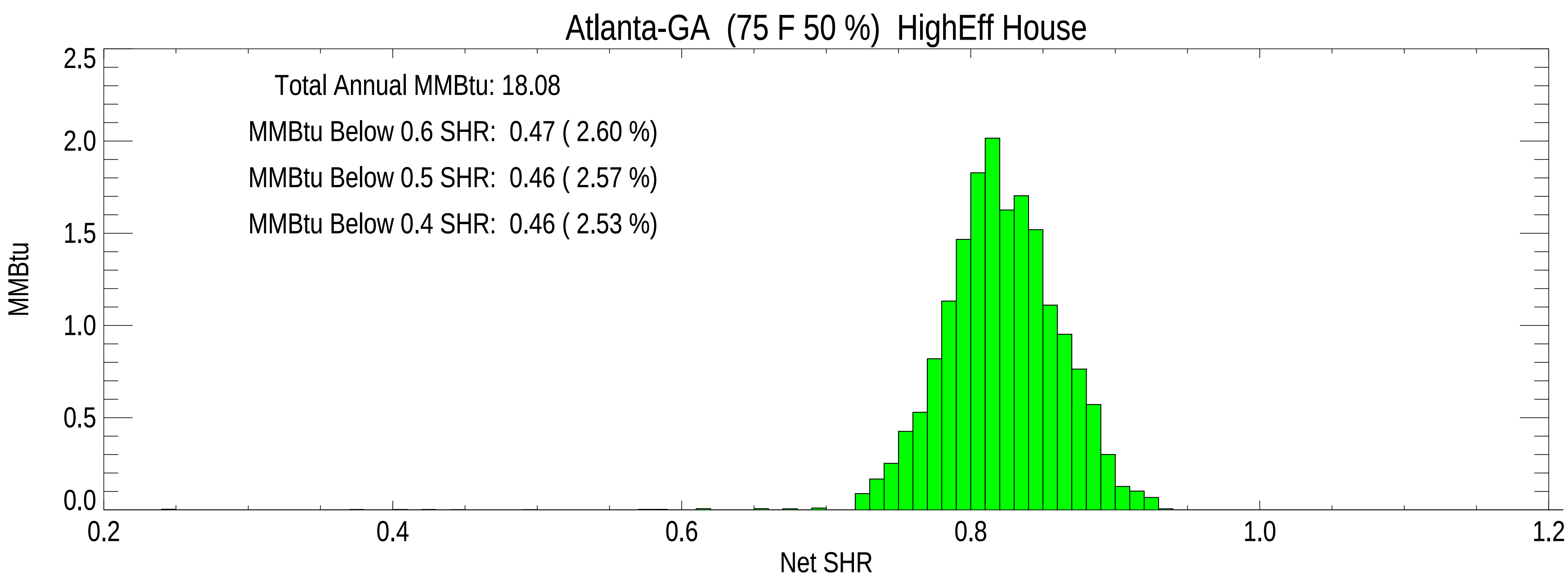

Miami-FL (75 F 50 %) HERS Reference House
Total Annual MMBtu: 68.60
MMBtu Below 0.6 SHR: 6.35 (9.26 %)
MMBtu Below 0.5 SHR: 4.07 (5.93 %)
MMBtu Below 0.4 SHR: 3.26 (4.75 %)
MMBtu
0
2
4
6
8
10
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

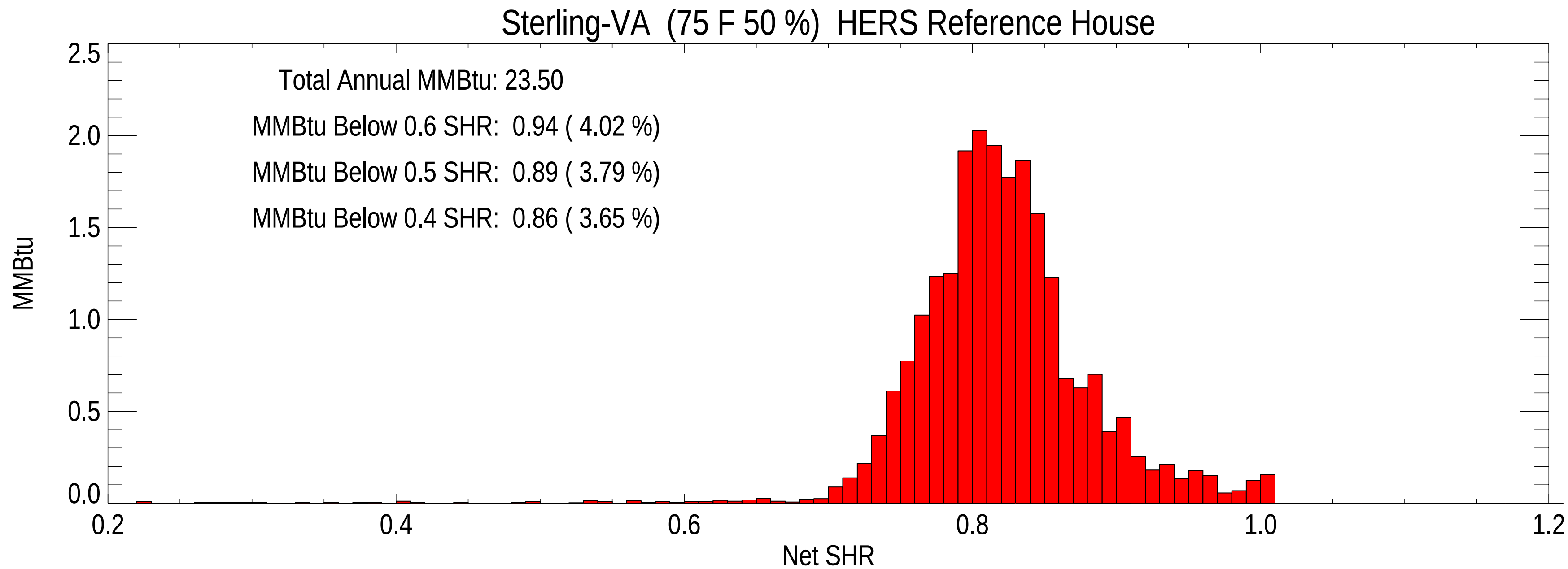

Miami-FL (75 F 50 %) HighEff House
Total Annual MMBtu: 37.43
MMBtu Below 0.6 SHR: 4.22 (11.26 %)
MMBtu Below 0.5 SHR: 2.97 (7.94 %)
MMBtu Below 0.4 SHR: 2.41 (6.45 %)
MMBtu
0
2
4
6
8
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

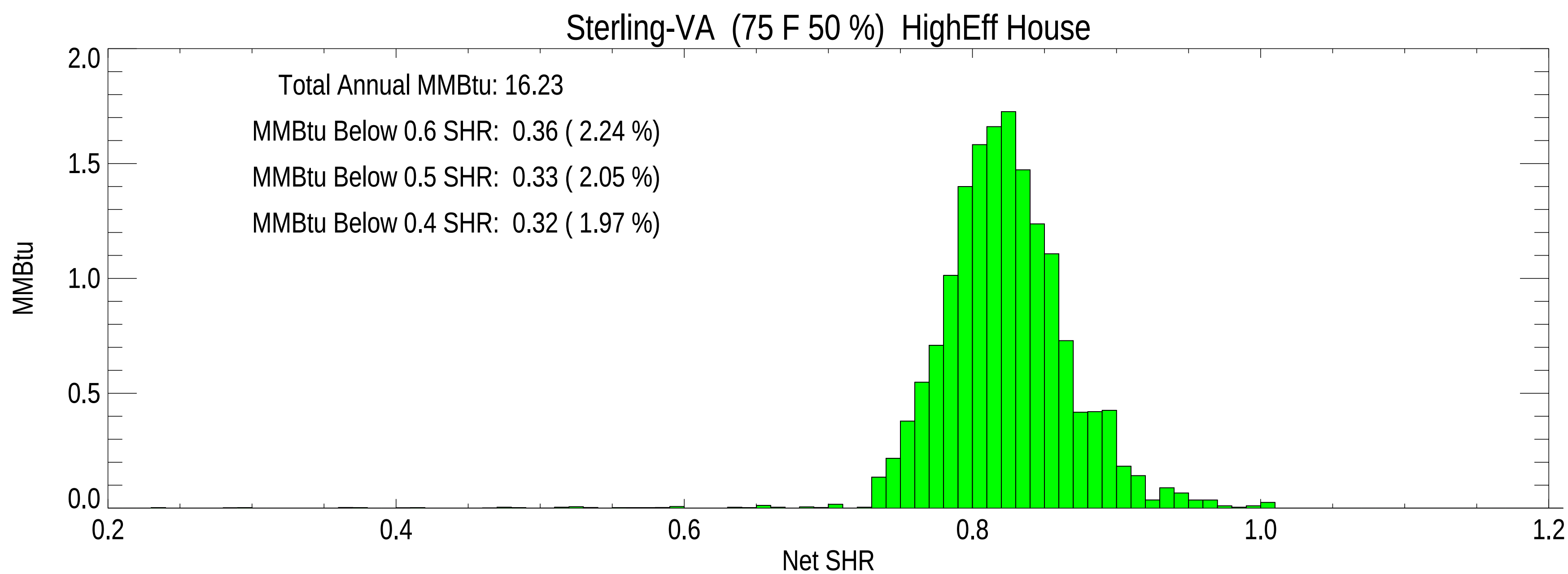

Jacksonville-FL (75 F 50 %) HERS Reference House
Total Annual MMBtu: 45.11
MMBtu Below 0.6 SHR: 4.46 (9.90 %)
MMBtu Below 0.5 SHR: 3.41 (7.55 %)
MMBtu Below 0.4 SHR: 2.90 (6.43 %)
MMBtu
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

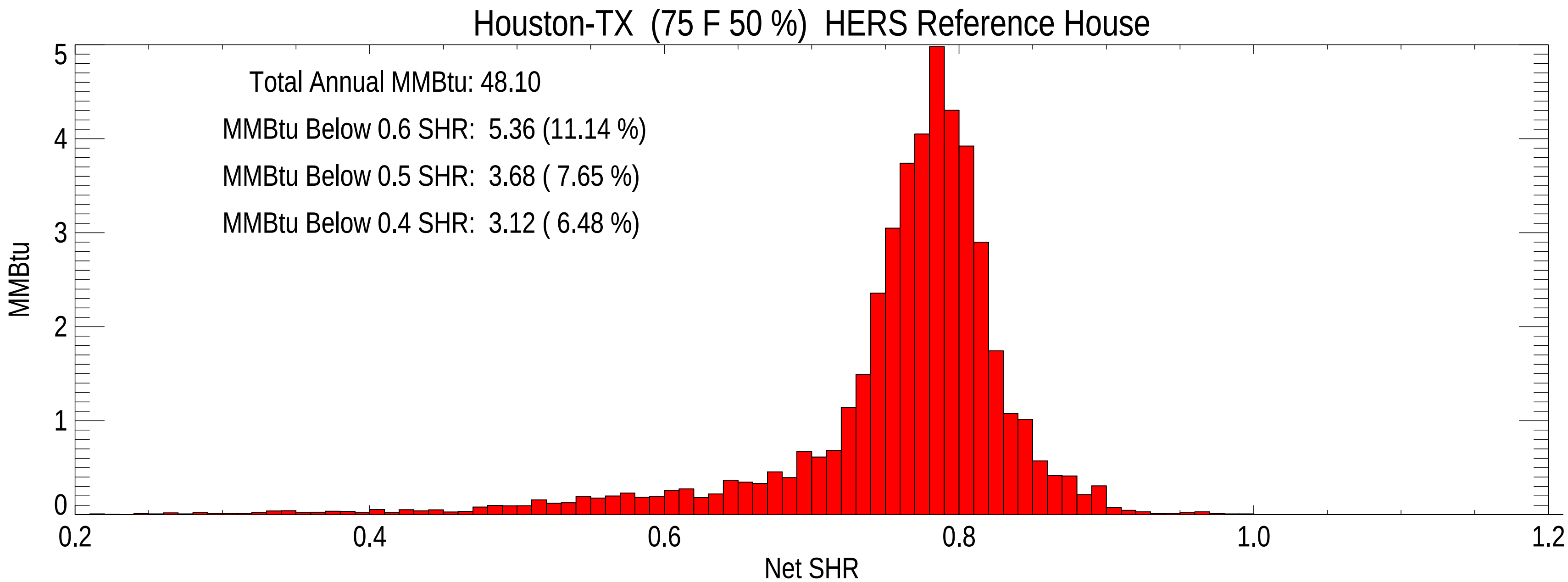

Jacksonville-FL (75 F 50 %) HighEff House
Total Annual MMBtu: 27.24
MMBtu Below 0.6 SHR: 2.62 (9.63 %)
MMBtu Below 0.5 SHR: 2.21 (8.10 %)
MMBtu Below 0.4 SHR: 1.96 (7.21 %)
MMBtu
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

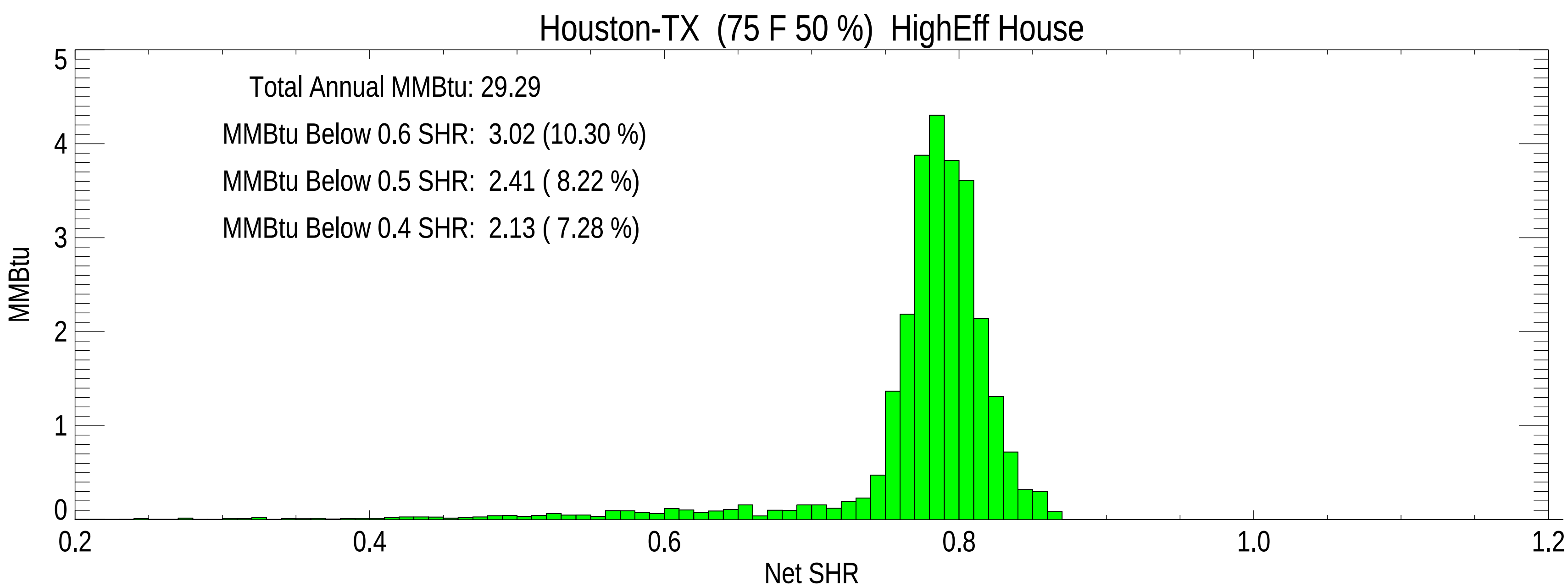

Atlanta-GA (75 F 50 %) HERS Reference House
Total Annual MMBtu: 25.33
MMBtu Below 0.6 SHR: 1.10 (4.33 %)
MMBtu Below 0.5 SHR: 1.06 (4.20 %)
MMBtu Below 0.4 SHR: 1.05 (4.15 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2

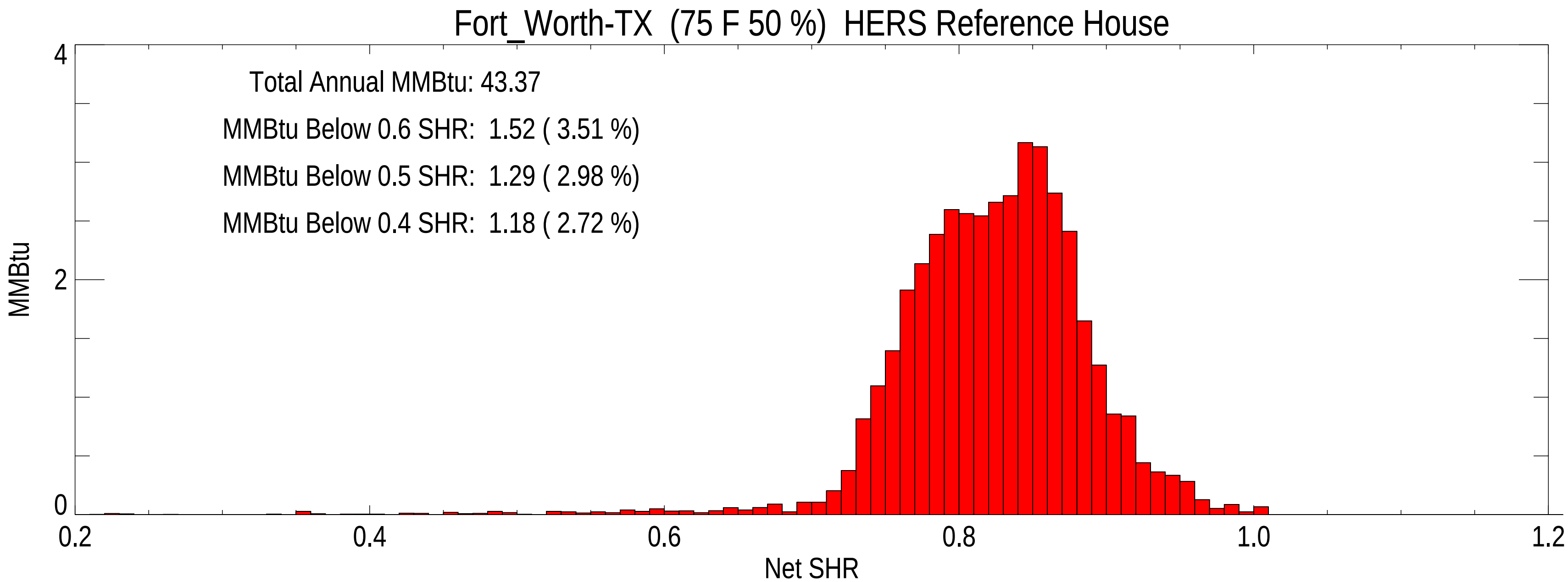

Atlanta-GA (75 F 50 %) HighEff House
Total Annual MMBtu: 18.08
MMBtu Below 0.6 SHR: 0.47 (2.60 %)
MMBtu Below 0.5 SHR: 0.46 (2.57 %)
MMBtu Below 0.4 SHR: 0.46 (2.53 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2

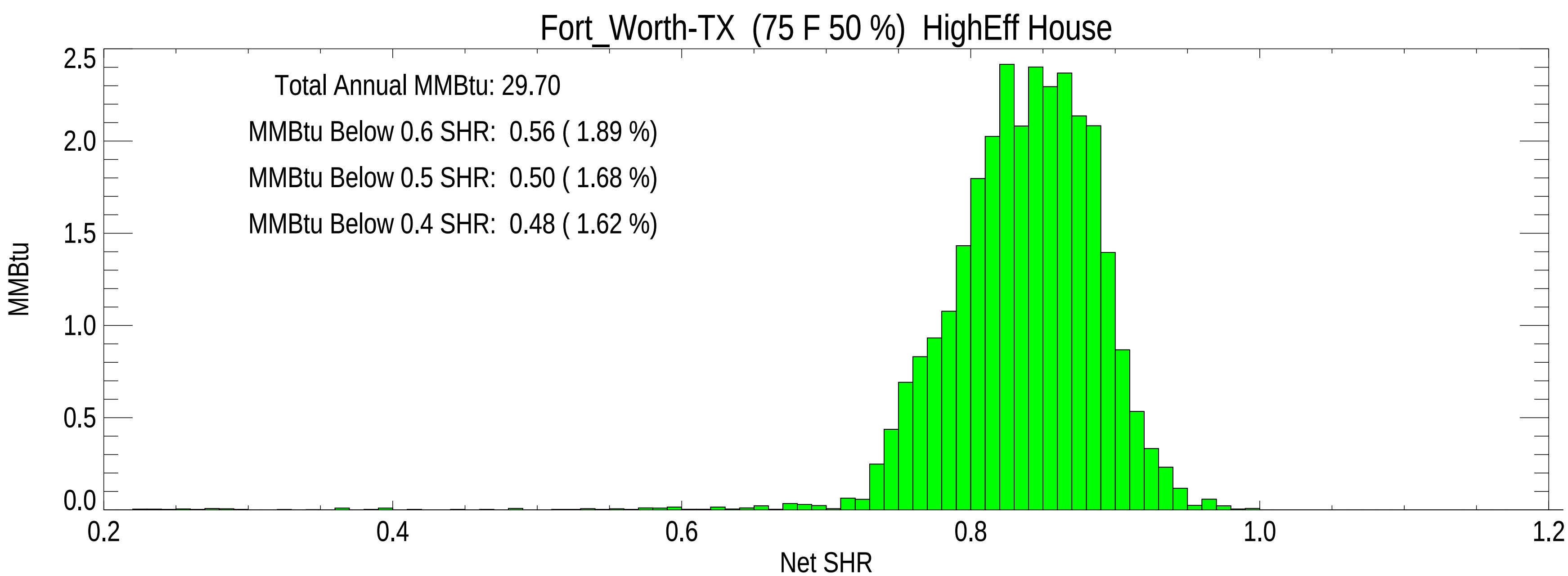

Sterling-VA (75 F 50 %) HERS Reference House
Total Annual MMBtu: 23.50
MMBtu Below 0.6 SHR: 0.94 (4.02 %)
MMBtu Below 0.5 SHR: 0.89 (3.79 %)
MMBtu Below 0.4 SHR: 0.86 (3.65 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2

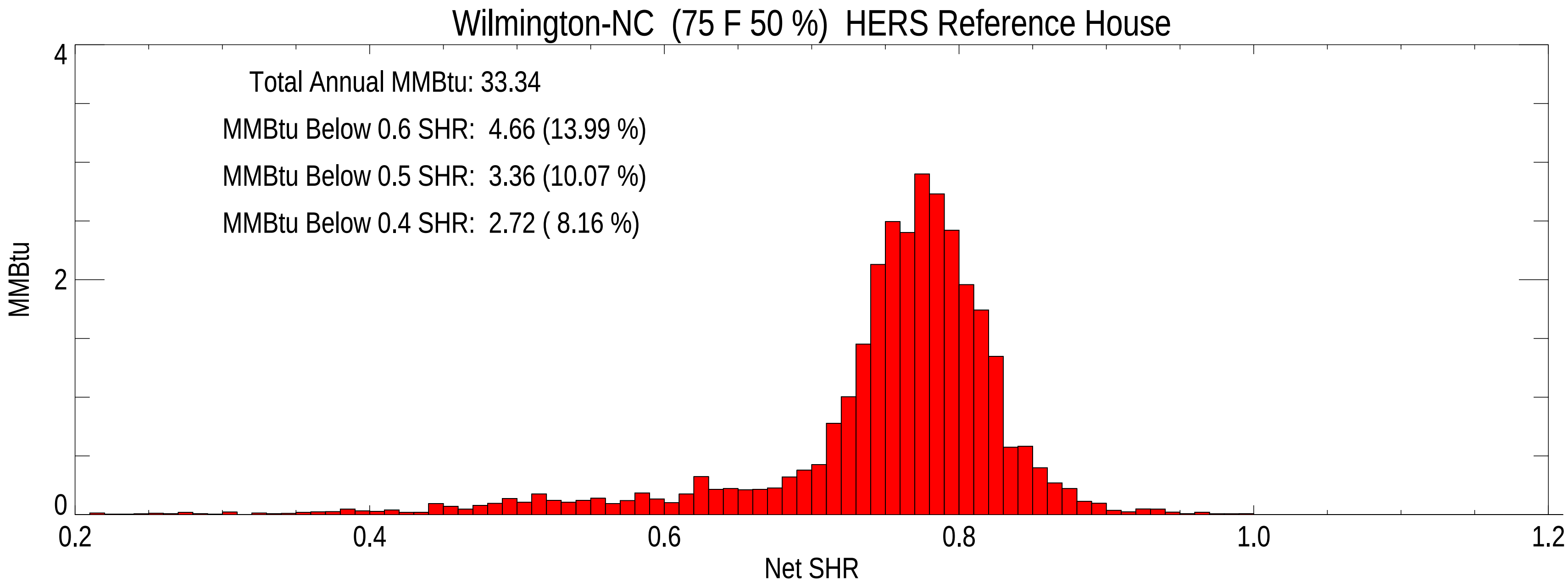

Sterling-VA (75 F 50 %) HighEff House
Total Annual MMBtu: 16.23
MMBtu Below 0.6 SHR: 0.36 (2.24 %)
MMBtu Below 0.5 SHR: 0.33 (2.05 %)
MMBtu Below 0.4 SHR: 0.32 (1.97 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
0.2
0.4
0.6
0.8
1.0
1.2

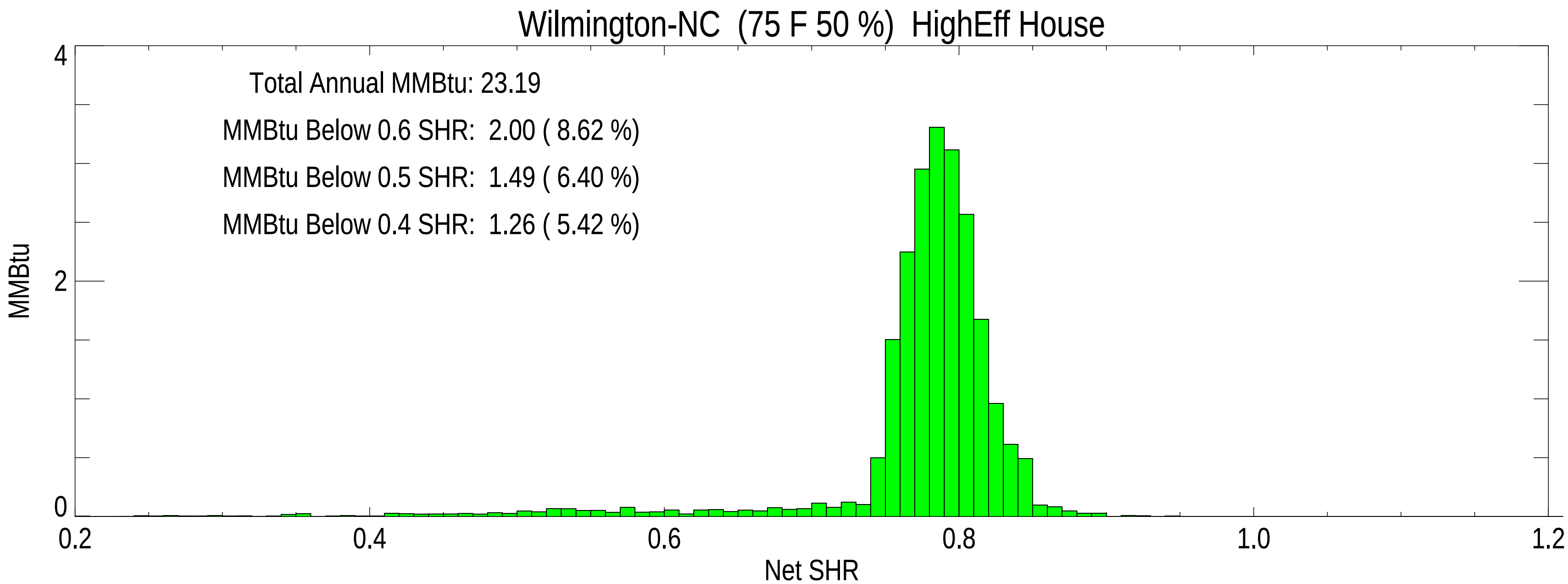

Houston-TX (75 F 50 %) HERS Reference House
Total Annual MMBtu: 48.10
MMBtu Below 0.6 SHR: 5.36 (11.14 %)
MMBtu Below 0.5 SHR: 3.68 (7.65 %)
MMBtu Below 0.4 SHR: 3.12 (6.48 %)
MMBtu
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

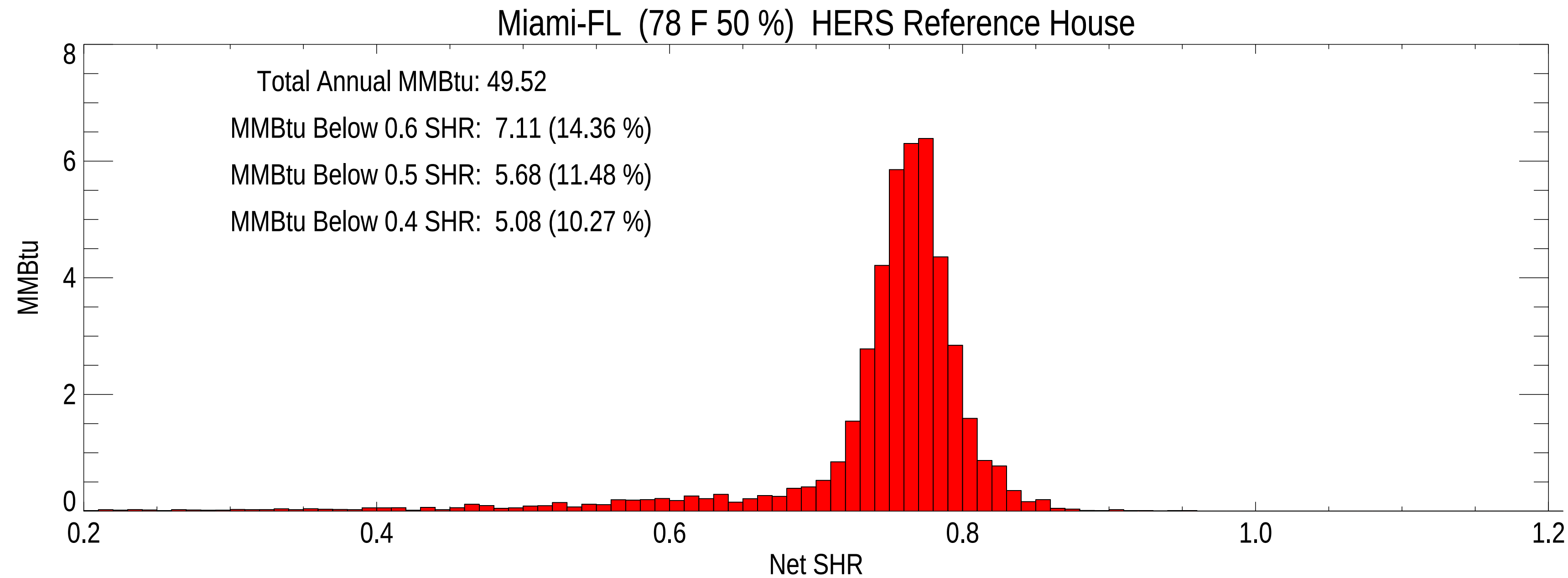

Houston-TX (75 F 50 %) HighEff House
Total Annual MMBtu: 29.29
MMBtu Below 0.6 SHR: 3.02 (10.30 %)
MMBtu Below 0.5 SHR: 2.41 (8.22 %)
MMBtu Below 0.4 SHR: 2.13 (7.28 %)
MMBtu
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

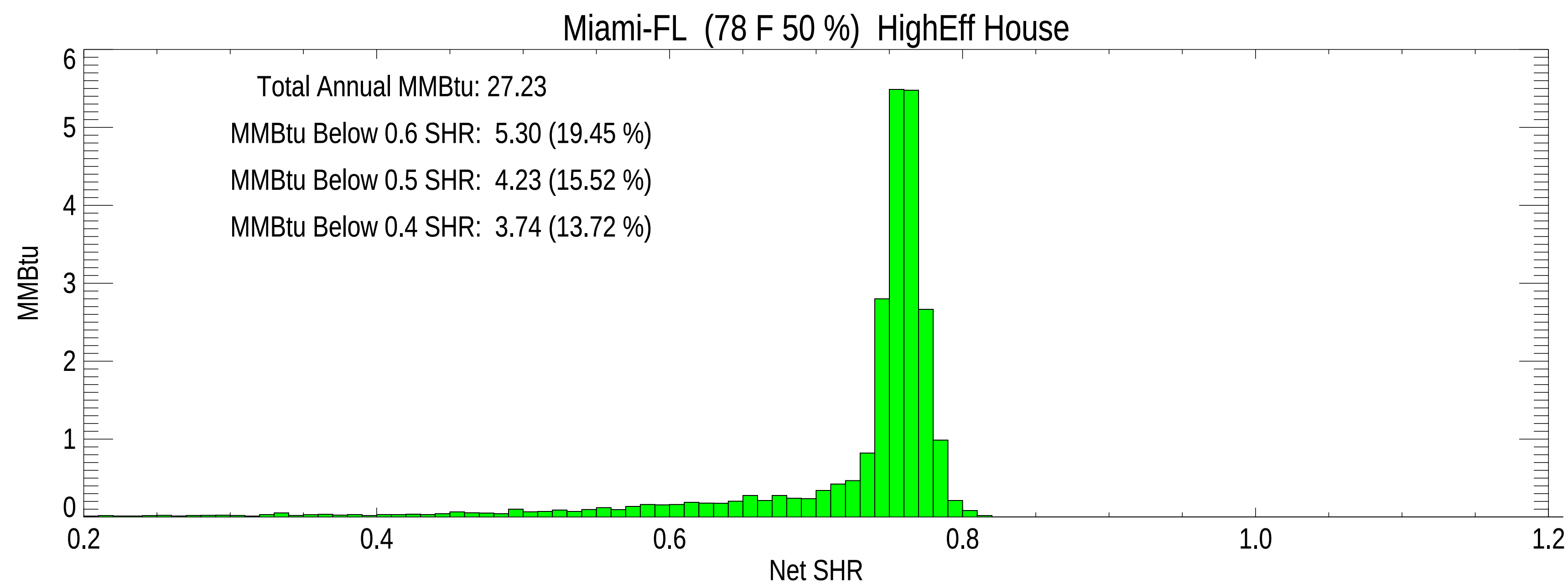

Fort_Worth-TX (75 F 50 %) HERS Reference House
Total Annual MMBtu: 43.37
MMBtu Below 0.6 SHR: 1.52 (3.51 %)
MMBtu Below 0.5 SHR: 1.29 (2.98 %)
MMBtu Below 0.4 SHR: 1.18 (2.72 %)
MMBtu
Net SHR
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2

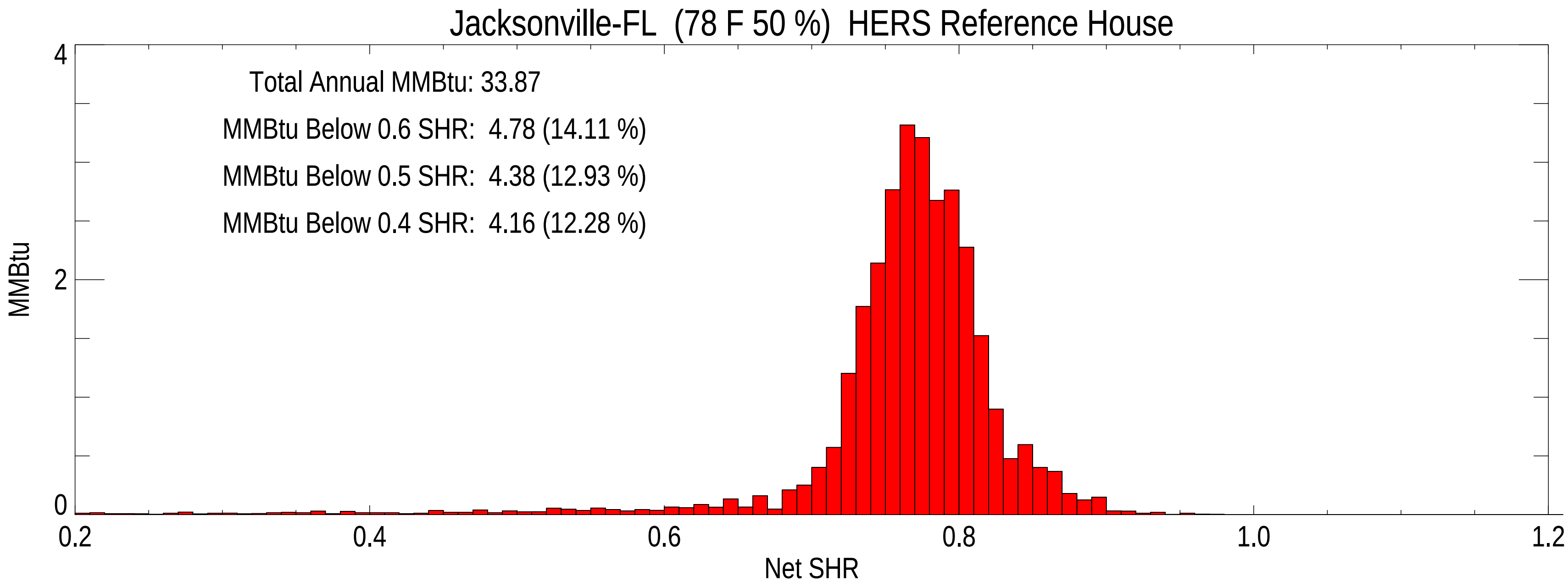

Fort_Worth-TX (75 F 50 %) HighEff House
Total Annual MMBtu: 29.70
MMBtu Below 0.6 SHR: 0.56 (1.89 %)
MMBtu Below 0.5 SHR: 0.50 (1.68 %)
MMBtu Below 0.4 SHR: 0.48 (1.62 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2

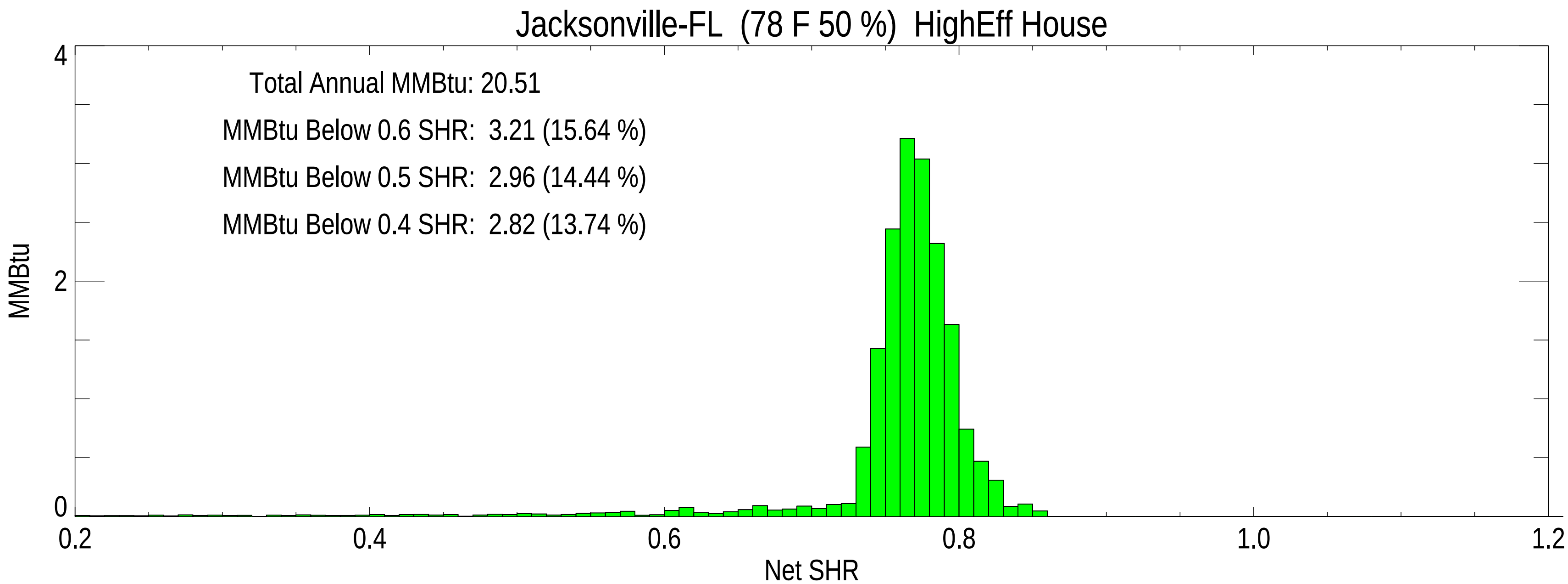

Wilmington-NC (75 F 50 %) HERS Reference House
Total Annual MMBtu: 33.34
MMBtu Below 0.6 SHR: 4.66 (13.99 %)
MMBtu Below 0.5 SHR: 3.36 (10.07 %)
MMBtu Below 0.4 SHR: 2.72 (8.16 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

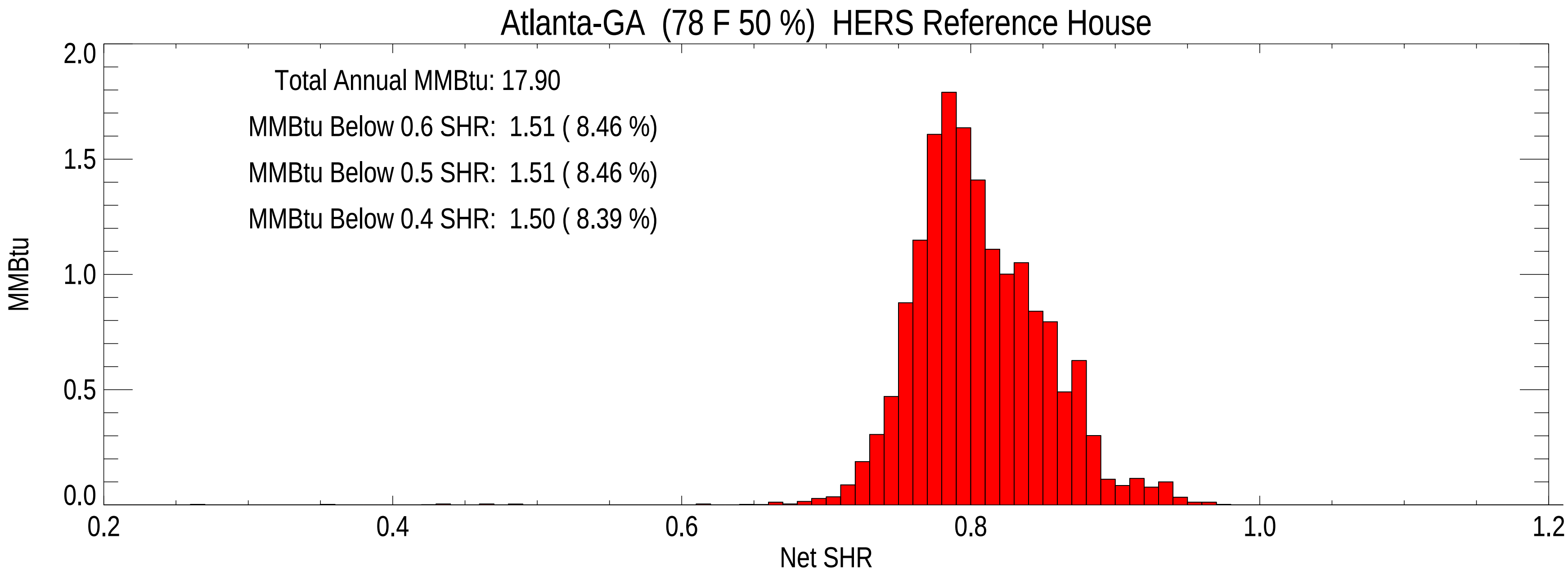

Wilmington-NC (75 F 50 %) HighEff House
Total Annual MMBtu: 23.19
MMBtu Below 0.6 SHR: 2.00 (8.62 %)
MMBtu Below 0.5 SHR: 1.49 (6.40 %)
MMBtu Below 0.4 SHR: 1.26 (5.42 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

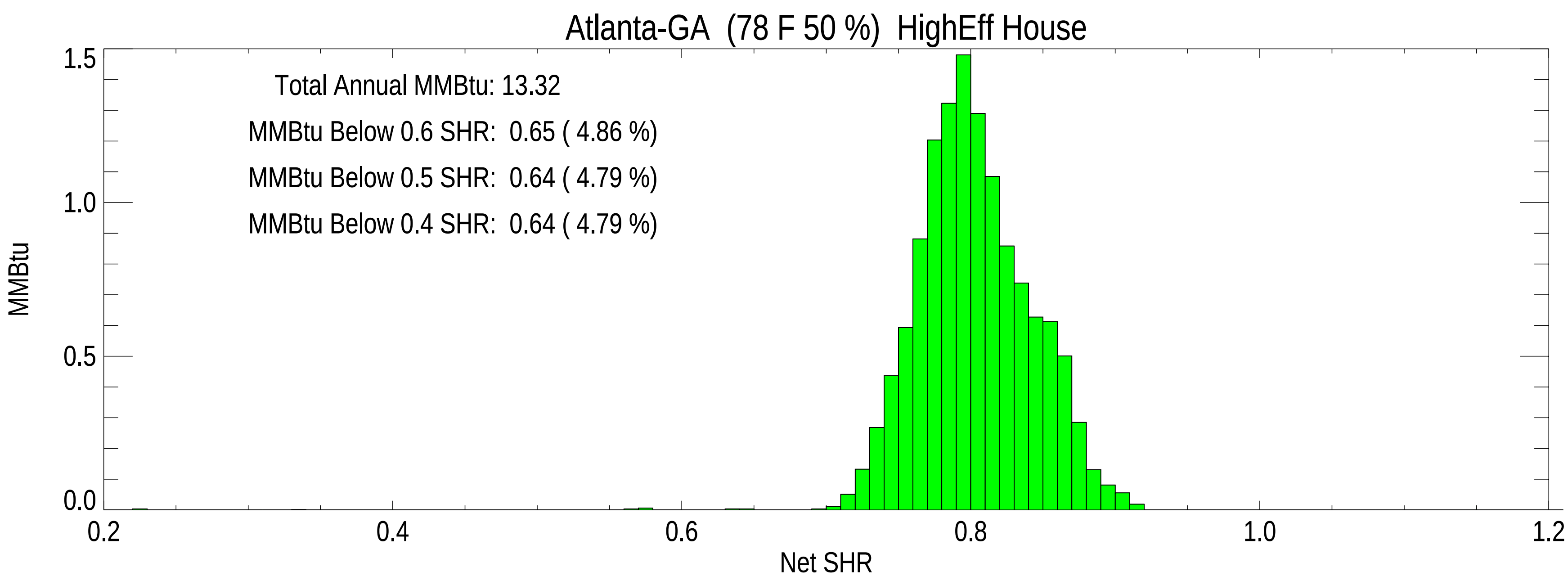

Miami-FL (78 F 50 %) HERS Reference House
Total Annual MMBtu: 49.52
MMBtu Below 0.6 SHR: 7.11 (14.36 %)
MMBtu Below 0.5 SHR: 5.68 (11.48 %)
MMBtu Below 0.4 SHR: 5.08 (10.27 %)
MMBtu
0
2
4
6
8
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

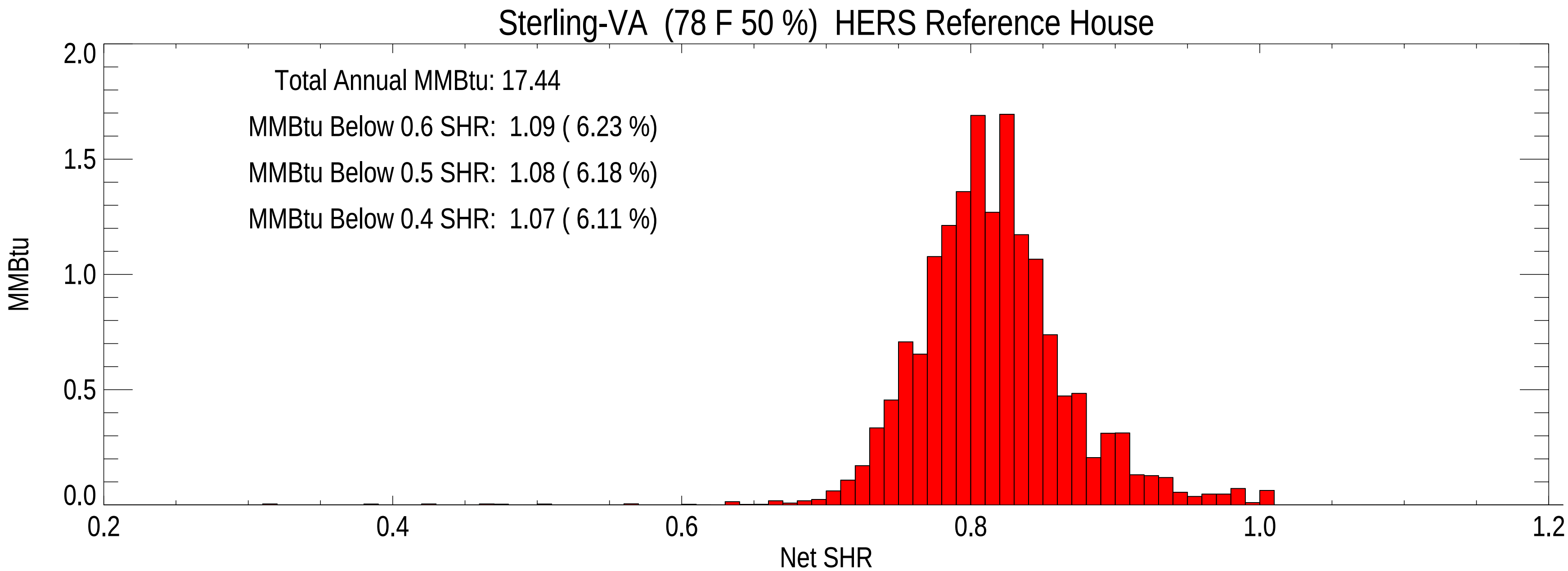

Miami-FL (78 F 50 %) HighEff House
Total Annual MMBtu: 27.23
MMBtu Below 0.6 SHR: 5.30 (19.45 %)
MMBtu Below 0.5 SHR: 4.23 (15.52 %)
MMBtu Below 0.4 SHR: 3.74 (13.72 %)
MMBtu
0
1
2
3
4
5
6
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

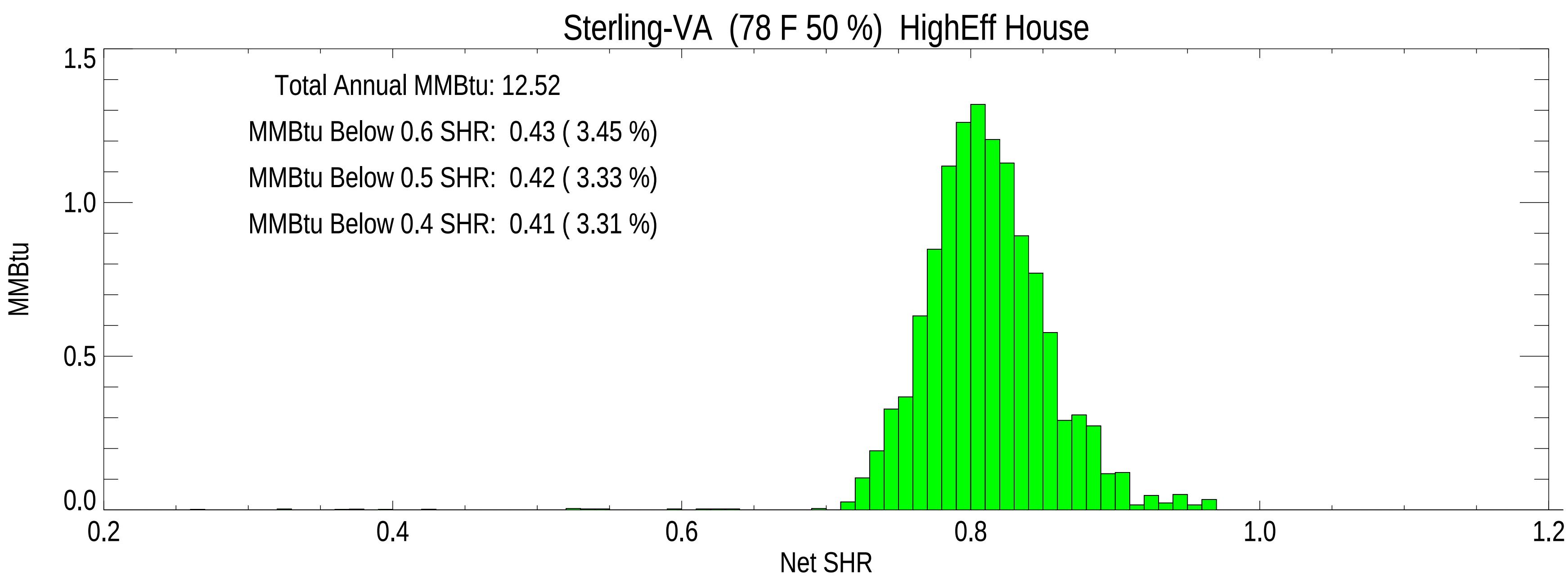

Jacksonville-FL (78 F 50 %) HERS Reference House
Total Annual MMBtu: 33.87
MMBtu Below 0.6 SHR: 4.78 (14.11 %)
MMBtu Below 0.5 SHR: 4.38 (12.93 %)
MMBtu Below 0.4 SHR: 4.16 (12.28 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR


Jacksonville-FL (78 F 50 %) HighEff House
Total Annual MMBtu: 20.51
MMBtu Below 0.6 SHR: 3.21 (15.64 %)
MMBtu Below 0.5 SHR: 2.96 (14.44 %)
MMBtu Below 0.4 SHR: 2.82 (13.74 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

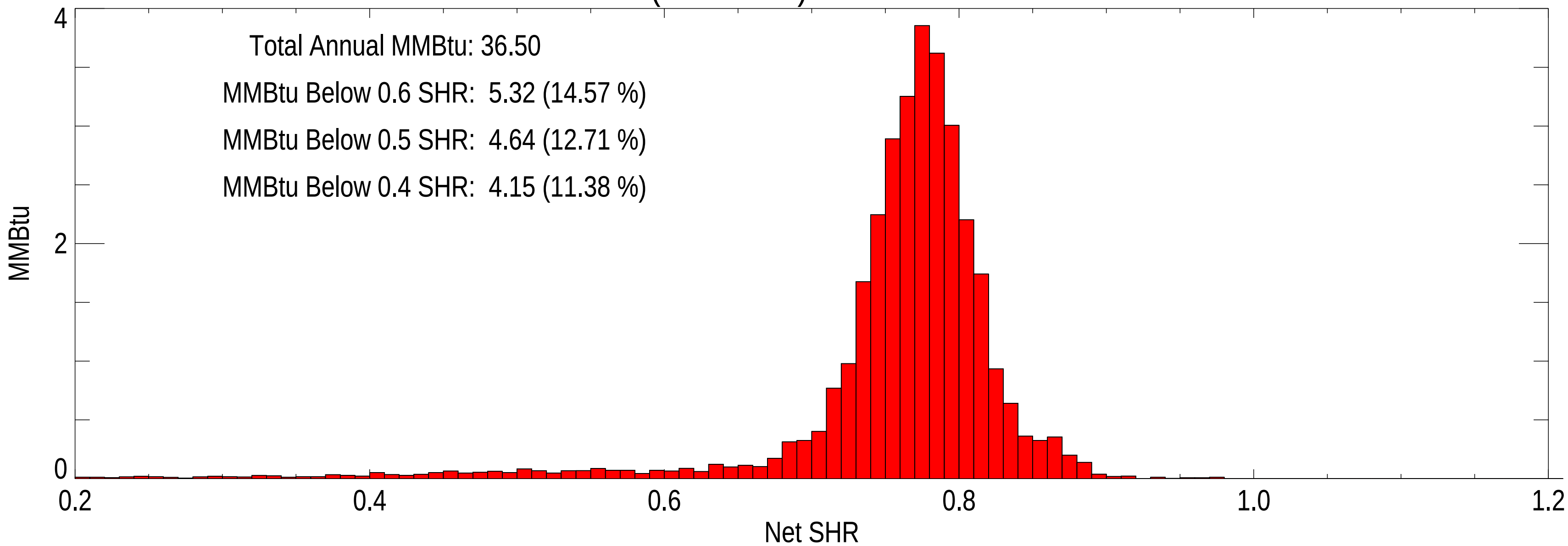

Atlanta-GA (78 F 50 %) HERS Reference House
Total Annual MMBtu: 17.90
MMBtu Below 0.6 SHR: 1.51 (8.46 %)
MMBtu Below 0.5 SHR: 1.51 (8.46 %)
MMBtu Below 0.4 SHR: 1.50 (8.39 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
0.2
0.4
0.6
0.8
1.0
1.2


Atlanta-GA (78 F 50 %) HighEff House
Total Annual MMBtu: 13.32
MMBtu Below 0.6 SHR: 0.65 (4.86 %)
MMBtu Below 0.5 SHR: 0.64 (4.79 %)
MMBtu Below 0.4 SHR: 0.64 (4.79 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
0.2
0.4
0.6
0.8
1.0
1.2

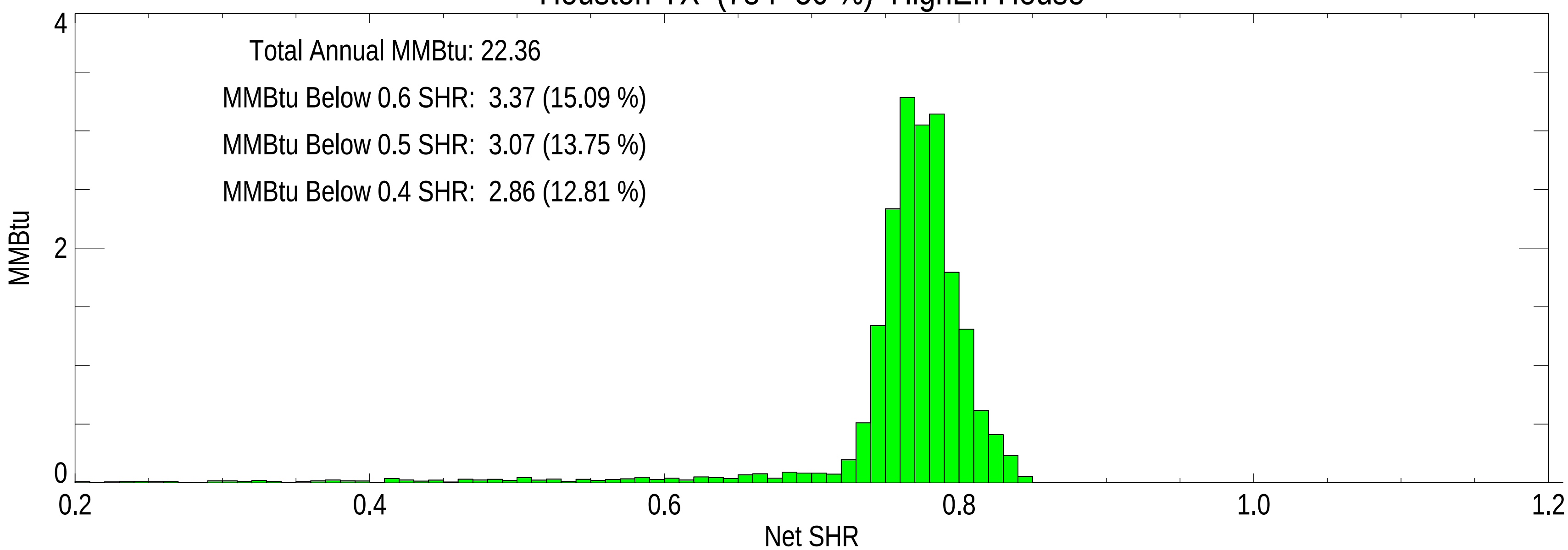

Sterling-VA (78 F 50 %) HERS Reference House
Total Annual MMBtu: 17.44
MMBtu Below 0.6 SHR: 1.09 (6.23 %)
MMBtu Below 0.5 SHR: 1.08 (6.18 %)
MMBtu Below 0.4 SHR: 1.07 (6.11 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

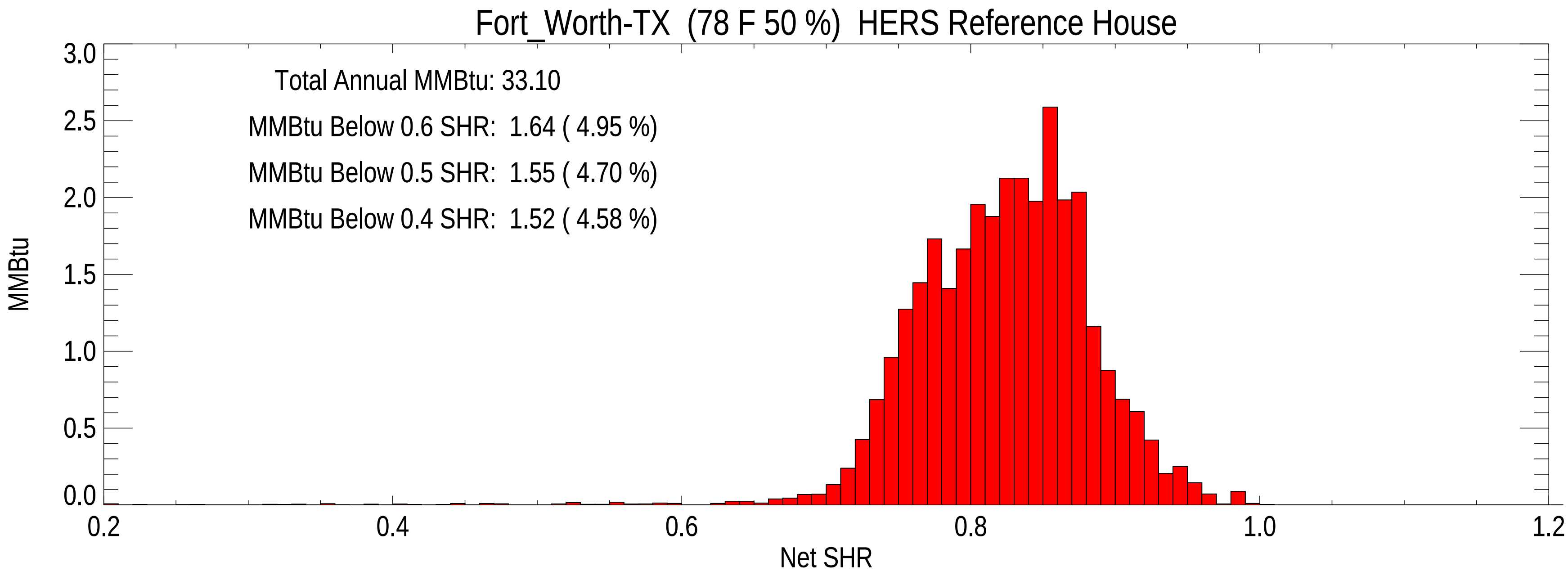

Sterling-VA (78 F 50 %) HighEff House
Total Annual MMBtu: 12.52
MMBtu Below 0.6 SHR: 0.43 (3.45 %)
MMBtu Below 0.5 SHR: 0.42 (3.33 %)
MMBtu Below 0.4 SHR: 0.41 (3.31 %)
MMBtu
0.0
0.5
1.0
1.5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

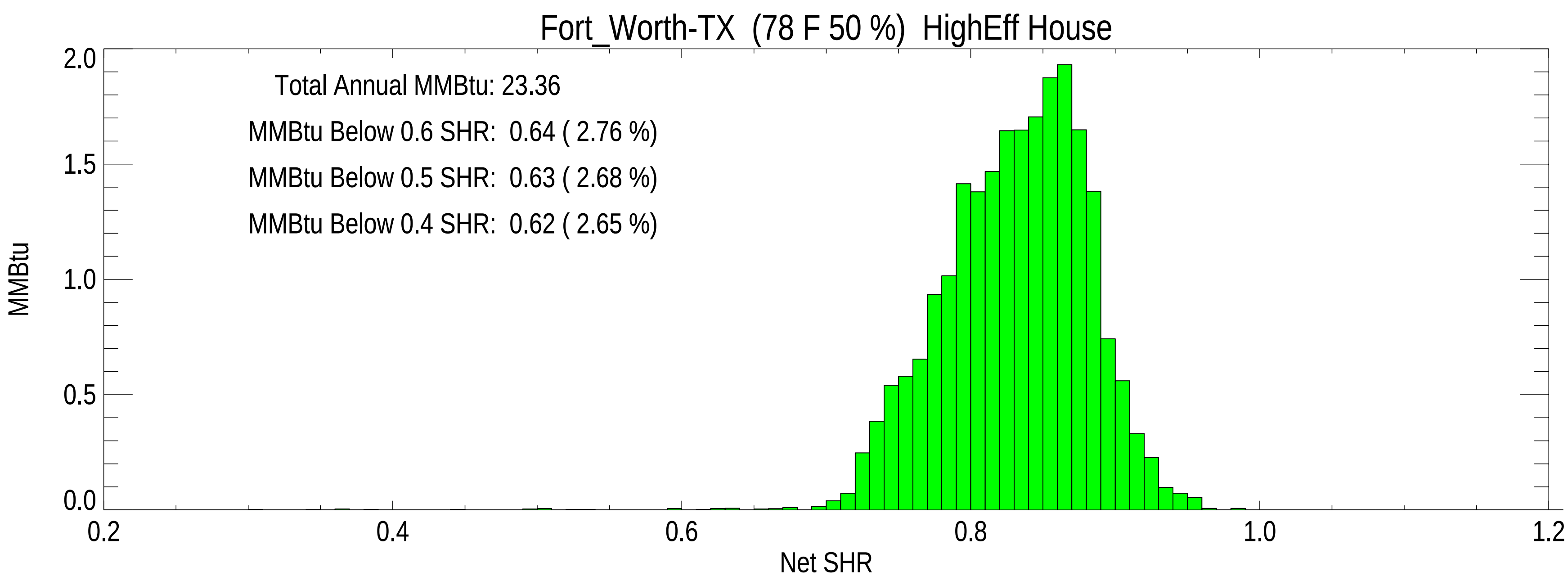
Houston-TX (78 F 50 %) HERS Reference House

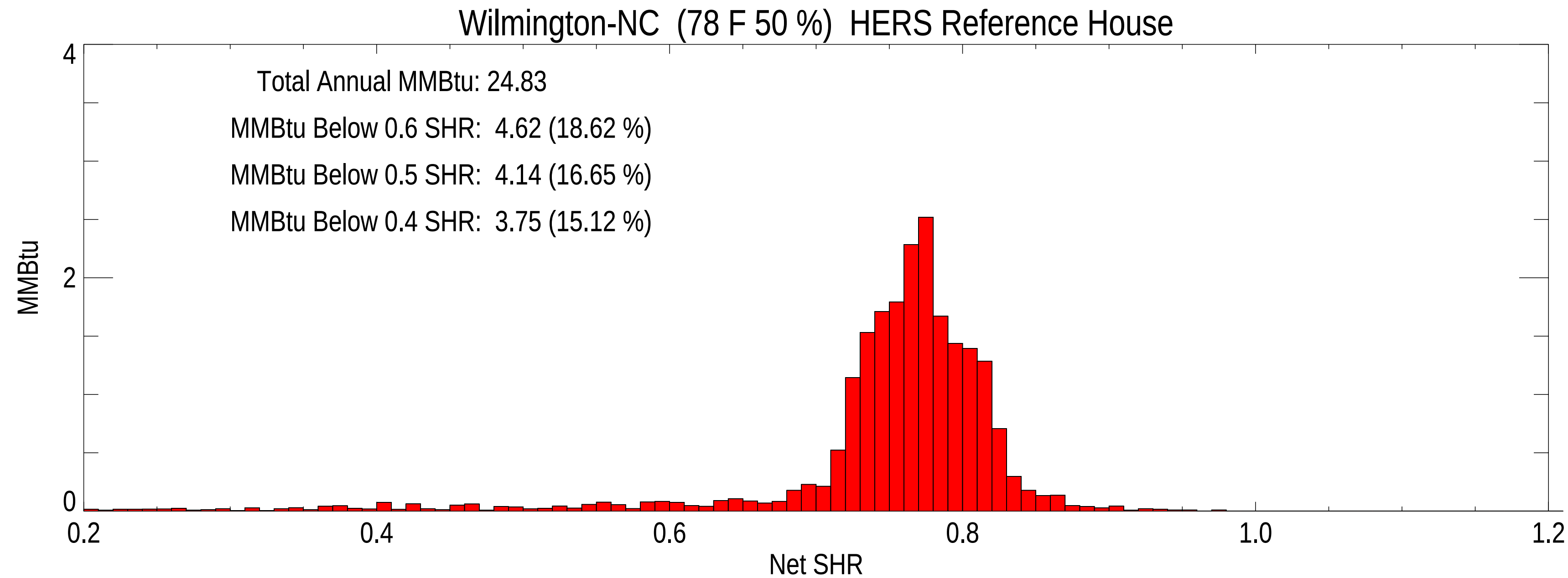


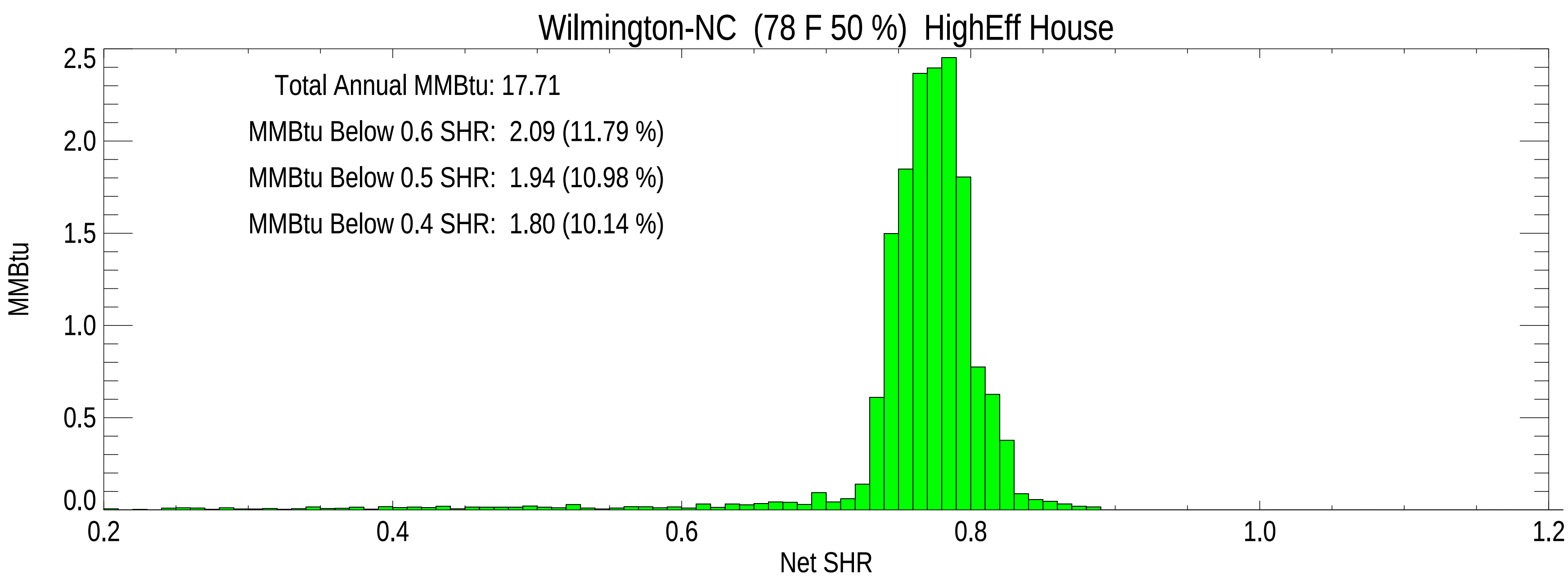
Houston-TX (78 F 50 %) HighEff House

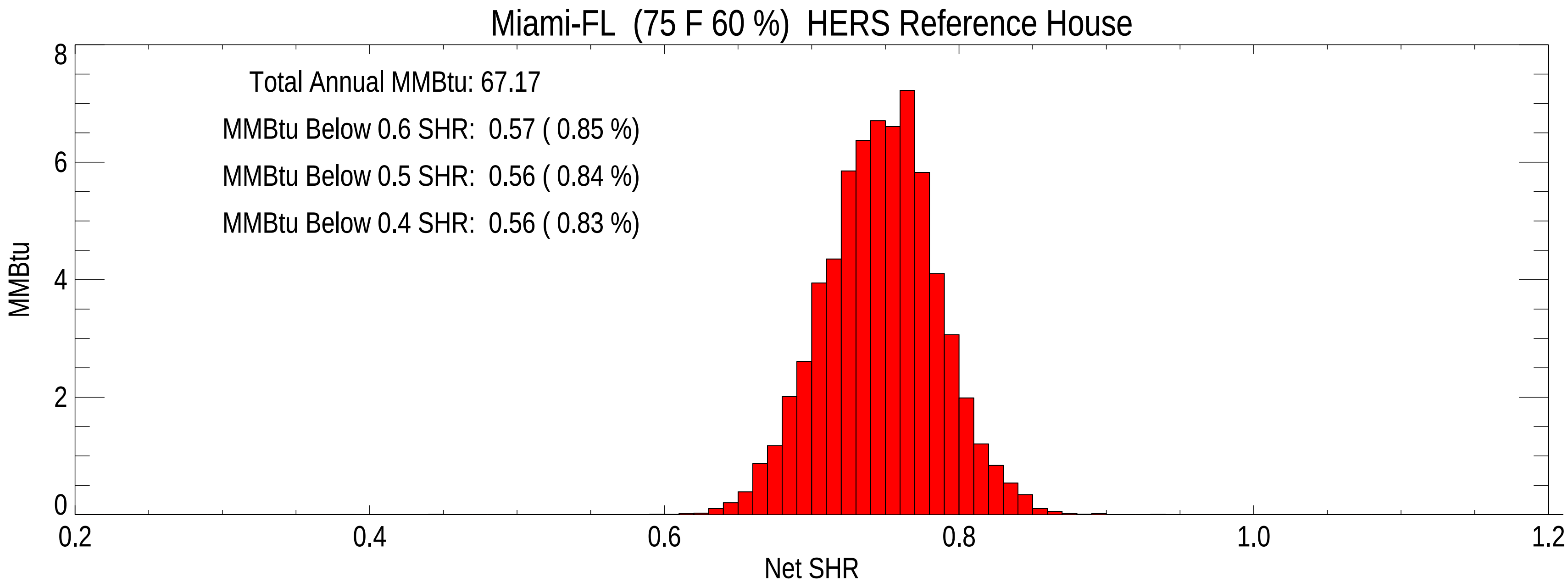


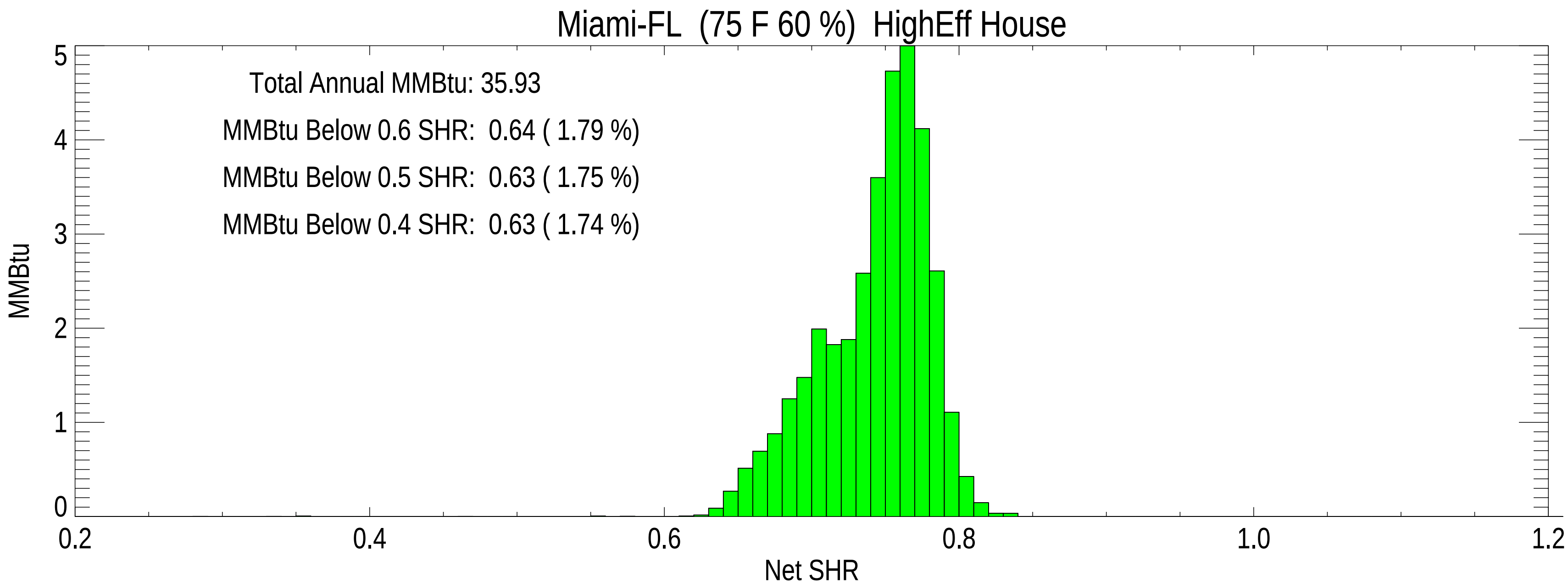

Fort_Worth-TX (78 F 50 %) HERS Reference House
Total Annual MMBtu: 33.10
MMBtu Below 0.6 SHR: 1.64 (4.95 %)
MMBtu Below 0.5 SHR: 1.55 (4.70 %)
MMBtu Below 0.4 SHR: 1.52 (4.58 %)
MMBtu
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

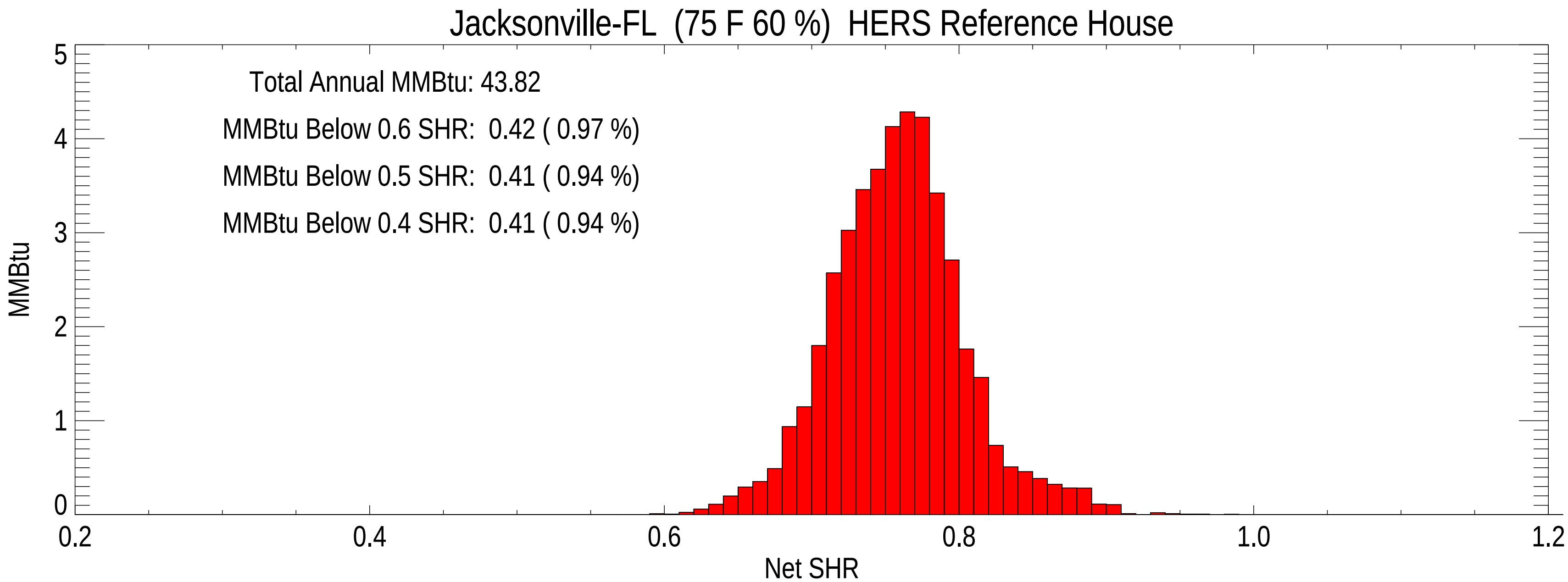

Fort_Worth-TX (78 F 50 %) HighEff House
Total Annual MMBtu: 23.36
MMBtu Below 0.6 SHR: 0.64 (2.76 %)
MMBtu Below 0.5 SHR: 0.63 (2.68 %)
MMBtu Below 0.4 SHR: 0.62 (2.65 %)
MMBtu
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

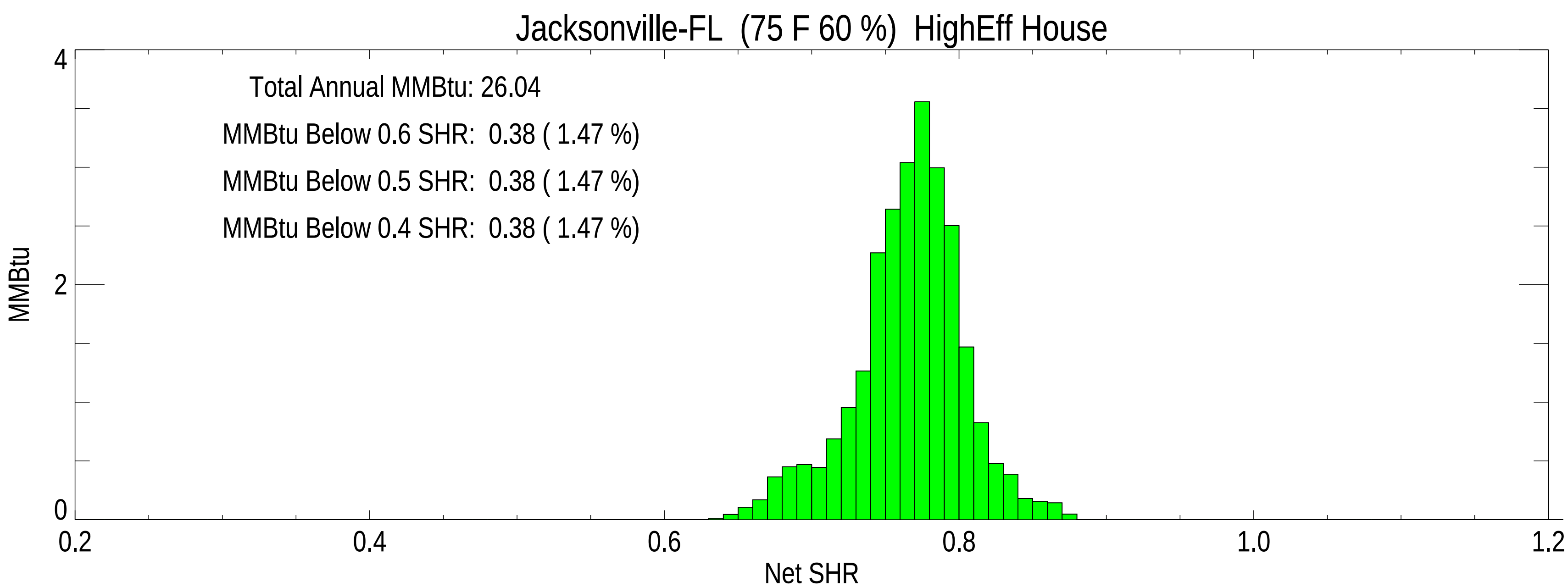

Wilmington-NC (78 F 50 %) HERS Reference House
Total Annual MMBtu: 24.83
MMBtu Below 0.6 SHR: 4.62 (18.62 %)
MMBtu Below 0.5 SHR: 4.14 (16.65 %)
MMBtu Below 0.4 SHR: 3.75 (15.12 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

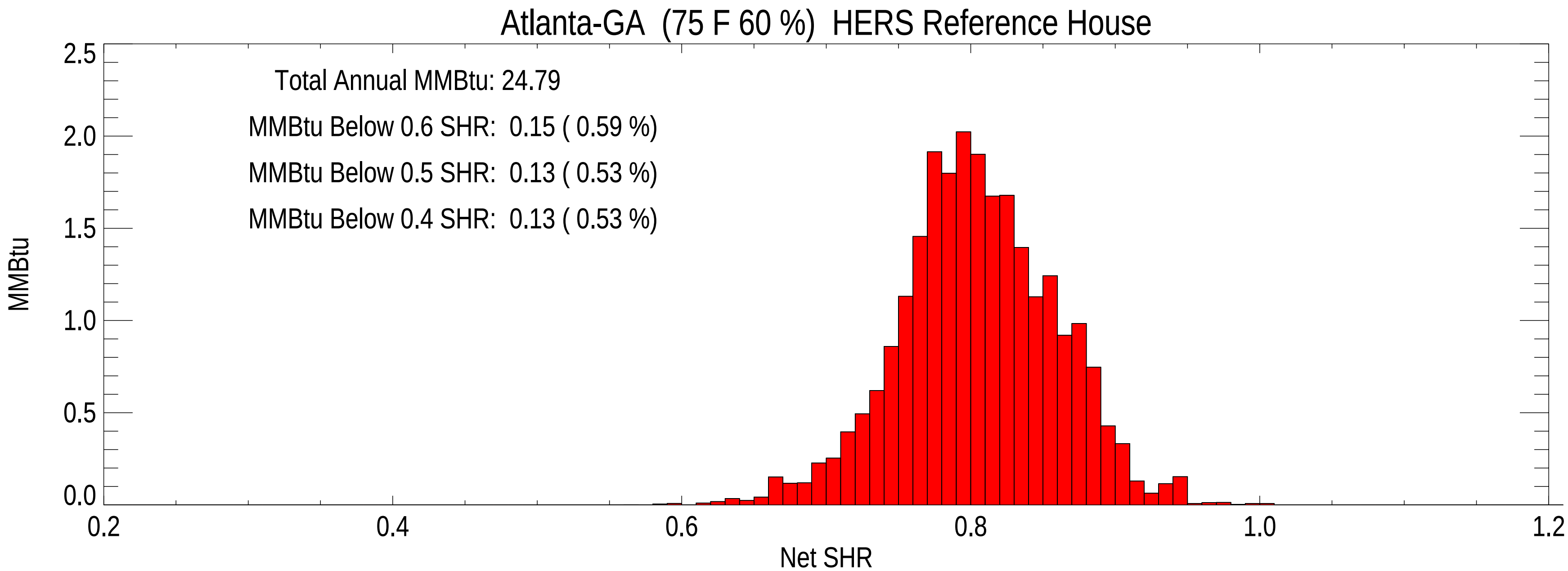

Wilmington-NC (78 F 50 %) HighEff House
Total Annual MMBtu: 17.71
MMBtu Below 0.6 SHR: 2.09 (11.79 %)
MMBtu Below 0.5 SHR: 1.94 (10.98 %)
MMBtu Below 0.4 SHR: 1.80 (10.14 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

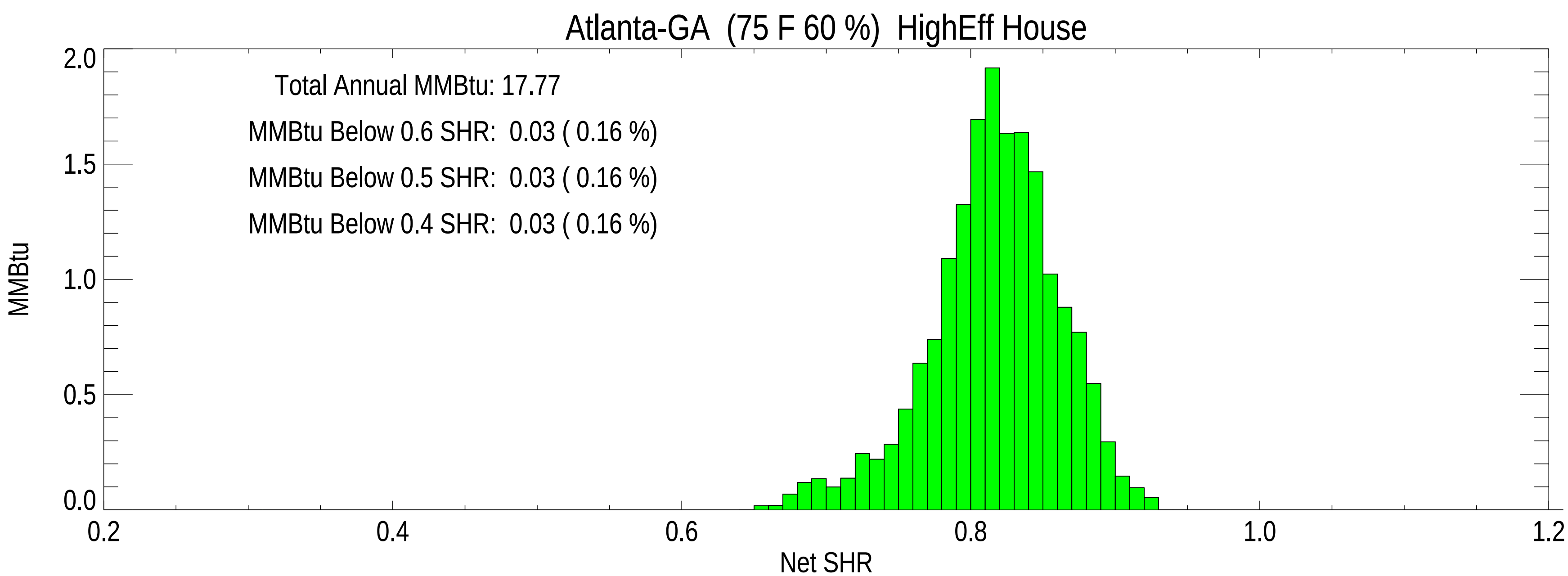

Miami-FL (75 F 60 %) HERS Reference House
Total Annual MMBtu: 67.17
MMBtu Below 0.6 SHR: 0.57 (0.85 %)
MMBtu Below 0.5 SHR: 0.56 (0.84 %)
MMBtu Below 0.4 SHR: 0.56 (0.83 %)
MMBtu
0
2
4
6
8
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

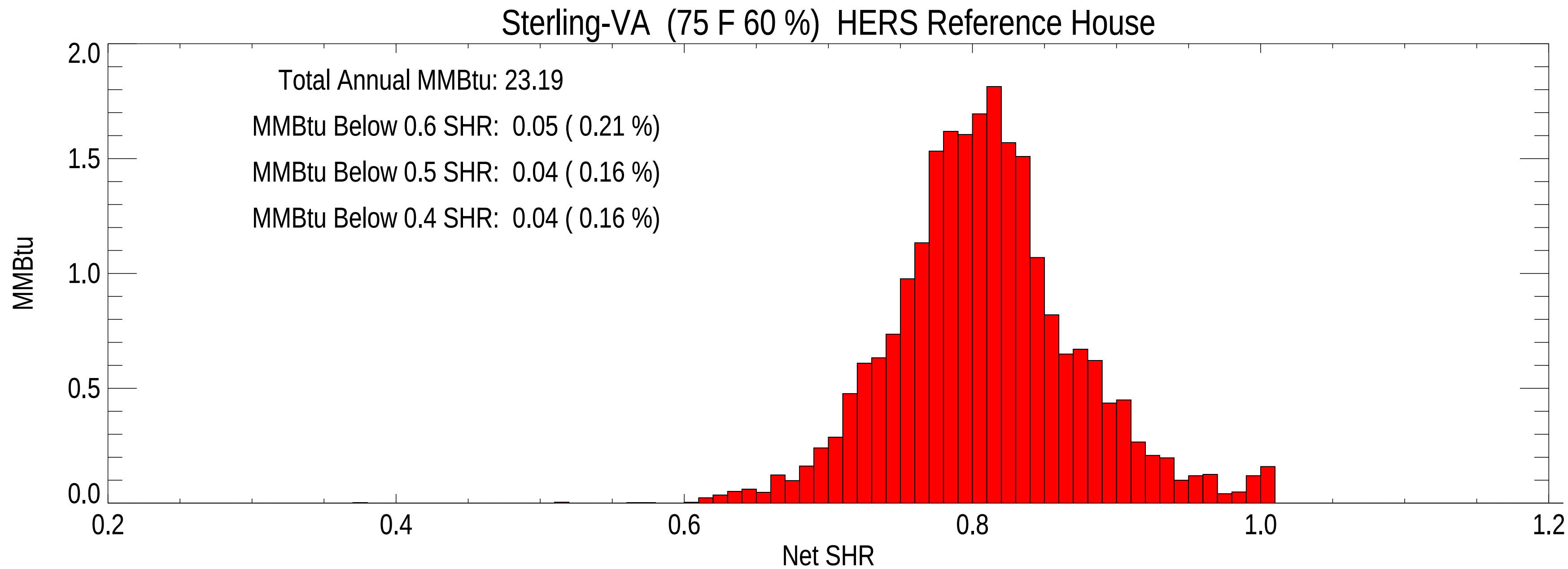

Miami-FL (75 F 60 %) HighEff House
Total Annual MMBtu: 35.93
MMBtu Below 0.6 SHR: 0.64 (1.79 %)
MMBtu Below 0.5 SHR: 0.63 (1.75 %)
MMBtu Below 0.4 SHR: 0.63 (1.74 %)
MMBtu
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

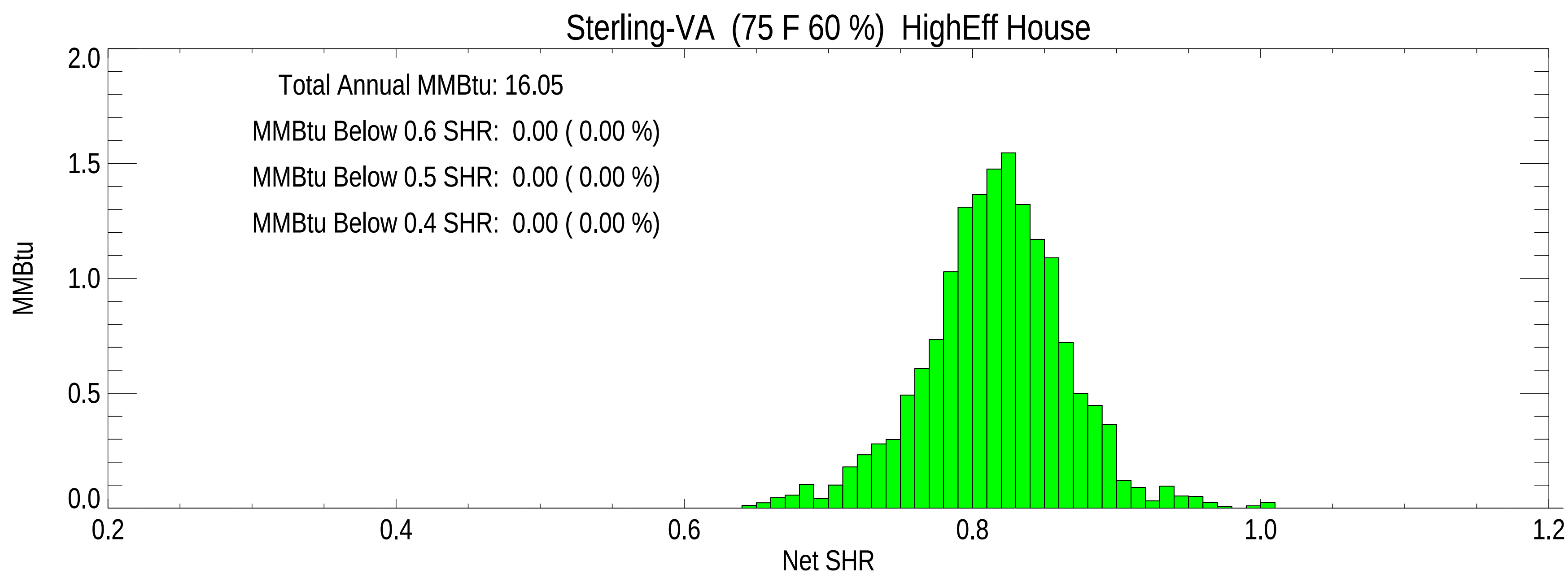

Jacksonville-FL (75 F 60 %) HERS Reference House
Total Annual MMBtu: 43.82
MMBtu Below 0.6 SHR: 0.42 (0.97 %)
MMBtu Below 0.5 SHR: 0.41 (0.94 %)
MMBtu Below 0.4 SHR: 0.41 (0.94 %)
MMBtu
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

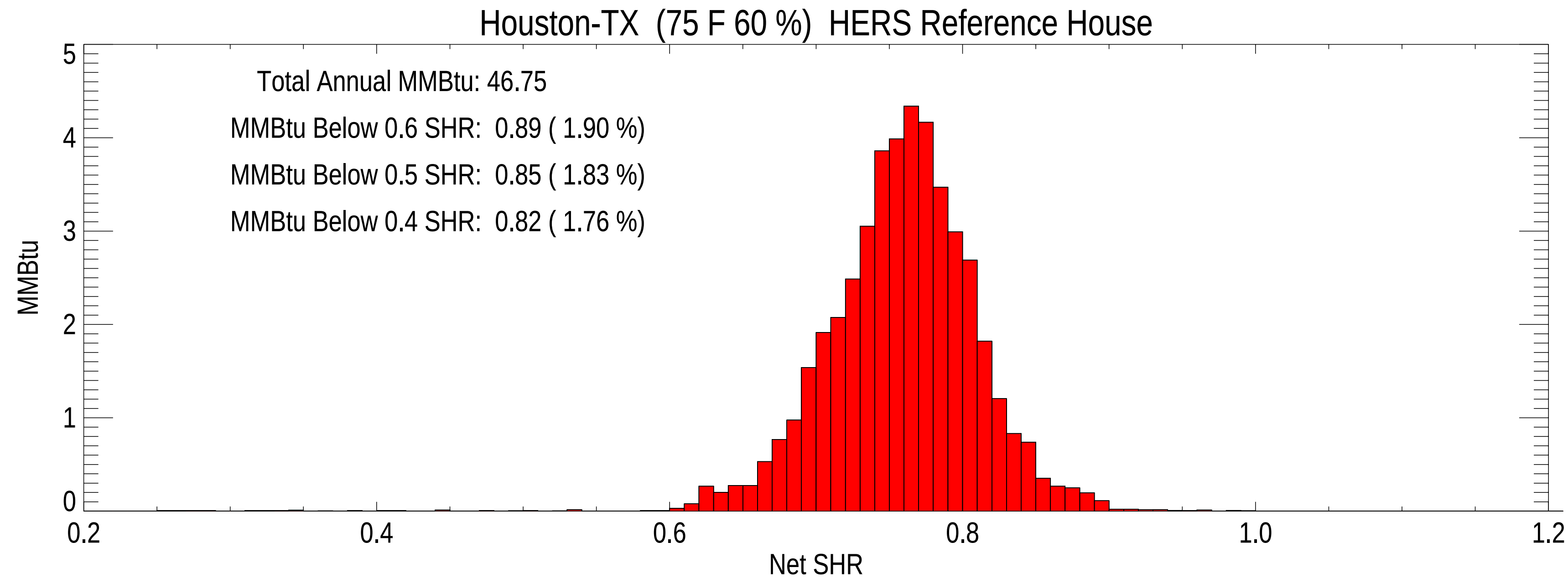

Jacksonville-FL (75 F 60 %) HighEff House
Total Annual MMBtu: 26.04
MMBtu Below 0.6 SHR: 0.38 (1.47 %)
MMBtu Below 0.5 SHR: 0.38 (1.47 %)
MMBtu Below 0.4 SHR: 0.38 (1.47 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

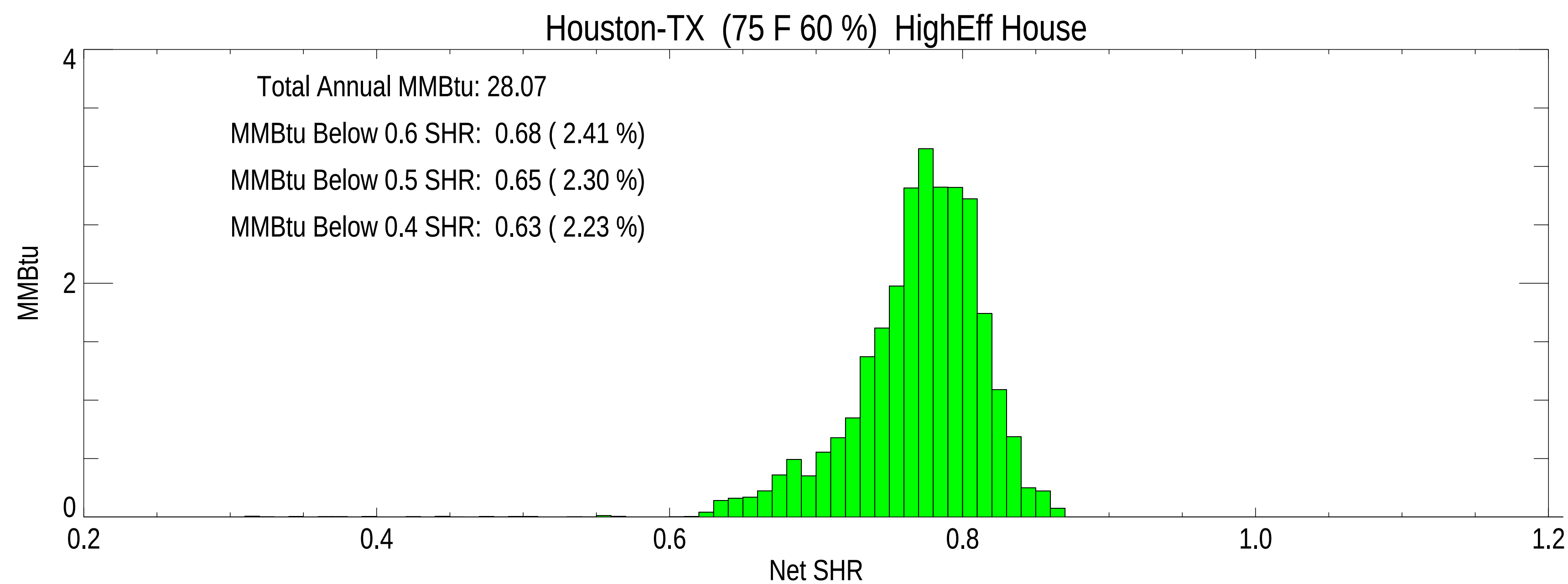

Atlanta-GA (75 F 60 %) HERS Reference House
Total Annual MMBtu: 24.79
MMBtu Below 0.6 SHR: 0.15 (0.59 %)
MMBtu Below 0.5 SHR: 0.13 (0.53 %)
MMBtu Below 0.4 SHR: 0.13 (0.53 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2

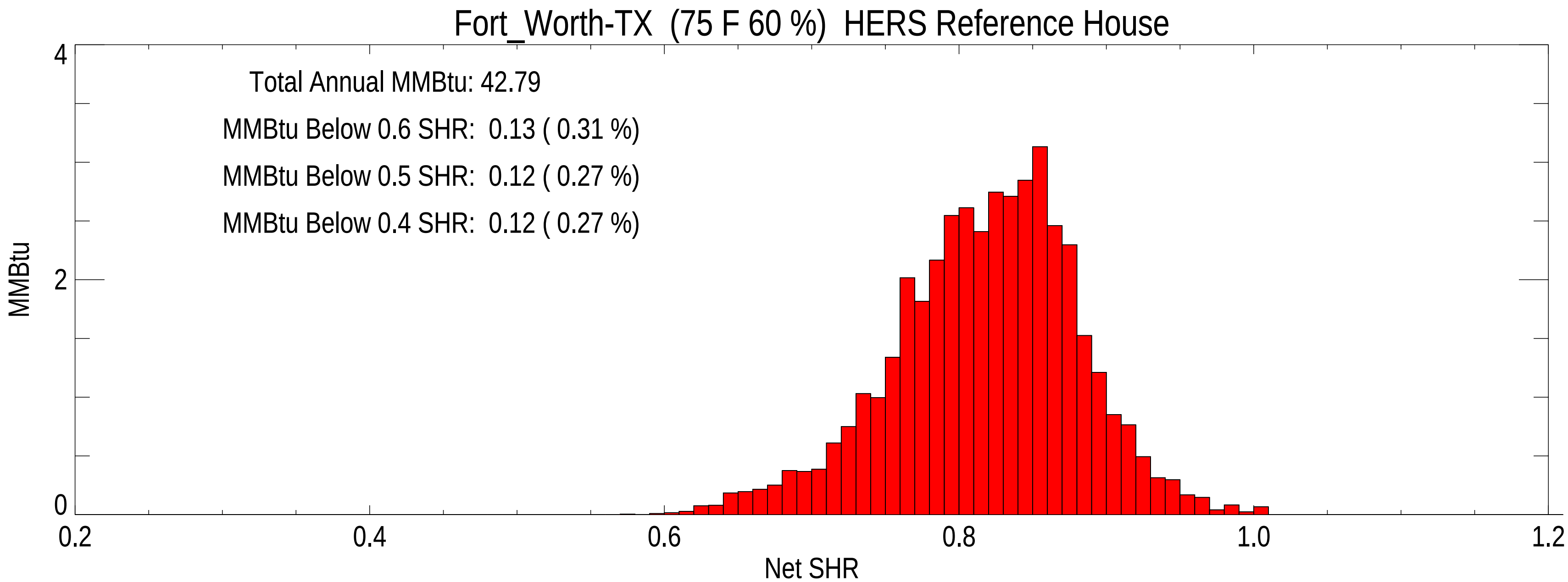

Atlanta-GA (75 F 60 %) HighEff House
Total Annual MMBtu: 17.77
MMBtu Below 0.6 SHR: 0.03 (0.16 %)
MMBtu Below 0.5 SHR: 0.03 (0.16 %)
MMBtu Below 0.4 SHR: 0.03 (0.16 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
0.2
0.4
0.6
0.8
1.0
1.2

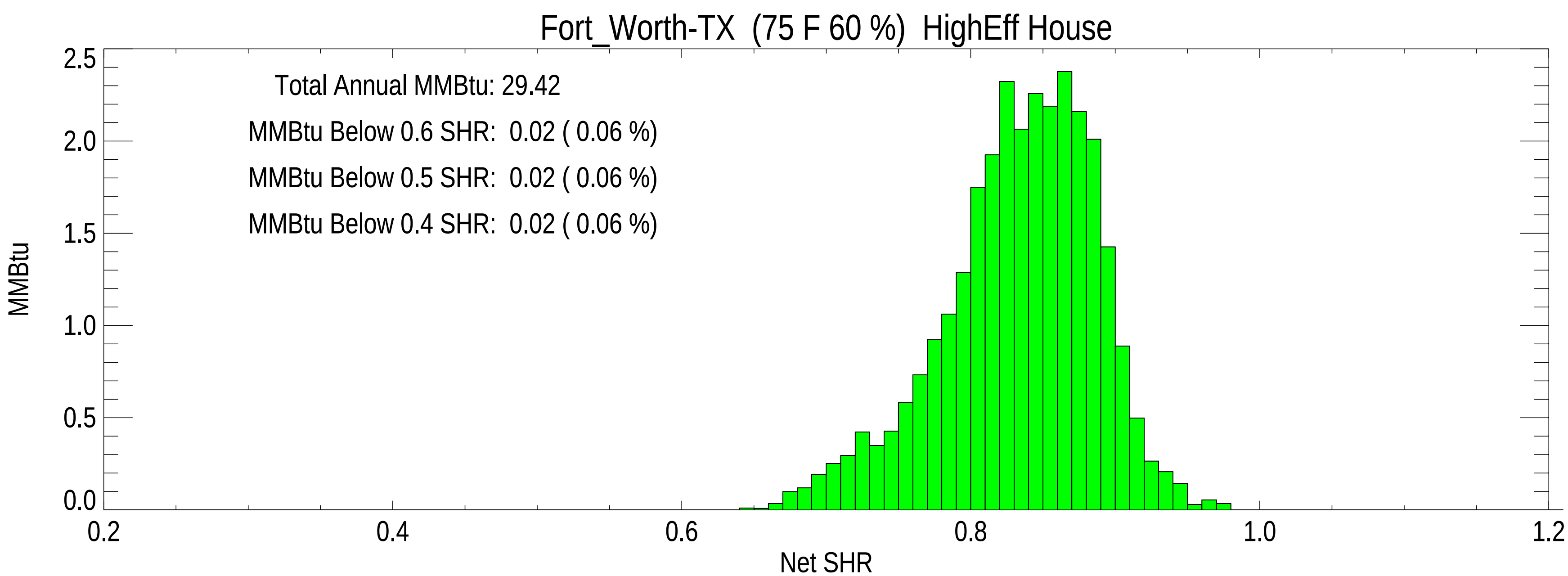

Sterling-VA (75 F 60 %) HERS Reference House
Total Annual MMBtu: 23.19
MMBtu Below 0.6 SHR: 0.05 (0.21 %)
MMBtu Below 0.5 SHR: 0.04 (0.16 %)
MMBtu Below 0.4 SHR: 0.04 (0.16 %)
MMBtu
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

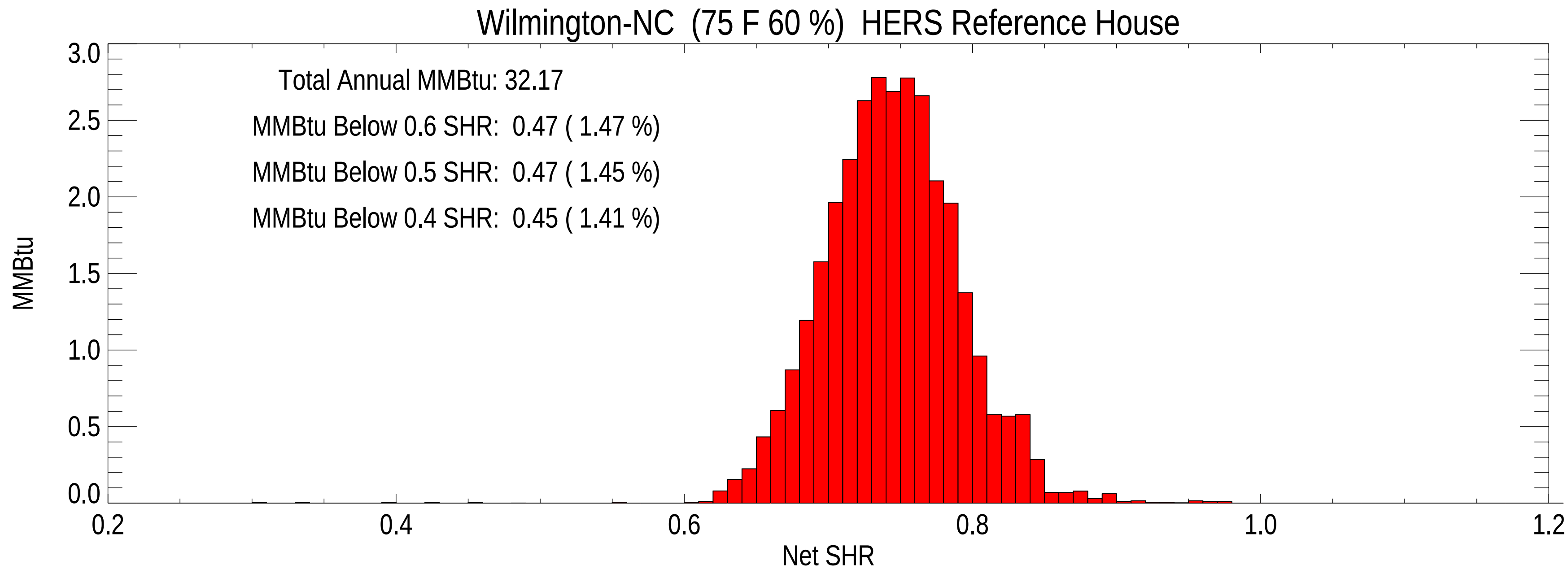

Sterling-VA (75 F 60 %) HighEff House
Total Annual MMBtu: 16.05
MMBtu Below 0.6 SHR: 0.00 (0.00 %)
MMBtu Below 0.5 SHR: 0.00 (0.00 %)
MMBtu Below 0.4 SHR: 0.00 (0.00 %)
MMBtu
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

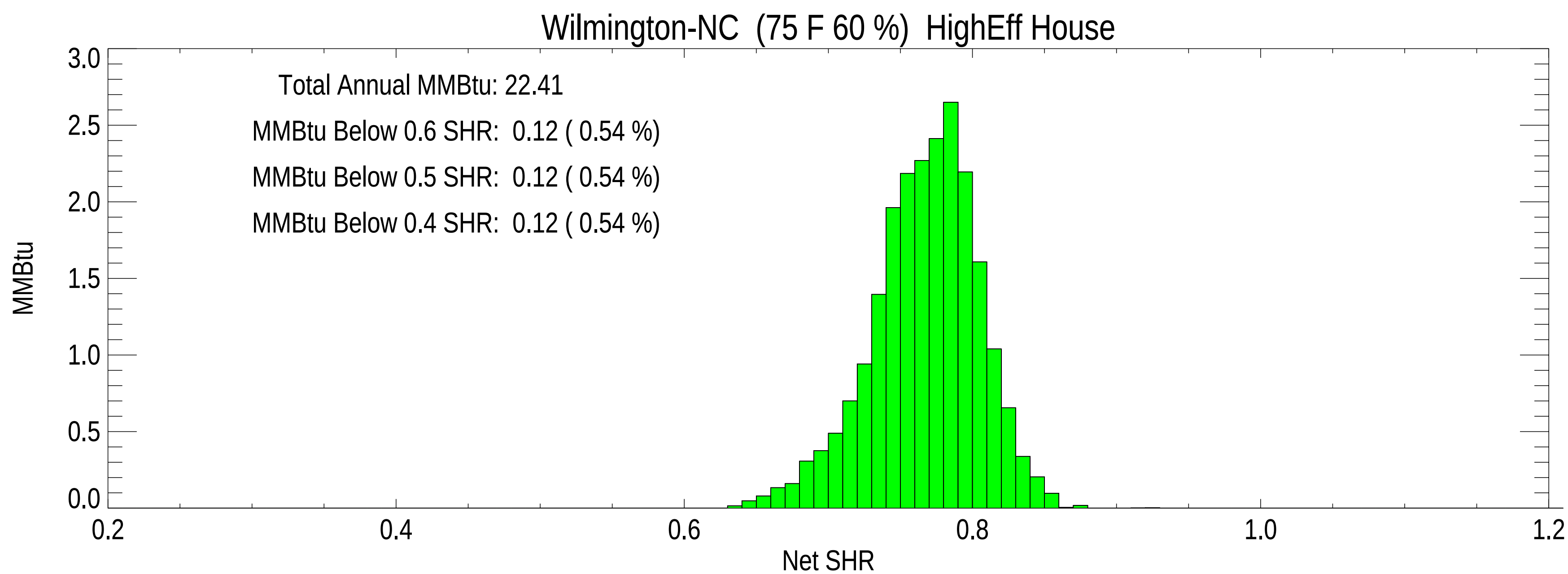

Houston-TX (75 F 60 %) HERS Reference House
Total Annual MMBtu: 46.75
MMBtu Below 0.6 SHR: 0.89 (1.90 %)
MMBtu Below 0.5 SHR: 0.85 (1.83 %)
MMBtu Below 0.4 SHR: 0.82 (1.76 %)
MMBtu
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

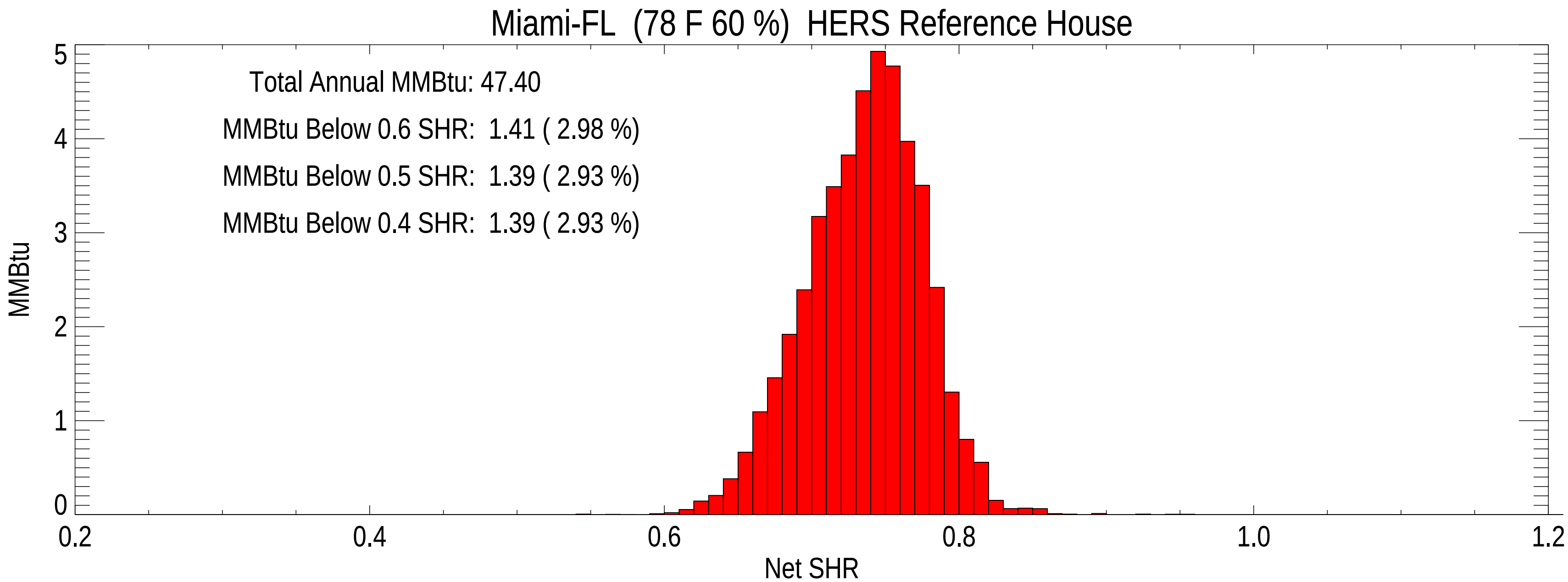

Houston-TX (75 F 60 %) HighEff House
Total Annual MMBtu: 28.07
MMBtu Below 0.6 SHR: 0.68 (2.41 %)
MMBtu Below 0.5 SHR: 0.65 (2.30 %)
MMBtu Below 0.4 SHR: 0.63 (2.23 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

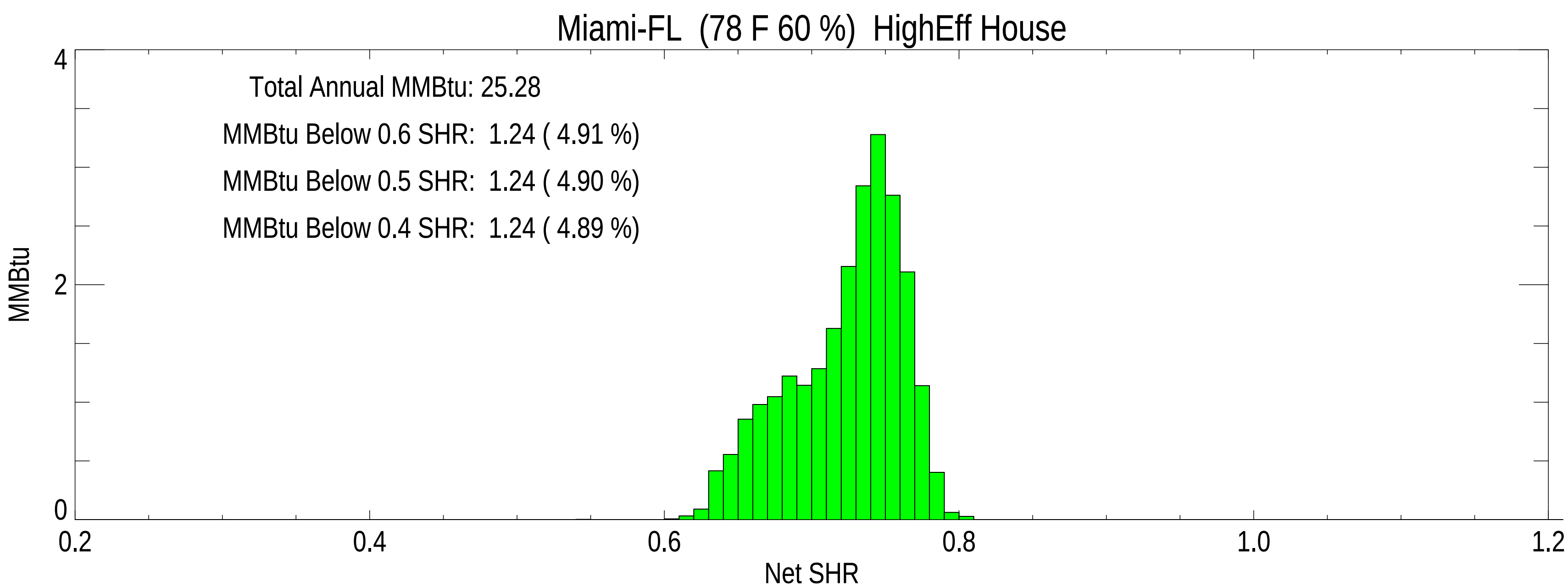

Fort_Worth-TX (75 F 60 %) HERS Reference House
Total Annual MMBtu: 42.79
MMBtu Below 0.6 SHR: 0.13 (0.31 %)
MMBtu Below 0.5 SHR: 0.12 (0.27 %)
MMBtu Below 0.4 SHR: 0.12 (0.27 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

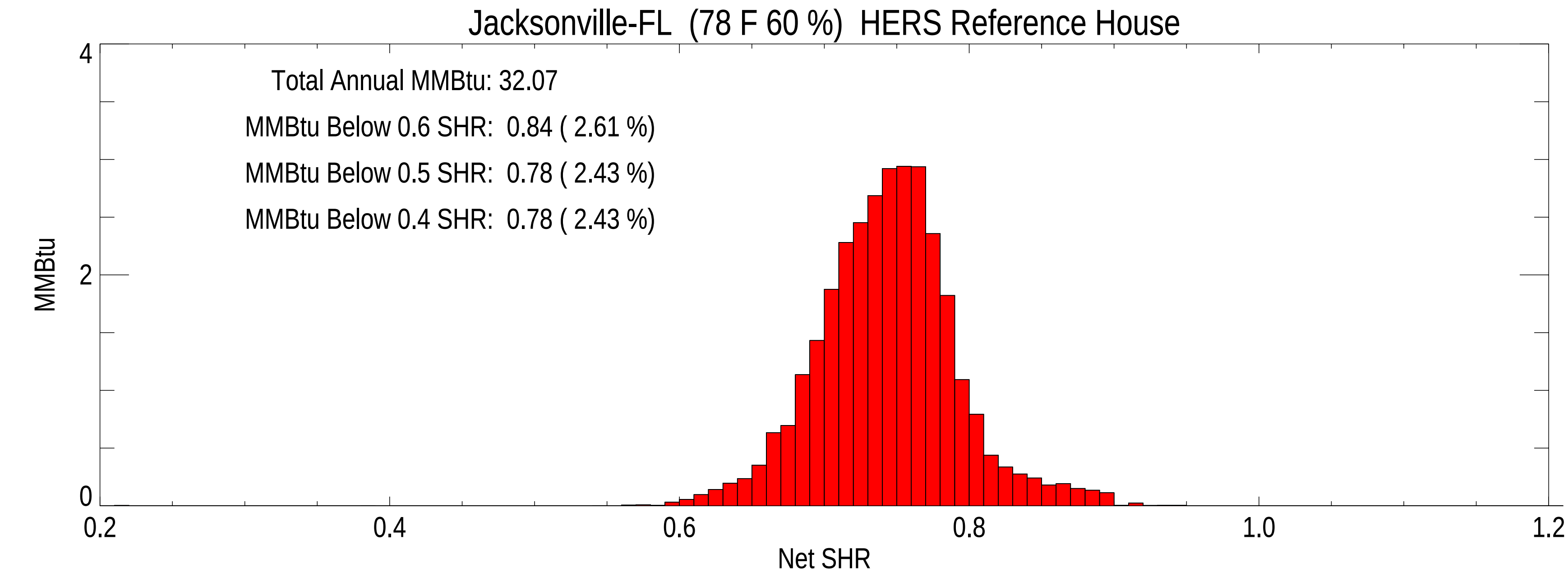

Fort_Worth-TX (75 F 60 %) HighEff House
Total Annual MMBtu: 29.42
MMBtu Below 0.6 SHR: 0.02 (0.06 %)
MMBtu Below 0.5 SHR: 0.02 (0.06 %)
MMBtu Below 0.4 SHR: 0.02 (0.06 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

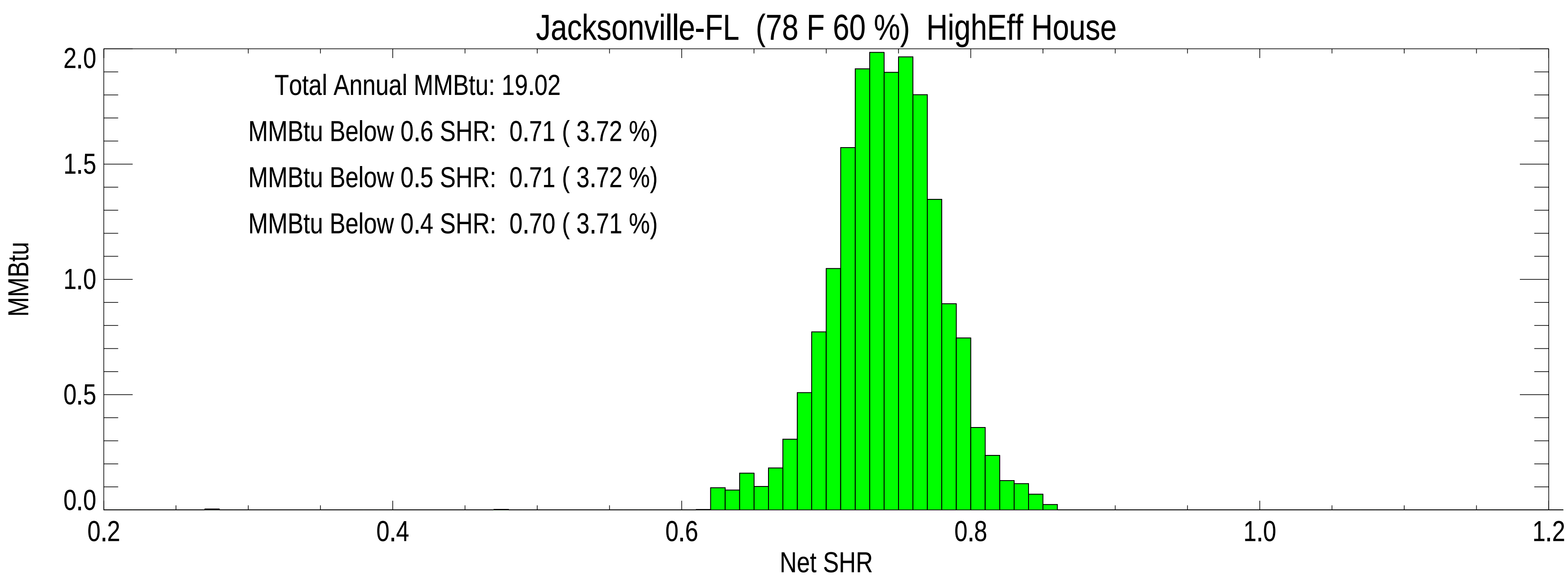

Wilmington-NC (75 F 60 %) HERS Reference House
Total Annual MMBtu: 32.17
MMBtu Below 0.6 SHR: 0.47 (1.47 %)
MMBtu Below 0.5 SHR: 0.47 (1.45 %)
MMBtu Below 0.4 SHR: 0.45 (1.41 %)
MMBtu
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

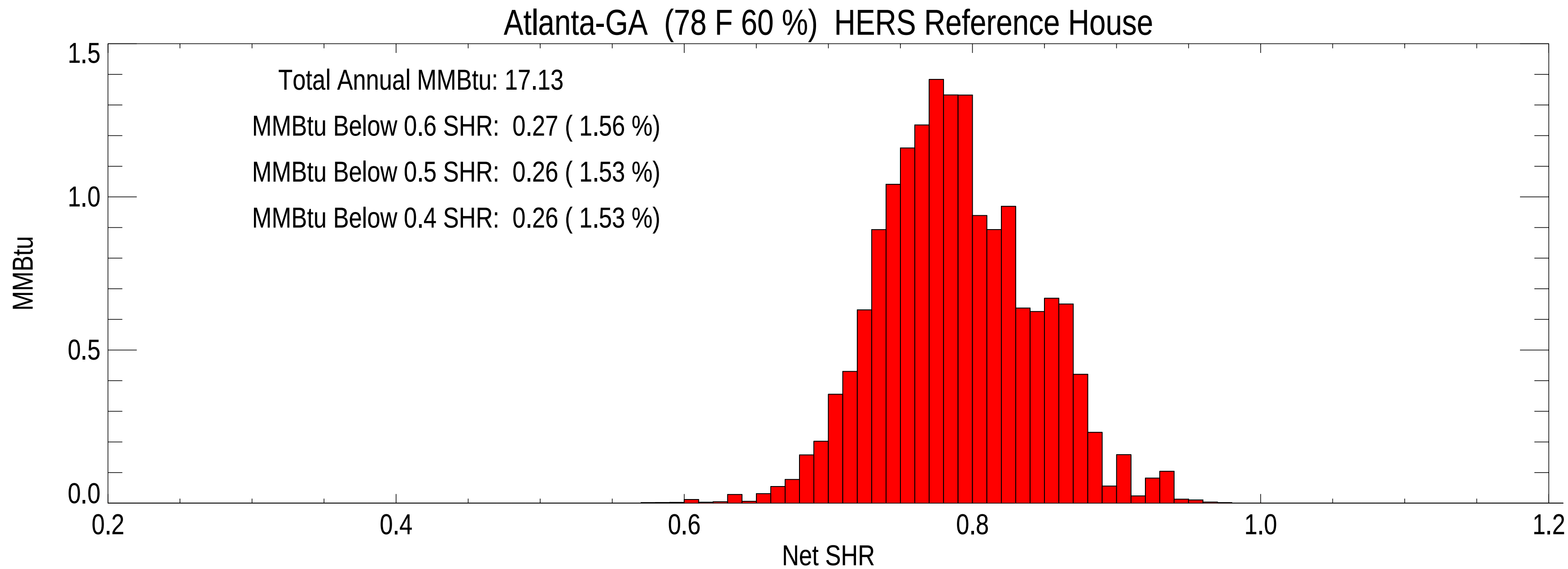

Wilmington-NC (75 F 60 %) HighEff House
Total Annual MMBtu: 22.41
MMBtu Below 0.6 SHR: 0.12 (0.54 %)
MMBtu Below 0.5 SHR: 0.12 (0.54 %)
MMBtu Below 0.4 SHR: 0.12 (0.54 %)
MMBtu
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

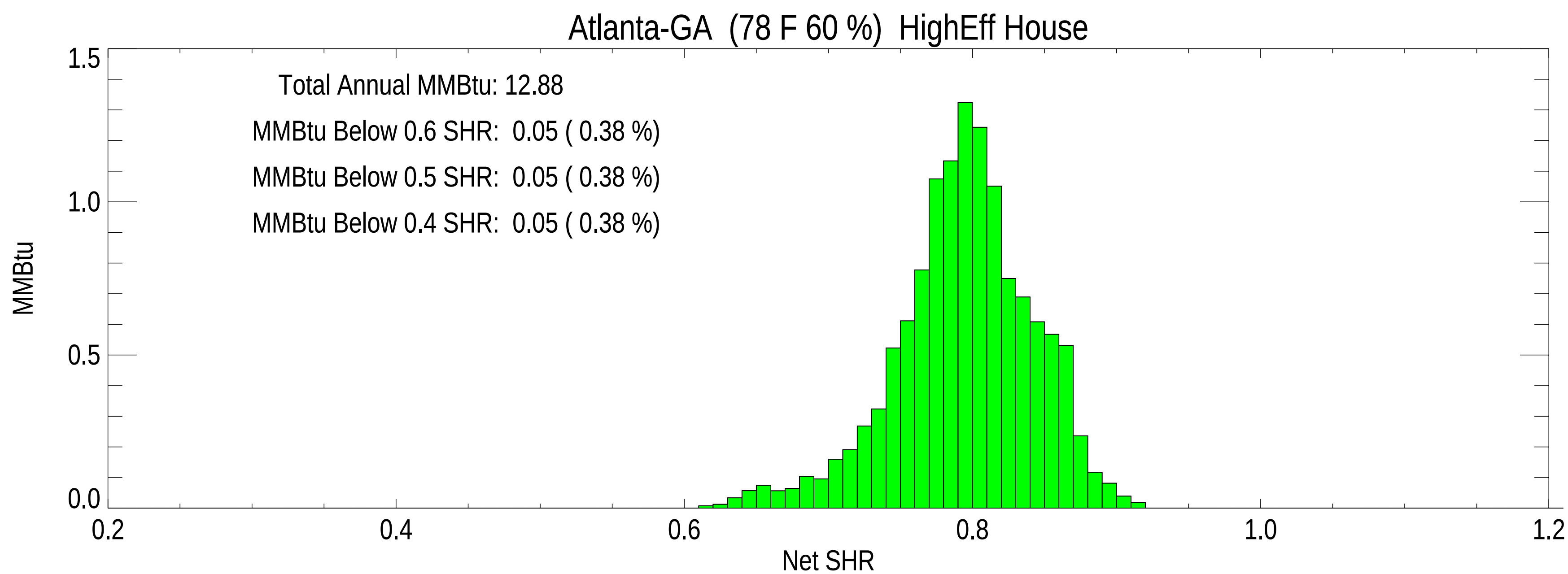

Miami-FL (78 F 60 %) HERS Reference House
Total Annual MMBtu: 47.40
MMBtu Below 0.6 SHR: 1.41 (2.98 %)
MMBtu Below 0.5 SHR: 1.39 (2.93 %)
MMBtu Below 0.4 SHR: 1.39 (2.93 %)
MMBtu
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

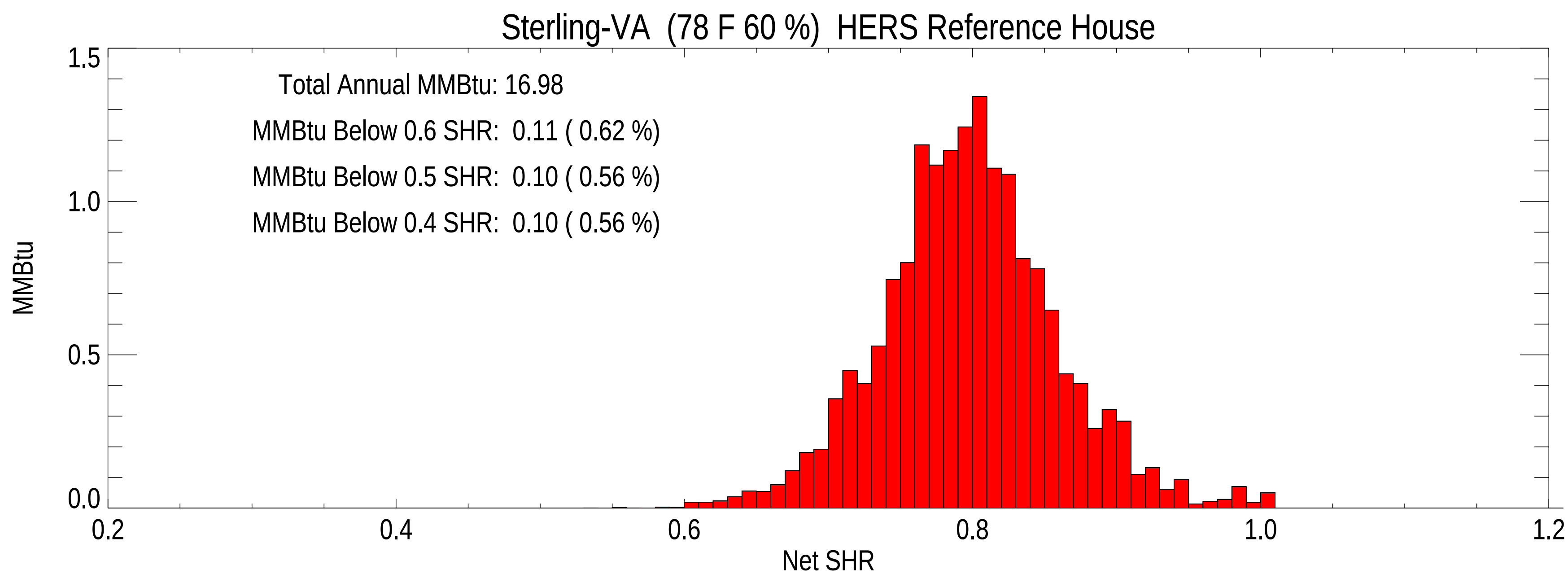

Miami-FL (78 F 60 %) HighEff House
Total Annual MMBtu: 25.28
MMBtu Below 0.6 SHR: 1.24 (4.91 %)
MMBtu Below 0.5 SHR: 1.24 (4.90 %)
MMBtu Below 0.4 SHR: 1.24 (4.89 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

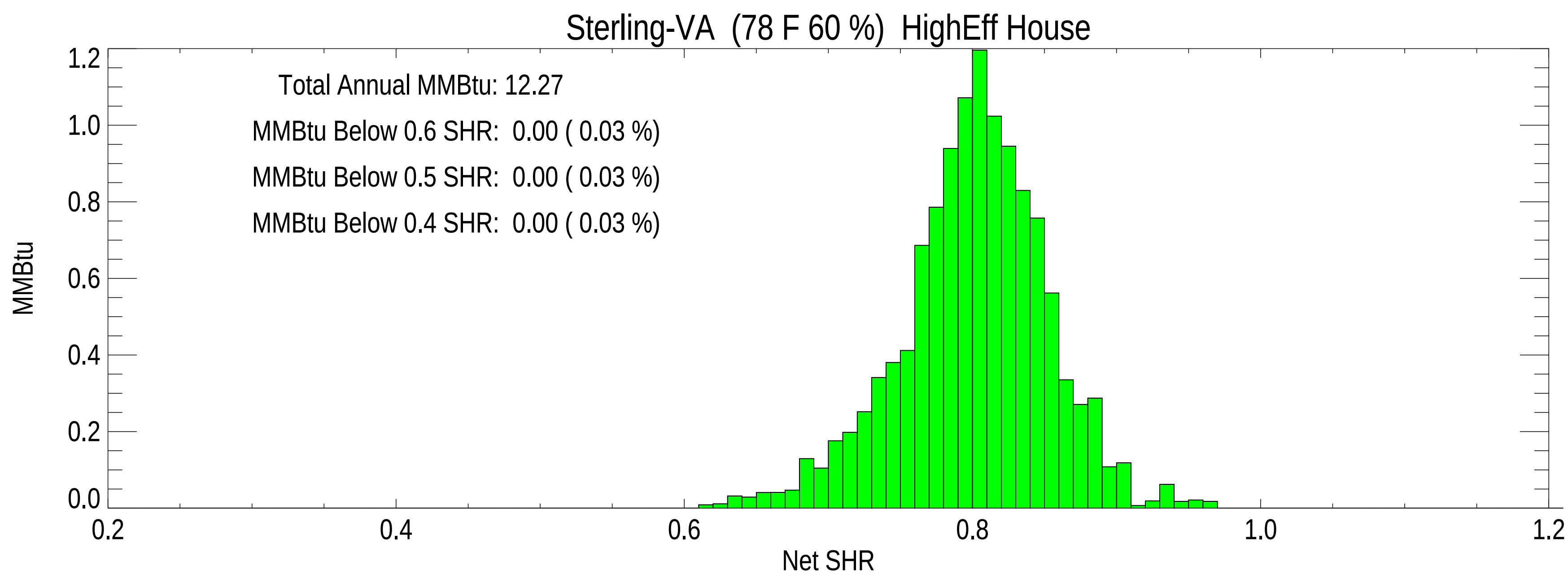

Jacksonville-FL (78 F 60 %) HERS Reference House
Total Annual MMBtu: 32.07
MMBtu Below 0.6 SHR: 0.84 (2.61 %)
MMBtu Below 0.5 SHR: 0.78 (2.43 %)
MMBtu Below 0.4 SHR: 0.78 (2.43 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

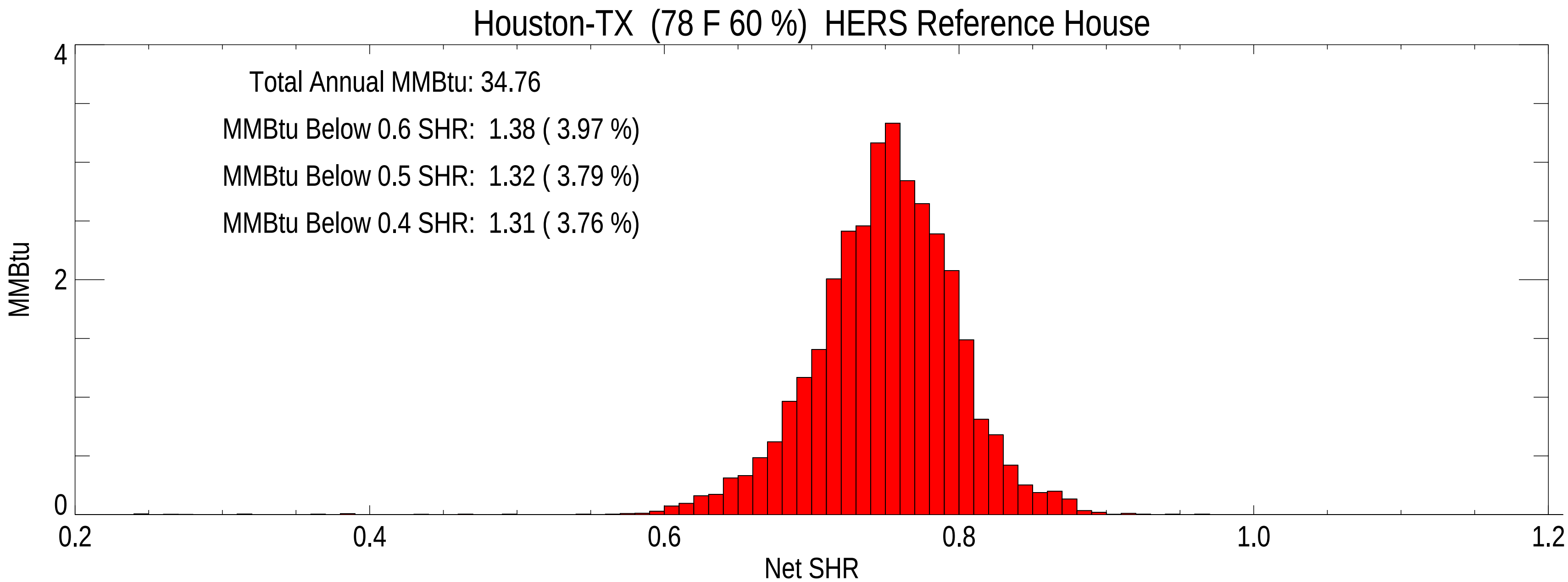

Jacksonville-FL (78 F 60 %) HighEff House
Total Annual MMBtu: 19.02
MMBtu Below 0.6 SHR: 0.71 (3.72 %)
MMBtu Below 0.5 SHR: 0.71 (3.72 %)
MMBtu Below 0.4 SHR: 0.70 (3.71 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

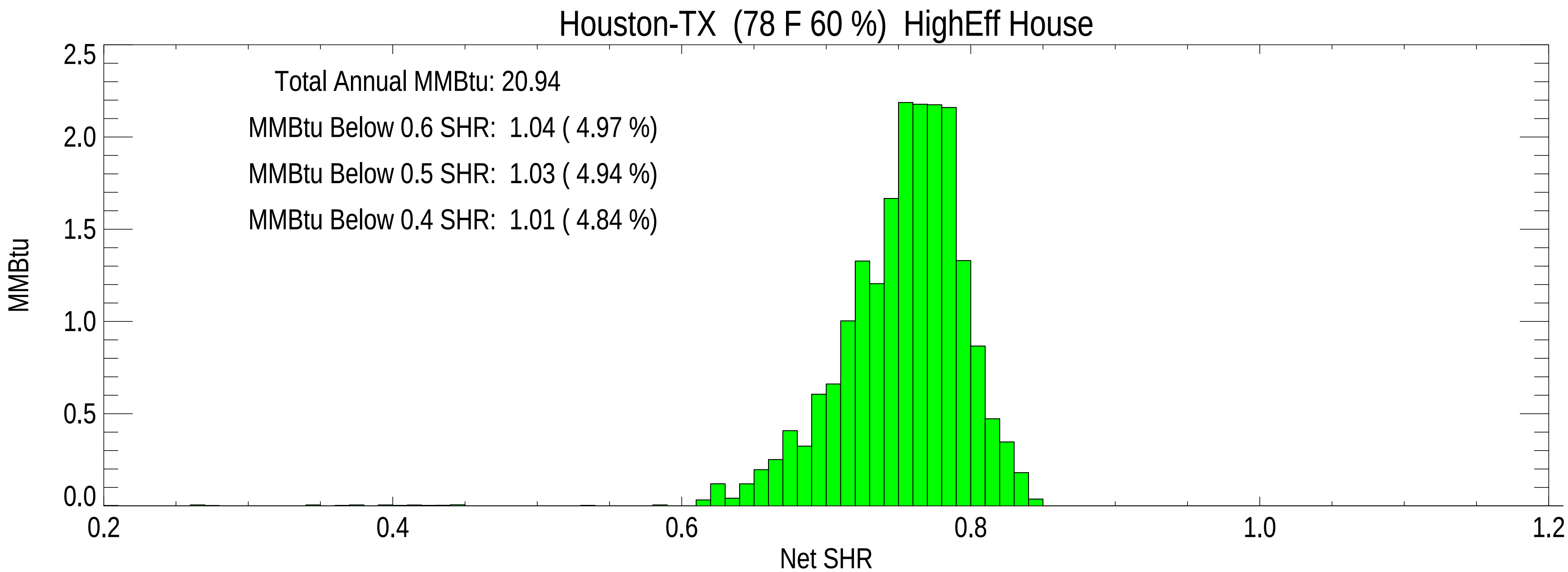

Atlanta-GA (78 F 60 %) HERS Reference House
Total Annual MMBtu: 17.13
MMBtu Below 0.6 SHR: 0.27 (1.56 %)
MMBtu Below 0.5 SHR: 0.26 (1.53 %)
MMBtu Below 0.4 SHR: 0.26 (1.53 %)
MMBtu
Net SHR
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2

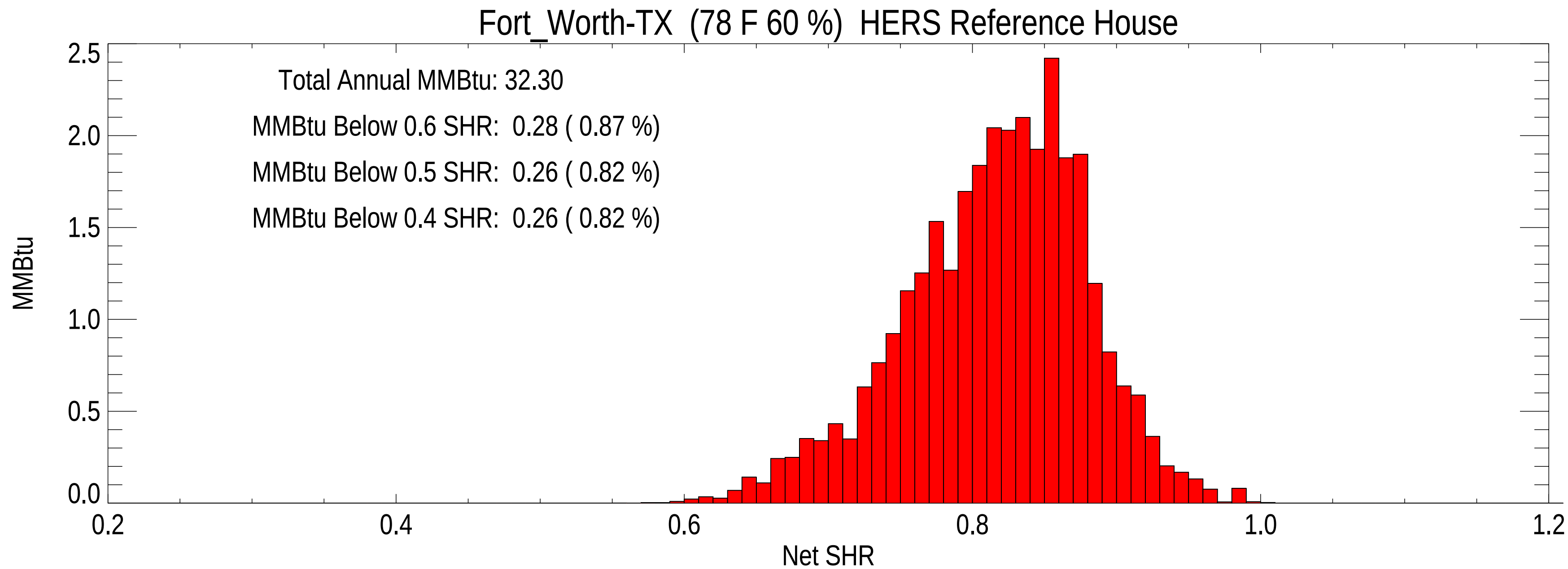

Atlanta-GA (78 F 60 %) HighEff House
Total Annual MMBtu: 12.88
MMBtu Below 0.6 SHR: 0.05 (0.38 %)
MMBtu Below 0.5 SHR: 0.05 (0.38 %)
MMBtu Below 0.4 SHR: 0.05 (0.38 %)
MMBtu
Net SHR
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2

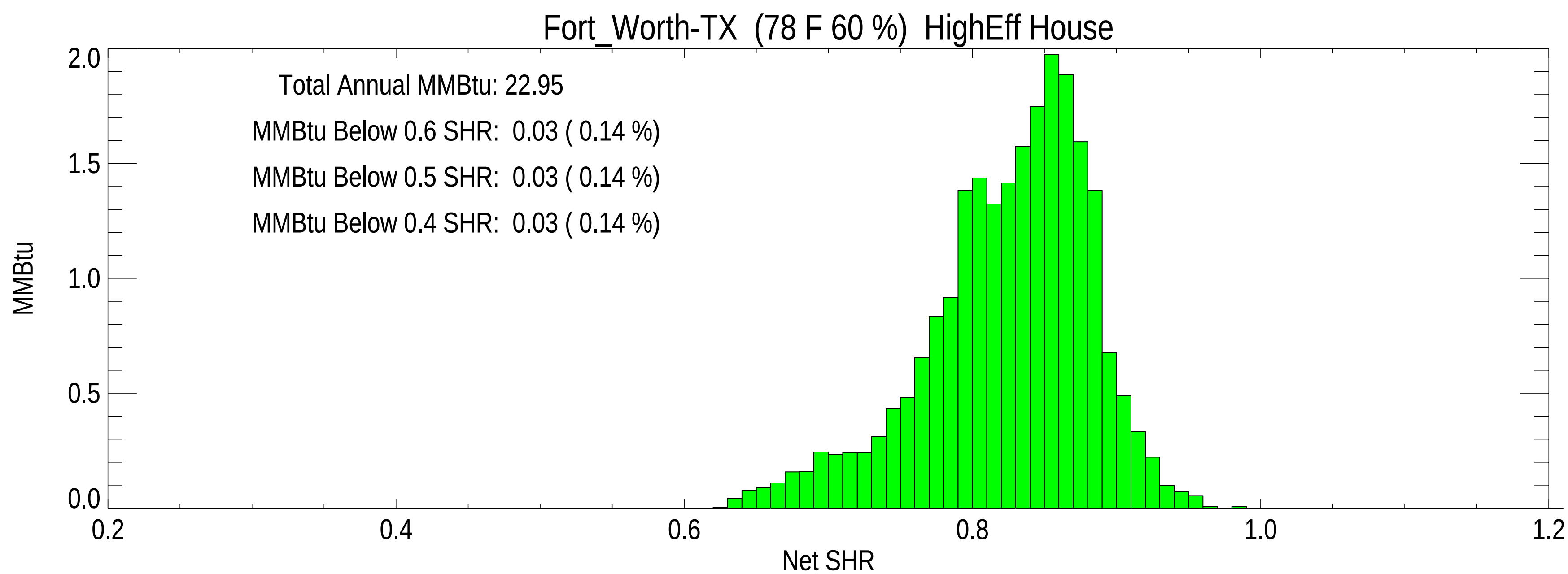

Sterling-VA (78 F 60 %) HERS Reference House
Total Annual MMBtu: 16.98
MMBtu Below 0.6 SHR: 0.11 (0.62 %)
MMBtu Below 0.5 SHR: 0.10 (0.56 %)
MMBtu Below 0.4 SHR: 0.10 (0.56 %)
MMBtu
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

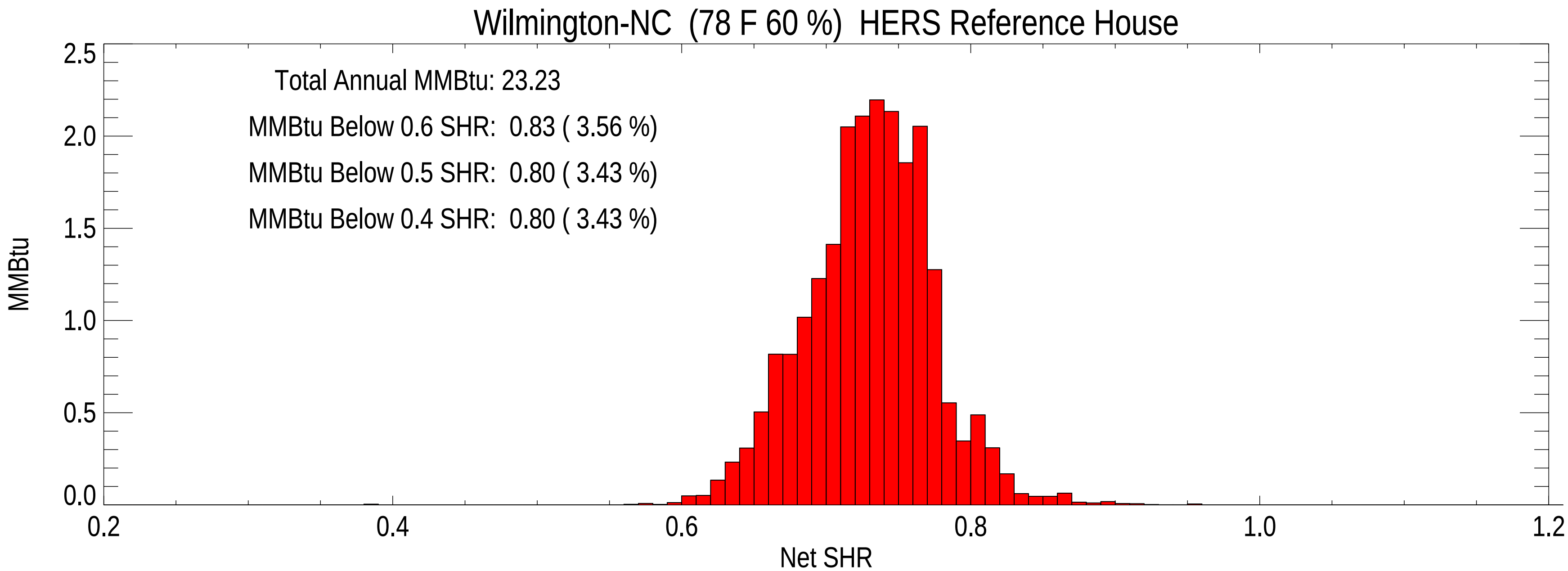

Sterling-VA (78 F 60 %) HighEff House
Total Annual MMBtu: 12.27
MMBtu Below 0.6 SHR: 0.00 (0.03 %)
MMBtu Below 0.5 SHR: 0.00 (0.03 %)
MMBtu Below 0.4 SHR: 0.00 (0.03 %)
MMBtu
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

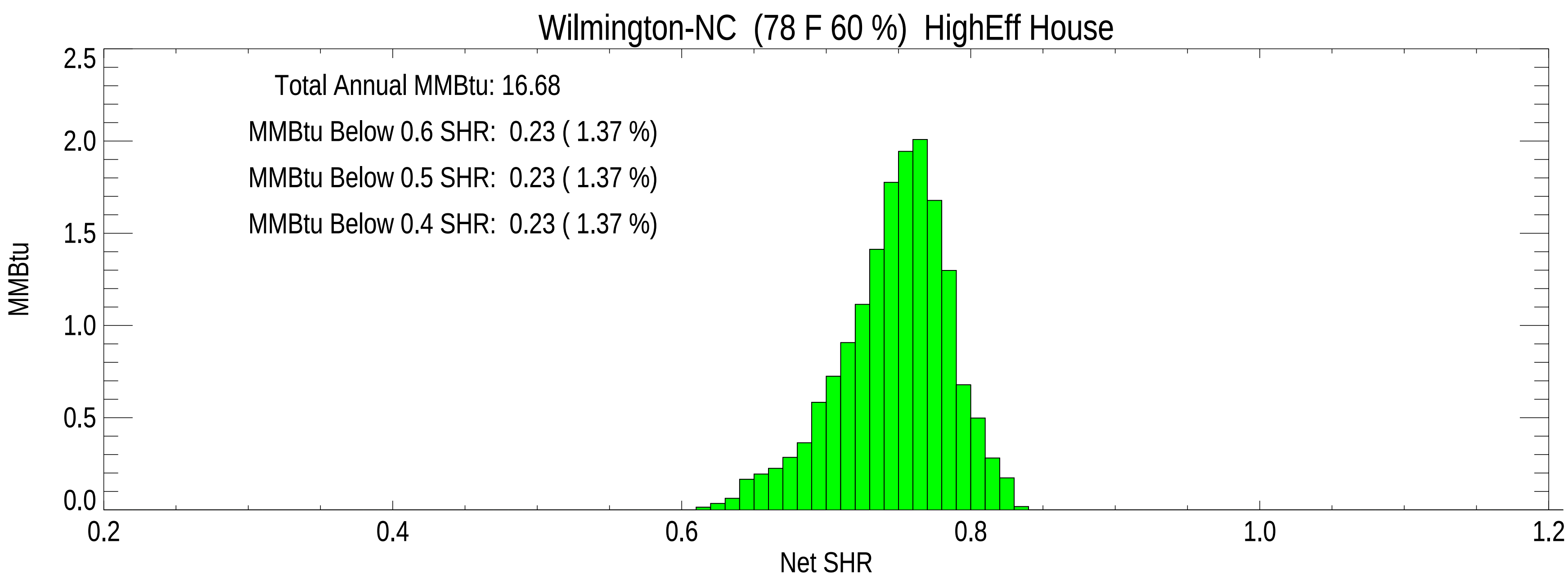

Houston-TX (78 F 60 %) HERS Reference House
Total Annual MMBtu: 34.76
MMBtu Below 0.6 SHR: 1.38 (3.97 %)
MMBtu Below 0.5 SHR: 1.32 (3.79 %)
MMBtu Below 0.4 SHR: 1.31 (3.76 %)
MMBtu
Net SHR
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2

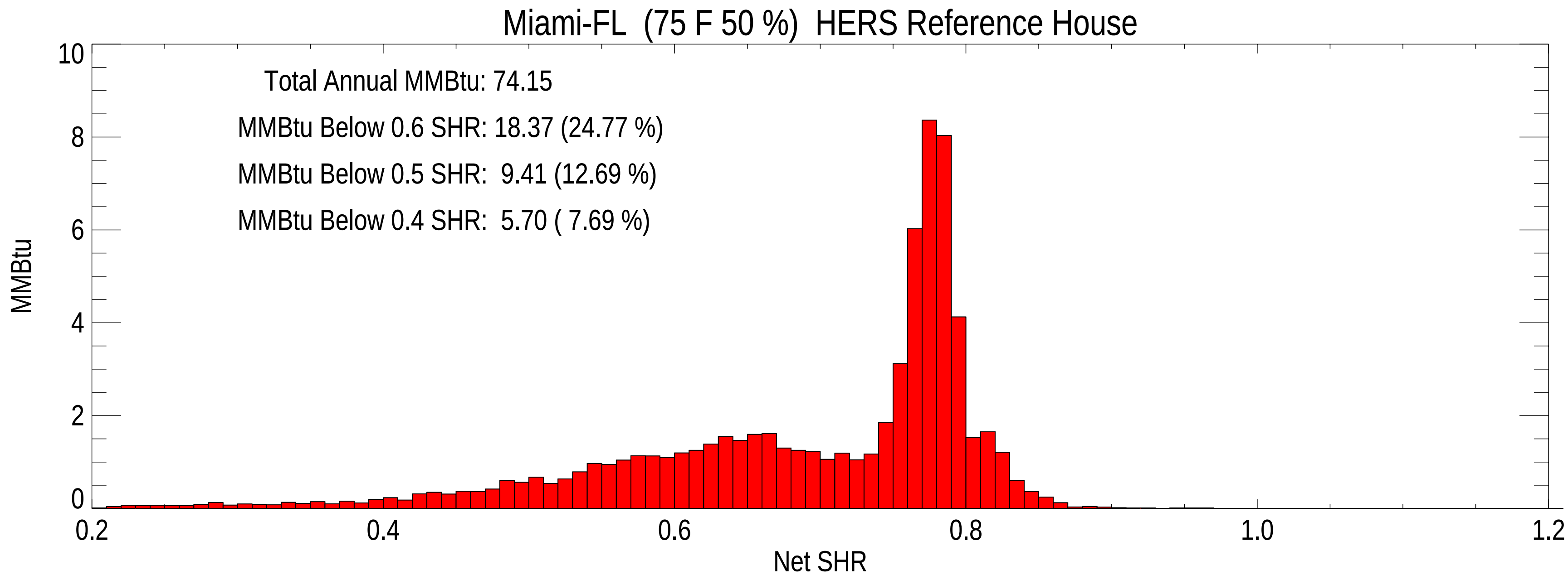

Houston-TX (78 F 60 %) HighEff House
Total Annual MMBtu: 20.94
MMBtu Below 0.6 SHR: 1.04 (4.97 %)
MMBtu Below 0.5 SHR: 1.03 (4.94 %)
MMBtu Below 0.4 SHR: 1.01 (4.84 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2

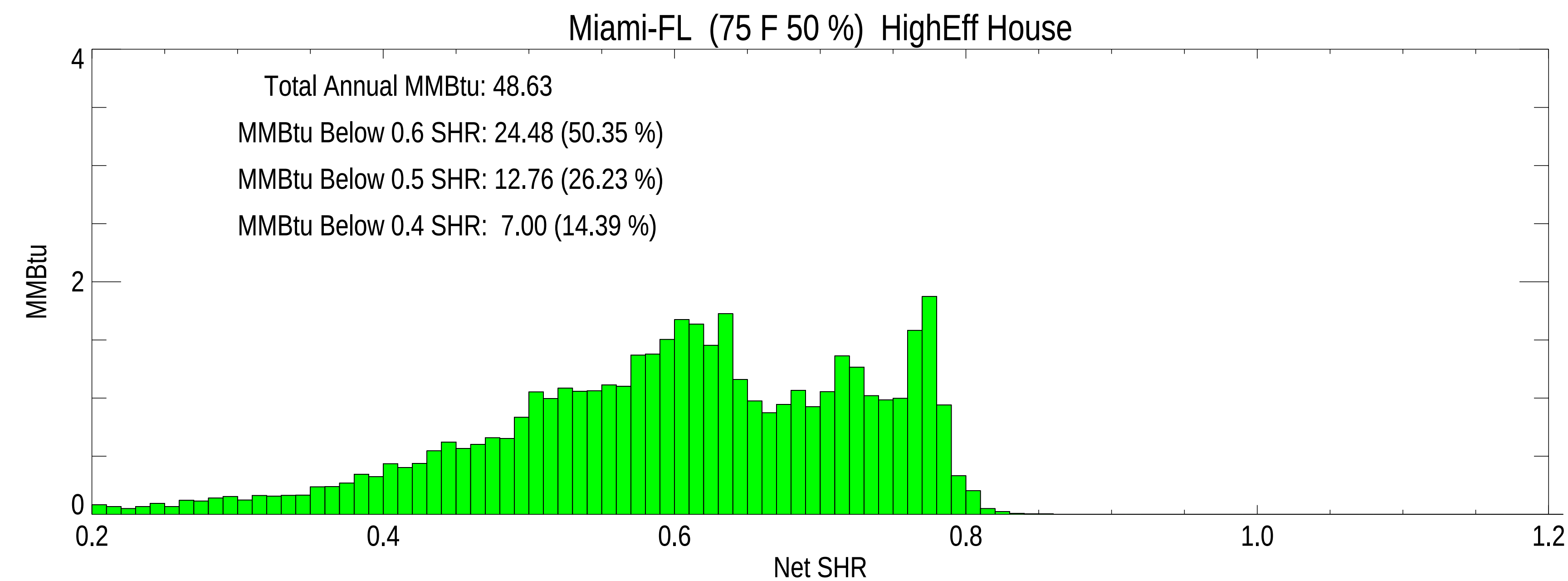

Fort_Worth-TX (78 F 60 %) HERS Reference House
Total Annual MMBtu: 32.30
MMBtu Below 0.6 SHR: 0.28 (0.87 %)
MMBtu Below 0.5 SHR: 0.26 (0.82 %)
MMBtu Below 0.4 SHR: 0.26 (0.82 %)
MMBtu
2.5
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

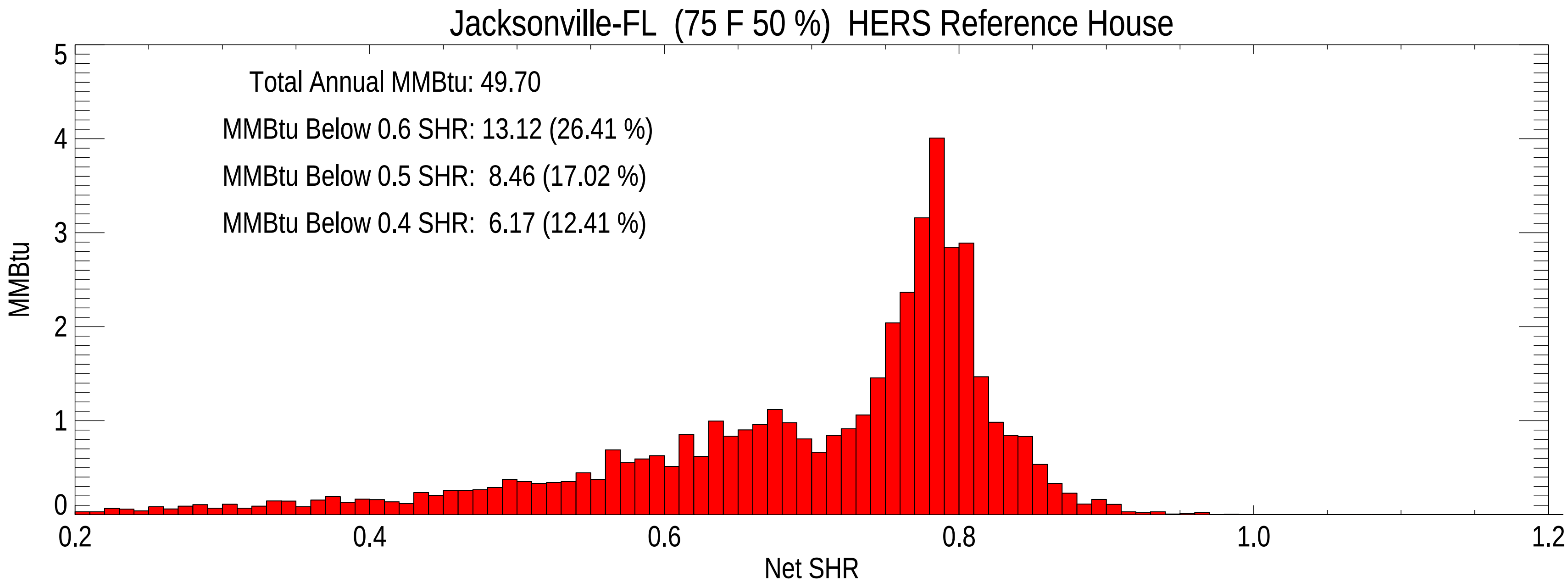

Fort_Worth-TX (78 F 60 %) HighEff House
Total Annual MMBtu: 22.95
MMBtu Below 0.6 SHR: 0.03 (0.14 %)
MMBtu Below 0.5 SHR: 0.03 (0.14 %)
MMBtu Below 0.4 SHR: 0.03 (0.14 %)
MMBtu
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

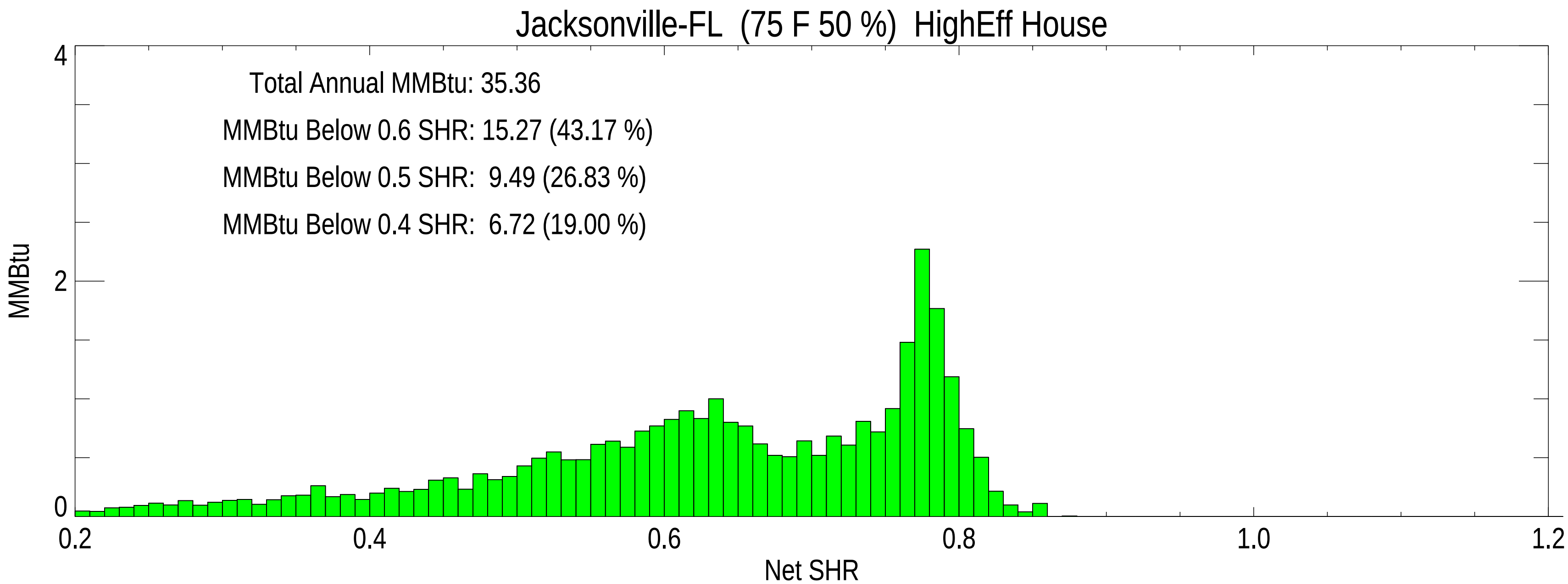

Wilmington-NC (78 F 60 %) HERS Reference House
Total Annual MMBtu: 23.23
MMBtu Below 0.6 SHR: 0.83 (3.56 %)
MMBtu Below 0.5 SHR: 0.80 (3.43 %)
MMBtu Below 0.4 SHR: 0.80 (3.43 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

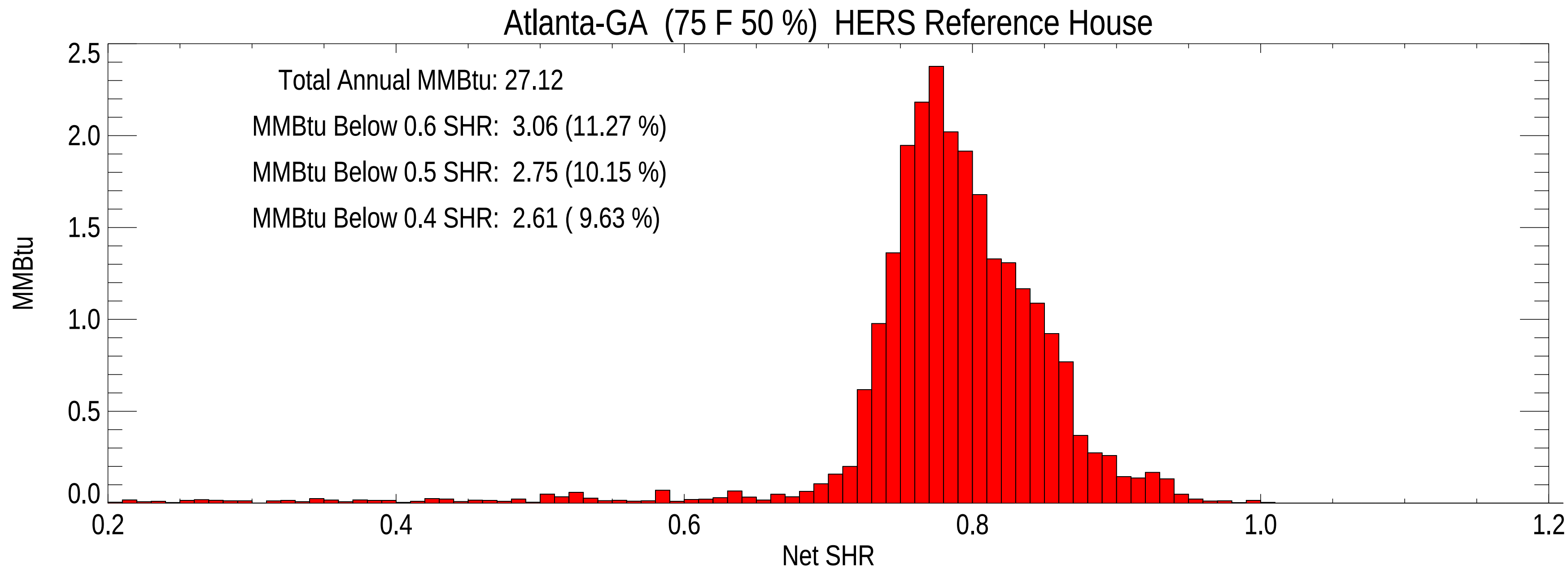

Wilmington-NC (78 F 60 %) HighEff House
Total Annual MMBtu: 16.68
MMBtu Below 0.6 SHR: 0.23 (1.37 %)
MMBtu Below 0.5 SHR: 0.23 (1.37 %)
MMBtu Below 0.4 SHR: 0.23 (1.37 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

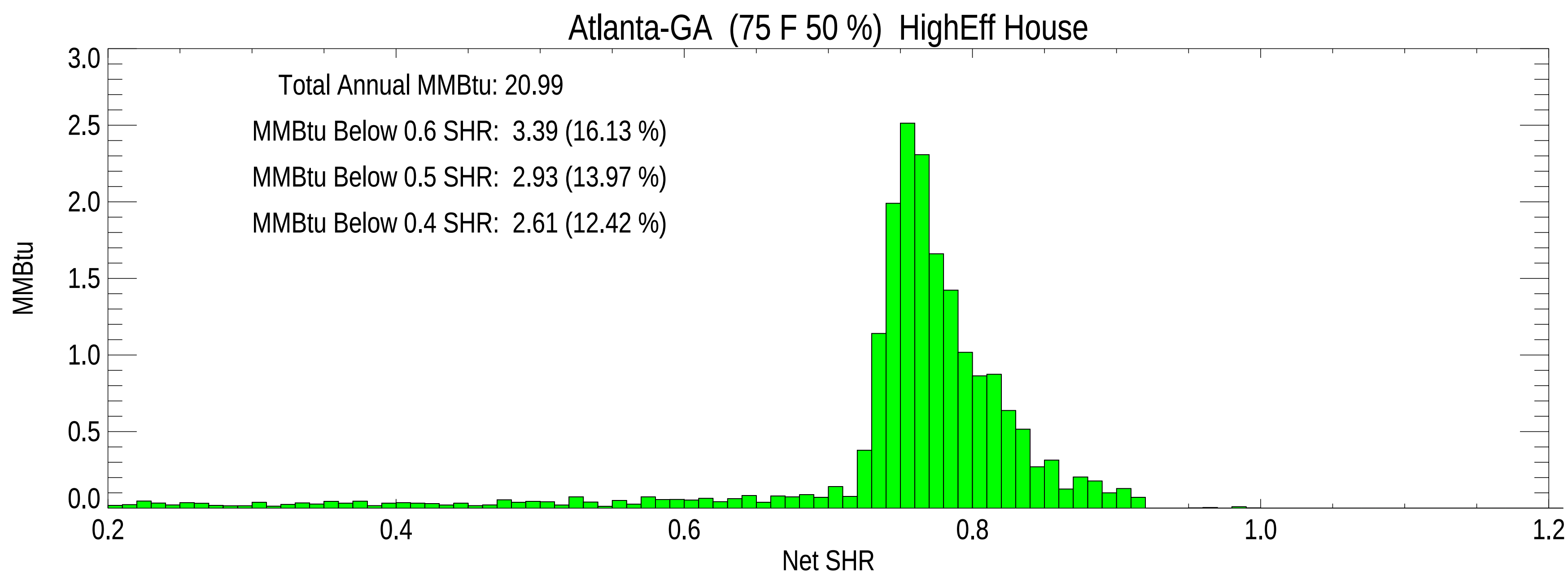

Miami-FL (75 F 50 %) HERS Reference House
Total Annual MMBtu: 74.15
MMBtu Below 0.6 SHR: 18.37 (24.77 %)
MMBtu Below 0.5 SHR: 9.41 (12.69 %)
MMBtu Below 0.4 SHR: 5.70 (7.69 %)
MMBtu
0
2
4
6
8
10
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

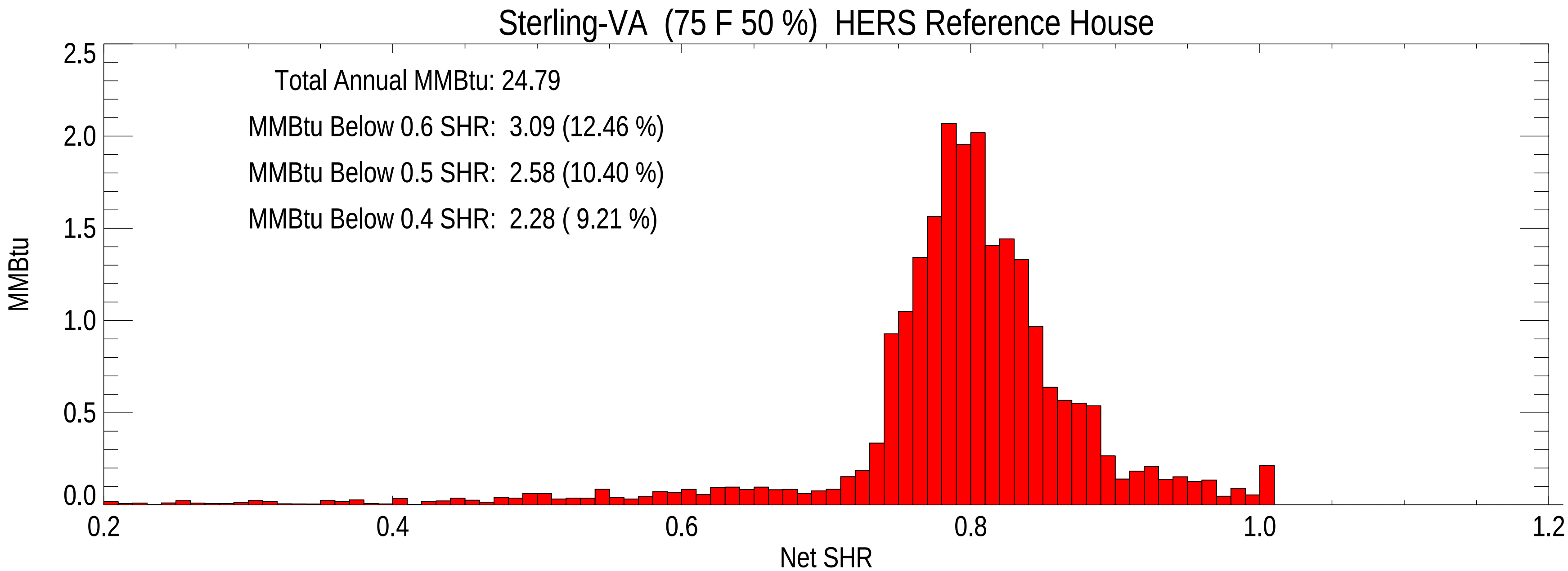

Miami-FL (75 F 50 %) HighEff House
Total Annual MMBtu: 48.63
MMBtu Below 0.6 SHR: 24.48 (50.35 %)
MMBtu Below 0.5 SHR: 12.76 (26.23 %)
MMBtu Below 0.4 SHR: 7.00 (14.39 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

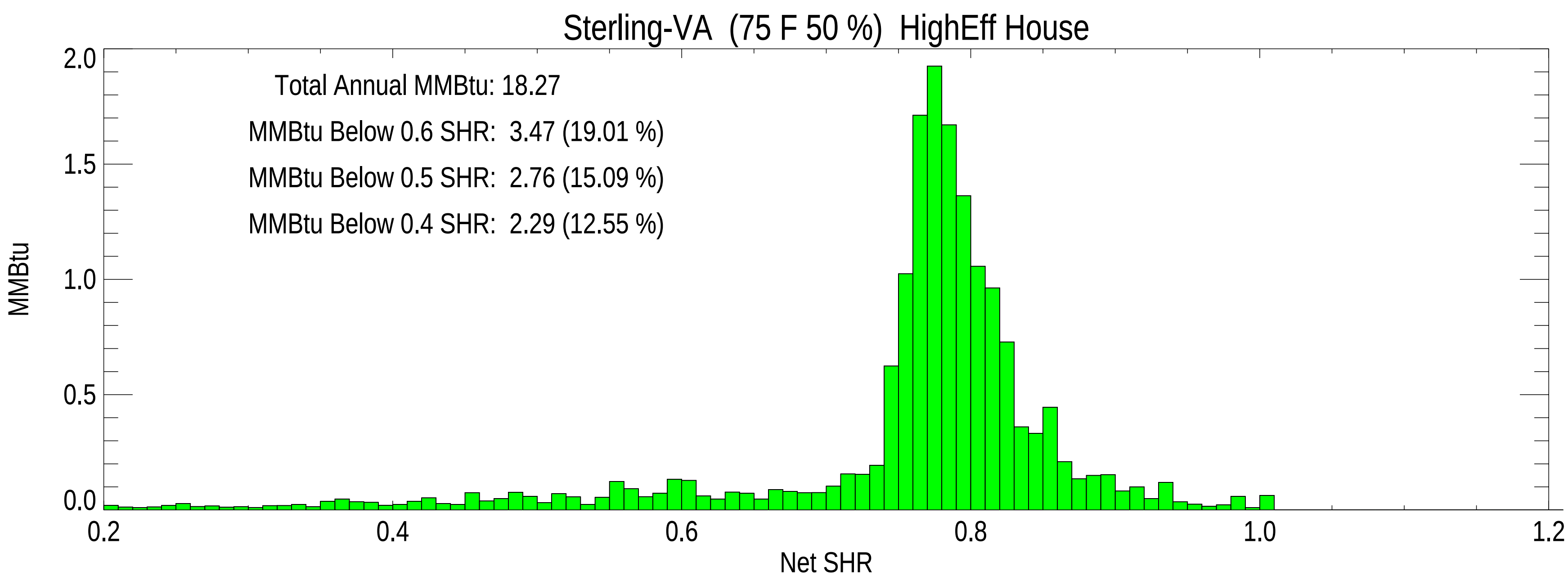

Jacksonville-FL (75 F 50 %) HERS Reference House
Total Annual MMBtu: 49.70
MMBtu Below 0.6 SHR: 13.12 (26.41 %)
MMBtu Below 0.5 SHR: 8.46 (17.02 %)
MMBtu Below 0.4 SHR: 6.17 (12.41 %)
MMBtu
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

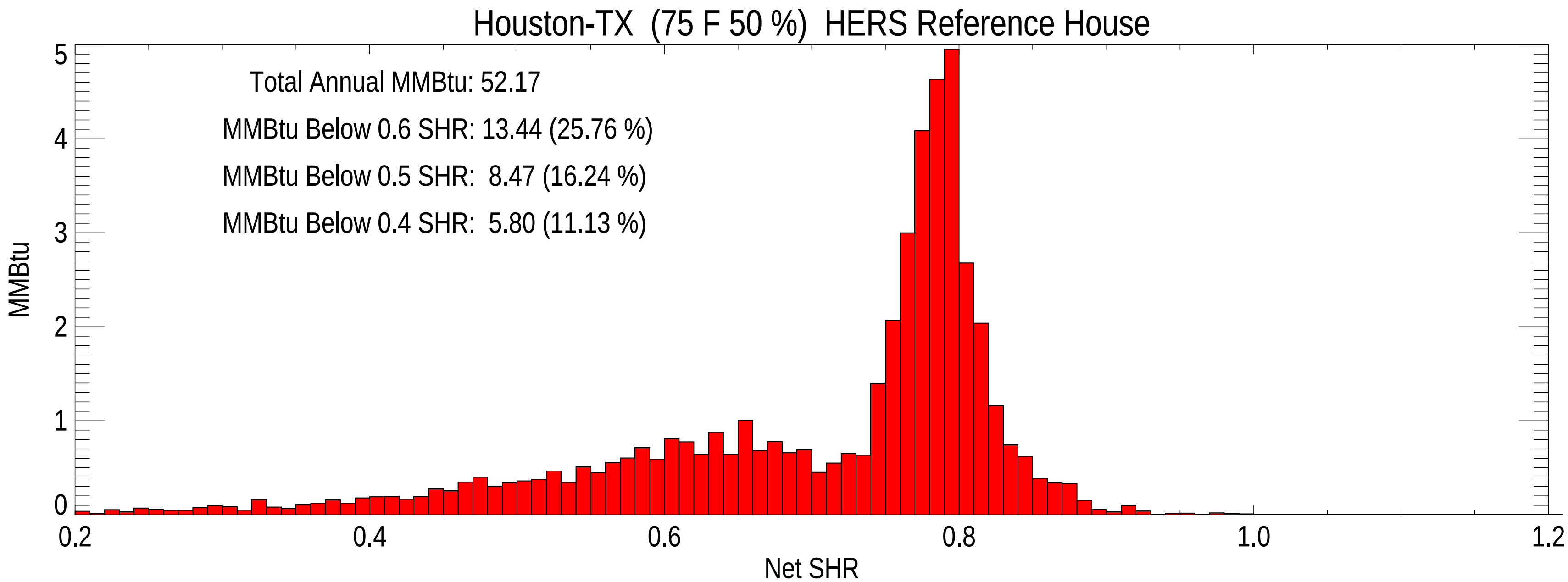

Jacksonville-FL (75 F 50 %) HighEff House
Total Annual MMBtu: 35.36
MMBtu Below 0.6 SHR: 15.27 (43.17 %)
MMBtu Below 0.5 SHR: 9.49 (26.83 %)
MMBtu Below 0.4 SHR: 6.72 (19.00 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

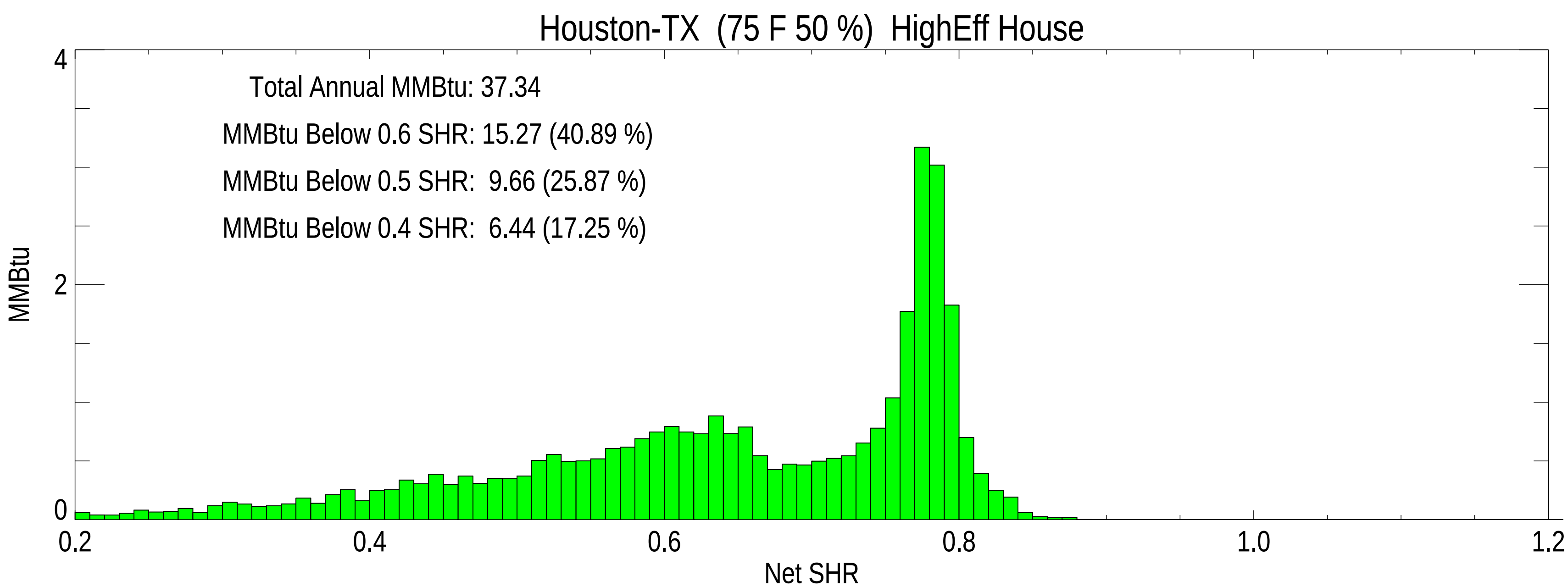

Atlanta-GA (75 F 50 %) HERS Reference House
Total Annual MMBtu: 27.12
MMBtu Below 0.6 SHR: 3.06 (11.27 %)
MMBtu Below 0.5 SHR: 2.75 (10.15 %)
MMBtu Below 0.4 SHR: 2.61 (9.63 %)
MMBtu
2.5
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

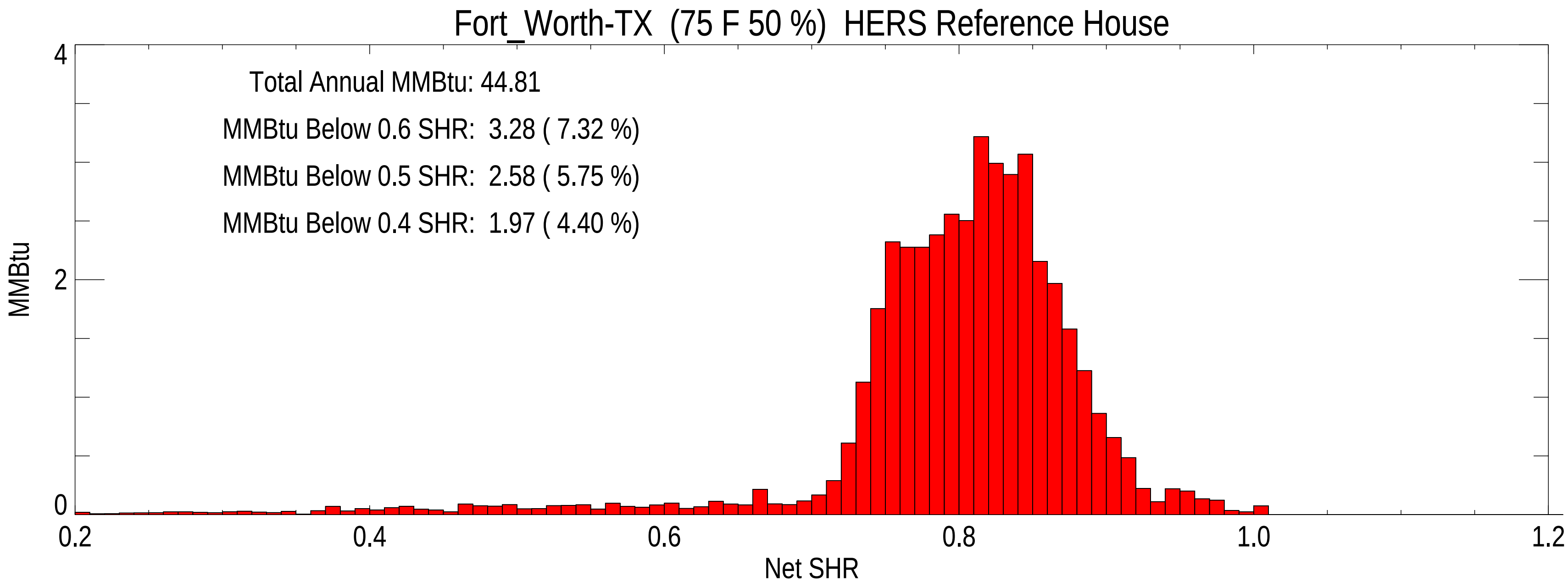

Atlanta-GA (75 F 50 %) HighEff House
Total Annual MMBtu: 20.99
MMBtu Below 0.6 SHR: 3.39 (16.13 %)
MMBtu Below 0.5 SHR: 2.93 (13.97 %)
MMBtu Below 0.4 SHR: 2.61 (12.42 %)
MMBtu
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

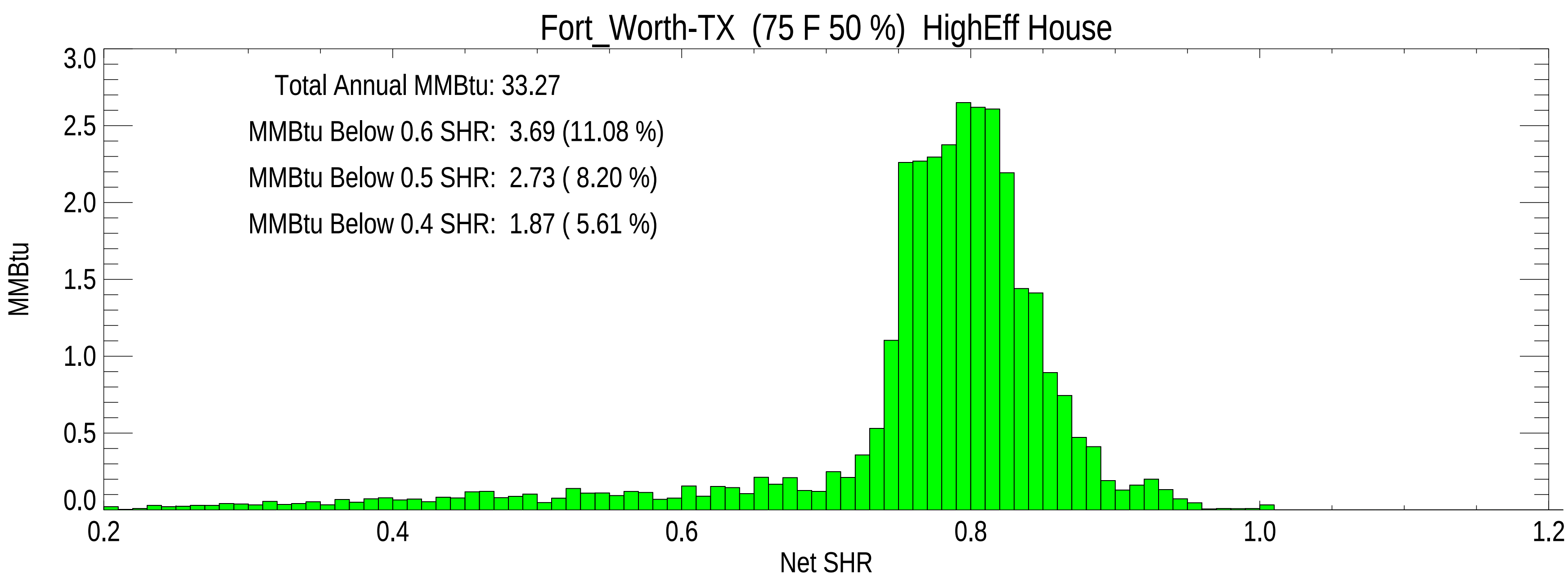

Sterling-VA (75 F 50 %) HERS Reference House
Total Annual MMBtu: 24.79
MMBtu Below 0.6 SHR: 3.09 (12.46 %)
MMBtu Below 0.5 SHR: 2.58 (10.40 %)
MMBtu Below 0.4 SHR: 2.28 (9.21 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2

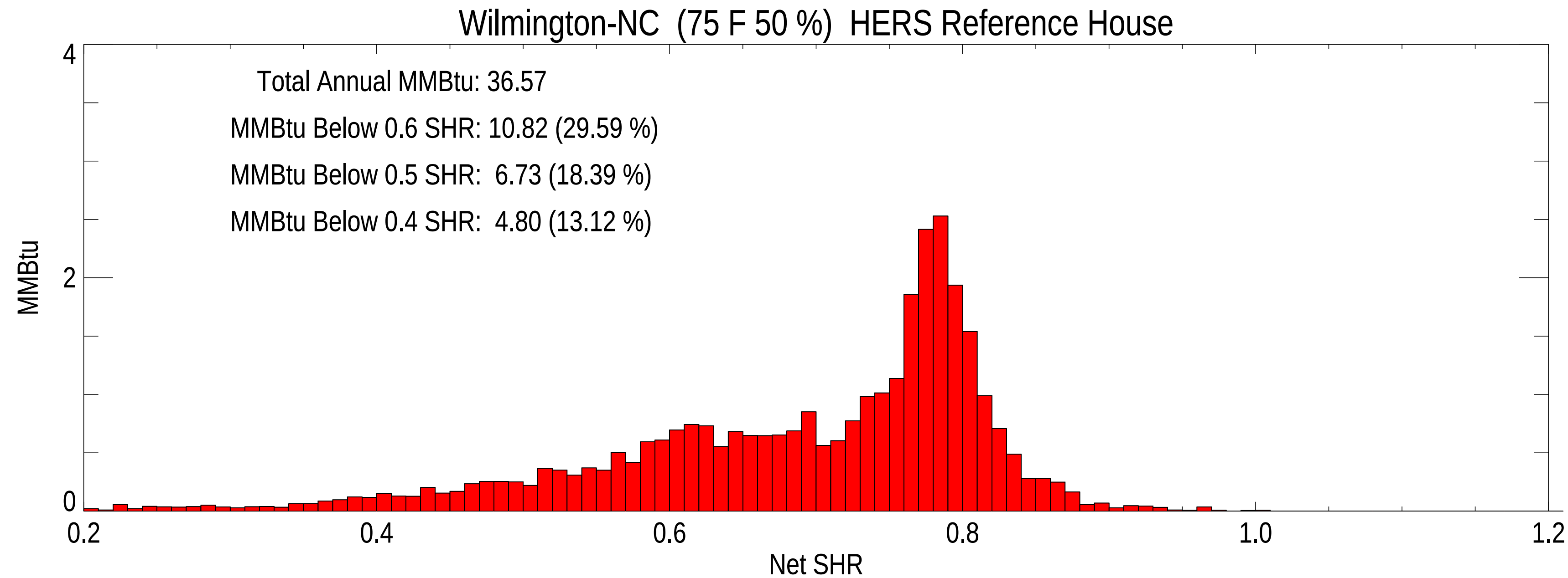

Sterling-VA (75 F 50 %) HighEff House
Total Annual MMBtu: 18.27
MMBtu Below 0.6 SHR: 3.47 (19.01 %)
MMBtu Below 0.5 SHR: 2.76 (15.09 %)
MMBtu Below 0.4 SHR: 2.29 (12.55 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
0.2
0.4
0.6
0.8
1.0
1.2

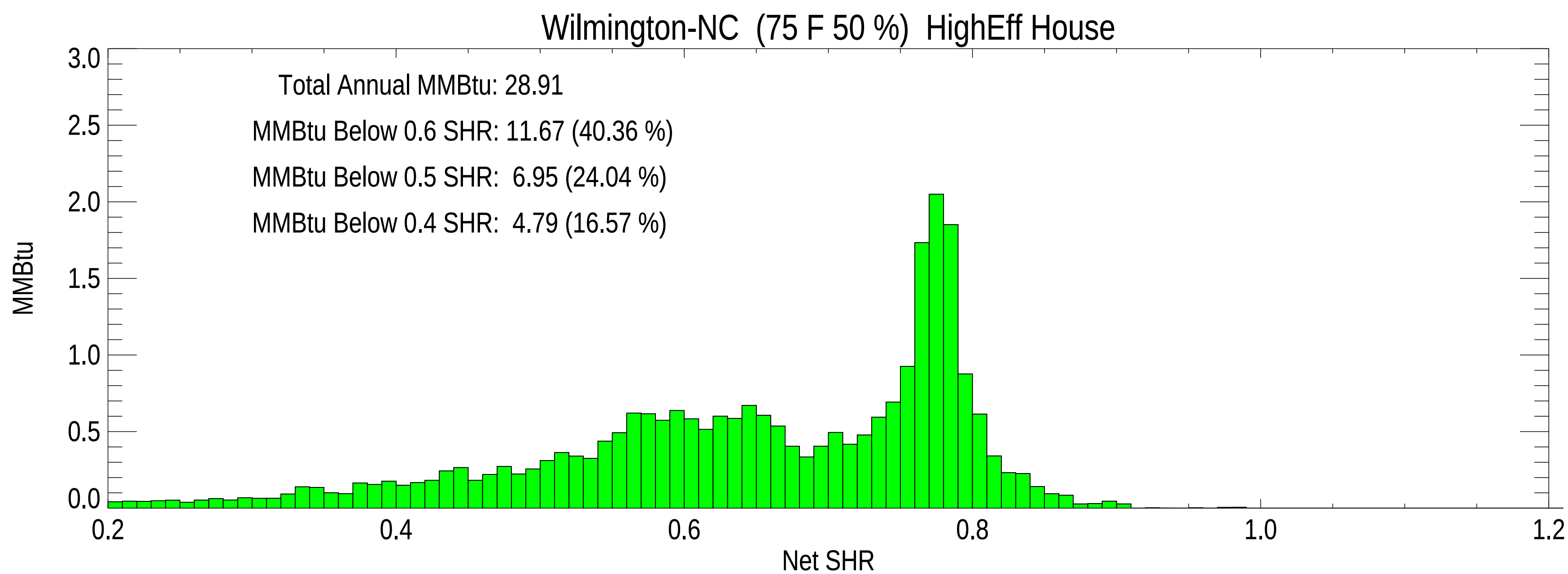

Houston-TX (75 F 50 %) HERS Reference House
Total Annual MMBtu: 52.17
MMBtu Below 0.6 SHR: 13.44 (25.76 %)
MMBtu Below 0.5 SHR: 8.47 (16.24 %)
MMBtu Below 0.4 SHR: 5.80 (11.13 %)
MMBtu
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

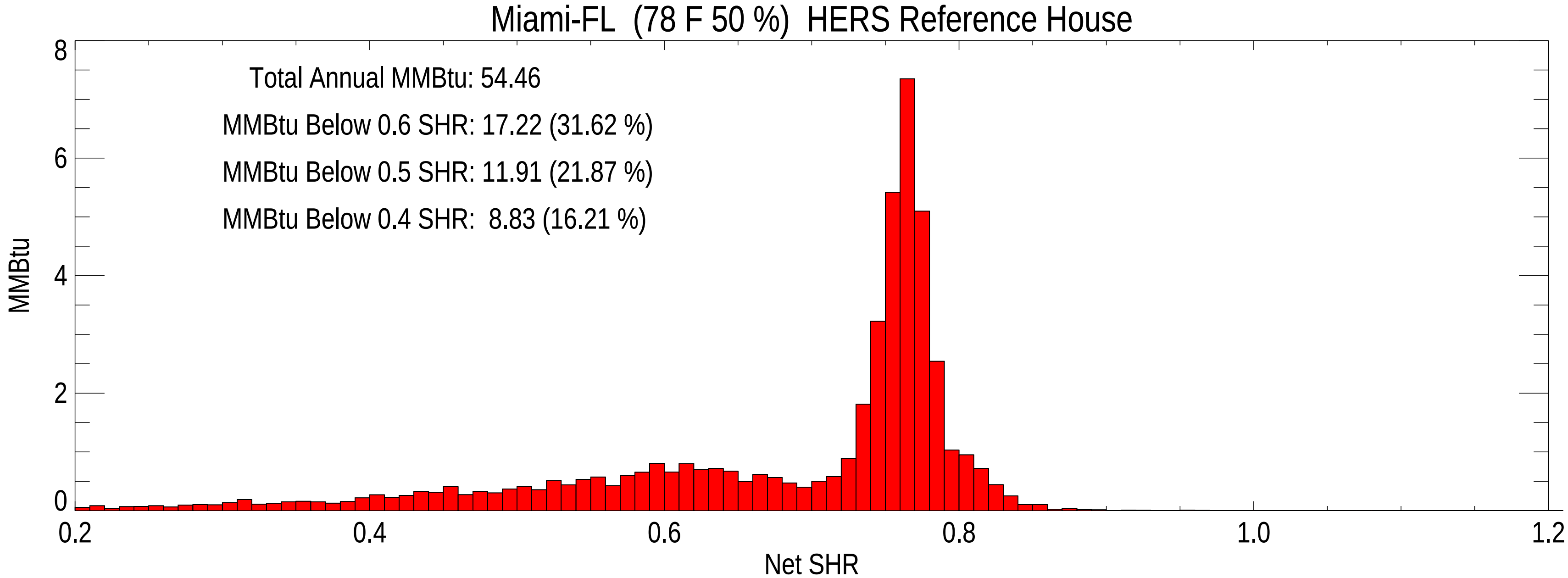

Houston-TX (75 F 50 %) HighEff House
Total Annual MMBtu: 37.34
MMBtu Below 0.6 SHR: 15.27 (40.89 %)
MMBtu Below 0.5 SHR: 9.66 (25.87 %)
MMBtu Below 0.4 SHR: 6.44 (17.25 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

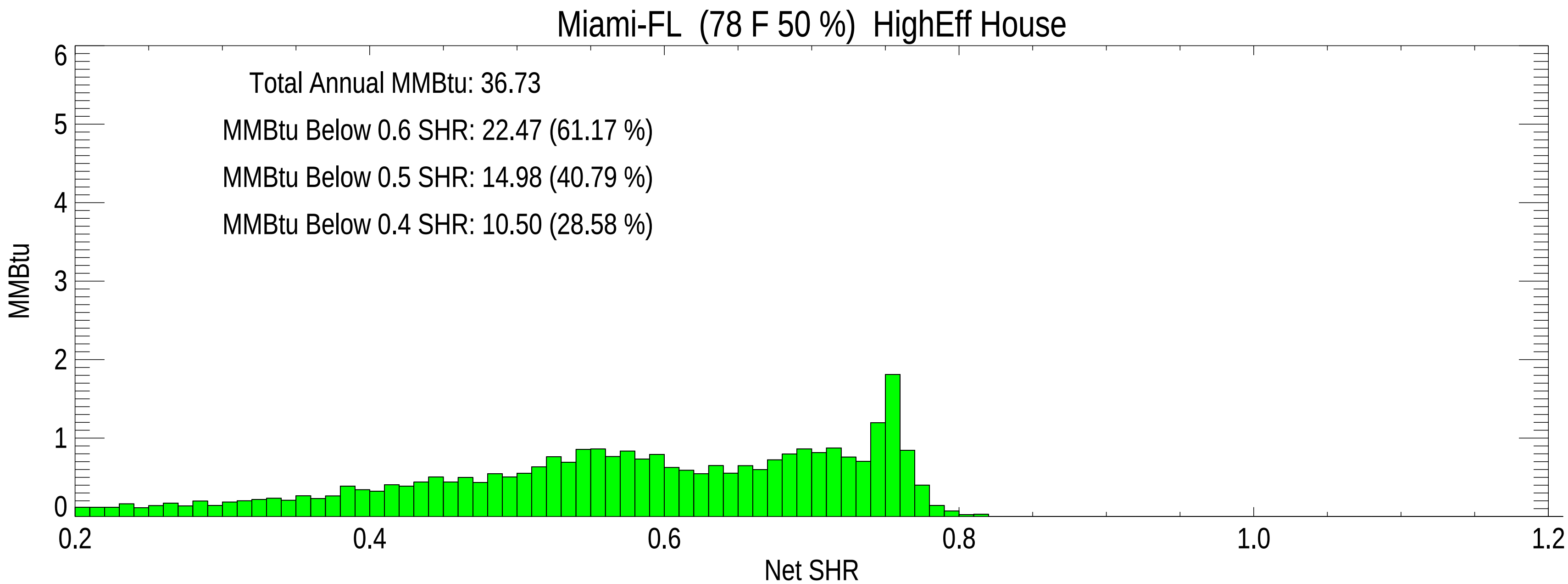

Fort_Worth-TX (75 F 50 %) HERS Reference House
Total Annual MMBtu: 44.81
MMBtu Below 0.6 SHR: 3.28 (7.32 %)
MMBtu Below 0.5 SHR: 2.58 (5.75 %)
MMBtu Below 0.4 SHR: 1.97 (4.40 %)
MMBtu
4
2
0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

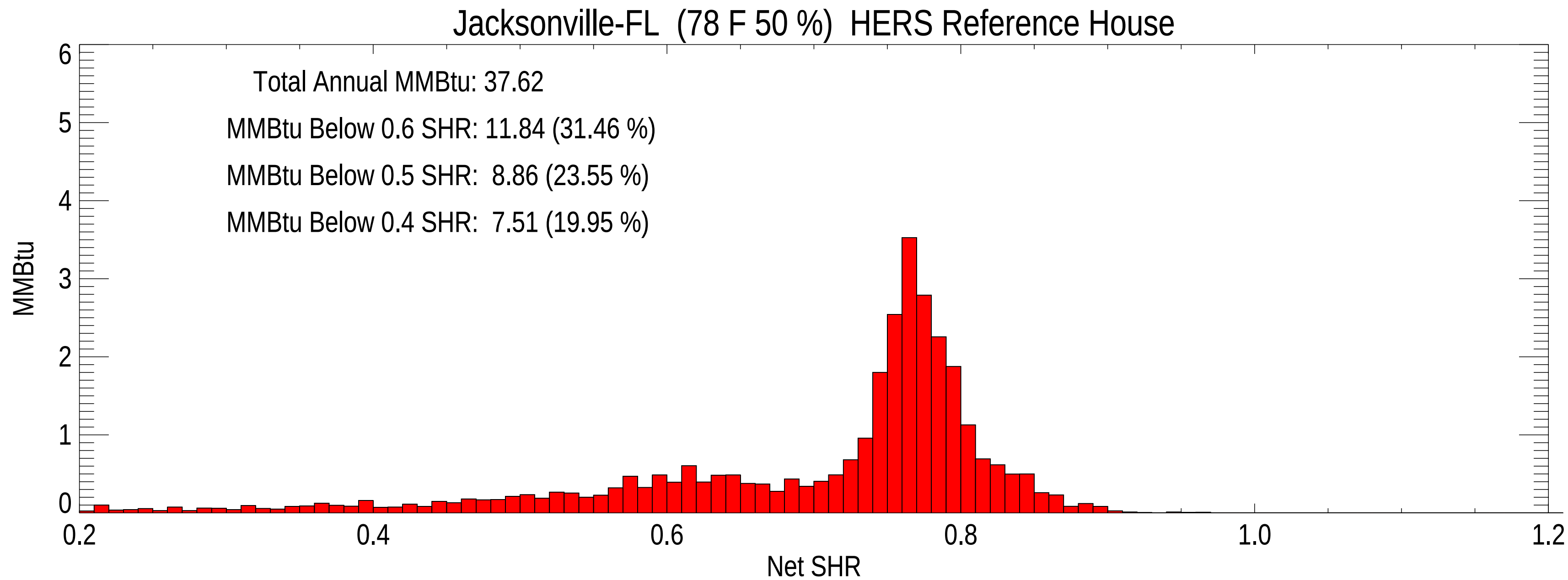

Fort_Worth-TX (75 F 50 %) HighEff House
Total Annual MMBtu: 33.27
MMBtu Below 0.6 SHR: 3.69 (11.08 %)
MMBtu Below 0.5 SHR: 2.73 (8.20 %)
MMBtu Below 0.4 SHR: 1.87 (5.61 %)
MMBtu
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

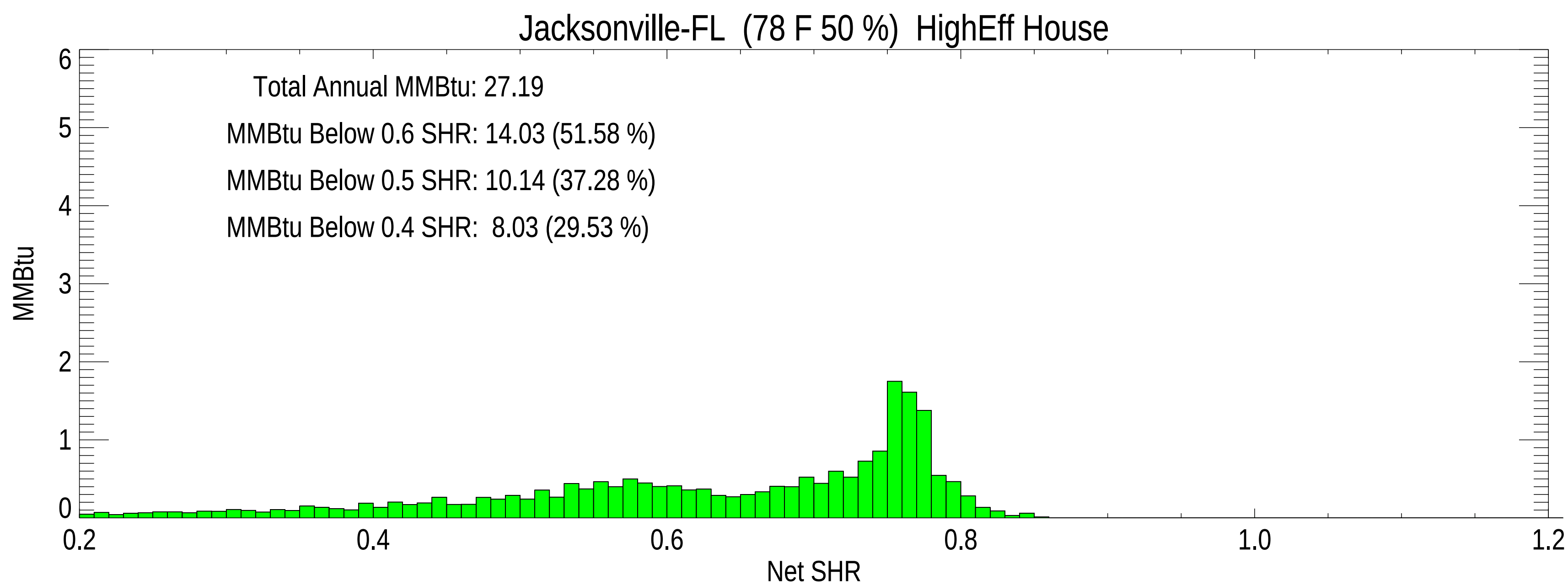

Wilmington-NC (75 F 50 %) HERS Reference House
Total Annual MMBtu: 36.57
MMBtu Below 0.6 SHR: 10.82 (29.59 %)
MMBtu Below 0.5 SHR: 6.73 (18.39 %)
MMBtu Below 0.4 SHR: 4.80 (13.12 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

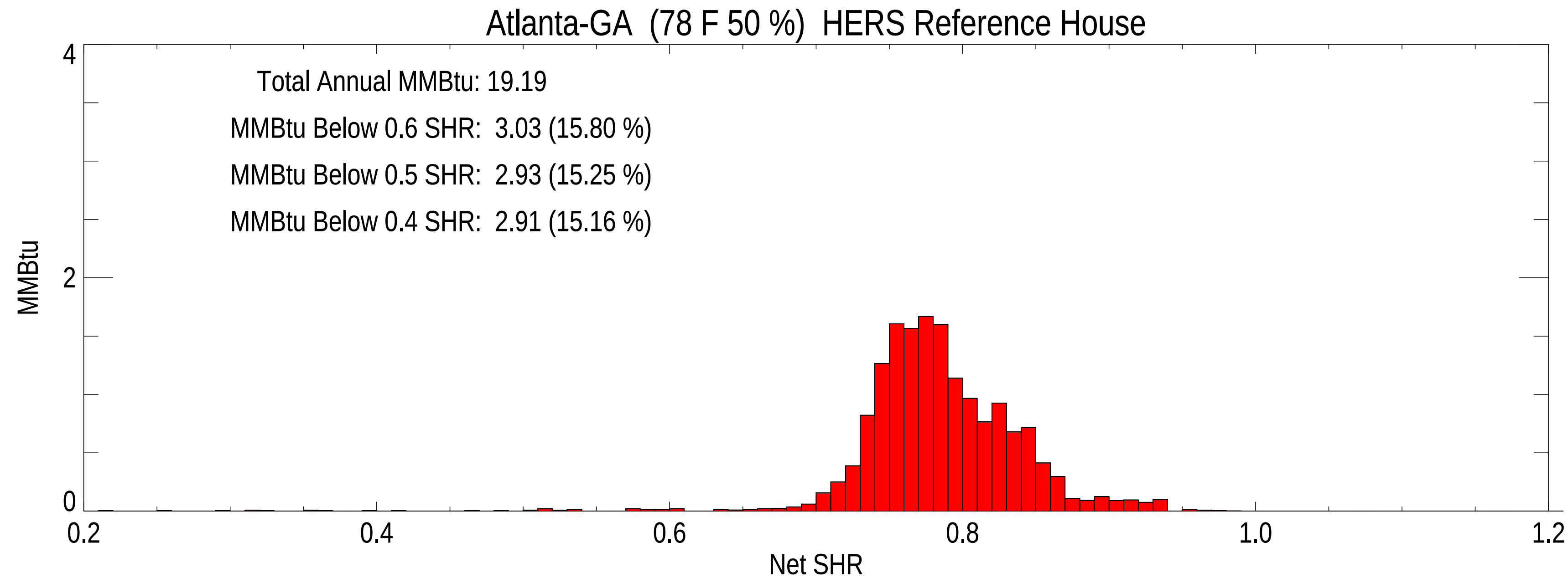

Wilmington-NC (75 F 50 %) HighEff House
Total Annual MMBtu: 28.91
MMBtu Below 0.6 SHR: 11.67 (40.36 %)
MMBtu Below 0.5 SHR: 6.95 (24.04 %)
MMBtu Below 0.4 SHR: 4.79 (16.57 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

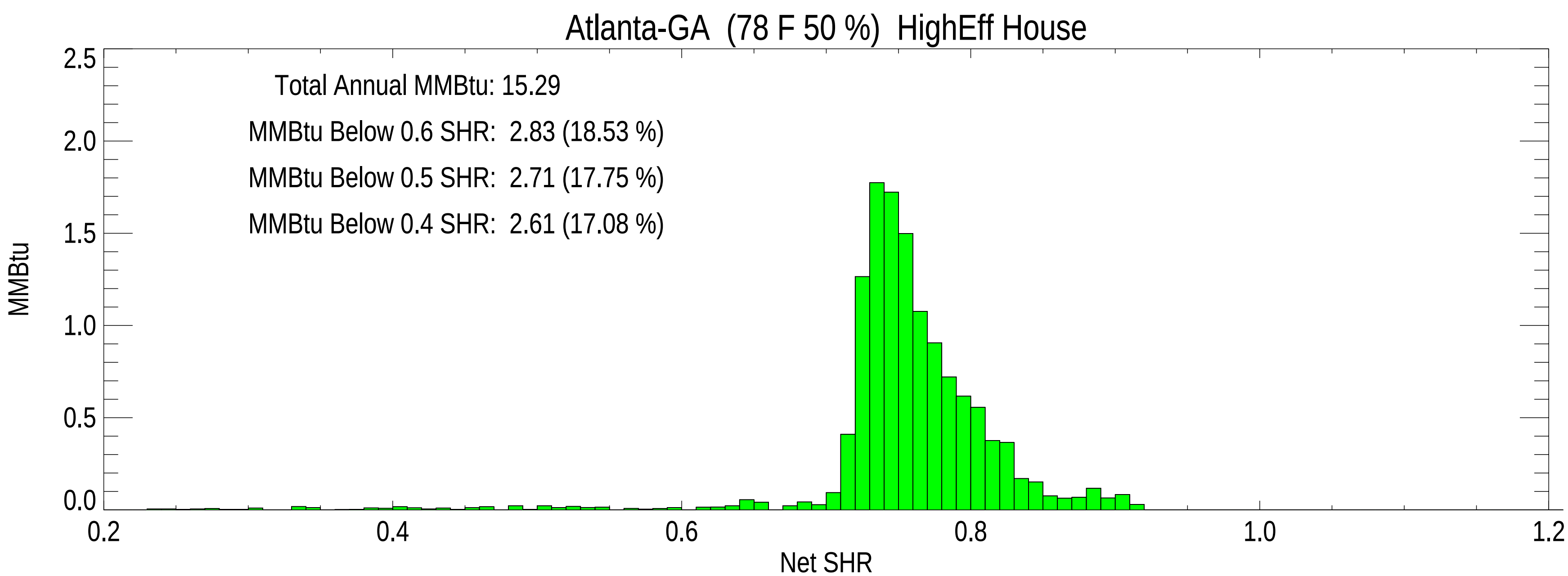

Miami-FL (78 F 50 %) HERS Reference House
Total Annual MMBtu: 54.46
MMBtu Below 0.6 SHR: 17.22 (31.62 %)
MMBtu Below 0.5 SHR: 11.91 (21.87 %)
MMBtu Below 0.4 SHR: 8.83 (16.21 %)
MMBtu
0
2
4
6
8
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

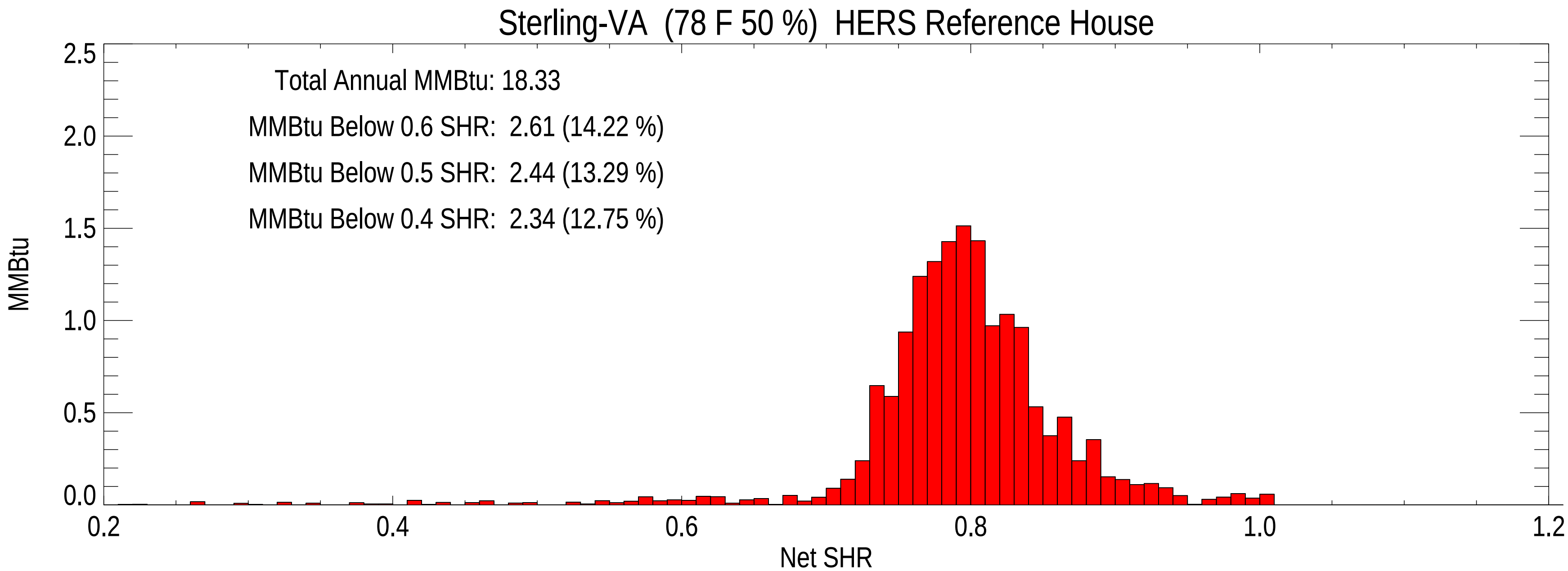

Miami-FL (78 F 50 %) HighEff House
Total Annual MMBtu: 36.73
MMBtu Below 0.6 SHR: 22.47 (61.17 %)
MMBtu Below 0.5 SHR: 14.98 (40.79 %)
MMBtu Below 0.4 SHR: 10.50 (28.58 %)
MMBtu
0
1
2
3
4
5
6
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

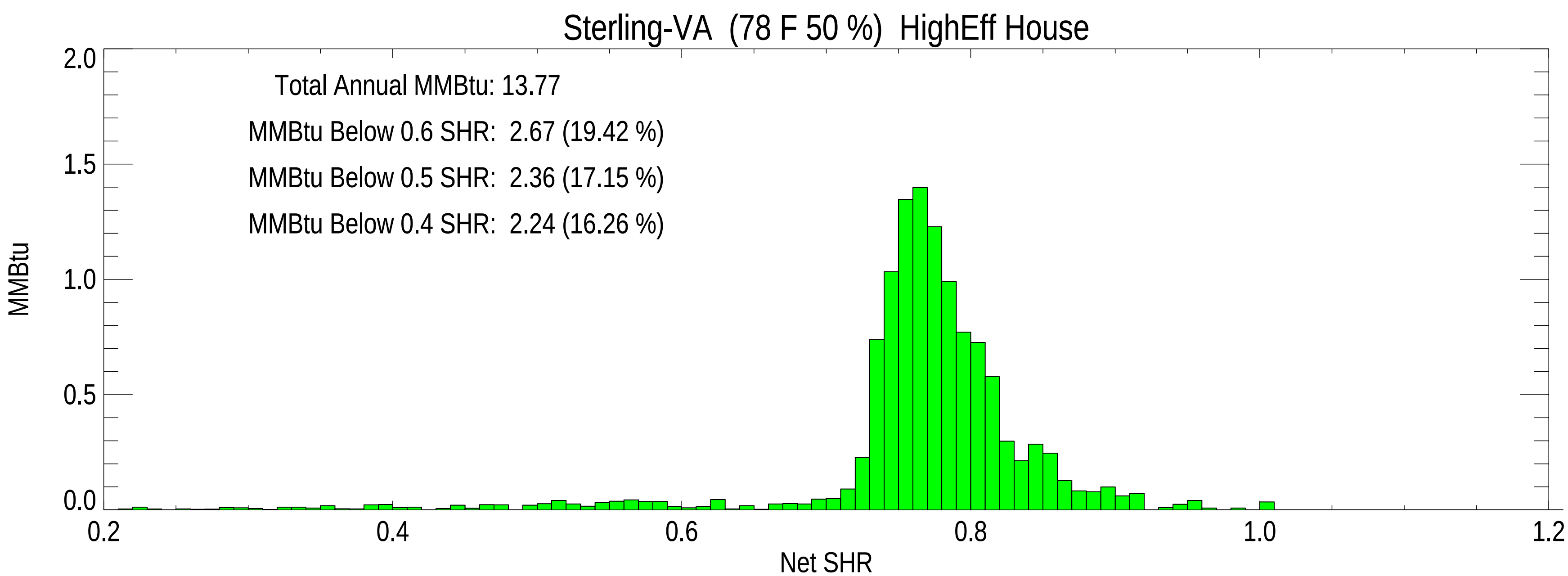

Jacksonville-FL (78 F 50 %) HERS Reference House
Total Annual MMBtu: 37.62
MMBtu Below 0.6 SHR: 11.84 (31.46 %)
MMBtu Below 0.5 SHR: 8.86 (23.55 %)
MMBtu Below 0.4 SHR: 7.51 (19.95 %)
MMBtu
Net SHR
0
1
2
3
4
5
6
0.2
0.4
0.6
0.8
1.0
1.2

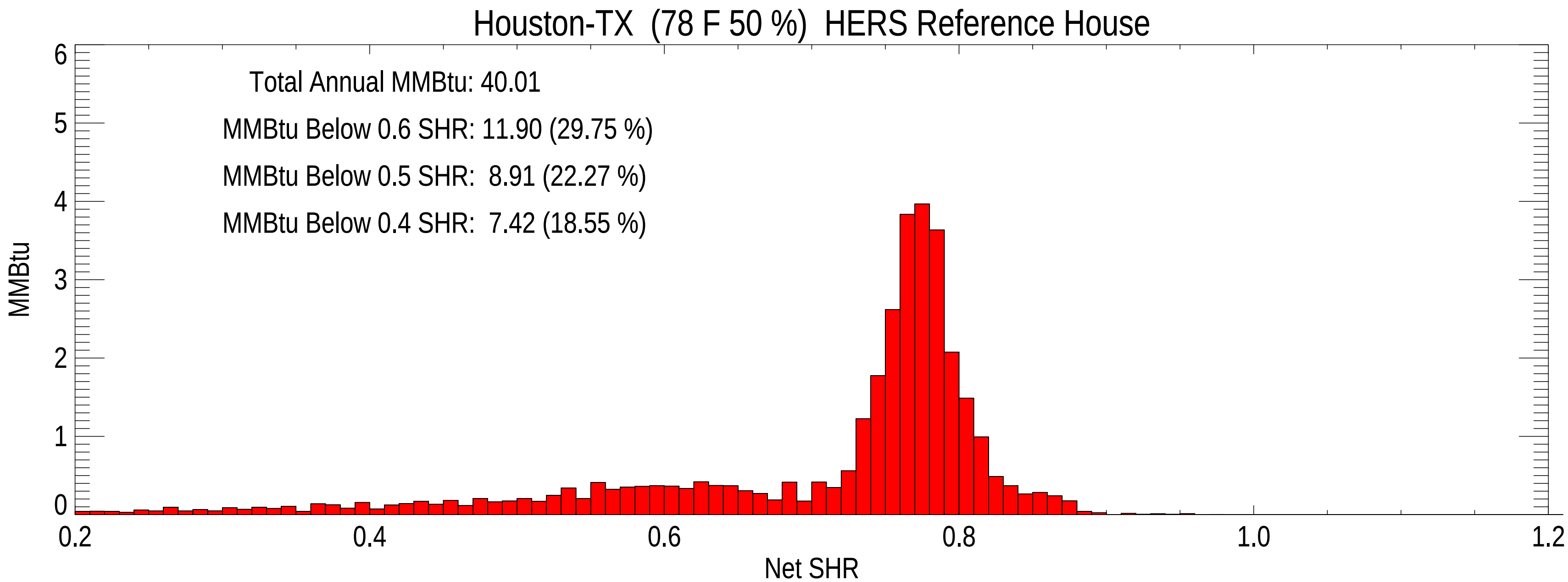

Jacksonville-FL (78 F 50 %) HighEff House
Total Annual MMBtu: 27.19
MMBtu Below 0.6 SHR: 14.03 (51.58 %)
MMBtu Below 0.5 SHR: 10.14 (37.28 %)
MMBtu Below 0.4 SHR: 8.03 (29.53 %)
MMBtu
Net SHR
0
1
2
3
4
5
6
0.2
0.4
0.6
0.8
1.0
1.2

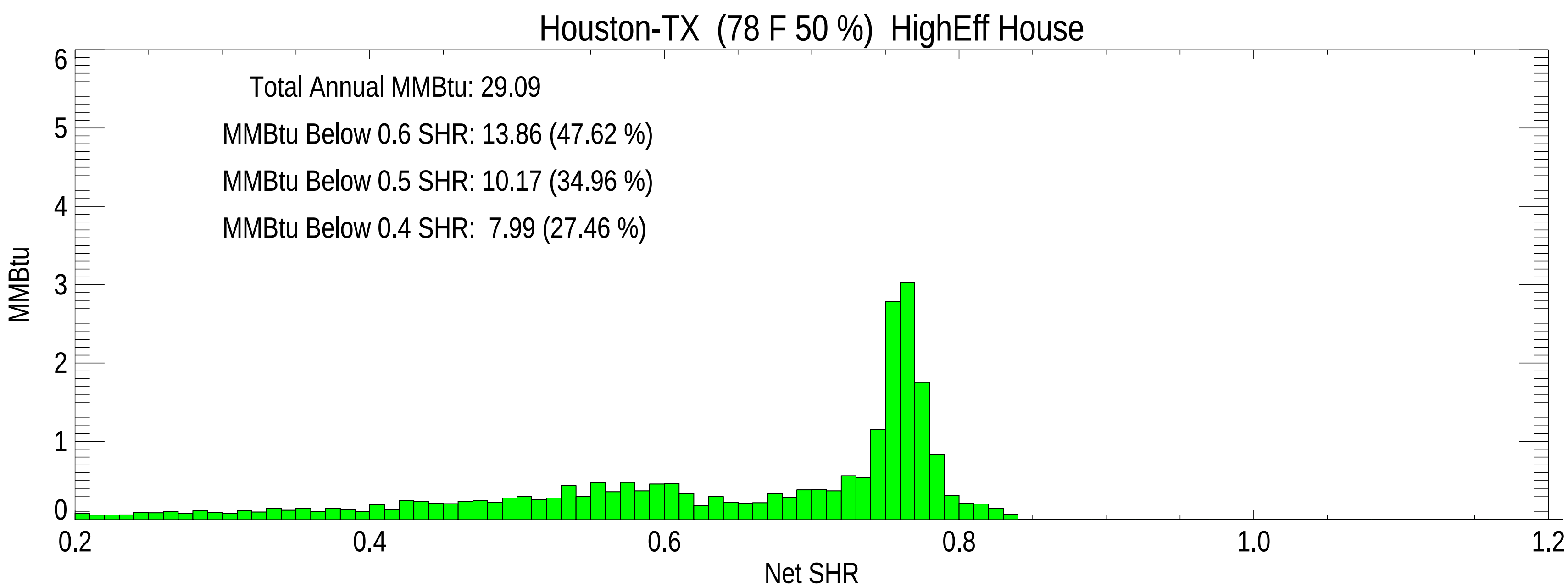

Atlanta-GA (78 F 50 %) HERS Reference House
Total Annual MMBtu: 19.19
MMBtu Below 0.6 SHR: 3.03 (15.80 %)
MMBtu Below 0.5 SHR: 2.93 (15.25 %)
MMBtu Below 0.4 SHR: 2.91 (15.16 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

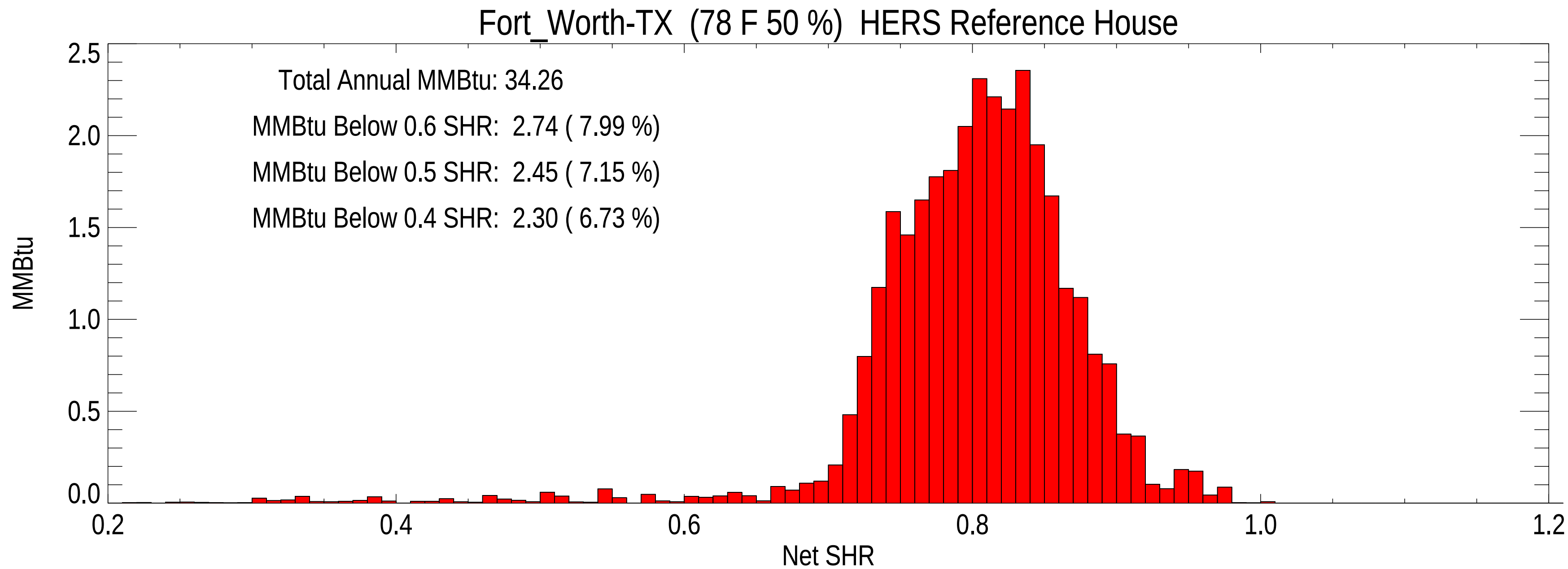

Atlanta-GA (78 F 50 %) HighEff House
Total Annual MMBtu: 15.29
MMBtu Below 0.6 SHR: 2.83 (18.53 %)
MMBtu Below 0.5 SHR: 2.71 (17.75 %)
MMBtu Below 0.4 SHR: 2.61 (17.08 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

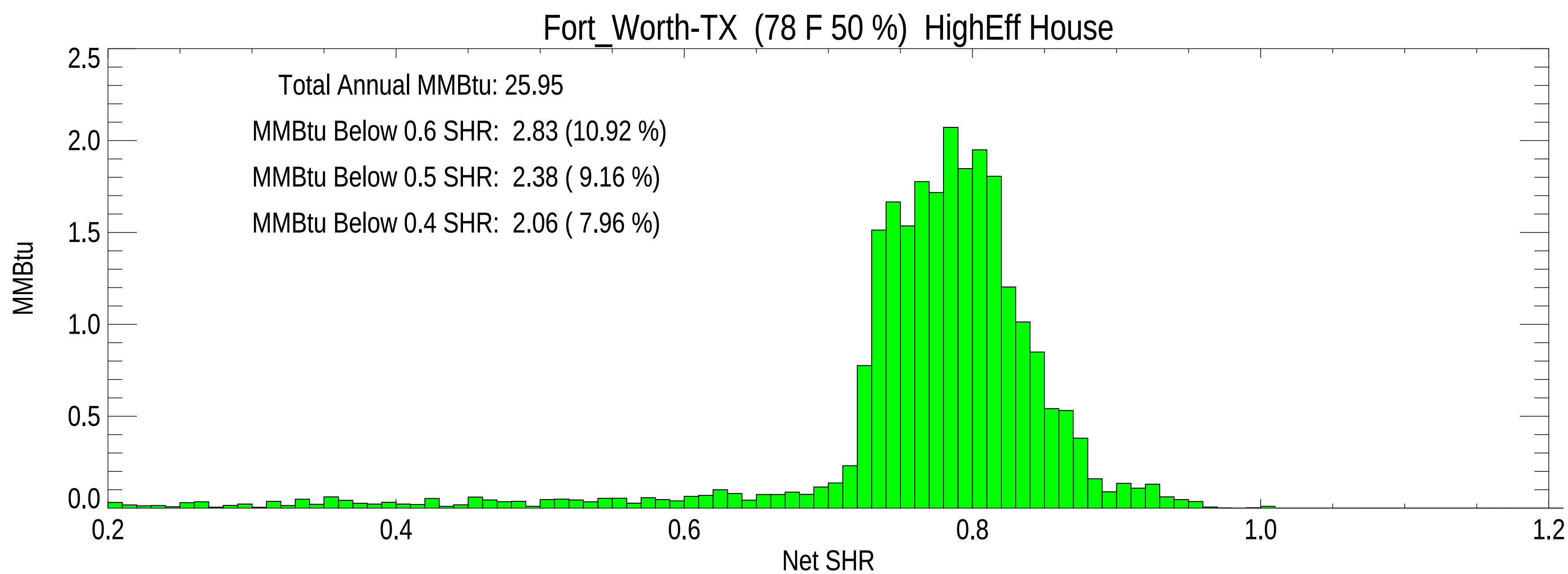

Sterling-VA (78 F 50 %) HERS Reference House
Total Annual MMBtu: 18.33
MMBtu Below 0.6 SHR: 2.61 (14.22 %)
MMBtu Below 0.5 SHR: 2.44 (13.29 %)
MMBtu Below 0.4 SHR: 2.34 (12.75 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

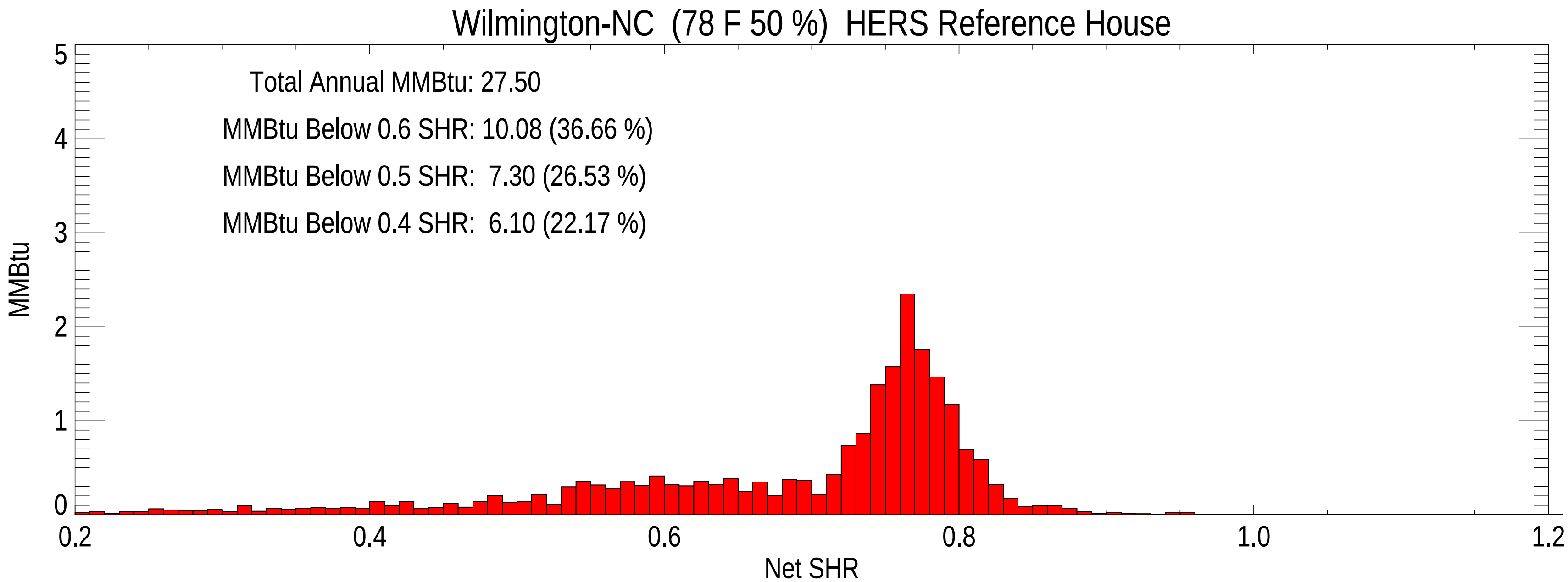

Sterling-VA (78 F 50 %) HighEff House
Total Annual MMBtu: 13.77
MMBtu Below 0.6 SHR: 2.67 (19.42 %)
MMBtu Below 0.5 SHR: 2.36 (17.15 %)
MMBtu Below 0.4 SHR: 2.24 (16.26 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

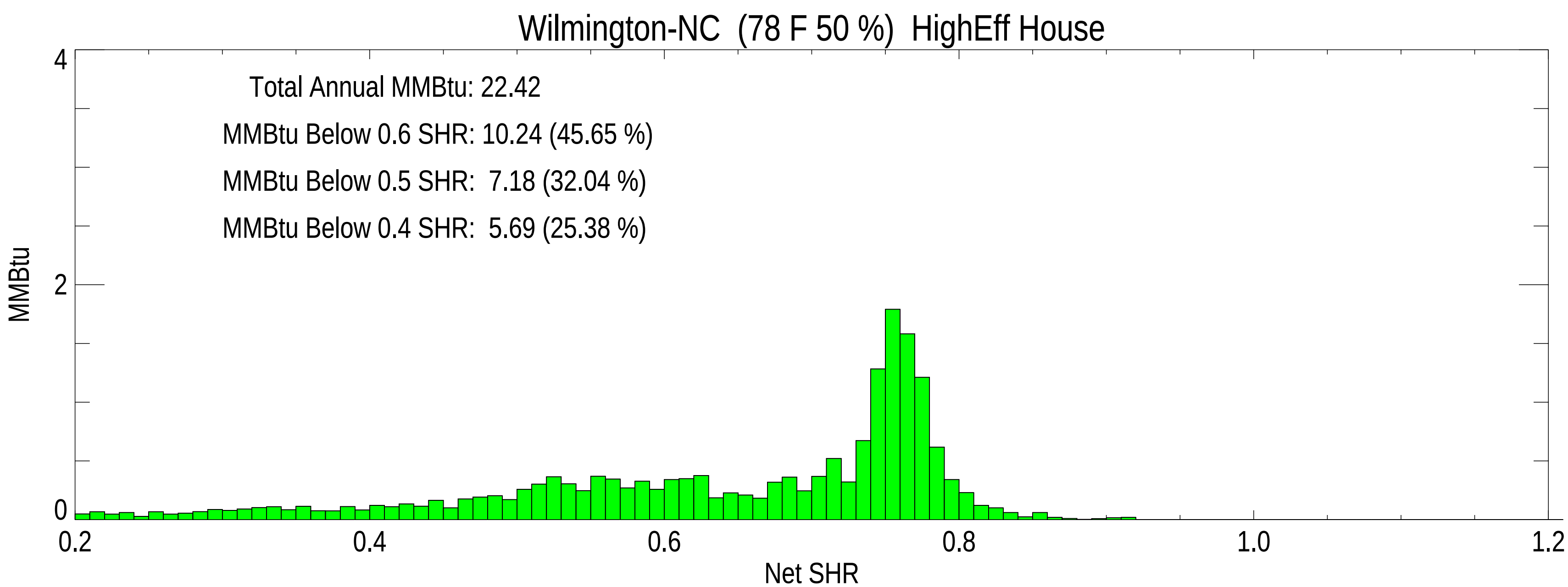

Houston-TX (78 F 50 %) HERS Reference House
Total Annual MMBtu: 40.01
MMBtu Below 0.6 SHR: 11.90 (29.75 %)
MMBtu Below 0.5 SHR: 8.91 (22.27 %)
MMBtu Below 0.4 SHR: 7.42 (18.55 %)
MMBtu
Net SHR
0
1
2
3
4
5
6
0.2
0.4
0.6
0.8
1.0
1.2

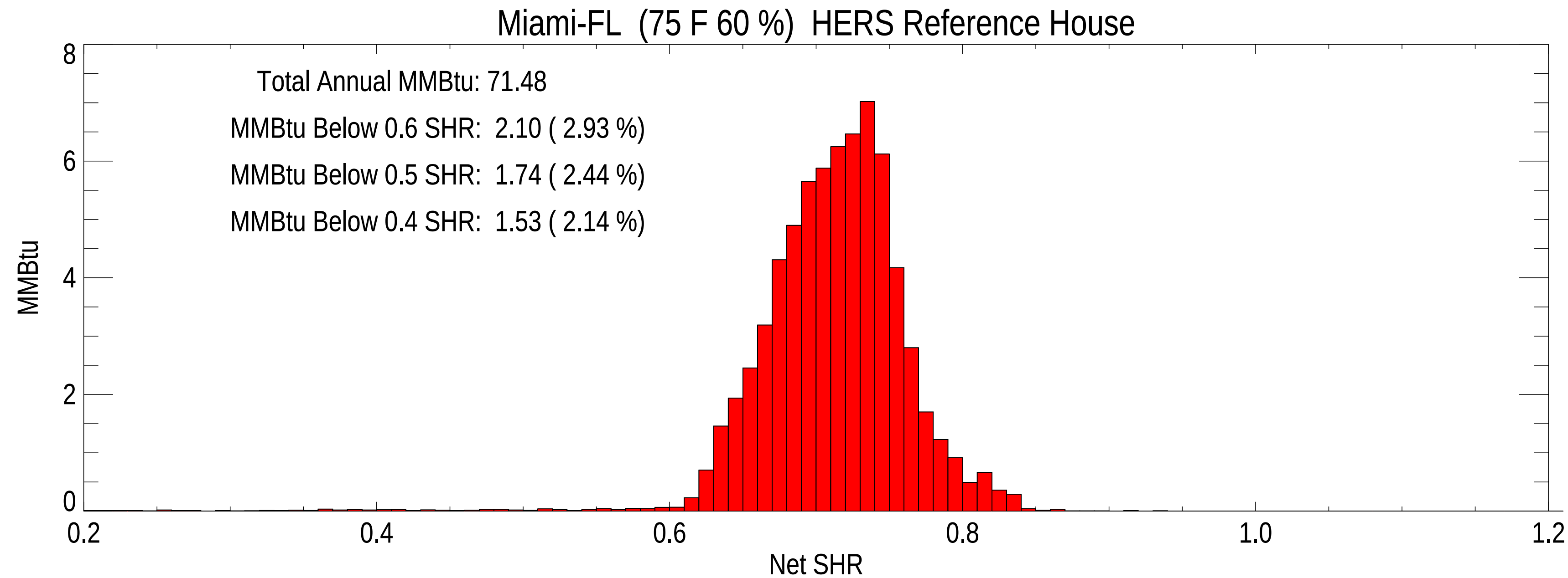

Houston-TX (78 F 50 %) HighEff House
Total Annual MMBtu: 29.09
MMBtu Below 0.6 SHR: 13.86 (47.62 %)
MMBtu Below 0.5 SHR: 10.17 (34.96 %)
MMBtu Below 0.4 SHR: 7.99 (27.46 %)
MMBtu
Net SHR
0
1
2
3
4
5
6
0.2
0.4
0.6
0.8
1.0
1.2

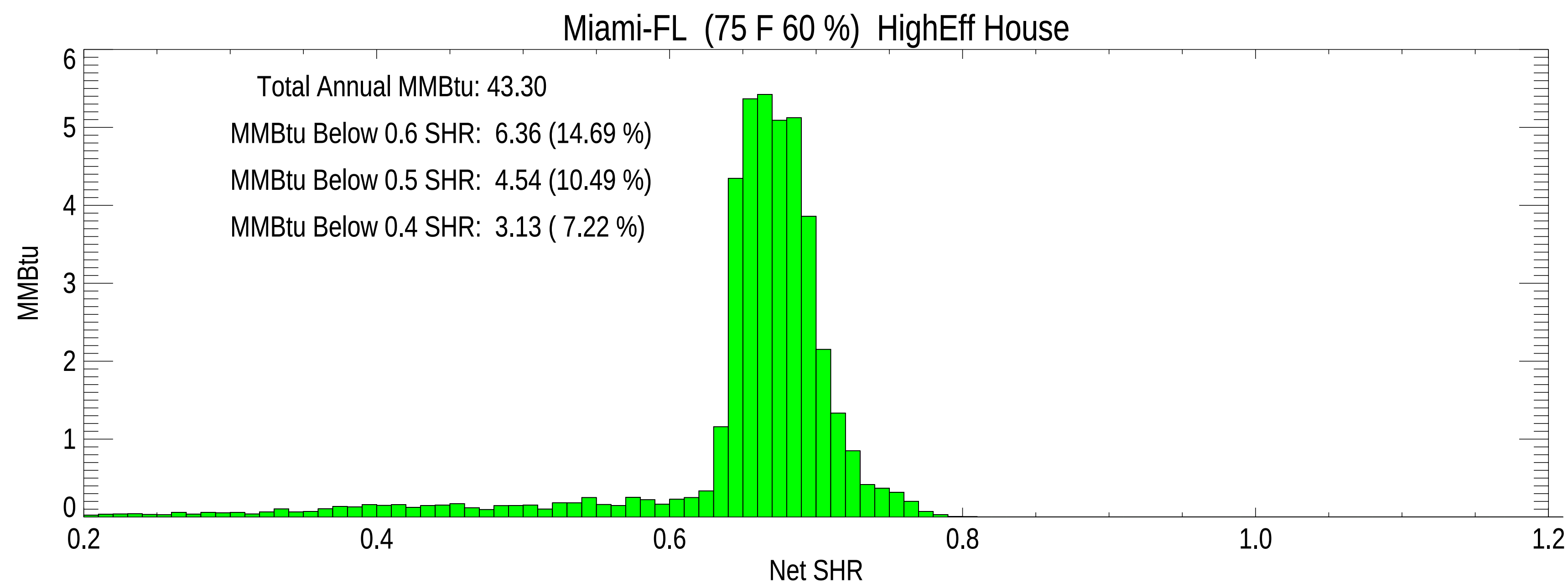

Fort_Worth-TX (78 F 50 %) HERS Reference House
Total Annual MMBtu: 34.26
MMBtu Below 0.6 SHR: 2.74 (7.99 %)
MMBtu Below 0.5 SHR: 2.45 (7.15 %)
MMBtu Below 0.4 SHR: 2.30 (6.73 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2

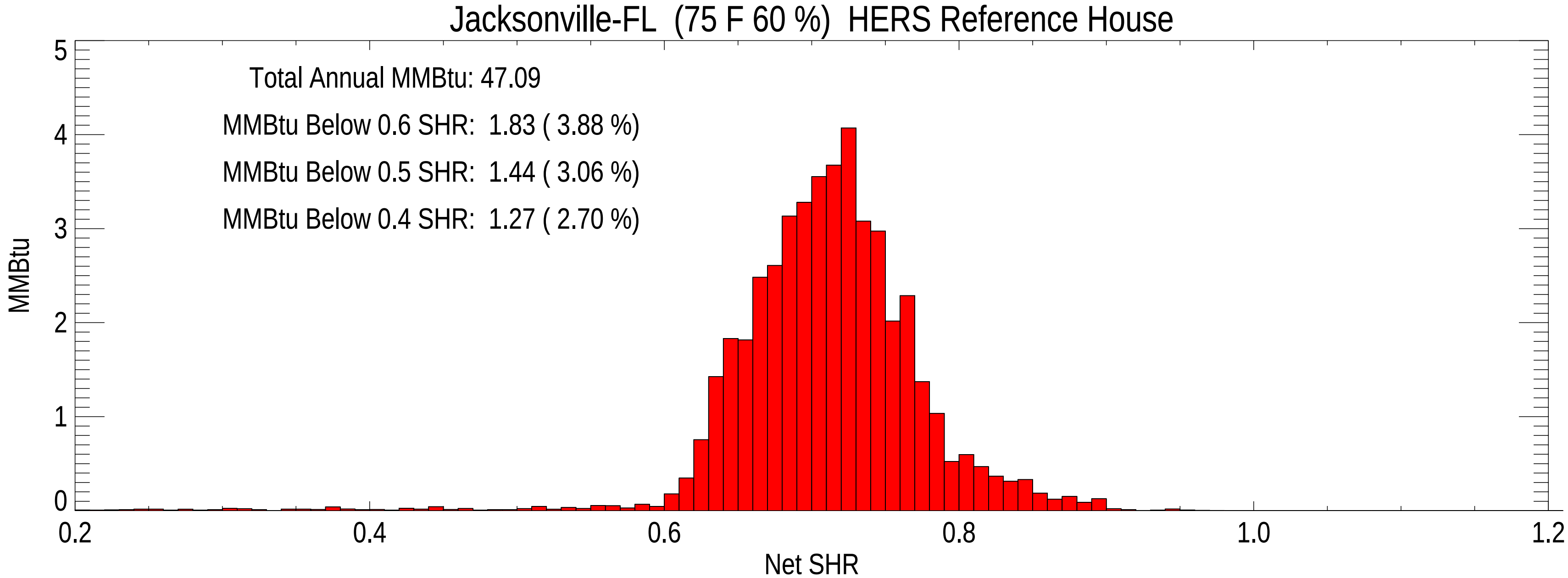

Fort_Worth-TX (78 F 50 %) HighEff House
Total Annual MMBtu: 25.95
MMBtu Below 0.6 SHR: 2.83 (10.92 %)
MMBtu Below 0.5 SHR: 2.38 (9.16 %)
MMBtu Below 0.4 SHR: 2.06 (7.96 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2

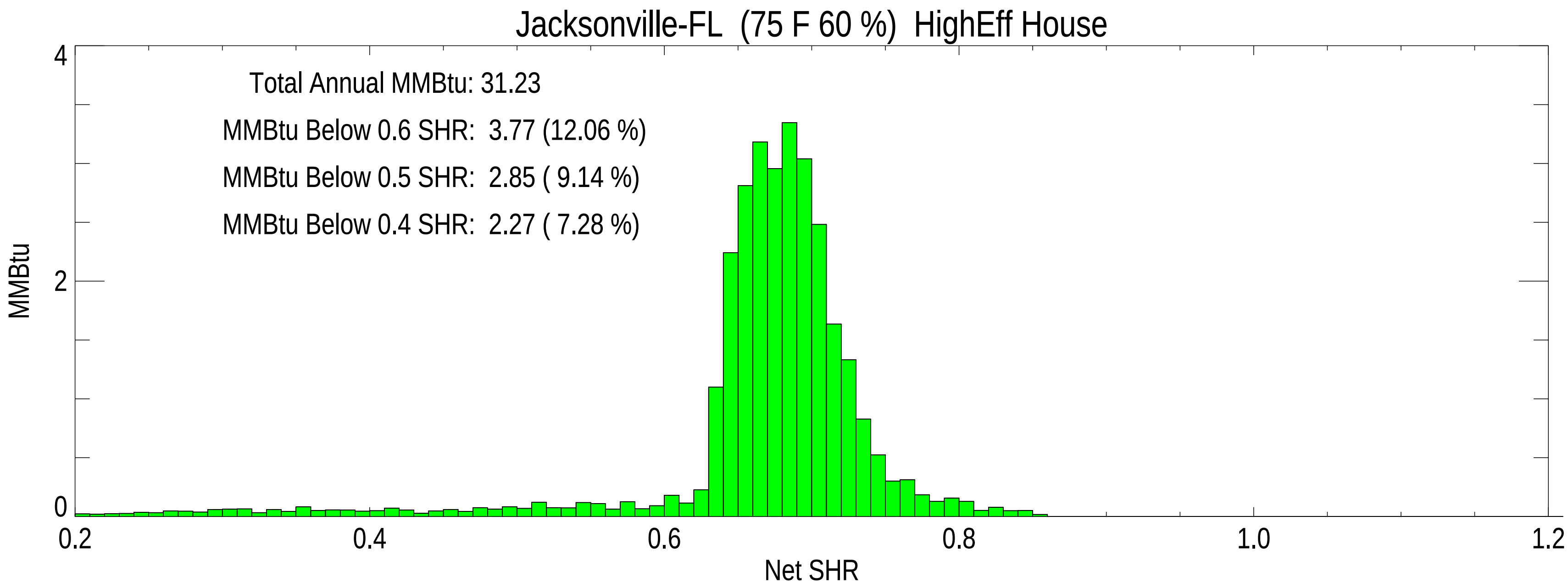

Wilmington-NC (78 F 50 %) HERS Reference House
Total Annual MMBtu: 27.50
MMBtu Below 0.6 SHR: 10.08 (36.66 %)
MMBtu Below 0.5 SHR: 7.30 (26.53 %)
MMBtu Below 0.4 SHR: 6.10 (22.17 %)
MMBtu
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

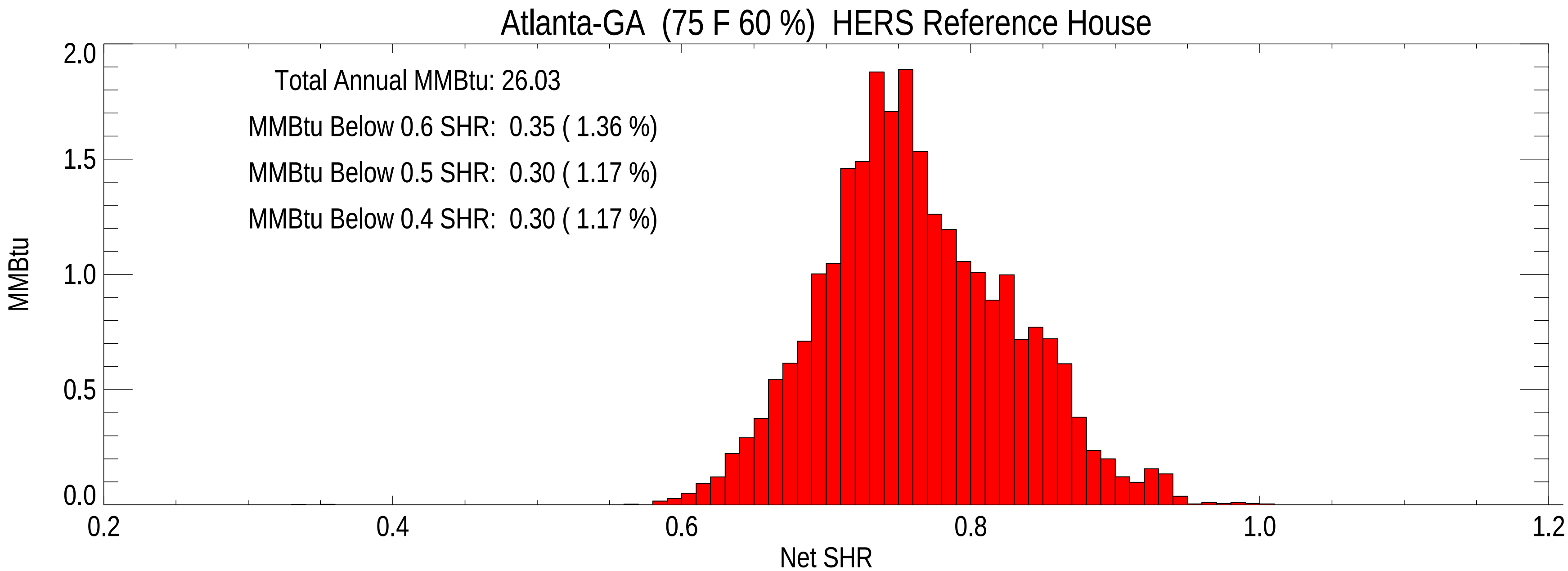

Wilmington-NC (78 F 50 %) HighEff House
Total Annual MMBtu: 22.42
MMBtu Below 0.6 SHR: 10.24 (45.65 %)
MMBtu Below 0.5 SHR: 7.18 (32.04 %)
MMBtu Below 0.4 SHR: 5.69 (25.38 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

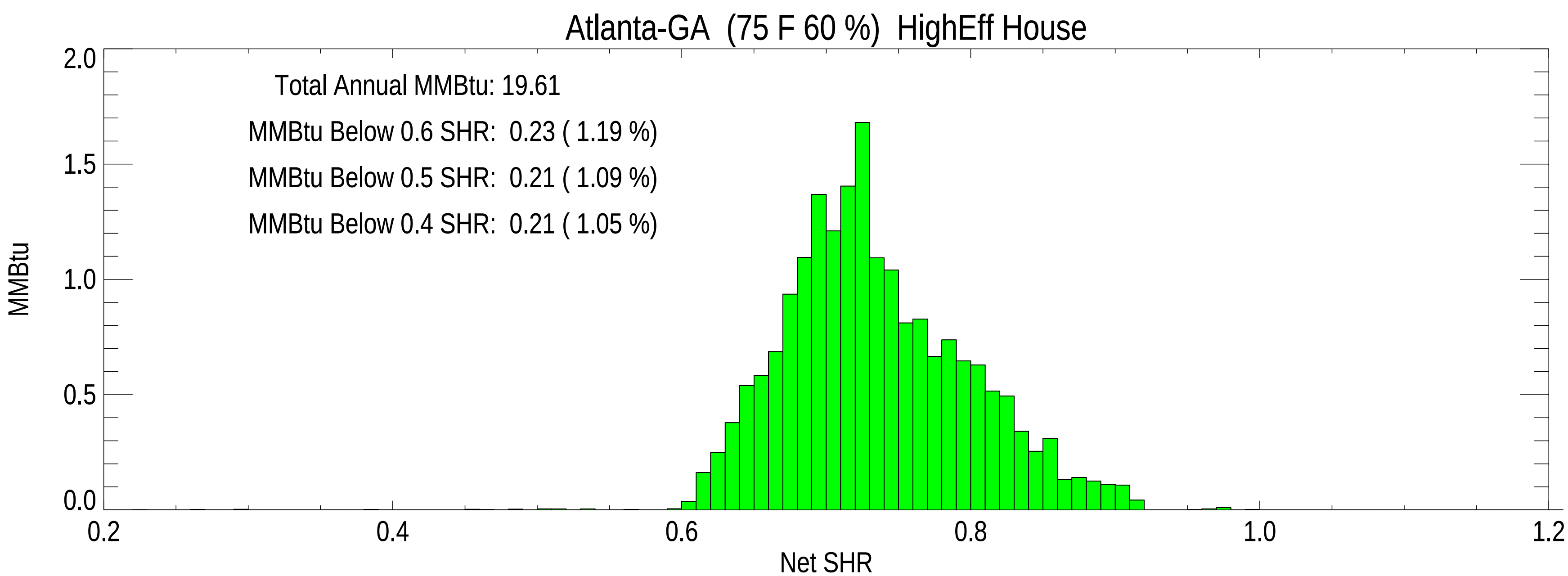

Miami-FL (75 F 60 %) HERS Reference House
Total Annual MMBtu: 71.48
MMBtu Below 0.6 SHR: 2.10 (2.93 %)
MMBtu Below 0.5 SHR: 1.74 (2.44 %)
MMBtu Below 0.4 SHR: 1.53 (2.14 %)
MMBtu
Net SHR
0
2
4
6
8
0.2
0.4
0.6
0.8
1.0
1.2

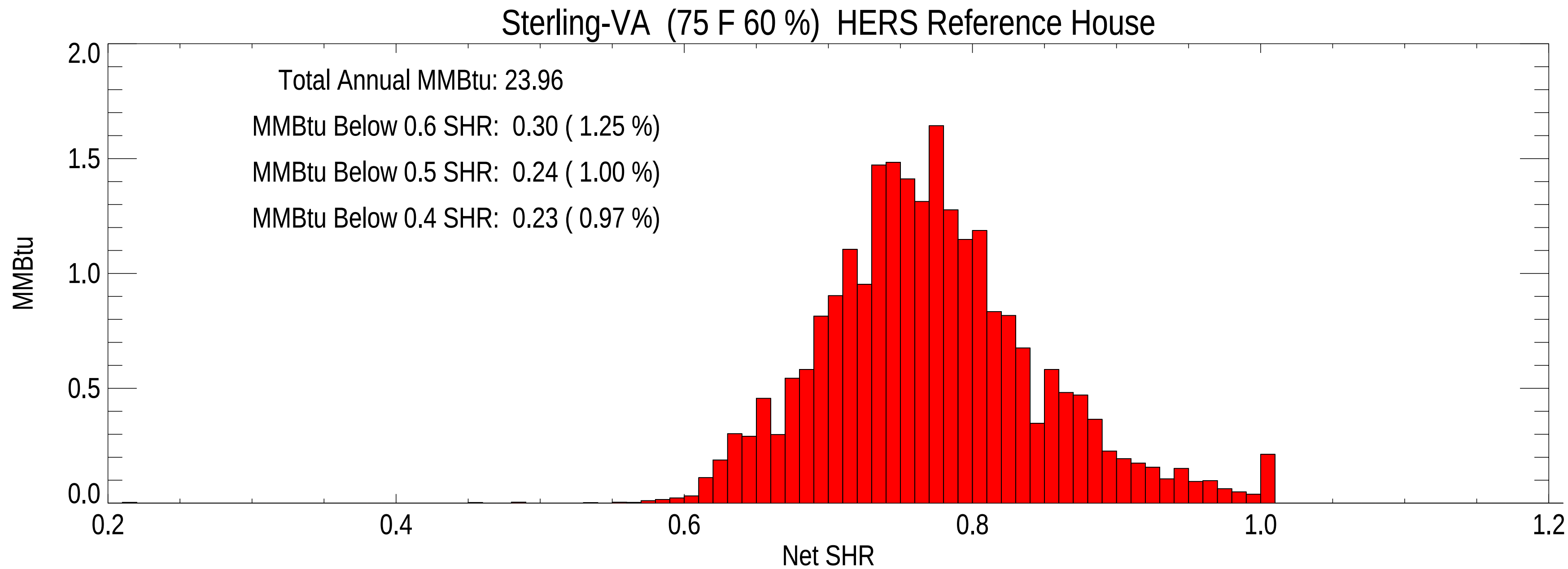

Miami-FL (75 F 60 %) HighEff House
Total Annual MMBtu: 43.30
MMBtu Below 0.6 SHR: 6.36 (14.69 %)
MMBtu Below 0.5 SHR: 4.54 (10.49 %)
MMBtu Below 0.4 SHR: 3.13 (7.22 %)
MMBtu
Net SHR
0
1
2
3
4
5
6
0.2
0.4
0.6
0.8
1.0
1.2

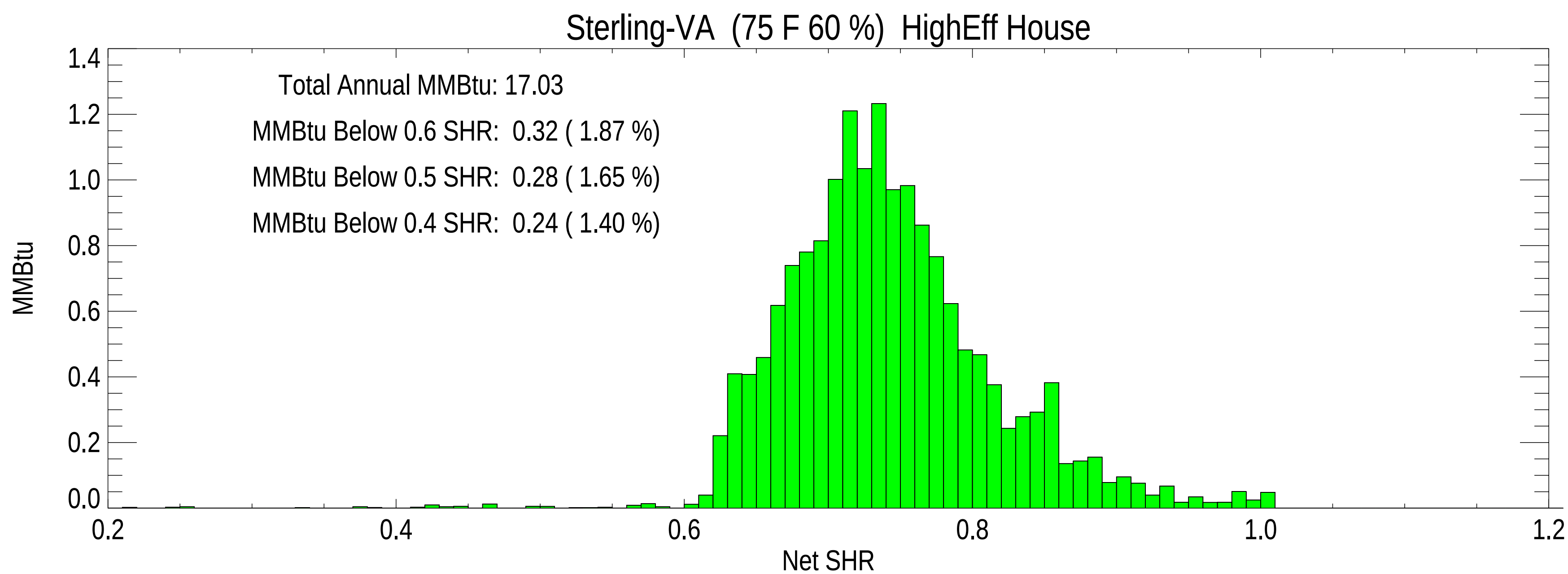

Jacksonville-FL (75 F 60 %) HERS Reference House
Total Annual MMBtu: 47.09
MMBtu Below 0.6 SHR: 1.83 (3.88 %)
MMBtu Below 0.5 SHR: 1.44 (3.06 %)
MMBtu Below 0.4 SHR: 1.27 (2.70 %)
MMBtu
Net SHR
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2

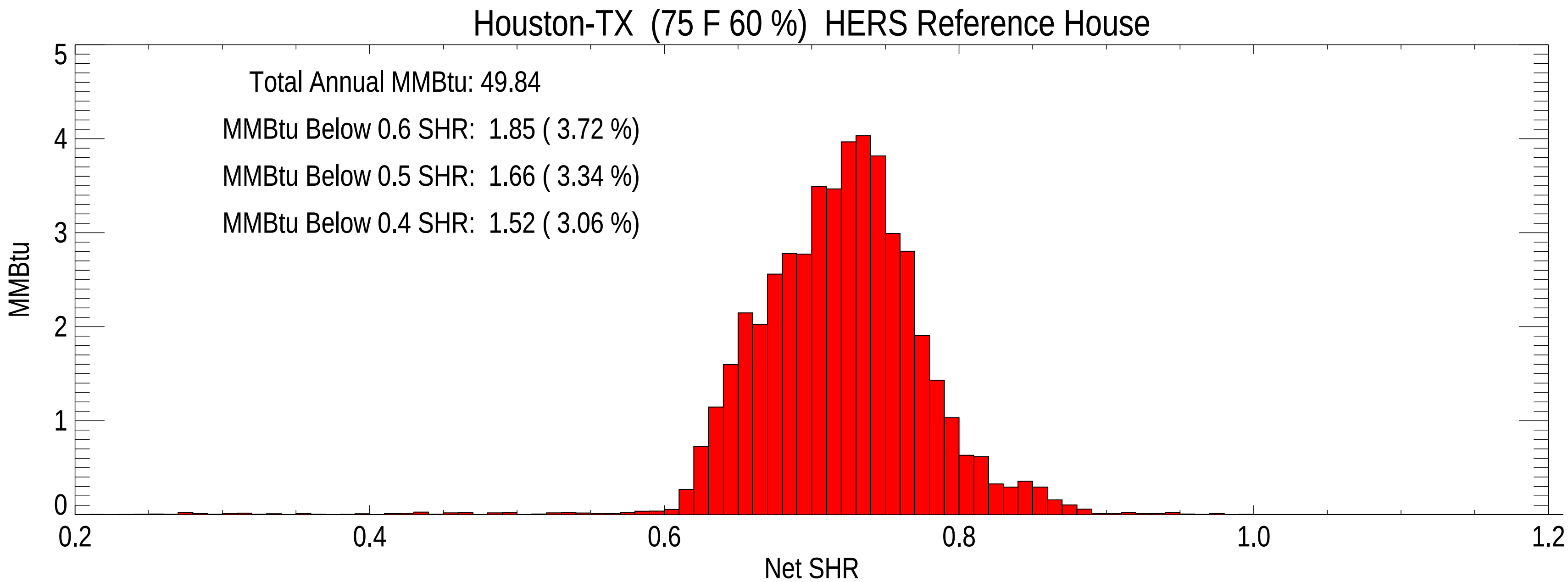

Jacksonville-FL (75 F 60 %) HighEff House
Total Annual MMBtu: 31.23
MMBtu Below 0.6 SHR: 3.77 (12.06 %)
MMBtu Below 0.5 SHR: 2.85 (9.14 %)
MMBtu Below 0.4 SHR: 2.27 (7.28 %)
MMBtu
Net SHR
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2

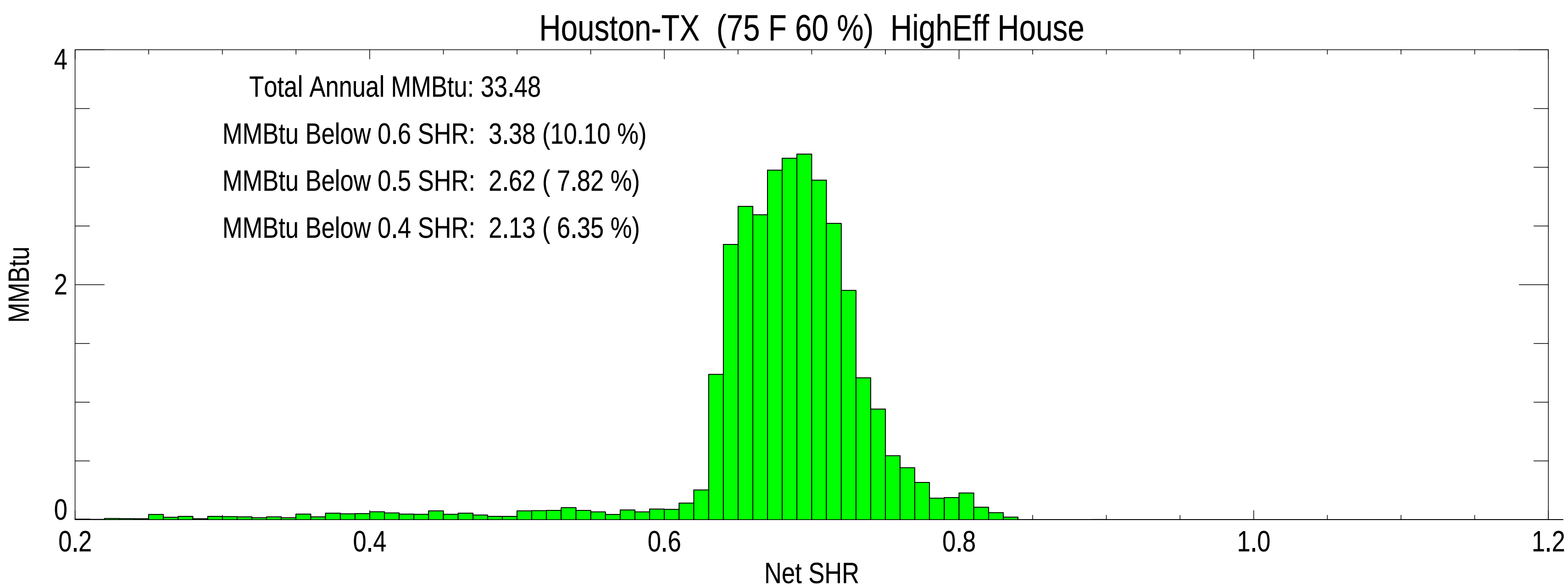

Atlanta-GA (75 F 60 %) HERS Reference House
Total Annual MMBtu: 26.03
MMBtu Below 0.6 SHR: 0.35 (1.36 %)
MMBtu Below 0.5 SHR: 0.30 (1.17 %)
MMBtu Below 0.4 SHR: 0.30 (1.17 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

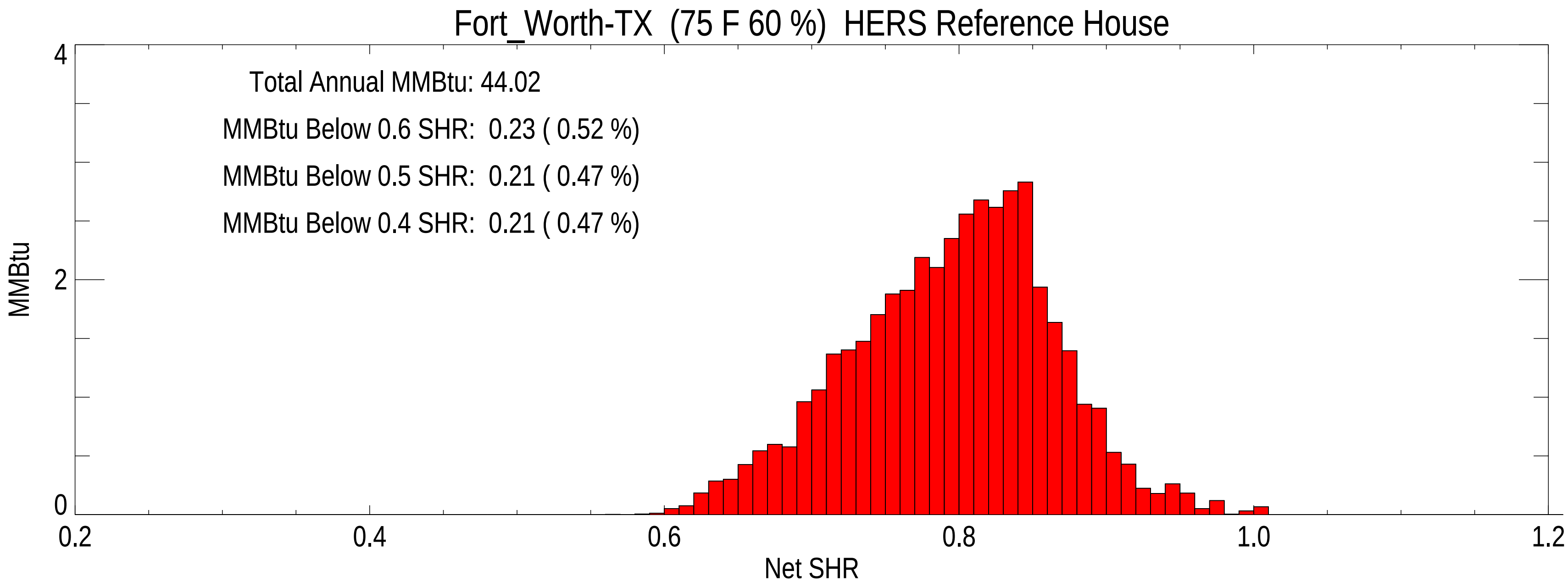

Atlanta-GA (75 F 60 %) HighEff House
Total Annual MMBtu: 19.61
MMBtu Below 0.6 SHR: 0.23 (1.19 %)
MMBtu Below 0.5 SHR: 0.21 (1.09 %)
MMBtu Below 0.4 SHR: 0.21 (1.05 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

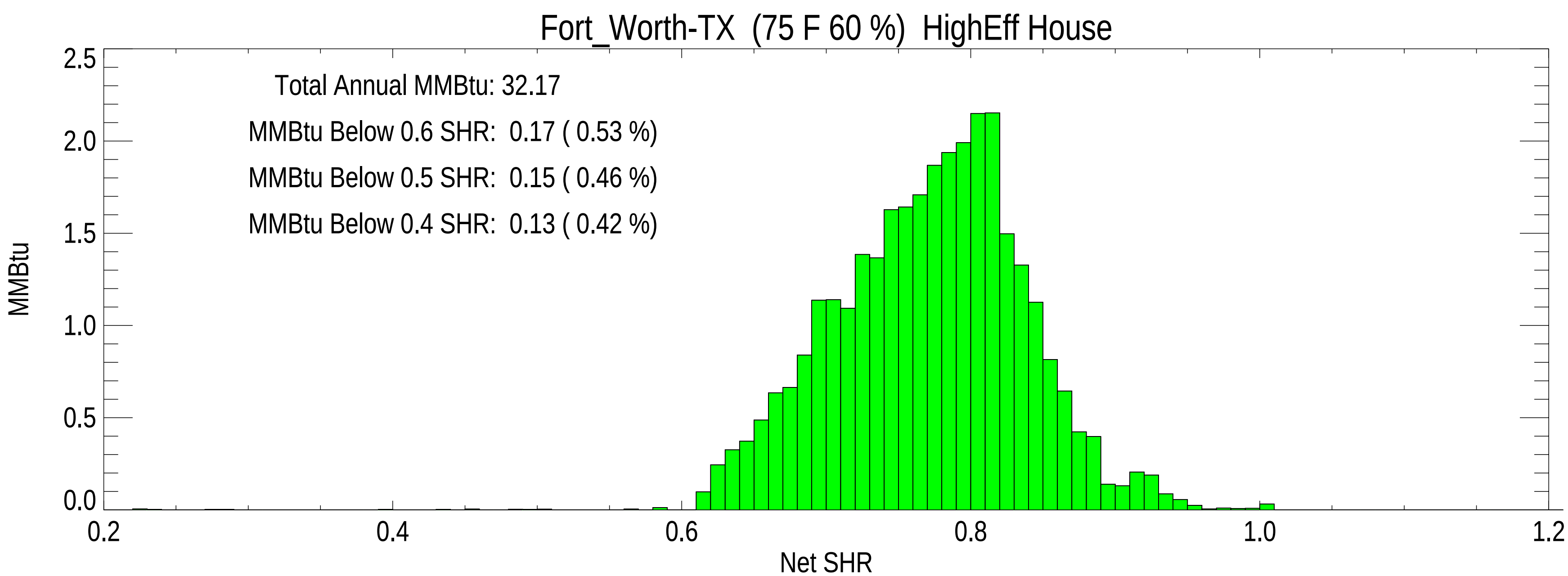

Sterling-VA (75 F 60 %) HERS Reference House
Total Annual MMBtu: 23.96
MMBtu Below 0.6 SHR: 0.30 (1.25 %)
MMBtu Below 0.5 SHR: 0.24 (1.00 %)
MMBtu Below 0.4 SHR: 0.23 (0.97 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
0.2
0.4
0.6
0.8
1.0
1.2

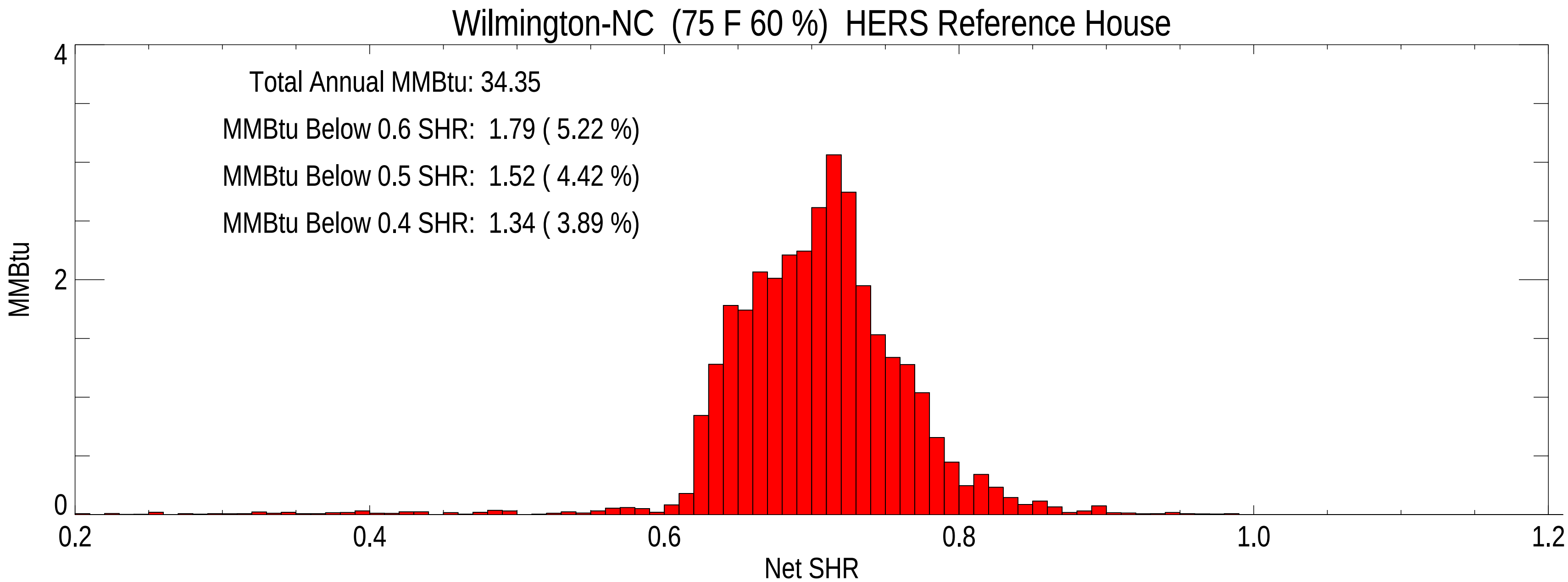

Sterling-VA (75 F 60 %) HighEff House
Total Annual MMBtu: 17.03
MMBtu Below 0.6 SHR: 0.32 (1.87 %)
MMBtu Below 0.5 SHR: 0.28 (1.65 %)
MMBtu Below 0.4 SHR: 0.24 (1.40 %)
MMBtu
Net SHR
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0.2
0.4
0.6
0.8
1.0
1.2

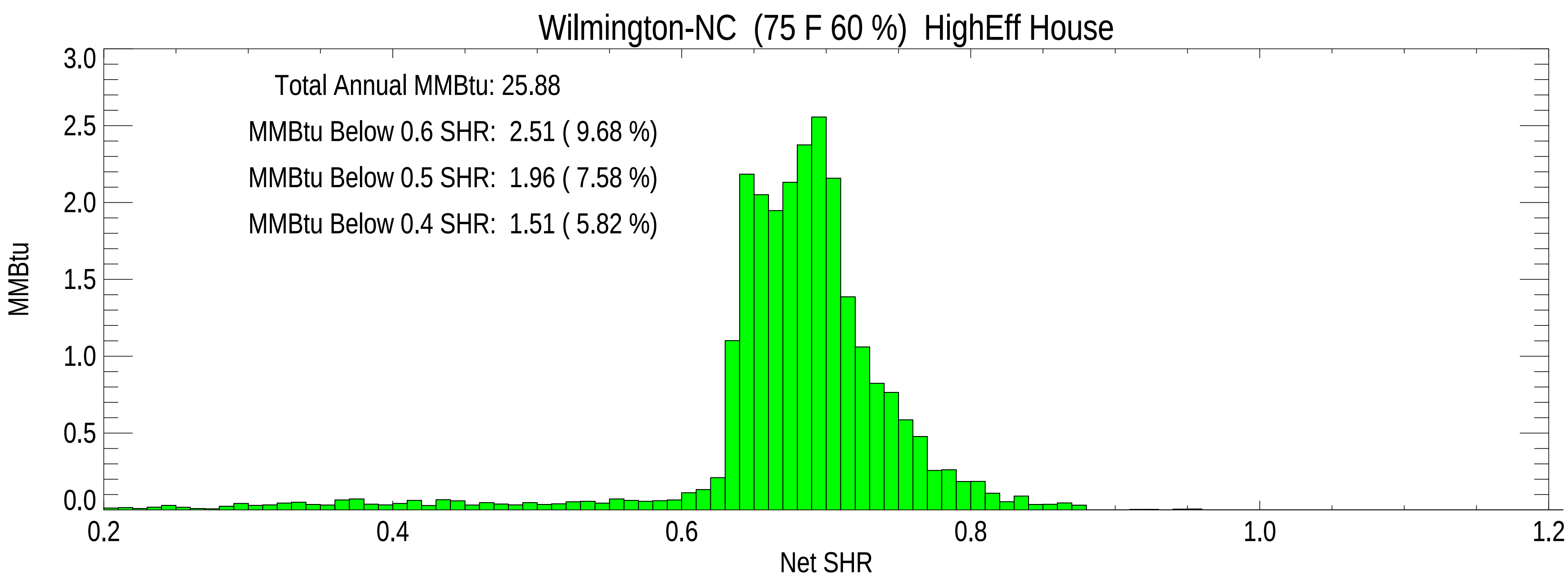

Houston-TX (75 F 60 %) HERS Reference House
Total Annual MMBtu: 49.84
MMBtu Below 0.6 SHR: 1.85 (3.72 %)
MMBtu Below 0.5 SHR: 1.66 (3.34 %)
MMBtu Below 0.4 SHR: 1.52 (3.06 %)
MMBtu
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

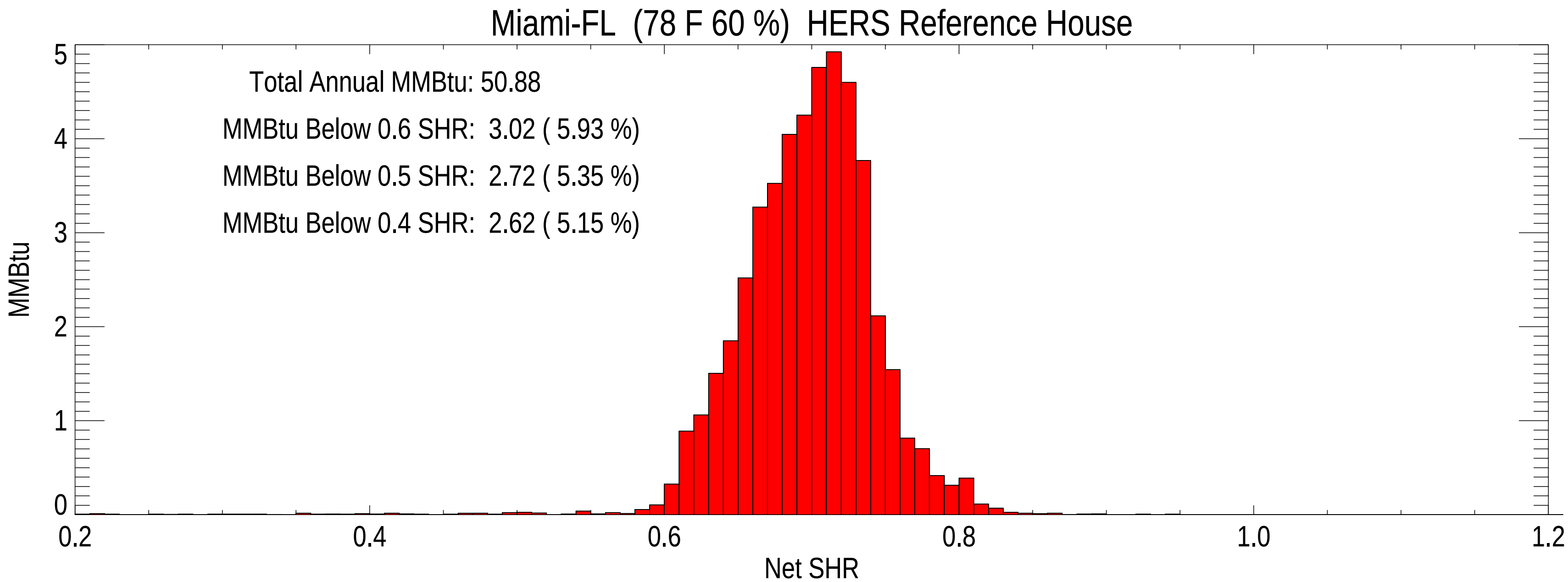

Houston-TX (75 F 60 %) HighEff House
Total Annual MMBtu: 33.48
MMBtu Below 0.6 SHR: 3.38 (10.10 %)
MMBtu Below 0.5 SHR: 2.62 (7.82 %)
MMBtu Below 0.4 SHR: 2.13 (6.35 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

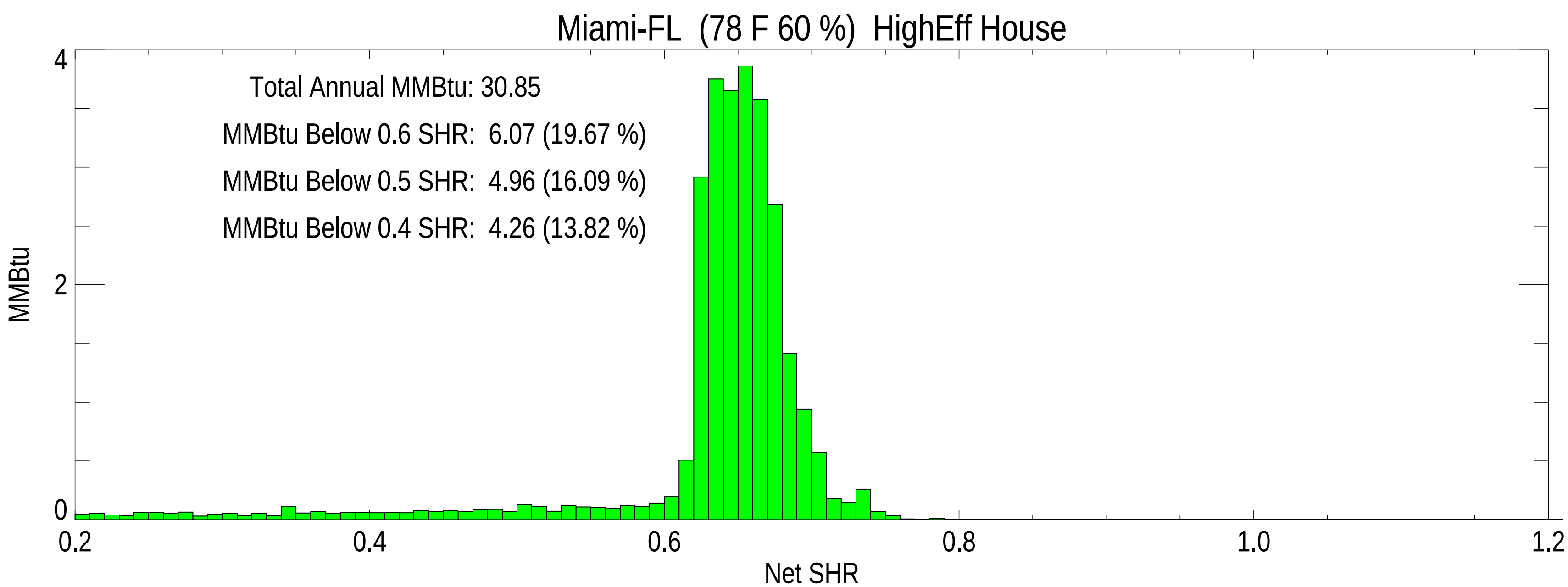

Fort_Worth-TX (75 F 60 %) HERS Reference House
Total Annual MMBtu: 44.02
MMBtu Below 0.6 SHR: 0.23 (0.52 %)
MMBtu Below 0.5 SHR: 0.21 (0.47 %)
MMBtu Below 0.4 SHR: 0.21 (0.47 %)
MMBtu
Net SHR
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2

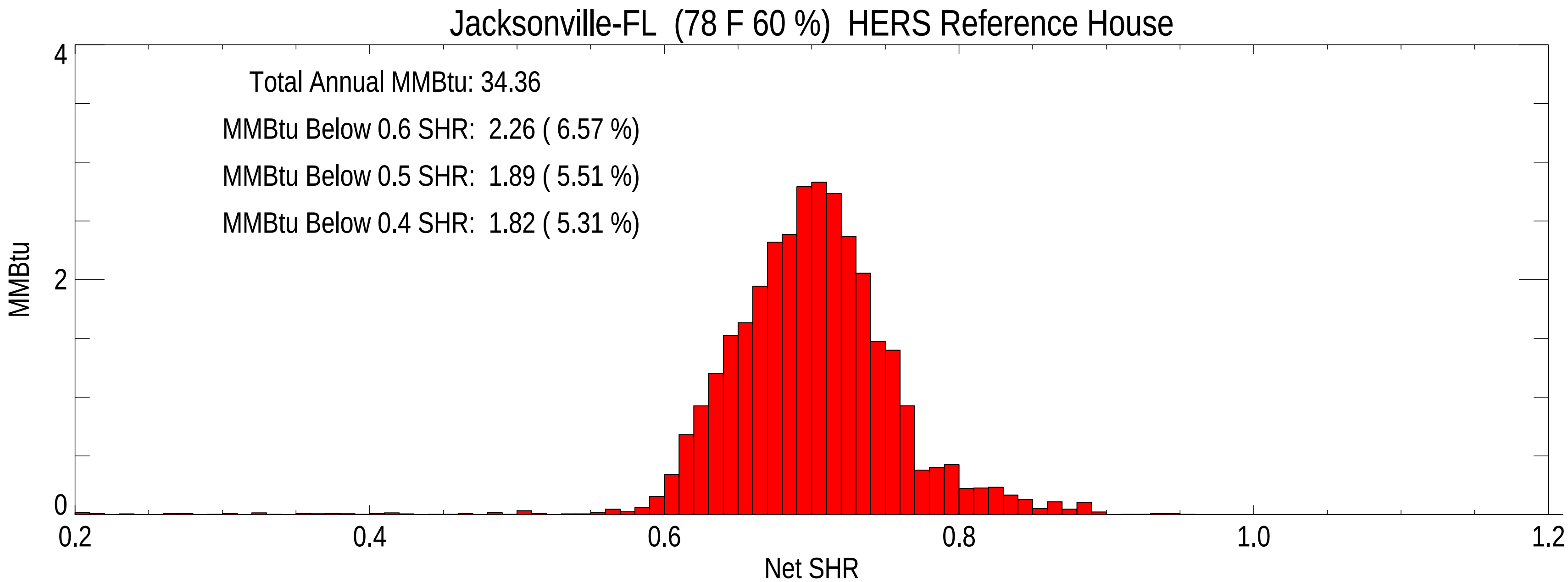

Fort_Worth-TX (75 F 60 %) HighEff House
Total Annual MMBtu: 32.17
MMBtu Below 0.6 SHR: 0.17 (0.53 %)
MMBtu Below 0.5 SHR: 0.15 (0.46 %)
MMBtu Below 0.4 SHR: 0.13 (0.42 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2

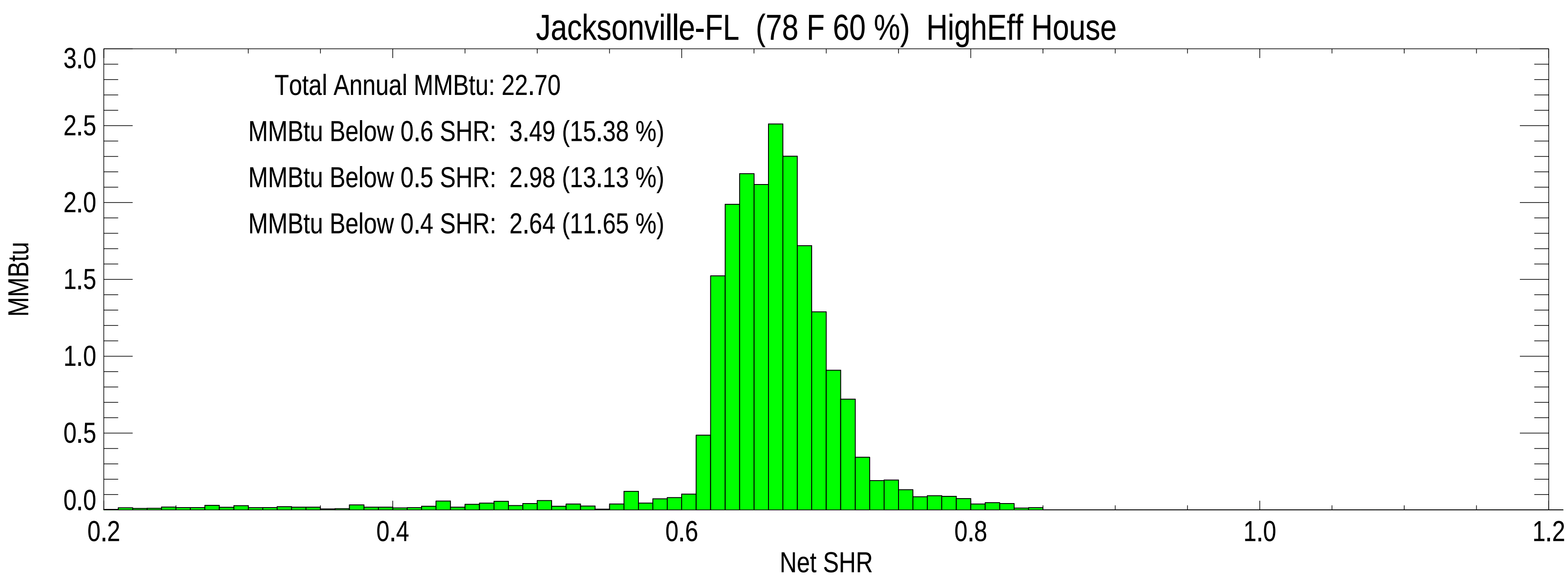

Wilmington-NC (75 F 60 %) HERS Reference House
Total Annual MMBtu: 34.35
MMBtu Below 0.6 SHR: 1.79 (5.22 %)
MMBtu Below 0.5 SHR: 1.52 (4.42 %)
MMBtu Below 0.4 SHR: 1.34 (3.89 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR


Wilmington-NC (75 F 60 %) HighEff House
Total Annual MMBtu: 25.88
MMBtu Below 0.6 SHR: 2.51 (9.68 %)
MMBtu Below 0.5 SHR: 1.96 (7.58 %)
MMBtu Below 0.4 SHR: 1.51 (5.82 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

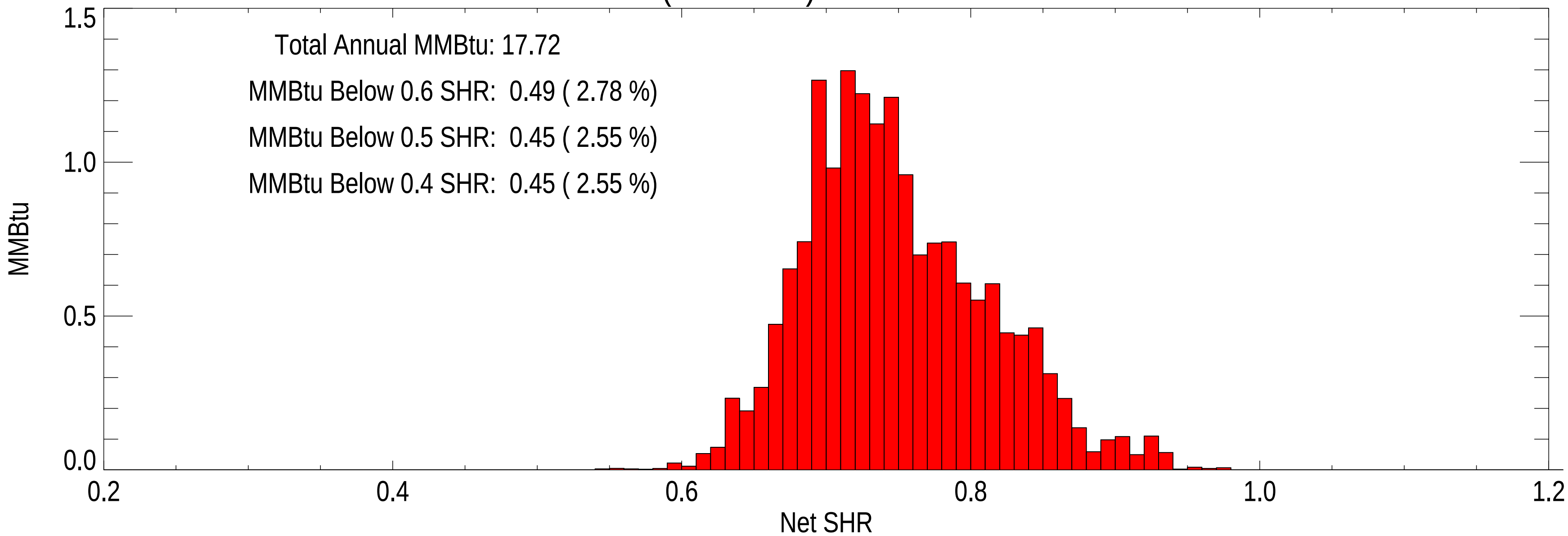

Miami-FL (78 F 60 %) HERS Reference House
Total Annual MMBtu: 50.88
MMBtu Below 0.6 SHR: 3.02 (5.93 %)
MMBtu Below 0.5 SHR: 2.72 (5.35 %)
MMBtu Below 0.4 SHR: 2.62 (5.15 %)
MMBtu
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR


Miami-FL (78 F 60 %) HighEff House
Total Annual MMBtu: 30.85
MMBtu Below 0.6 SHR: 6.07 (19.67 %)
MMBtu Below 0.5 SHR: 4.96 (16.09 %)
MMBtu Below 0.4 SHR: 4.26 (13.82 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

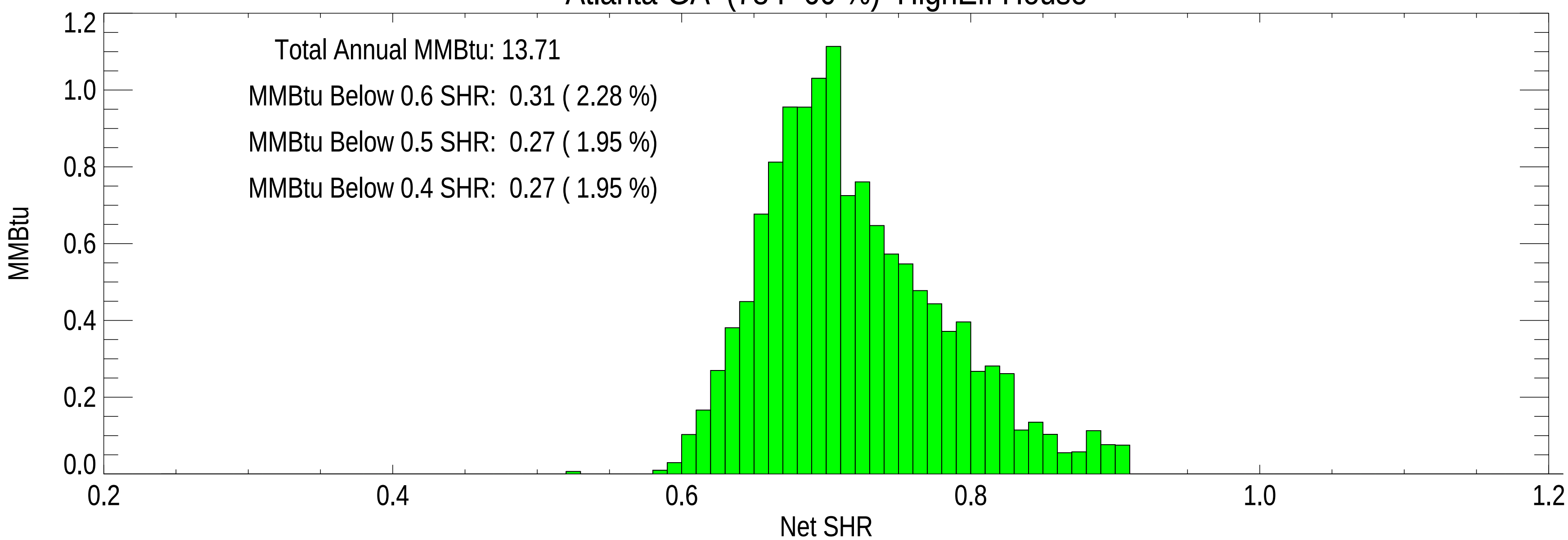

Jacksonville-FL (78 F 60 %) HERS Reference House
Total Annual MMBtu: 34.36
MMBtu Below 0.6 SHR: 2.26 (6.57 %)
MMBtu Below 0.5 SHR: 1.89 (5.51 %)
MMBtu Below 0.4 SHR: 1.82 (5.31 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

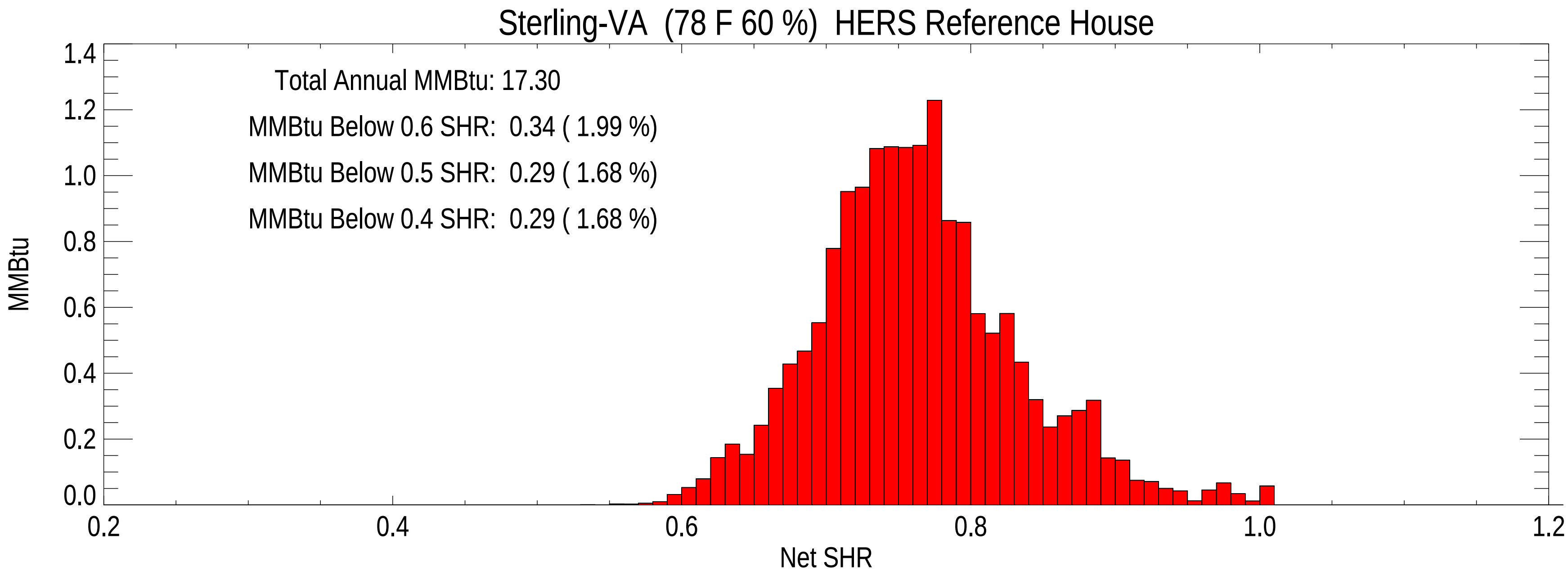

Jacksonville-FL (78 F 60 %) HighEff House
Total Annual MMBtu: 22.70
MMBtu Below 0.6 SHR: 3.49 (15.38 %)
MMBtu Below 0.5 SHR: 2.98 (13.13 %)
MMBtu Below 0.4 SHR: 2.64 (11.65 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

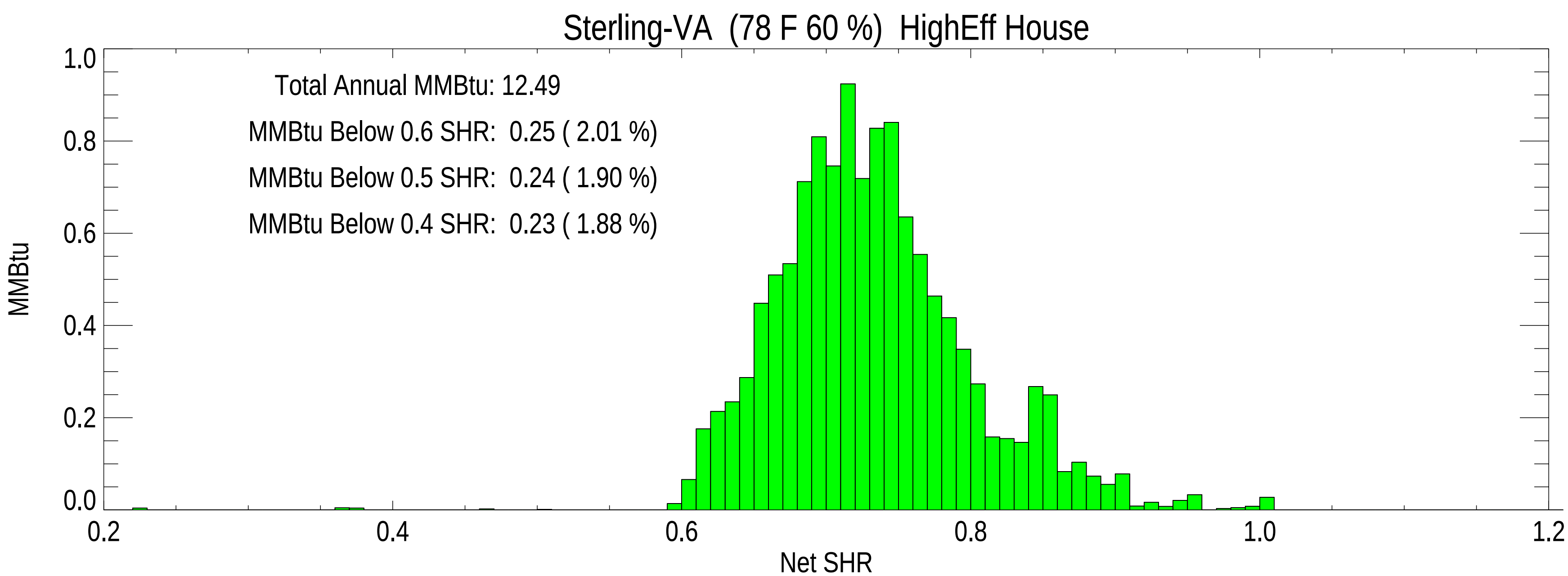
Atlanta-GA (78 F 60 %) HERS Reference House

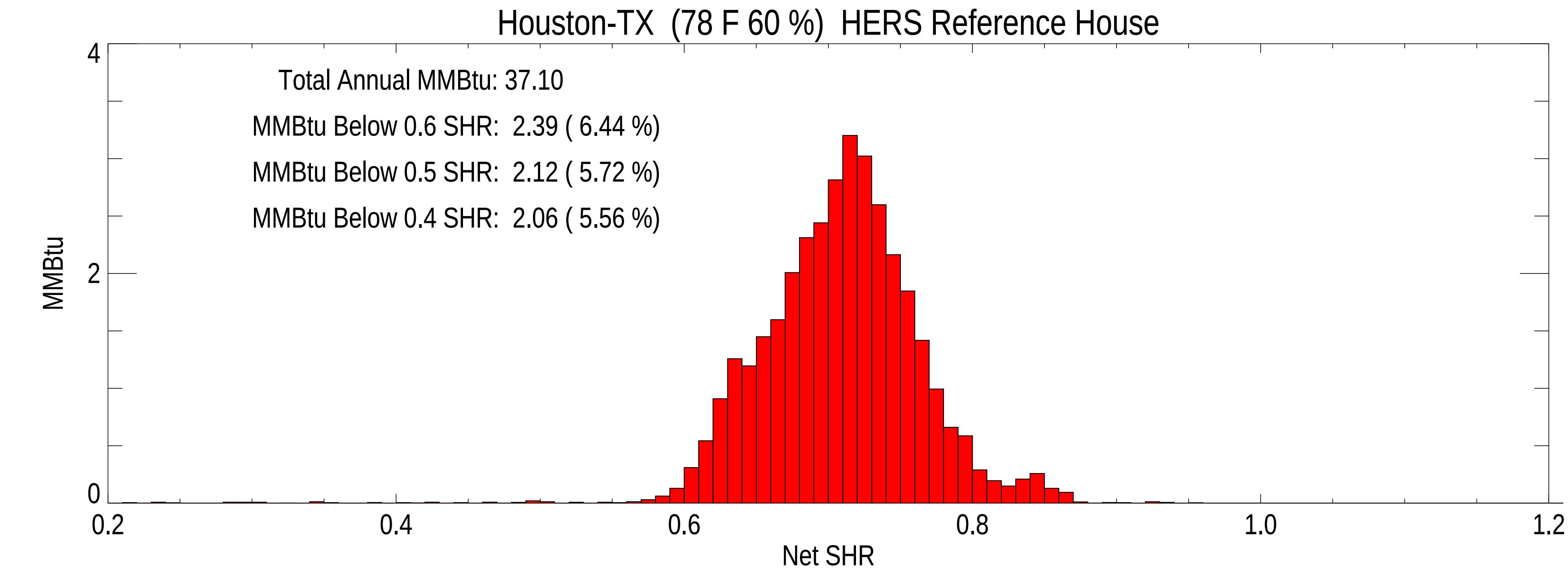


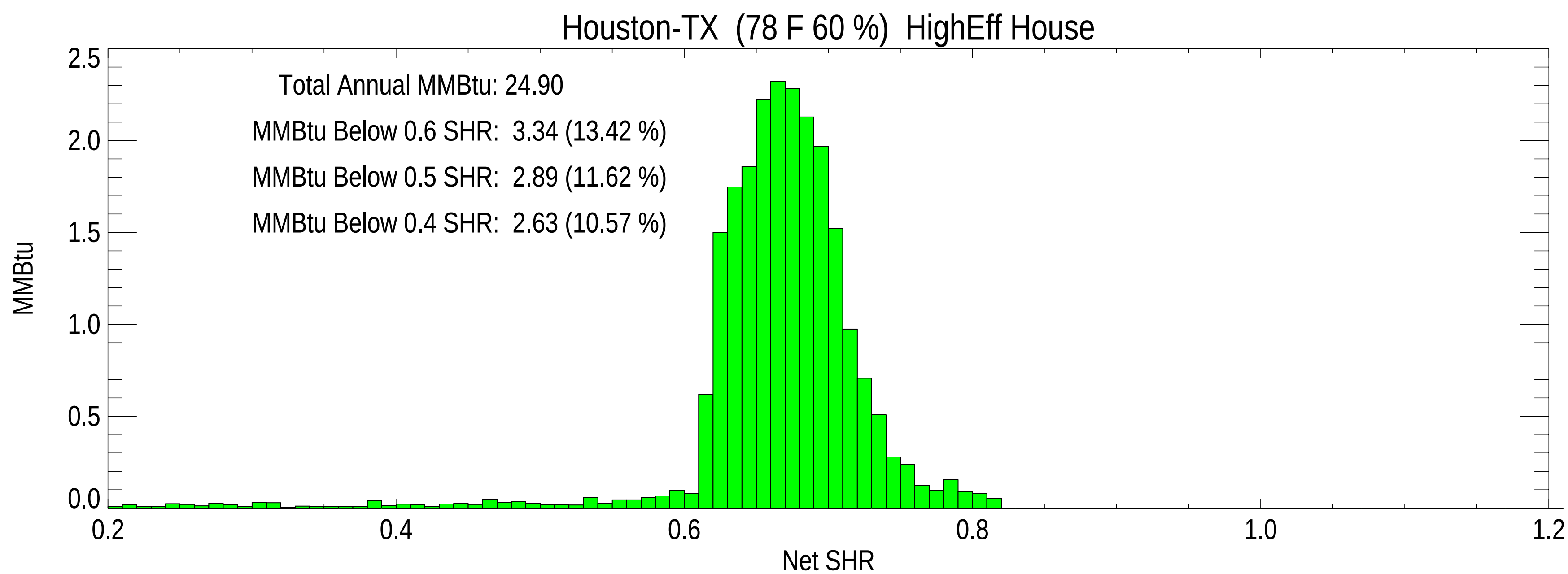
Atlanta-GA (78 F 60 %) HighEff House

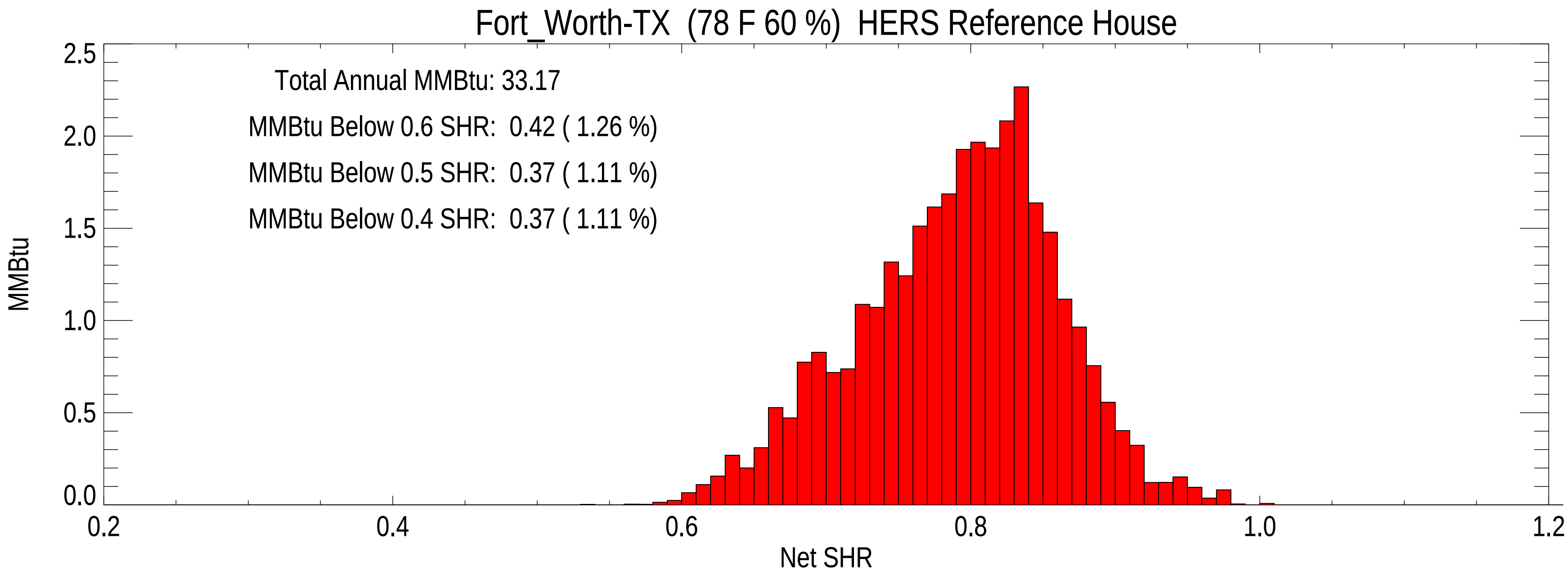


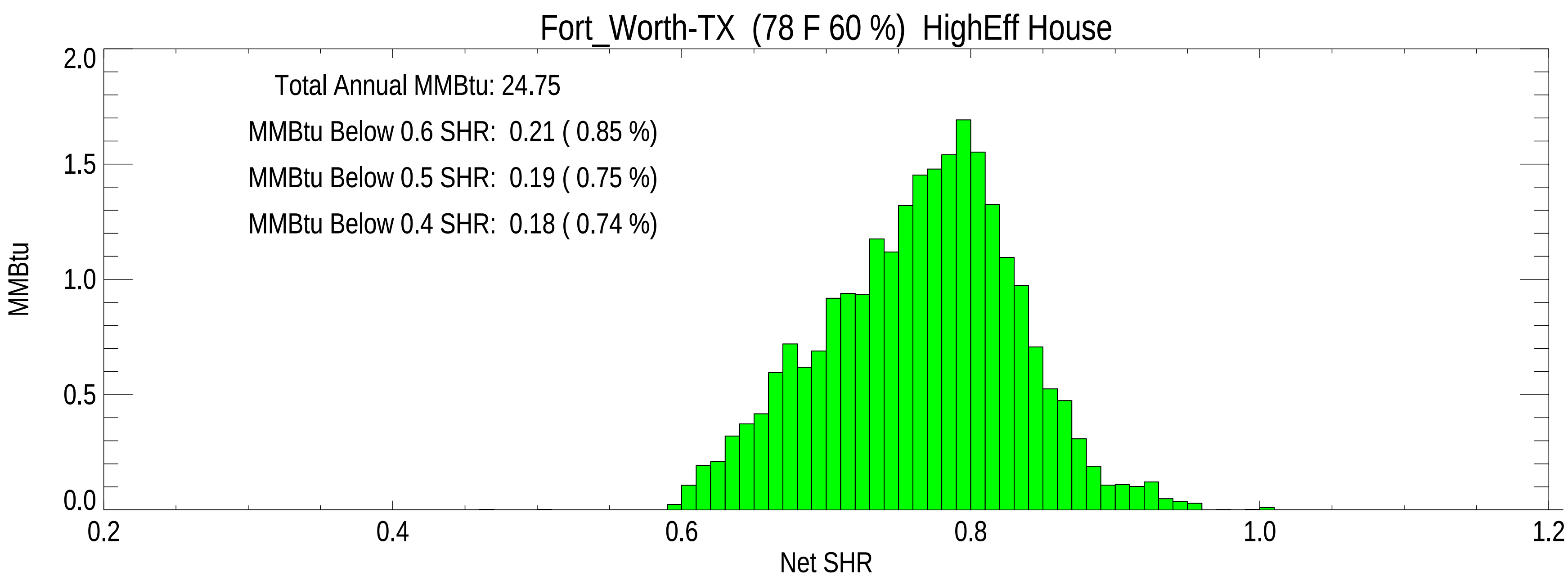

Sterling-VA (78 F 60 %) HERS Reference House
Total Annual MMBtu: 17.30
MMBtu Below 0.6 SHR: 0.34 (1.99 %)
MMBtu Below 0.5 SHR: 0.29 (1.68 %)
MMBtu Below 0.4 SHR: 0.29 (1.68 %)
MMBtu
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

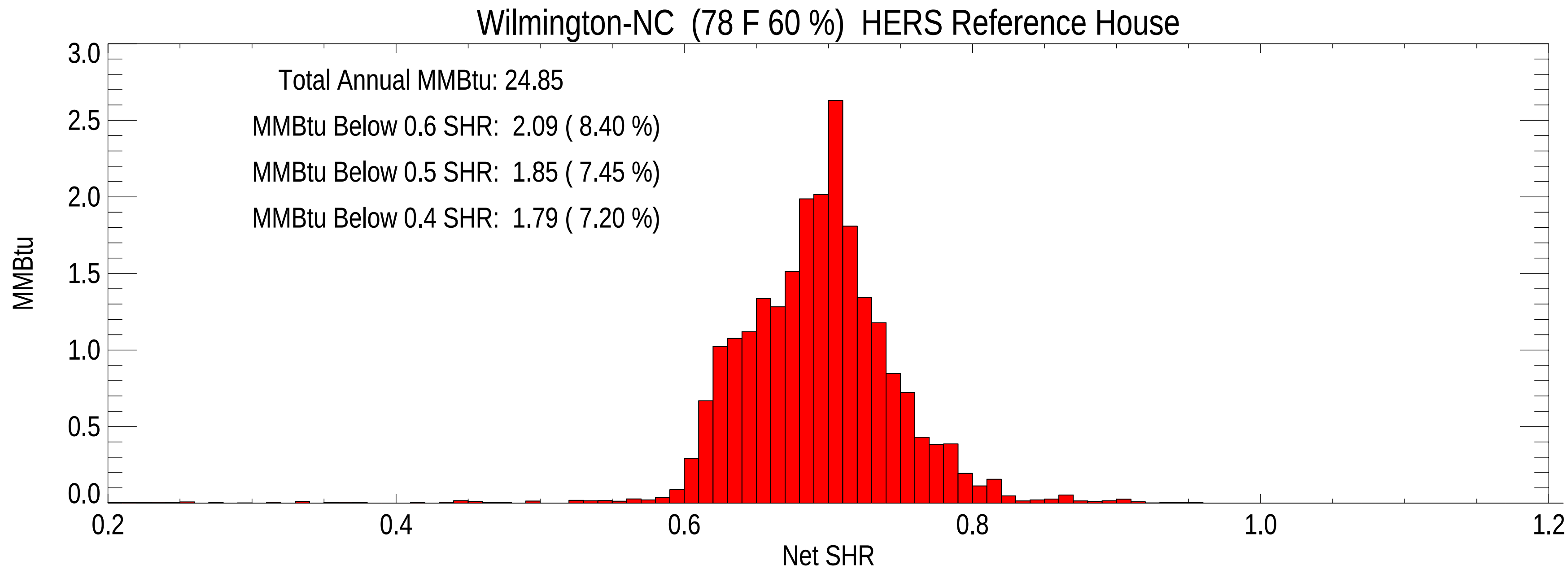

Sterling-VA (78 F 60 %) HighEff House
Total Annual MMBtu: 12.49
MMBtu Below 0.6 SHR: 0.25 (2.01 %)
MMBtu Below 0.5 SHR: 0.24 (1.90 %)
MMBtu Below 0.4 SHR: 0.23 (1.88 %)
MMBtu
0.0
0.2
0.4
0.6
0.8
1.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

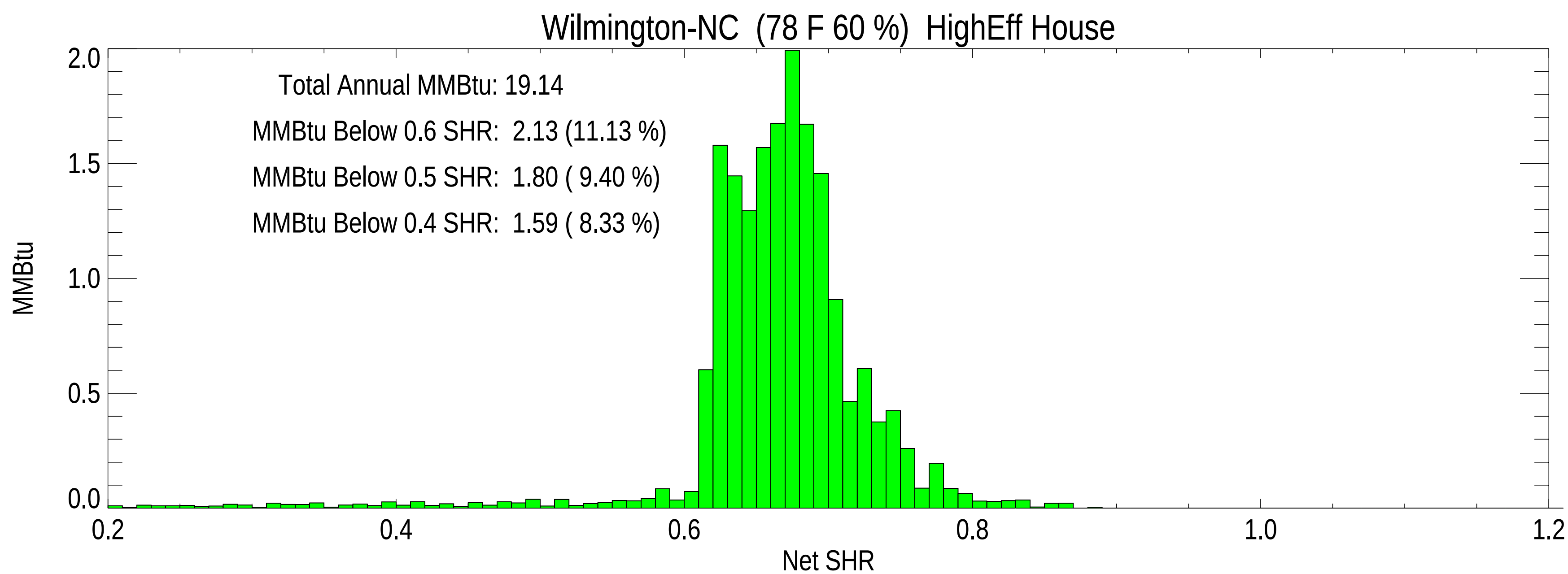

Houston-TX (78 F 60 %) HERS Reference House
Total Annual MMBtu: 37.10
MMBtu Below 0.6 SHR: 2.39 (6.44 %)
MMBtu Below 0.5 SHR: 2.12 (5.72 %)
MMBtu Below 0.4 SHR: 2.06 (5.56 %)
MMBtu
0
2
4
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

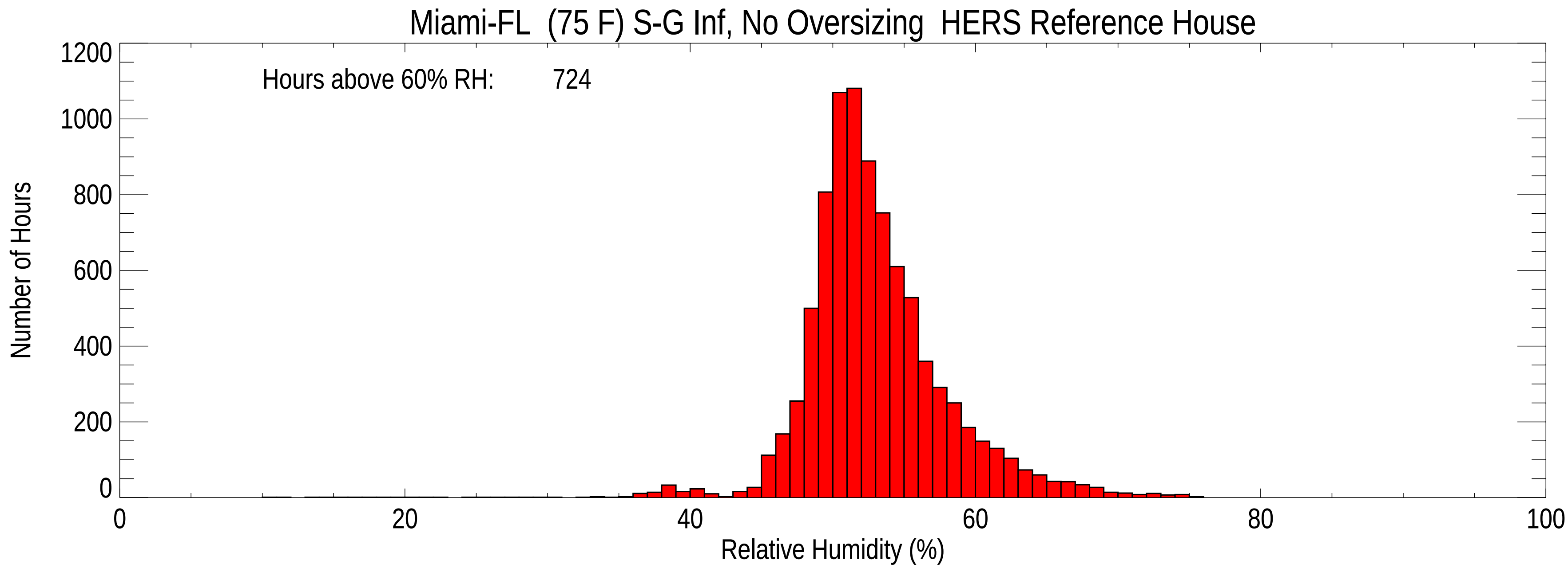

Houston-TX (78 F 60 %) HighEff House
Total Annual MMBtu: 24.90
MMBtu Below 0.6 SHR: 3.34 (13.42 %)
MMBtu Below 0.5 SHR: 2.89 (11.62 %)
MMBtu Below 0.4 SHR: 2.63 (10.57 %)
MMBtu
0.0
0.5
1.0
1.5
2.0
2.5
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR


Fort_Worth-TX (78 F 60 %) HERS Reference House
Total Annual MMBtu: 33.17
MMBtu Below 0.6 SHR: 0.42 (1.26 %)
MMBtu Below 0.5 SHR: 0.37 (1.11 %)
MMBtu Below 0.4 SHR: 0.37 (1.11 %)
MMBtu
2.5
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR

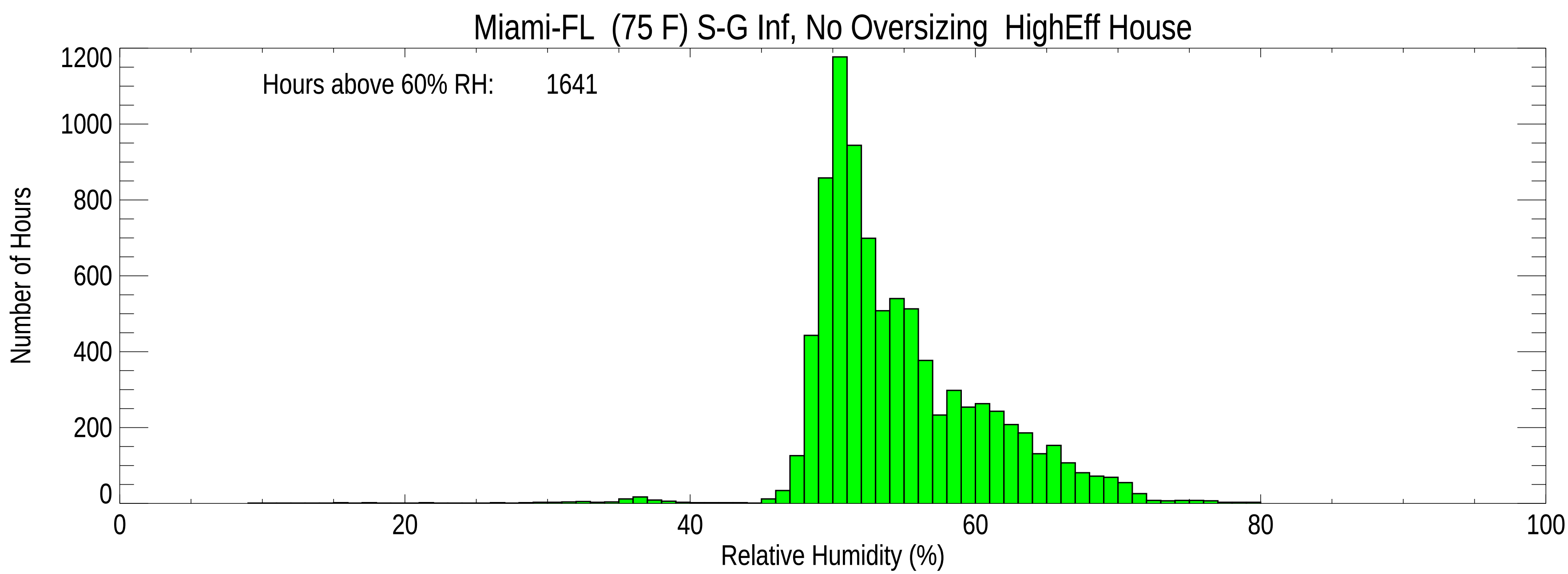

Fort_Worth-TX (78 F 60 %) HighEff House
Total Annual MMBtu: 24.75
MMBtu Below 0.6 SHR: 0.21 (0.85 %)
MMBtu Below 0.5 SHR: 0.19 (0.75 %)
MMBtu Below 0.4 SHR: 0.18 (0.74 %)
MMBtu
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Net SHR


Wilmington-NC (78 F 60 %) HERS Reference House
Total Annual MMBtu: 24.85
MMBtu Below 0.6 SHR: 2.09 (8.40 %)
MMBtu Below 0.5 SHR: 1.85 (7.45 %)
MMBtu Below 0.4 SHR: 1.79 (7.20 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0.2
0.4
0.6
0.8
1.0
1.2

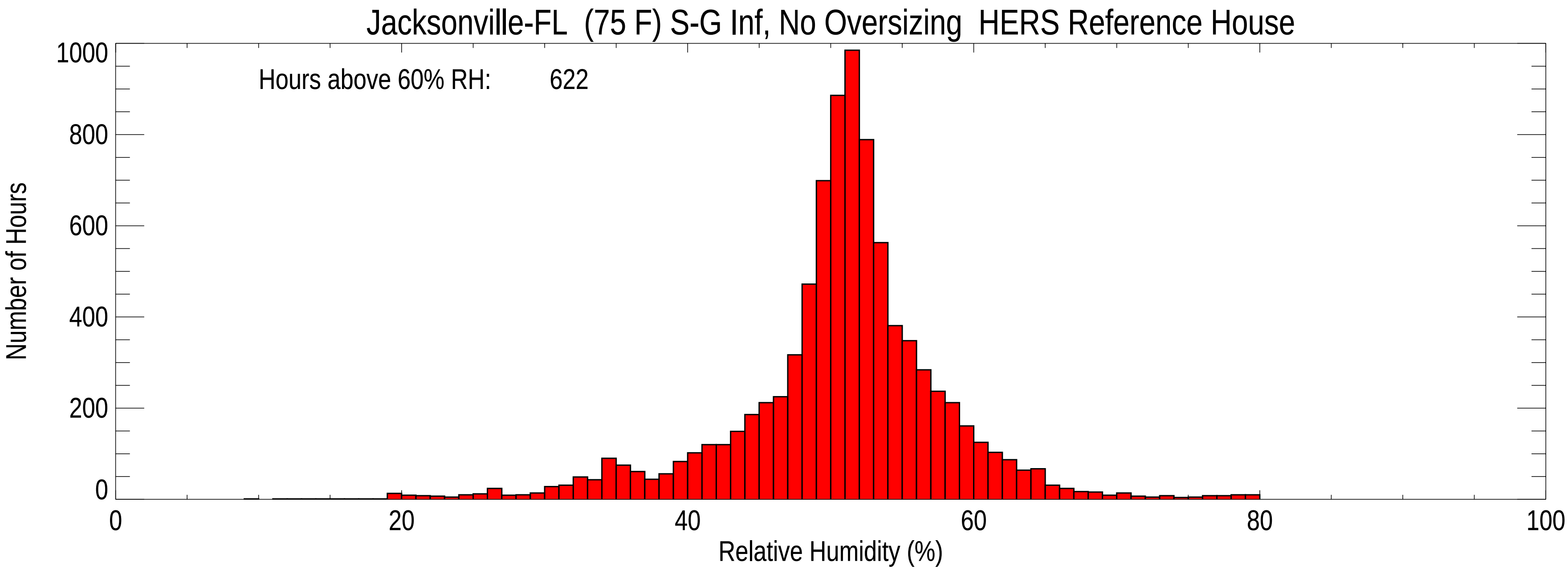

Wilmington-NC (78 F 60 %) HighEff House
Total Annual MMBtu: 19.14
MMBtu Below 0.6 SHR: 2.13 (11.13 %)
MMBtu Below 0.5 SHR: 1.80 (9.40 %)
MMBtu Below 0.4 SHR: 1.59 (8.33 %)
MMBtu
Net SHR
0.0
0.5
1.0
1.5
2.0
0.2
0.4
0.6
0.8
1.0
1.2

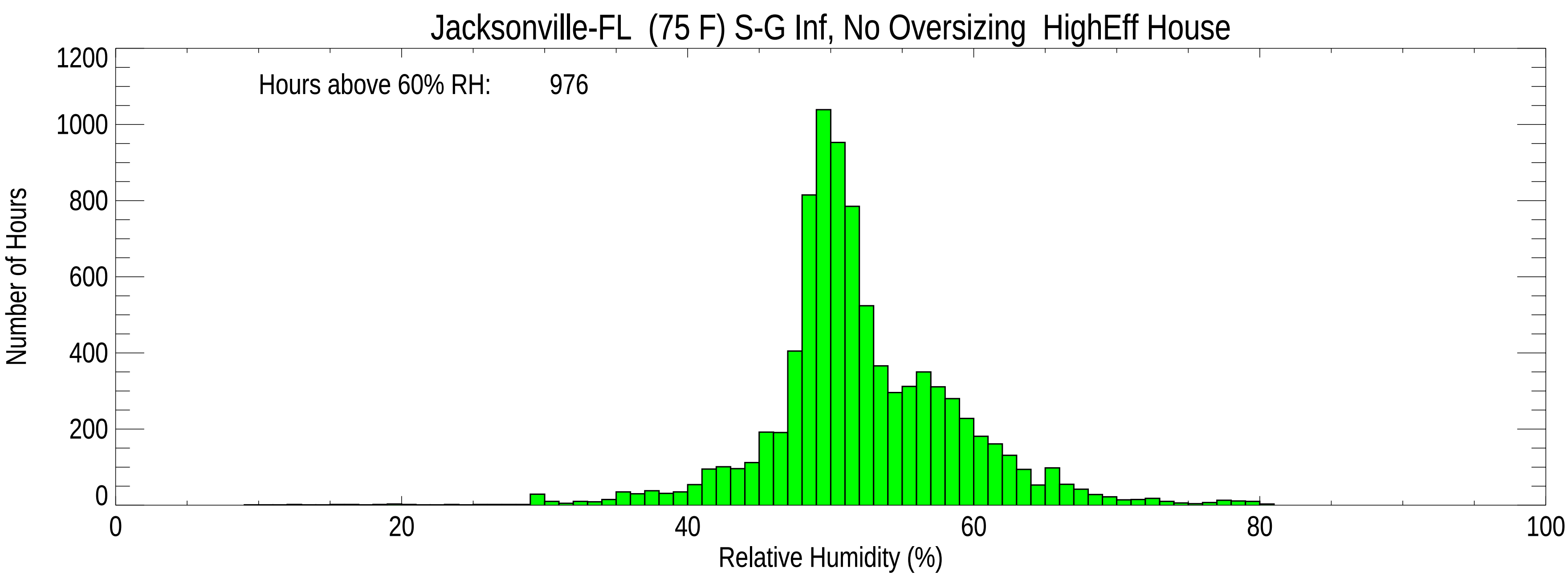


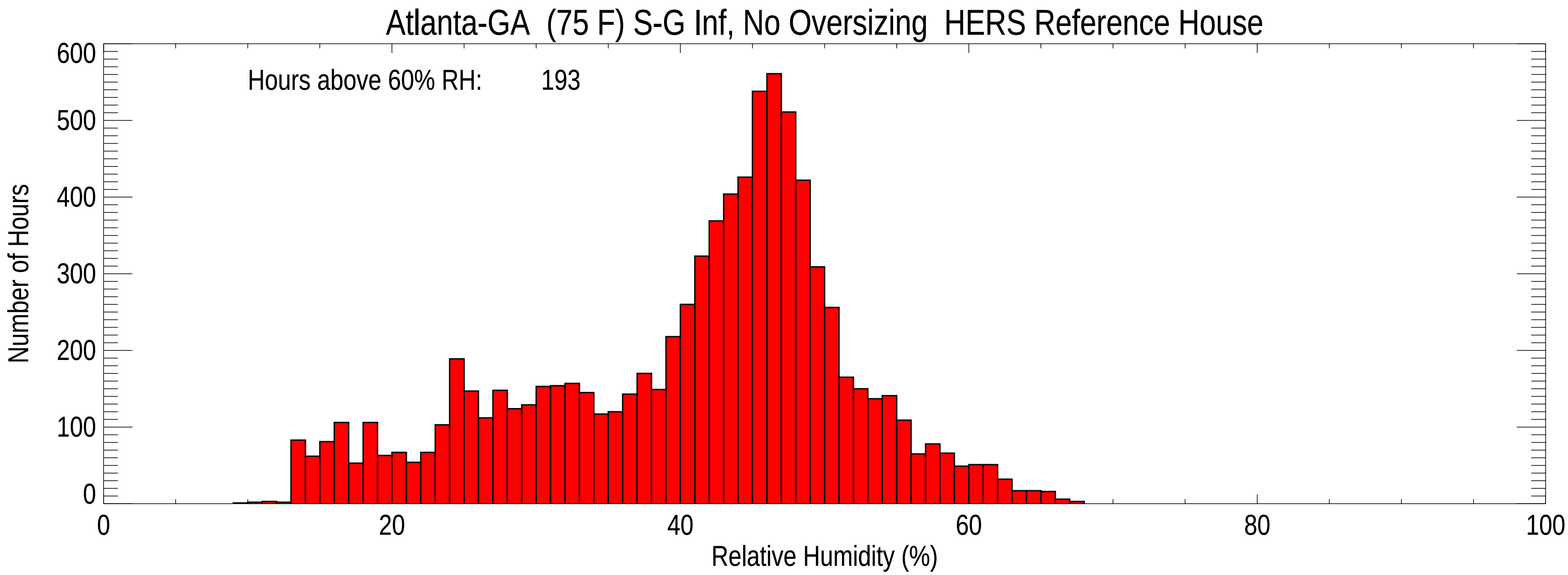
Miami-FL (75 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 724
Number of Hours
Relative Humidity (%)
0
200
400
600
800
1000
1200
0
20
40
60
80
100

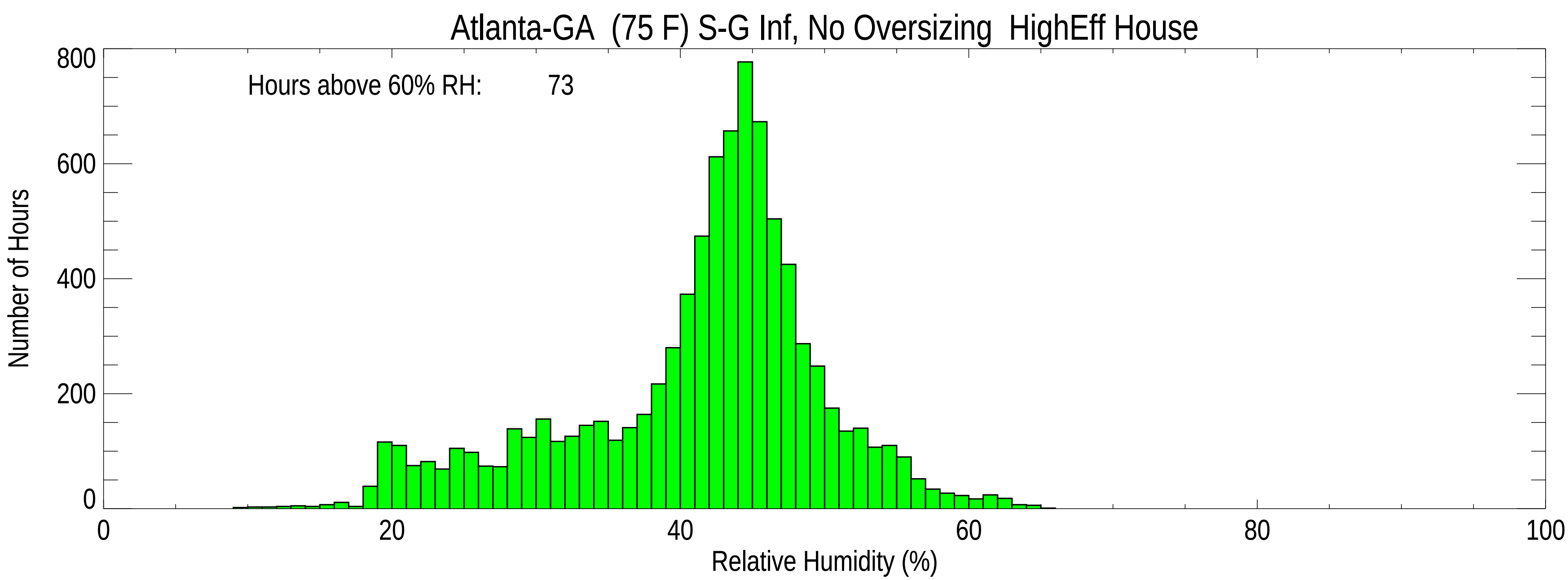


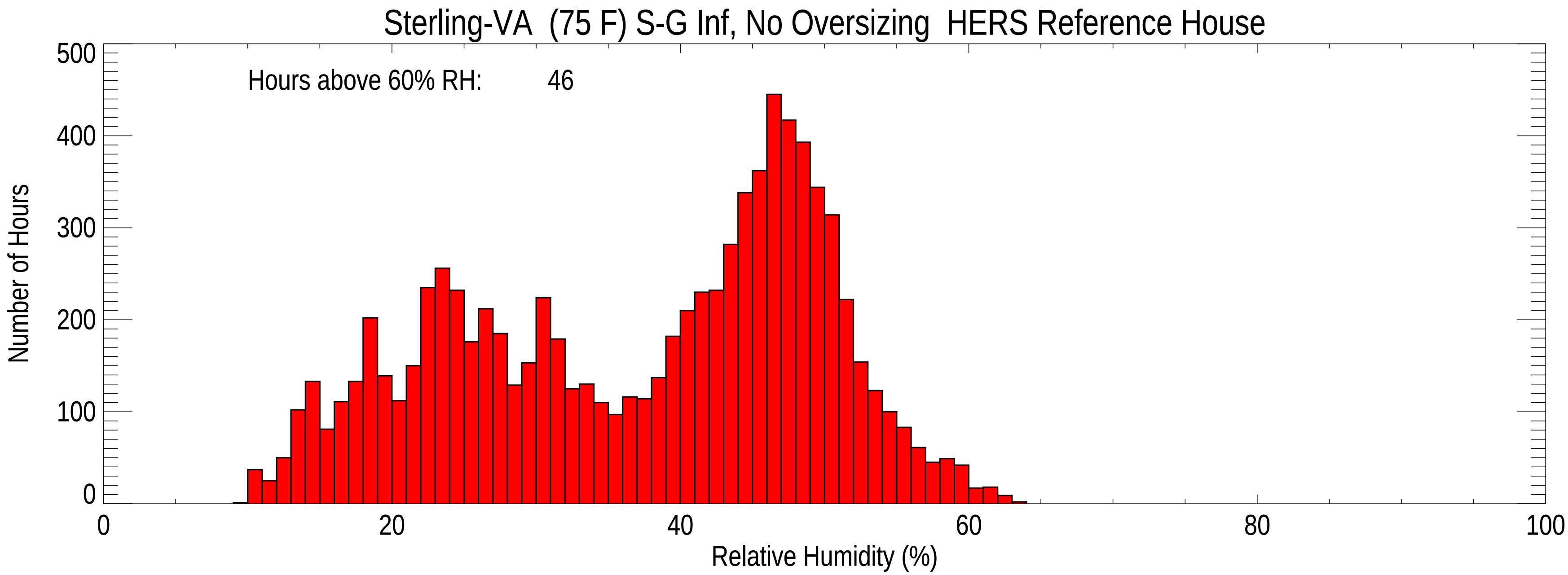
Miami-FL (75 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 1641
Number of Hours
Relative Humidity (%)
0
200
400
600
800
1000
1200
0
20
40
60
80
100

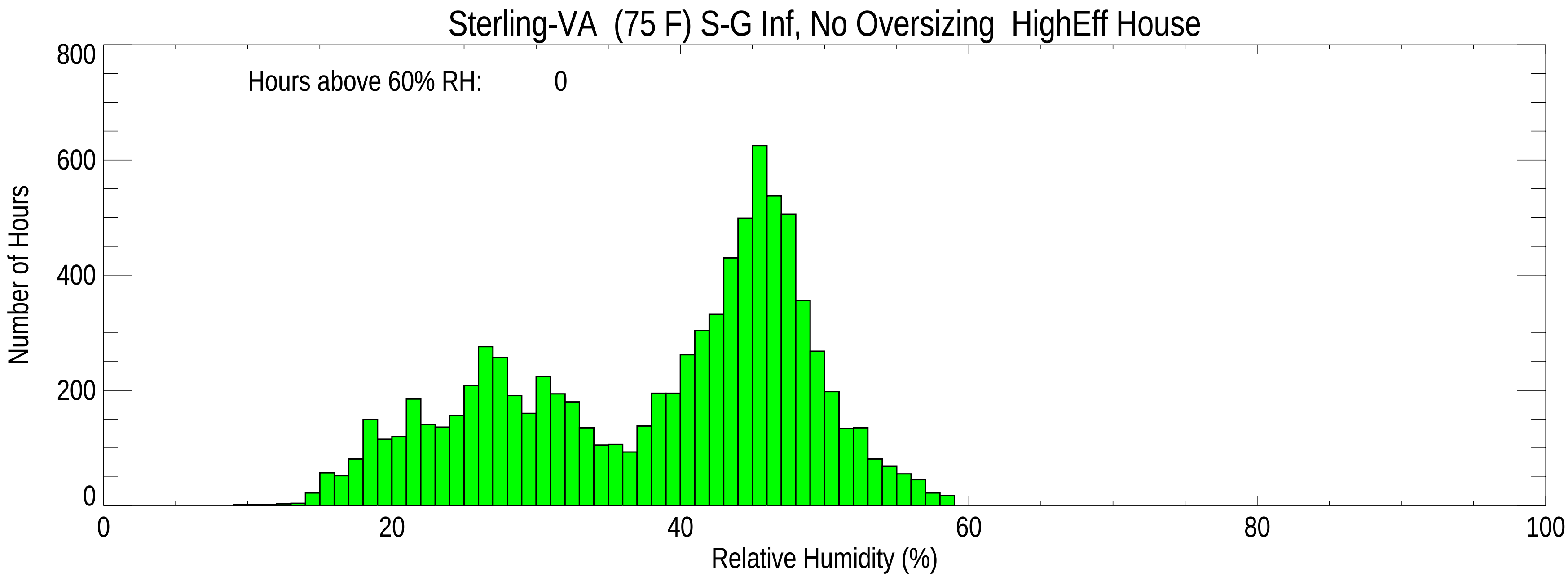

Jacksonville-FL (75 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 622
Number of Hours
0
200
400
600
800
1000
0
20
40
60
80
100
Relative Humidity (%)

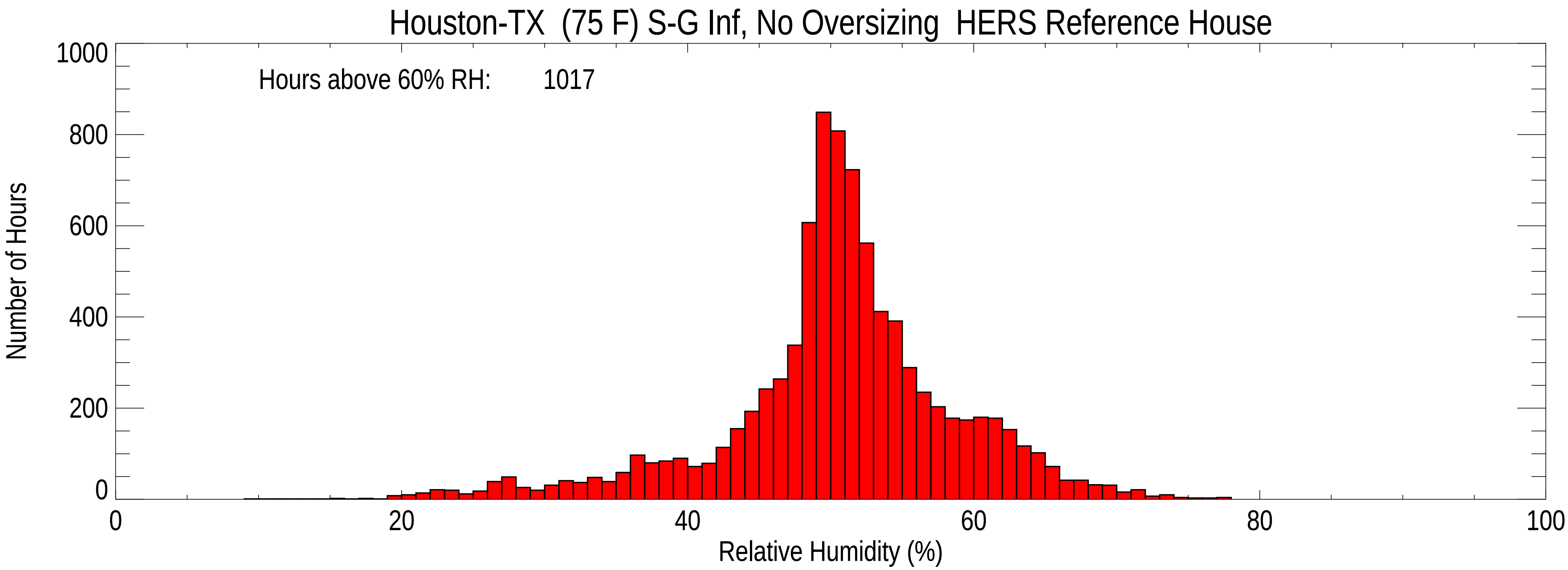

Jacksonville-FL (75 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 976
Number of Hours
0
200
400
600
800
1000
1200
0
20
40
60
80
100
Relative Humidity (%)

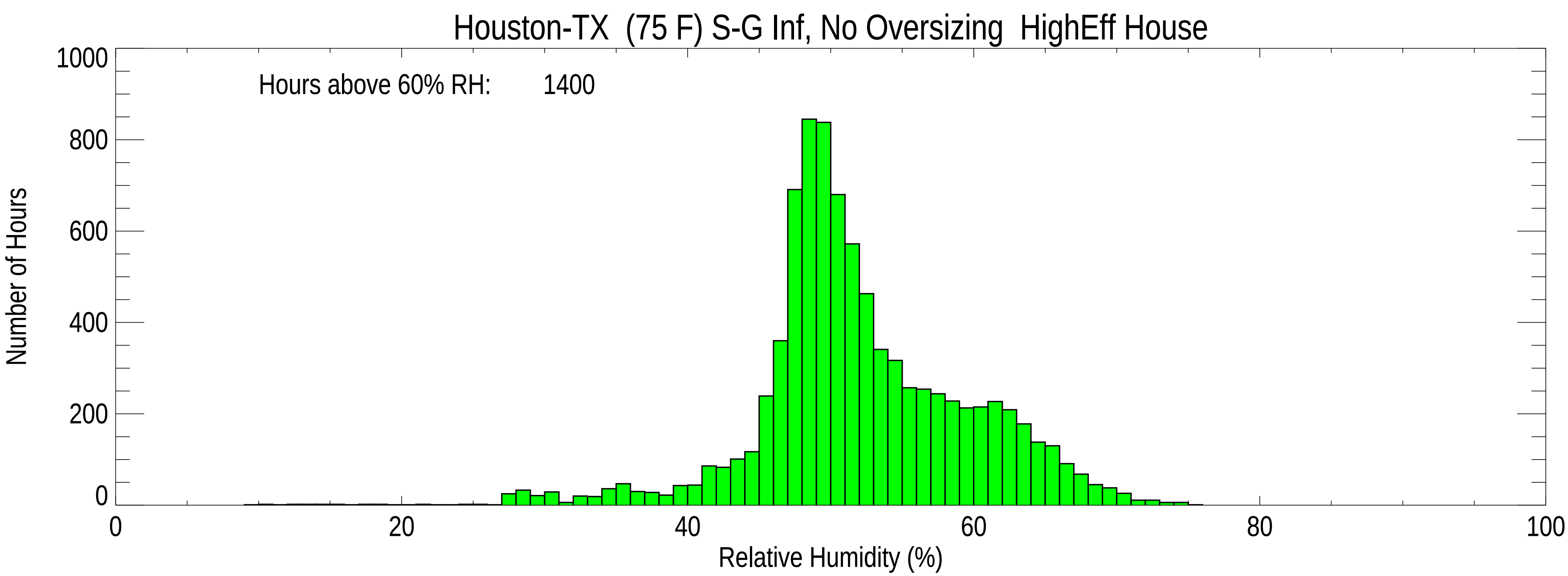

Atlanta-GA (75 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 193
Number of Hours
Relative Humidity (%)
0
100
200
300
400
500
600
0
20
40
60
80
100

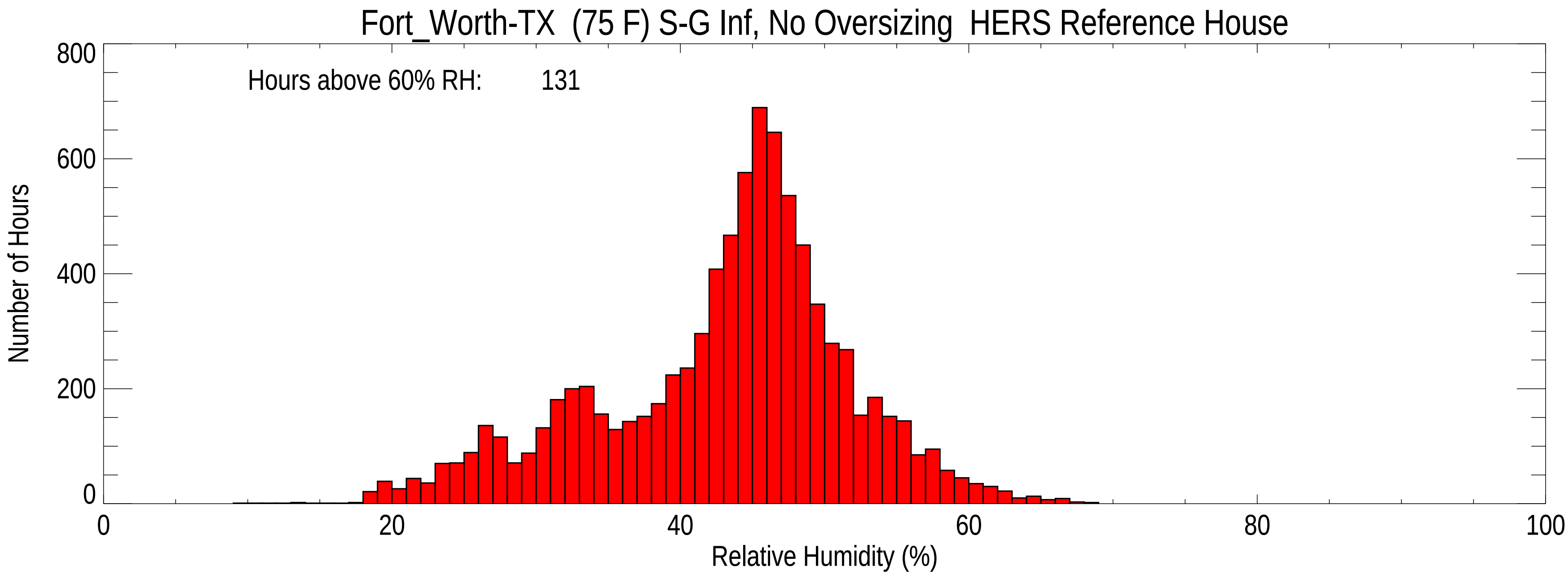

Atlanta-GA (75 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 73
Number of Hours
Relative Humidity (%)
0
200
400
600
800
0
20
40
60
80
100


Sterling-VA (75 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 46
Number of Hours
500
400
300
200
100
0
0
20
40
60
80
100
Relative Humidity (%)

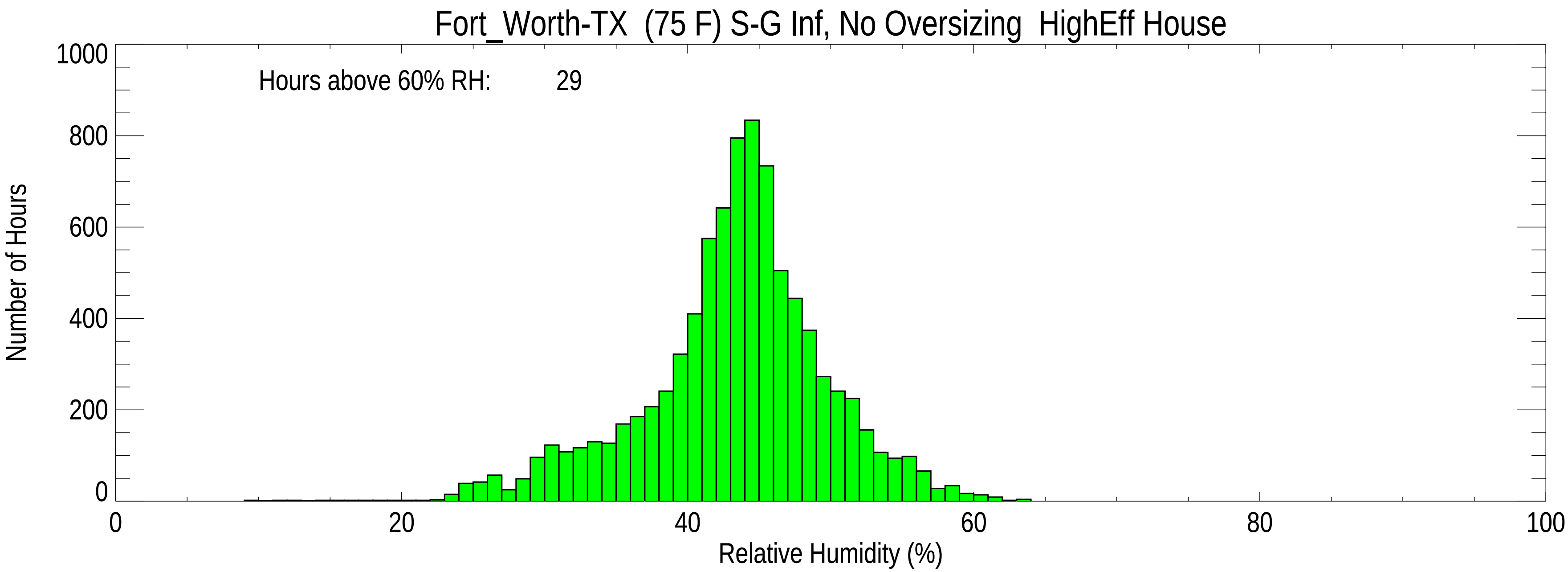

Sterling-VA (75 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 0
Number of Hours
800
600
400
200
0
0
20
40
60
80
100
Relative Humidity (%)


Houston-TX (75 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 1017
Number of Hours
Relative Humidity (%)
0
200
400
600
800
1000
0
20
40
60
80
100

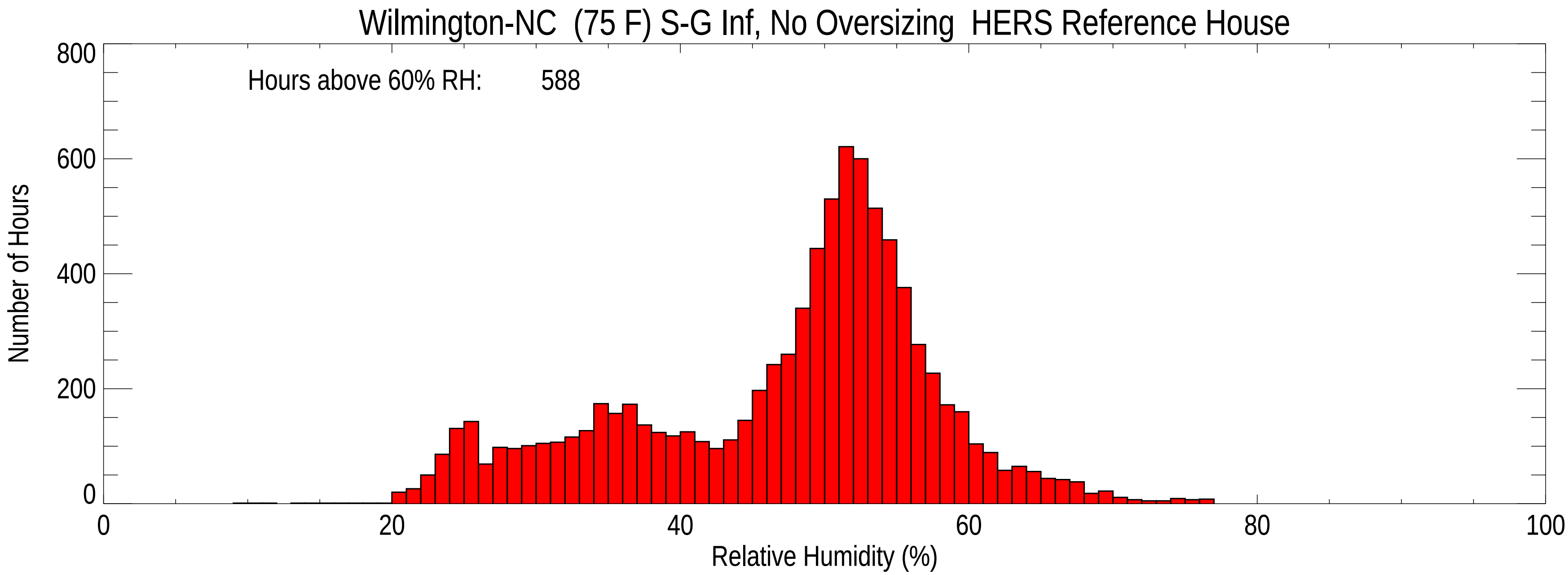

Houston-TX (75 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 1400
Number of Hours
Relative Humidity (%)
0
200
400
600
800
1000
0
20
40
60
80
100

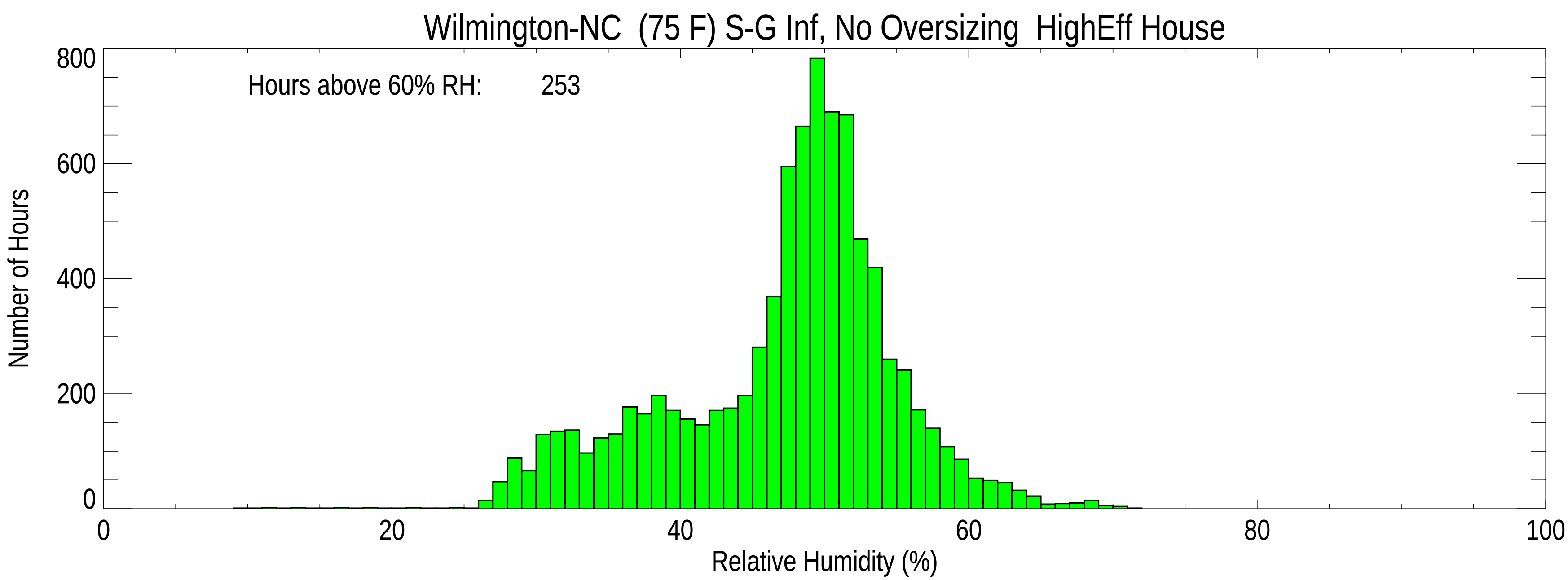


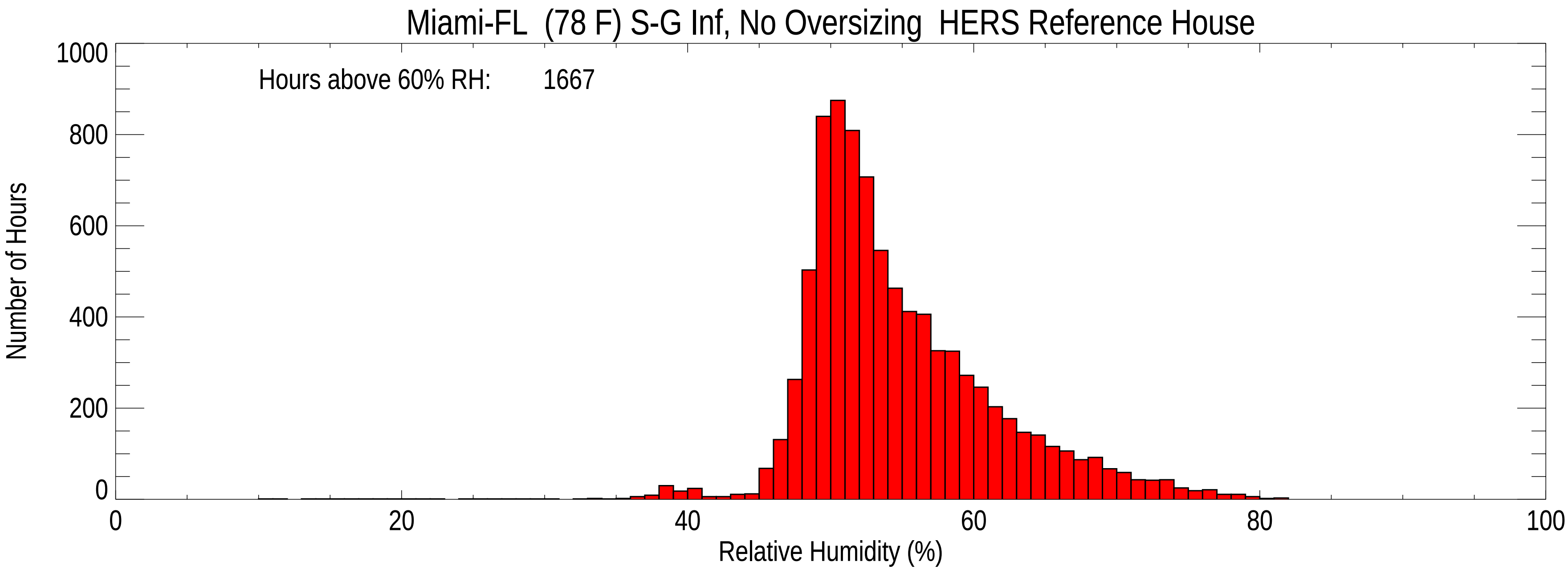
Fort_Worth-TX (75 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 131
Number of Hours
800
600
400
200
0
0
20
40
60
80
100
Relative Humidity (%)



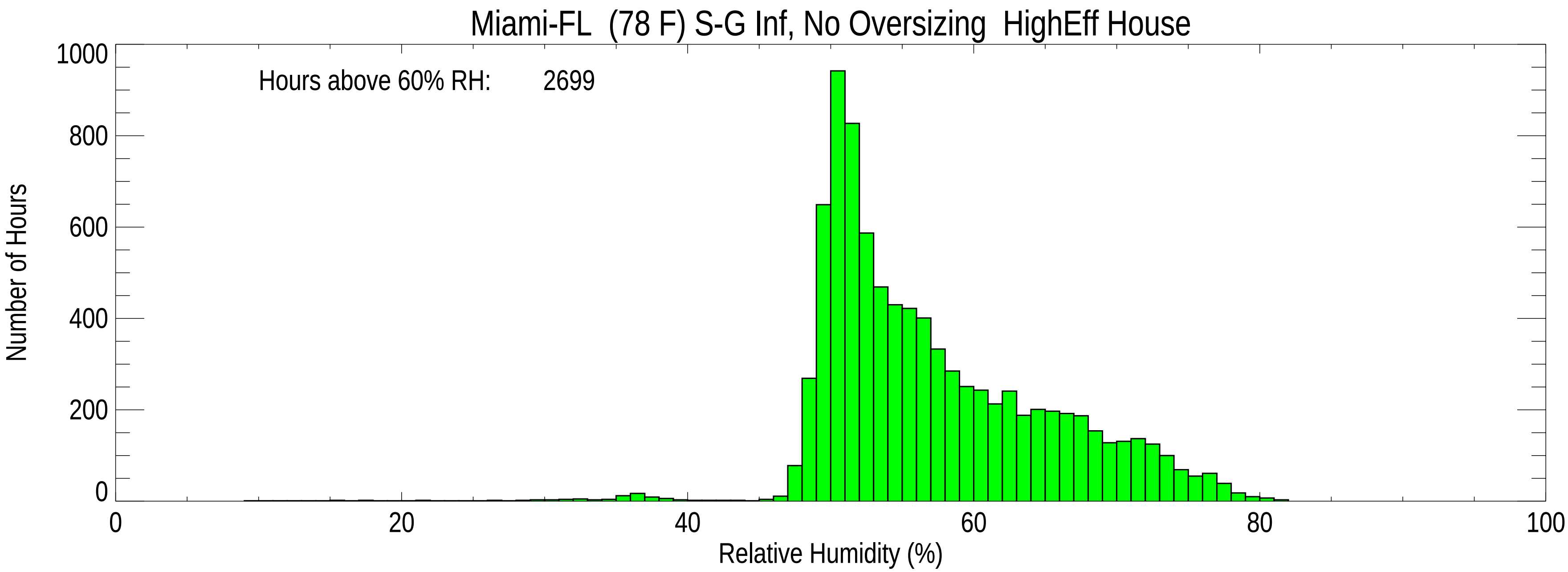
Fort_Worth-TX (75 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 29
Number of Hours
1000
800
600
400
200
0
0
20
40
60
80
100
Relative Humidity (%)


Wilmington-NC (75 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 588
Number of Hours
800
600
400
200
0
0
20
40
60
80
100
Relative Humidity (%)

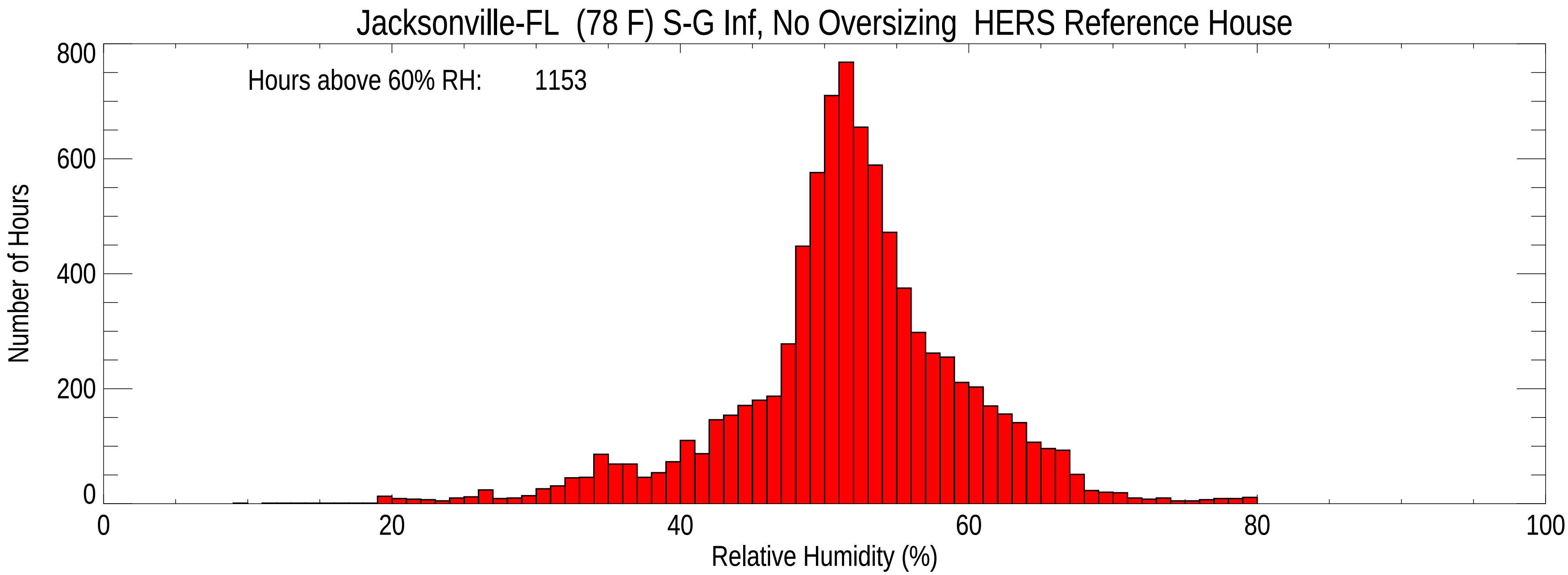

Wilmington-NC (75 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 253
Number of Hours
800
600
400
200
0
0
20
40
60
80
100
Relative Humidity (%)

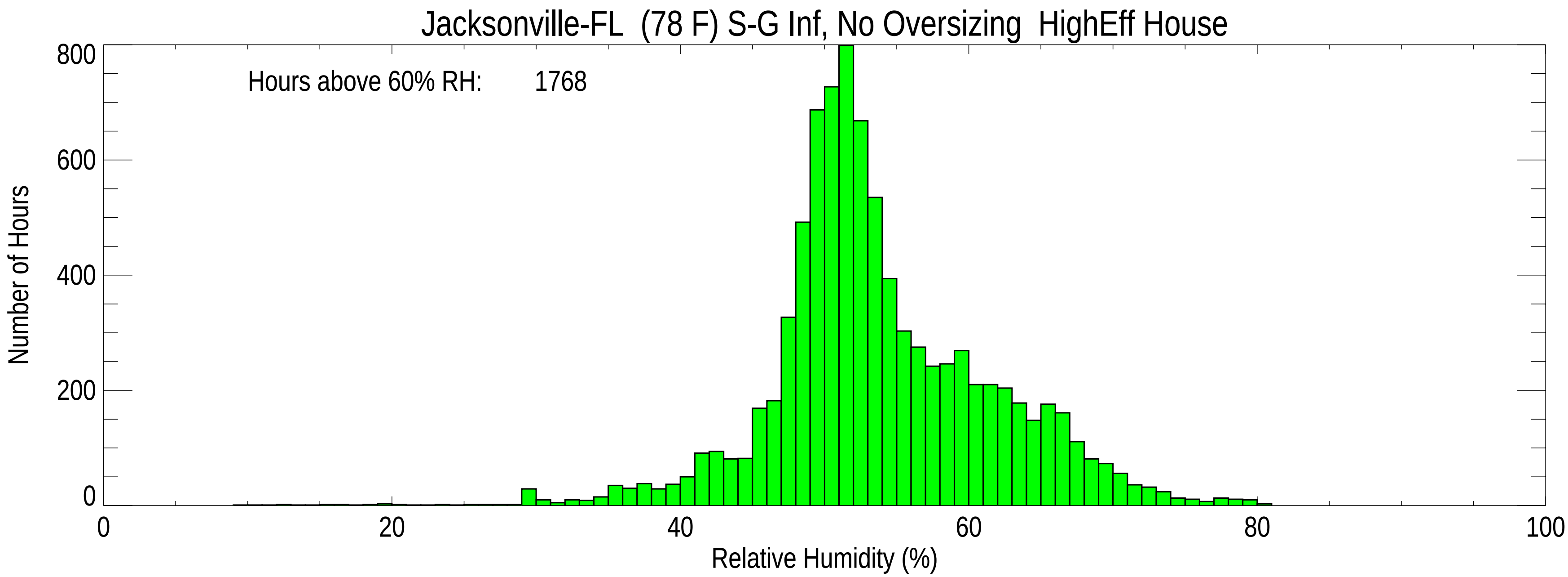


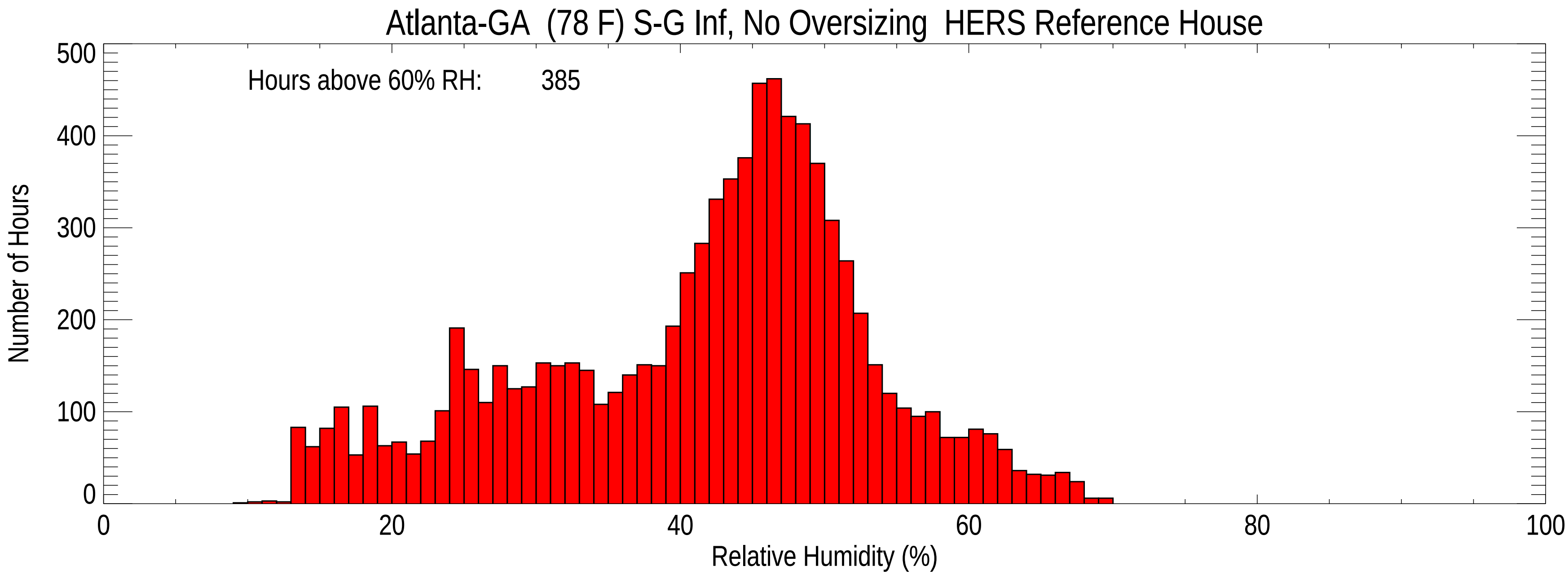
Miami-FL (78 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 1667
Number of Hours
Relative Humidity (%)

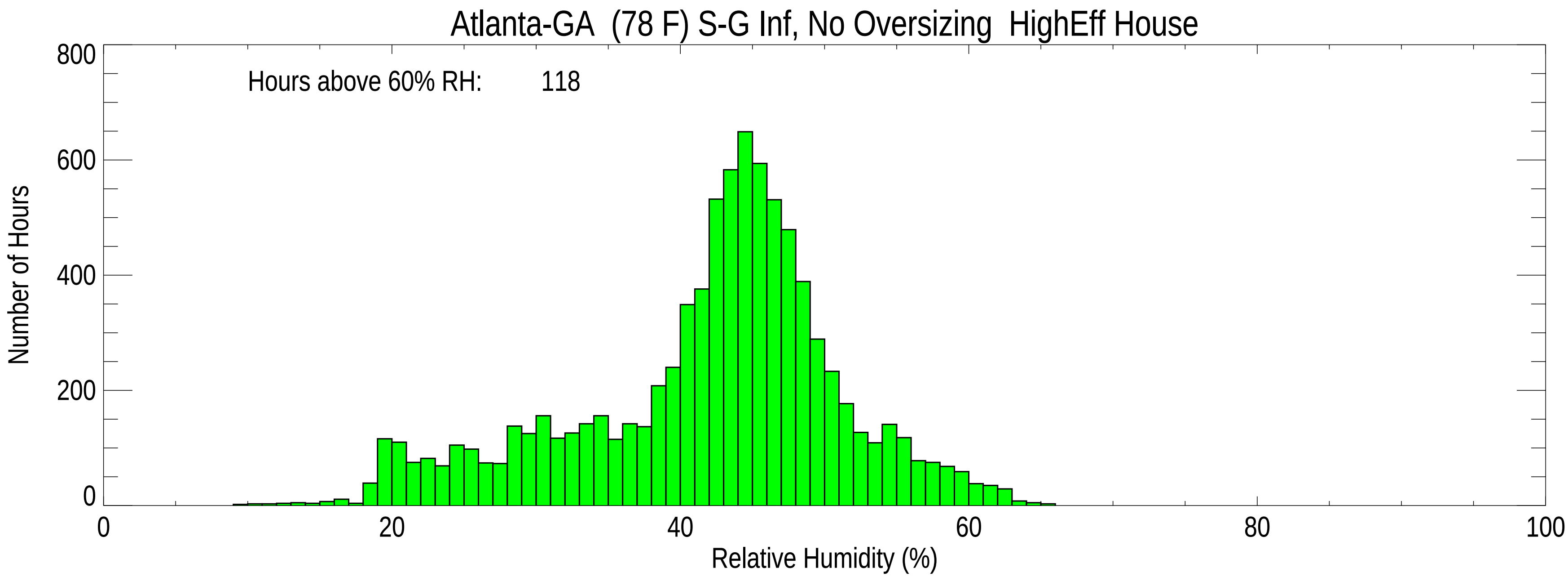


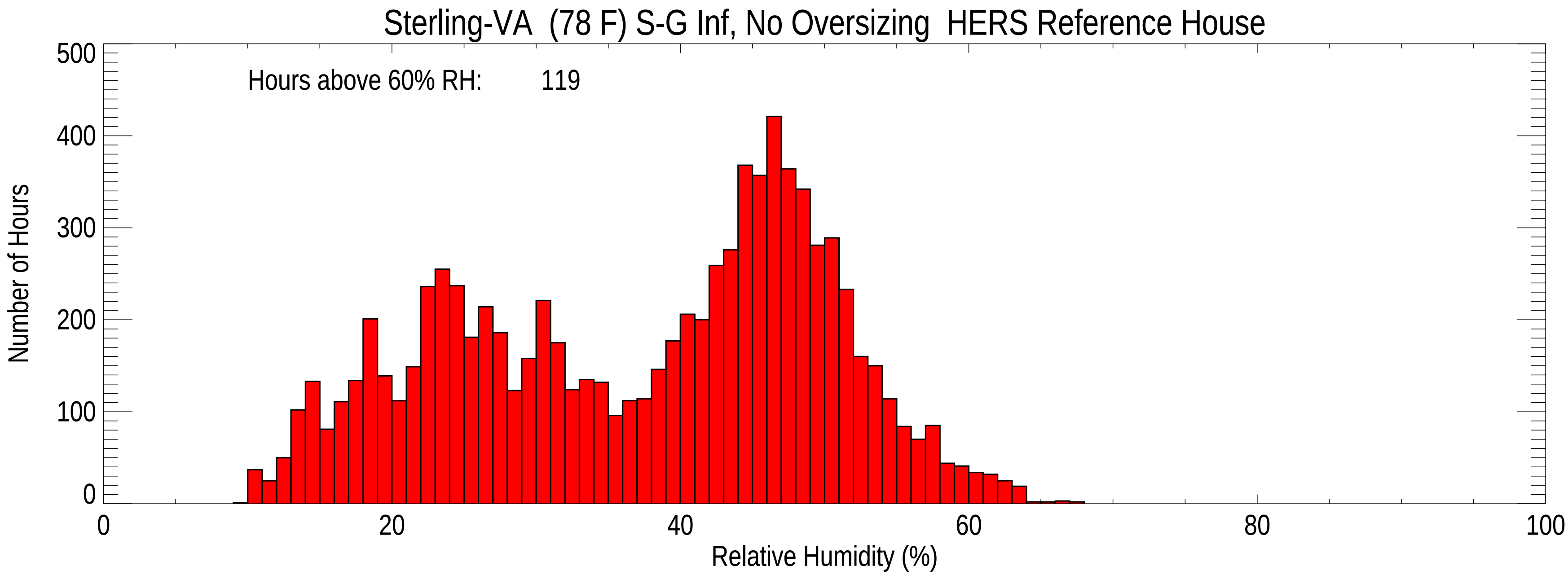
Miami-FL (78 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 2699
Number of Hours
Relative Humidity (%)

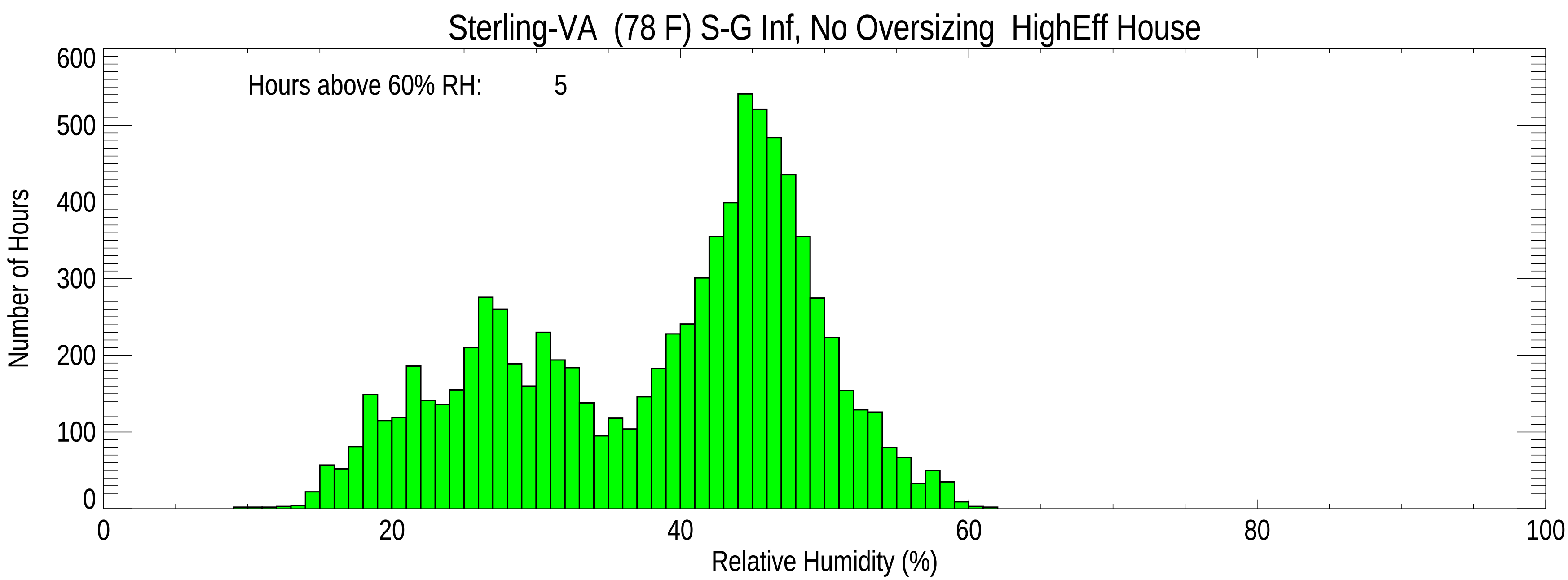

Jacksonville-FL (78 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 1153
Number of Hours
800
600
400
200
0
0
20
40
60
80
100
Relative Humidity (%)

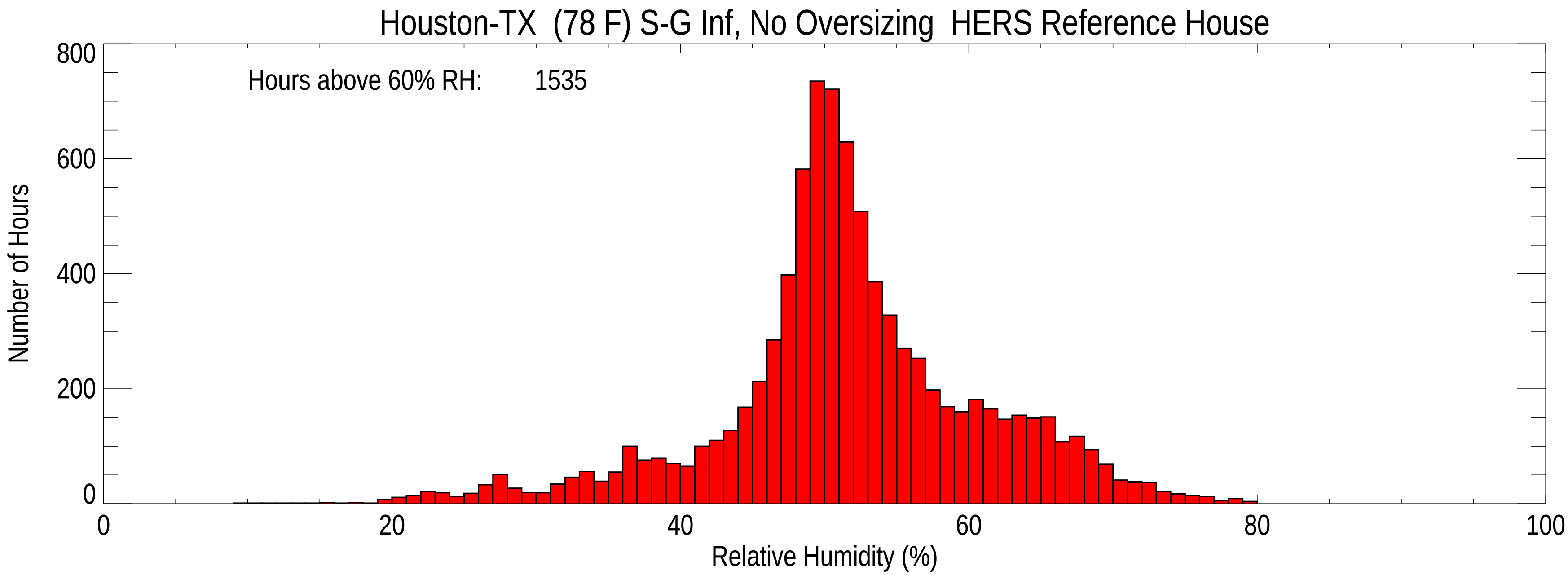

Jacksonville-FL (78 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 1768
Number of Hours
800
600
400
200
0
0
20
40
60
80
100
Relative Humidity (%)

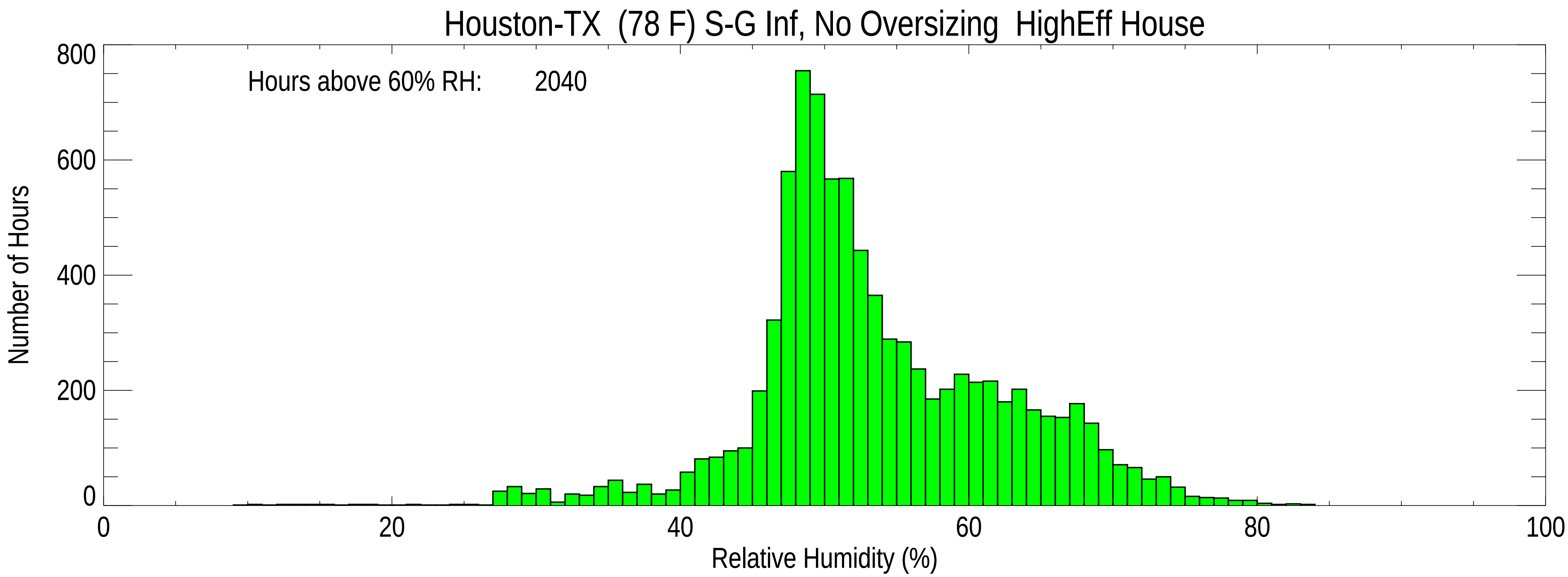

Atlanta-GA (78 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 385
Number of Hours
0
100
200
300
400
500
0
20
40
60
80
100
Relative Humidity (%)

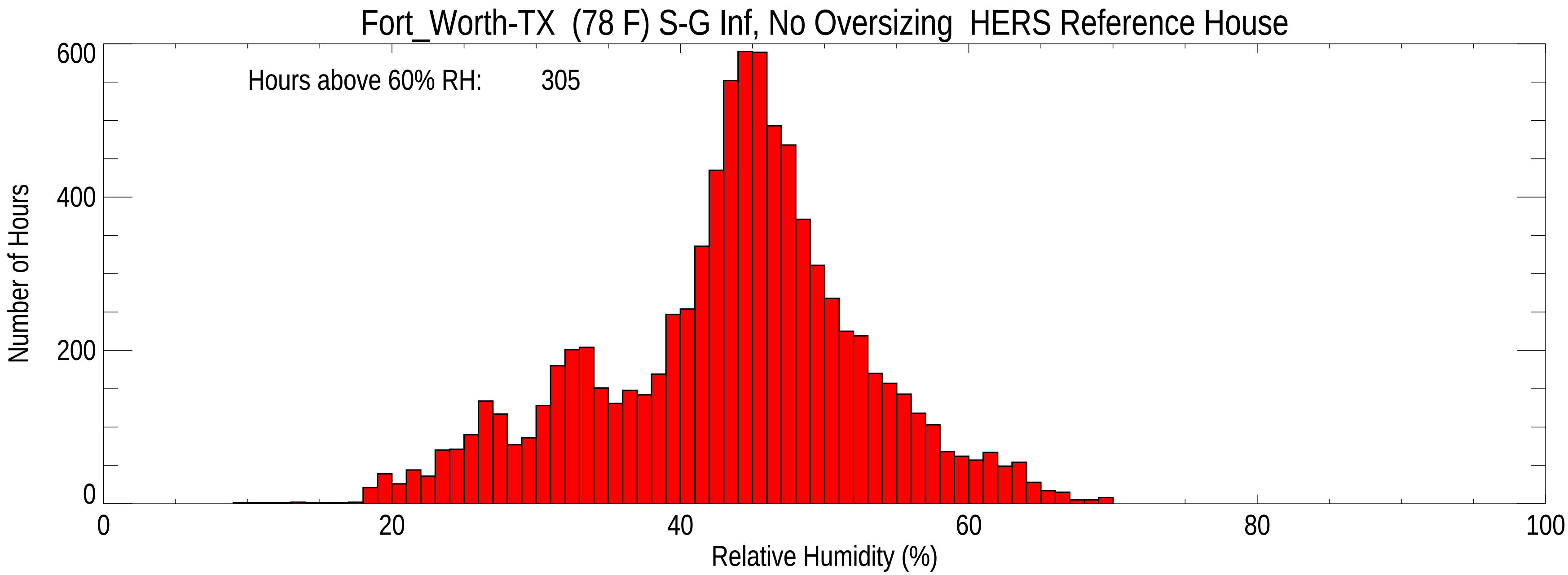

Atlanta-GA (78 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 118
Number of Hours
0
200
400
600
800
0
20
40
60
80
100
Relative Humidity (%)

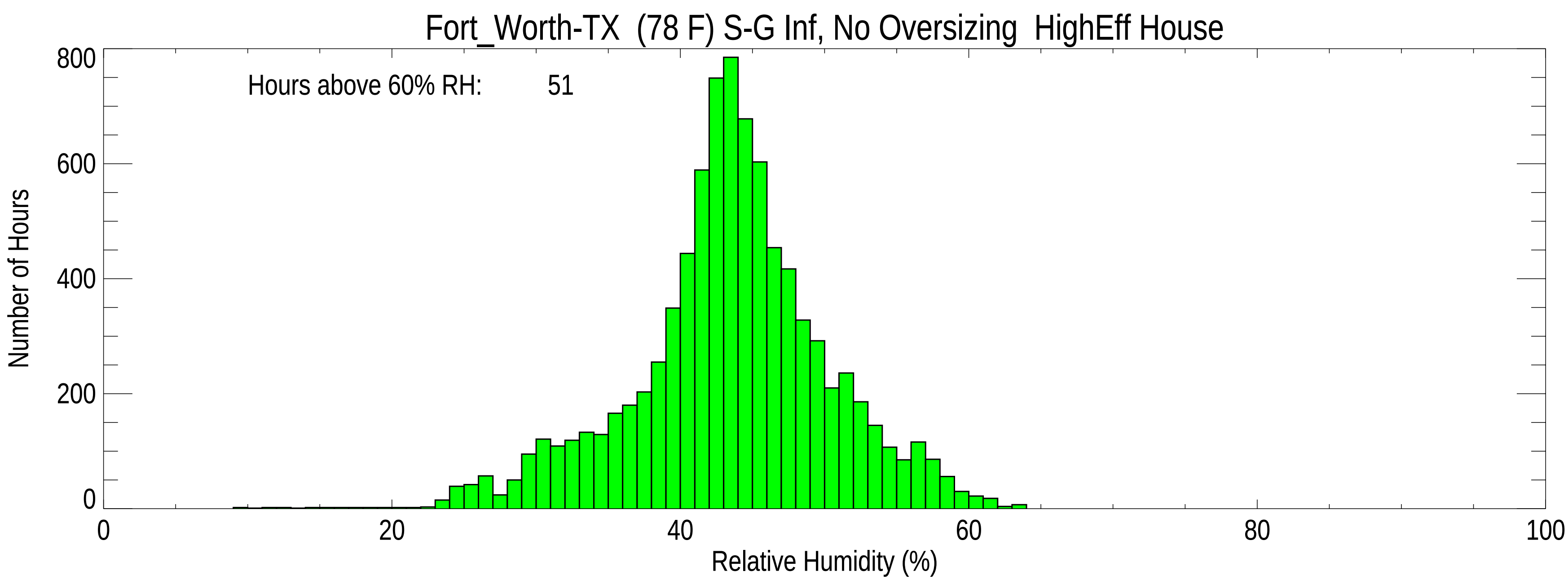

Sterling-VA (78 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 119
Number of Hours
0
100
200
300
400
500
0
20
40
60
80
100
Relative Humidity (%)

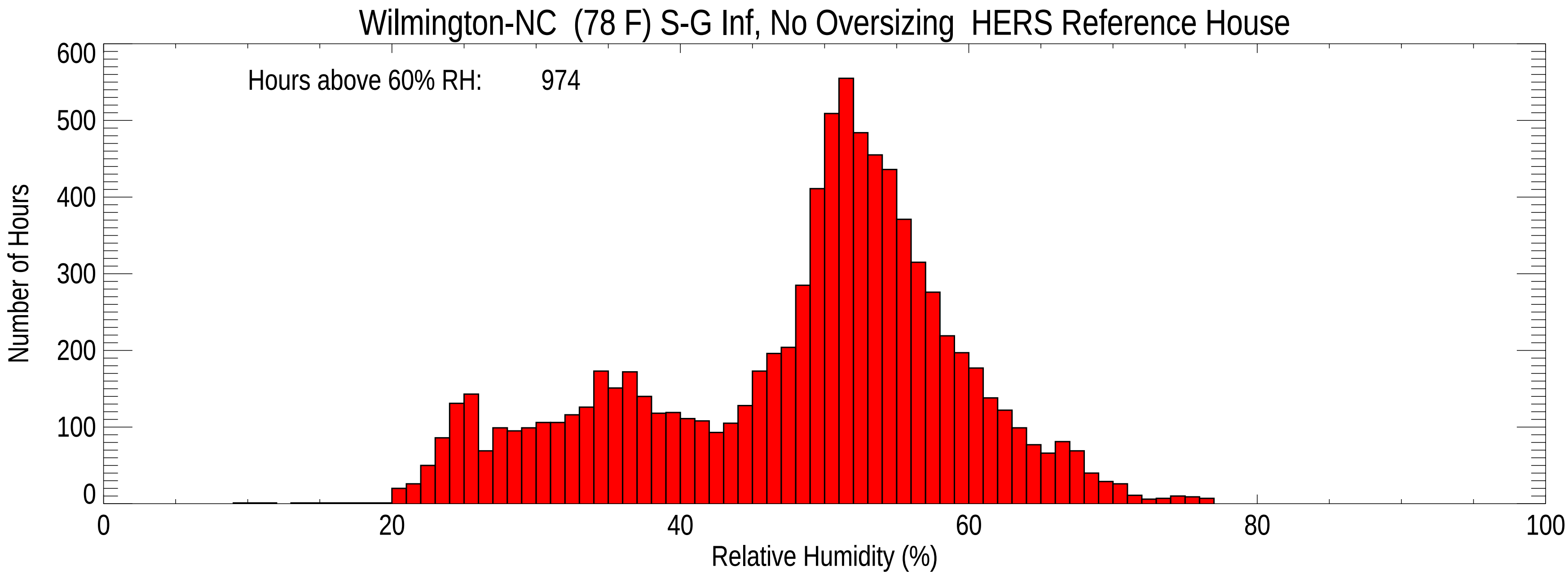

Sterling-VA (78 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 5
Number of Hours
0
100
200
300
400
500
600
0
20
40
60
80
100
Relative Humidity (%)


Houston-TX (78 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 1535
Number of Hours
800
600
400
200
0
0
20
40
60
80
100
Relative Humidity (%)

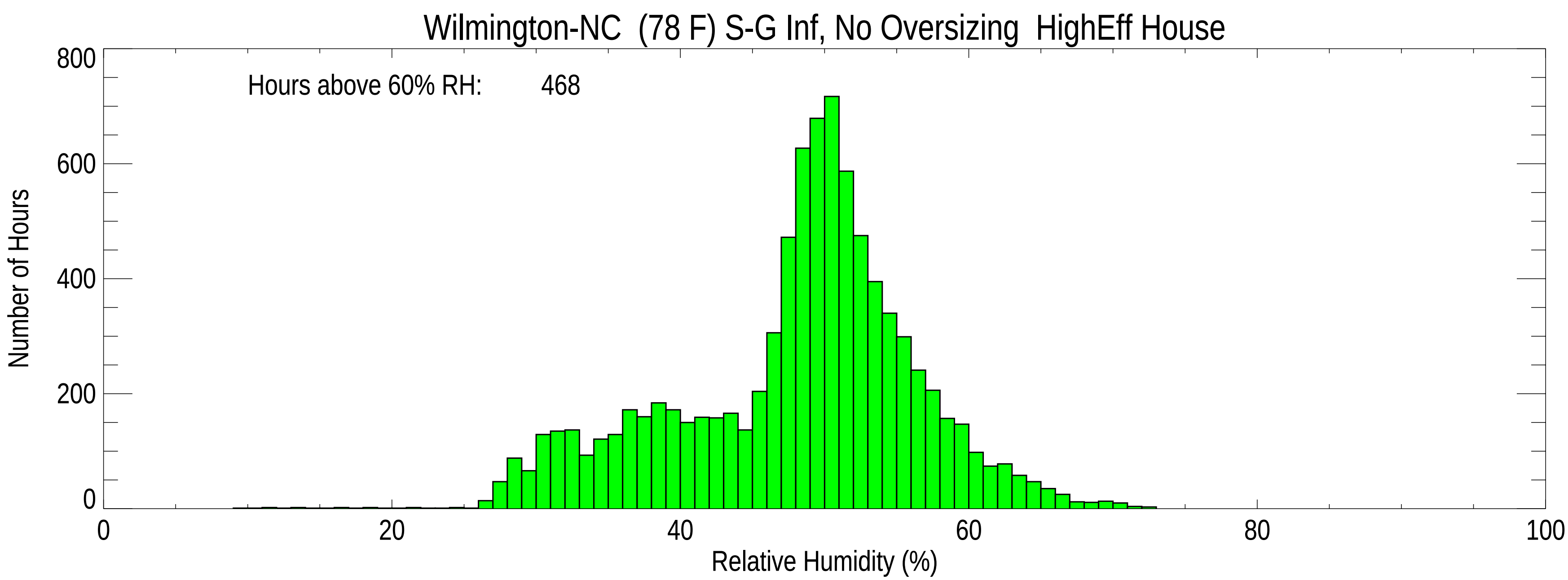

Houston-TX (78 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 2040
Number of Hours
800
600
400
200
0
0
20
40
60
80
100
Relative Humidity (%)


Fort_Worth-TX (78 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 305
Number of Hours
Relative Humidity (%)
0
200
400
600
0
20
40
60
80
100

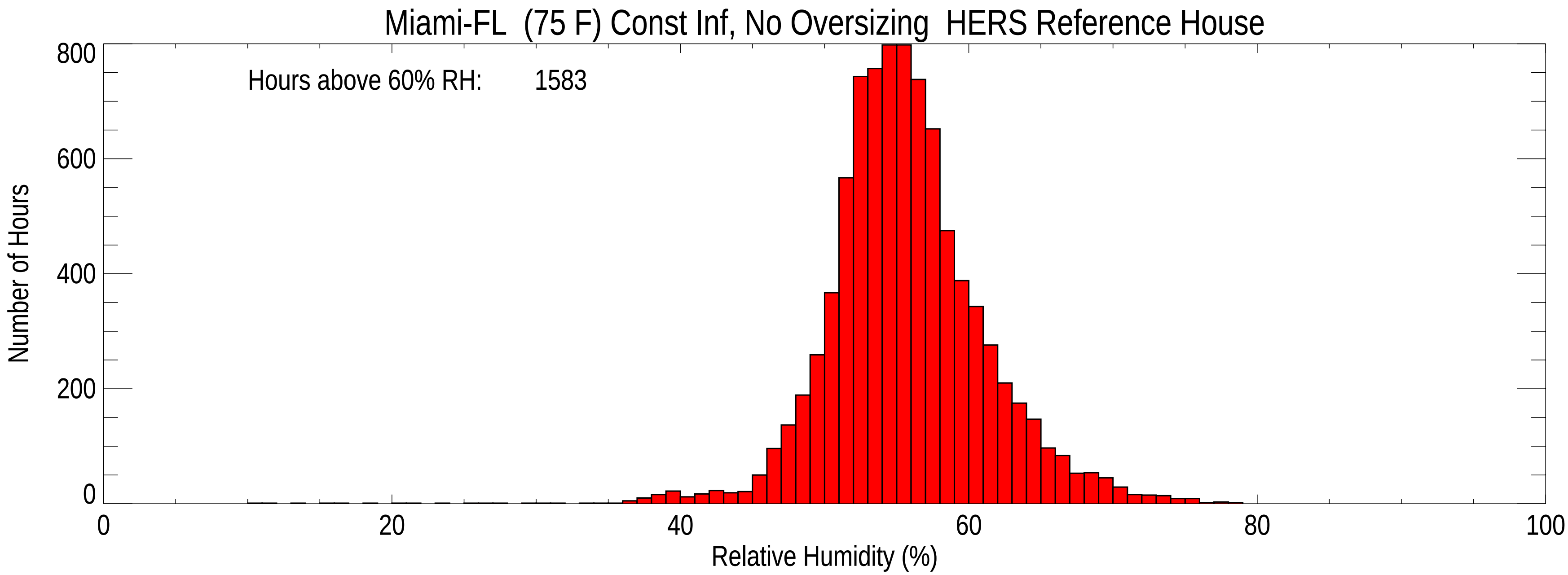

Fort_Worth-TX (78 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 51
Number of Hours
Relative Humidity (%)
0
200
400
600
800
0
20
40
60
80
100

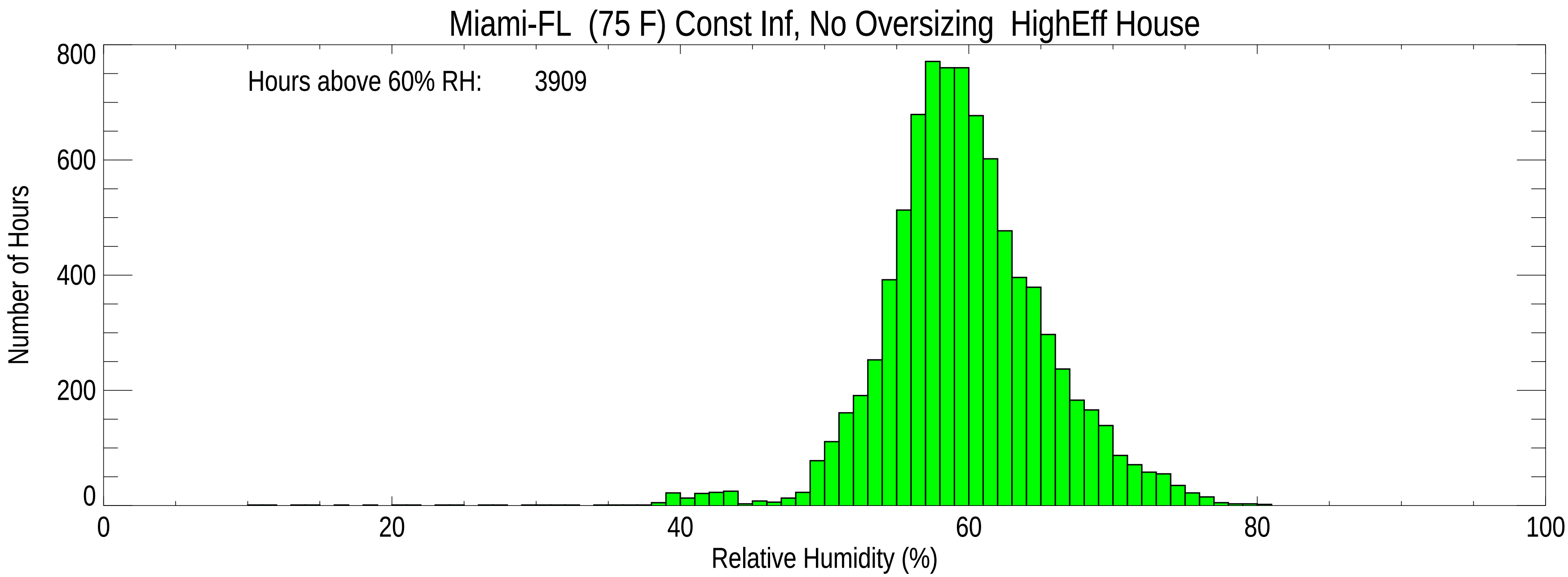


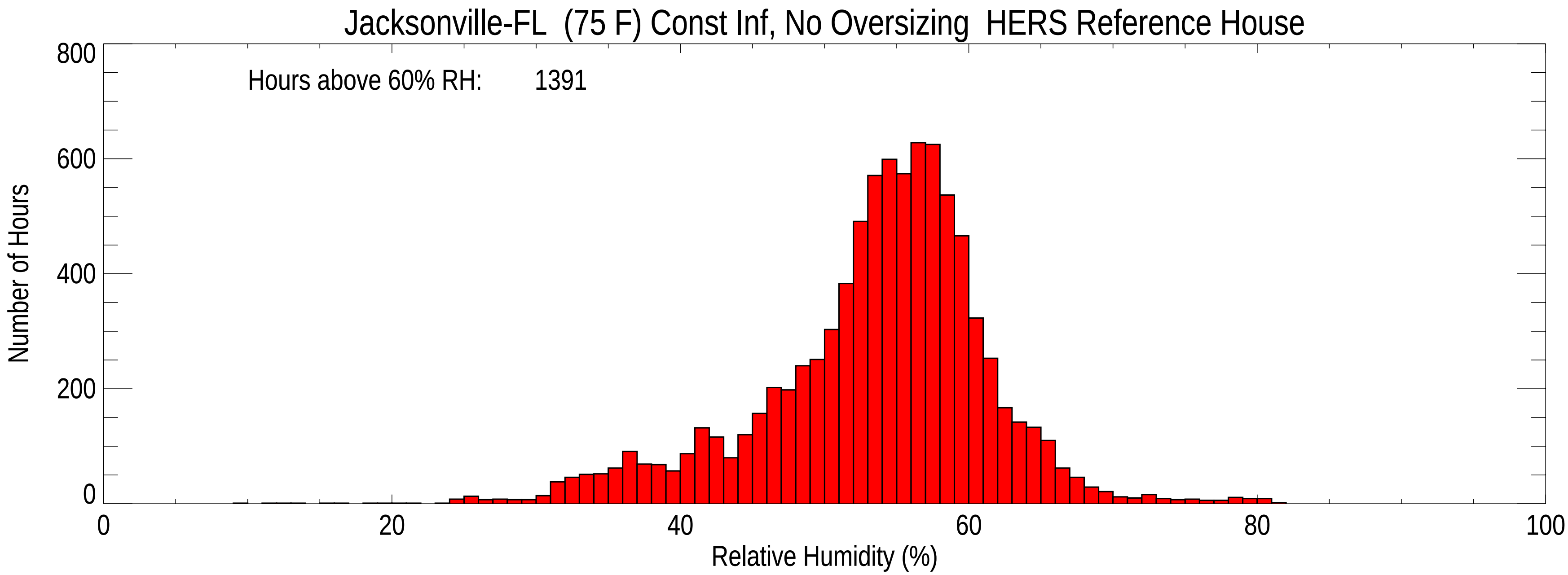
Wilmington-NC (78 F) S-G Inf, No Oversizing HERS Reference House
Hours above 60% RH: 974
Number of Hours
Relative Humidity (%)
0
100
200
300
400
500
600
0
20
40
60
80
100

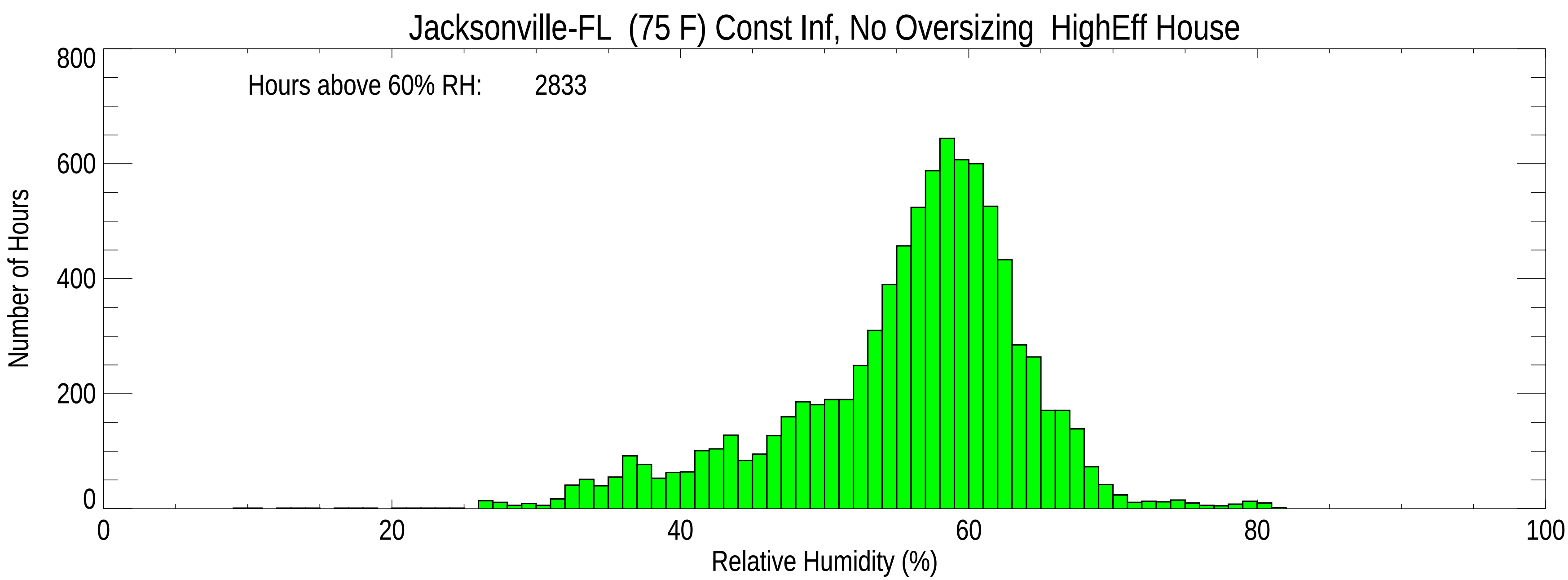


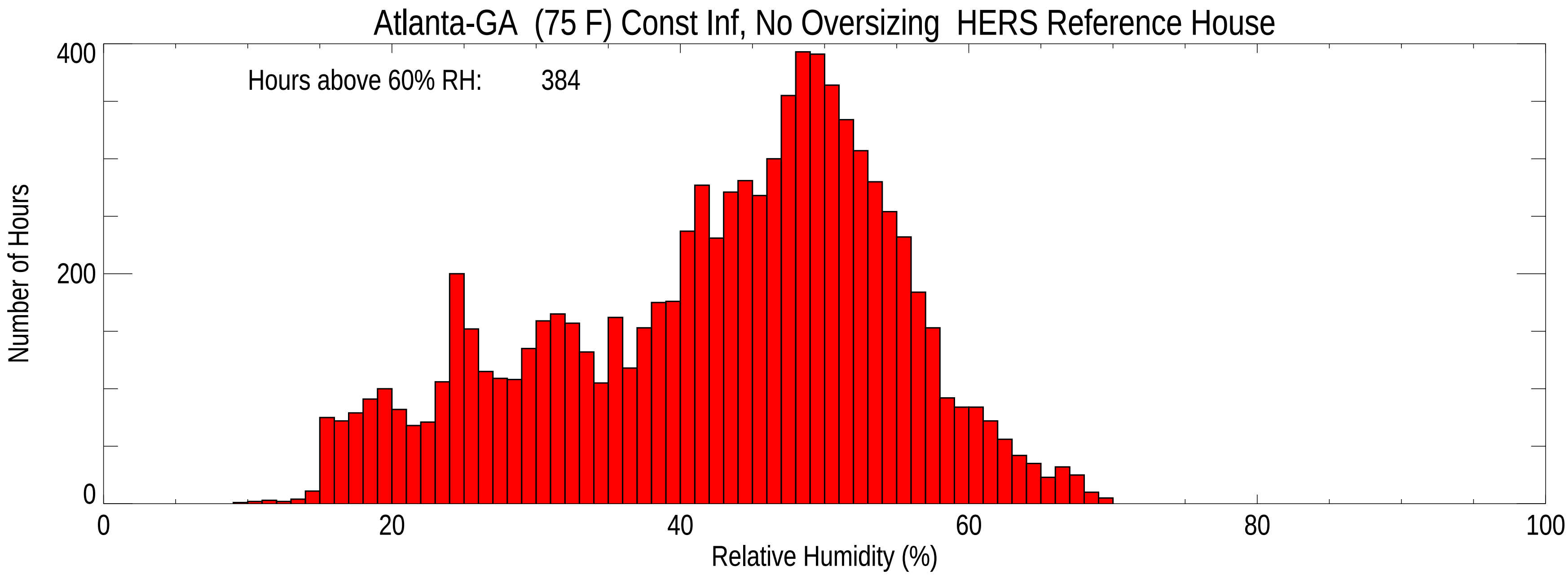
Wilmington-NC (78 F) S-G Inf, No Oversizing HighEff House
Hours above 60% RH: 468
Number of Hours
Relative Humidity (%)
0
200
400
600
800
0
20
40
60
80
100

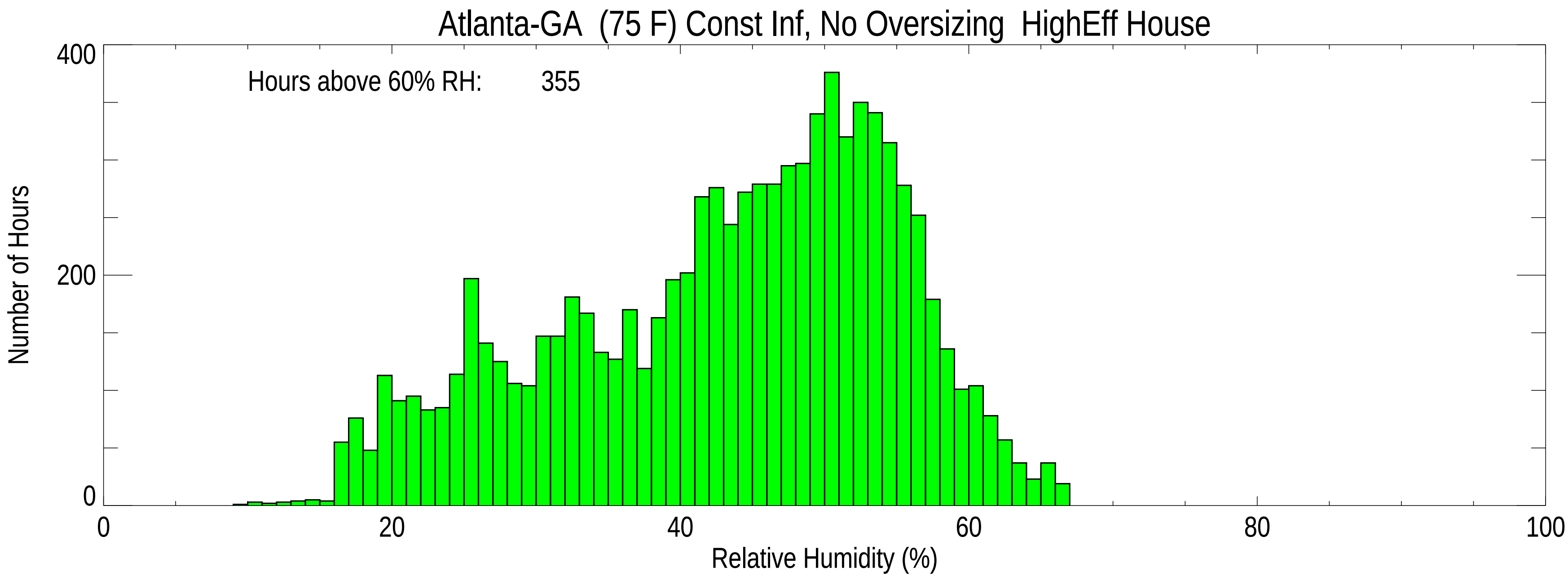

Miami-FL (75 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH: 1583
Number of Hours
0
200
400
600
800
0
20
40
60
80
100
Relative Humidity (%)

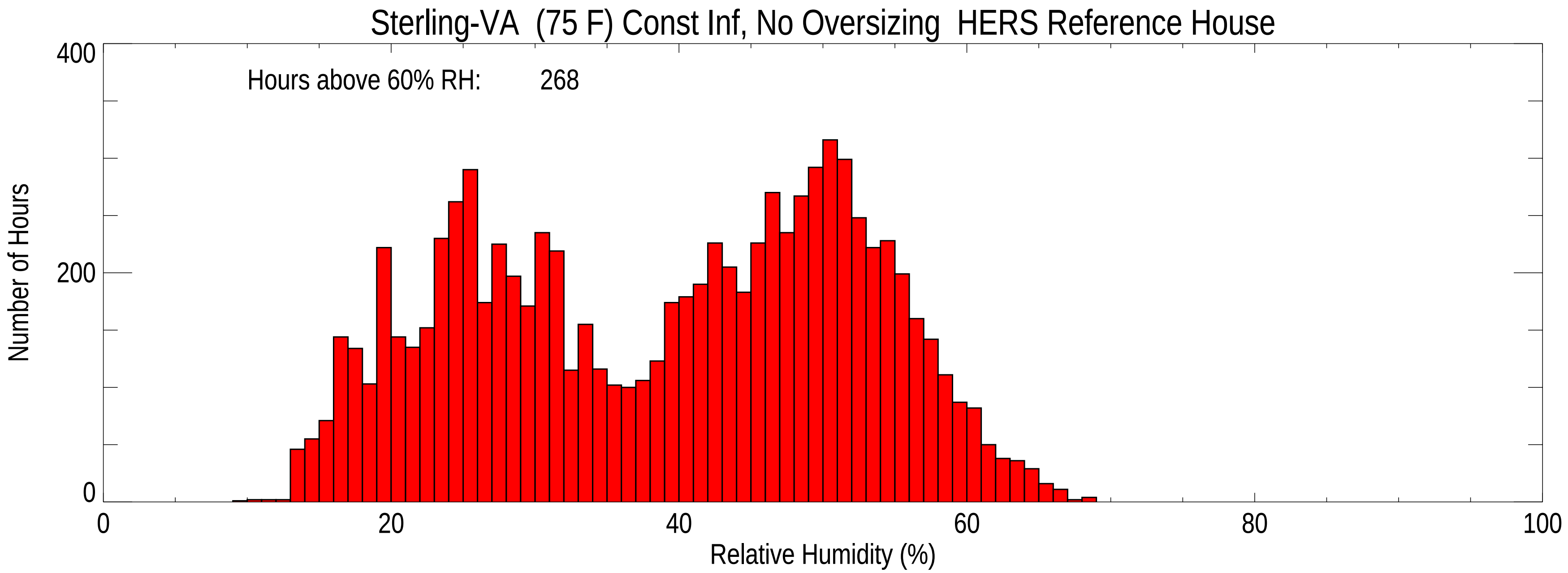

Miami-FL (75 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH: 3909
Number of Hours
0
200
400
600
800
0
20
40
60
80
100
Relative Humidity (%)

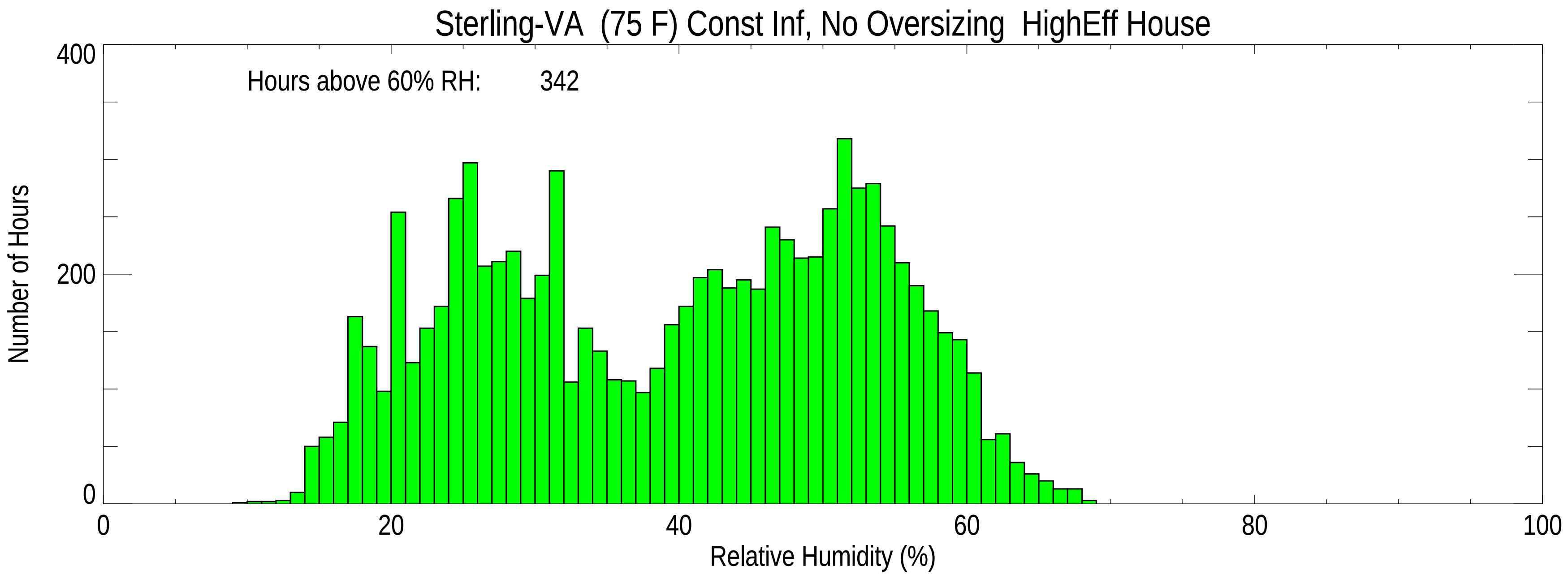

Jacksonville-FL (75 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH: 1391
Number of Hours
800
600
400
200
0
0
20
40
60
80
100
Relative Humidity (%)

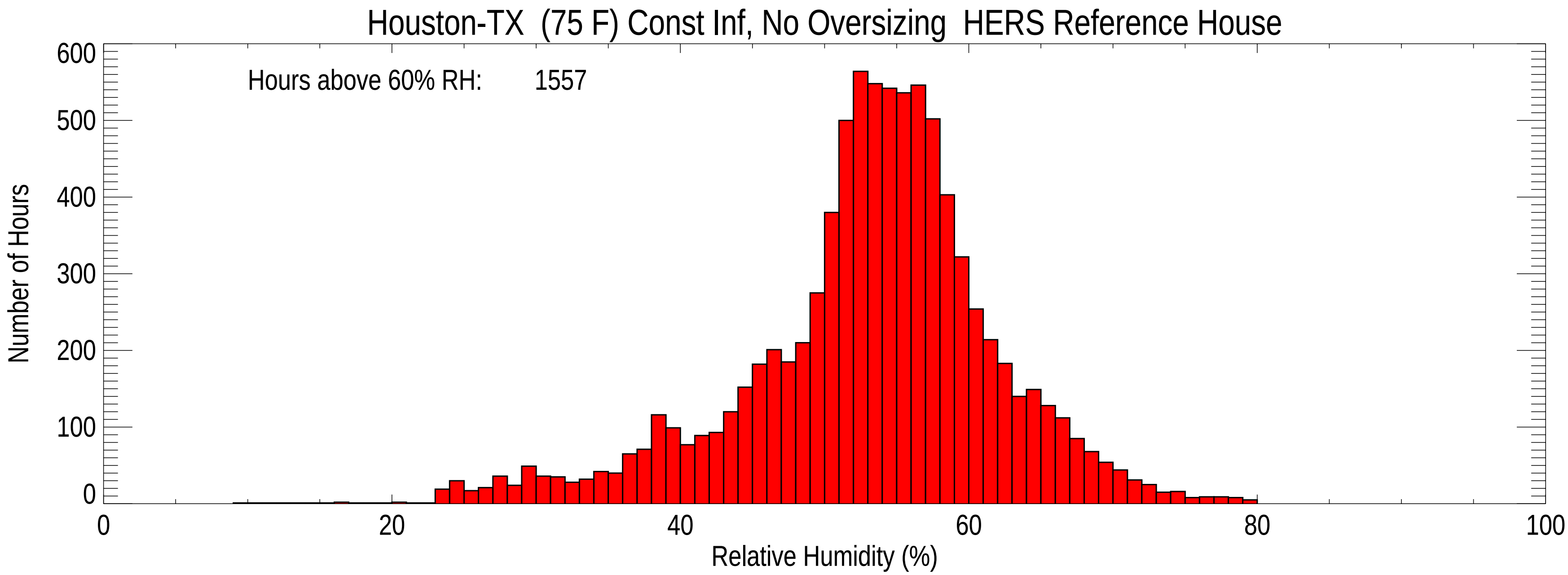

Jacksonville-FL (75 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH: 2833
Number of Hours
800
600
400
200
0
0
20
40
60
80
100
Relative Humidity (%)


Atlanta-GA (75 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH: 384
Number of Hours
400
200
0
0
20
40
60
80
100
Relative Humidity (%)

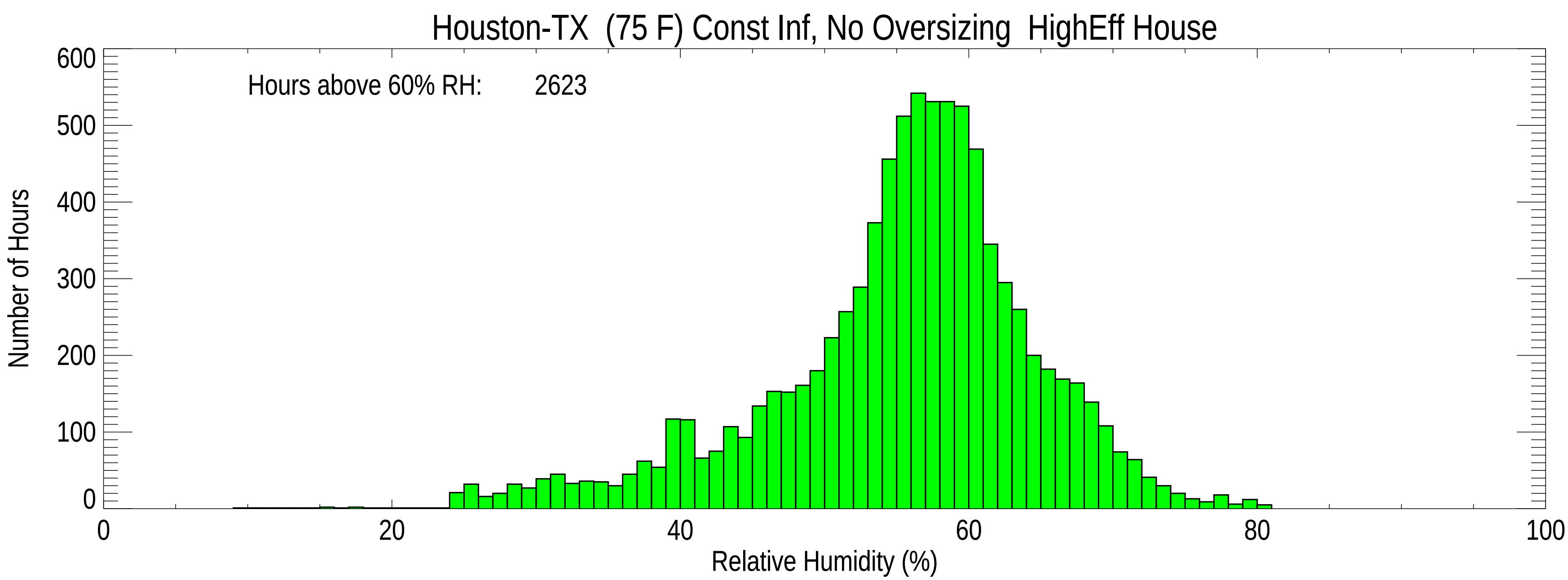

Atlanta-GA (75 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH: 355
Number of Hours
400
200
0
0
20
40
60
80
100
Relative Humidity (%)


Sterling-VA (75 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH: 268
Number of Hours
Relative Humidity (%)
0
200
400
0
20
40
60
80
100

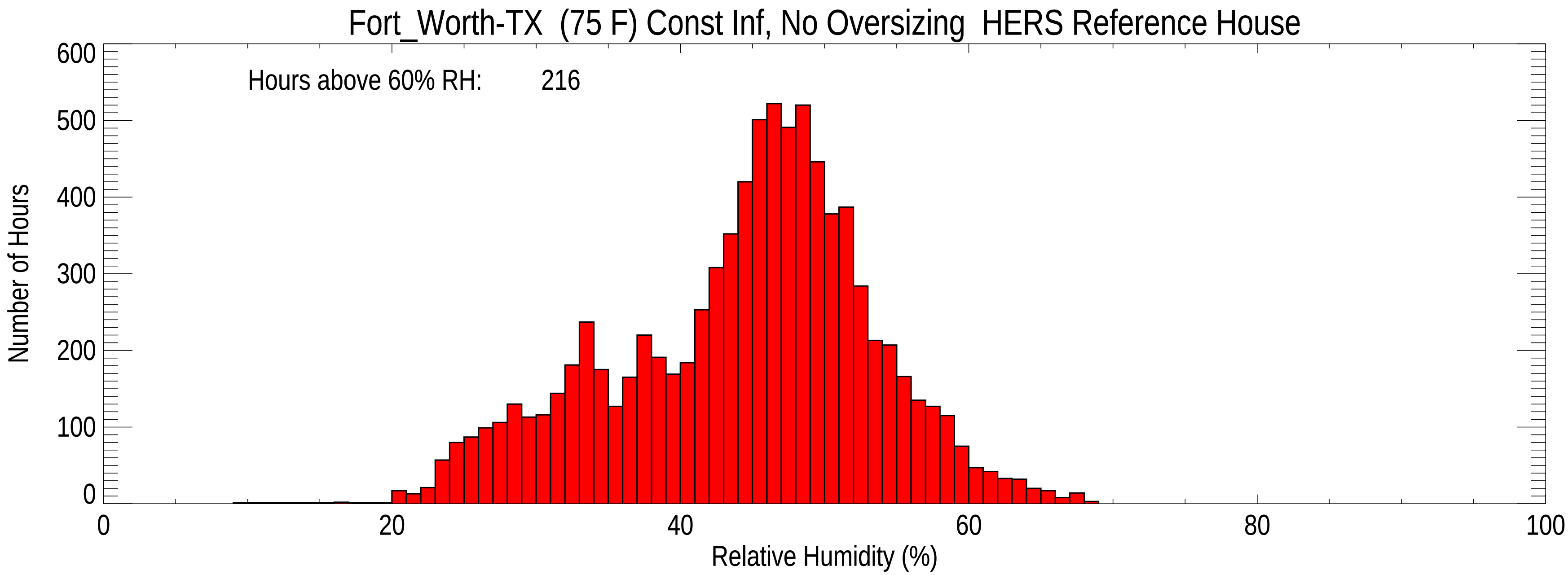

Sterling-VA (75 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH: 342
Number of Hours
Relative Humidity (%)
0
200
400
0
20
40
60
80
100



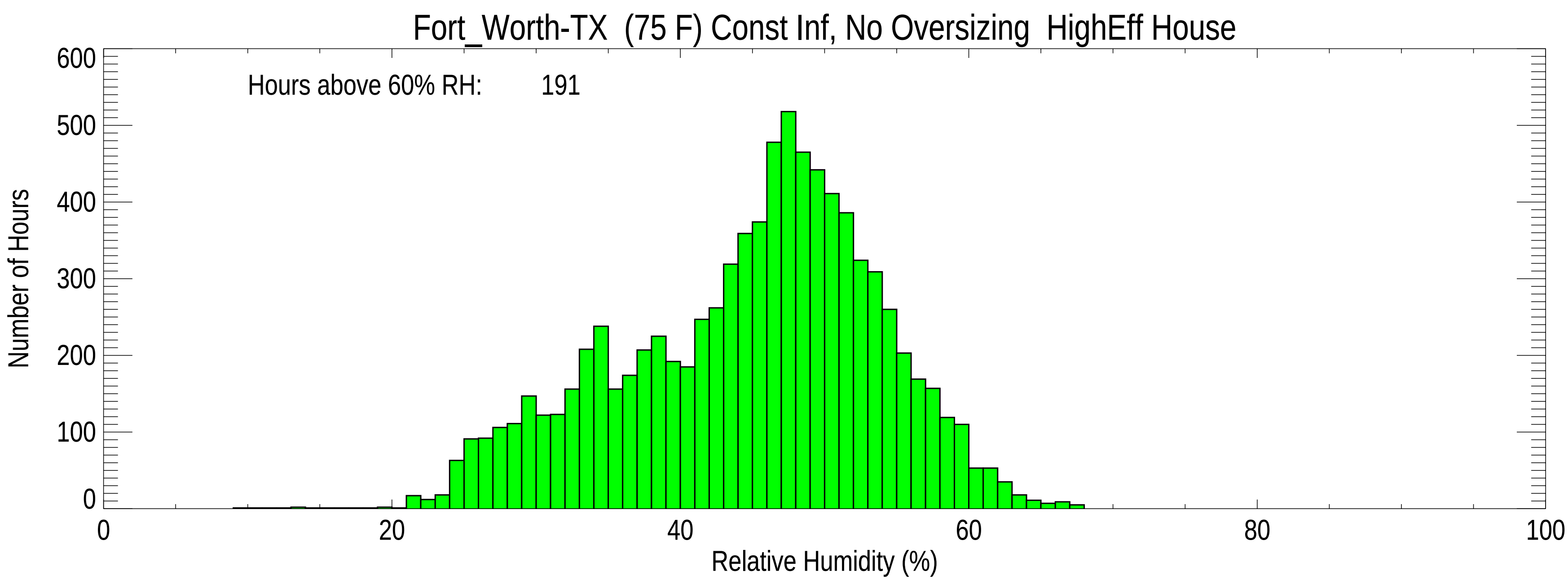
Houston-TX (75 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH: 1557
Number of Hours
Relative Humidity (%)
0
100
200
300
400
500
600
0
20
40
60
80
100



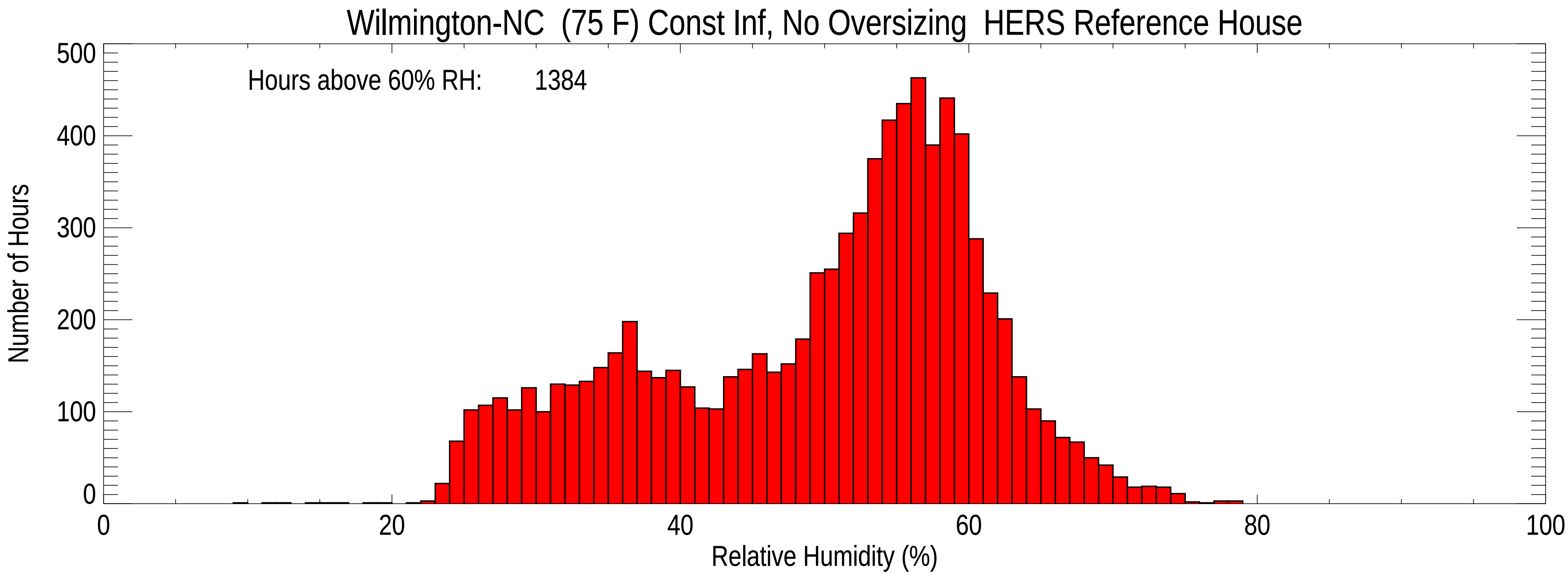
Houston-TX (75 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH: 2623
Number of Hours
Relative Humidity (%)
0
100
200
300
400
500
600
0
20
40
60
80
100

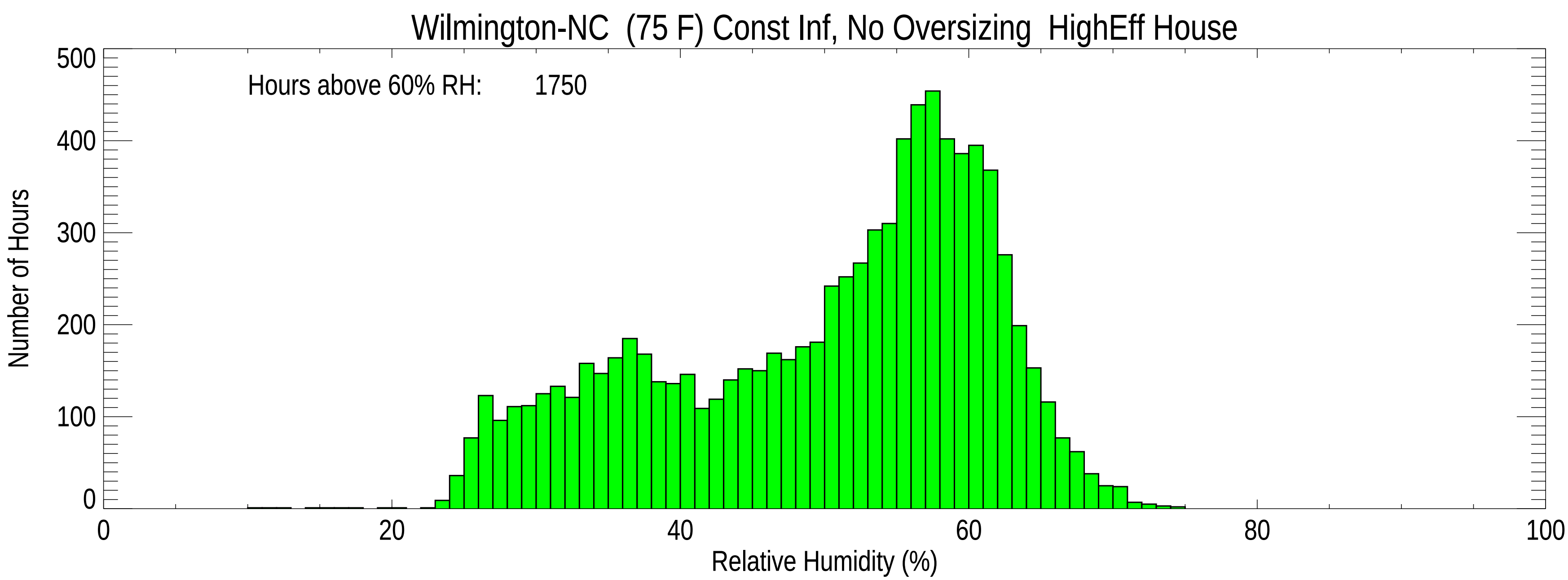


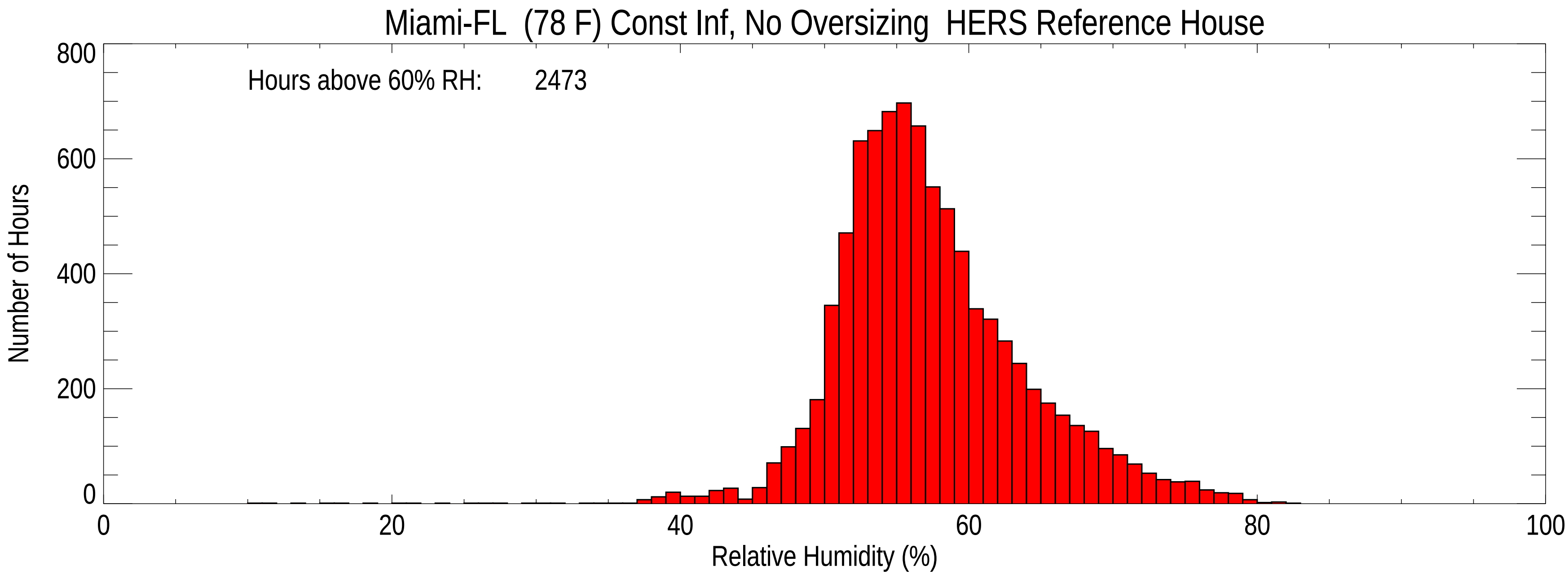
Fort_Worth-TX (75 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH: 216
Number of Hours
0
100
200
300
400
500
600
0
20
40
60
80
100
Relative Humidity (%)

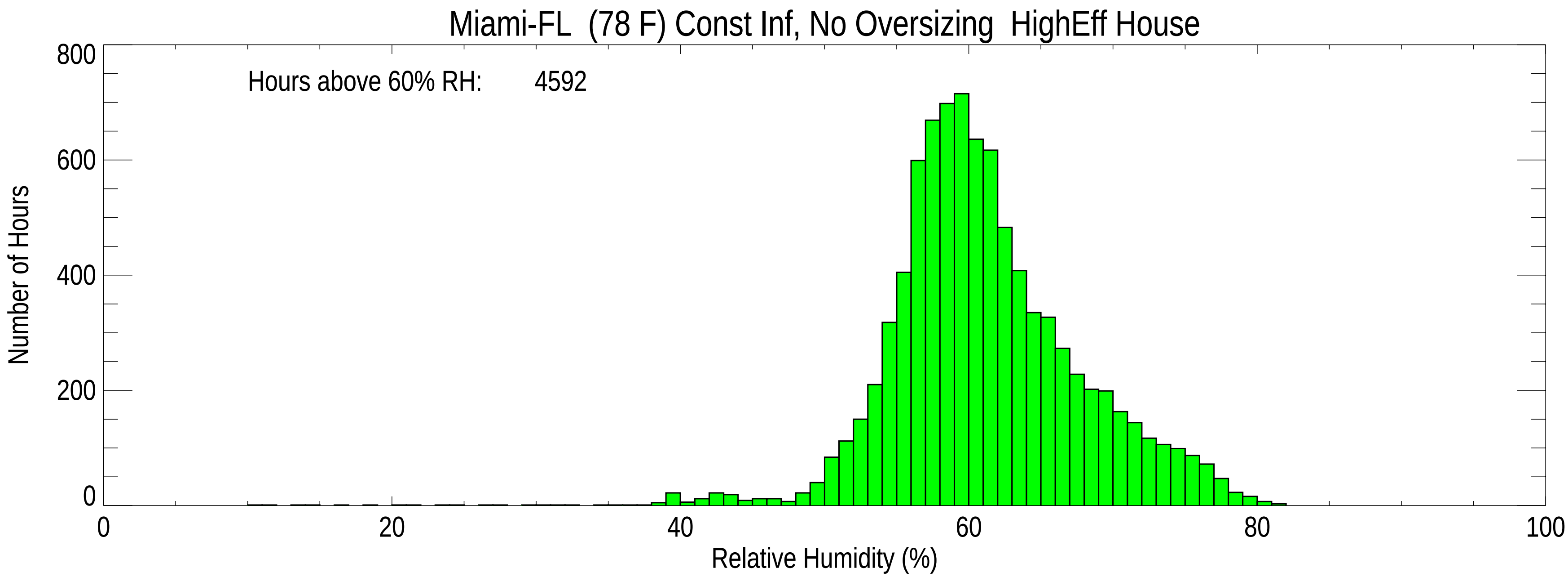


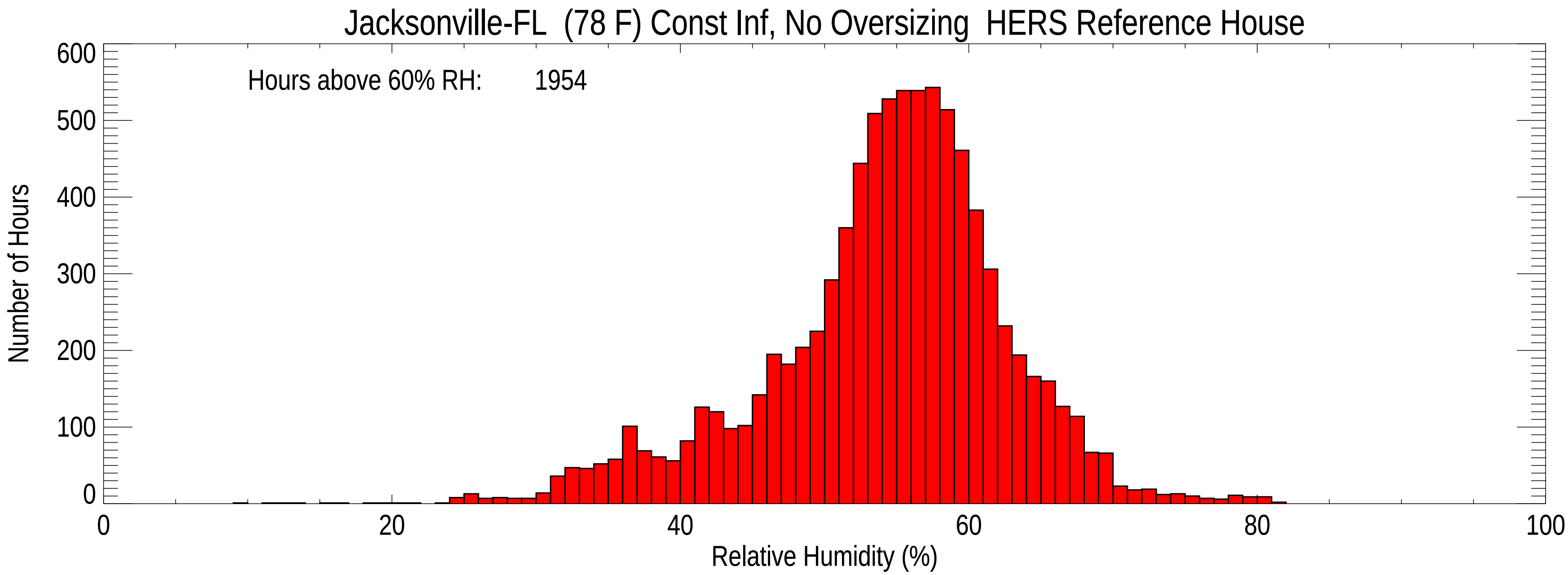
Fort_Worth-TX (75 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH: 191
Number of Hours
0
100
200
300
400
500
600
0
20
40
60
80
100
Relative Humidity (%)


Wilmington-NC (75 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH:
1384
Number of Hours
Relative Humidity (%)
0
100
200
300
400
500
0
20
40
60
80
100

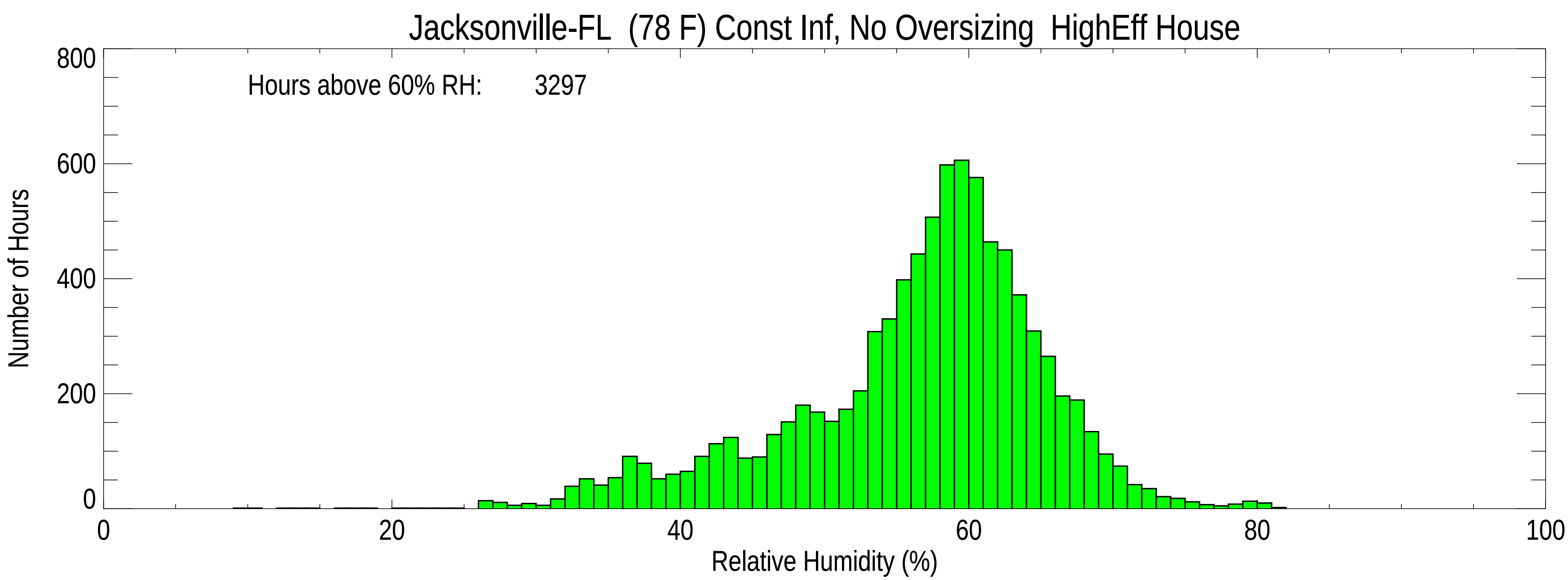

Wilmington-NC (75 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH:
1750
Number of Hours
Relative Humidity (%)
0
100
200
300
400
500
0
20
40
60
80
100


Miami-FL (78 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH: 2473
Number of Hours
0
200
400
600
800
0
20
40
60
80
100
Relative Humidity (%)

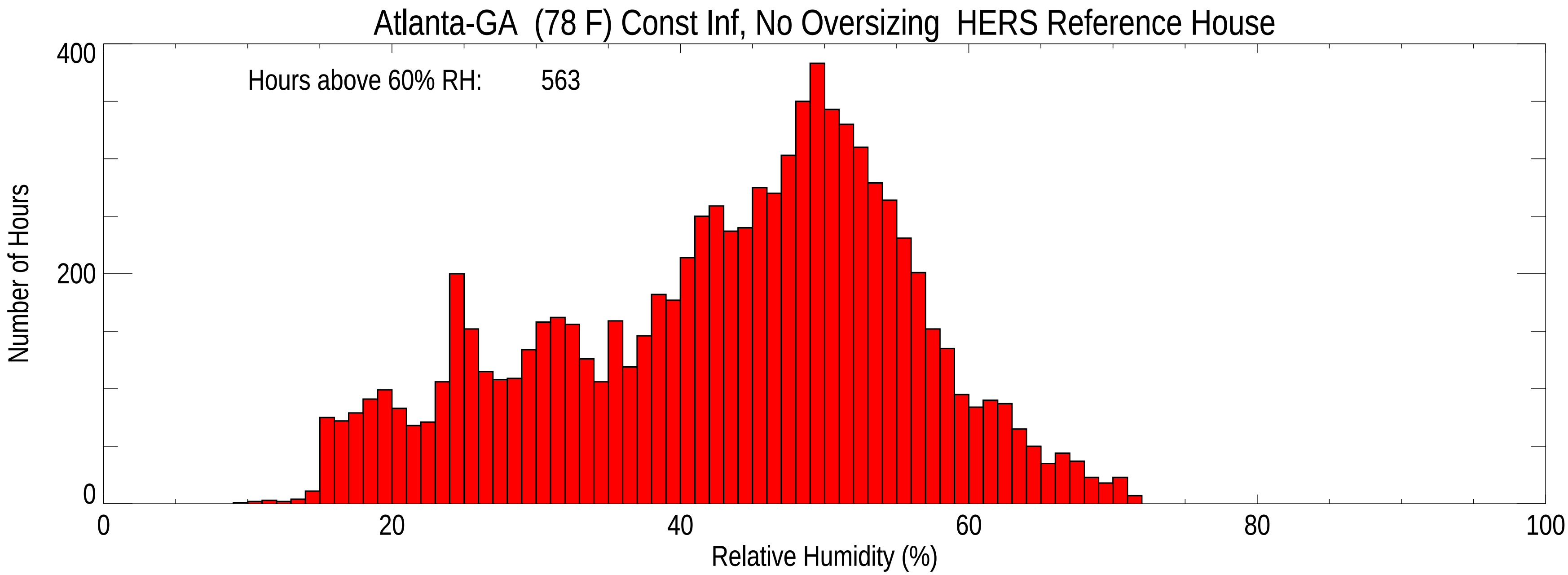

Miami-FL (78 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH: 4592
Number of Hours
0
200
400
600
800
0
20
40
60
80
100
Relative Humidity (%)

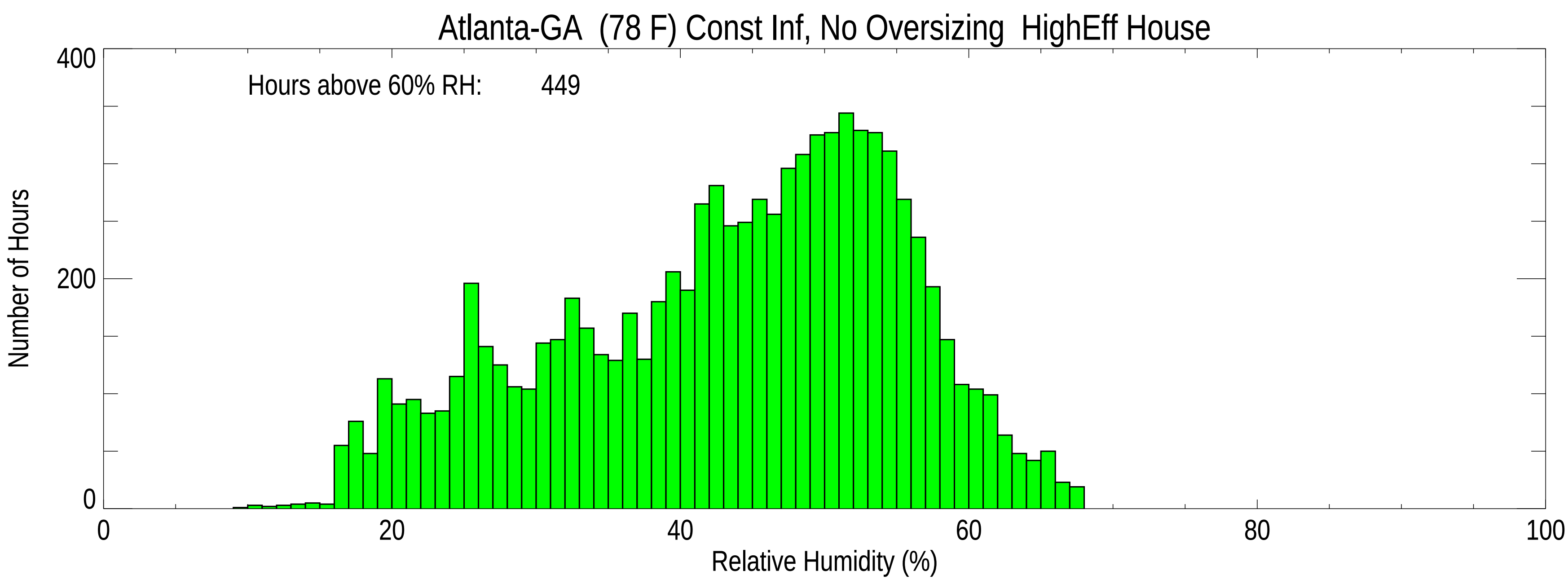


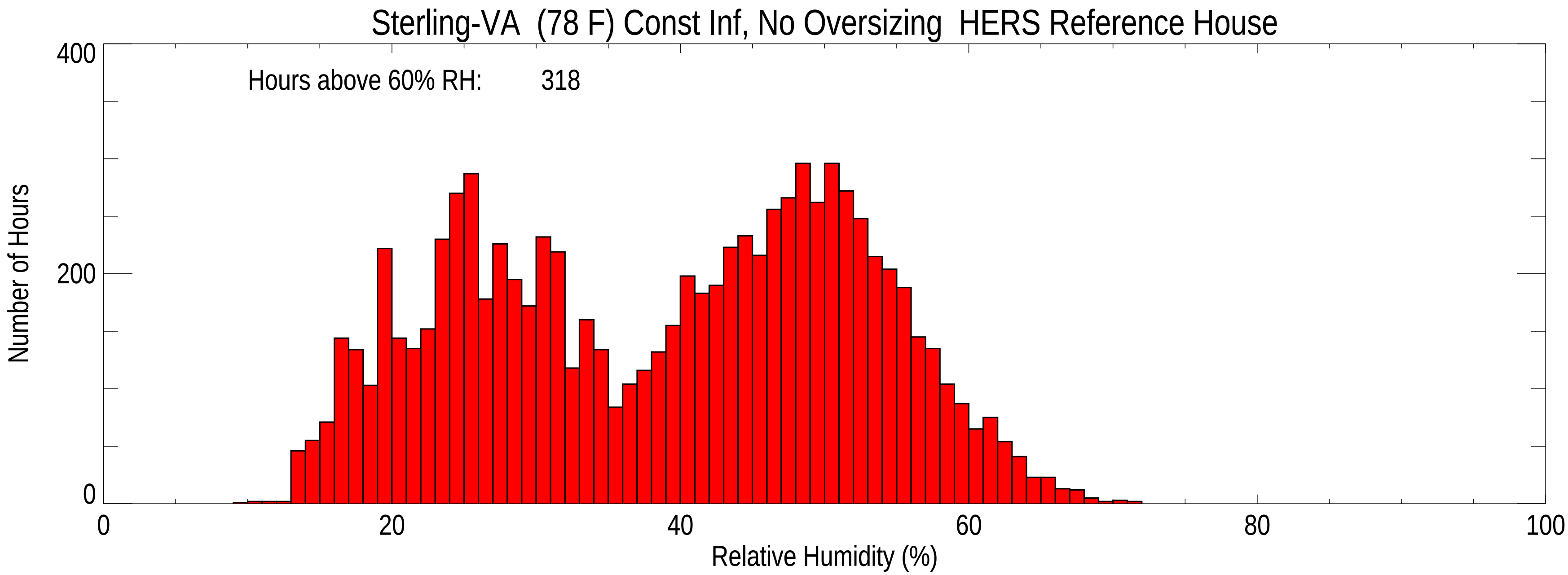
Jacksonville-FL (78 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH: 1954
Number of Hours
600
500
400
300
200
100
0
0
20
40
60
80
100
Relative Humidity (%)

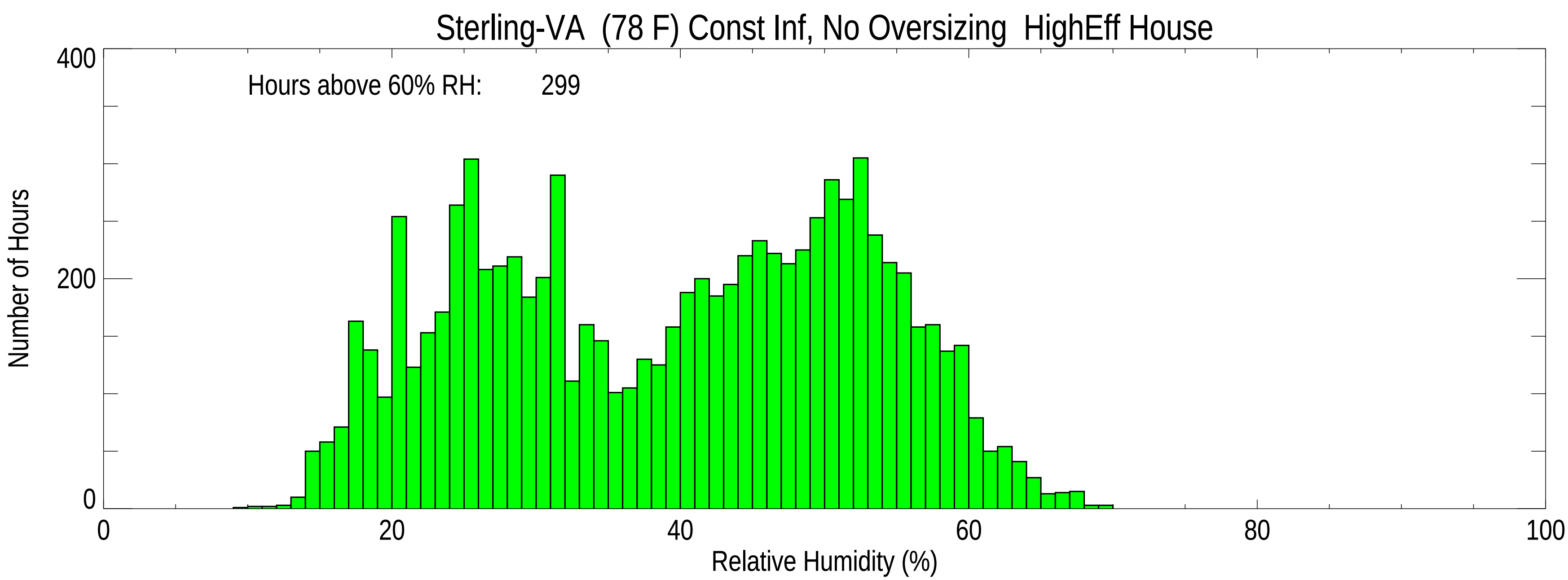


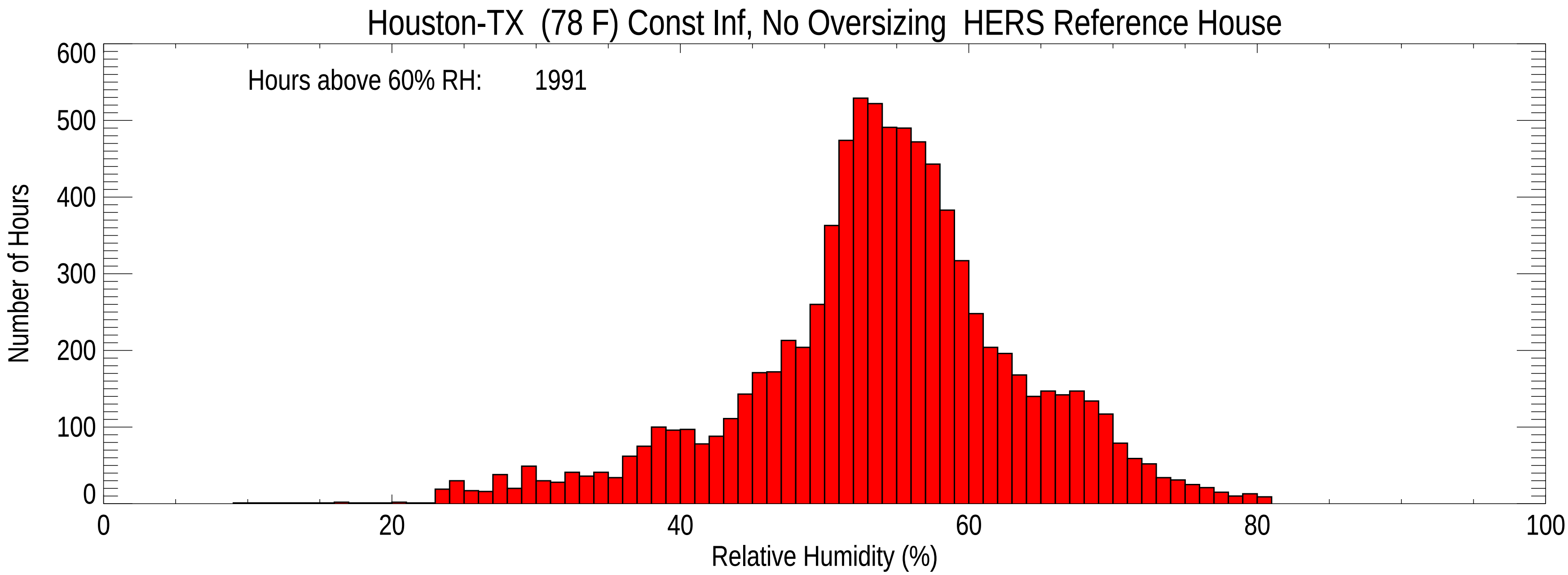
Jacksonville-FL (78 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH: 3297
Number of Hours
800
600
400
200
0
0
20
40
60
80
100
Relative Humidity (%)

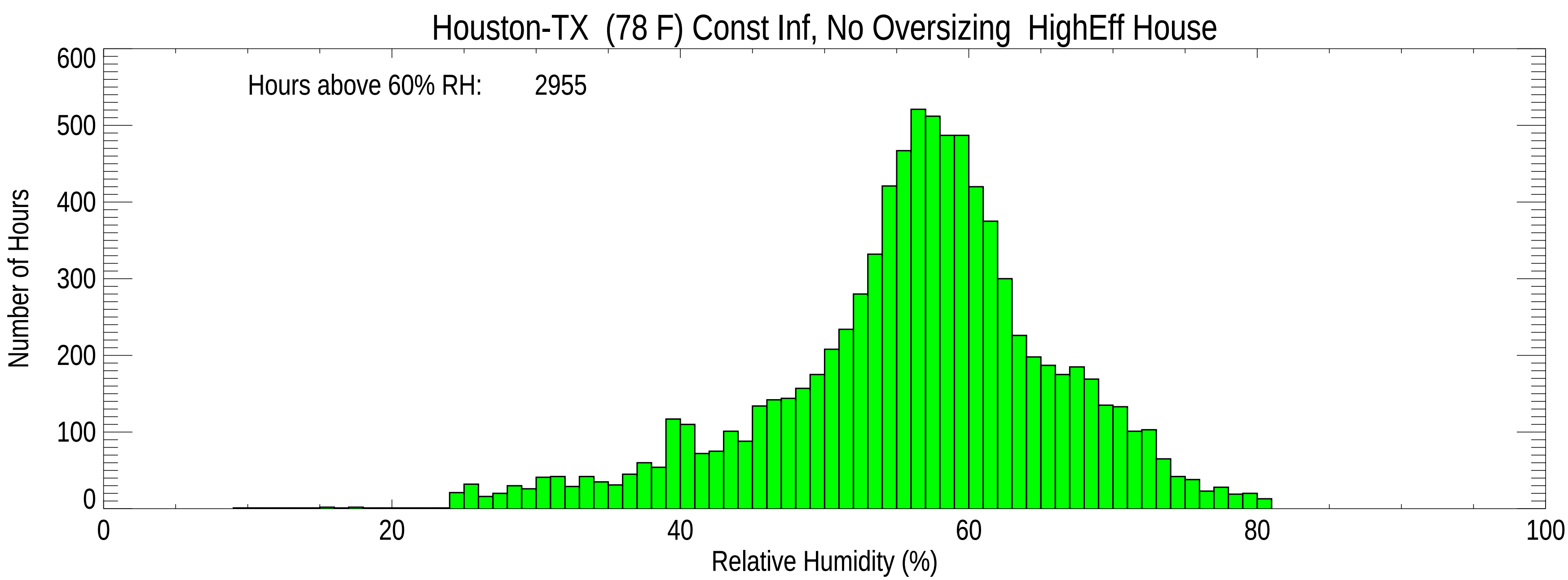

Atlanta-GA (78 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH: 563
Number of Hours
400
200
0
0
20
40
60
80
100
Relative Humidity (%)

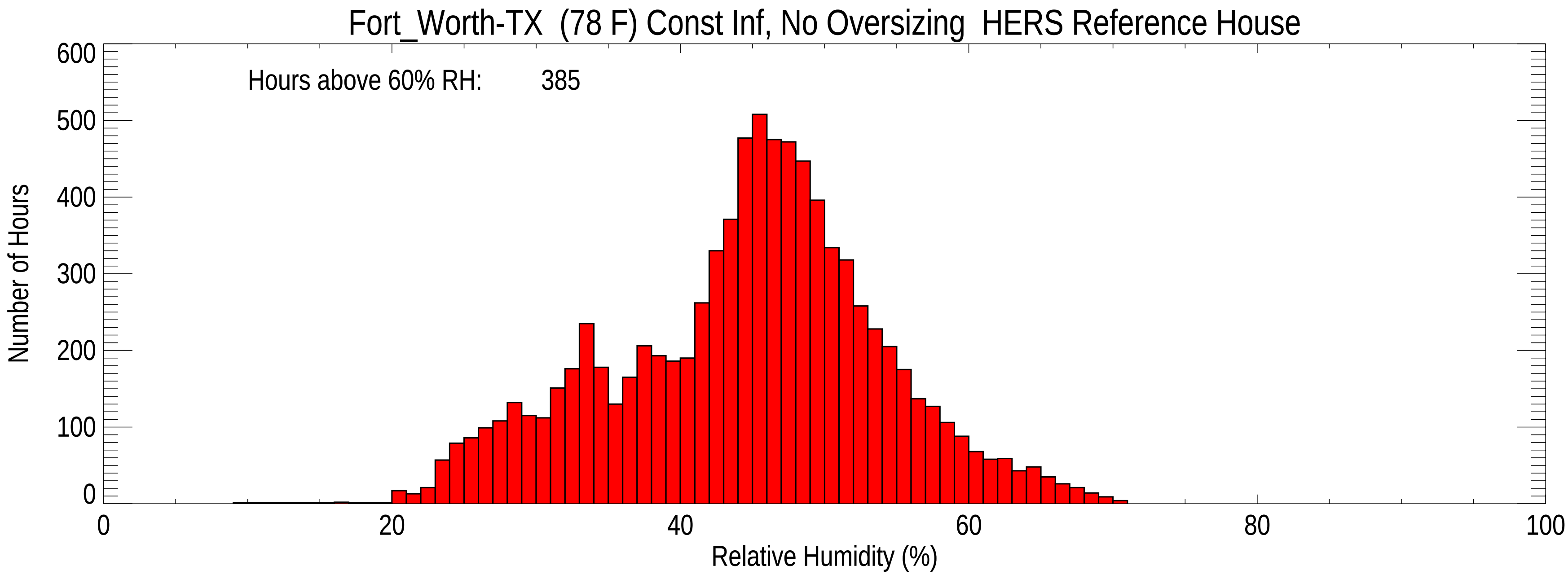

Atlanta-GA (78 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH: 449
Number of Hours
400
200
0
0
20
40
60
80
100
Relative Humidity (%)

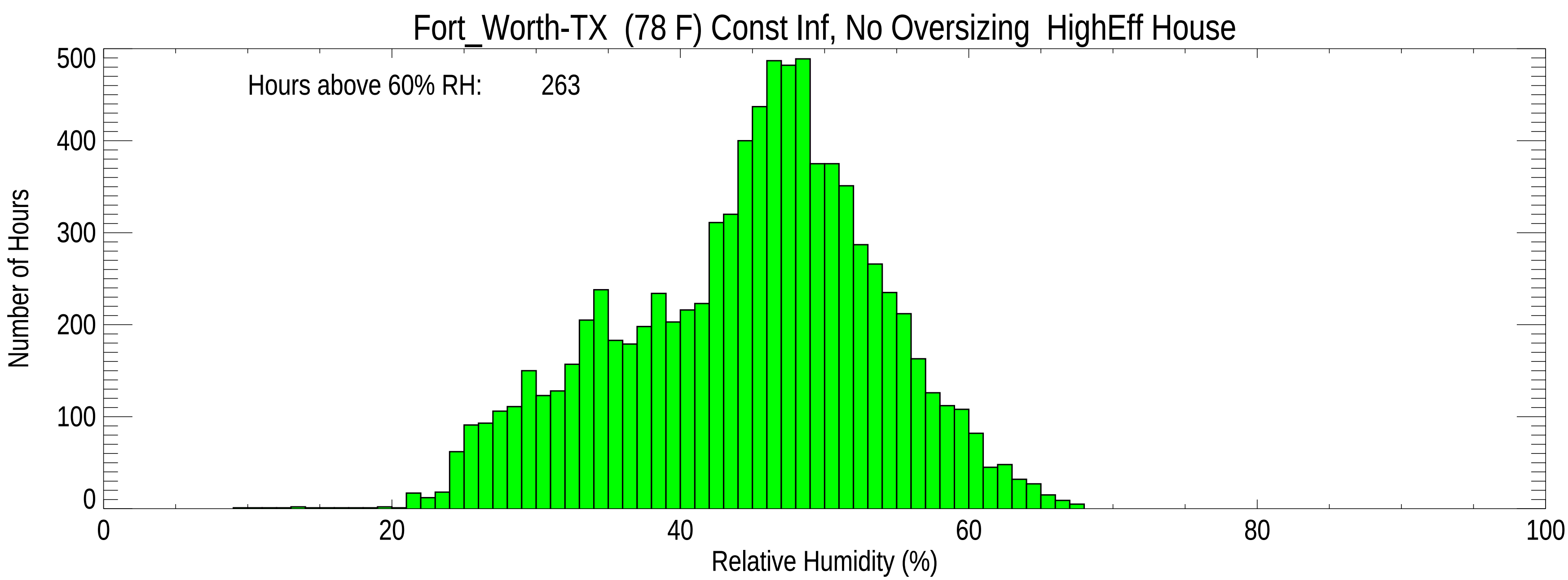

Sterling-VA (78 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH: 318
Number of Hours
400
200
0
0
20
40
60
80
100
Relative Humidity (%)

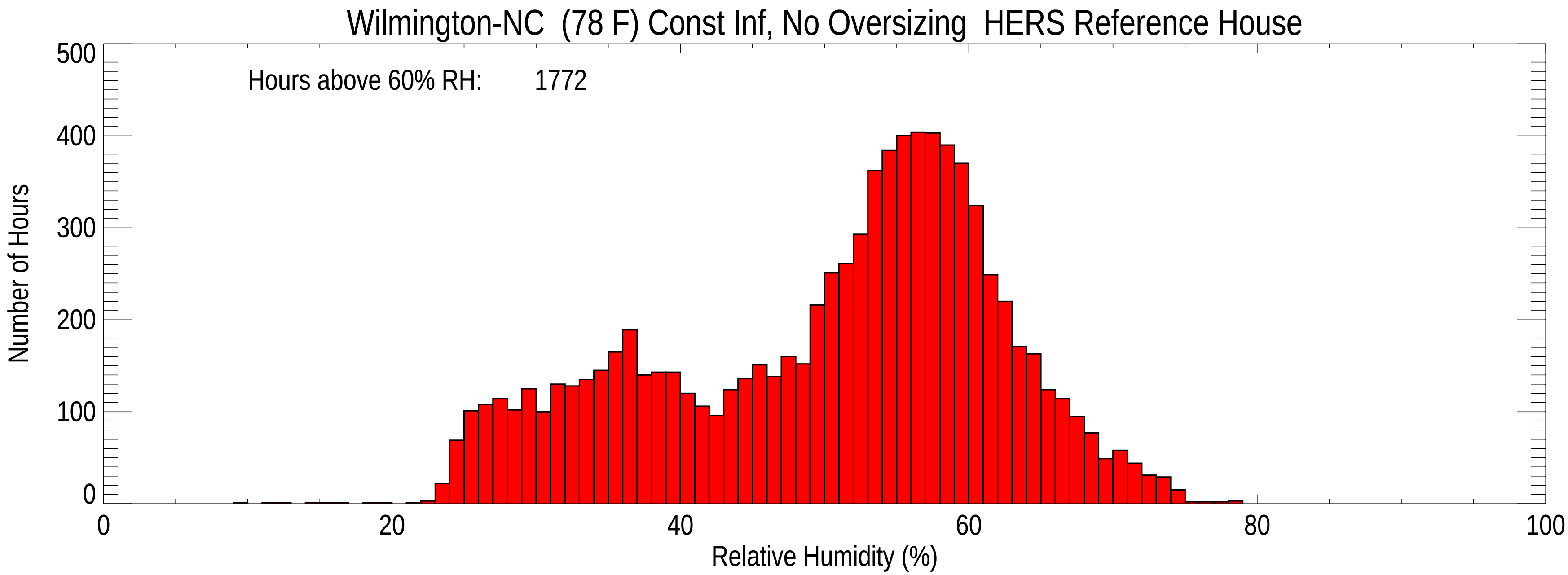

Sterling-VA (78 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH: 299
Number of Hours
400
200
0
0
20
40
60
80
100
Relative Humidity (%)

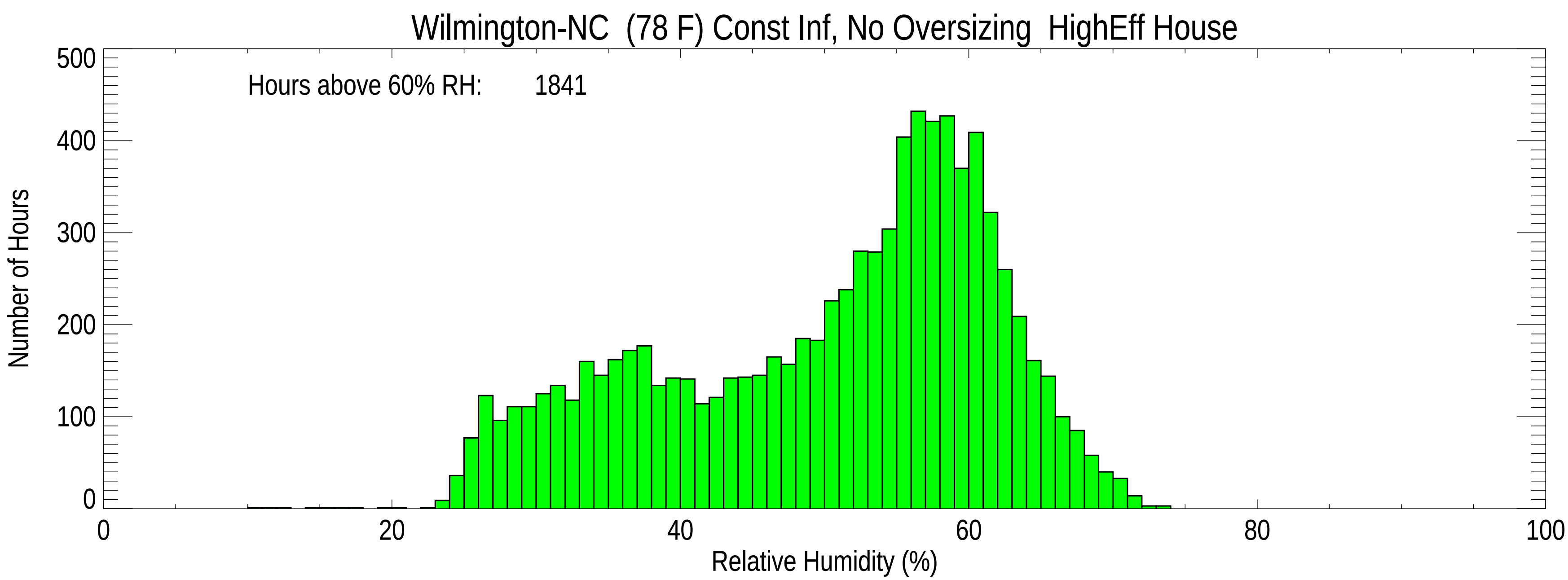

Houston-TX (78 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH: 1991
Number of Hours
Relative Humidity (%)
0
100
200
300
400
500
600
0
20
40
60
80
100


Houston-TX (78 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH: 2955
Number of Hours
Relative Humidity (%)
0
100
200
300
400
500
600
0
20
40
60
80
100


Fort_Worth-TX (78 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH: 385
Number of Hours
0
100
200
300
400
500
600
0
20
40
60
80
100
Relative Humidity (%)


Fort_Worth-TX (78 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH: 263
Number of Hours
0
100
200
300
400
500
0
20
40
60
80
100
Relative Humidity (%)


Wilmington-NC (78 F) Const Inf, No Oversizing HERS Reference House
Hours above 60% RH: 1772
Number of Hours
Relative Humidity (%)
0
100
200
300
400
500
0
20
40
60
80
100


Wilmington-NC (78 F) Const Inf, No Oversizing HighEff House
Hours above 60% RH: 1841
Number of Hours
Relative Humidity (%)
0
100
200
300
400
500
0
20
40
60
80
100

Appendix C

Equipment Capital Cost Assumptions

The dehumidification options described in this report were simulated to estimate their impact on annual energy use, operating costs, and indoor humidity levels. An economic analysis was also performed to estimate the cost effectiveness of each option as described in Section 6 of this report. Table C-1 and Table C-2 below summarize the assumed first cost for each dehumidification option, cost of additional items associated with each option, and installation costs. The first cost for each option (e.g., cost for a stand-alone dehumidifier, Santa Fe High Efficiency DH, etc.) was gathered via searches on the world wide web of appropriate equipment (when available) or telephone quotes from manufacturers. Additional associated costs were gathered in a similar fashion when available or estimated using the RS Means 2005 Mechanical Cost Data handbook.

The following assumptions were made for each dehumidification option:

- Standalone Dehumidifier. The dehumidifier is placed in an existing central closet or storage room and requires installation of a condensate drain line. The humidistat is integral to the dehumidifier (i.e., a separate humidistat is not required). The MIXED version of this option requires use of a CYCLER fan controller. In this case, the first cost premium for a combined thermostat/FanCycler controller[1] is shown ($131 minus $70 for a standard thermostat) and no installation cost premium for this thermostat/controller is assumed (i.e., for a new installation, the installation costs for a conventional thermostat would be the same as for a combined thermostat/FanCycler controller). The CYC/DMP version of this option requires the use of a CYCLER fan controller and also outdoor ventilation ductwork with a control damper to avoid over-ventilation[2]. Equipment costs for the 37- and 75-pint dehumidifiers were obtained through web searches[3, 4]

- Santa Fe high efficiency dehumidifier from Therma-Stor. Similar assumptions to those for the standalone dehumidifier option above. The first cost for the Santa Fe unit was obtained from a web search[5]. The humidistat is integral to the unit (i.e., a separate humidistat is not required).

- Mini MAU. The mini makeup air unit (MAU) was assumed to be similar to the Ultra-Aire dehumidifier[6] and was estimated to cost 40-45% of the Ultra-Aire's cost due to the reduced capacity. This dehumidification option is assumed to require 25 ft of insulated 6" flexible duct. A separate humidistat and a condensate drain line are also required.

- Residential Munters HCU. The first cost for the Munters HCU dehumidification option was estimated to be approximately 20% of the cost for a Munters HCU1000 humidity

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[1] ERV24 Series Wall Mount Thermostat and FanCycler, http://www.thermostatshop.com/erv24-series.shtml
[2] Aprilaire Ventilation Control System Model 8126, http://www.iaqsource.com/index.php?module=product&prod_cat=43&prod_mfg=0&prod_sub_cat=0&prod_id=119
[3] Soleus CFM-40 dehumidifier, http://www.air-n-water.com/product/CFM40.html
[4] Haier 65 pint Dehumidifier http://www.compactappliance.com/xq/JSP.jump/itemType.CATEGORY/itemID.41/qx/Dehumidifiers.htm
[5] Santa Fe High Efficiency Basement/Whole House Dehumidifier, http://www.iaqsource.com/index.php?module=product&prod_cat=0&prod_mfg=3&prod_sub_cat=0&prod_id=25
[6] Ultra-Aire APD UA-100V Purifying Dehumidifier, http://www.aircareonline.com/Ultra-Aire-100v.html

control unit. This dehumidification option is assumed to require 50 ft of insulated 6” flexible duct. A separate humidistat is required. A condensate drain line is not required for this dehumidification option since it is assumed to be installed outdoors. Electrical hook-up is required and was estimated using RS Means 2005.

- Enthalpy Wheel/ERV. The energy recovery ventilator (ERV) was assumed to be the Aprilaire 8100 Energy Recovery Ventilator[7]. This dehumidification option was assumed to require 50 ft of insulated 6” flexible duct. A separate humidistat is not required due to the unit’s continuous operation. Electrical hook-up is required and estimated using RS Means 2005.

- Conventional AC with Heat Pipe HX. This estimate includes the cost of a heat pipe heat exchanger and it is assumed to be installed at the manufacturer’s facility (i.e., no additional field installation costs). This cost is assumed to be $250/ton for a 2.5-ton unit.

- Condenser Reheat. This dehumidification option is assumed to cost approximately 1/3 of the cost for a heat pipe heat exchanger. Refrigerant tubing is required from the condensing unit to the reheat coil. A separate humidistat is also required.

Table C-1. Cost Summary of Dehumidification Options

Option	First Cost ($)	Additional Associated Costs ($)							**Subtotal ($)**	Install Costs ($)	**Total ($)**
		Humidistat	Cycler[1] (Tstat)	Ductwork	Cond. Drain	Electrical	Refrig. Tubing	OA Damper			
Standalone Dehum (37 pint)	190	(Integral)			20				**210**	40	**250**
Standalone Dehum (75 pint)	249	(Integral)			20				**269**	40	**309**
Standalone Dehum (75 pint) MIXED	249	(Integral)	61		20				**330**	40	**370**
Standalone Dehum (75 pint)CYC/DMP	249	(Integral)	61	39	20			139	**508**	69	**577**
Santa Fe High Efficiency DH	1,119	(Integral)			20				**1,139**	40	**1,179**
Mini MAU (0.2 tons, 288 cfm/ton)	676	70		39	20				**805**	258	**1,063**
Mini MAU (0.3 tons, 192 cfm/ton)	761	70		39	20				**890**	258	**1,148**
Munters HCU	1,420	70		78		82			**1,650**	749	**2,399**
Conv AC (AUTO) w/ ERV (CONST)	850			78		82			**1,010**	621	**1,631**
AC with HP HX	625								**625**		**625**
Condenser Reheat System	208	70					73		**351**	320	**671**

Notes: 1) Cycler cost reflects premium above standard thermostat
2) Grey shaded rows indicate systems that provide good indoor humidity control

[7] Aprilaire 8100 Energy Recovery Ventilator, http://www.iaqsource.com/index.php?module=product&prod_cat=0&prod_mfg=0&prod_sub_cat=0&prod_id=120

Table C-2. Breakdown of Additional Associated Costs

Item	Each or Length	Unit Cost ($)	Total Material ($)	Unit Labor Cost ($)	Total Labor ($)	Total ($)
Thermostat (or humidistat)	1 ea	70	70	128	128	198
Thermostat with Cycler	1 ea	131	131	128	128	259
6" Ductwork (insulated)	25 ft	1.56	39	3.60	90	129
6" Ductwork (insulated)	15 ft	1.56	23	3.60	54	77
Cond. Drain	1 ea	20	20	40	40	60
ERV or HCU Installation	1 ea	-	-	108	108	108
Residential electrical wiring	1 ea	82	82	333	333	415
1/2' refrigeration line to/from reheat coil	60 ea	1.22	73	3.20	192	265
OA damper/vent controller	1 ea	139	139	29	29	168

Note: Labor costs include overhead and profit. Data from RS Means 2005, except the unit cost for the thermostat/humidistat, thermostat with Cycler, and OA damper/vent controller were obtained from a search of the world wide web.