COMPARISON OF ASHRAE STANDARD 90.1, 189.1 AND IECC CODES FOR LARGE OFFICE BUILDINGS IN TEXAS

Jaya Mukhopadhyay, Juan-Carlos Baltazar, Ph.D.
Hyojin Kim, Jeff S. Haberl, Ph.D., P.E., Cyndi Lewis, Bahman Yazdani, P.E.

Energy Systems Laboratory, Texas A&M University
College Station, Texas

ABSTRACT

Six energy codes were compared in terms of annual site and source energy consumption. This comparison includes ASHRAE Standard 90.1-1989, ASHRAE Standard 90.1-1999, ASHRAE Standard 90.1-2007, ASHRAE Standard 90.1-2010, IECC 2009 and ASHRAE 189.1-2009. The analysis was performed for three Texas counties: Harris (climate zone 2A), Tarrant (climate zone 3A) and Potter (climate zone 4B). Both annual site and source energy consumption were compared. ASHRAE Standard 90.1-1989 was considered as the base case.

ASHRAE Standard 90.1-1989 was considered as the base-case. When considering site energy consumption, ASHRAE Standard 90.1-1999 provides an improvement of 16.7%-18.6%. ASHRAE Standard 90.1-2004 provides an improvement of 22.3%-32.6%, ASHRAE Standard 90.1-2007 provides an improvement of 28.1%-33.9%, IECC 2009 provides an improvement of 27.4%-35.3%, ASHRAE Standard 90.1-2010 provides an improvement of 42.1%-47.7%, and ASHRAE 189.1-2009 provides an improvement of 46.9%-54.9% above the ASHRAE Standard 90.1-1989 base-case.

When considering source energy consumption, ASHRAE Standard 90.1-1999 provides an improvement of 14.5%- 15.0%, ASHRAE Standard 90.1-2004 provides an improvement of 21.6%-27.2%, ASHRAE Standard 90.1-2007 provides an improvement of 23.5%-28.4%, and IECC 2009 provides an improvement of 23.4%-30.5%. ASHRAE Standard 90.1-2010 provides an improvement of 41.8%-45.7% and ASHRAE 189.1-2009 provides an improvement of 44.5%-51.8% above the ASHRAE Standard 90.1-1989 base-case.

BACKGROUND

This study is a comparison of several versions of ASHRAE Standard 90.1, IECC and 189.1 energy codes. Such a comparison was needed to determine whether or not the new building codes are more stringent than the older codes. For this purpose the ASHRAE Standard 90.1-1989 was considered as the base-case against which all the other codes were compared. The ASHRAE Standard 90.1-1989 code was selected as the base case because it was determined to be most widely used code in the State of Texas before the implementation of Texas Building Energy Performance Standards (TBEPS) program in the state in 2001. The performance option offered in all the codes was considered for analysis.

To cover the entire State of Texas, the analysis was performed for three Texas counties each of which represent one of the three climate zones in the state. A code-compliant model of an office building was used for comparison of the codes (Ahmad et al. 2005, Kim et al., 2009).

METHODOLOGY

Overview

In order to quantify the savings from the implementation of the different versions of the ASHRAE and IECC codes, a simulation model for a large office was created using DOE-2.1e for a large office building[1]. The model was created to be flexible to incorporate the differences specific to each of the codes. The next sections of this paper describe the simulation model and the inputs specific to each of the ASHRAE and IECC codes that are being compared. To better organize the efforts to create and develop the model, the input was categorized into building program, building form, building fabric and building equipment as specified in Deru et al. (2011).

Climate zones

The State of Texas is divided into three climate zones (ASHRAE 2004) – Zone 2, Zone 3 and Zone 4 (Figure 1). An analysis was performed for the three Texas counties with each county representing a climate zone: Harris (climate zone 2A), Tarrant (climate zone 3A) and Potter (climate zone 4B). These counties cover the major population centers in the State of Texas.

[1] OFFICE.inp (Version 2.06).

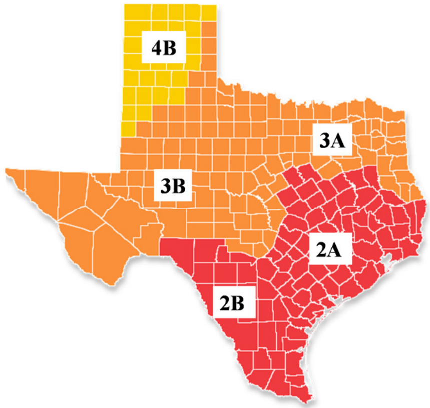

Figure 1: ASHRAE Climate Zones in Texas Building Program

Plug loads
Except for ASHRAE Standard 90.1-1989, none of the codes used for comparison have information regarding the plug and process loads. Therefore, a single value of 0.75 W/ sqft. for process loads was assumed across all the codes. This value is taken from Table 8.4 of the ASHRAE Standard 90.1-1989 code and used to specify the plug and process loads for all the codes.

Ventilation requirements
For ventilation requirements the referenced standards and the respective specifications are provided in Table 1 below.

Table 1: Ventilation Requirements for Energy Codes Referencing ASHRAE 62.1 Standards

Energy Code	Ver. of ASHRAE 62.1	cfm/ per.	cfm/ sqft.	Resultant OA cfm
ASHRAE 90.1-1989	1981	5	-	1625
ASHRAE 90.1-1999	1989	20	-	6500
ASHRAE 90.1-2004	1999	20	-	6500
ASHRAE 90.1-2007	2004	5	0.06	6983
ASHRAE 90.1-2010	2007	5	0.06	6983
IECC 2009	2007	5	0.06	6983
ASHRAE 189.1-2009	2007	5	0.06	6983

Except for ASHRAE Standard 90.1-1989 none of the codes had information regarding the peak occupancy and occupancy schedules. Therefore, peak occupancy and occupancy schedules are taken from Table 13.2 and Table 13.3 of ASHRAE Standard 90.1-1989 and are used for all the codes. The peak occupancy is assumed to be 275 sqft. / person.

Space temperatures
The simulation model assumes space conditions to be at 70°F for space heating and 75°F for space cooling as specified in Section 13.7.6.2 of the ASHRAE Standard 90.1-1989 code. A thermostat setback of 80 F for cooling and 65 F for heating is assumed to reflect practical operating conditions in a typical office building (Leach et al. 2010).

Operating schedules
Additional operating schedules include service hot water demand, lighting and process loads and HVAC system schedules (e.g. fans, heating and cooling). The values used for these schedules are taken from Table 13.3 of the ASHRAE Standard 90.1-1989 with modifications[2] and are used across all the codes except for process loads in ASHRAE Standard 90.1-2010. The schedule for process loads in ASHRAE Standard 90.1-2010 code has been modified to reflect 50% of 120V receptacle outlets being automatically switched off when the space in which they are located is not in use[3].

Building Form
The base-case building is a six story office building as described in studies by Ahmad et al., (2005) and Kim et al., (2009). The aspect ratio for ASHRAE Standard 90.1-1989 is kept at 2.5:1 as prescribed in the code. The resulting building dimensions were 192.89 ft. x 77.16 ft. which translates to a footprint area of 14,884 ft^2 and a total conditioned floor area of 89,304 ft^2. The aspect ratio for the other codes is kept at 1.5:1 (Leach et al., 2010). The resulting building dimensions are 149.42 ft x 99.62 ft. Each floor of the building is divided into four perimeter zones and a central core zone. The perimeter zones face the four orientations and have a width of 15 feet as described in the ASHRAE codes.

In ASHRAE Standard 90.1-1989, specifications were used for the floor height of all the base-case buildings which is a floor-to-floor height of 13 feet. As there is no information in the other codes regarding the floor to floor height, the same floor to floor height is assumed for all the other codes.

ASHRAE Standard 90.1-1989 provides for several configurations of window-to-wall area ratio (WWAR) depending on the lighting and equipment power density, as well as window specifications. From ASHRAE Standard 90.1-1999 onwards it is

[2] Schedules published in the original version of Standard 90.1-1989 were modified by Addendum L in 1994 by a public review process, and are published with minor modifications[2] in Section G of the User's Manual for Standard 90.1-2004 (ASHRAE 2004b).
[3] As per Section 8.4.2, ASHRAE 90.1 2010.

required to have the WWAR of the budget building to be the same as that of the proposed design building. The codes however fix the maximum possible WWAR of the budget building with an upper limit of WWAR being set at 50% for ASHRAE Standard 90.1-1999 and 90.1 2004 and 40% for ASHRAE Standard 90.1-2007, 90.1 2010, 189.1 2009 and IECC 2009. Therefore, a 40% window to wall area ratio was assumed for all the codes in this analysis.

In the model considered for the analysis, the location of the windows is in the insulation part of the wall. The windows are five ft. high and typically are at a sill height of three ft. The location of the windows does not affect the thermal properties of the simulation model but does affect the daylighting analysis[4] which is required in ASHRAE Standard 90.1-2010 and ASHRAE 189.1-2009 codes.

The base-case building as prescribed in the ASHRAE Standard 90.1 and IECC 2009 codes does not have shading. The ASHRAE 189.1 code prescribes a projection factor (PF) of 0.25 on the east, west and south orientation of the base-case building which translates into a horizontal shade with a width of 2.5ft.

Building Fabric

Building envelope characteristics

Using the advice from Ahmad et al., (2005) and Kim et al., (2009) steel frame walls were selected for the base-case building. Six inch metal studs placed 16" on center were used. The exterior finish material of the wall was stucco. The roof was modeled as insulation entirely above a metal deck. Slab-on-grade construction was selected for the floor. The building simulation model assumes all interior walls to be air type walls. Window specifications were used according to each of the codes. Envelope specifications for all codes are compiled in Table 4.

Infiltration

ASHRAE Standard 90.1 1989 provides an infiltration requirement for the building envelope to be 0.038 cfm/sqft. However, no specifications are provided for infiltration rates in either ASHRAE Standard 90.1-1999, 2004 or 2007 codes. The use of air-barriers is introduced as a mandatory requirement in the ASHRAE Standard 90.1 2010 code which reduces the infiltration values for opaque building components to 0.04 cfm/sqft. This analysis assumes the use of the Air-Change method for simulating infiltration in the input file. The values reported in the ASHRAE codes are at a pressure difference of 0.3 in. w.c., which is different that the pressure difference of 0.017 in. w.c. required of the values input to the DOE-2 code. An NREL report by Leach et. al., (2010) on the analysis of large office buildings provides typical infiltration values for a large office building at a pressure difference of 0.017 in. w.c. The values are reported in Table 2 below. The report also provides reduced infiltration values as a result of installation of air-barriers. The reduced values are also provided in Table 2 below. When the HVAC system is operating, the total infiltration is reduced by 75%.

Table 2: Infiltration Specifications (cfm / sqft.)

Energy Code	Operating Hours ACH	Non-Operating Hours ACH
ASHRAE 90.1-1989 – 2007 & IECC 2009		
Core Zones	0.043	0.170
Perimeter Zones	0.070	0.280
ASHRAE 90.1-2010 & 189.1-2009		
Core Zones	0.0095	0.0375
Perimeter Zones	0.0155	0.0618

ACH: Air Changes per Hour

Absorptance and emmitance

For roofs, an absorptance value of 0.7 was used for ASHRAE Standard 90.1-1989, 1999, 2004 and 2007. A value of 0.75 was used for the IECC 2009 code. ASHRAE Standard 90.1-2010 specifies a roof absorptance value of 0.45 for climate zones 2 and 3, and 0.7 for climate zone 4. ASHRAE 189.1-2009 specifies a roof absorptance value of 0.55 for climate zone 2 and 3 and 0.7 for climate zone 4. A wall absorptance of 0.7 was assumed for all the codes unless specified otherwise. IECC 2009 specifies the wall absorptance to be 0.75. A default emittance of 0.9 for both roofs and walls was used from the DOE-2.1e User's Manual (LBNL 1993) with the exception of the IECC 2009 which specifies the roof emittance to be 0.75.

Building Equipment

Lighting systems: Lighting power density (LPD) in terms of W/sqft. is provided in all the codes. ASHRAE Standard 90.1-1989 provides two methods for compliance - total allowable unit lighting power allowance (ULPA) by building type and system performance criteria. The ULPA is based on the gross lighted area of total building and is used for the performance path comparison option provided in the code. The method for determining the lighting power density was changed from ASHRAE Standard 90.1-1999 code onward. Since then LPDs have been

[4] This analysis will rely on the approximate results generated by the existing daylighting model due to time constraints involved in developing a separate more accurate daylighting model.

defined either using the building area method or by using the space–by–space method. For this analysis, values from the building area method are considered for all codes from ASHRAE Standard 90.1-1999 onward. Table 3 provides the different values for LPD for each code. Daylight dimming controls have been assumed in the ASHRAE Standard 90.1-2010 and ASHRAE Standard 189.1-2009 codes. The controls are simulated using two daylight sensors in each of the perimeters zones of the simulation model.

Table 3: Lighting Power Densities (W/sqft.)

Energy Code	Lighting Power Density (W/sqft.)
ASHRAE 90.1-1989	1.57 (Note 1)
ASHRAE 90.1-1999	1.3
ASHRAE 90.1-2004	1
ASHRAE 90.1-2007	1
IECC 2009	1
ASHRAE 90.1-2010	0.9
ASHRAE 189.1-2009	0.9

Note 1: For 50,001 to 250,000 ft^2 of total building

Table 4: Building Envelope Requirements

Climate Zone	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009
Steel Frame Walls						
2A	R-6.5	R-13	R-13	R-13	R-13	R-13+R-5 c.i
3A	R-6.5	R-13	R-13+R3.8 c.i	R-13+R3.8 c.i	R-13+R3.8 c.i	R-13+R-5 c.i
4B	R-16.5	R-13	R-13+R7.5c.i	R-13+R7.5c.i	R-13+R7.5c.i	R-13+R10 c.i
Insulation Entirely Above Roof						
2A	R-13.5 c.i	R-15 c.i	R-20 c.i	R-20 c.i	R-20 c.i	R-25 c.i
3A	R-15.75 c.i	R-15 c.i	R-20 c.i	R-20 c.i	R-20 c.i	R-25 c.i
4B	R-15.5 c.i	R-15 c.i	R-20 c.i	R-20 c.i	R-20 c.i	R-25 c.i
Window U-Value						
2A	U-1.15	U-1.22	U-0.75	U-0.75	U-0.75	U-0.75
3A	U-1.15	U-1.22	U-0.65	U-0.65	U-0.65	U-0.65
4B	U-0.81	U-0.46	U-0.55	U-0.55	U-0.55	U-0.45
Window SHGC						
2A	0.61	0.17	0.25	0.25	0.25	0.25
3A	0.61	0.15	0.25	0.25	0.25	0.25
4B	0.61	0.25	0.40	0.40	0.40	0.40
Slab On Grade						
2A	N.R	N.R	N.R	N.R	N.R	N.R
3A	N.R	N.R	N.R	N.R	N.R	N.R
4B	N.R	N.R	N.R	N.R	N.R	R-10 at 4ft.

HVAC systems: The selection of the appropriate HVAC system and service hot water (SHW) equipment for the building was based on several criteria elaborated in each of the codes selected for the analysis. To perform a simulation, a set of two simulations was needed to determine the type, number and efficiency of HVAC and SHW equipment used in the analysis of the codes. The initial run auto-sizes the HVAC and the SHW equipment, which provide the basis of the type, number and efficiency of the equipment to be used in the second run.

Figure 2 presents a flow chart used to run the ASHRAE Standard 90.1-1989. Seven system types are defined according to the type of building and conditioned floor area (ASHRAE Standard 90.1-1989, Table 13-6). For the office building considered for this analysis, the system requirements were chosen according to square footage (ASHRAE Standard 90.1-1989, Table 13-5). The system selected is the built-up central VAV with perimeter reheat. Figure 3 presents the flow chart used to run the ASHRAE Standard 90.1-1999. Flow charts for ASHRAE Standard 90.1-2004, 2007, 2010 and IECC 2009 can be found in the report by Mukhopadhyay et al. (2011). These flow charts for the above mentioned codes are similar in structure. However, the efficiencies determined for each code are different. These standards define four additional system types providing base-case options for a total of eleven systems. For the office building considered for this analysis, the system requirements were chosen based on condenser cooling source and heating system classification. For this analysis the assumed condenser cooling source is water and the assumed heating system classification is fossil fuel. Hence, the system selected is a built-up, central VAV with perimeter reheat. The system was auto-sized in the first run, and the boiler and chiller sizes obtained from the PV-A report. These sizes help to determine the number and type of boilers and chillers as well as the equipment efficiency as reported in Table 6.

The flow chart for ASHRAE Standard 189.1-2009 is similar to the Standard 90.1 charts with some modifications. For example, an appropriate system is selected from Table D3.1.1A of the 189.1 code, and there are 8 base-line system descriptions available. These systems are described in Table D3.1.1B of the 189.1 code. Equipment capacities are established in section D3.1.2.2 of the code. Four sizing runs need to be executed for each orientation of the building with cooling systems being oversized by 15% and heating systems being oversized by 25%. Table D3.1.3.7 of the 189.1 code provides the selection of type and number of chillers. The boiler and chiller sizes are obtained from the PV-A report. These sizes help to determine the number and type of boilers and chillers as well as the equipment efficiency as reported in Table 6.

Economizers: Requirements for implementing economizers have become more stringent with newer versions of the codes. For ASHRAE Standard 90.1-1989, 1999, 2004 and 2007 economizers are required to be installed in climate zone 4B only. Section 9.3.1 of the ASHARE Standard 90.1-1989 provides specifications for economizers. Table 6.3.1 of the ASHRAE Standard 90.1-1999 code provides the minimum system size for which an economizer is required. Table 6.5.1 of ASHRAE Standard 90.1-2004 and 2007 code provides the requirements minimum system size for which an economizer is required. For climate zone 4B the minimum system size for which an economizer is required is ≥ 65,000 Btu/hr. In ASHRAE Standard 90.1-2010 economizers have been introduced for all the climate zones considered for this analysis. Table 6.5.1A of the ASHRAE Standard 90.1-2010 code provides fan-cooling unit sizes for which an economizer is required for comfort cooling. For all the climate zones the minimum system size for which an economizer is required is ≥ 54,000 Btu/hr.

Table 503.3.1(1) of the IECC 2009 provides the economizer requirements. IECC 2009 does not require any economizer requirements for climate zone 2A. For all other climate zones analyzed by this report, the economizer requirements are on all cooling systems ≥ 54,000 Btu/hr. Table 7.4.3.4A of the ASHRAE 189.1-2009 provides the economizer requirements. ASHRAE 189.1-2009 also does not require any economizer for climate zone 2A. For all other climate zone analyzed the minimum system size for which an economizer is required is ≥ 33,000 Btu/hr. This value is more stringent than the values presented in the other ASHRAE and IECC codes. The codes also provide specifications for the type of economizers for each climate zone. Table 6.3.1.1.3A of ASHRAE Standard 90.1-1999, Table 6.5.1.1.3A of ASHRAE Standard 90.1-2007 and 2010, Table 7.4.3.4B of ASHRAE 189.1-2009 code provide allowed control types for economizers. ASHRAE Standard 90.1-1989 and the IECC 2009 do not have any requirements for control types for economizers.

Trade-offs[5] are provided in some codes for economizer requirements by increasing cooling efficiency. Table 6.3.2 in ASHRAE Standard 90.1-2010, Table 503.3.1(2) in IECC 2009 and Table 7.4.3.4C in ASHRAE 189.1-2009 provide trade-offs requirements for economizers.

Service Hot Water (SHW): SHW equipment for the building is based on several criteria elaborated in each of the codes. The baseline service hot water system is defined as a gas-fired storage water heater with a hot water circulation loop. Table 5 below provides a comparison of the minimum performance specifications for water heating equipment. The maximum gallons/hour per person required for calculating the energy consumption of the SHW equipment was set at 0.4 gallons/hour (Grondzik et al. 2010). The peak usage is calculated to be 73.87 gallons/hr. Assuming a useable capacity of 70% (ASHRAE 1999b), the storage tank is sized as 106 gallons. The temperature of water delivered from lavatory faucets in public facility restrooms is set as 110 F (Grondzik et al. 2010). The standby losses are calculated using a input rating of 100,000Btu/hr which is typical for 100 gallon gas water heaters.

Table 5: Comparison of Service Hot Water Equipment Efficiencies

Standard	Specifications	Min. Perf. Specifications
ASHRAE 90.1-1989 Table 11.1	Fuel Type: Gas Storage Capacity: >100 gals Input Rating: > 75,000 Btu/hr	Et: 77% SL: < 1.3 + 38/V (%)
ASHRAE 90.1-1999 Table 7.2.2	Fuel Type: Gas Storage Capacity: >100 gals Input Rating: > 75,000 Btu/hr	Et: 80% SL: $Q/800 + 110(V)^{0.5}$ (Btu/hr)
ASHRAE 90.1-2004 Table 7.8		
IECC 2009 Table 504.2		
ASHRAE 90.1-2007 Table 7.8		
ASHRAE 90.1-2010 Table 7.8		
ASHRAE 189.1-2009 Table C-12		

[5] The simulation model used for this analysis takes advantage of the trade-off option when modeling economizers for climate zone 2 and 3.

Supply air fans: The simulation assumes one fan for two floors of the building which results in three fans for the entire building (Ahmad et al., 2005). Hence all the results obtained from auto-sizing the fans have to be divided by three. In ASHRAE Standard 90.1-1989 the supply fans for the simulated VAV systems were set at variable speed drive. From ASHRAE Standard 90.1-1999 onwards if supply, return or relief fan motors are 25 hp or larger, the corresponding fan are assumed to have variable speed drive. For smaller fans a forward-curved centrifugal fan with inlet vanes are assumed. The same rules apply to ASHRAE 189.1 and IECC 2009 codes. From the initial runs for all the codes, the fan power obtained from the SV-A report is divided by three. The resulting fan power for all the codes is greater than 25 hp. Fan power specifications for all codes are compiled in Table 7.

Renewable energy systems: ASHRAE Standard 189.1-2009 requires a compliant building to produce an annual energy production equivalent of not less than 6 kBtu/sqft. of on-site renewable energy. For the base-case building of 89,304 sqft. area, the total on-site renewable energy produced would have to be equal to 535.8 MMBtu annually. There are several options that are available to generate this amount of energy on-site. These include provisions for solar thermal systems for water heating and installation of photovoltaic systems for generating on-site electricity.

RESULTS

Both site and source energy consumption were compared for the ASHRAE and IECC codes. The source energy multipliers are 3.16 for electricity and 1.1 for gas (IECC, 2009). ASHRAE Standard 90.1-1989 was considered as the base-case. When considering site energy consumption:

- ASHRAE Standard 90.1-1999 provides an improvement of 16.7%-18.6%;
- ASHRAE Standard 90.1-2004 provides an improvement of 22.3%- 32.6%;
- ASHRAE Standard 90.1-2007 provides an improvement of 28.1%-33.9%;
- IECC 2009 provides an improvement of 27.4%-35.3%;
- ASHRAE Standard 90.1-2010 provides an improvement of 42.1%-47.7%; and
- ASHRAE 189.1-2009 provides an improvement of 46.9%-54.9% above the ASHRAE Standard 90.1-1989 base-case.

The comparison tables and figures are provided below (Table 9, and Figure 4). When considering source energy consumption:

- ASHRAE Standard 90.1-1999 provides an improvement of 14.5%-15.0%;
- ASHRAE Standard 90.1-2004 provides an improvement of 21.6%-27.2%;
- ASHRAE Standard 90.1-2007 provides an improvement of 23.5%-28.4%,
- IECC 2009 provides an improvement of 23.4%-30.5%;
- ASHRAE Standard 90.1-2010 provides an improvement of 41.8%-45.7%; and
- ASHRAE 189.1-2009 provides an improvement of 44.5%-51.8% above the ASHRAE Standard 90.1-1989 base-case. The comparison tables and graphs are provided below (Table 9 and Figure 5).

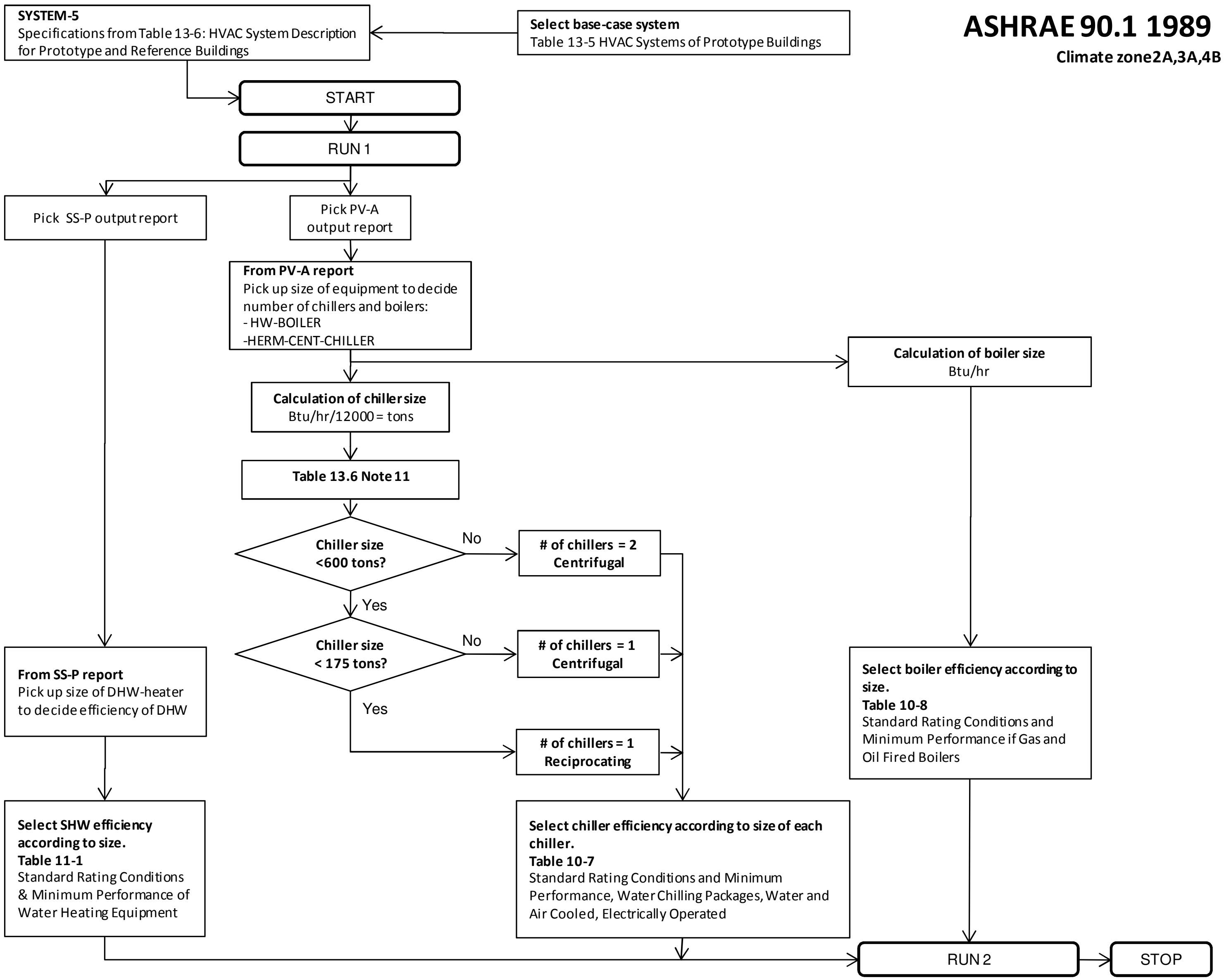

Figure 2: Flow Chart for ASHRAE 90.1-1989

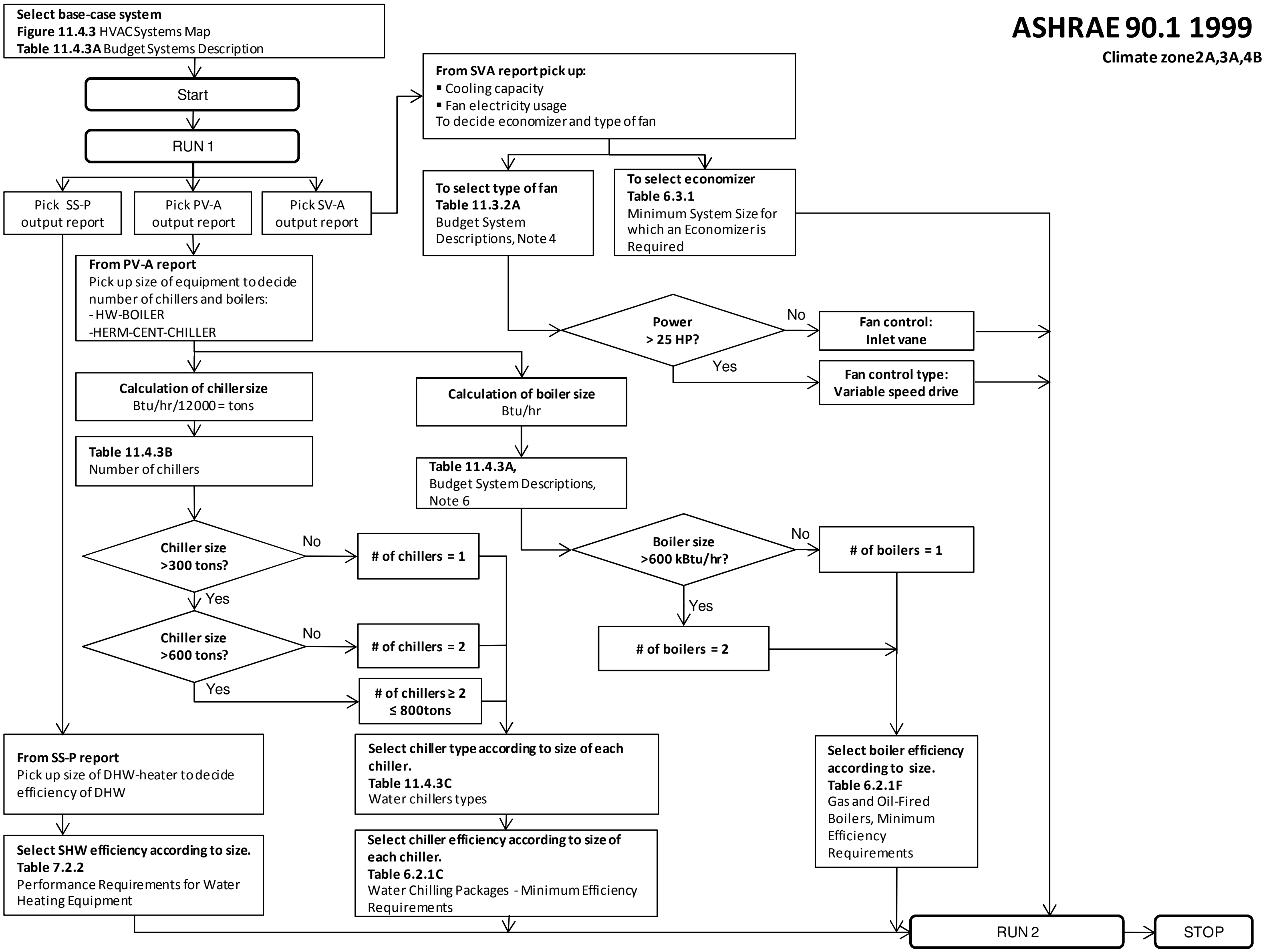

Figure 3: Flow Chart for ASHRAE 90.1-1999

Table 6: Comparison of Chiller and Boiler Specifications for the Analyzed Climate Zones

Climate Zone	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009
Chiller Type and Specifications						
2A	Number: 1[6] Recip.[6] COP 3.8[7]	Number: 1[8] Screw[9] COP 4.45[10]	Number: 1[11] Screw[12] COP 4.45[13]	Number: 1[14] Screw[15] COP 4.54[16]	Number: 1[17] Screw[18] COP: 4.54[19]	Number: 1[20] Screw[20] COP: 4.54[21]
3A	Number: 1[6] Recip.[6] COP 3.8[7]	Number: 1[8] Screw[9] COP 4.45[10]	Number: 1[11] Screw[12] COP 4.45[13]	Number: 1[14] Recip.[15] COP 4.54[16]	Number: 1[17] Recip.[18] COP: 4.54[19]	Number: 1[20] Screw[20] COP: 4.54[21]
4B	Number: 1[6] Recip.[6] COP 3.8[7]	Number: 1[8] Screw[9] COP 4.45[10]	Number: 1[11] Screw[12] COP 4.45[13]	Number: 1[14] Recip.[15] COP 4.54[16]	Number: 1[17] Recip.[18] COP: 4.54[19]	Number: 1[20] Screw[20] COP: 4.54[21]
Gas Boiler Type and Specifications (Ec %)[22]						
2A 3A 4B	Number: 1[23] 80[24]	Number: 2[25] 80[26]	Number: 2[27] 82[28]	Number: 2[29] 80[29]	Number: 2[30] 82[31]	Number: 2[32] 91[33]

Table 7: Specifications for Supply and Return Fans for the Analyzed Energy Codes

	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009
Fan Control							
	VSD			≥ 25 hp VSD < 25 hp Inlet vane			≥ 5 hp VSD
Fan Specifications							
Supply	Total SP: 4 in wc Eff.: 55%	For VAV fans ≥ 20,000cfm 1.5 hp/1000 cfm			For VAV fans 1.5 hp/1000 cfm		For VAV fans 1.35 hp/1000 cfm
Return	Total SP: 1 in wc Eff.: 30%						

SP: Static Pressure
VSD: Variable Speed Drive

6 ASHRAE 90.1-1989, Table 13-6, Note 11
7 ASHRAE 90.1-1989, Table 10-7
8 ASHRAE 90.1-1999, Table 11.4.3B
9 ASHRAE 90.1-1999, Table 11.4.3C
10 ASHRAE 90.1-1999, Table 6.2.1C
11 ASHRAE 90.1-1999, Table 11.3.2B
12 ASHRAE 90.1-2007, Table 11.3.2C
13 ASHRAE 90.1-2007, Table 6.8.1C
14 IECC 2009, Table 506.5.1(4)
15 IECC 2009, Table 506.5.1(5)
16 IECC 2009, Table 503.2.3(7)
17 ASHRAE 90.1-2010, Table 11.3.2B
18 ASHRAE 90.1-2010, Table 11.3.2C
19 ASHRAE 90.1-2010, Table 6.8.1C
20 ASHRAE 189.1- 2009, Table D3.1.3.7
21 ASHRAE 189.1-2009, Table C-3
22 Ec = Et + % Flue Losses. Ec: Combustion Efficiency Et: Thermal Efficiency Flue losses are assumed to be 2%
23 No specifications in the code. Hence assume 1 boiler.
24 ASHRAE 90.1-1989, Table 10-8
25 ASHRAE 90.1-1999, Table 11.4.3A, Note 6
26 ASHRAE 90.1-1999, Table 6.2.1F
27 ASHRAE 90.1-2007, Table 11.3.2A, Note f
28 ASHRAE 90.1- 2007, Table 6.8.1F
29 IECC 2009, Table 503.2.3(5)
30 ASHRAE 90.1- 2010, Table 11.3.2A, Note f
31 ASHRAE 90.1-2010, Table 6.8.1F
32 ASHRAE 189.1-2009, Section D3.1.3.2
33 ASHRAE 189.1-2009, Table C-7

Table 8: Comparison of Economizer Requirements for the Analyzed Climate Zones

Climate Zone	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009
2A	×	×	×	×	×	✓ Diff. Enthalpy Trade-off: 17%	×
3A	×	×	×	×	✓ Diff. Enthalpy Trade-off: 15%	✓ Diff. Enthalpy Trade-off: 27%	✓ Diff. Enthalpy Trade-off: 15%
4B (Note 1)	✓ Diff. Drybulb	✓ Fixed Drybulb	✓ Fixed Drybulb	✓ Diff. Drybulb	✓ Diff. Drybulb	✓ Diff. Drybulb	✓ Diff. Drybulb
Specs for minimum size of system	No Specifications	Table 6.3.1	Table 6.5.1	≥ 65 kBtu/hr Table 6.5.1	≥ 54 kBtu/hr Table 503.3.1(2)	≥ 54 kBtu/hr Table 6.5.1A	≥ 33 kBtu/hr Table 7.4.3.4A
Specs for Control Type	No Specifications	Table 6.3.1.1.3A	Table 6.5.1.1.3A	Table 6.5.1.1.3A	No Specifications	Table 6.5.1.1.3B	Table 7.4.3.4B
Economizer Trade-off					Table 503.3.1(2)	Table 6.3.2	Table 7.4.3.4C

×: No economizer requirement
✓: Economizer required
Note 1: Trade-offs are not implemented in climate zone 4A.

Table 9: Site and Source Energy Calculations

SITE ENERGY

	Building Energy Performance Summary (MMBtu)							% Difference w/ ASHRAE 90.1 1989					
							Climate Zone 2A						
	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009
ELEC	4652.6	4045.5	3671.6	3570.3	3557.9	2683.8	2655.3	13.0	21.1	23.3	23.5	42.3	42.9
GAS	1262.8	884.9	924.3	607.1	640.0	681.0	485.8	29.9	26.8	51.9	49.3	46.1	61.5
TOTAL	**5915.4**	**4930.3**	**4595.9**	**4177.3**	**4197.9**	**3364.8**	**3141.1**	**16.7**	**22.3**	**29.4**	**29.0**	**43.1**	**46.9**
							Climate Zone 3A						
	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009
ELEC	4684.2	4034.7	3595.2	3541.7	3416.0	2610.8	2364.3	13.9	23.2	24.4	27.1	44.3	49.5
GAS	1634.5	1230.2	664.1	637.0	670.7	693.8	487.5	24.7	59.4	61.0	59.0	57.6	70.2
TOTAL	**6318.6**	**5264.9**	**4259.1**	**4178.6**	**4086.5**	**3304.6**	**2851.8**	**16.7**	**32.6**	**33.9**	**35.3**	**47.7**	**54.9**
							Climate Zone 4B						
	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009
ELEC	4385.7	3873.2	3516.3	3508.1	3495.4	2562.1	2349.3	11.7	19.8	20.0	20.3	41.6	46.4
GAS	1906.2	1246.1	1129.3	1015.0	1072.0	1078.3	695.1	34.6	40.8	46.8	43.8	43.4	63.5
TOTAL	**6291.9**	**5119.2**	**4645.6**	**4523.1**	**4567.5**	**3640.3**	**3044.4**	**18.6**	**26.2**	**28.1**	**27.4**	**42.1**	**51.6**

SOURCE ENERGY

	Building Energy Performance Summary (MMBtu)							% Difference w/ ASHRAE 90.1 1989					
							Climate Zone 2						
	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009
ELEC	14655.7	12743.3	11565.5	11246.4	11207.4	8454.0	8364.2	13.0	21.1	23.3	23.5	42.3	42.9
GAS	1389.1	973.4	1016.7	667.8	704.0	749.1	534.4	29.9	26.8	51.9	49.3	46.1	61.5
TOTAL	**16044.8**	**13716.7**	**12582.3**	**11914.3**	**11911.4**	**9203.1**	**8898.6**	**14.5**	**21.6**	**25.7**	**25.8**	**42.6**	**44.5**
							Climate Zone 3						
	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009
ELEC	14755.2	12709.3	11324.9	11156.4	10760.4	8224.0	7447.5	13.9	23.2	24.4	27.1	44.3	49.5
GAS	1798.0	1353.2	730.5	700.7	737.8	763.2	536.3	24.7	59.4	61.0	59.0	57.6	70.2
TOTAL	**16553.2**	**14062.5**	**12055.4**	**11857.1**	**11498.2**	**8987.2**	**7983.8**	**15.0**	**27.2**	**28.4**	**30.5**	**45.7**	**51.8**
							Climate Zone 4						
	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	ASHRAE 90.1 2010	ASHRAE 189.1 2009
ELEC	13815.0	12200.6	11076.3	11050.5	11010.5	8070.6	7400.3	11.7	19.8	20.0	20.3	41.6	46.4
GAS	2096.8	1370.7	1242.2	1116.5	1179.2	1186.1	764.6	34.6	40.8	46.8	43.8	43.4	63.5
TOTAL	**15911.8**	**13571.3**	**12318.6**	**12167.0**	**12189.7**	**9256.7**	**8164.9**	**14.7**	**22.6**	**23.5**	**23.4**	**41.8**	**48.7**

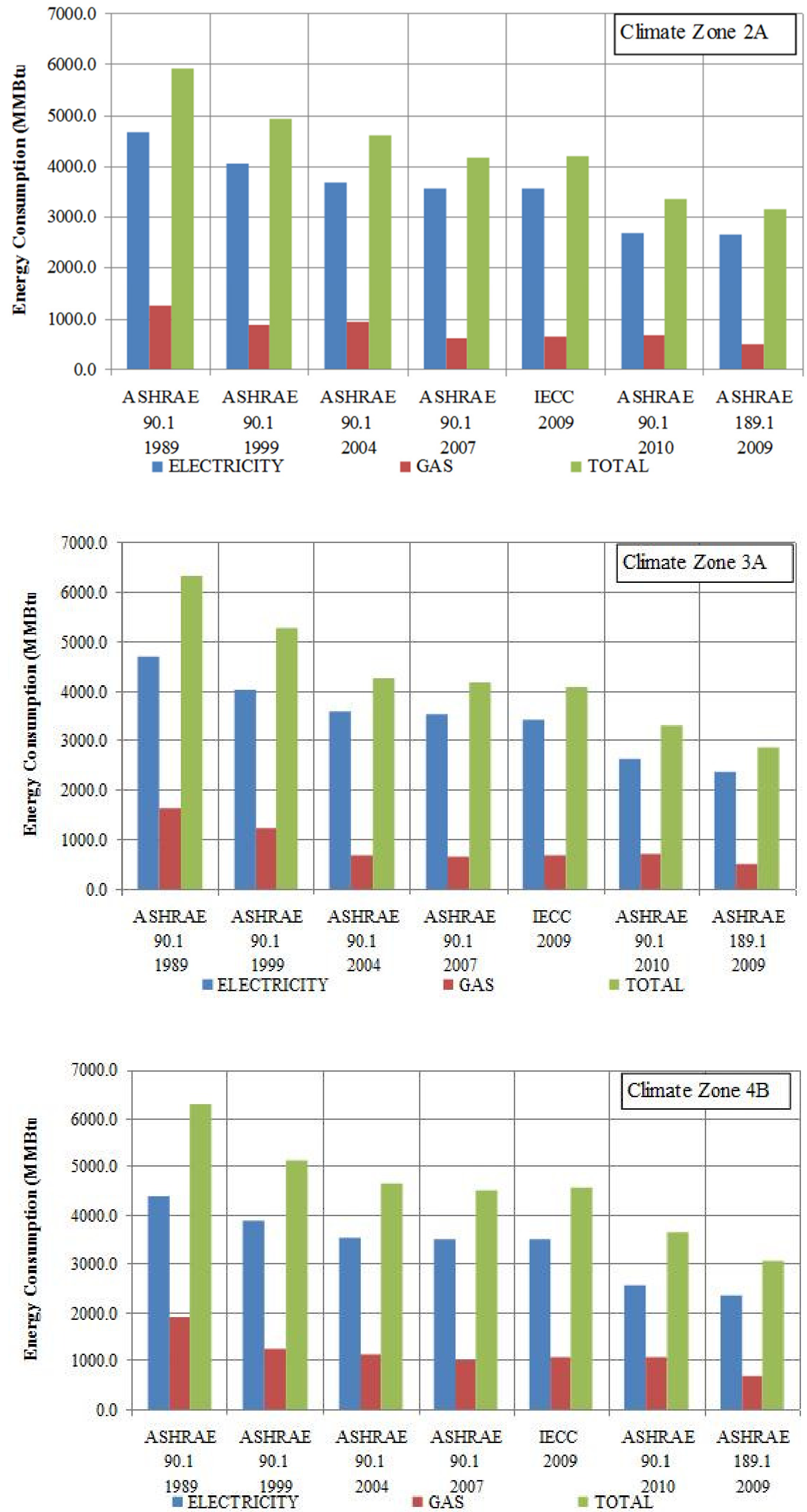

Figure 4: Site Energy Consumption for Climate Zones 2A, 3A and 4B

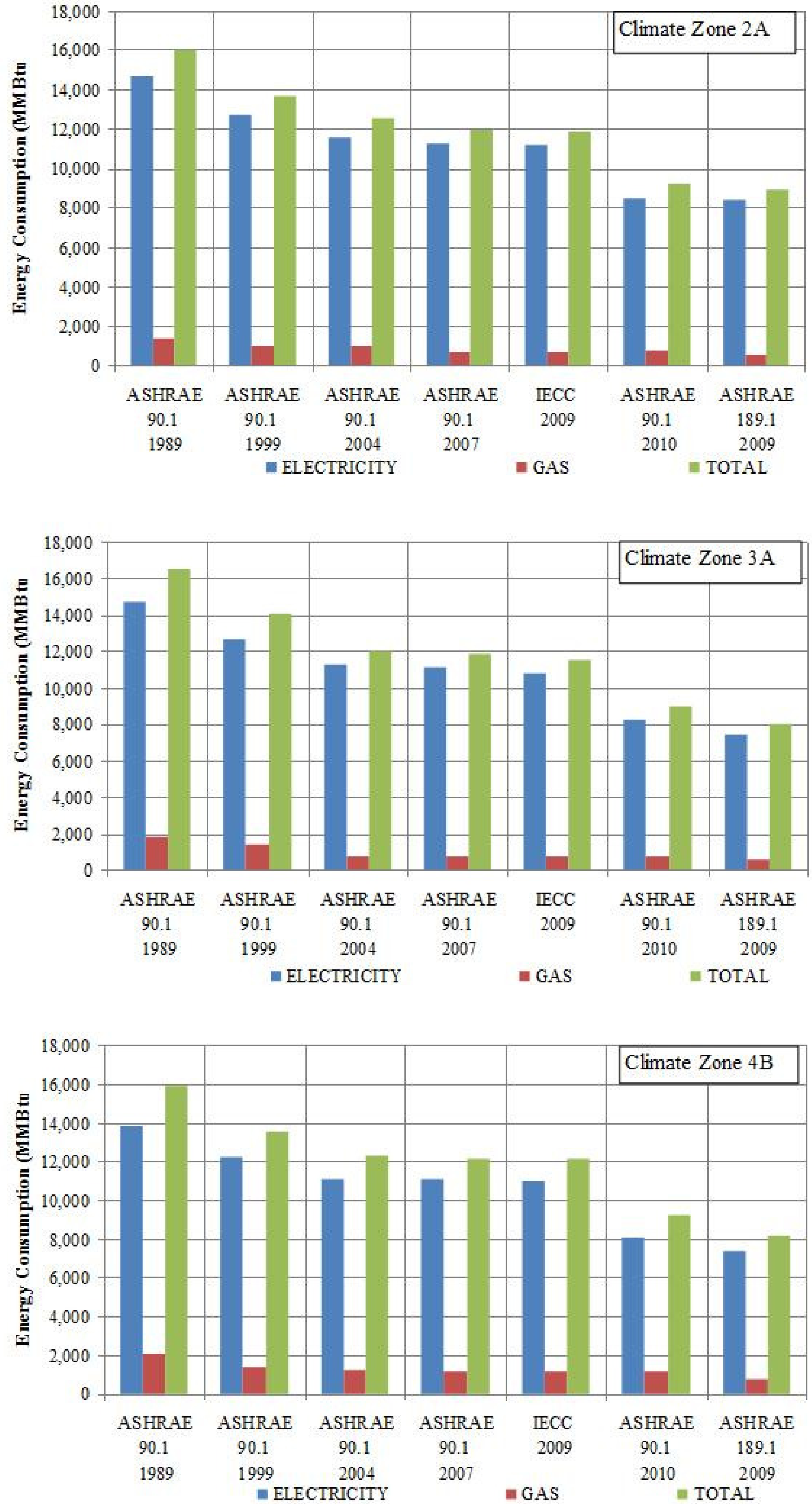

Figure 5: Source Energy Consumption for Climate Zones 2A, 3A and 4B

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