Development of DOE-2-Based Simulation Models for the Code-Complaint Commercial Construction Based on the ASHRAE Standard 90.1

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ABSTRACT

In 2001, the Texas State Senate passed Senate Bill 5 to reduce ozone levels by encouraging the reduction of emissions of NOx that were not regulated by the Texas Natural Resource Conservation Commission. These include point sources (power plants), area sources (such as residential emissions), road mobile sources, and non-road mobile sources. For the building energy sector, the Texas State Legislature adopted the 2000 International Energy Conservation Code, as modified by the 2001 Supplement, as the state's building energy code. The 2000/2001 IECC is a comprehensive energy conservation code that establishes a standard for the insulation levels, glazing, cooling and heating system efficiencies through the use of prescriptive and performance-based provisions.

This paper provides a detailed description of the procedures that were developed to calculate the electricity and natural gas savings in new office construction that is being built in compliance with Chapter 8 of the 2000/2001 International Energy Conservation Code. Since most of the commercial portion of the 2000/2001 International Energy Conservation Code refers to ASHRAE Standard 90.1-1999 as the current code requirement for commercial construction, the simulation models based on the ASHRAE Standard 90.1, with general commercial configurations, are created to quantify the electricity and gas savings. Then, simulation models are modified to accommodate the different scenarios of construction and HVAC equipment based on three different codes (i.e., ASHRAE Standard 90.1-1989 (pre-code), 1999 (code-compliant), and 2004 (new-code)). The "pre-code" designation is meant to represent the commercial construction characteristics before the passage of Texas Emission Reduction Plan (TERP) in September 2001. In the simulations, "pre-code", "code-complaint" and "new code" represent the commercial constructions in compliance with ASHRAE Standard 90.1-1989, ASHRAE Standard 90.1-1999, and ASHRAE Standard 90.1-2004, respectively.

This paper includes an explanation of the simulation models developed for the different versions of ASHRAE Standard 90.1, as mentioned above, which are used for investigating the electricity and gas energy savings.

INTRODUCTION

In 2001, the Texas State Legislature formulated and passed the Texas Emissions Reduction Plan (TERP) to reduce ozone levels by encouraging the reduction of emissions of NOx from sources that are not currently regulated by the state. An important part of this legislation is the State's energy efficiency program, which includes reductions in energy use and demand that are associated with the adoption of the 2000/2001 International Energy Conservation Code (2000/2001 IECC).

This paper presents detailed simulation procedures and analysis of the electricity and gas energy savings using the DOE-2.1e simulation program (LBNL 1993a & 1993b) based on the different versions of ASHRAE Standard 90.1.

METHODOLOGY

<u>Overview</u>

In order to investigate the energy savings by the implementation of ASHRAE Standard 90.1-1989, 1999 and 2004 (ASHRAE 1989, 1999 & 2004) in new constructions, the base-case simulation model was developed based on the average characteristics of commercial buildings being built to the specifications of the F.W. Dodge survey data. The models were then modified to simulate the different scenarios of the fenestration, envelope properties, and HVAC equipment based on the ASHRAE Standard 90.1. In this analysis, an office building (122ft x 122ft,

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6-stories in height) located in Houston, Texas was used.

For complete comparison of the different scenarios, three DOE-2.1e simulations were performed: 1) a pre-code run based on the minimum requirement by ASHRAE Standard 90.1-1989 (ASHRAE 1989), 2) code run based on the minimum requirements of ASHRAE Standard 90.1-1999 (ASHRAE 1999), and 3) code run based on the minimum requirement of ASHRAE Standard 90.1-2004 (ASHRAE 2004).

The minimum requirements of ASHRAE Standard 90.1 are based on the climate zone. For this analysis, the code and pre-code envelope and glazing characteristics are assigned for a building in Harris County, which includes Houston, Texas. The TMY2 weather file for Houston was used to carry out the simulations.

Building Configurations

Since ASHRAE Standard 90.1-1989 fixed the building aspect ratio as 2.5 to 1, the base case configuration (122 ft x 122 ft) is modified to 192.89 ft x 77.16 ft with the longer side oriented on an east-west axis to perform the simulation. For the building configurations of ASHRAE Standard 90.1-1999 and 2004, the basic building shape (122 ft x 122 ft, 6-story, oriented north-south) is used because ASHRAE Standard 90.1-1999 does not require a specific aspect ratio or orientation.

For the window-to-wall ratio, ASHRAE Standard 90.1-1989 specified the value according to the Internal Load Density (ILD) including the occupancy, lighting and receptacle load. For this analysis, the ILD due to occupancy, lighting and receptacles is obtained from Table 13-2, Section 6 and Table 13-4 of Standard 90.1-1989, which yields an occupancy density of 275 ft^2/person, a Lighting Power Density (LPD) of 1.57 W/ ft^2, and receptacle loads of 0.75 W/ ft^2. The resultant ILD is then used to determine the window-to-wall area ratio (WWR) for the base case building. For this analysis, an 18% window-to-wall area ratio is selected for the simulation (Table 1). For the simulations using ASHRAE Standard 90.1-1999 and 2004, the same window-to-wall area ratio (18%) was used for the reasonable comparisons since ASHRAE Standard 90.1-1999 and 2004 do not require a specific window-to-wall area ratio.

Table 1 shows the pre-code and code building characteristics of fenestration and envelope properties for Harris County from ASHRAE Standard 90.1.

Building Envelope

In the DOE-2 program there are two methods to specify the building envelopes: 1) the "quick" mode option, which uses U-values for the walls and roofs, a lumped thermal mass and pre-calculated ASHRAE weighting factors for the wall's thermal mass components, or 2) the delayed mode option which uses layered walls and roof construction and DOE-2's Custom Weighting Factors (CWFs) to calculate a more accurate heat transfer through the layered building components (LBNL 1993), which includes a proper accounting of a building's thermal mass elements.

Since the ASHRAE Standard provides no advice on how the thermal mass should be treated in a simulation program, such as DOE-2, two simulations using quick mode and thermal mass mode were performed to investigate the energy saving difference of the two different methods. The quick mode uses U-values from Table 1 instead of layered materials while the delayed mode uses a 2"x4" steel-framed wall with studs 16" O.C. with insulation between the studs. In order to match the U-factor of the thermal mass materials to the overall U-factor in Table 1, the thickness of the insulation was adjusted.

Harris County	Fenestration properties			Envelope properties	
	U-factor	SHGC	Window to Wall ratio (%)	Wall U-value	Roof U-value
ASHRAE 90.1-1989 ACP Table 8A-10	**1.15**	**0.61**	23 (for ILD < 1.5)	**0.15**	**0.066**
			18 (1.51 < ILD < 3)		
			23 (for ILD > 3)		
ASHRAE 90.1-1999 Table B-5	**1.22**	**0.25**	**< 40%**	**0.124**	**0.063**
	1.22	0.17	> 40%	0.089	
ASHRAE 90.1-2004 Table 5.5-2	**1.22**	**0.25**	**< 40%**	**0.124**	**0.063**
	1.22	0.17	> 40%	0.089	

Table 1: Code and Pre-Code Building Characteristics for Harris County

System Simulations

The HVAC requirements were selected according to end use, building size and building loads. In order to run a complete pre-code (ASHRAE Standard 90.1-1989) and code run (ASHRAE Standard 90.1-1999 and 2004) without simplification, at least eleven DOE-2 runs were required—three for the pre-code (ASHRAE Standard 1989) and four each for the codes ASHRAE Standard 1999 and 2004 version.

System Simulation According to ASHRAE Standard 90.1-1989

ASHRAE Standard 90.1-1989 defines 7 system types according to the type of building and conditioned floor areas of each. (ASHRAE Standard 90.1-1989, Table 13-5) Each system type describes an HVAC component such as fan control, cooling system and heating system (ASHRAE Standard 90.1-1989, Table 13-6). This standard also explains how to decide on the number of chillers and chiller type (ASHRAE Standard 90.1-1989, Table 13-6 Note 11) as well as how to decide on the efficiency of the cooling, heating and DHW system.

In order to run an ASHRAE Standard 90.1-1989 code-compliant building with DOE-2, three steps should be performed: 1) the selection of system type, 2) the decision about the number and type of chillers, and 3) the decision about the cooling, heating and DHW system efficiency according to the size of the system.

The following example explains how the sample office building (122 ft x 122 ft, 6-story building) was run with the DOE-2 simulation program. The heating and DHW system for the sample run were fixed to hot water fossil fuel and gas storage water heaters. Since ASHRAE Standard 90.1-1989 does not give all the detailed characteristics for a DOE-2 simulation, the default values from DOE-2 BDL Summary (1993) were used in this case. According to ASHRAE Standard 90.1-1989 table 13-5, an office building that is 75,000 ft^2 or higher and that is taller than 3 floors, is assigned to use the number 5 system type, which is a built-up central VAV with perimeter reheat (Table 2).

The other characteristics of the system, including fan control, static pressure rise and fan efficiencies, are taken from Table 13-6 of Standard 90.1-1989. In Table 13-6, the values for supply and return static are 4.0 in. of WC and 1.0 in. of WC, respectively. The required supply and return fan efficiencies were set to 61% and 32%, which are the combined efficiencies for the motor and the fan including the variable frequency drives. Using these inputs in the DOE-2 input file, the first DOE-2 run can be performed.

Office Building Size	System
≤ 20,000 ft^2	Packaged roof top single zone system
≥ 20,000 ft^2 and either ≤ 3 floors or ≤ 75,000 ft^2	Packaged roof top VAV with perimeter reheat
> 3 floors or > 75,000ft^2	Built-up central VAV with perimeter reheat

Table 2: System Requirements According to the Total Floor Area for ASHRAE Standard 90.1-1989

After the first run, the cooling equipment size from the PV-A DOE-2 report should be inspected to decide the number and type of chillers according to ASHRAE Standard 90.1 1989 Table 13-6 note 11. From the PV-A report of the first run, the chiller size is 1.912 MMBtu/hr (1.912 $*10^6$ Btu/hr /12000 = 159.33 ton). For this size, the chiller type should be reciprocating and the number of chillers should be just one because ASHRAE Standard 90.1 1989 states that chilled water systems should be modeled using a reciprocating chiller for systems with total cooling capacities of less than 175 tons.

These two values were then added to the DOE-2 input file. After the second run, the boiler, chiller and DHW efficiency should be decided according to the size of equipment. The PV-A DOE-2 report is again used to figure out the size of the equipment. Based on the PV-A report, the size of the hot water boiler is 1.206 MMBtu/hr, DHW-heater is 0.017 MMBtu/hr and chiller is 1.912 MMBtu/hr (1.912 $*10^6$ Btu/hr /12000 = 159.33 ton).

In order to decide the equipment efficiency, Table 10-7 in ASHRAE Standard 90.1 1989 was used where a 4.2 COP is required between 150 tons and 300 tons of chiller. Table 10-8 in ASHRAE Standard 90.1 1989 determines 80% of the efficiency, if the size of gas-fired boiler is more than 300,000 Btu/hr. For the gas-fired domestic water heater, if the rating is less than 75,000 Btu/hr, the energy factor is determined by the NAECA requirement (NAECA 1987): Energy Factor = 0.62 – 0.0019 x V, where V = storage capacity of the domestic water heater, which is taken as 75 gallons[1] and yields an energy factor of 0.4775.

[1] This is the value from the USDOE's COMCHECK program 1.1, release 2 (USDOE 2003)

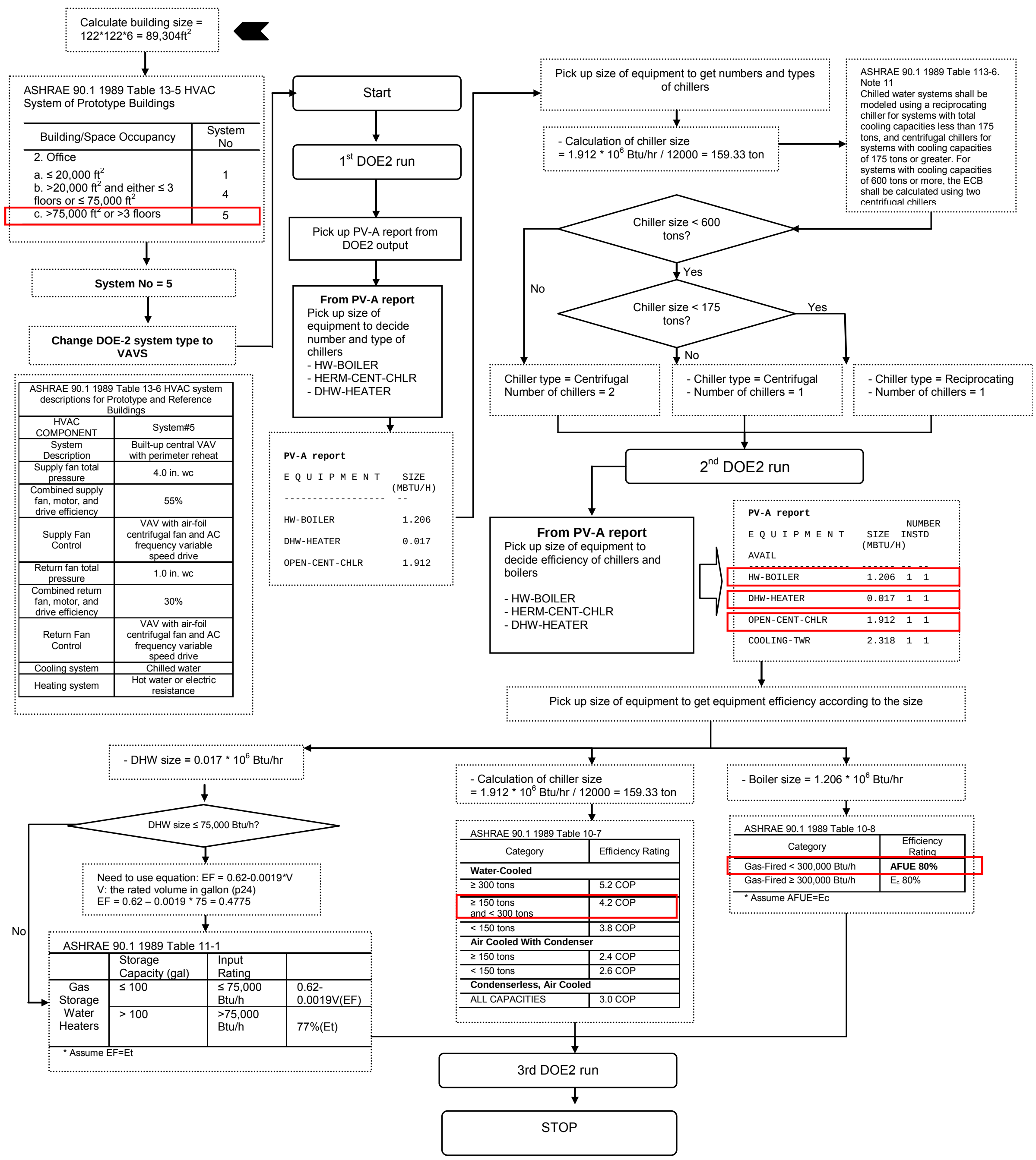


Figure 1: Flow Chart of the Procedure to Run an ASHRAE Standard 90.1 1989 Simulation

After this run was completed, the efficiencies of the chiller, boiler and domestic water heater were entered into the DOE-2 simulation using the DOE-2 keywords: ELEC-INPUT-RATIO, HW-BOILER-HIR and DHW-HIR. These values were then updated in the input file to complete the system selection process, according to ASHRAE Standard 90.1-1989. The annual energy consumption from this third run, which includes the correctly-sized systems, is then used to determine the pre-code energy use of the building.

System Simulation According to ASHRAE Standard 90.1-1999 and 2004

The system simulation procedure of ASHRAE Standard 90.1-1999 and 2004 is the same, except for the lighting density. The lighting density is decreased from 1.3 W/ft^2 requirements in ASHRAE Standard 90.1-1989 to 1.0 W/ft^2 in ASHRAE Standard 90.1-1999. Table 3 shows the changes in the lighting power density of the office building according to ASHRAE Standard 90.1 1989, 1999 and 2004.

Lighting Power Density	ASHRAE 1989	ASHRAE 1999	ASHRAE 2004
LPD (W/SQ.FT)	1.57	1.3	1

Table 3: Changes of the Lighting Power Density of the ASHRAE Standard 90.1

As expected, the requirements for ASHRAE Standard 90.1-1999 and 2004 are different from those of ASHRAE Standard 90.1-1989. The simulation for ASHRAE Standard 90.1-1999 starts differently from ASHRAE Standard 90.1-1989 in that ASHRAE Standard 90.1-1999 does not first decide the system types (ASHRAE Standard 90.1-1989 Table 13-5) according to the total conditioned area. Instead, Standard 90.1-1999 assigns the system type according to the information provided in Figure 11.4.3. Also, Standard 90.1-1999 has a lower limit of 25 hp on the VSD fan size, below which variable inlet vanes are used to meet the VAV specification (Table 11.4.3.A, Note 4).

In order to run ASHRAE Standard 90.1-1999 and 2004 code-compliant building with DOE-2, four steps were used: 1) the selection of the number and type of fan, 2) the decision about the number of chillers and boilers, 3) the decision about the chiller type, and 4) the decision about the cooling, heating and DHW system efficiency. In this analysis, the same building that was used for the ASHRAE Standard 90.1-1989 run (122 ft x 122 ft, 6-story building) was used to perform the simulation.

The heating and DHW systems for the sample run were fixed to hot water fossil fuel and gas storage water heaters. Default values from the DOE-2 BDL Summary (1993) were used if there was no detailed information in the ASHRAE Standard 90.1-1989 simulation.

According to ASHRAE Standard 90.1-1999 Table 11.4.3.A note 4, when the system in the proposed design has a supply, return, or relief fan motor of 25 hp or larger, the corresponding fan in the VAV system of the budget building shall be modeled assuming a variable speed drive. For smaller fans, a forward-curved, centrifugal fan with inlet vanes should be modeled. Therefore, in order to investigate fan size, an initial DOE-2 run should be performed. From the SV-A DOE-2 report, it is found that the electricity use (kW) of the fan is 141.260 kW. For the 90.1-1999 and 2004 simulations, 6 fans were used because the sample building was a 6-story building. Therefore, each fan size was 141.260 / 6 = 23.54 kW which is 23.54 kW/0.7457 = 31.56 hp. Since the fan size is more than 25 hp, the fan control type was decided to be a variable speed drive.

From this same simulation output, verification report PV-A was checked to determine the number of chillers and boilers required to meet the cooling and heating load. For this sample building simulation, the size of the boiler was 1.190 MMBtu/hr and the size of chiller was 1.960 MMBtu/hr (=1.960 * 10^6 Btu/hr / 12000 = 163.33 ton). According to ASHRAE Standard 90.1-1999, Table 11.4.3.B, if chiller capacity is less than 300 tons, the number of chillers was one. Therefore, the number of chillers for this sample building is one. In the case of the boiler, ASHRAE Standard 90.1-1999, Table 11.4.3.A specifies that the budget building design boiler should be modeled with a single boiler if the budget building design plant load is 600,000 Btu/h or less and two equal-sized boilers for plant capacities exceeding 600,000 Btu/h. Since the size of the boiler in the sample building exceeded 600,000 Btu/hr, the number of boilers must be two.

According to ASHRAE Standard 90.1-1999, Table 11.4.3.C, if the chiller size is between 100-300 tons, then chiller type is a screw chiller. However, since the current DOE-2 version does not have a screw chiller performance curve, the chiller curve from ComCheck 1.1 release 2 (USDOE 2003) was used for this simulation. After changing the chiller type, the third run was performed to decide the efficiency of the chiller, boiler and DHW. From the PV-A report of the third run, it was found that the chiller size is 1.960 MMBtu/hr (=1.960*10^6 Btu/hr / 12000 = 163.33 ton), the boiler size is 0.595 MMBtu/hr, and the size of the DHW-heater is 0.017 MMBtu/hr. For chiller efficiency, ASHRAE Standard 90.1-1999, Table 6.2.1.C says that if the chiller type is water-cooled electrically operated, the positive displacement (rotary screw and scroll) chiller and the size is between 150-300 tons, then the COP of the chiller is 4.90. In the case of the boiler, ASHRAE Standard 90.1-1999, Table 6.2.1.F describes the efficiency of the boiler. If boiler size is between 300,000- 2,500,000 Btu/hr, then a 75% efficiency boiler is used.

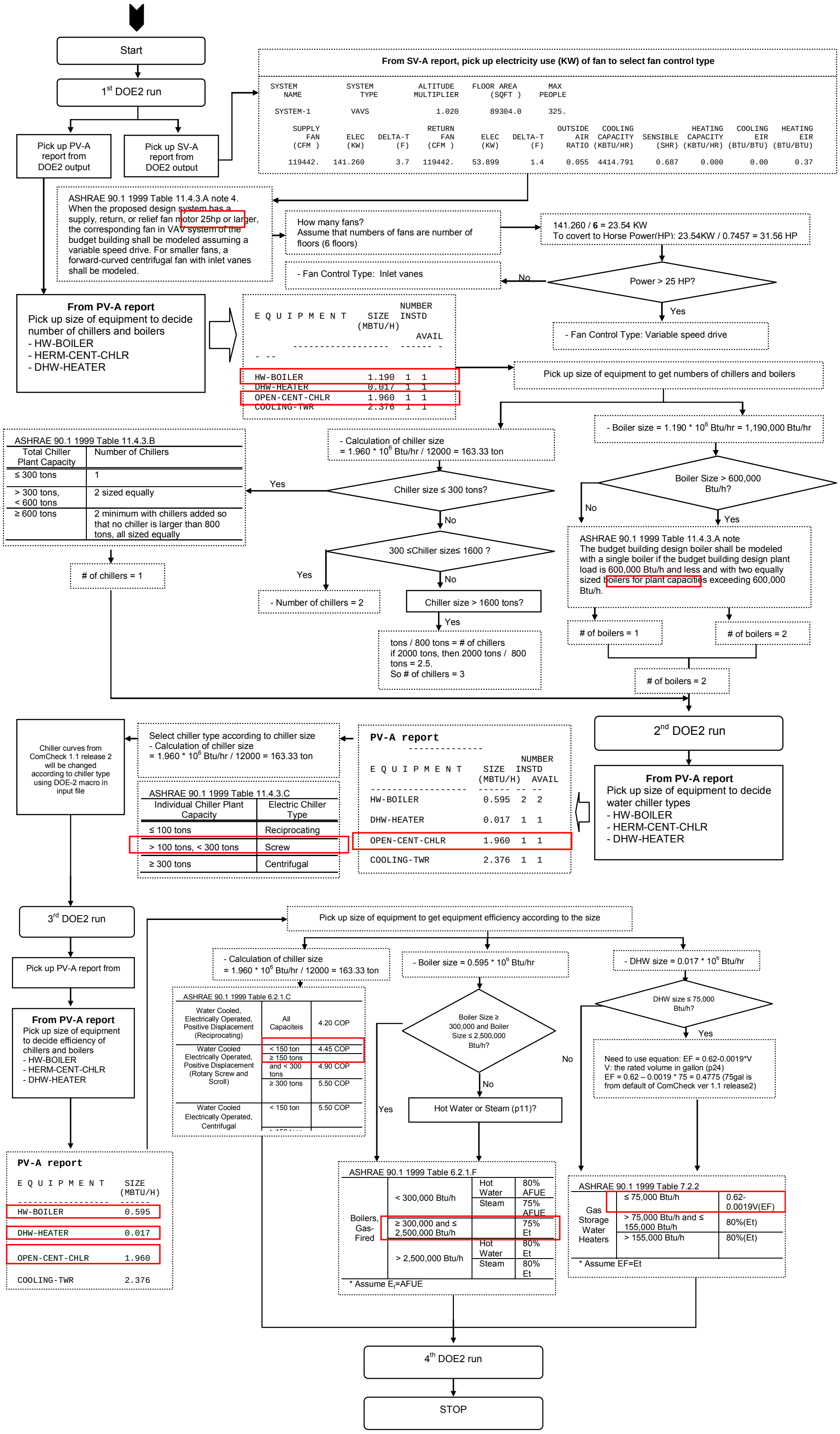


Figure 2: Flow Chart of the Procedure to Run an ASHRAE 90.1 1999 and 2004 Simulation

To select a gas storage water heater, the same table in ASHRAE Standard 90.1-1989 was used. For the domestic water heater, an energy factor[2] (EF) of 0.4775 is selected.

The fourth simulation reflects the equipment that complies with Standard 90.1-1999. Figure 2 shows the flow chart of the procedures required to run an ASHRAE Standard 90.1-1999 and 2004 simulation.

RESULTS

Figures 3 through 6 illustrate the comparisons between annual energy consumption of the example building in Houston, which was constructed based on the ASHRAE Standard 90.1-1989, 1999 and 2004 codes. Figure 3 and 4 show the annual energy consumption using DOE-2's quick mode and Figure 5 and 6 show the annual energy consumption using DOE-2's delayed mode from the DOE-2's Building Energy Performance Summary (BEPS) report. The value at the top of the graph indicates the total energy use (MMBtu).

In Figure 3 and Figure 4 (the quick mode simulation), it was observed that ASHRAE Standard 90.1-1999 showed 9.4% less annual energy consumption (3354.1 MMBtu) versus the simulation based on ASHRAE Standard 90.1-1989 (3703.3 MMBtu). The total annual energy use of ASHRAE Standard 90.1-2004 (3112.5 MMBtu) is 16% less than the total annual energy use of ASHRAE Standard 90.1-1989 (3703.3 MMBtu).

A comparison of the simulation results based on the delayed mode shows a similar energy saving pattern to the quick mode simulations. ASHRAE Standard 90.1-1999 shows an 8.8% reduction of annual energy consumption from ASHRAE Standard 90.1-1989 (from 3758.4 MMBtu to 3428.1 MMBtu), and ASHRAE Standard 90.1-2004 shows a 15.4% savings from ASHRAE Standard 90.1-1989 (from 3758.4 MMBtu to 3178.2 MMBtu).

From the comparison of the simulation results, it is found that a major portion of the savings is due to the decrease in the lighting load density specified in the ASHRAE Standard 90.1 standard (Table 3). ASHRAE Standard 90.1-1999 and 2004 show a 17.2% and 36.3% reduction of lighting energy use from ASHRAE Standard 90.1-1989, respectively.

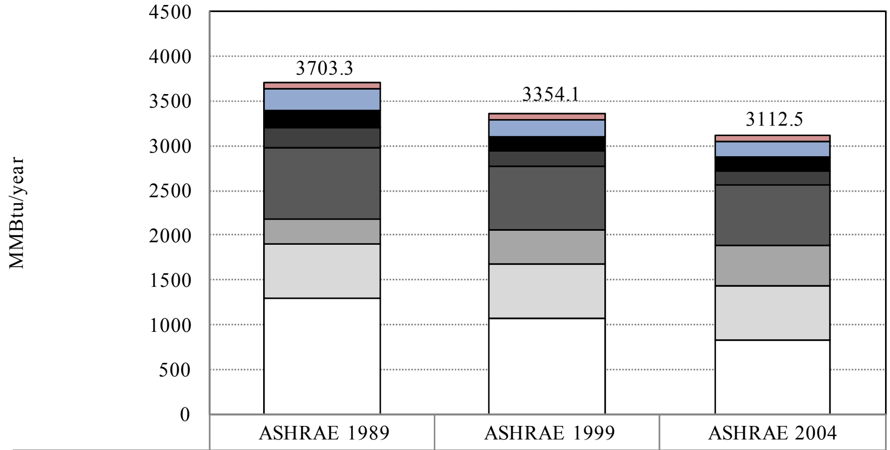
The energy consumption related to the cooling energy (i.e., the summation of the space cool, heat reject, pump & miscellaneous, and fan from BEPS categories) also shows reductions, which are due to the improved COP and the decrease of the internal load from the low lighting density. For the quick mode simulations (Figure 3 and Figure 4), ASHRAE Standard 90.1-1999 (1231 MMBtu) shows a 15.3% reduction while ASHRAE Standard 90.1-2004 (1157.4 MMBtu) shows a 20.3% reduction from ASHRAE Standard 90.1-1989 (1453 MMBtu). For the delayed mode simulation, ASHRAE Standard 90.1-1999 (1214.2 MMBtu) and 2004 (1135.7 MMBtu) show a 9.9% and 15.8% reduction from ASHRAE Standard 90.1-1989 (1348.3 MMBtu), respectively.

However, in the case of the changes in heating energy use, it is evident that ASHRAE Standard 90.1-1999 and 2004 show more energy consumption than ASHRAE Standard 90.1-1989. The reason for this could be the low lighting density, which can decrease the space heating from lighting fixture, or the low SHGC (Solar Heat Gain Coefficient) that blocks the sun's heat in the winter, which can benefit the space heating.

For the quick mode simulations, the heating energy use of ASHRAE Standard 90.1-1999 (367.3 MMBtu) and ASHRAE Standard 90.1-2004 (445.8 MMBtu) have been increased to 34.7% and 63.5%, respectively. The simulation results of the delayed mode show a 5.9% increase for ASHRAE Standard 90.1-1999 (458.1 MMBtu) and a 23.3% increase for ASHRAE Standard 90.1-2004 (533.2 MMBtu) from ASHRAE Standard 90.1-1989 (432.4 MMBtu).

Finally, the results showed that the changes in the heating and cooling energy consumption for the quick mode simulations were more than those for the delayed mode simulation. The reasons for this are complex, involving differences in the weighting factors and subroutines within the DOE-2 program. However, one of the primary results shows that the quick simulation (i.e., ASHRAE pre-calculated weighting factors) requires additional heating and cooling operation hours to maintain the thermostat settings in the quick mode. This is because of the hourly on/off cycling of the system when heating/cooling loads are light as the zone drifts quickly in and out of the dead band because of the difference in the way the pre-calculated ASHRAE weighting factors (quick mode) interact with the zone air node versus the custom weighting factors (delayed mode).

[2] This uses the same approach as Standard 90.1-1989.



	ASHRAE 1989	ASHRAE 1999	ASHRAE 2004
DOMHOT WATER	71.5	71.5	71.5
VENT FANS	239.0	180.9	175.0
PUMPS & MISC	183.8	151.2	144.2
HEAT REJECT	233.4	179.6	167.8
SPACE COOL	796.8	719.3	670.4
SPACE HEAT	272.6	367.3	445.8
MISC EQUIPMT	616.2	616.2	616.2
AREA LIGHTS	1290.0	1068.1	821.6

Figure 3: Total Annual Energy Use Using DOE-2's Quick Mode

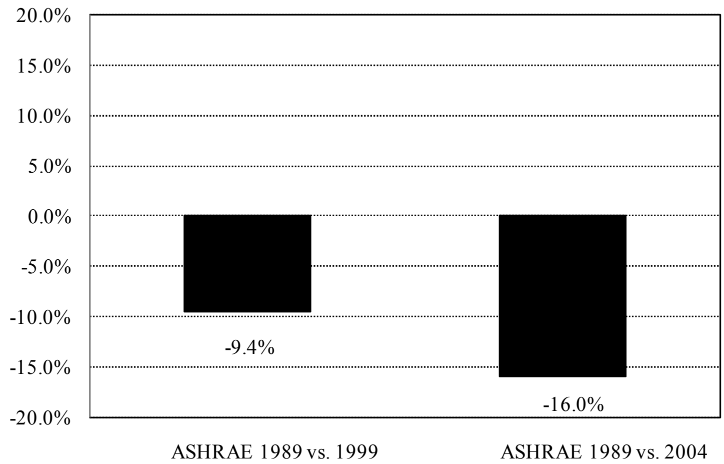
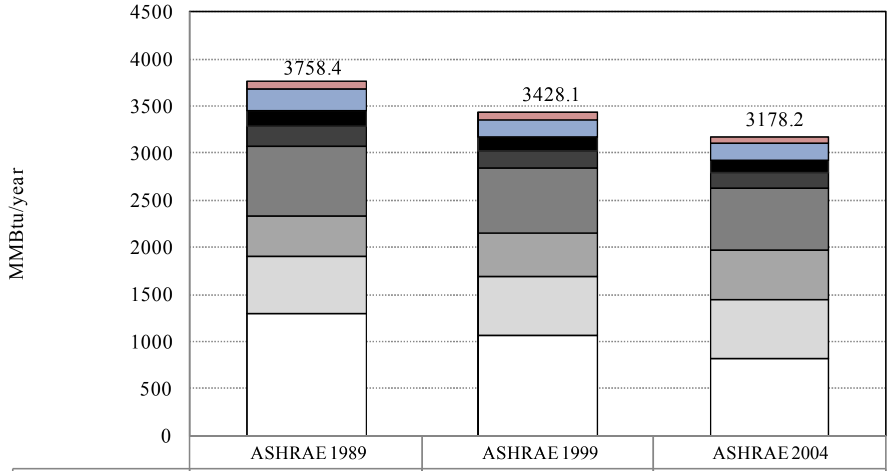


Figure 4: Change in Annual Total Energy Consumption from ASHRAE Standard 1989 to ASHRAE Standard 1999 and 2004 (Quick Mode)



	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 5: Total Annual Energy Use Using DOE-2's Delayed Mode (Custom Weighting Factors)

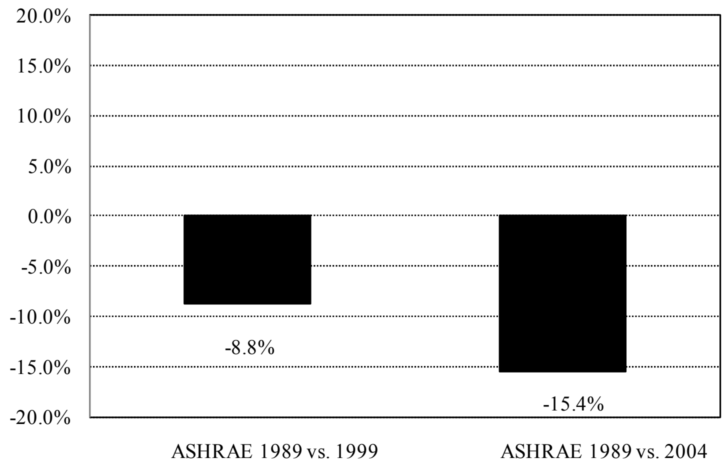


Figure 6: Change in Annual Total Energy Consumption From ASHRAE Standard 1989 to ASHRAE Standard 1999 and 2004 (Delayed Mode)

SUMMARY

This paper examines, in detail, the use of DOE-2 simulation models for code-complaint commercial construction simulation and provides a performance comparison for a 6-story building in Houston, Texas, based on ASHRAE Standard 90.1-1989, 1999 and 2004. Two different simulation methods (the quick mode and delayed mode) were used to perform the comparisons. ASHRAE Standard 90.1-1999 shows an average of 9.1% energy savings and ASHRAE Standard 90.1-2004 shows an average of 15.7% energy savings when compared to ASHRAE Standard 90.1-1989.

From the comparison between the quick mode and the delayed mode simulations, the quick mode simulation results showed more changes than the delayed mode simulations. It was found that the heating energy use of ASHRAE Standard 90.1-1999 and ASHRAE

Standard 90.1-2004 have been increased to 34.7% and 63.5%, respectively while the simulation results of the delayed mode show a 5.9% increase for ASHRAE Standard 90.1-1999 and a 23.3% increase for ASHRAE Standard 90.1-2004 from ASHRAE Standard 90.1-1989.

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