DEVELOPMENT OF A WEB-BASED EMISSIONS REDUCTION CALCULATOR FOR CODE-COMPLIANT COMMERCIAL CONSTRUCTION

Mushtaq Ahmad
Research Engineer

Don Gilman, P.E.
Senior Software Engineer

Seongchan Kim
Graduate Research Assistant

Chayapa Choncharoensuk
Graduate Research Assistant

Mini Malhotra
Graduate Research Asst.

Jeff Haberl, Ph.D., P.E.
Professor/Assc.Director

Charles Culp, Ph.D., P.E.
Assc.Professor/Assc.Director

Energy Systems Laboratory, Texas A&M University System

ABSTRACT

Four areas in Texas, involving 16 counties, have been designated by the United States Environmental Protection Agency (EPA) as non-attainment areas because ozone levels exceed the National Ambient Air Quality Standard (NAAQS) maximum allowable limits. These areas face severe sanctions if attainment is not reached by 2007. Four additional areas in the state are also approaching national ozone limits (i.e., affected areas).

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 by sources that are currently not regulated by the state. Ozone results from photochemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOCs) in the presence of sunlight. 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 International Energy Conservation Code (IECC IECC 2000), including the 2001 Supplement (IECC 2001) which represents one of the first times that the EPA is considering State Implementation Plan (SIP) credits from energy conservation and renewable energy– an important new development for building efficiency professionals, since this could pave the way for documented procedures for financial reimbursement for building energy conservation from the state's emissions reductions funding.

This paper provides a detailed description of the procedures that have been developed to calculate the electricity and natural gas savings in new office and retail construction that is built in compliance with Chapter 8 of the IECC 2000 Code[1]. For most parts the commercial portion of the IECC 2000 code (i.e., Chapter 8), refers to the ASHRAE 90.1-1999 as current code requirement for commercial construction. Included in the description is an explanation of the simulation models created for code-compliant and pre-code characteristics[2], which are used for calculating NOx emissions reductions for the electric utility provider associated with the user.

BACKGROUND

In 2001, the Texas State Legislature formulated and passed Senate Bill 5 to further reduce ozone levels by encouraging the reduction of emissions of NOx by sources that are currently not regulated by the state, including area sources (e.g., residential emissions), on-road mobile sources (e.g., all types of motor vehicles), and non-road mobile sources (e.g., aircraft, locomotives, etc.)[3]. An important part of this legislation is the evaluation of the State's new energy efficiency programs, which includes reductions in energy use and demand that are associated with specific utility-based energy conservation measures, and mandatory

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[1] Simulations for office and retail commercial construction were created first since they represent the largest two categories of commercial construction in the state. Additional simulation types are being developed for the largest energy using categories.

[2] The "pre-code" designation is meant to represent commercial construction characteristics that were in use before the passage of the Texas Emissions Reduction Plan, which became effective in September 2001. In the case of commercial construction, "pre-code" is meant to represent commercial construction that is compliant with ASHRAE Standard 90.1-1989.

[3] In the 2003 Texas State legislative session, the emissions reductions legislation in Senate Bill 5 was modified by House bill 3235, and House bill 1365. In general, this new legislation strengthens the previous legislation, and did not reduce the stringency of the building code or the reporting of the emissions reductions.

implementation of the International Energy Conservation Code (IECC), published in 2000 as amended by the 2001 Supplement (IECC 2000; 2001). In 2001 thirty-eight counties in Texas were designated by the EPA as either non-attainment or affected areas[4]. In 2003, three additional counties were classified as affected counties[5], bringing the total to forty-one counties (sixteen non-attainment and twenty-five affected counties). This paper provides a detailed discussion of the procedures and simulation tools that have been developed to calculate the electricity savings and NOx reductions from fuel-neutral[6], commercial construction in non-attainment and affected counties out of 254 counties in Texas.

METHODOLOGY

In order to quantify the reduction of NOx emissions by the implementation of ASHRAE 90.1-1999 (ASHRAE 1999) in new construction, simulation models were created for a general commercial configuration, which could be used both for office and retail end-uses. The simulation models were then modified to accommodate the different scenarios of construction and HVAC equipment typically used in the commercial sector. The simulation models, created with the DOE-2.1e simulation program (LBNL 1993a; 1993b), were then linked to a web-based graphic user interface and the US EPA's eGRID[7] to convert the energy savings to NOx emissions reduction.

Overview:

For commercial buildings, office or retail, a complete set of comparison includes three simulation runs[8]: 1) a Pre-code run based on the construction characteristics required by ASHRAE Standard 90.1-1989 (ASHRAE 1989)[9], 2) a Code run based on the minimum construction requirement of ASHRAE 90.1-1999 (ASHRAE 1999) and 3) the user input. The complete process flow is depicted in Figure 1.

The code characteristics for the office and retail are based on the minimum requirements according to climate zone. Examples of the envelope (i.e., opaque construction) and fenestration code requirements for ASHRAE Standard 90.1-1999 and ASHRAE Standard 90.1-1989 are given in Tables 1 and 2 respectively. The HVAC requirements are selected according to the end use, building size and building loads. Without simplification, in order to run a complete code and pre-code simulation, at least seven DOE-2 runs are required -- four for the code run and three for the pre-code run respectively.

The code and pre-code envelope and glazing characteristics[10] are assigned according to the county chosen by the user as shown in Figure 2. For example, if the user chooses Harris County,

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[4] The sixteen counties designated as non-attainment counties include: Brazoria, Chambers, Collin, Dallas, Denton, El Paso, Fort Bend, Hardin, Harris, Jefferson, Galveston, Liberty, Montgomery, Orange, Tarrant, and Waller counties. The twenty-two counties designated as affected counties include: Bastrop, Bexar, Caldwell, Comal, Ellis, Gregg, Guadalupe, Harrison, Hays, Johnson, Kaufman, Nueces, Parker, Rockwall, Rusk, San Patricio, Smith, Travis, Upshur, Victoria, Williamson, and Wilson County.

[5] These counties are Henderson, Hood and Hunt counties in the Dallas – Fort Worth area.

[6] The use of the term "fuel neutral" is used signify that several configurations were developed to represent the new construction in a given county. These construction types include: buildings with air conditioning, and electric heating (i.e., electric resistance of heat pumps), and buildings with air conditioning and natural gas-fired heating and service water heating systems.

[7] eGRID, is the EPA's Emissions and Generation Resource Integrated Database (Version 2). This publicly available database can be found at www.epa.gov/airmarkets/egrid/. The information in this table is from a special edition of the eGRID database, provided by Art Diem at the USEPA for the TCEQ for use with Senate Bill 5.

[8] Three simulations are needed for the assessment of emissions reductions because the EPA only allows the TCEQ to claim emissions reductions credits from those measures that were implemented after the September 2001 start date for the TERP. Therefore, the pre-code simulation is used to represent the average building characteristics of new commercial being built to the specifications reported by F.W. Dodge and ASHRAE Standard 90.1-1989. The code-compliant simulation represents a simulation of a building with specific characteristics made compliant with ASHRAE Standard 90.1-1989. The user input then represents the current building that the user intends to analyze. The comparison of the user's input to the pre-code shows the savings that would result from conditions that existed prior to September of 2001. The comparison of the user's input to the code-complaint simulation allows the user to see if their building is more efficient than a code-complaint building.

[9] The assumption to use ASHRAE Standard 90.1-1989 was based in part on conversations with engineers from several ASHRAE Chapters in Texas who confirmed that, prior to the legislation, most buildings were built to be compliant to ASHRAE Standard 90.1-1989. This is a conservative assumption since it assumes that buildings built before September 1st, 2001 were built to meet the requirements of Standard 90.1-1989. This assumption will be verified by site visits in future work.

[10] To calculate the compliance for a building in a specific county the calculator has to assume certain characteristics about the building that are compliant with 90.1-1989 and 90.1-1999. These characteristics include the budget building assumptions for the performance modeling and the prescriptive requirements for each county/climate zone.

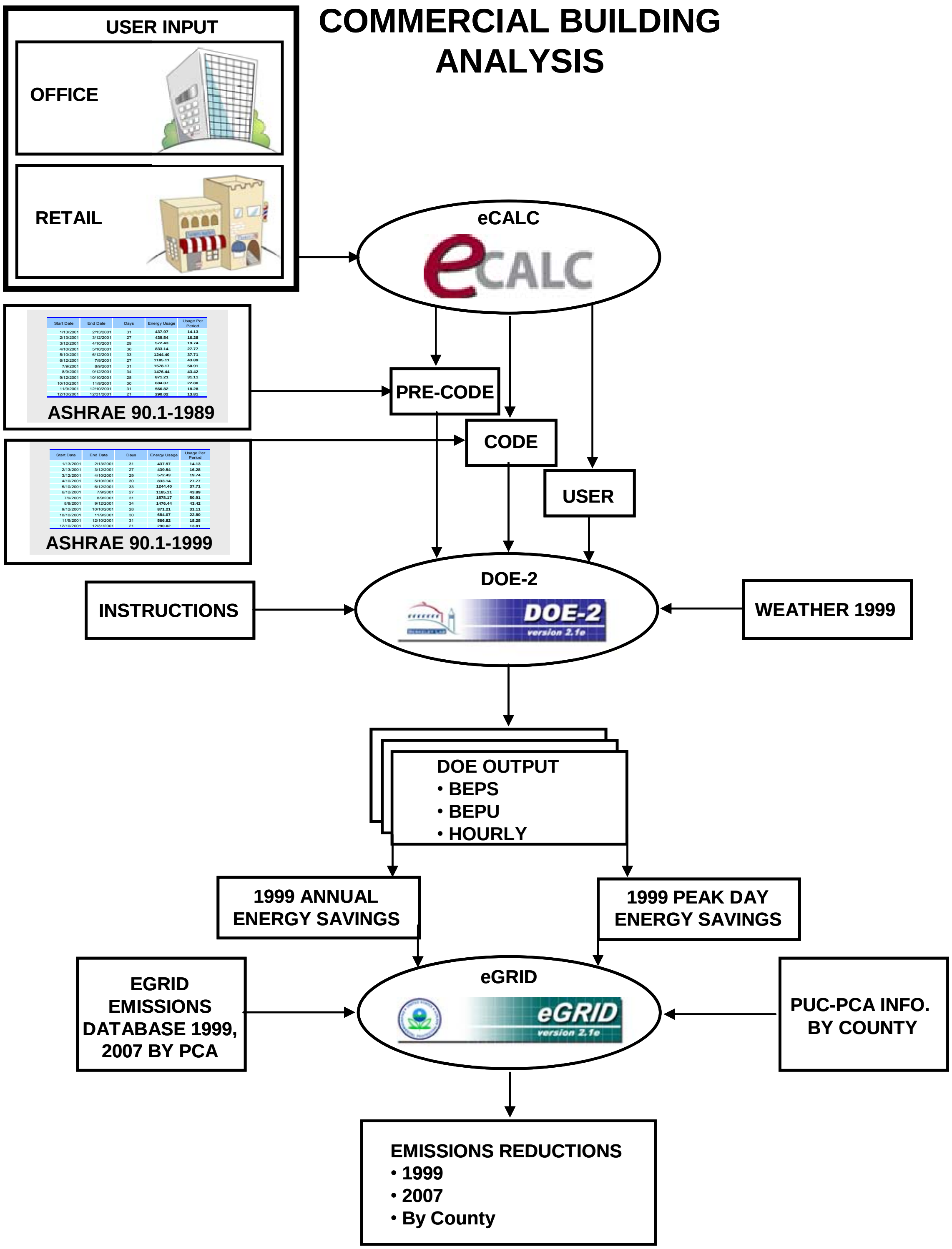

Figure 1: Office and Retail Analysis Flowchart

TABLE B-6
Building Envelope Requirements (HDD65: 901-1800, CDD50: 5401-7200)

Opaque Elements	Nonresidential Assembly Maximum	Nonresidential Insulation Min. R-Value	Residential Assembly Maximum	Residential Insulation Min. R-Value	Semiheated Assembly Maximum	Semiheated Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.063	R-15.0 ci	U-0.063	R-15.0 ci	U-0.218	R-3.8 ci
Metal Building	U-0.065	R-19.0	U-0.065	R-19.0	U-0.167	R-6.0
Attic and Other	U-0.034	R-30.0	U-0.034	R-30.0	U-0.081	R-13.0
Walls, Above Grade						
Mass	U-0.580	NR	U-0.151*	R-5.7 ci*	U-0.580	NR
Metal Building	U-0.113	R-13.0	U-0.113	R-13.0	U-0.184	R-6.0
Steel Framed	U-0.124	R-13.0	U-0.124	R-13.0	U-0.352	NR
Wood Framed and Other	U-0.089	R-13.0	U-0.089	R-13.0	U-0.292	NR
Wall, Below Grade						
Below Grade Wall	C-1.140	NR	C-1.140	NR	C-1.140	NR
Floors						
Mass	U-0.137	R-4.2 ci	U-0.107	R-6.3 ci	U-0.322	NR
Steel Joist	U-0.052	R-19.0	U-0.052	R-19.0	U-0.350	NR
Wood Framed and Other	U-0.051	R-19.0	U-0051	R-19.0	U-0.282	NR
Slab-On-Grade Floors						
Unheated	F-0.730	NR	F-0.730	NR	F-0.730	NR
Heated	F-1.020	R-7.5 for 12 in.	F-1.020	R-7.5 for 12 in.	F-1.020	R-7.5 for 12 in.
Opaque Doors						
Swinging	U-0.700		U-0.700		U-0.700	
Non-Swinging	U-1.450		U-1.450		U-1.450	
Fenestration	**Assembly Max. U (Fixed/ Operable)**	**Assembly Max. SHGC (All Orientations/ North-Oriented)**	**Assembly Max. U (Fixed/ Operable)**	**Assembly Max. SHGC (All Orientations/ North-Oriented)**	**Assembly Max. U (Fixed/ Operable)**	**Assembly Max. SHGC (All Orientations/ North-Oriented)**
Vertical Glazing,% of Wall						
0-10.0%	U_{fixed}-1.22	$SHGC_{all}$-0.39	U_{fixed}-1.22	$SHGC_{all}$-0.61	U_{fixed}-1.22	$SHGC_{all}$-NR
	U_{oper}-1.27	$SHGC_{north}$-0.61	U_{oper}-1.27	$SHGC_{north}$-0.61	U_{oper}-1.27	$SHGC_{north}$NR
10.1-20.0%	U_{fixed}-1.22	$SHGC_{all}$-0.25	U_{fixed}-1.22	$SHGC_{all}$-0.44	U_{fixed}-1.22	$SHGC_{all}$-NR
	U_{oper}-1.27	$SHGC_{north}$-0.61	U_{oper}-1.27	$SHGC_{north}$-0.61	U_{oper}-1.27	$SHGC_{north}$NR
20.1-30.0%	U_{fixed}-1.22	$SHGC_{all}$-0.25	U_{fixed}-1.22	$SHGC_{all}$-0.44	U_{fixed}-1.22	$SHGC_{all}$-NR
	U_{oper}-1.27	$SHGC_{north}$-0.61	U_{oper}-1.27	$SHGC_{north}$-0.61	U_{oper}-1.27	$SHGC_{north}$NR
30.1-40.0%	U_{fixed}-1.22	$SHGC_{all}$-0.25	U_{fixed}-1.22	$SHGC_{all}$-0.40	U_{fixed}-1.22	$SHGC_{all}$-NR
	U_{oper}-1.27	$SHGC_{north}$-0.61	U_{oper}-1.27	$SHGC_{north}$-0.61	U_{oper}-1.27	$SHGC_{north}$NR
40.1-50.0%	U_{fixed}-1.22	$SHGC_{all}$-0.17	U_{fixed}-1.22	$SHGC_{all}$-0.29	U_{fixed}-0.98	$SHGC_{all}$-NR
	U_{oper}-1.27	$SHGC_{north}$-0.42	U_{oper}-1.27	$SHGC_{north}$-0.41	U_{oper}-1.02	$SHGC_{north}$NR
Skylight with Curb, Glass,% of Roof						
0-2.0%	U_{all}-1.98	$SHGC_{all}$-0.39	U_{all}-1.98	$SHGC_{all}$-0.36	U_{all}-1.98	$SHGC_{all}$-NR
2.1-5.0%	U_{all}-1.98	$SHGC_{all}$-0.25	U_{all}-1.98	$SHGC_{all}$-0.19	U_{all}-1.98	$SHGC_{all}$-NR
Skylight with Curb, Plastic,% of Roof						
0-2.0%	U_{all}-1.90	$SHGC_{all}$-0.65	U_{all}-1.90	$SHGC_{all}$-0.27	U_{all}-1.90	$SHGC_{all}$-NR
2.1-5.0%	U_{all}-1.90	$SHGC_{all}$-0.39	U_{all}-1.90	$SHGC_{all}$-0.27	U_{all}-1.90	$SHGC_{all}$-NR
Skylight without Curb, All,% of Roof						
0-2.0%	U_{all}-1.36	$SHGC_{all}$-0.39	U_{all}-1.36	$SHGC_{all}$-0.36	U_{all}-1.36	$SHGC_{all}$-NR
2.1-5.0%	U_{all}-1.36	$SHGC_{all}$-0.25	U_{all}-1.36	$SHGC_{all}$-0.19	U_{all}-1.36	$SHGC_{all}$-NR

Table 1: Example (Table B-6) of code requirements from ASHRAE 90.1-1999

ALTERNATE COMPONENT PACKAGES FOR: TABLE NUMBER: 8A- 10

HDD50 =	1 - 1000	Baton Rouge LA	Jackson MS	Meridian MS	Port Arthur TX
CDD65 =	2001 - 3250	Charleston SC	Lake Charles LA	Mobile AL	Savannah GA
VSEW =	560 - 845	Columbia SC	Lufkin TX	Montgomery AL	Shreveport LA
HDD65 =	1 - 3000	Houston TX	Macon GA	New Orleans LA	

FENESTRATION (Max. Pct. Fenestr.)

INTERNAL LOAD DENSITY (ILD) RANGE	PROJECTION FACTOR (PF)	SHADING COEFF RANGE (SCx)	BASE CASE Uof 1.15 to 0.82	BASE CASE Uof 0.81 to 0	BASE CASE Uof N/A	PERIMETER DAYLIGHTING Uof 1.15 to 0.82	PERIMETER DAYLIGHTING Uof 0.81 to 0	PERIMETER DAYLIGHTING Uof 0.81 to 0 (VLT>=SC)
0 - 1.50	0.000 - 0.249	1.000 - 0.71	19	19		21	22	22
		0.709 - 0.60	23	24		26	27	27
		0.599 - 0.50	27	28		30	32	32
		0.499 - 0.38	32	34		36	38	38
		0.379 - 0.25	41	44		45	49	50
		0.249 - 0.00	59	66		63	72	73
	0.250 - 0.499	1.000 - 0.71	26	27		29	31	31
		0.709 - 0.60	32	34		36	38	38
		0.599 - 0.50	38	40		41	44	45
		0.499 - 0.38	44	47		48	53	54
		0.379 - 0.25	55	61		60	67	69
	0.500 +	1.000 - 0.71	34	36		38	40	41
		0.709 - 0.60	41	44		46	49	50
		0.599 - 0.50	48	52		52	58	59
		0.499 - 0.38	56	61		60	68	69
1.51 - 3.00	0.000 - 0.249	1.000 - 0.71	15	15		21	21	23
		0.708 - 0.60	18	18		26	27	28
		0.599 - 0.50	22	22		30	31	33
		0.499 - 0.38	26	27		36	38	40
		0.379 - 0.25	34	35		46	49	52
		0.249 - 0.00	49	53		65	72	76
	0.250 - 0.499	1.000 - 0.71	21	21		29	30	32
		0.709 - 0.60	26	26		36	38	40
		0.599 - 0.50	30	31		42	45	47
		0.499 - 0.38	36	37		49	53	56
		0.379 - 0.25	46	49		61	66	72
	0.500 +	1.000 - 0.71	27	28		38	40	42
		0.709 - 0.60	33	35		46	49	52
		0.599 - 0.50	39	41		53	58	61
		0.499 - 0.38	46	49		61	68	72
3.01 - 3.50	0.000 - 0.249	1.000 - 0.71	12	12		19	20	22
		0.709 - 0.60	15	15		24	25	27
		0.599 - 0.50	18	18		28	29	32
		0.499 - 0.38	22	22		33	35	38
		0.379 - 0.25	28	29		43	46	50
		0.249 - 0.00	42	45		61	68	73
	0.250 - 0.499	1.000 - 0.71	17	17		27	28	31
		0.709 - 0.60	21	22		33	35	38
		0.599 - 0.50	25	26		39	42	45
		0.499 - 0.38	30	31		46	50	54
		0.379 - 0.25	39	41		57	64	69
	0.500 +	1.000 - 0.71	23	23		36	37	41
		0.709 - 0.60	28	29		43	46	50
		0.599 - 0.50	33	34		50	54	59
		0.499 - 0.38	39	41		57	64	69

Daylight Sensing Controls

OPAQUE WALL (Max. Uow)

ILD RANGE	LIGHT WEIGHT WALL Uow (HC<5)	MASS WALL HC RANGE	PCT FEN	INT INS	EXT INS
0 - 1.50	0.15	HC >= 5	19	0.17	0.24
		HC >= 10	19	0.23	0.33
		HC >= 15	19	0.30	0.36
		HC >= 5	73	0.17	0.24
		HC >= 10	73	0.22	0.30
		HC >= 15	73	0.28	0.33
1.51 - 3.00	0.15	HC >= 5	15	0.17	0.24
		HC >= 10	15	0.24	0.36
		HC >= 15	15	0.34	0.39
		HC >= 5	76	0.17	0.24
		HC >= 10	76	0.23	0.33
		HC >= 15	76	0.30	0.36
3.01 - 3.50	0.15	HC >= 5	12	0.17	0.24
		HC >= 10	12	0.25	0.36
		HC >= 15	12	0.34	0.39
		HC >= 5	73	0.17	0.24
		HC >= 10	73	0.23	0.33
		HC >= 15	73	0.31	0.37

OTHER CRITERIA

Minimum R-Value					Max Uo
WALL BELOW GRADE:		0		ROOF:	0.066
UNHEATED SLAB ON GRADE:	24"	36"	48"	WALL ADJACENT TO UNCOND SPACE:	0.24
Horizontal	0	0	0	FLOOR OVER UNCOND. SPACE:	0.11
Vertical	0	0	0		

Table 2: Example (Table 8A) of pre-code requirements from ASHRAE 90.1-1989

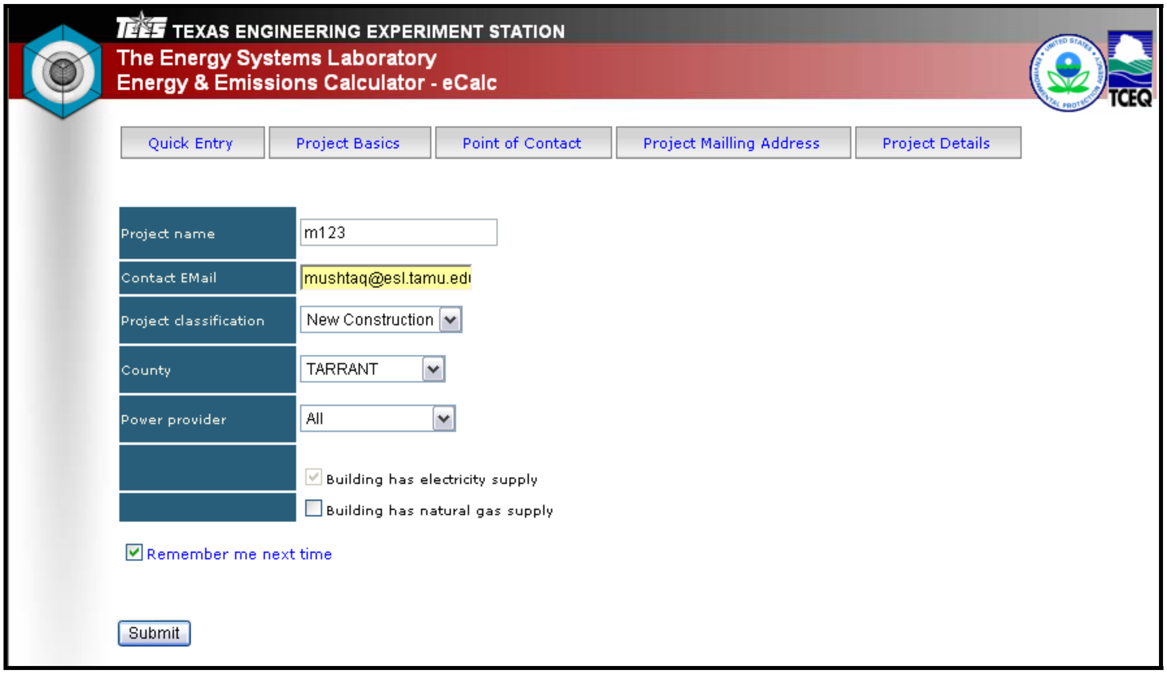

Figure 2: Input screen for county and PCA information

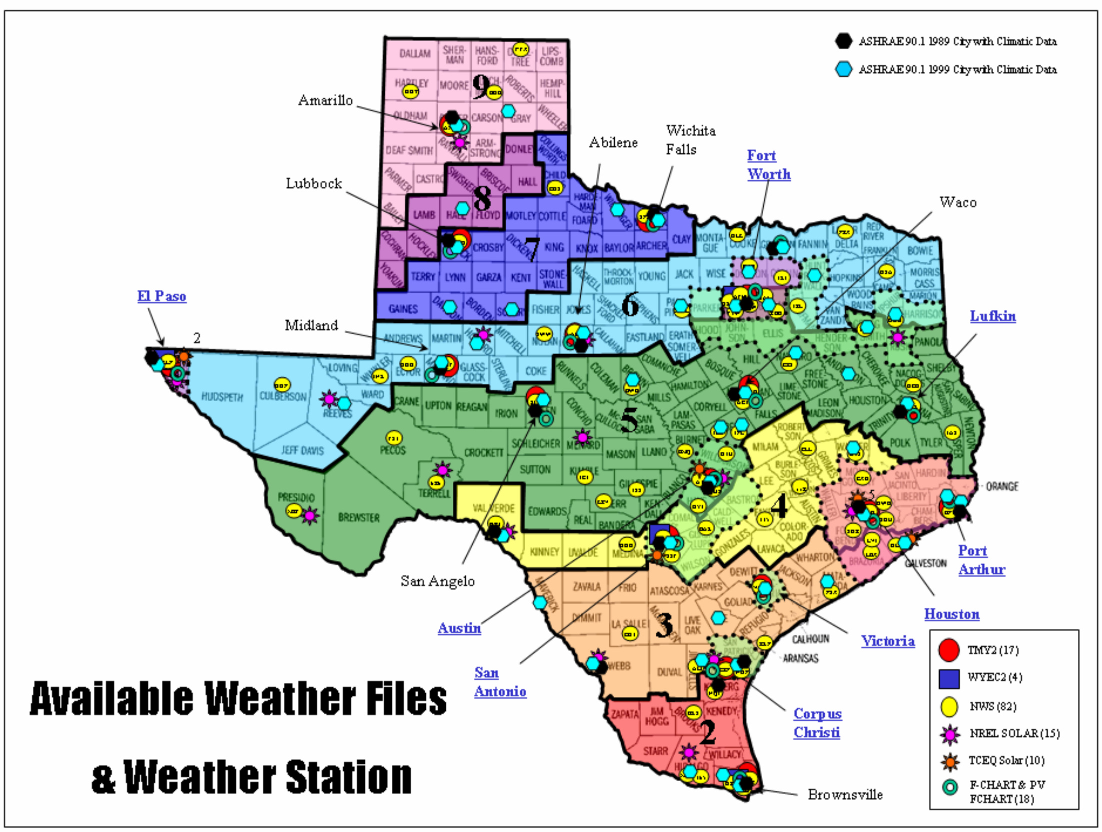

Figure 3: Available Weather Stations in Texas

then the pre-code and code characteristics would be as shown in Table 3. If the pre-code characteristics are more stringent than the code requirements then the pre-code characteristics are used to simulate the code-compliant building. In Table 3 (i.e., Harris County) it can be seen that the pre-code glazing U-factor is are more stringent than the code requirements, therefore, no savings are attributed to this characteristic since the pre-code value would be used in both the code and pre-code simulation.

Currently, the web-based emissions calculator uses measured weather data for 1999, from the National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), packed into the TRY weather format for nine stations in Texas, to perform the energy simulations for the 41 non-attainment and affected counties (Figure 2). Weather files are assigned according to the counties chosen by the user according to the nearest weather station. For Harris County, measured weather data from Houston's Bush Intercontinental Airport will be used.

The three sets of inputs are then processed through the DOE-2 simulation program to determine the energy consumption of the building. The values of interest from the DOE-2 output are the annual and peak day electricity and gas consumption in kWh and Therms respectively[11]. These values from the user input are then compared with the output from the pre-code and code runs to determine the annual and peak day energy consumption savings. The electricity saving values are then processed through the EPA's eGRID to calculate the annual and peak day NOx emissions reduction number in lbs and tons. Natural gas savings are converted into NOx emissions using the EPA's emissions factors[12].

Office/Retail Input File:

Table 4a and 4b describe the DOE-2 parameters that are required to generate the office simulation model. The parameters are divided into three major categories; loads, systems and plant[13]. The loads are then further divided into building, construction, space and shading parameters. The building parameters are used to define the location, orientation and the basic dimensions and layout of the building. Currently, the simulation model has the provision of only creating a 4-sided building model with up to one hundred stories with or without a basement. This portion of the input file also has the "building type" parameter which switches between the office and retail version of the inputs.

If a retail building is chosen then 4 additional parameters are activated, which allow the retail store to be placed within a larger conditioned space. The switch between quick and thermal mass mode is fixed at quick construction for the current version[14]. This means that the current DOE-2 simulation is using ASHRAE pre-calculated weighting factors for the calculation of a code-complaint building[15].

The construction parameters include the material properties and U-values for the different components including the glazing properties and the window-to-wall area ratio. The user has the provision of entering different window areas for the different orientations. The upper limit on the window-to-wall ratio depends on the plenum height (i.e., the plenum height is added to the building section to calculate the maximum window-to-wall area ratio for that building. The maximum upper limit is 90%.

With regards to internal load, Table 6.5, 13.2 and 13.4 of ASHRAE Standard 90.1-1989 describes the requirements for lighting, occupancy and receptacles according to the square footage and end-use. ASHRAE Standard

[11] The peak sizing calculations rely on the accuracy of the DOE-2 simulation. Although ASHRAE has developed more accurate methods for accomplishing this, it was appropriate to use the peak sizing algorithms in DOE-2 since much of the simulation work for Standard 90.1-1999 and 90.1-1989 was performed with the DOE-2 or BLAST programs. Newer versions of 90.1 will be using these newer peak load sizing methods, for example Radiant Time Series. In general the impact of equipment sizing was small when compared to other parameters, such as equipment efficiency, window loads, etc. Sizing does have an impact at the boundaries of Standard 90.1's equipment tables.

[12] EPA AP42 Project, published in 2003, www.epa.gov/ttn/chief/ap42/ap42supp.html.

[13] These categories were chosen to align the input with the DOE-2 BDL, which divides a building's description into LOADS, SYSTEMS and PLANT input files.

[14] The "quick" and "thermal mass" modes are used to denote the use of pre-calculated ASHRAE weighting factors (quick), or Custom Weighting Factors (thermal mass). Future versions of the calculator are being developed to utilize the thermal mass mode, which requires layered walls and roof, as well as other factors.

[15] The use of pre-calculated weighting factors has been shown to be problematic because of the impact of the thermal mass on the cooling and heating loads. For more information see the ESL's 2004 report to the TCEQ (Haberl et al. 2004 a, b, c).

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 (Requires Internal Load Density ILD)	1.15	0.61	23 (for ILD < 1.5)	0.15 (Light weight)	0.066
			18 (for 1.51< ILD < 3		
			15 (for ILD > 3)		
ASHRAE 90.1-1999 Table B-5 (Requires Window to Wall ratio %)	1.22	0.25	< 40%	0.124 (Steel framed)	0.063
	1.22	0.17	> 40%	0.089 (Wood framed)	

Table 3: Code and pre-code building characteristics for Harris County

90.1-1999 does not give requirements for occupancy and receptacles, but defines the lighting power density (LPD) requirements for different building types in Table 9.3.1.1. For example, Standard 90.1-1989 allows a LPD of 1.3 W/ft^2 and 1.9 W/ft^2 for office and retail respectively.

The system parameters include the type of systems, the system capacity and the efficiencies of the system selected. Currently the user can choose from three kinds of system: 1) a Variable Air Volume (VAV) system with a central HVAC plant, 2) a packaged variable air volume (PVAV) system, and 3) a packaged single zone (PSZ) system with either gas or electric heating. The DHW heater can be either gas or electric. If the DHW heater is gas then one pilot light is assumed at a fixed load of 500 Btu/hr.

System Simulation according to ASHRAE 90.1-1989:

As previously mentioned, for the code and pre-code runs, several simulations need to be performed in order to select the correct size and number of the HVAC equipment for both ASHRAE 90.1-1989 and 1999. Figure 4 shows the complete flow diagram of all the processes required to run an ASHRAE Standard 90.1-1989 performance-based simulation. Standard 90.1-1989 defines 7 system types according to the type of building and conditioned floor area (ASHRAE 90.1-1989, Table 13-5). For office and retail the system requirements are chosen according to the square footage (Table 5). Table 13-6 of ASHRAE Standard 90.1-1989 provides the requirements of the different system components. For buildings with a central plant the number and size of the chillers and boilers is determined by the simulated cooling and heating loads for the building (ASHRAE 90.1-1989, Table 13-6, Note 11). Equipment efficiencies are determined by the final size of each plant component. Therefore, in order to analyze an ASHRAE Standard 90.1-1989 code-compliant building with the DOE-2 simulation program, three simulations are run: 1) after choosing the system type from the building's conditioned area, the first simulation provides the peak heating and cooling load to allow for the number of selection of chillers, 2) after the type and size of chiller is chosen, a second simulation is performed to choose the efficiency of the chiller, and 3) a third and final simulation is performed with the chosen chiller, boiler and domestic water heater.

The following example illustrates the procedure used to calculate the pre-code run (i.e., a building that is assumed to be compliant with ASHRAE Standard 90.1-1989)[16]. In this analysis, an office building (122 ft x 122 ft, 6-stories in height) located in Houston, Texas, is used. To simulate a building that is compliant with ASHRAE Standard 90.1-1989, the building aspect ratio is first fixed at 2.5 is to 1, with the longer side oriented with an east-west axis, yielding an equivalent footprint of 192.89 x 77.16 ft. The envelope details for the building are according to the prescriptive requirements of Standard 90.1-1989 for Harris County (Table 2). In Standard 90.1-1989, the specific values in Table 2 are chosen according to the Internal

[16] The user can also perform parametrics, for example, varying the width and length of the building to see if there is a difference in energy use.

NAME	DESCRIPTION	DEFAULT	STATUS	COMMENT
LOADS				
b01	Quick or thermal mode (Q or T)	Quick (Q)	Fixed	Q simulates the building as massless, T will include thermal mass
b02	Location	Bastrop (BAS)	User Defined	41 counties linked to 9 TRY packed weather files according to climate zone
b03	Azimuth of building (degree)	0	User Defined	Orientation of the building
b04	Length of building (ft)	122	User Defined	
b05	Width of building (ft)	122	User Defined	
b06	Floor to ceiling height (ft)	9	User Defined	
b07	Door height (ft)	7	Fixed	
b08	Door width (ft)	6	Fixed	
b09	Run year	2000	User Defined	
b10	Floor to floor height (ft)	13	User Defined	This defines the plenum height in conjunction with b06
b11	Number of floor	6	User Defined	
b12	Perimeter depth (ft)	15	Fixed	Used for thermal zoning
b13	Void			
b14	Underground floor mode	No (N)	User Defined	This allows the user to activate/deactivate underground floors
b15	Front wall: Attached to another building?	No (N)	User Defined	These 4 parameters are used to attach buildings to the different orientations of the model for the retail scenario
b16	Right wall: Attached to another building?	No (N)	User Defined	
b17	Back wall: Attached to another building?	No (N)	User Defined	
b18	Left wall: Attached to another building?	No (N)	User Defined	
b19	Building type	Office (O)	User Defined	Allows the user to switch between Office and Retail
b20	Code compliance	Code (C)	User Defined	Allows user to run user defined model or either of ASHRAE 90.1 1989 or 1999
c01	Roof absorptance	0.45	User Defined	c01 and c03 are used to determine "roof color"
c02	Roof roughness	1	Fixed	This is used to calculate the outside film coefficient for heat transfer calculations, DOE-2 allows values from 1 to 6 increasing in smoothness
c03	Roof outside emissivity	0.89	User Defined	c01 and c03 are used to determine "roof color"
c04	Roof insulation R-value (hr-sq.ft-F/Btu)	R-15	User Defined	
c05	Wall absorptance	0.57	User Defined	c05 and c07 are used to define "wall color"
c06	Wall roughness	2	Fixed	This is used to calculate the outside film coefficient for heat transfer calculations, DOE-2 allows values from 1 to 6 increasing in smoothness
c07	Wall outside emissivity	0.9	User Defined	c05 and c07 are used to define "wall color"
c08	Wall insulation R-value (hr-sq.ft-F/Btu)	R-13	User Defined	
c09	Ground reflectance	0.24	Fixed	This defines the fraction of sunlight reflected from the ground
c10	Void			
c11	U-Factor of glazing (Btu/hr-sq.ft-F)	1.22	User Defined	
c12	Solar Heat Gain Coefficient(SHGC)	0.17	User Defined	
c13	Number of pane of glazing	1	Fixed	
c14	Frame absorptance of glazing	0.7	Fixed	
c15	Frame type - A,B,C,D,E	Aluminum w/o thermal break (A)	User Defined	Allows user to select from 5 different frame types
c16	Void			
c17	Floor weight (lb/sq-ft)	70	User Defined	This corresponds to medium construction, user has a choice of light, medium or heavy construction
c18	Slab-on-grade floor insulation R-value (Exterior insulation, horizontal) (hr-sq.ft-F/Btu)	R-0 (A)	User Defined	User can choose from 9 insulation R-values and insulation depths
c19	Slab-on-grade floor R-value (hr-sq.ft-F/Btu)	0.88	Fixed	
c20	Below-grade wall insulation R-value (hr-sq.ft-F/Btu) (Exterior insulation, vertical, basement wall = 8 ft)	R-0 (A)	User Defined	User can choose from 9 insulation R-values
c21	Below-grade wall R-value (concrete wall) (hr-sq.ft-F/Btu)	0.88	Fixed	
c22	Void			
c23	Floor R-value	1.67	Fixed	
c24	Void			
c25	Ceiling R-value (hr-sq.ft-F/Btu)	1.89	Fixed	
c26	Interior wall R-value (hr-sq.ft-F/Btu)	2.01	Fixed	
c27	Percent window-front (%)	50	User Defined	
c28	Percent window-right (%)	50	User Defined	
c29	Percent window-back (%)	50	User Defined	
c30	Percent window-left (%)	50	User Defined	
sp01	void			
sp02	void			
sp03	Area per person (ft^2/person) for office	275	User Defined	
sp04	Lighting load (W/ft2) for office	1.3	User Defined	
sp05	Equipment load (W/ft2) for office	0.75	User Defined	
sp06	Area per person (ft^2/person) for retail	300	User Defined	
sp07	Lighting load (W/ft2) for retail	1.9	User Defined	
sp08	Equipment load (W/ft2) for retail	0.25	User Defined	
s01	Front Shade (S)	0	User Defined	
s02	Back Shade (N)	0	User Defined	
s03	Left Shade (W)	0	User Defined	
s04	Right Shade (E)	0	User Defined	

Table 4a: Office/retail input parameters.

NAME	DESCRIPTION	DEFAULT	STATUS	COMMENT
SYSTEM				
sy01	Mode of system	Variable air volume (2)	User Defined	User can choose from Packaged single zone, variable air volume or packaged variable volume system
sy02	Cooling Capacity of cooling system (Btu/hr)	0	Fixed	DOE-2 is autosizing the system
sy03	Heating Capacity of heating system (Btu/hr)	0	Fixed	DOE-2 is autosizing the system
sy04	Seasonal Energy Efficiency Ratio (SEER) for PVAVS and PSZ	10	User Defined	
sy05	ANNUAL FUEL UTILIZATION EFFICIENCY (AFUE) for PSZ	0.8	User Defined	
sy06	**Spare parameter for systems other than VAVS**HEATING SEASONAL PERFORMANCE FACTOR (HSPF)	6.8	User Defined	Unused, since heatpump systems are not included in the office/retail scenario
sy07	**Spare parameter for Pilot light	0	Fixed	Unused
sy08	**Spare parameter for Pilot light	0	Fixed	Unused
sy09	**Spare parameter for Pilot light	0	Fixed	Unused
sy10	Void			
sy11	Exterior lighting (kW)	0	Fixed	
sy12	Void			
sy13	Fan control type	Variable frequency drives (1)	User Defined	User can choose from 4 different type of fan control
sy14	Economizer type	None (1)	User Defined	
sy15	Economizer drybulb limit (F) (use when economizer type(sy14) = dry bulb(2))	65	Fixed	This corresponds to the temperature above which the outside air dampers return to the minimum position
sy16	User input for numbers of fans	Autosized (A)	Fixed	Autosized by DOE-2
sy17	Number of Fans	6	Fixed	equal to the number of floors
sy18	Supply fan total pressure (in W.G)	5.5	Fixed	
sy19	Supply fan efficiency	0.54	Fixed	
sy20	Return fan total pressure (in W.G)	2	Fixed	
sy21	Return fan efficiency	0.51	Fixed	
sy22	Supply motor efficiency	0.5	Fixed	
sy23	Return motor efficiency	0.5	Fixed	
sy24	User input for DHW gallon/hr-person	Autosized (A)	Fixed	The size of DHW depends on the gallons per hour per person requirements of ASHRAE 90.1
sy25	Maximum DHW gallon/h-person (maximum hourly, to be used with occupancy schedule)	0.4	Fixed	
PLANT				
p01	Chiller type	Electric Centrifugal (1)	Fixed	
p02	Number of chillers	1	Fixed	
p03	Chillers size (MBtu/h)	-999	Fixed	Chiller is being autosized by DOE-2
p04	Condenser type	water-cooled (W)	Fixed	
p05	COP	5	User Defined	
p06	Switch for a chiller sizing	Autosized (A)	Fixed	Chiller is being autosized by DOE-2
p07	Cooling tower type	Open tower (O)		
p08	Void			
p09	Gpm/hp	38.2	Fixed	Value from ASHRAE 90.1 1999 for axial fan cooling towers
p10	Cooling tower capacity control	Two-speed fan (1)	Fixed	
p11	Boiler type	Gas fired-hotwater boiler (1)	User Defined	User can choose from gas fired or electric boilers
p12	Number of boilers	1	Fixed	
p13	Boiler size (MBtu/h)	-999	Fixed	Boiler is being autosized by DOE-2
p14	Boiler fuel type	Gas (G)	Fixed	Depends on the value of p10
p15	Boilers efficiency (Et,Ec,AFUE) (%)	80	User Defined	
p16	Switch for a boiler sizing	Autosized (A)	Fixed	Boiler is being autosized by DOE-2
p17	Void			
p18	DHW heater type	Gas water heater (1)	User Defined	User can choose from gas fired or electric water heaters
p19	Number of DHW heater	1	Fixed	
p20	DHW size (MBtu/h)	-999	Fixed	Water heater is being autosized by DOE-2
p21	DHW fuel type	Gas (G)	Fixed	Depends on the value of p18
p22	DHW heater Efficiency (Et,Ec,Energy factor) (%)	54	User Defined	
p23	Switch for a DHW heater sizing	Autosized (A)	Fixed	Water heater is being autosized by DOE-2
p24	DHW Storage Capacity (gal)	75	Fixed	

Table 4b: Office/retail input parameters.

Building Type	System
Office	
a) ≤ 20,000 ft^2	Packaged roof top single zone system
b) ≥ 20,000 ft^2 and either ≤ 3 floors or ≤ 75,000 ft^2	Packaged roof top VAV with perimeter reheat
c) > 3 floors or > 75,000 ft^2	Built-up central VAV with perimeter reheat
Retail	
a) ≤ 50,000 ft^2	Package roof top single zone **or** air-handler per zone with central plant
b) > 50,000 ft^2	Packaged roof top VAV with perimeter reheat **or** built-up central VAV with perimeter reheat

Table 5: System requirements according the total conditioned floor area for ASHRAE-90.1 1989

Load Density (ILD) which includes the occupancy, lighting and receptacle loads. For this building the ILD due to occupancy, lighting and receptacles was obtained from Table 13-2, Section 6 and Table 13-4 of Standard 90.1-1989, yielding an occupancy density of 275 ft^2 / person, the Lighting Power Density (LPD) is 1.57 W/ft^2 and receptacle loads are 0.75 W/ft^2. In Standard 90.1-1989 the resultant ILD density is then used to determine the window-to-wall area ratio (WWR) for the standard building that is used for the simulation. For this example an 18% window-to-wall area is calculated for the building.

Since the total square footage is more than 75,000 ft^2 and the number of floors exceeds 3, according to Table 5, the system should be a built-up VAV system with perimeter reheat. The remaining characteristics of the system, including fan control, static pressure rise and fan efficiencies are taken from Table 13-6 of Standard 90.1-1989. From 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 are set at 61% and 32%, respectively, which are the combined efficiencies for the motor and the fan including the variable frequency drives.

For the first run, the system is auto-sized by the DOE-2 simulation to meet the peak heating and cooling load requirements for the whole-building, including the envelope characteristics and interior loads defined by Table 2. From DOE-2's verification report (PV-A), from the plant portion of the DOE-2 simulation output, the number and type of chillers are determined. For this example, the chiller size comes out to be 1.806 MMBtu/hr which corresponds to 150.5 tons. According to ASHRAE Standard 90.1-1989 (Table 13-6, Note 11), for cooling loads less than 175 tons, a single reciprocating chiller should be used. Therefore, for the second simulation run, one reciprocating chiller is used and the simulation is used again to determine the size of the one chiller.

The results of the second run are then used to determine the efficiency of the chiller, size and efficiency of the boiler and DHW heater. For a reciprocating chiller between 150 and 300 tons, Standard 90.1-1989 requires that the COP is 4.2 (Table 10-7). The boiler size from the second run is 1,241,000 Btu/hr, which corresponds to an efficiency of 80% for boiler sizes > 300,000 Btu/hr (Table 10-8). For the gas-fired domestic water heater, if the rating is less than 75,000 Btu/hr, the energy factor is determined from the NAECA requirement (NAECA 1987): Energy Factor = 0.62 - 0.0019 x V, where V = storage capacity of the tank in gallons. For this example, the storage capacity of the domestic water heater is taken as 75 gallons[17], which yields an energy factor of 0.4775.

The efficiencies of the chiller, boiler and domestic water heater are entered into the DOE-2 simulation using the DOE-2 keywords: ELEC-INPUT-RATIO, HW-BOILER-HIR and DHW-HIR[18]. These values are then updated in the input file to complete the system selection process according to ASHRAE 90.1-1989. The annual energy consumption from this third run, which includes the correctly-sized systems according to ASHRAE Standard 90.1-1989, is then used to determine the pre-code energy use of the building.

The variations from the 1st to 3rd simulations of the Standard 90.1-1989 simulation, which include the change in the system sizing, type of equipment and equipment efficiency, can be seen

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

[18] Values for equipment quadratics use the appropriate values from the COMCHECK program 1.1, release 2.

from Figure 6(a). In this figure the cooling energy consumption in the second run reduces by approximately 25% compared to the first run. This reduction is from the change in the chiller type from centrifugal to reciprocating, and reflects the difference in efficiency factors. The third run shows an increase in cooling energy use of about 15% compared to the second run, which reflects a change in the default COP of 5, which is reset to the required COP of 4.2 for the chosen chiller. Heating equipment efficiency is changed in the third simulation to match the requirements of Standard 90.1-1989, which results in the heating consumption decreasing by approximately 10%. In the third run the domestic hot water consumption goes up by 20%, this is caused by the change in the domestic water heating efficiency, which is reset to the required 47.75% from the default of 75%.

System Simulation according to ASHRAE 90.1-1999:

As expected, the requirements for ASHRAE Standard 90.1-1999 are different from ASHRAE Standard 90.1-1989. The complete process flow for simulating Standard 90.1-1999 is shown in Figure 5. In difference to the Standard 90.1-1989, Standard 90.1-1999 does not specify the type of system according the to the total conditioned floor area of the building. 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 a similar fashion as Standard 90.1-1989, Standard 90.1-1999 chooses the number, type and efficiency of the chiller according to the peak building cooling load (Table 11.4.3A to 11.4.3C), with efficiencies determined by sequencing the runs for each plant component.

Using this approach, an ASHRAE Standard 90.1-1999 code-compliant simulation is completed in four simulations: 1) The first run determines the peak building cooling load that is used to determine the number of chillers and boilers, and the size and type of fans, 2) the second simulation then uses this information to determine the size of the chillers from which the type of chiller is chosen, 3) in the third run the number and type of chiller(s) are fixed and the size determined again by DOE-2 to allow for the efficiency to be determined, and 4) in the fourth run, the number, type, size and efficiency of the fans, chillers, boilers, and domestic water heating equipment are fixed, yielding the total annual energy use for all equipment complying with Standard 90.1-1999.

In difference to Standard 90.1-1989, the physical characteristics of the building are input as-is into the Standard 90.1-1999 simulation (i.e., 122 ft * 122 ft, 6-story building, oriented North-South) to perform the simulation, since Standard 90.1-1999 does not require a specific aspect ratio and orientation[19]. For this example, the window-to-wall ratio was assumed to be 18%, to allow for a more meaningful comparison to Standard 90.1-1989 for comparison purposes[20]. The envelope characteristics for the Standard 90.1-1999 simulation were taken from Table B-5 of the standard (Harris County). The internal gains from occupancy and equipment were the same as for the Standard 90.1-1989 run, while the lighting power density (LPD) is taken as 1.3 W/ft^2.

In Standard 90.1-1999 (Table 11.4.3.A, Note 4), when the proposed design system has a supply, return, or relief fan motor 25 hp or larger, the corresponding fan in 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 is required for the budget building model. Therefore, DOE-2's verification report "SV-A" is checked to determine the total fan power consumption of the fan. For this example, the total fan kW is 68.73 kW, from "SV-A", which is equivalent to 92 hp, thus allowing a VSD for variable air flow.

From this same simulation output, verification report "PV-A" is checked to determine the number of chillers and boilers required to meet the cooling and heating load. For the sample building simulation, the size of boiler is 1.166 MBtu/hr and the size of chiller is 1.346 MBtu/hr (=1.346 * 10^6 Btu/hr / 12,000 = 112.17 tons). Since the chiller capacity is less than 300 tons, according to Standard 90.1-1999 (Table 11.4.3.B), the number of chillers is set to "1". In determine the code-compliant boiler

[19] Standard 90.1-1999 requires that the budget building have the same orientation and aspect ratio as the proposed building, which was assumed to be a square building oriented so each façade faced N,S,E,W.

[20] Standard 90.1-1999 requires that the budget building have the same window-to-wall ratio as proposed building. Hence, if one were running one's building against 90.1-1989 and 90.1-1999, Standard 90.1-1989 would require the fixed aspect ratio of 2.5:1, and Standard 90.1-1999 would use the aspect ratio of the proposed building. In most cases, this fixed aspect ratio for the budget building makes Standard 90.1-1989 more stringent.

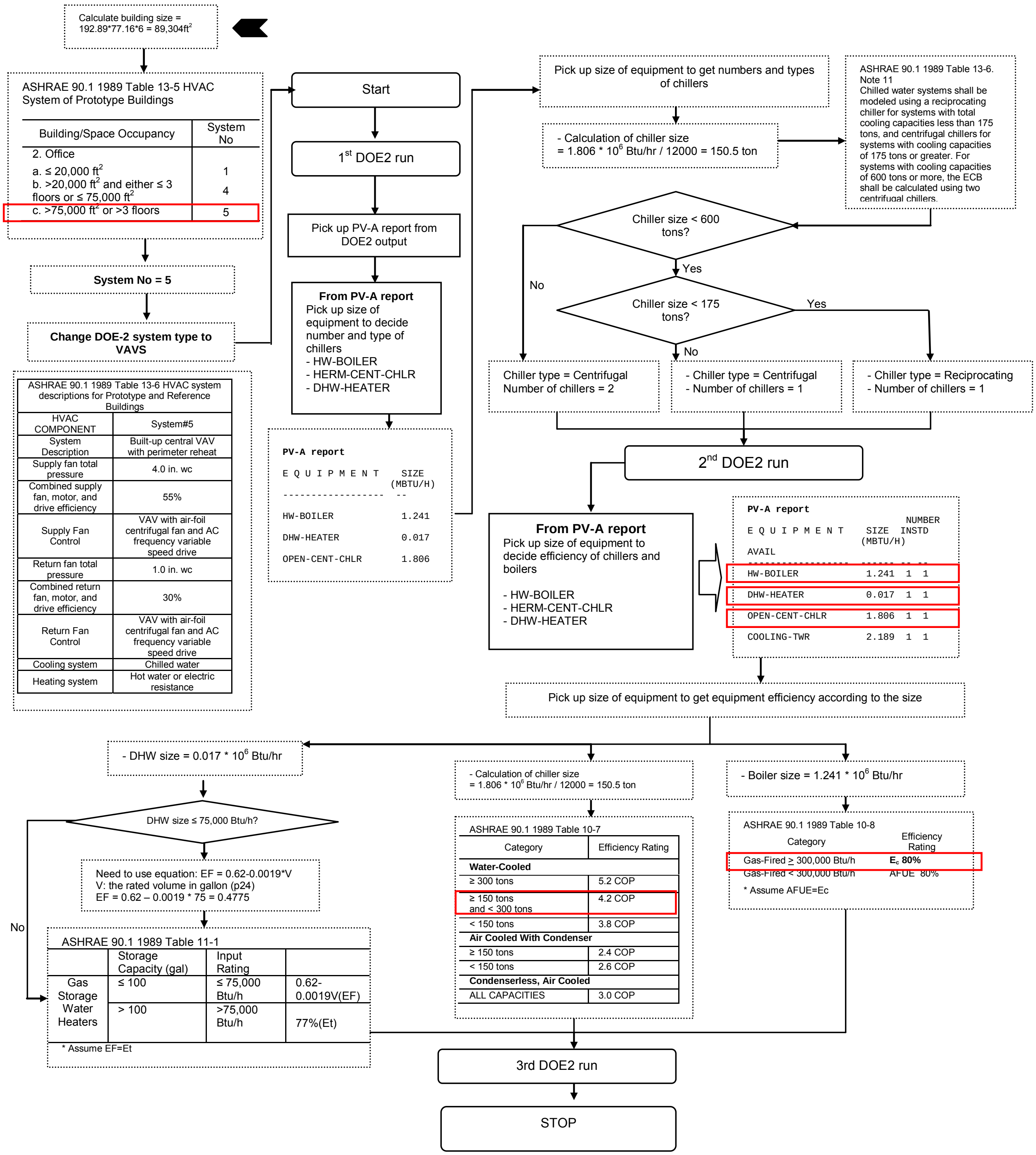

Figure 4: Flow chart of the procedure required to run an ASHRAE 90.1 1989 simulation

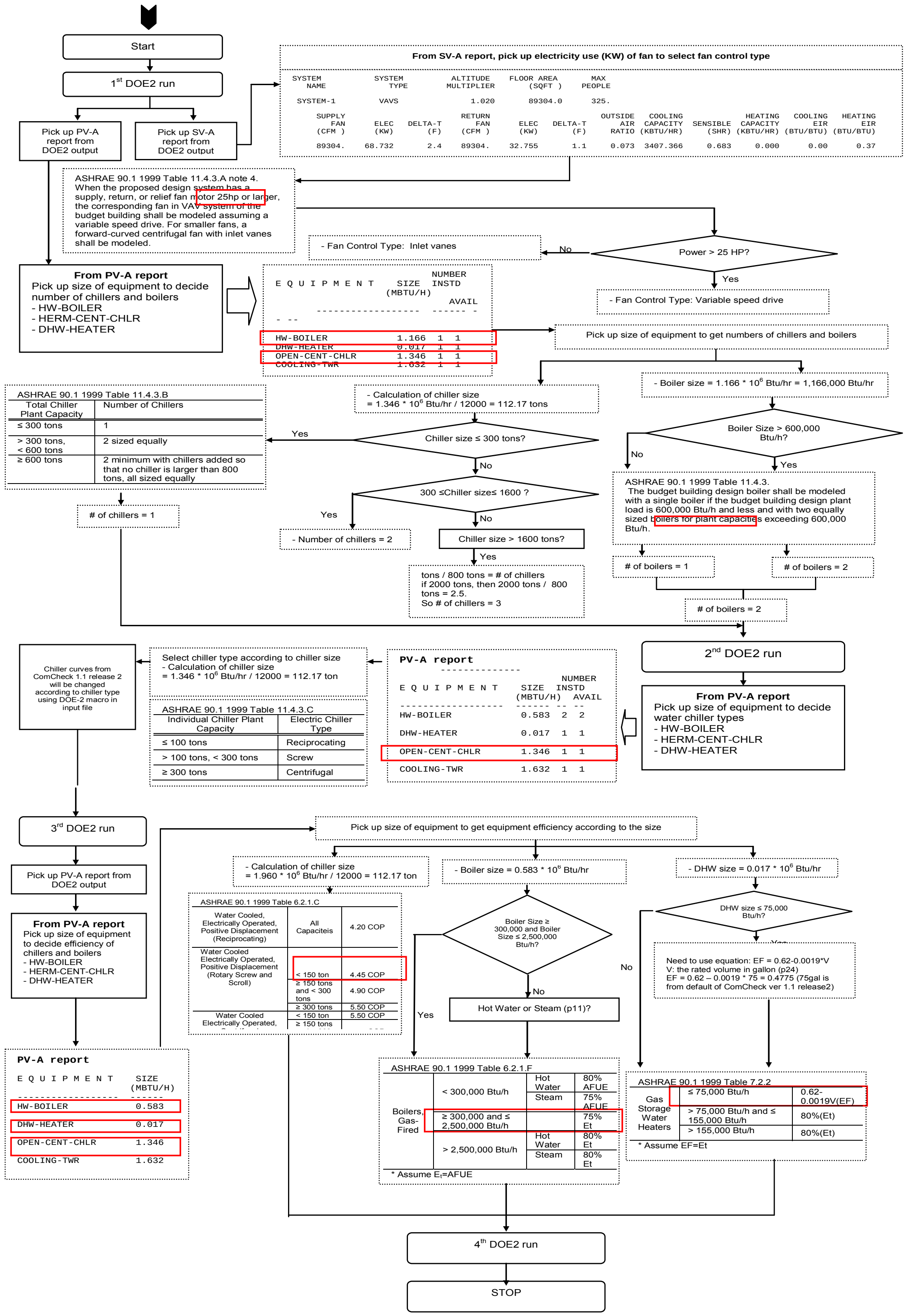

Figure 5: Flow chart of the procedure required to run an ASHRAE 90.1 1999 simulation

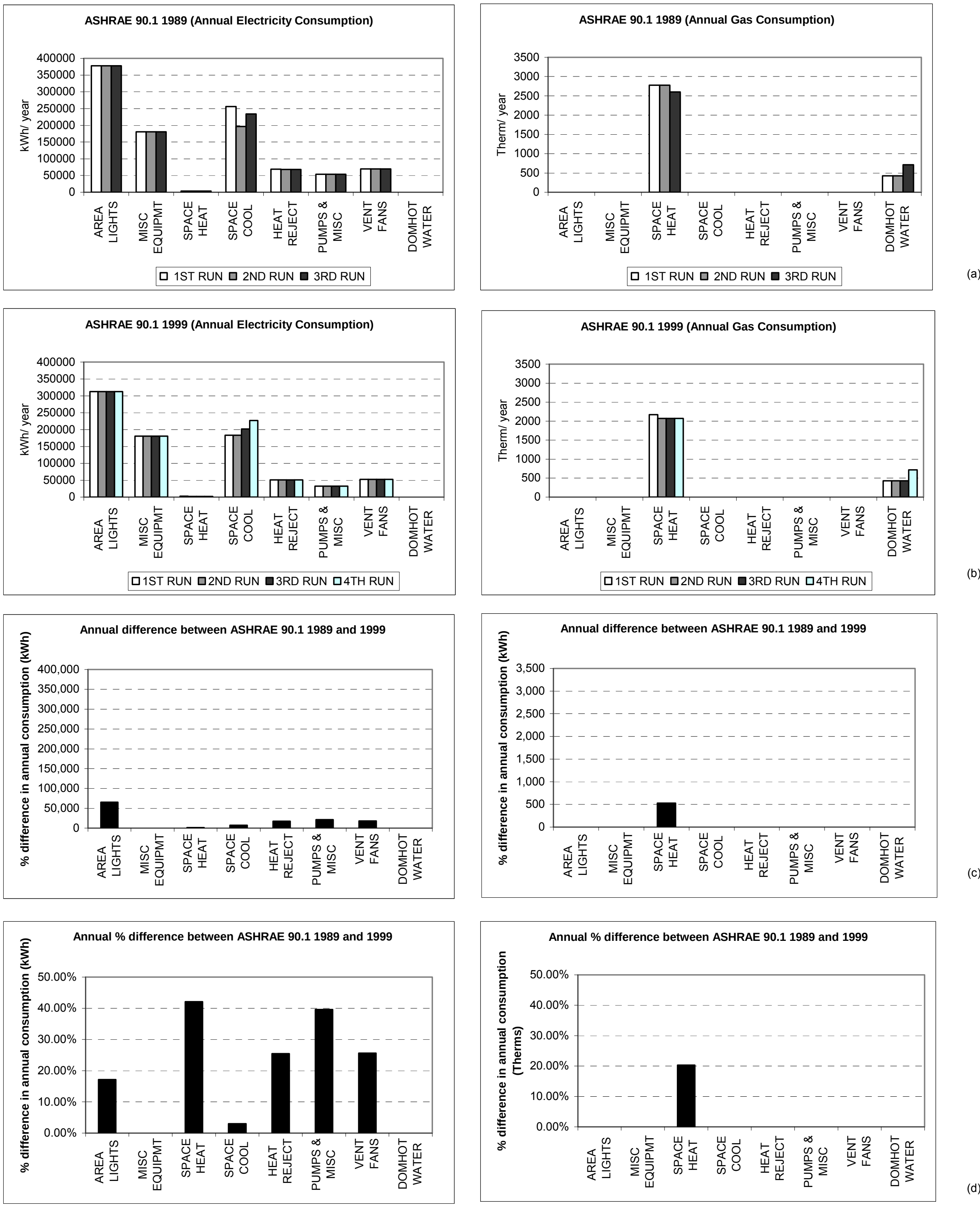

Figure 6(a,b,c,d): Comparison between ASHRAE 90.1 1989 and 1999.

characteristics, Standard 90.1-1999 (Table 11.4.3.A, Note 6) requires that the budget building design boiler shall be modeled with a single boiler if the budget building design plant load is 600,000 Btu/h or less, or with two equally-sized boilers for plant capacities exceeding 600,000 Btu/h. Since the size of boiler of sample building exceeds 600,000 Btu/hr, two boilers were chosen, with a final size of each boiler of 583,000 Btu/hr[21]. For the second simulation, the above adjustments are incorporated into the input file. From the "PV-A" report of second simulation output, the size of the cooling equipment is re-evaluated using the number of chillers from the first simulation. However, in this example, it remains the same because only one chiller is used for the simulation. Since the chiller size is between 100 and 300 tons, a screw-type chiller should be selected according to Standard 90.1-1999 (Table 11.4.3.C)[22].

In the third simulation the updated chiller type and performance curves are used to determine the size of the chiller. Boiler and domestic water heater sizes are also determined. From the "PV-A" report of the third simulation output, the chiller size is 1.346 MBtu/hr ($=1.346*10^6$ Btu/hr / 12,000 = 112.17 ton), the boiler size is 0.583 MBtu/hr, and the DHW-heater is 0.017 MBtu/hr. According to Standard 90.1-1999 (Table 6.2.1.C), if the chiller is a water-cooled, electrically operated, positive displacement machine (rotary screw and scroll) and the size is less than 150 tons, then the COP is determined to be 4.45. In the case of the boiler, from Standard 90.1-1999 (Table 6.2.1.F), the efficiency of the boiler is determined to be 75% if boiler size is between 300,000 Btu/hr and 2,500,000 Btu/hr. For the domestic water heater, the energy factor (EF)[23] is calculated using equation 1, which results in an EF = 0.4775.

In the fourth simulation the annual energy consumption reflects equipment that complies with Standard 90.1-1999. The variations in the system sizing, type of equipment and efficiencies for all four simulations can be seen in Figure 6(b). For the first two runs, there are no changes in the cooling energy consumption and the DHW consumption. However the heating energy use goes down by around 5%, due to the selection of two boilers in the third simulation, from the previous one boiler in the first two simulations, with the decrease energy use attributable to the part load operation of the one boiler.

In the third simulation, updating the chiller type and curves from centrifugal to screw, increases the energy consumption by 9%. The heating and DHW consumption remains the same. In the fourth simulation, use of the required efficiencies for the chiller, boiler, fans and DHW increases the cooling energy and DHW consumption. This is because in the case of chiller the default COP of 5 (used in the third simulation) is more efficient than the COP of 4.45 required by Standard 90.1-1999, and for the DHW, the default 75% efficiency used in the third simulation, is more efficient than the energy factor of 0.4775 required by Standard 90.1-1999.

Figures 6(c, d) and Figure 7 summarize the comparison between the annual energy performance of the example building, in Houston, constructed according to ASHRAE 90.1-1989 and 1999. Overall, the total annual energy use of ASHRAE Standard 90.1-1999 (3,207.81 MMBtu/year) is 13.4% less than the same building built to the specifications of ASHRAE Standard 90.1-1989 (3,705 MMBtu/year). The major portion of this (45% of the annual decrease, or a 17% reduction in the lighting load) is coming from the more stringent LPD criteria in ASHRAE Standard 90.1-1999 which limits the LPD to 1.3 W/ft^2. Another significant improvement is coming from the use of two smaller, staged boilers in the 1999 versus the one large boiler in 1989, which runs at lower

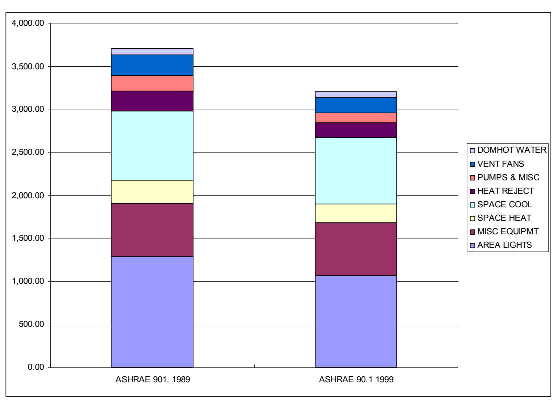

Figure 7: Comparison of Annual Energy Use (90.1-1989 vs 90.1-1999)

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[21] This is probably an unrealistic boiler size, since boilers are usually available in fixed sizes. Therefore, a more realistic simulation would have an index of actual boiler sizes to choose from.

[22] For this simulation the performance curves from the USDOE's COMCHECK program input file were used, Version 1.1, Release 2.

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

part-load levels for a larger portion of the year (12% of the total annual savings, or a 21% reduction in the heating energy use). The fans, cooling energy and cooling tower also show an improvement because of the lower heating/cooling loads and more stringent envelope and interior load requirements (i.e., the BEPS categories: heat rejection, pumps and misc., and vent fans, 39% of the total annual savings).

Using the web-based calculator.

Figures 8 and 9 show the main menu and the "Express Calc" page of the Energy System Laboratory's web-based calculator for a commercial building. The "Express Calc" option was created to simplify the use of the analysis, and only requires 14 inputs to complete an analysis of the user input, code-compliant and pre-code simulations. If the user has more detailed information about the project, the input screen can be switched to the detailed mode by pressing the tab at the bottom of the page. This detailed mode allows for more information to be entered by the user, such as shading, surface colors, and system characteristics. To complete the simulated comparison of the user input with ASHRAE 90.1-1989 and ASHRAE 90.1-1999, seven simulations are run, and the results emailed to the user. The resultant savings from the simulations are then processed by the EPA's eGRID program to calculate the annual and peak NOx emissions reductions at the power plants that provided the electricity to the building. Additional information about the emissions calculations can be found in Haberl et al. (2003a,b; 2004a,b,c).

SUMMARY

This paper explains in detail the commercial DOE-2 simulation models that are employed in the Energy Systems Laboratory's web-based emissions reduction calculator (ecalc.tamu.edu[24]) and provides an example performance comparison for a 6 story building in Houston, Texas, built to meet ASHRAE Standard 90.1-1989, or Standard 90.1-1999. These models are used to determine the annual and peak day energy savings attained by constructing code-complaint buildings for office and retail buildings[25]. These resultant savings from the simulations are then processed by the EPA's eGRID program to calculate the annual and peak NOx emissions reductions at the power plants that provided the electricity to the building.

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[24] To obtain copies of the DOE-2 input files, which include the .INC include files necessary for it to run, please contact the authors.

[25] Additional models are being developed for other commercial/institutional building types, such as schools, hotels, etc.

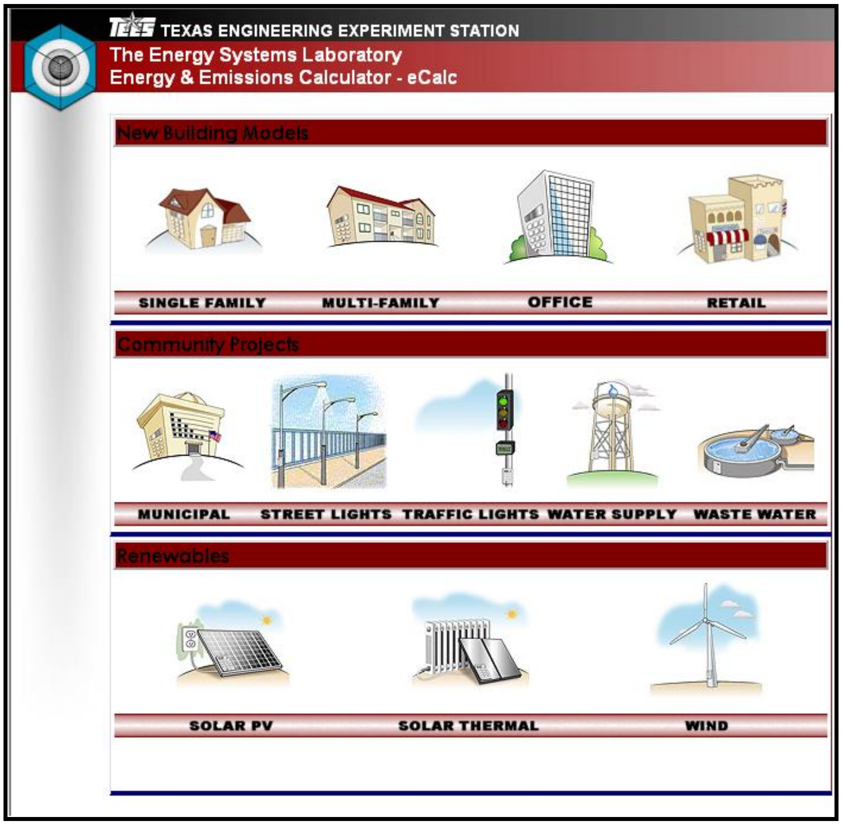

Figure 8: Main menu of the emissions calculator

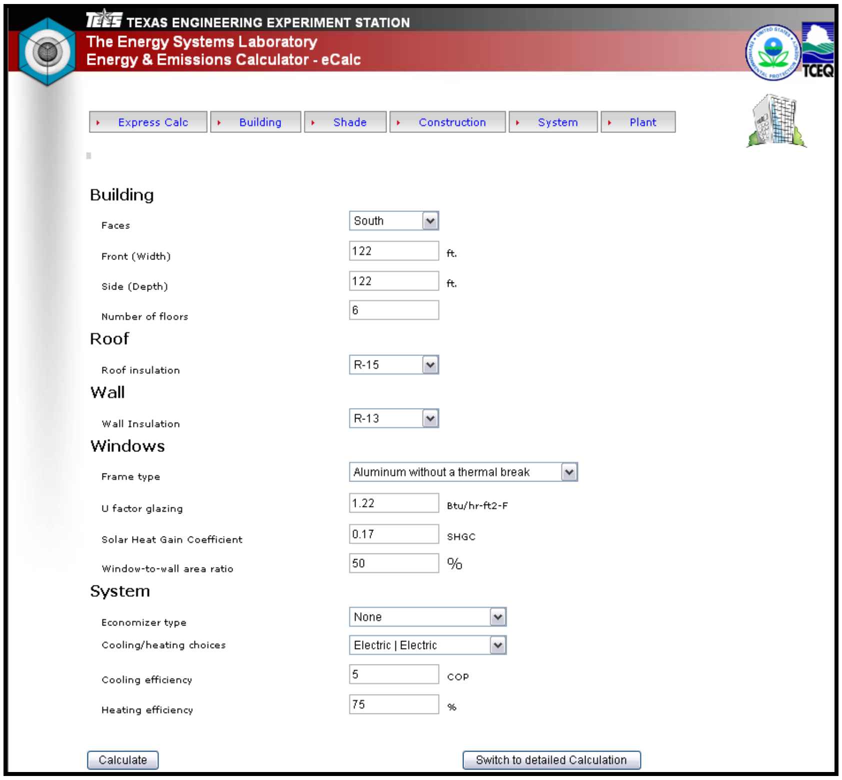

Figure 9: Office/retail input parameters screen

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