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

A Report

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Executive summary

Six energy codes were compared in terms of 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, IECC 2012 and ASHRAE Standard 189.1-2009. Analysis was performed for three Texas counties: Harris (Climate Zone 2A), Tarrant (Climate Zone 3A) and Potter (Climate Zone 4B). Both site and source energy consumption were compared. The source energy multipliers for electricity is 3.16 and for gas is 1.1 (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 19.6% -21.1%. ASHRAE Standard 90.1-2004 provides an improvement of 25.5%-33.7%, ASHRAE Standard 90.1-2007 provides an improvement of 30.3%-35.0%, IECC 2009 provides an improvement of 30.0%-36.4%, IECC 2012 provides an improvement of 38.1%-41.0%, ASHRAE Standard 90.1-2010 provides an improvement of 43.1%-51.3% and ASHRAE Standard 189.1-2009 provides an improvement of 51.4%-57.0% above the ASHRAE Standard 90.1-1989 base-case. When considering source energy consumption, ASHRAE Standard 90.1-1999 provides an improvement of 18.6% -19.2%, ASHRAE Standard 90.1-2004 provides an improvement of 25.8%-29.2%, ASHRAE Standard 90.1-2007 provides an improvement of 27.0%-30.4%, IECC 2009 provides an improvement of 27.4%-32.5%, IECC 2012 provides an improvement of 31.9%-35.3%, ASHRAE Standard 90.1-2010 provides an improvement of 43.5%-50.4% and ASHRAE Standard 189.1-2009 provides an improvement of 50.2%-54.9% above the ASHRAE Standard 90.1-1989 base case.

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1. Organization of Report

This report is organized in the following order. Section 1 presents the organizational structure of the report. Section 2 presents the introduction and purpose of the report. Section 3 describes the base case office building which is used for analysis in reference to the energy codes being considered for analysis. Section 4 presents the results of the analysis.

2. Introduction

The study is a comparison of several versions ASHRAE Standard 90.1, IECC and ASHRAE Standard 189.1 energy codes. The purpose is to determine the stringency of each code. For this purpose the ASHRAE Standard 90.1-1989 is considered as the base-case against which all the other codes are compared. The ASHRAE Standard 90.1-1989 code is selected as it is assumed to be the code to be implemented in the State of Texas before the implementation of Texas Building Energy Performance Standards (TBEPS) program in the state in 2001. The codes that are compared include the 1999, 2004, 2007 and 2010 versions of the ASHRAE Standard 90.1 code as well as the IECC 2009, IECC 2012 and ASHRAE Standard 189.1-2009 codes. 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.

3. Base Case Building Description

Each of the codes considered for this analysis has mandatory requirements as well as provisions for providing compliance using either the prescriptive path or the performance path. This analysis opts for using the performance path method to show compliance. In order to comply with the performance path outlined in each of the codes the energy cost of the proposed buildings should be lesser than the energy cost of the corresponding reference design. However, this report discusses savings in terms of site as well as source energy consumption.

Sections of the codes selected for analysis that provide performance based compliance are – Section 13 for ASHRAE Standard 90.1-1989; Section 11 for ASHRAE Standard 90.1-1999, 2007 and 2010; Section 506 for IECC 2009, Section C407 for IECC 2012 and Appendix D for ASHRAE Standard 189.1-2009. Selecting this path for compliance requires that the simulation model is modeled as per specifications provided for a base-case budget building in the codes. The comparison is carried out using the simulation model for a large office building initially developed by Ahmad et al. (2005) and Kim et al. (2009) using DOE-2.1e simulation program. The model has been updated and modified as per the requirements of this analysis. This analysis uses Version 2.07 of the input file OFFICE.inp. To better organize and document the efforts to create the model, the input was categorized into program, form, fabric and equipment as specified in Deru et al. (2011).

Table 1: Building Energy Model Input Categories (Adopted from: Deru et al. 2011)

Building Program	Building Form	Building Envelope	Equipment
Location	Floor Area and Zoning	Exterior Walls	Lighting and Plug Loads
Ventilation Requirements	Number of Floors	Roof	HVAC System Types
Occupancy and Occupancy Schedules	Aspect Ratio	Floor	Economizers
Space Environmental Conditions	Window Fraction	Window Specifications	Water Heating Equipment
Service Hot Water Demand	Window Locations	Interior Partitions	Component Efficiency
Operating Schedule	Shading	Internal Mass	Control Setting
	Floor Height	Infiltration	
	Orientation		

3.1 Building Program

3.1.1 Location

As per the climate zones determined by ASHRAE (2004) the State of Texas is divided into three Zones – Zone 2, Zone 3 and Zone 4 (Figure 1). Zones 2 and 3 are further divided into dry and humid regions. The analysis was performed for three Texas counties: Harris (Climate Zone 2A), Tarrant (Climate Zone 3A) and Potter (Climate Zone 4B). The selection of the three above mentioned counties covers all the major population centers in the state.

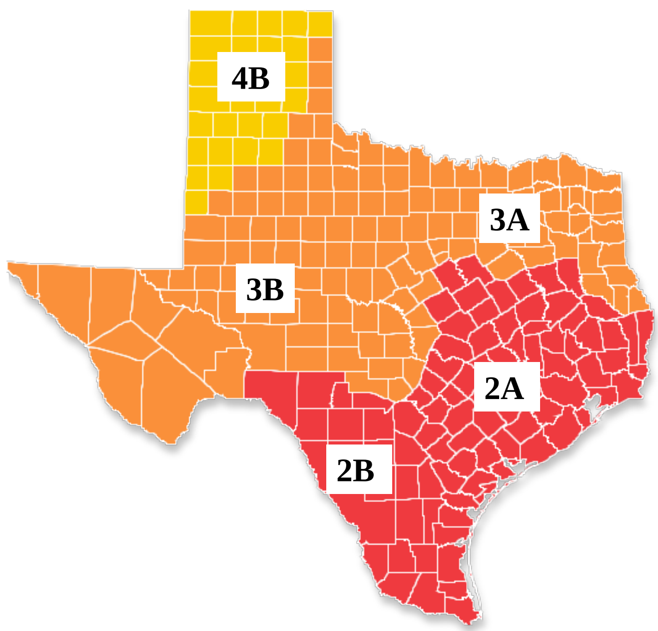


Figure 1: Climate Zones in Texas

3.1.2 Ventilation Requirements

For outdoor ventilation requirements the referenced standards and the respective specifications are provided in the Table 2 below. ASHRAE Standard 90.1-1989 considers 5 cfm of outside air per person. The ventilation rates increase to 20 cfm on going to the ASHRAE Standard 90.1-1999 and 2004 codes. The specifications for outdoor air requirements changed from 2007 onwards. The requirements now also account for floor area in to the calculations. The specifications now require 5 cfm/person and 0.06 cfm/sqft of conditioned floor area.

Table 2: Ventilation Requirements for Energy Codes Referencing ASHRAE 62.1 Standards

Energy Code	Version of ASHRAE 62.1 code	cfm/person	cfm/sqft
ASHRAE 90.1-1989	1981	5	-
ASHRAE 90.1-1999	1989	20	-
ASHRAE 90.1-2004	1999	20	-
ASHRAE 90.1-2007	2004	5	0.06
ASHRAE 90.1-2010	2007	5	0.06
IECC 2009	2007	5	0.06
IECC 2012	2010	5	0.06
ASHRAE 189.1-2009	2007	5	0.06

3.1.3 Occupancy and Occupancy Schedules

Except ASHRAE Standard 90.1-1989 none of the codes taken up for comparison have information regarding the peak occupancy and occupancy schedules. 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 and the occupancy schedule is presented in Figure 2 below.

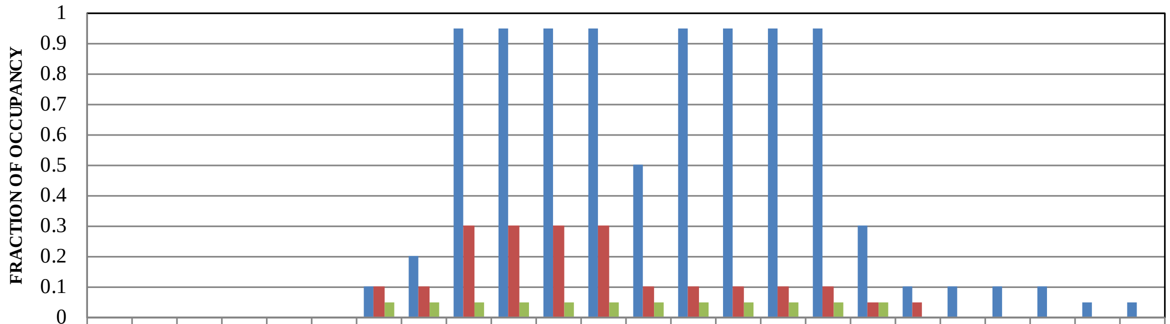
3.1.4 Operating Schedules

Operating schedules include service hot water demand, lighting and equipment loads and HVAC system schedules (fans, heating and cooling). 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 in Section G of the User's Manual for Standard 90.1-2004 (ASHRAE 2004b). Except for equipment schedules, the same sets of schedules are used across all the codes. In the case of equipment operation, more realistic schedules as discussed in Deru et al. (2011) have been used[1]. Also, as described in Section 8.4.2 of the ASHRAE Standard 90.1-2010 standard, the schedules 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. Figure 3 presents the daily schedule for lighting; Figure 4 and Figure 5 provide the equipment schedules. Figure 6 presents the daily schedule for SHW consumption. Figure 7 presents the daily schedule for fan operations in the building.

3.1.5 Space Conditions

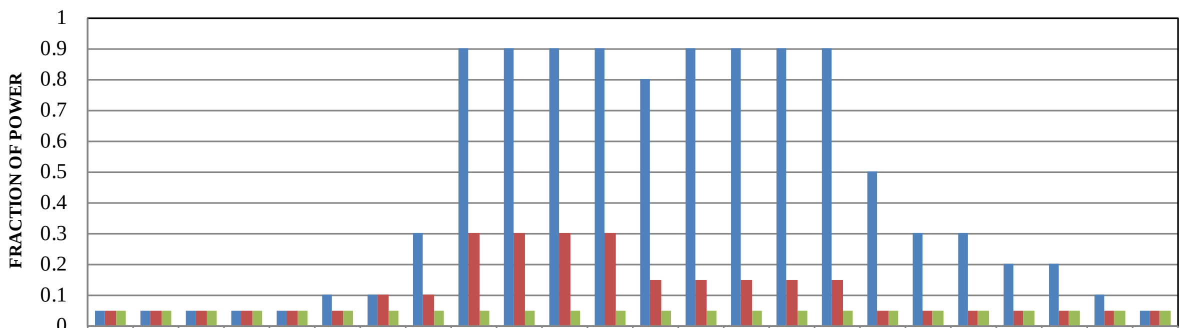
The simulation model assumes space conditions to be at 70 F for space heating and 75 F for space cooling as specified in Section 13.7.6.2 of the ASHRAE Standard 90.1-1989 code. A thermostat setback of 80 F for cooling and 65 F for heating is assumed to reflect practical operating conditions in a typical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

[1] As pointed out in Deru et al. (2011) the plug and process loads don't track lighting loads. Also during off hours the plug loads are higher, probably because of information technology and security equipment. Therefore alternative plug and process load schedules have been developed.



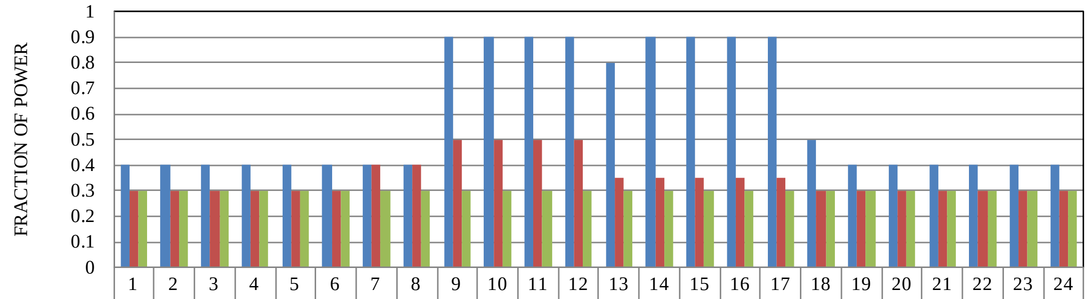
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Wk	0	0	0	0	0	0	0.1	0.2	0.95	0.95	0.95	0.95	0.5	0.95	0.95	0.95	0.95	0.3	0.1	0.1	0.1	0.1	0.05	0.05
Sat	0	0	0	0	0	0	0.1	0.1	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.05	0.05	0	0	0	0	0
Sun	0	0	0	0	0	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0

Figure 2: Occupancy Schedule for the Office Building



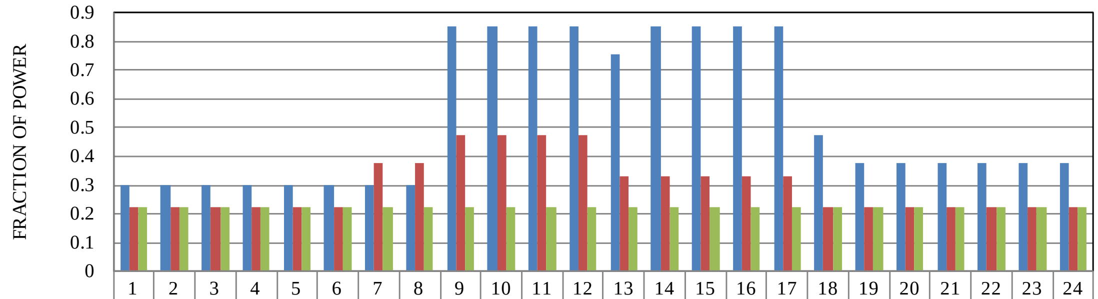
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Wk	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.3	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.5	0.3	0.3	0.2	0.2	0.1	0.05
Sat	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.3	0.3	0.3	0.3	0.15	0.15	0.15	0.15	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Sun	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Figure 3: Lighting Schedule for the Office Building



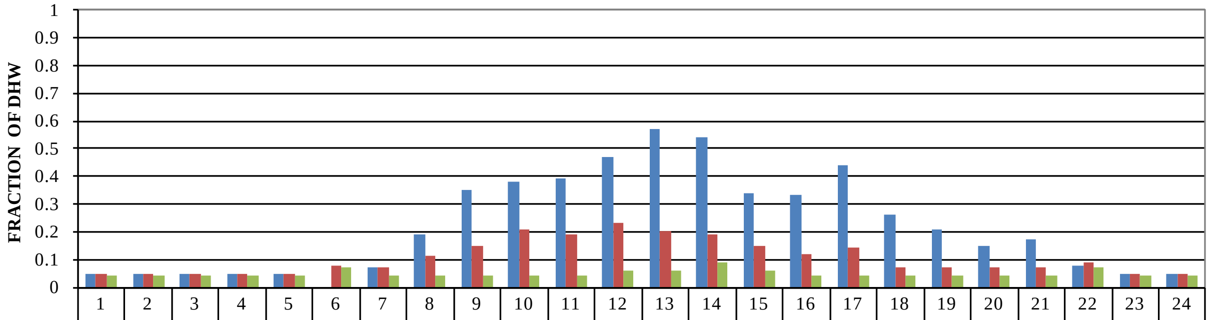
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Wk	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.5	0.4	0.4	0.4	0.4	0.4	0.4
Sat	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.35	0.35	0.35	0.35	0.35	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Sun	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Figure 4: Equipment Schedule for the Office Building



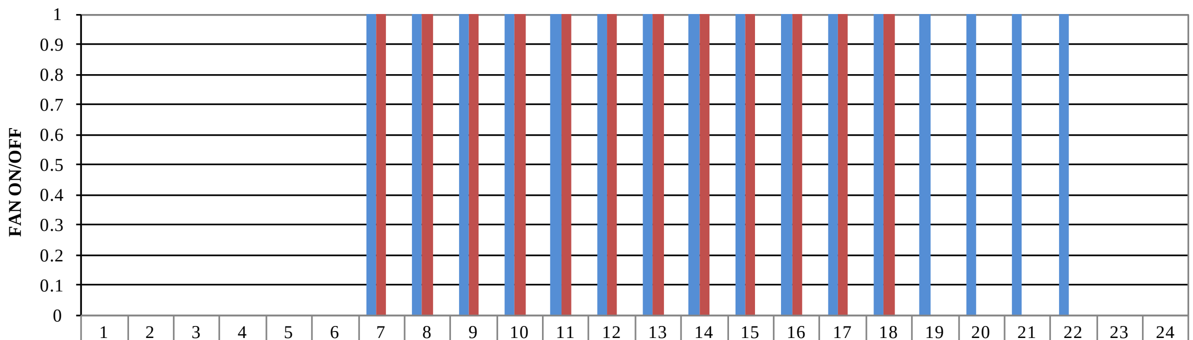
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Wk	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.85	0.85	0.85	0.85	0.76	0.85	0.85	0.85	0.85	0.47	0.38	0.38	0.38	0.38	0.38	0.38
Sat	0.22	0.22	0.22	0.22	0.22	0.22	0.38	0.38	0.47	0.47	0.47	0.47	0.33	0.33	0.33	0.33	0.33	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Sun	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22

Figure 5: Equipment Schedule for the Office Building (ASHRAE 90.1-2010)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Wk	0.05	0.05	0.05	0.05	0.05	0	0.07	0.19	0.35	0.38	0.39	0.47	0.57	0.54	0.34	0.33	0.44	0.26	0.21	0.15	0.17	0.08	0.05	0.05
Sat	0.05	0.05	0.05	0.05	0.05	0.08	0.07	0.11	0.15	0.21	0.19	0.23	0.2	0.19	0.15	0.12	0.14	0.07	0.07	0.07	0.07	0.09	0.05	0.05
Sun	0.04	0.04	0.04	0.04	0.04	0.07	0.04	0.04	0.04	0.04	0.04	0.06	0.06	0.09	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.07	0.04	0.04

Figure 6: Service Hot Water Consumption for the Office Building



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Wk	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
Sat	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
Sun	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 7: Fan Schedule for the Office Building

3.2 *Building Form*

The base-case building is an office building 6 stories high as described in studies by Ahmad et al., (2005) and Kim et al., (2009). The base-case building has a foot print area of 14,884 ft^2 and a total conditioned floor area of 89,304 ft^2. The aspect ratio for ASHRAE Standard 90.1-1989 is kept at 2.5:1 as prescribed in the code. The resulting building dimensions are set at 192.89 ft x 77.16 ft. For the other codes the specific aspect ratio is required to be the same as that of the proposed design. The aspect ratio is kept at 1.5:1 (Deru et. al. 2011). The resultant building dimensions are set at 149.42 ft x 99.62 ft. Each floor of the building is divided into 4 perimeter zones and a central core zone. The perimeter zones face the four orientations and have a width of 15 feet as described in all the codes being compared in this analysis.

ASHRAE Standard 90.1-1989 provides specifications for the floor height of the base-case building. A floor to floor height of 13 feet has been specified. A floor to ceiling height of 9 feet is also specified. As there is no information in the other codes regarding the floor to floor and floor to ceiling 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 the base-case building is 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 window to wall area ratio of the budget building with a upper limit of window to wall area ratio being set at 50% for ASHRAE Standard 90.1-1999 and 2004 and 40% for all the other codes. A 40% window to wall area ratio is assumed for all the codes in this analysis.

In the model considered for the analysis, the location of windows is in the insulation part of the wall. The windows are 5ft high and are typically at a sill height of 3ft. The location of the windows does not affect the thermal properties of the simulation model but affects the daylighting analysis which is required in ASHRAE Standard 90.1-2010 and ASHRAE Standard 189.1-2009 codes. Due to time contraints involved in developing a separate more accurate daylighting model this analysis will rely on the aproximate results generated by the existing daylighting model.

The base-case building as prescribed in the all the ASHRAE Standard 90.1 and IECC 2009 codes does not have shading. The ASHRAE Standard 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 using dimensions of the modeled windows.

3.3 *Building Fabric*

3.3.1 Building Envelope Characteristics

Using advice from Ahmad et al., (2005) and Kim et al., (2009) steel frame walls have been selected for the base-case building. Metal studs of 6” depth are placed 16” on center. The exterior finish material of the wall is selected as stucco. The roof of the base-case building is selected as insulation entirely above deck. Slab-on-grade construction has been selected for the base-case floor. The building simulation model assumes all interior walls to be of air type. Window specifications selected for metal framed windows. Specifications for exterior building envelope components are provided in all the codes. These specifications are climate specific and are compiled in Table 3.

Table 3: Building Envelope Requirements for the Analyzed Codes

Climate Zone	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	ASHRAE 90.1 2010	IECC 2009	IECC 2012	ASHRAE 189.1 2009
Steel Frame Walls								
2A	R-6.5	R-13	R-13	R-13	R-13	R-13	R-13 + R-5 c.i	R-13+ R-5 c.i
3A	R-6.5	R-13	R-13	R-13+ R-3.8 c.i	R-13+ R-3.8 c.i	R-13+ R-3.8 c.i	R-13 + R-7.5 c.i	R-13+ R-5 c.i
4B	R-16.5	R-13	R-13	R-13+ R-7.5c.i	R-13+ R-7.5c.i	R-13+ R-7.5c.i	R-13+ R-7.5 c.i	R-13+ R-10 c.i
Insulation Entirely Above Roof								
2A	R-13.5 c.i	R-15 c.i	R-15 c.i	R-20 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-15 c.i	R-20 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-15 c.i	R-20 c.i	R-20 c.i	R-20 c.i	R-25 c.i	R-25 c.i
Metal Framed Window U-Value								
2A	U-1.15	U-1.22	U-1.22	U-0.75	U-0.75	U-0.75	U-0.50	U-0.75
3A	U-1.15	U-1.22	U-0.57	U-0.65	U-0.65	U-0.65	U-0.46	U-0.65
4B	U-0.81	U-0.46	U-0.57	U-0.55	U-0.55	U-0.55	U-0.38	U-0.45
Window SHGC								
2A	0.61	0.25/ 0.61(N)	0.25/ 0.61(N)	0.25	0.25	0.25	0.25	0.25
3A	0.61	0.25/ 0.61(N)	0.25/ 0.39(N)	0.25	0.25	0.25	0.25	0.25
4B	0.61	0.39/ 0.49(N)	0.39/ 0.49(N)	0.40	0.40	0.40	0.40	0.40
Slab On Grade								
2A	N.R	N.R	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	N.R	N.R
4B	N.R	N.R	N.R	N.R	N.R	N.R	R-10 at 2ft.	R-10 at 4ft.

Note: N indicates North orientation.

For roof and wall absorptance value of 0.7 are taken from Section 13.7.3.3 of ASHRAE Standard 90.1-1989 unless specified otherwise. Both the 2009 and 2012 IECC specify the roof and wall absorptance to be 0.75. AHRAE Standard 90.1 2010 specifies the roof absorptance to be 0.45 for Climate Zone 2 and 3 and ASHRAE Standard 189.1 -2009 specifies the roof absorptance to be 0.55 for Climate Zone 2 and 3. A default emittance of 0.9 for both roofs and walls is taken from the DOE-2.1e User's Manual (LBNL 1993).

3.3.2 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 whole building envelope infiltration in either ASHRAE Standard 90.1-1999, 2004 or 2007 as well as the IECC 2009 codes. The use of air-barriers is introduced as a mandatory requirement in the ASHRAE Standard 90.1-2010 code and in the IECC 2012 code (for Climate Zone 4) which reduces the infiltration values for opaque building components to 0.04 cfm/sqft. The values reported in the 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. Therefore, this analysis uses the AIR-CHANGE method[2] for simulating infiltration in the input file. An NREL report by Leach et al., (2010) for the analysis of large office buildings provide typical infiltration values at a pressure difference of 0.017 in. w.c. These values have been used to represent infiltration in the model. The values are reported in Table 4 below. The report also provides reduced infiltration values as a result of installation of air-barriers. The reduced values are also provided in Table 4 below. When the HVAC system is set at ON during occupied hours the total infiltration is reduced by 75%.

Table 4: Infiltration Specifications (cfm / ft^2) for the Analyzed Codes (Source: Leach et al. 2010)

Energy Code	**Operating Hours** ACH	**Non-operating Hours** ACH
ASHRAE 90.1-1989 – 2007, IECC 2009 & IECC 2012 (Climate Zones 2 and3)		
Core Zones	0.043	0.170
Perimeter Zones	0.070	0.280
ASHRAE 90.1-2010 & 189.1-2009 & IECC 2012 (Climate Zone 4)		
Core Zones	0.0095	0.0375
Perimeter Zones	0.0155	0.0618

3.4 Equipment

3.4.1 Lighting Power Density and Daylighting Controls

Lighting power density (LPD) in terms of W/ft^2 is provided in all the codes. Table 5 provides the different values for LPD as appropriated by 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. Provision of ULPA is based on the gross lighted area of total building. Method for determining the lighting power density were changed from ASHRAE Standard 90.1-1999 code onwards LPDs have been defined either using the building area method or using the space by space method. For this analysis values from the building area method are considered. Automatic daylight controls have been assumed in the ASHRAE Standard 90.1-2010 (Section 9.4.1.4) and ASHRAE Standard 189.1-2009 (Section 7.4.6.5) codes. The controls are simulated using two daylight sensors in each of the perimeters zones of the simulation model.

[2] The AIR-CHANGE method requires the input of the number of infiltration-caused air changes per hour at a wind speed of 10mph for a space (LBNL, 1980).

Table 5: Lighting Power Densities (W/ft^2) for the Analyzed Codes

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
IECC 2012	0.9
ASHRAE 90.1-2010	0.9
ASHRAE 189.1-2009	0.9

Note 1: These values are specified for 50,001 to 250,000 ft^2 of total building

3.4.2 Power

Except ASHRAE Standard 90.1-1989 none of the codes taken up for comparison have information regarding the plug and process loads. A single value of 0.75 W/ ft^2 for process loads is 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.

3.4.3 HVAC Systems

The selection of an appropriate HVAC system and service hot water (SHW) equipment types for the building is based on several criteria elaborated in each of the codes selected for the analysis. A set of two simulations is needed to finalize the type, number and efficiency of HVAC and SHW equipment used in the analysis of the codes. The initial run sizes the HVAC and the SHW equipment according to the design day criteria for each climate zone being simulated. The weather conditions used in the sizing runs to determine the baseline equipment capacities is based on design days developed using 99.6% heating design temperatures and 1% dry-bulb and 1% wet-bulb cooling design temperatures. Design day characteristics are obtained from ASHRAE Handbook of Fundamentals (ASHRAE 2009). The resultant sizing for chillers and boilers obtained from the first run provide the basis of the type, number and efficiency of the equipment which are input in the second run.

Figure 8 presents the flow diagram required to run the ASHRAE Standard 90.1-1989. 7 system types are defined according to the types 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 are 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 9, Figure 10, Figure 11, Figure 12, Figure 13 and Figure 14 present the flow diagram required to run the ASHRAE Standard 90.1-1999, 2004, 2007, 2010, IECC 2009 and IECC 2012. These flow diagrams for the above mentioned codes are similar in structure. However, the efficiencies determined for each of the code are different. These standards define 4 additional system types providing base-case options for a total of 11 systems. For the office building considered for this analysis, the system requirements are chosen based on condenser cooling source and heating system classification. The condenser cooling source is water and the heating system classification is fossil fuel. Hence the system selected is a built-up central VAV with perimeter reheat. The system is auto-sized in the first run. 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 of this report. The selection procedure and specifications for economizers are described in Section 3.4.4 of this report.

Figure 15 presents the flow diagram required to run the ASHRAE Standard 189.1-2009. In this case too, the flow charts are similar to the previous flow charts. An appropriate system is selected from Table D3.1.1A of the code. There are 8 base-line system descriptions available. These systems are described in Table D3.1.1B of the ASHRAE Standard 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 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 of this report. The specifications for economizers are described in Section 3.4.4 of this report.

The design heating and cooling temperature are set at 70°F and 75°F respectively (Section 13.7.6.2 of ASHRAE 90.1 1989). As per code the throttling range is set at 5°F. The minimum supply air temperature is set at 55°F establishing a 20°F ΔT between the zone and supply air temperatures as required by all the codes. The maximum supply air temperature is set at 110°F (Thornton et al., 2011). Cooling and heating reset schedule are implemented as per code requirements. The reset schedule increases the minimum supply temperature by 5°F at minimum cooling conditions and decreases the maximum supply temperature by 20°F at minimum heating (RESNET 2010). Figure 16 presents a graph of the reset schedules. A reheat ΔT of 45°F is specified. The system fans operate continuously during occupied hours and cycle during unoccupied hours to maintain zone temperature. A minimum VAV terminal box flow fraction of 0.3 has been specified as prescribed by the codes.

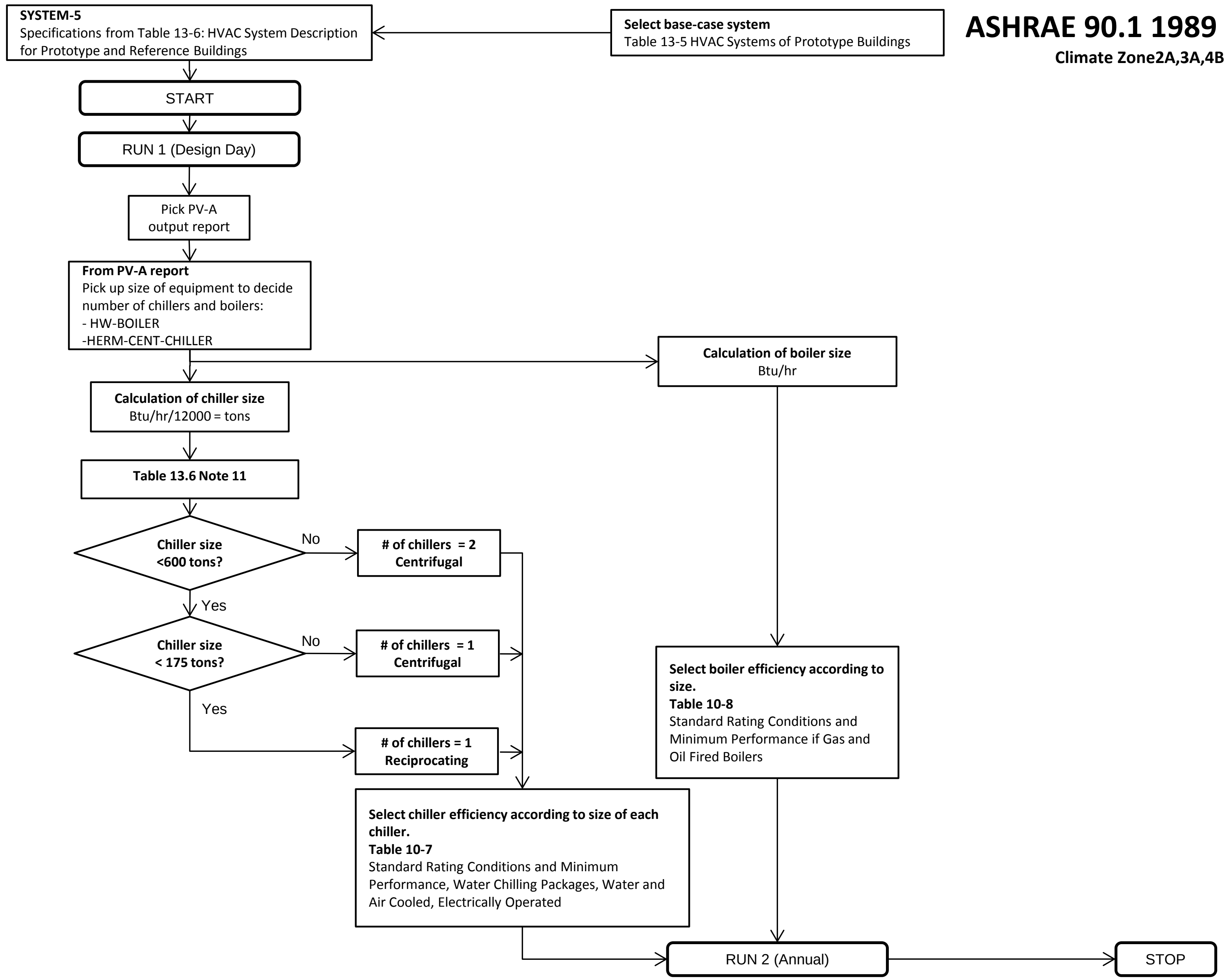


Figure 8: Flow Chart for ASHRAE 90.1-1989

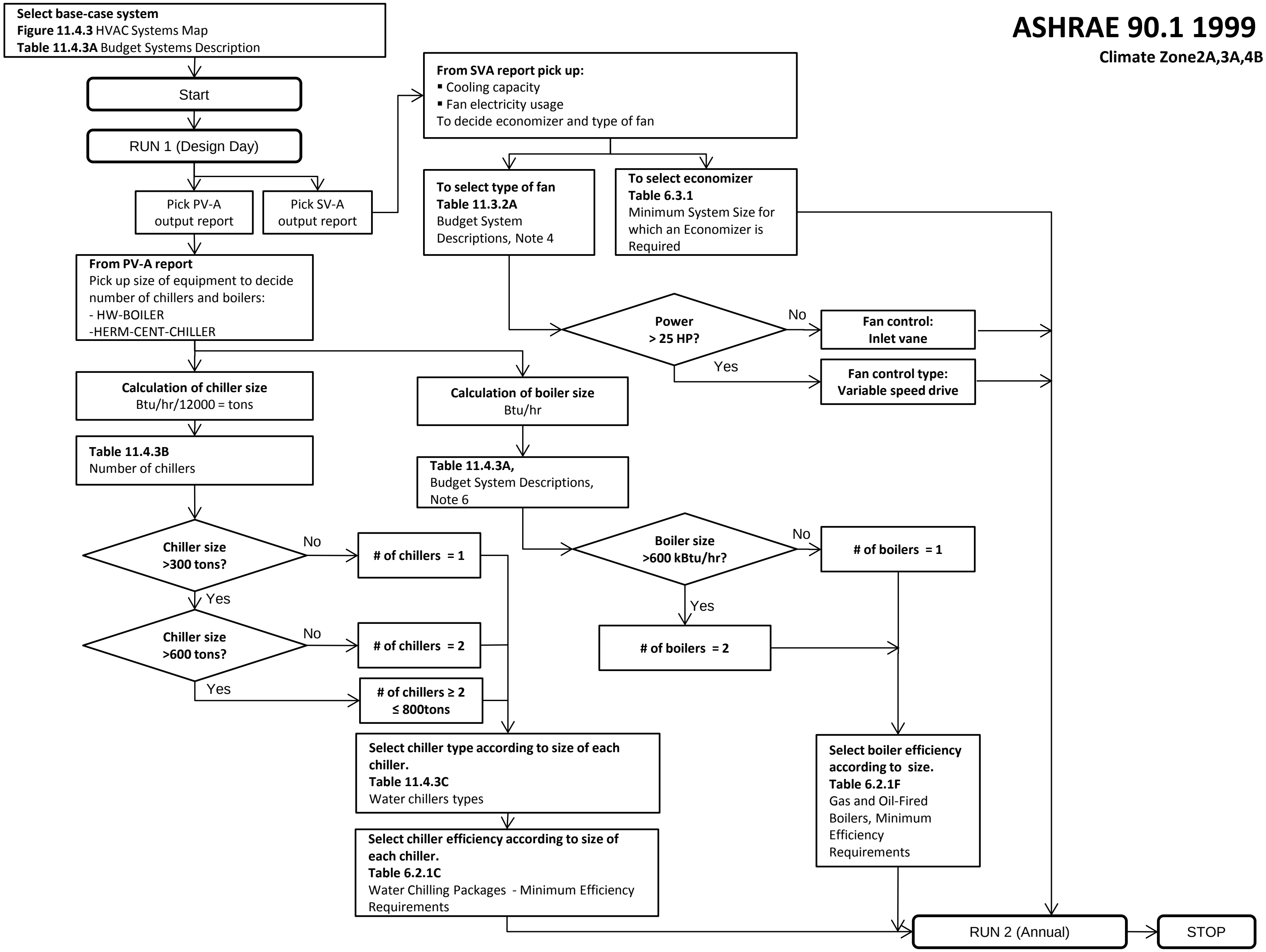


Figure 9: Flow Chart for ASHRAE 90.1-1999

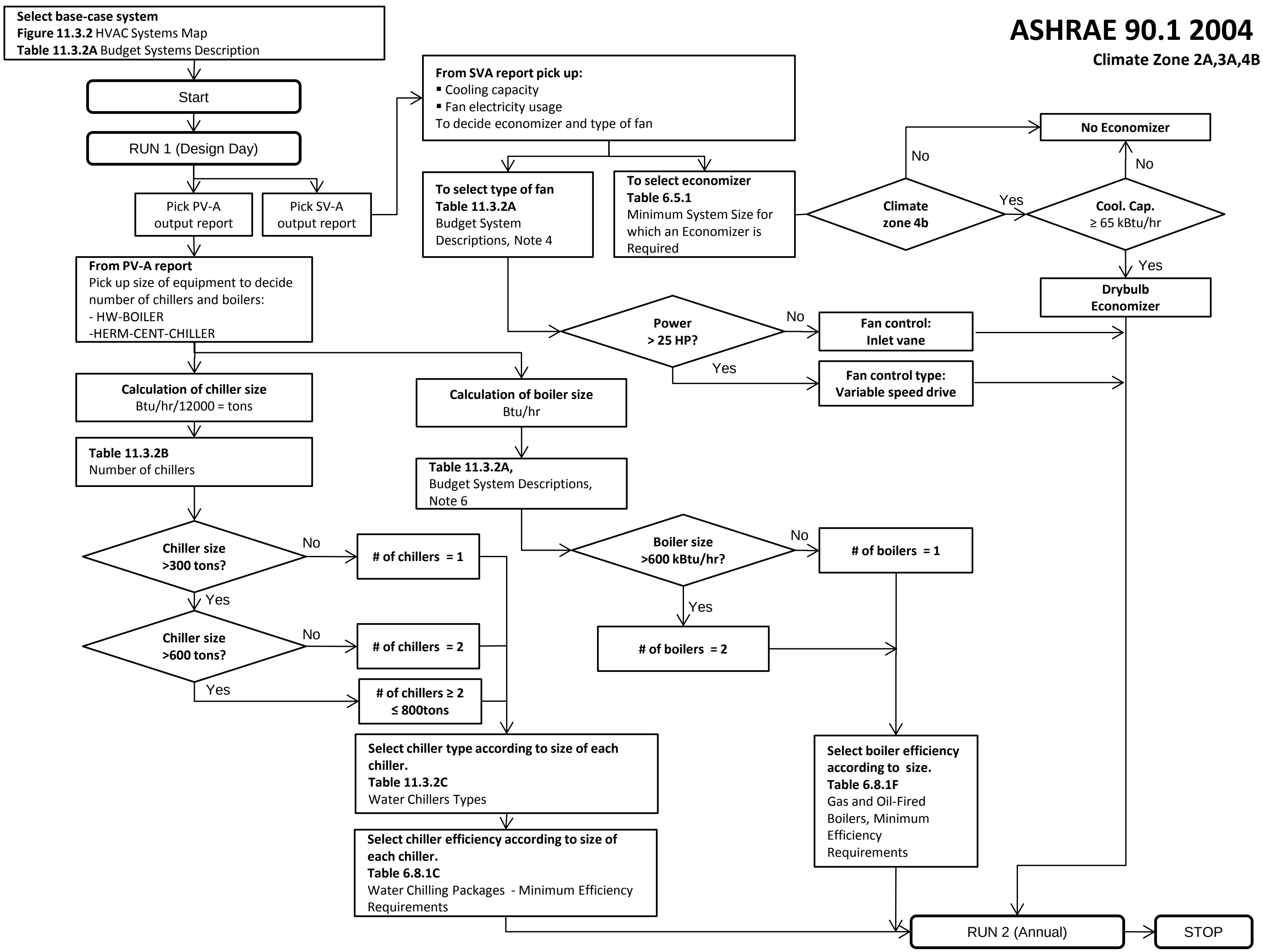


Figure 10: Flow Chart for ASHRAE 90.1-2004

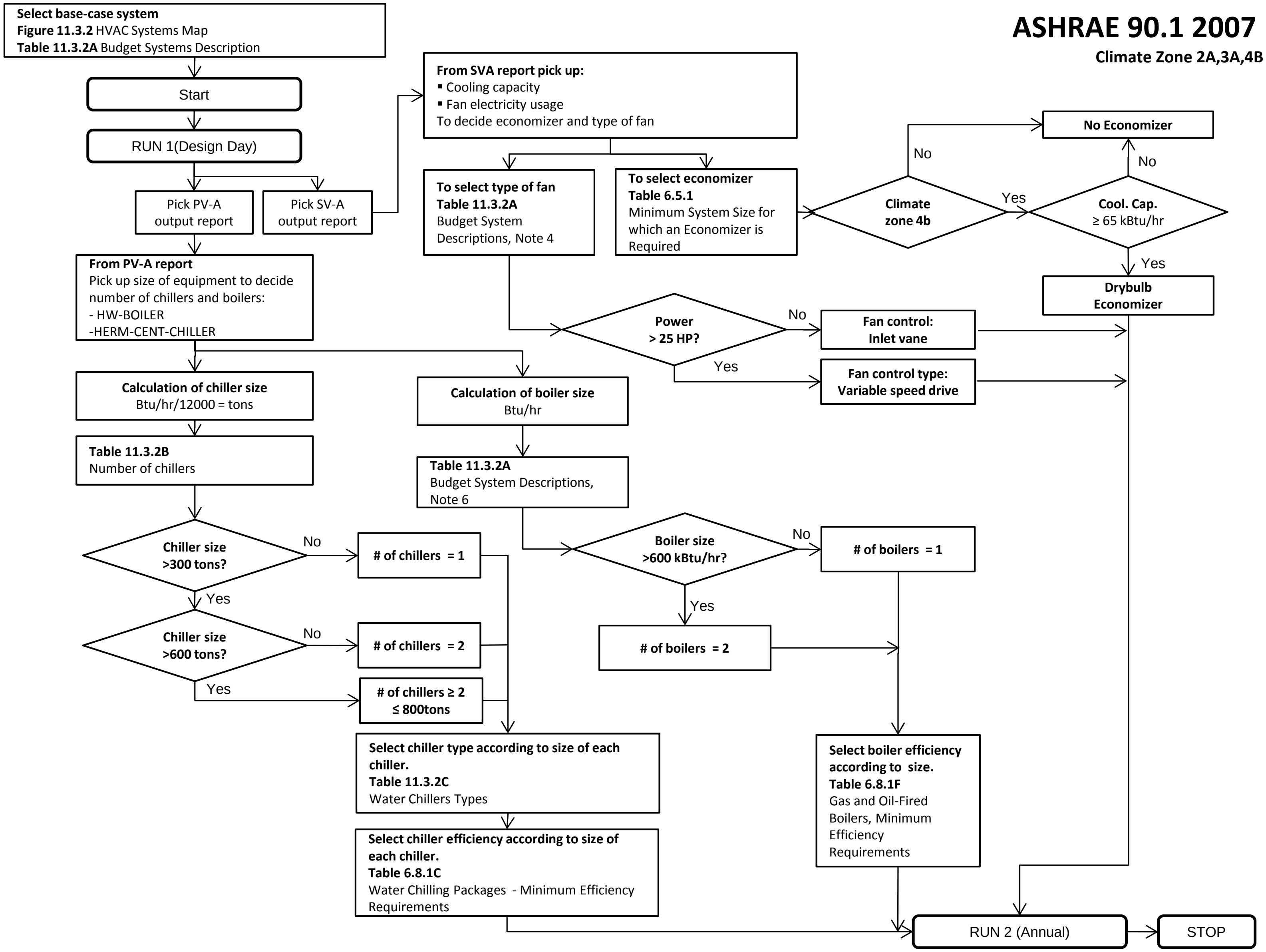


Figure 11: Flow Chart for ASHRAE 90.1-2007

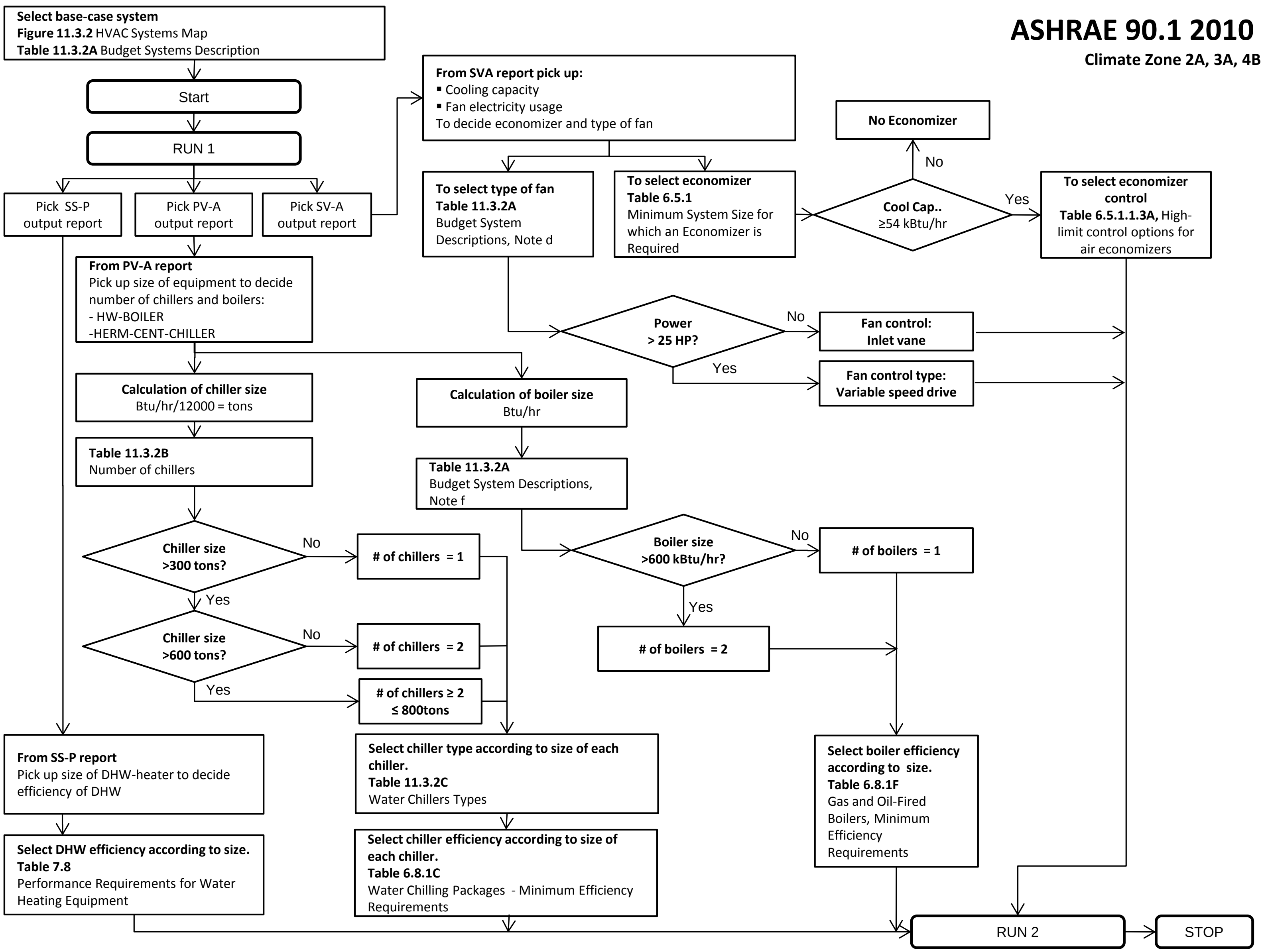


Figure 12: Flow Chart for ASHRAE 90.1-2010

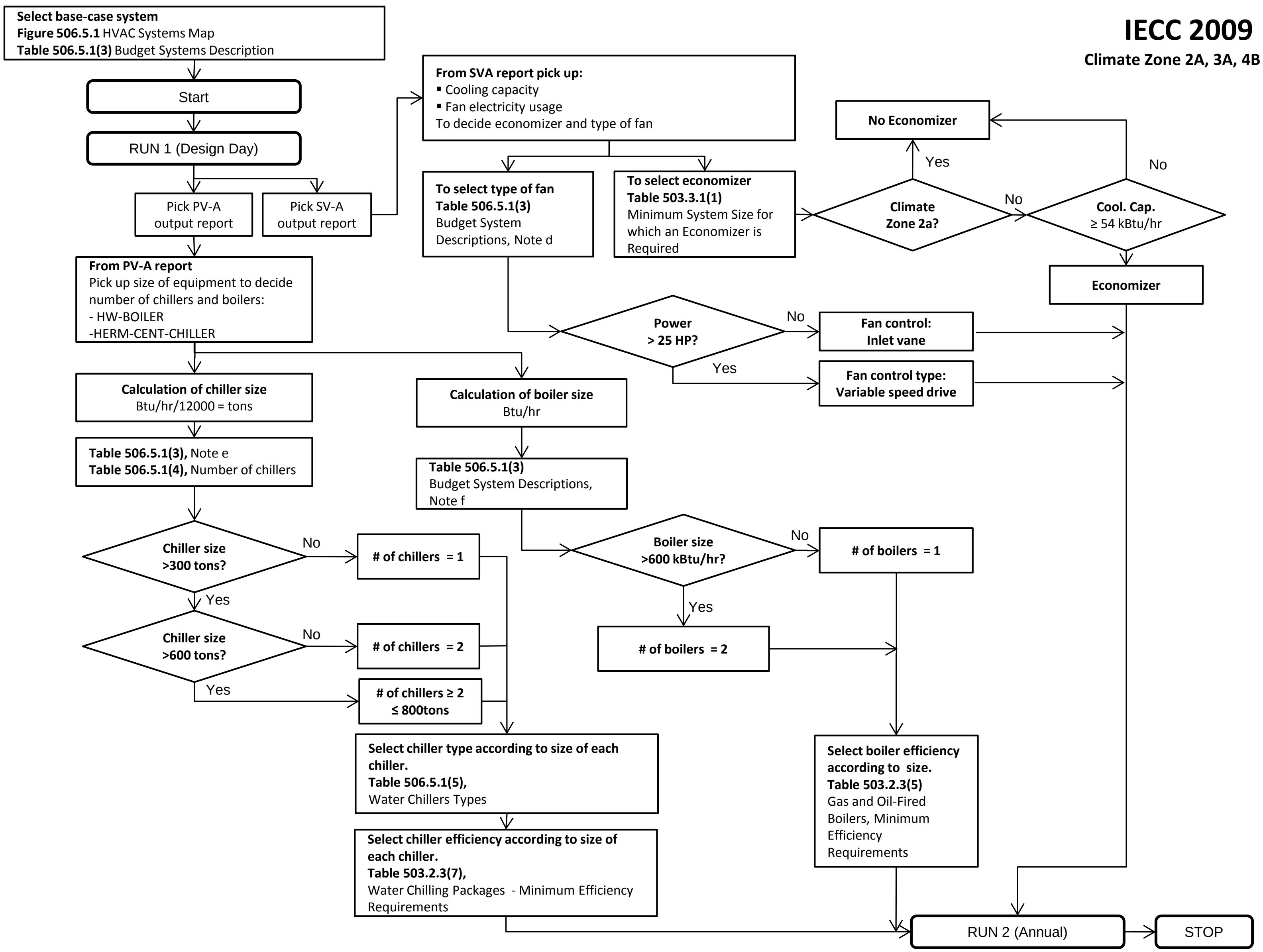


Figure 13: Flow Chart for IECC 2009

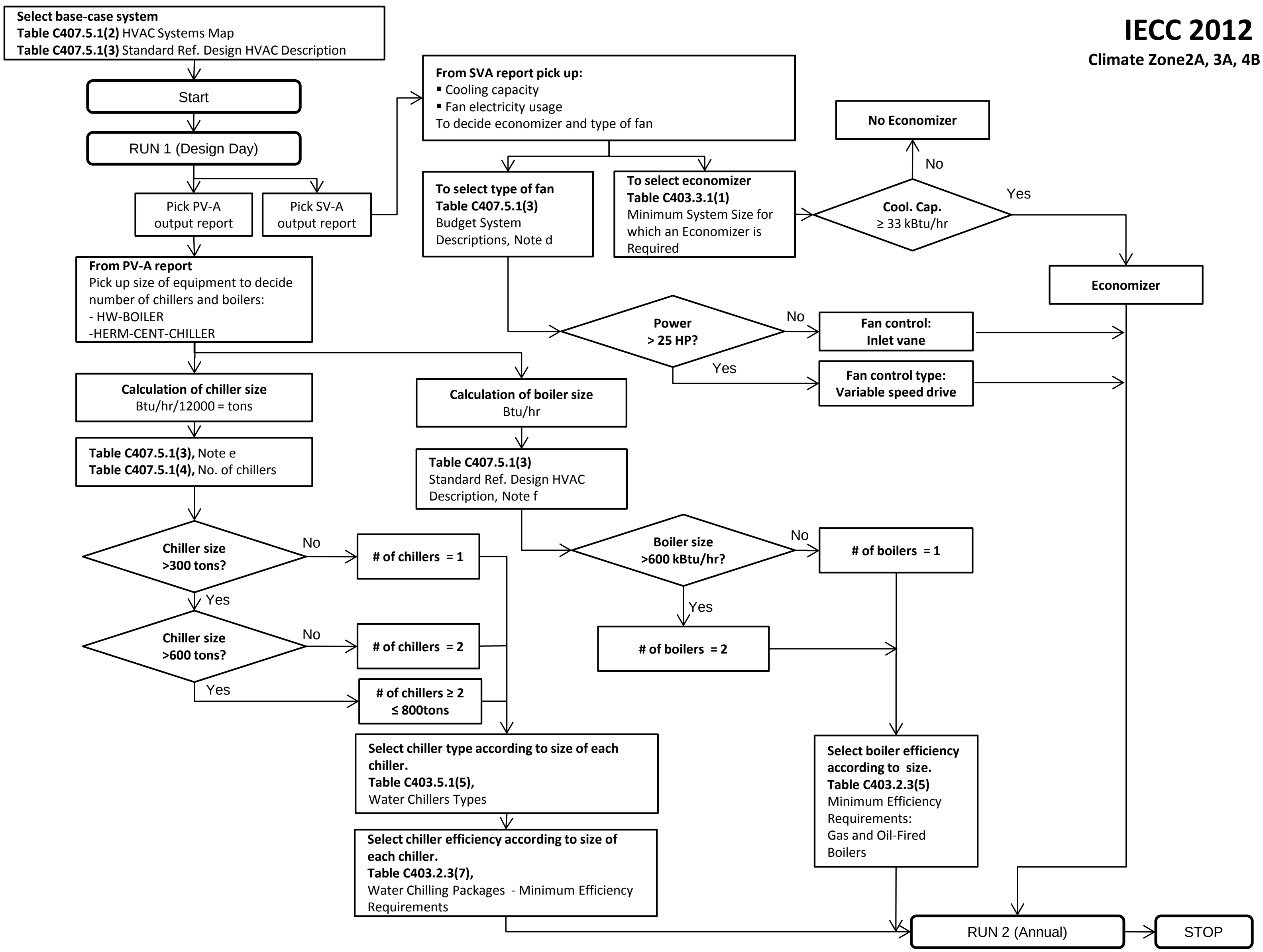


Figure 14: Flow Chart for IECC 2012

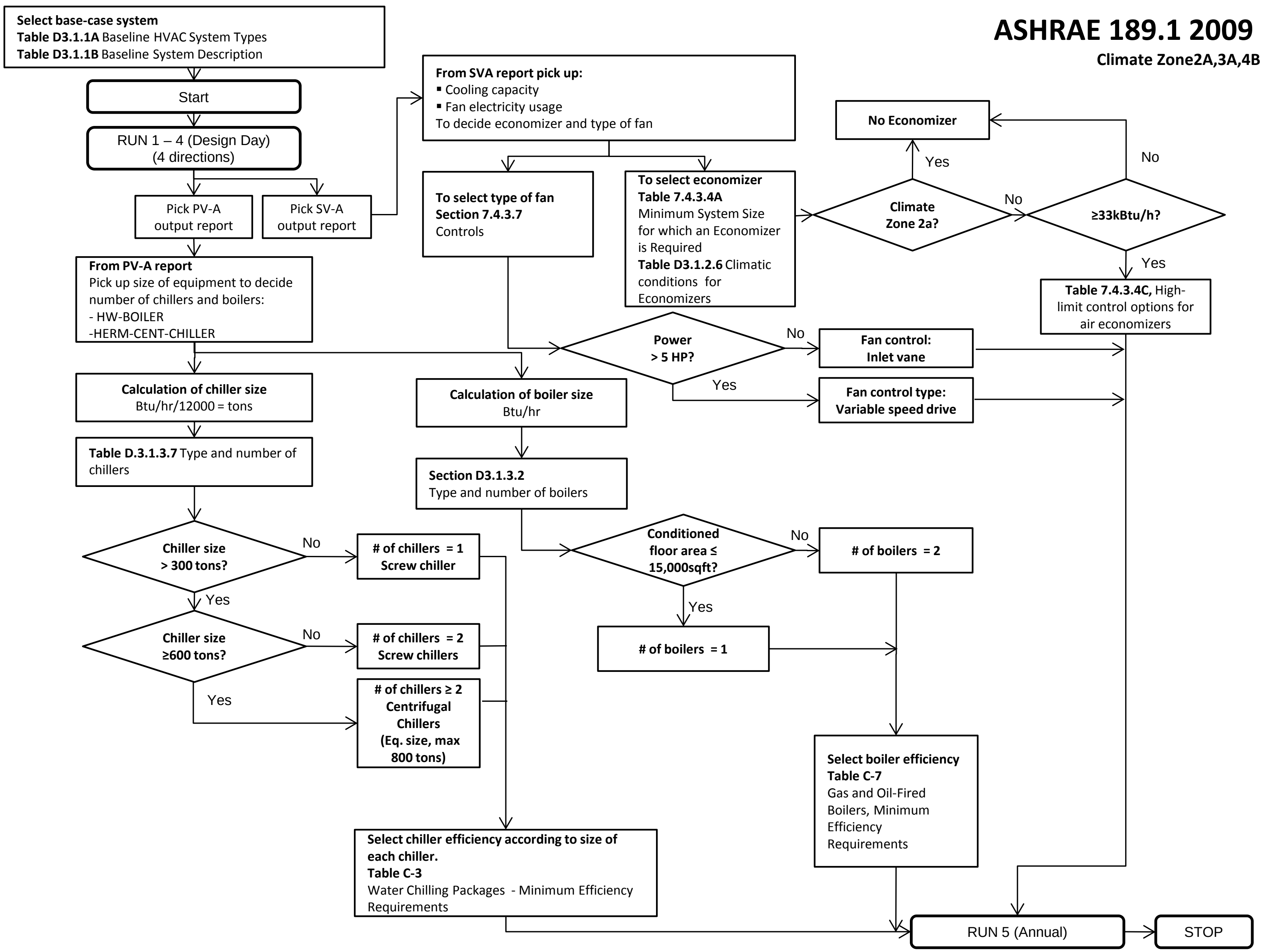


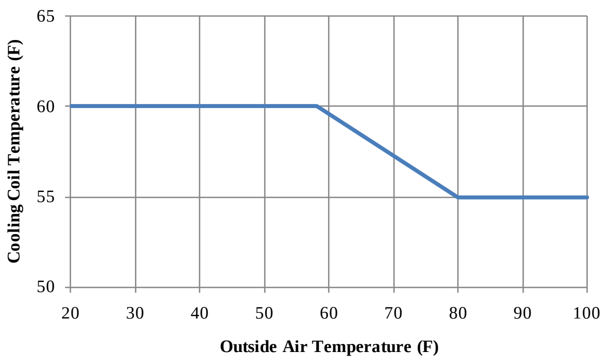
Figure 15: Flow Chart for ASHRAE Standard 189.1-2009

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 2004	ASHRAE 90.1 2007	ASHRAE 90.1 2010	IECC 2009	IECC 2012	ASHRAE 189.1 2009
Chiller Type and Specifications Number Type COP								
2A	1[3] Cent.[3] 4.2[4]	1[5] Screw[6] 4.9[7]	1[8] Screw[9] 4.9[10]	1[11] Screw[12] 4.9[13]	1[14] Recip.[15] 4.5[16]	1[17] Screw[18] 5.2[19]	1[20] Screw[21] 5.2[22]	1[23] Screw[23] 4.54[24]
3A	1[3] Cent.[3] 4.2[4]	1[5] Screw[6] 4.9[7]	1[8] Screw[9] 4.45[10]	1[11] Screw[12] 4.45[13]	1[14] Recip.[15] 4.5[16]	1[17] Screw[18] 4.5[19]	1[20] Screw[21] 4.5[22]	1[23] Screw[23] 4.54[24]
4B	1[3] Cent.[3] 4.2	1[5] Screw[6] 4.9[7]	1[8] Screw[9] 4.9[10]	1[11] Screw[12] 4.9[13]	1[14] Recip.[15] 4.5[16]	1[17] Screw[18] 5.2[19]	1[20] Screw[21] 5.2[22]	1[23] Screw[23] 4.54[24]
Gas Boiler Type and Specifications (Et %)[25] Number Efficiency								
2A 3A 4B	1[26] 75[27]	2[28] 75[29]	2[30] 75[31]	2[32] 80[33]	2[34] 80[35]	2[36] 75[37]	2[38] 80[39]	2[40] 89[41]

Assumption: Ec = Et + 5%

[3] ASHRAE-90.1, 1989, Table 13-6, Note 11
[4] ASHRAE-90.1, 1989, Table 10-7
[5] ASHRAE-90.1, 1999, Table 11.4.3B
[6] ASHRAE-90.1, 1999, Table 11.4.3C
[7] ASHRAE-90.1, 1999, Table 6.2.1C
[8] ASHRAE-90.1, 2004, Table 11.3.2B
[9] ASHRAE-90.1, 2004, Table 11.3.2C
[10] ASHRAE-90.1, 2004, Table 6.8.1C
[11] ASHRAE-90.1 2007, Table 11.3.2B
[12] ASHRAE-90.1, 2007, Table 11.3.2C
[13] ASHRAE-90.1, 2007, Table 6.8.1C
[14] ASHRAE-90.1, 2010, Table 11.3.2B
[15] ASHRAE-90.1, 2010, Table 11.3.2C
[16] ASHRAE-90.1, 2010, Table 6.8.1C
[17] IECC 2009, Table 506.5.1(4)
[18] IECC 2009, Table 506.5.1(5)
[19] IECC 2009, Table 503.2.3(7)
[20] IECC 2012, Table C407.5.1(4)
[21] IECC 2012, Table C407.5.1(5)
[22] IECC 2012, Table C403.2.3(7)
[23] ASHRAE-189.1, 2009, Table D3.1.3.7
[24] ASHRAE-189.1, 2009, Table C-3
[25] Et: Thermal Efficiency
[26] No specifications in the code. Hence assume 1 boiler.
[27] ASHRAE-90.1, 1989, Table 10-8
[28] ASHRAE-90.1, 1999, Table 11.4.3A, Note 6
[29] ASHRAE-90.1, 1999, Table 6.2.1F
[30] ASHRAE-90.1, 2004, Table 11.3.2A, Note 6
[31] ASHRAE-90.1, 2004, Table 6.8.1F
[32] ASHRAE-90.1, 2007, Table 11.3.2A, Note f
[33] ASHRAE-90.1, 2007, Table 6.8.1F
[34] ASHRAE-90.1, 2010, Table 11.3.2A, Note f
[35] ASHRAE-90.1, 2010, Table 6.8.1F
[36] IECC 2009, Table 506.5.1(3) Note f.
[37] IECC 2009, Table 503.2.3(5)
[38] IECC 2012, Table C406.5.1(3) Note f.
[39] IECC 2012, Table C403.2.3(5)
[40] ASHRAE-189.1, 2009, Section D3.1.3.2
[41] ASHRAE-189.1, 2009, Table C-7



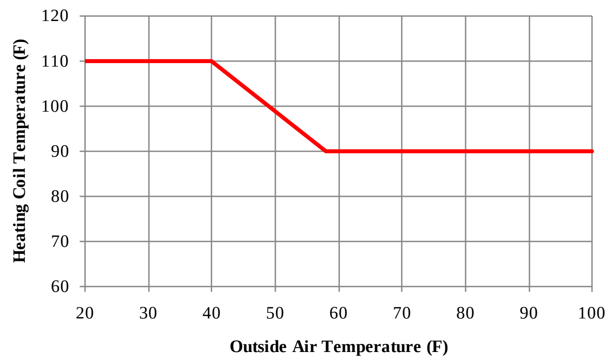


Figure 16: Cooling and Heating Coil Temperature Reset Conditions
Note: Cooling coil temperature reset for humid climates (zone 2 & 3 A) is set between 58 F and 65 F.

3.4.3 Economizers

Requirements for implementing economizers have become more stringent with newer versions of codes. For ASHRAE Standard 90.1-1989, 1999, 2004 and 2007 economizers are required to be installed in Climate Zone 4B only. For Climate Zone 4B in these codes, the minimum system size for which an economizer is required is ≥ 65,000 Btu/hr. For ASHRAE Standard 90.1-2010 economizers have been introduced for all the climate zones considered for this analysis. For all the three climate zones considered for this analysis, the minimum system size for which an economizer is required is ≥ 54,000 Btu/hr. IECC 2009 does not require any economizer requirements for Climate Zone 2A. For Climate Zones 3A and 4B economizers are required for all cooling systems ≥ 54,000 Btu/hr. IECC 2012 requires economizers for the three zones considered in this analysis. The minimum requirement for economizers in Climate Zones 2A, 3A and 4B is ≥ 33,000 Btu/hr. ASHRAE Standard 189.1-2009 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. The codes also provide specifications for the type of economizers for each climate zone.

Enthalpy economizers cannot be modeled by DOE-2.1e program when modeling VAV system with reheat. Hence the simulation suite takes advantage of the trade-offs 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, Table C403.3.1(1) in IECC 2012 and Table 7.4.3.4C in ASHRAE Standard 189.1-2009 provide trade-offs requirements for economizers.

Table 7: 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	ASHRAE 90.1 2010	IECC 2009	IECC 2012	ASHRAE 189.1 2009
2A	×	×	×	×	✓ Diff. Enthalpy Trade-off: 17%	×	✓ Fixed Drybulb	×
3A	×	×	×	×	✓ Diff. Enthalpy Trade-off: 27%	✓ Diff. Enthalpy Trade-off: 15% (1)	✓ Fixed Drybulb	✓ Diff. Enthalpy Trade-off: 15%
4B (Note 1)	✓ Diff. Drybulb	✓ Fixed Drybulb	✓ Fixed Drybulb	✓ Diff. Drybulb	✓ Diff. Drybulb	✓ Diff. Drybulb	✓ Fixed Drybulb	✓ Diff. Drybulb
Specs. for Min. Size of System	≥ 90 kBtu/hr Section 9.5.3	≥ 65 kBtu/hr Table 6.3.1	≥ 65 kBtu/hr Table 6.5.1	≥ 65 kBtu/hr Table 6.5.1	≥ 54 kBtu/hr Table 6.5.1A	≥ 54 kBtu/hr Table 503.3.1	≥ 33 kBtu/hr Table C403.3.1(1)	≥ 33 kBtu/hr Table 7.4.3.4A
Specs. for Control Type	Temp. or Enthalpy Section 9.5.3	Table 6.3.1.1.3A	Table 6.5.1.1.3A	Table 6.5.1.1.3A	Table 6.5.1.1.3B	-	Table C403.3.1.1.3(1)	Table 7.4.3.4B
Economizer Trade-off	-	-	-	-	Table 6.3.2 (2)	Table 503.3.1 (1,2)	Table C403.3.1(2)	Table 7.4.3.4C (2)

×: No economizer requirement
✓: Economizer required
Note 1: In IECC 2009 trade-off is provided for Climate Zone 3B but is implemented for Climate Zone 3A.
Note 2: Trade-offs are not implemented in Climate Zone 4A.

Table 8: 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	ASHRAE 90.1 2010	IECC 2009	IECC 2012	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%							
Nominal Efficiency for Motors								
	No specs	92.4						94.1

SP: Static Pressure
VSD: Variable Speed Drive

3.4.4 Supply and Return Air Fans

The simulation assumes one fan for 2 floors of the building which results in three fans for the entire building. Hence all the results obtained from auto-sizing the fans have to be divided by three. Only supply fans are modeled in the baseline models. The method of modeling is adopted from report by Deru et al. (2011) and Appendix G of the ASHRAE Standard 189.1 code. As per the method described in Deru, the reference building models use a single fan mechanical efficiency 65%. All motors are assumed to be closed, four-pole, 1800 rpm as per requirements from

Section D 3.1.2.9 in Appendix G of the ASHRAE Standard 189.1 code. The overall fan efficiency is subsequently calculated as the product of nominal motor efficiency (obtained from respective tables of the codes) and the fan mechanical efficiency. Fan power limitations are provided in all the codes and are reported in Table 8. The static pressure rise is then varied to achieve the desired fan power by using equation 1 and 2 described in this section.

In ASHRAE Standard 90.1-1989 the supply fans for the simulated VAV systems are set at variable speed drive. Specifications for both the supply and return fans are provided and are reported in Table 8. From ASHRAE Standard 90.1-1999 onwards if supply, return or relief fan motors are 25 hp or larger the corresponding fans are assumed to have variable speed drive. For smaller fan sizes, forward-curved centrifugal fan with inlet vanes are specified. The same rules apply to ASHRAE Standard 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. Equations used for calculating are referenced from the Engineering Manual for DOE-2.1e program (LBL, 1982) and are written out below. The equations are:

$$DTS = \frac{SUPPLY - STATIC}{SUPPLY - EFF} \tag{1}$$

$$SUPPLY - KW = \frac{SUPPLY - CFM * DTS}{8520} \tag{2}$$

Where:

$SUPPLY - STATIC$ = Static pressure (inch of water)

$SUPPLY - EFF$ = Overall fan efficiency including motor efficiency (%)

$SUPPLY - KW$ = Allowable fan power (kW)

$SUPPLY - CFM$ = Supply-CFM of the building, and

8520 is a conversion factor that converts (standard cfm × inches of water) / efficiency to kilowatts.

3.4.4 Service Hot Water Equipment

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 9 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 an input rating of 100,000Btu/hr which is typical for 100 gallon gas water heaters (Degelman 2011).

Table 9: Comparison of Service Hot Water Equipment Efficiencies

Standard	Specifications	Minimum Performance
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		

Et: Thermal efficiency
SL:Standby loss
Q: Nameplate input rate
V: rated volume in gallons

3.4.5 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/ft^2 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. Details of possible options are presented in Appendix C of this report.

4. Results

Both site and source energy consumption was 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 19.6%-21.1%;
- ASHRAE Standard 90.1-2004 provides an improvement of 25.5%- 33.7%;
- ASHRAE Standard 90.1-2007 provides an improvement of 30.3%-35.0%;
- IECC 2009 provides an improvement of 30.0%-36.4%;
- IECC 2012 provides an improvement of 38.1%-41.0%; and
- ASHRAE Standard 90.1-2010 provides an improvement of 43.1%-51.3%;
- ASHRAE Standard 189.1-2009 provides an improvement of 51.4%-57.0% above the ASHRAE Standard 90.1-1989 base-case.

The comparison tables and figures are provided below (Table 10 and Figure 16).

When considering source energy consumption:

- ASHRAE Standard 90.1-1999 provides an improvement of 18.6%-19.2%;
- ASHRAE Standard 90.1-2004 provides an improvement of 25.8%-29.2%;
- ASHRAE Standard 90.1-2007 provides an improvement of 27.0%-30.4%;
- IECC 2009 provides an improvement of 27.4%-32.5%;
- IECC 2012 provides an improvement of 31.9%-35.3%;
- ASHRAE Standard 90.1-2010 provides an improvement of 43.5%-50.4%; and
- ASHRAE Standard 189.1-2009 provides an improvement of 50.2%-54.9% above the ASHRAE Standard 90.1-1989 base-case.

The comparison tables and graphs are provided below (Table 11 and Figure 17).

Table 10: Site Energy Calculations

	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	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009	ASHRAE 189.1 2009_90	ASHRAE 189.1 2009_0	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009
Area Lights ELEC	1358.8	1125.3	865.6	865.6	865.6	779.0	460.0	576.9	577.0	576.7	17.2	36.3	36.3	36.3	42.7	66.1	57.5
Misc Equip ELEC	1013.1	1013.1	1013.1	1013.1	1013.1	1013.1	892.0	1013.1	1013.1	1013.1	0.0	0.0	0.0	0.0	0.0	12.0	0.0
Space Heat ELEC	49.0	27.1	28.3	19.7	19.7	11.3	22.6	17.5	17.8	17.2	44.7	42.2	59.8	59.8	76.9	53.9	64.3
Space Cool ELEC	1274.3	933.8	874.4	826.9	782.3	729.5	550.1	693.3	703.9	682.7	26.7	31.4	35.1	38.6	42.8	56.8	45.6
Heat Reject ELEC	454.4	299.5	282.1	261.4	262.2	248.3	224.0	194.0	200.4	187.6	34.1	37.9	42.5	42.3	45.4	50.7	57.3
Pumps & Misc ELEC	226.3	213.1	208.8	202.6	202.9	198.4	193.8	189.1	189.4	188.7	5.8	7.7	10.5	10.3	12.3	14.4	16.5
Vent Fans ELEC	513.5	381.2	349.5	333.6	334.7	332.2	270.6	243.1	244.2	241.9	25.8	31.9	35.0	34.8	35.3	47.3	52.7
DHW ELEC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Space Heat GAS	1109.7	782.3	821.8	504.6	537.4	282.4	578.5	368.0	373.2	362.8	29.5	25.9	54.5	51.6	74.6	47.9	66.8
DHW GAS	106.5	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Renewable Energy								-535.8	-535.8	-535.8							
ELEC	4889.4	3993.1	3621.9	3523.0	3480.4	3311.8	2613.3	2471.0	2410.0	2532.0	18.3	25.9	27.9	28.8	32.3	46.6	49.5
GAS	1216.1	884.5	923.9	606.7	639.5	384.6	680.7	497.1	475.4	518.7	27.3	24.0	50.1	47.4	68.4	44.0	59.1
TOTAL	**6105.6**	**4877.5**	**4545.7**	**4129.6**	**4120.0**	**3696.3**	**3293.7**	**2968.1**	**2885.4**	**3050.7**	**20.1**	**25.5**	**32.4**	**32.5**	**39.5**	**46.1**	**51.4**
	Climate Zone 3A																
	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009	ASHRAE 189.1 2009_90	ASHRAE 189.1 2009_0	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009
Area Lights ELEC	1358.8	1125.3	865.6	865.6	865.6	779.0	460.4	577.3	577.5	577.1	17.2	36.3	36.3	36.3	42.7	66.1	57.5
Misc Equip ELEC	1013.1	1013.1	1013.1	1013.1	1013.1	1013.1	892.0	1013.1	1013.1	1013.1	0.0	0.0	0.0	0.0	0.0	12.0	0.0
Space Heat ELEC	60.1	35.1	17.6	18.0	18.0	12.3	20.0	19.2	19.7	18.7	41.6	70.7	70.0	70.0	79.5	66.7	68.1
Space Cool ELEC	1288.4	912.2	913.9	881.5	753.5	788.8	402.5	610.7	628.7	592.7	29.2	29.1	31.6	41.5	38.8	68.8	52.6
Heat Reject ELEC	446.5	289.9	253.0	246.4	246.6	235.2	209.1	208.2	220.9	195.4	35.1	43.3	44.8	44.8	47.3	53.2	53.4
Pumps & Misc ELEC	244.7	229.2	217.2	215.4	215.5	212.3	205.9	200.9	201.2	200.6	6.3	11.2	12.0	11.9	13.2	15.9	17.9
Vent Fans ELEC	500.6	380.6	353.5	338.9	339.7	336.9	275.4	243.5	245.3	241.6	24.0	29.4	32.3	32.1	32.7	45.0	51.4
DHW ELEC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Space Heat GAS	1458.6	1119.7	553.9	526.8	560.6	336.1	583.7	375.8	384.5	367.0	23.2	62.0	63.9	61.6	77.0	60.0	74.2
DHW GAS	114.4	109.7	109.7	109.7	109.7	109.7	109.7	109.7	109.7	109.7	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Renewable Energy								-535.8	-535.8	-535.8							
ELEC	4912.3	3985.4	3633.9	3579.0	3452.1	3377.6	2465.3	2284.9	2370.6	2199.2	18.9	26.0	27.1	29.7	31.2	49.8	53.5
GAS	1572.9	1229.5	663.7	636.5	670.3	445.9	693.4	506.8	494.2	519.4	21.8	57.8	59.5	57.4	71.7	55.9	67.8
TOTAL	**6485.2**	**5214.8**	**4297.5**	**4215.4**	**4122.3**	**3823.4**	**3158.7**	**2791.7**	**2864.8**	**2718.6**	**19.6**	**33.7**	**35.0**	**36.4**	**41.0**	**51.3**	**57.0**
	Climate Zone 4B																
	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009	ASHRAE 189.1 2009_90	ASHRAE 189.1 2009_0	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009
Area Lights ELEC	1358.8	1125.3	865.6	865.6	865.6	779.0	459.3	575.7	575.8	575.5	17.2	36.3	36.3	36.3	42.7	66.2	57.6
Misc Equip ELEC	1013.1	1013.1	1013.1	1013.1	1013.1	1013.1	892.0	1013.1	1013.1	1013.1	0.0	0.0	0.0	0.0	0.0	12.0	0.0
Space Heat ELEC	69.2	37.1	32.8	31.1	31.1	17.9	33.5	26.6	27.2	26.0	46.4	52.6	55.1	55.1	74.1	51.6	61.6
Space Cool ELEC	1030.0	738.8	697.9	692.0	653.3	663.7	432.3	531.2	543.7	518.6	28.3	32.2	32.8	36.6	35.6	58.0	48.4
Heat Reject ELEC	363.4	247.7	230.0	229.3	229.7	220.8	198.4	158.1	165.4	150.7	31.8	36.7	36.9	36.8	39.2	45.4	56.5
Pumps & Misc ELEC	269.5	256.8	250.8	250.4	250.5	246.1	242.0	231.6	232.2	231.0	4.7	6.9	7.1	7.1	8.7	10.2	14.1
Vent Fans ELEC	523.3	435.7	407.9	408.9	409.4	430.3	344.4	264.3	267.3	261.3	16.7	22.1	21.9	21.8	17.8	34.2	49.5
DHW ELEC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0							
Space Heat GAS	1695.6	1109.6	994.3	879.6	936.3	492.8	942.9	551.0	561.6	540.4	34.6	41.4	48.1	44.8	70.9	44.4	67.5
DHW GAS	139.4	133.8	133.8	133.8	133.8	133.8	133.8	133.8	133.8	133.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Renewable Energy								-535.8	-535.8	-535.8							
ELEC	4627.2	3854.5	3498.1	3490.4	3452.7	3371.0	2601.9	2241.3	2289.0	2193.6	16.7	24.4	24.6	25.4	27.1	43.8	51.6
GAS	1835.0	1243.4	1128.1	1013.4	1070.1	626.5	1076.7	721.4	695.4	747.3	32.2	38.5	44.8	41.7	65.9	41.3	60.7
TOTAL	**6462.3**	**5097.9**	**4626.2**	**4503.8**	**4522.8**	**3997.5**	**3678.6**	**2962.7**	**2984.4**	**2940.9**	**21.1**	**28.4**	**30.3**	**30.0**	**38.1**	**43.1**	**54.2**

Note: The IECC 2012 requires the proposed building to show compliance by showing an energy cost which is equal to or less than 85 percent of the corresponding standard reference design building.

Table 11: Source Energy Calculations

	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	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009	ASHRAE 189.1 2009_90	ASHRAE 189.1 2009_0	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009
ELEC	15401.6	12578.3	11409.0	11097.5	10963.3	10432.2	8231.9	7783.7	7591.5	7975.8	18.3	25.9	27.9	28.8	32.3	46.6	49.5
GAS	1337.7	973.0	1016.3	667.4	703.5	423.1	748.8	546.8	522.9	570.6	27.3	24.0	50.1	47.4	68.4	44.0	59.1
TOTAL	**16739.3**	**13551.2**	**12425.3**	**11764.8**	**11666.7**	**10855.2**	**8980.7**	**8330.4**	**8114.4**	**8546.4**	**19.0**	**25.8**	**29.7**	**30.3**	**35.2**	**46.3**	**50.2**
	Climate Zone 3																
	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009	ASHRAE 189.1 2009_90	ASHRAE 189.1 2009_0	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009
ELEC	15473.7	12554.0	11446.8	11273.9	10874.1	10639.4	7765.7	7197.4	7467.4	6927.5	18.9	26.0	27.1	29.7	31.2	49.8	53.5
GAS	1730.2	1352.5	730.1	700.2	737.3	490.5	762.7	557.5	543.6	571.3	21.8	57.8	59.5	57.4	71.7	55.9	67.8
TOTAL	**17203.9**	**13906.5**	**12176.9**	**11974.0**	**11611.4**	**11129.9**	**8528.4**	**7754.9**	**8011.0**	**7498.8**	**19.2**	**29.2**	**30.4**	**32.5**	**35.3**	**50.4**	**54.9**
	Climate Zone 4																
	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009	ASHRAE 189.1 2009_90	ASHRAE 189.1 2009_0	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009
ELEC	14575.7	12141.7	11019.0	10994.8	10876.0	10618.7	8196.0	7060.1	7210.4	6909.8	16.7	24.4	24.6	25.4	27.1	43.8	51.6
GAS	2018.5	1367.7	1240.9	1114.7	1177.1	689.2	1184.4	793.5	764.9	822.0	32.2	38.5	44.8	41.7	65.9	41.3	60.7
TOTAL	**16594.2**	**13509.4**	**12259.9**	**12109.5**	**12053.1**	**11307.8**	**9380.4**	**7853.6**	**7975.3**	**7731.9**	**18.6**	**26.1**	**27.0**	**27.4**	**31.9**	**43.5**	**52.7**

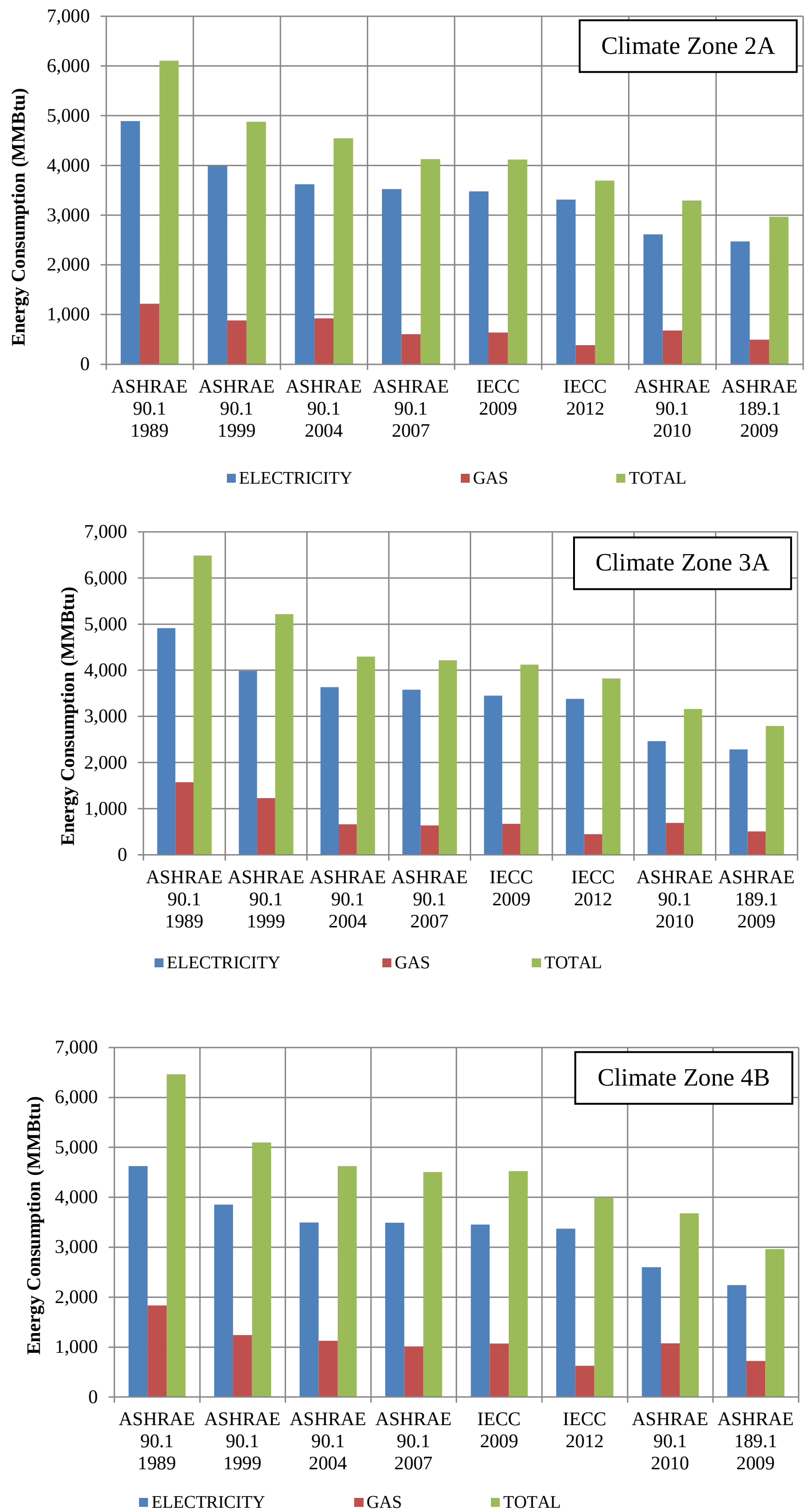
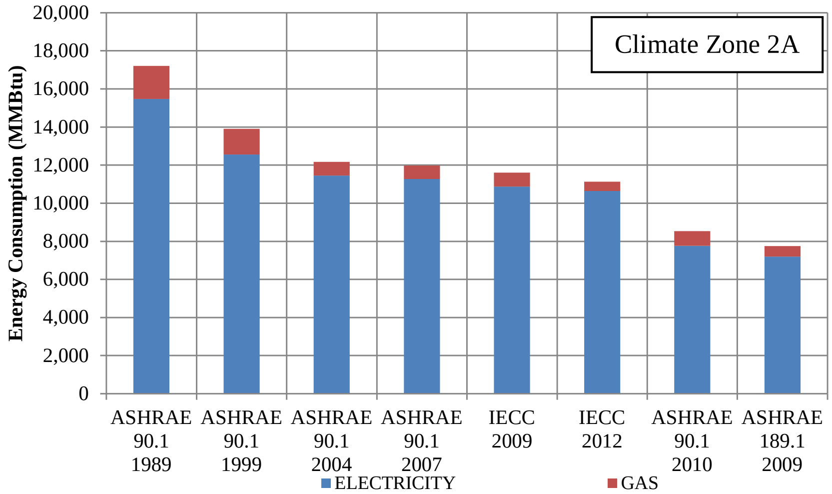
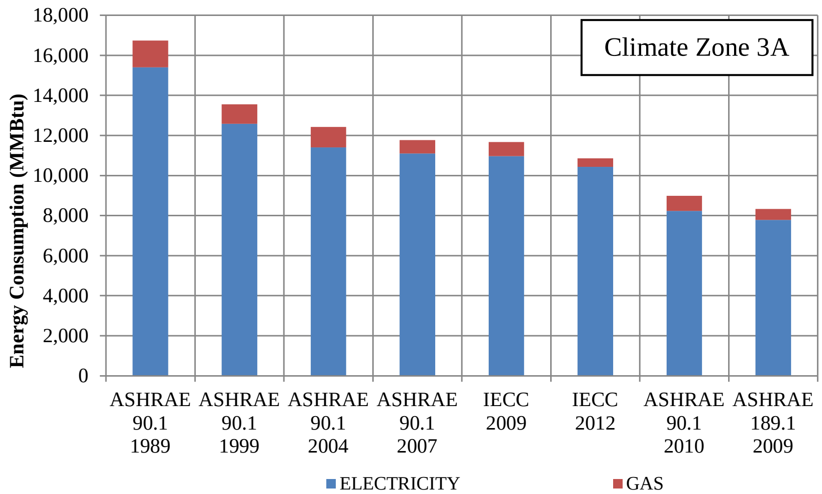


Figure 17: Site Energy Consumption.





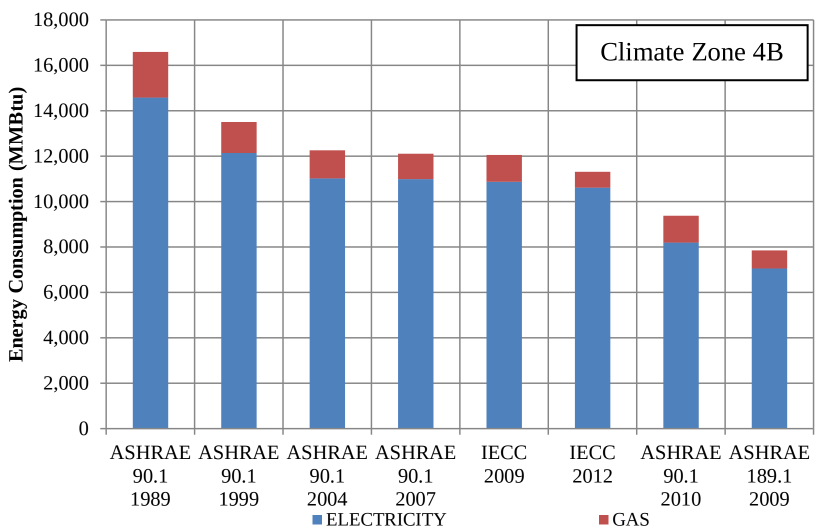


Figure 18: Source Energy Consumption

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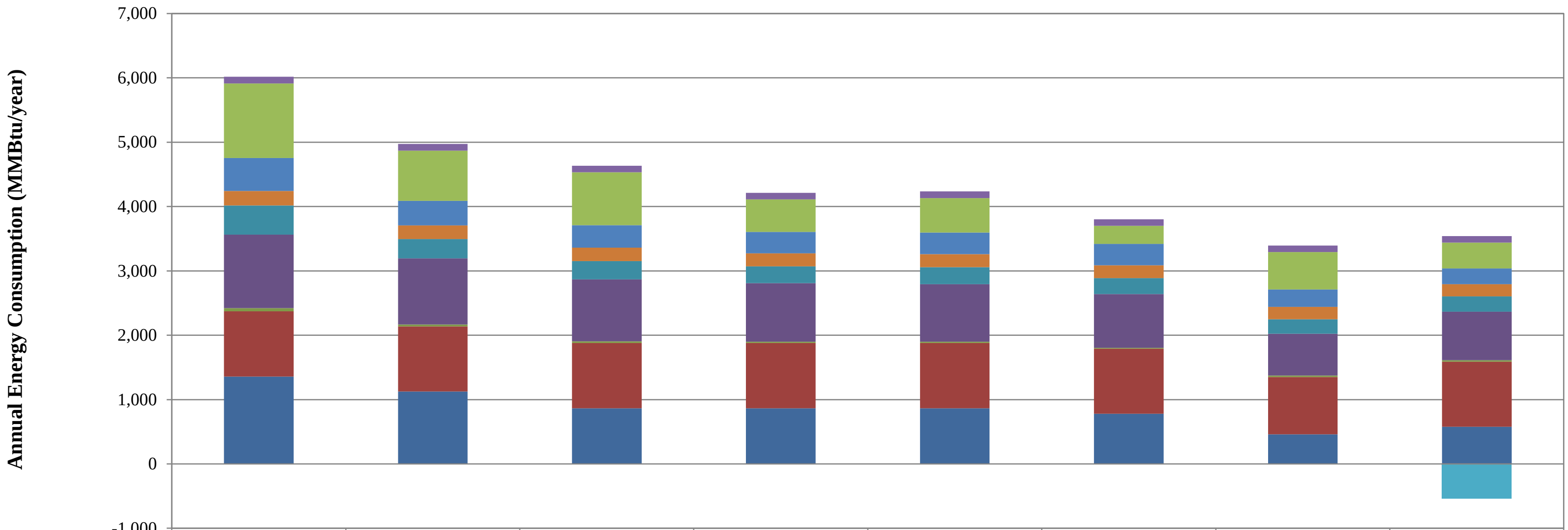
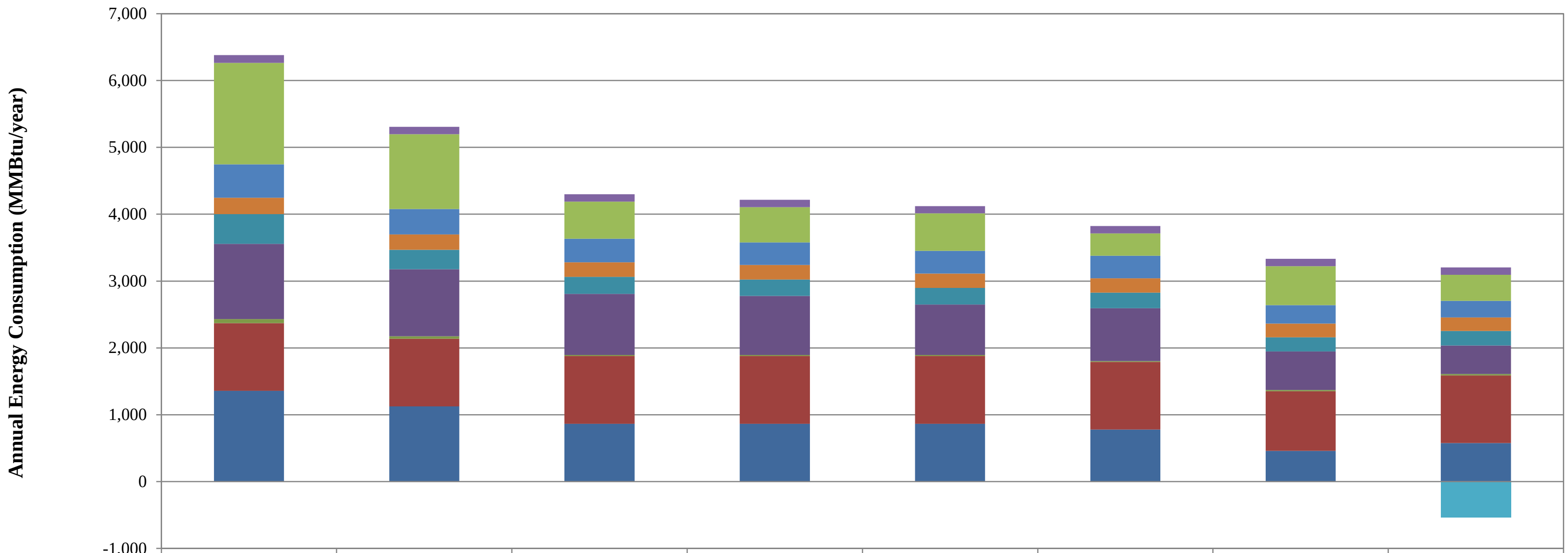
Appendix A: Building Energy Performance Summary (BEPS) Report Details



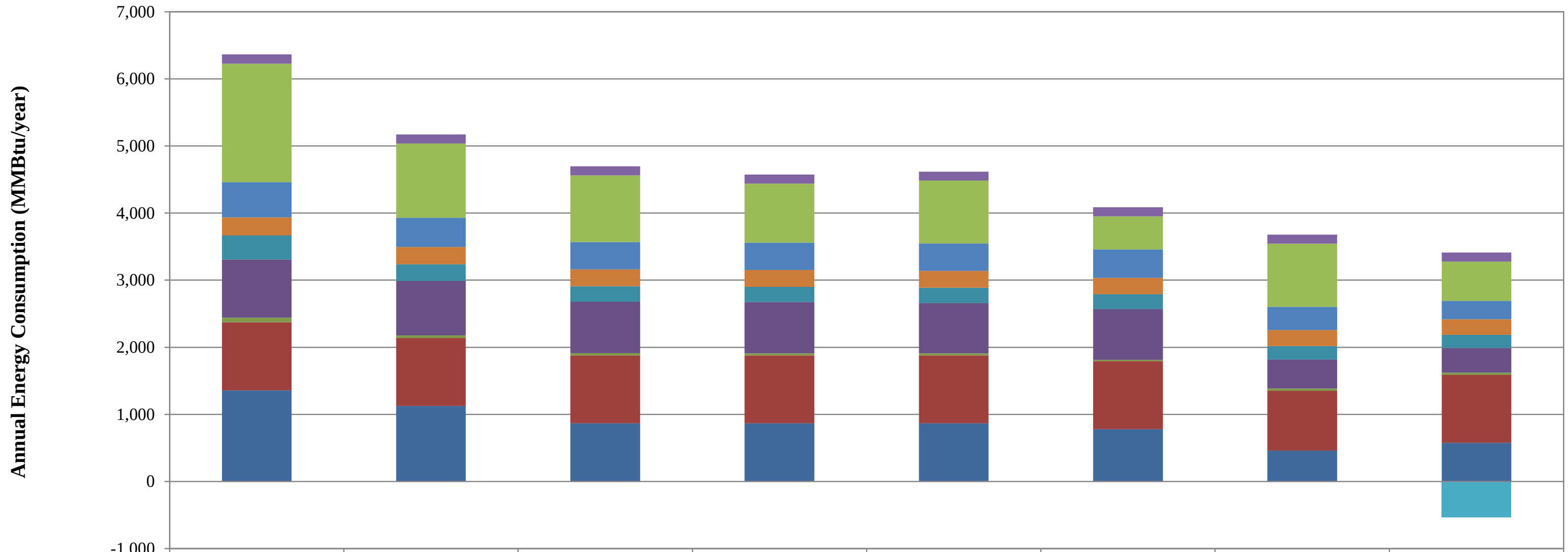
	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009
TOTAL	6017.8	4972.2	4634.4	4213.5	4234.1	3803.0	3393.1	3005.8
Renewable Energy								-535.8
DHW GAS	106.5	102.1	102.1	102.1	102.1	102.1	102.1	102.1
Space Heat GAS	1155.9	782.3	821.8	504.6	537.4	282.4	578.5	400.0
Vent Fans ELEC	513.5	381.2	349.5	333.6	334.7	332.2	270.6	246.2
Pumps & Misc ELEC	226.3	213.1	208.8	202.6	202.9	198.4	193.8	189.8
Heat Reject ELEC	452.9	299.9	282.5	261.8	262.7	248.8	225.0	236.4
Space Cool ELEC	1141.8	1028.1	962.7	910.4	895.9	835.7	648.5	754.9
Space Heat ELEC	49.0	27.1	28.3	19.7	19.7	11.3	22.6	22.4
Misc Equip ELEC	1013.1	1013.1	1013.1	1013.1	1013.1	1013.1	892.0	1013.1
Area Lights ELEC	1358.8	1125.3	865.6	865.6	865.6	779.0	460.0	576.7

Figure 19: BEPS for Climate Zone 2A



	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009
TOTAL	6379.6	5307.0	4297.5	4215.4	4122.3	3823.8	3333.0	2668.2
Renewable Energy								-535.8
DHW GAS	114.4	109.7	109.7	109.7	109.7	109.7	109.7	109.7
Space Heat GAS	1519.3	1119.7	553.9	526.8	560.6	336.1	583.7	389.1
Vent Fans ELEC	500.6	380.6	353.5	338.9	339.7	336.9	275.4	248.3
Pumps & Misc ELEC	244.7	229.2	217.2	215.4	215.5	212.3	205.9	202.2
Heat Reject ELEC	444.5	290.1	253.0	246.4	246.6	235.2	210.0	219.4
Space Cool ELEC	1124.1	1004.2	913.9	881.5	753.5	789.2	575.9	424.9
Space Heat ELEC	60.1	35.1	17.6	18.0	18.0	12.3	20.0	20.2
Misc Equip ELEC	1013.1	1013.1	1013.1	1013.1	1013.1	1013.1	892.0	1013.1
Area Lights ELEC	1358.8	1125.3	865.6	865.6	865.6	779.0	460.4	577.2

Figure 20: BEPS for Climate Zone 3A



	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004	ASHRAE 90.1 2007	IECC 2009	IECC 2012	ASHRAE 90.1 2010	ASHRAE 189.1 2009
TOTAL	6366.1	5172.4	4696.6	4573.7	4617.5	4085.9	3678.6	2875.5
Renewable Energy								-535.8
DHW GAS	139.4	133.8	133.8	133.8	133.8	133.8	133.8	133.8
Space Heat GAS	1766.3	1109.6	994.3	879.6	936.3	492.9	942.9	586.9
Vent Fans ELEC	523.3	435.7	407.9	408.9	409.4	424.7	344.4	273.2
Pumps & Misc ELEC	269.5	256.8	250.8	250.4	250.5	246.0	242.0	232.7
Heat Reject ELEC	361.2	247.6	229.9	229.3	229.6	220.3	198.4	196.1
Space Cool ELEC	865.3	813.4	768.4	761.9	748.1	758.1	432.3	368.5
Space Heat ELEC	69.2	37.1	32.8	31.1	31.1	18.0	33.5	31.5
Misc Equip ELEC	1013.1	1013.1	1013.1	1013.1	1013.1	1013.1	892.0	1013.1
Area Lights ELEC	1358.8	1125.3	865.6	865.6	865.6	779.0	459.3	575.6

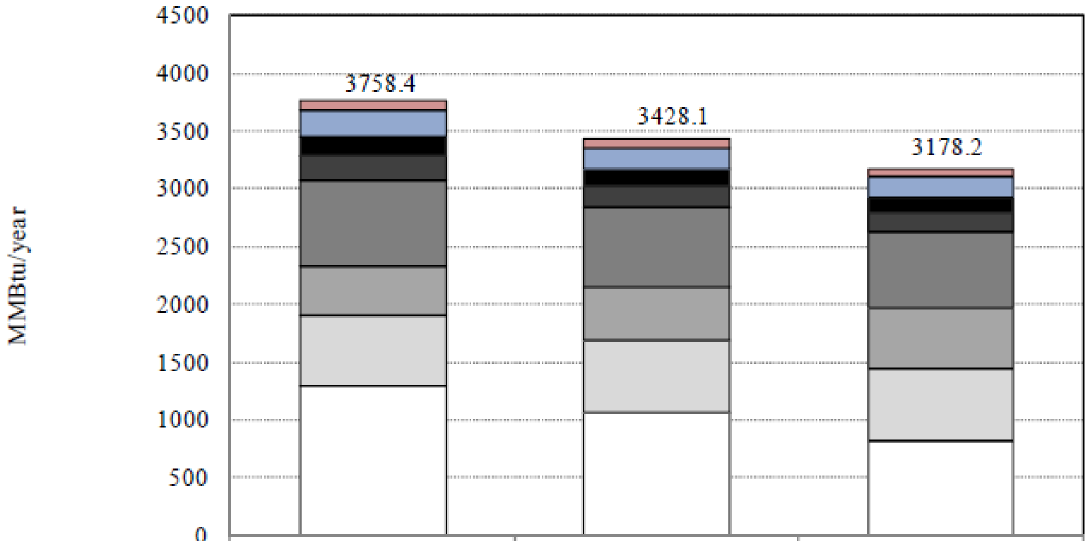
Figure 21: BEPS for Climate Zone 4B

Appendix B: Comparison of Simulation Results with Earlier Versions of the Simulation File

(Version 2.06 vs. 2.00)

Table 12: Comparison of Simulation Input Files Version 2.00 and Version 2.06

Parameter	OFFICE.inp Version 2.00	OFFICE.inp Version 2.06
Building Envelope		
Window area	18% WWAR used for analysis.	40% WWAR used for analysis.
Carpet	Slab on grade without the carpet.	Option of carpet added and used in the simulation.
Infiltration	NONE is used to modeling infiltration in the building model.	AIR-CHANGE method used to model infiltration in the building model.
Schedules	From ASHRAE 90.1 1989	From ASHRAE 90.1 1989 modified by Addendum L in 1994 and published in Section G of the User's Manual for 90.1-2004 (ASHRAE 2004c). Modified schedules for equipment
Building Systems		
Economizers	Deactivated.	Options of economizers activated. Included upper and lower drybulb temperature limits.
DHW system	DHW specifications defined in PLANT. 0.23gpm/person	DHW system redefined in SYSTEMS. 0.4gpm/person
Reset Schedule	From DOE-2 Samp3.inp input file	Modified to match COMNET specifications for Dry and Humid climates
Thermostat Setting Cooling Heating	77 68	75 70
Throttling Range	4	5
Supply Air	Defined as 1 cfm/sqft	Auto-defined



	ASHRAE 1989	ASHRAE 1999	ASHRAE 2004
DOMHOT WATER	71.5	71.5	71.5
VENT FANS	237.8	187	180.4
PUMPS & MISC	170.5	145.3	138.1
HEAT REJECT	214.5	176.3	163.3
SPACE COOL	725.5	705.6	653.9
SPACE HEAT	432.4	458.1	533.2
MISC EQUIPMT	616.2	616.2	616.2
AREA LIGHTS	1290	1068.1	821.6

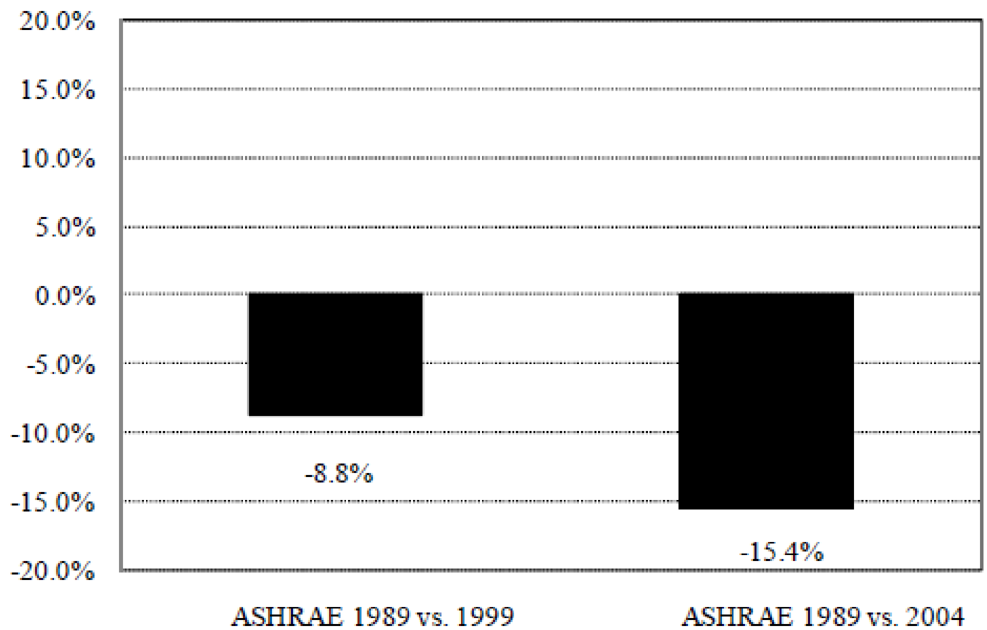
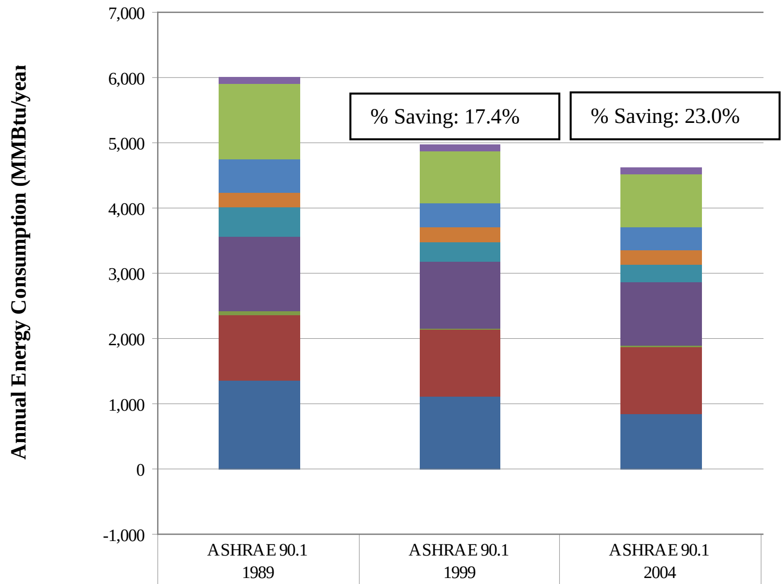


Figure 22: Change in Annual Total Energy Consumption for Harris County from ASHRAE 90.1 1989 to ASHRAE 90.1-1999 and ASHRAE 90.1-2004 as reported by S. Kim (2009) using Version 2.00 of Input file.



	ASHRAE 90.1 1989	ASHRAE 90.1 1999	ASHRAE 90.1 2004
TOTAL	6017.8	4972.2	4634.4
Renewable Energy			
DHW GAS	106.5	102.1	102.1
Space Heat GAS	1155.9	782.3	821.8
Vent Fans ELEC	513.5	381.2	349.5
Pumps & Misc ELEC	226.3	213.1	208.8
Heat Reject ELEC	452.9	299.9	282.5
Space Cool ELEC	1141.8	1028.1	962.7
Space Heat ELEC	49.0	27.1	28.3
Misc Equip ELEC	1013.1	1013.1	1013.1
Area Lights ELEC	1358.8	1125.3	865.6

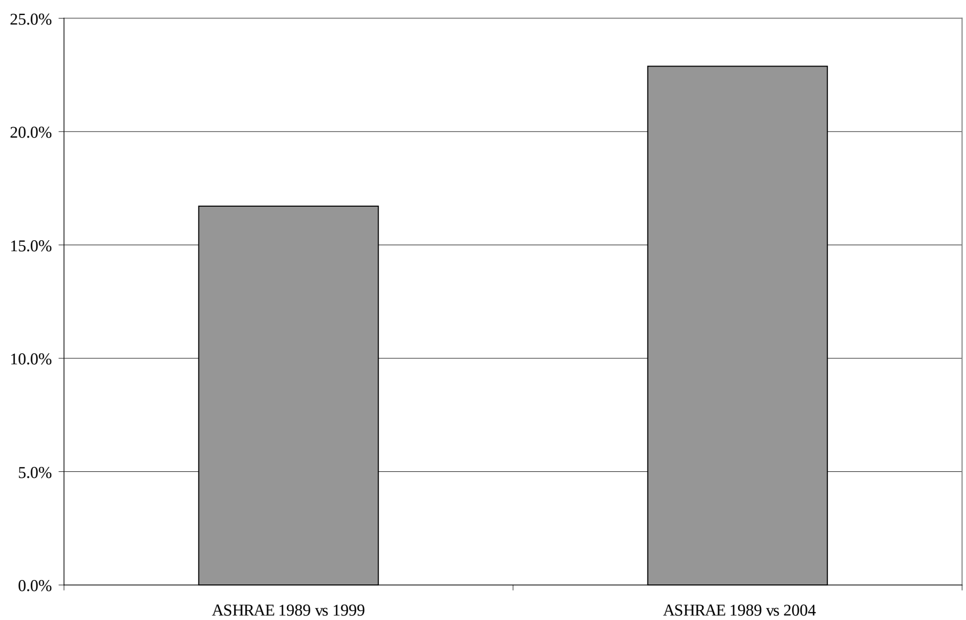


Figure 23: Change in Annual Total Energy Consumption for Harris County from ASHRAE 90.1-1989 to ASHRAE 90.1-1999 and ASHRAE 90.1-2004 using Version 2.06 of Input file.

Appendix C: Comparison of Simulation Results with Earlier Versions of the Simulation File

ASHRAE Standard 189.1-2009 requires a compliant building to produce an annual energy production equivalent of not less than 6.kBtu/ft^2 of on-site renewable energy. For the base-case building of 89,304 ft^2 area, the total on-site renewable energy produced would have to be equal to 535.8 MMBtu annually.

In order to meet this annual on-site renewable energy production of 535.8 MMBtu, several simulations were performed to estimate the use of solar energy for the service hot water heating requirement of the building model as well as renewable electricity generation. The simulations were performed using the F-Chart Ver. 6.72W (Klein and Beckman 1983a) and the PVF-Chart Ver. 3.41W (Klein and Beckman 1983a) software. TMY2 climate data for the three counties – Harris, Tarrant and Potter were used for the analysis.

The use of a water storage heating system with flat plate collectors was assumed to simulate the service hot water heating requirements. The specifications for the water storage heating system with flat plate collectors are provided in Table 13. The use of a standalone system with flat plate array was assumed for on-site electricity generation. The specifications for the standalone system with flat plate array are provided in Table 14. The roof area of the building model was utilized to install the solar collectors as well as photovoltaic (PV) panels. 4% of the roof area was assumed to be covered by flat plate storage collectors. The percentage of the remaining roof area covered by PV panels was varied in order to meet the requirements set by the code. Two options were considered for the analysis:

- Option 1: 4% of the roof area used for the installation of solar hot water heating system and remaining used for PV panels for electricity generation.
- Option 2: The entire roof area used for the installation of the PV panels for electricity generation.

Table 15, Table 16 and Table 17 present the results for F-chart and PVF-chart for the three counties. It is observed that for Harris County:

- Option 1 requires the use of 4% of roof area for solar hot water heating and the use of 80% of roof area for PV panels to generate a total of 555 MMBtu of renewable energy.
- Option 2 requires the use of 90% of roof area for PV panels to generate a total of 527.55 MMBtu of renewable energy.

For Tarrant county:

- Option 1 requires the use of 4% of roof area for solar hot water heating and the use of 65% of roof area for PV panels to generate a total of 526.83 MMBtu of renewable energy.
- Option 2 requires the use of 80% of roof area for PV panels to generate a total of 533.22 MMBtu of renewable energy.

For Potter county:

- Option 1 requires the use of 4% of roof area for solar hot water heating and the use of 65% of roof area for PV panels to generate a total of 585.2 MMBtu of renewable energy.
- Option 2 requires the use of 75% of roof area for PV panels to generate a total of 545.4 MMBtu of renewable energy.

A summary of the options and results are presented in Table 18 below.

Table 13: Specifications input for F-Chart (5% of Total Roof Area for Solar Collectors for DHW)

Element	Amount	Units
Location	**Harris/Tarrant/Potter [1]**	
Water Volume / collector area	**0.951[2]**	**gal/ft²**
Building UA	**0 [3]**	**Btu/hr-°F**
Fuel	**Gas [4]**	
Efficiency of fuel usage	**67 [5]**	**%**
Domestic hot water	**Yes**	
Daily hot water usage	**566 [6]**	**gal**
Water set temperature	**110 [7]**	**°F**
Environmental temperature	**72.5[8]**	**°F**
UA of auxiliary storage tank	**0 [9]**	**Btu/hr.-°F**
Pipe heat loss	**No (Default)**	
Inlet pipe UA	**5 (Default)**	**Btu/hr.-°F**
Outlet pipe UA	**5 (Default)**	**Btu/hr.-°F**
Relative load heat exchanger size	**1 (Default)**	
Collector-store heat exchanger	**No (Default)**	
Tank-side flowrate/area	**11 (Default)**	**lb./hr-ft²**
Heat exchanger effectiveness	**0.5 (Default)**	**lb./hr-ft²**
Number of collector panels	**19 [10]**	
Collector panel area	**32 [11]**	**ft²**
FR*UL (Test slope)	**0.74 (Default)**	**Btu/hr-ft²-°F**
FR*Tau*ALPHA(Test intercept)	**0.7 (Default)**	
Collector slope	**Harris 30 Tarrant 32 Potter 35 [12]**	**° (Degrees)**
Collector azimuth (South=0)	**0 [13]**	**° (Degrees)**
Incidence angle modifier calculation	**Glazing[14]**	
Number of glass covers	**1 [15]**	
Inc. angle modifier constant	**0.05 (Default)**	
Inc. angle modifier value(s)	**Ang Dep (Default)**	
Collector flowrate/area	**11 (Default)**	**lb./hr-ft²**
Collector fluid specific heat	**0.8 (Default)**	**Btu/lb.-°F**
Modify test values	**No (Default)**	
Test collector flowrate/area	**11 (Default)**	**lb./hr-ft²**
Test fluid specific heat	**1 (Default)**	**Btu/lb.-°F**

Note: The parameters for F-Chart are indicated by default, unless they are referenced.
[1] The cities were input by the user for this study.
[2] Calculated using the total gallons/day consumed and the total area of the collector.
[3] Building UA was not considered this study.
[4] Gas was considered for this system for auxiliary heating requirements.
[5] This parameter was taken from Table 7.8 of the ANSI/ASHRAE/IESNA Standard 90.1-2007.
[6] DHW usages are calculated by the following formula: ((Area of each floor*Number of floors)/275 ft²/person)* Domestic Hot Water requirements from Table 21.10 Domestic Hot Water, Commercial/Institutional (p.927) from the *Mechanical and Electrical Equipment for Buildings* by Stein et al., (2006). Values for DHW requirements are set at 0.4 Gallons/hr./person.
[7] This parameter was input from the DOE-2.1e file.
[8] This temperature was assumed by the user.
[9] UA of tank was assumed to be zero.
[10] This parameter was calculated for 4% of total roof area.
[11] The solar collector considered has a dimension of 8 ft. X 3 ft.
[12] Angles input by the user.
[13] The 6 floor building is facing south.
[14] This parameter was selected from a drop down list for the flat-plate collector.
[15] This parameter was input by the user for this study.

Table 14: Specifications input for PV F-Chart (10%, 95% or 100% of Total Roof Area for Photovoltaic)

Element	Amount	Units
	Harris/Tarrant/Potter [1]	
Cell Temperature (NOCT conditions)	**44**	**°F**
Array reference efficiency	**0.104 (Default)**	
Array reference temperature	**82.4 (Default)**	**°F**
Array temperature coefficient*1000	**2.389 (Default)**	**1/°F**
Power tracking efficiency	**0.9 (Default)**	
Power conditioning efficiency	**0.88 (Default)**	
% Standard deviation of load	**0 (Default)**	**%**
Array area (no. of panels X panel area)	**1,489 (10%)** [2]	**ft^2**
	7,443 (50%)	
	9,675 (65%)	
	11,164 (75%)	
	11,908 (80%)	
	12,652 (85%)	
	13,397 (90%)	
	14,141 (95%)	
Array slope	**Harris 30** [3]	**° (Degrees)**
	Tarrant 32	
	Potter 35	
Array azimuth (South=0)	**0** [4]	**° (Degrees)**

Note: The parameters for PV F-Chart are indicated by default, unless they are referenced.
[1] The cities were input by the user for this study.
[2] The areas correspond to different PV array percentage for total roof area (14,890 ft^2).
[3] Angles input by the user.
[4] The 6 floor building is facing south. Hence the PV array faces south.

Table 15: Results from F-Chart and PV F-Chart for Harris County

Harris County, TX																					
		From f-chart				From PVf-Chart (w/ TMY2)															
	DOE-2.1e SS-P report 10^6 Btu/hr	w/ TMY2 weather tape			Loads met by Solar Collector	Roof Area:10%		Roof Area: 50%		Roof Area: 65%		Roof Area: 75%		Roof Area: 80%		Roof Area: 85%		Roof Area: 90%		Roof Area: 95%	
						1489		7443		9675		11164		11908		12652		13397		14141	
Month		Dhw 10^6 Btu/hr	Aux 10^6 Btu/hr	f		kW-hr	MMBtu	kW-hr	MMBtu	kW-hr	MMBtu	kW-hr	MMBtu	kW-hr	MMBtu	kW-hr	MMBtu	kW-hr	MMBtu	kW-hr	MMBtu
Jan	6.9	6.92	1.95	0.72	4.98	1138	3.88	5689	19.41	7395	25.23	8533	29.12	9102	31.06	9671	33.00	10240	34.94	10808	36.88
Feb	6.4	6.56	1.06	0.84	5.49	1206	4.12	6029	20.57	7837	26.74	9043	30.86	9646	32.91	10249	34.97	10852	37.03	11454	39.08
Mar	7.4	7.29	0.48	0.93	6.81	1476	5.03	7375	25.16	9587	32.71	1063	3.63	11800	40.26	12538	42.78	13276	45.30	14012	47.81
Apr	6.8	6.90	0.00	1.00	6.90	1512	5.16	7558	25.79	9825	33.53	11338	38.69	12093	41.26	12849	43.84	13605	46.42	14360	49.00
May	6.5	6.47	0.00	1.00	6.47	1598	5.45	7989	27.26	10386	35.44	11984	40.89	12783	43.62	13582	46.34	14381	49.07	15178	51.79
Jun	5.7	5.64	0.00	1.00	5.64	1581	5.39	7903	26.96	10273	35.05	11854	40.45	12644	43.14	13434	45.84	14225	48.54	15014	51.23
Jul	5.1	5.26	0.00	1.00	5.26	1631	5.56	8150	27.81	10594	36.15	12225	41.71	13040	44.49	13855	47.27	14670	50.06	15484	52.83
Aug	5.1	4.91	0.00	1.00	4.91	1635	5.58	8173	27.89	10624	36.25	12260	41.83	13077	44.62	13894	47.41	14712	50.20	15528	52.98
Sept	4.4	4.72	0.00	1.00	4.72	1526	5.21	7628	26.03	9916	33.84	11442	39.04	12205	41.64	12968	44.25	13731	46.85	14492	49.45
Oct	5.2	5.16	0.00	1.00	5.16	1563	5.33	7814	26.66	10158	34.66	11721	39.99	12503	42.66	13284	45.33	14066	47.99	14846	50.66
Nov	5.3	5.53	0.82	0.85	4.70	1230	4.20	6150	20.98	7995	27.28	9225	31.48	9840	33.58	10455	35.67	11070	37.77	11684	39.87
Dec	6.0	6.34	1.82	0.71	4.52	1088	3.71	5436	18.55	7066	24.11	8154	27.82	8697	29.68	9241	31.53	9785	33.39	10328	35.24
TOTAL					**65.55**		**58.63**		**293.08**		**380.99**		**405.50**		**468.93**		**498.24**		**527.55**		**556.81**

Table 16: Results from F-Chart and PV F-Chart for Tarrant County

Tarrant, TX															
		From f-chart				From PVf-Chart (w/ TMY2)									
	DOE-2.1e SS-P report 10^6 Btu/hr	w/ TMY2			Loads met by Solar Collector	Roof Area: 10%		Roof Area: 50%		Roof Area: 65%		Roof Area: 75%		Roof Area: 80%	
Month		Dhw 10^6 Btu/hr	Aux 10^6 Btu/hr	f		kW-hr	MMBtu	kW-hr	MMBtu	kW-hr	MMBtu	kW-hr	MMBtu	kW-hr	MMBtu
Jan	7.6	7.60	1.54	0.80	6.06	1373	4.68	6861	23.41	8918	30.43	10291	35.11	10976.90	37.45
Feb	7.1	7.26	0.71	0.90	6.55	1396	4.76	6977	23.81	9069	30.95	10465	35.71	11162.60	38.09
Mar	8.2	8.06	0.00	1.00	8.06	1716	5.85	8576	29.26	11148	38.04	12864	43.89	13721.40	46.82
Apr	7.5	7.61	0.00	1.00	7.61	1723	5.88	8611	29.38	11193	38.19	12916	44.07	13776.60	47.01
May	7.0	7.01	0.00	1.00	7.01	1786	6.09	8926	30.46	11603	39.59	13389	45.68	14281.00	48.73
Jun	6.0	5.98	0.00	1.00	5.98	1801	6.15	9003	30.72	11702	39.93	13503	46.07	14403.40	49.15
Jul	5.9	5.45	0.00	1.00	5.45	1902	6.49	9507	32.44	12357	42.17	14259	48.65	15209.70	51.90
Aug	5.2	4.99	0.00	1.00	4.99	1863	6.36	9314	31.78	12107	41.31	13970	47.67	14900.90	50.84
Sept	4.5	4.79	0.00	1.00	4.79	1673	5.71	8363	28.54	10871	37.09	12544	42.80	13379.80	45.65
Oct	5.3	5.33	0.00	1.00	5.33	1648	5.62	8240	28.12	10711	36.55	12359	42.17	13182.90	44.98
Nov	5.6	5.84	0.70	0.88	5.14	1368	4.67	6838	23.33	8889	30.33	10257	35.00	10940.70	37.33
Dec	6.5	6.85	1.51	0.78	5.34	1292	4.41	6460	22.04	8398	28.65	9690	33.06	10336.10	35.27
TOTAL					**72.31**		**66.67**		**333.28**		**433.23**		**499.90**		**533.22**

Table 17: Results from F-Chart and PV F-Chart for Potter County

Potter, TX													
		From f-chart				From PVf-Chart (w/ TMY2)							
	DOE-2.1e SS-P report 10^6 Btu/hr	w/ TMY2			Loads met by Solar Collector	10%		Roof Area: 50%		Roof Area: 65%		Roof Area: 75%	
Month		Dhw 10^6 Btu/hr	Aux 10^6 Btu/hr	f		kW-hr	MMBtu	kW-hr	MMBtu	kW-hr	MMBtu	kW-hr	MMBtu
Jan	9.2	9.25	1.66	0.82	7.58	1592	5.43	7959	27.16	10345	35.30	11937	40.73
Feb	8.6	8.83	0.63	0.93	8.20	1582	5.40	7907	26.98	10278	35.07	11860	40.47
Mar	9.9	9.82	0.00	1.00	9.82	1910	6.52	9549	32.58	12413	42.35	14323	48.87
Apr	9.2	9.26	0.00	1.00	9.26	1959	6.69	9793	33.42	12730	43.44	14690	50.12
May	8.6	8.56	0.00	1.00	8.56	1928	6.58	9639	32.89	12529	42.75	14457	49.33
Jun	7.3	7.31	0.00	1.00	7.31	1882	6.42	9410	32.11	12231	41.73	14114	48.16
Jul	6.5	6.68	0.00	1.00	6.68	1922	6.56	9610	32.79	12491	42.62	14414	49.18
Aug	6.3	6.13	0.00	1.00	6.13	1896	6.47	9479	32.35	12322	42.04	14219	48.52
Sept	5.5	5.88	0.00	1.00	5.88	1768	6.03	8835	30.15	11485	39.19	13252	45.22
Oct	6.5	6.53	0.00	1.00	6.53	1849	6.31	9244	31.54	12016	41.00	13865	47.31
Nov	6.9	7.14	0.73	0.90	6.41	1548	5.28	7737	26.40	10057	34.31	11604	39.60
Dec	7.9	8.36	1.71	0.80	6.64	1481	5.05	7403	25.26	9623	32.83	11103	37.89
TOTAL					**89.00**		**72.74**		**363.61**		**472.65**		**545.39**

Table 18: Summary of Possible Configurations for Renewable Results from F-Chart and PV F-Chart for Harris, Tarrant and Potter County

	Configuration		**Annual Energy from Each Option** (MMBtu)	**Total Annual Energy from Renewable Sources** (MMBtu)
For Harris	Option 1	4% roof area for solar collectors	65.55	**534.48**
		80% roof area for PV panels	468.93	
	Option 2	4% roof area for solar collectors	65.55	**563.79**
		85% roof area for PV panels	498.24	
	Option 3	90% of roof area for PV panels	527.55	**527.55**
	Option 4	95% of roof area for PV panels	556.81	**556.81**
For Tarrant	Option 1	4% roof area for solar collectors	72.31	**572.2**
		75% roof area for PV panels	499.9	
	Option 2	80% roof area for PV panels	533.22	**533.22**
For Potter	Option 1	4% roof area for solar collectors	89.00	**561.65**
		65% roof area for PV panels	472.65	
	Option 2	65% roof area for PV panels	545.39	**545.39**