DEVELOPMENT OF A WEB-BASED EMISSIONS REDUCTION CALCULATOR FOR CODE-COMPLIANT SINGLE-FAMILY AND MULTI-FAMILY CONSTRUCTION

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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), 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 and used to calculate the electricity and gas savings in new single-family and multi-family construction that is built to meet the 2000 IECC Code. Included in the description is the explanation of the simulation model created for code-compliant and pre-code characteristics, 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 NO_x 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.)[1]. 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 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[2]. In 2003, three additional counties were classified as affected counties[3], bringing the total to forty-one counties (sixteen non-attainment and twenty-five affected counties) out of 254

[1] 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.

[2] 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.

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

counties in Texas. This paper provides a detailed discussion of the procedures and simulation tools that have been developed and used to calculate the electricity savings and NOx reductions from fuel-neutral[4], single-family and multi-family residential construction in non-attainment and affected counties.

METHODOLOGY

In order to quantify the reduction of NOx emissions by the implementation of 2000 IECC and 2001 Supplement in new construction, simulation models were created for both single-family and multi-family configuration. Each simulation model was then modified to accommodate the different scenarios of envelope construction and HVAC equipment typically used in residences. 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[5] to convert the energy savings to NOx emissions reduction. The DOE-2 residential simulation is unique among other web-based simulations[6], because it is code-compliant with the 2000 IECC and the 2001 Supplement, and it uses actual weather data from 1999, from the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service, for Texas, to allow for an analysis of the peak loads on the peak ozone days during the 1999 base year[7].

Overview:

For both single-family and multi-family house types, a complete set of comparisons includes three simulation runs; 1) a Pre-code run based on the construction characteristics published by the National Association of Home Builders (NAHB 2004) for 1999, 2) a Code-compliant run based on the minimum construction requirement of the 2000 IECC including the 2001 Supplement, and 3) a run using the user input[8]. The complete process flow is depicted in Figure 1. The pre-code NAHB characteristics are different for counties situated in east or west Texas for single-family construction, the main difference being the window-to-wall area ratio and the glazing characteristics. However, for multi-family residential the NAHB characteristics are same for all of Texas. The typical characteristics of single and multi-family residences according to NAHB 1999 are provided in Tables 1 and 2, which include significant differences in the reported window-to-wall areas for the east and west Texas single-family residences.

The 2000 IECC code characteristics for the single and multi-family residences are based on the minimum requirements according to climate zone. For a performance simulation, exterior wall and glazing U-factors are found in Tables 402.1.1(1) and 402.1.1(2) of the Chapter 4 of 2000 IECC and 2001 Supplement. The remaining envelope characteristics and minimum HVAC equipment efficiency requirements are acquired from the prescriptive tables in Chapter 5.

The code and pre-code characteristics for each run are assigned according to the climate zone that user's county (Figure 2) falls in as shown in Figure 3. For example, if the user chooses Harris County then the pre-code and

[4] The fuel-neutral analysis that was performed is described in detail in the ESL's 2004 report to the TCEQ. In this analysis several houses are used in the simulation to represent the different types of houses in one county. These houses include three types of HVAC systems: houses with an air conditioner, natural gas-fired furnace and DHW, houses with an air conditioner, a heat pump and electric resistance DHW, and houses with electric resistance heating and DHW. Housing configurations also include: one story, two story, slab on-on-grade and crawl spaces. Populations of the different housing types were determined with data from the NAHB builder's survey.

[5] 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.

[6] For example, LBNL's Home Energy Saver, EQuest, VisualDOE, etc.

[7] The ESL's calculator was extensively tested against ResCheck, and Home Energy Saver, with mixed results. Additional information concerning the comparison with ResCheck can be found in the Laboratory's 2004 report. Comparisons against Home Energy Saver were also performed. However, differences in input assumptions, degradation factors, internal loads, and numerous other input assumptions were found to be problematic.

[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 housing characteristics of new houses being built to the specifications reported by the NAHB. The code-compliant simulation represents a simulation of the same house with specific characteristics made compliant with the 2000 IECC as modified by the 2001 Supplement. The user input then represents the current house 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 house is more efficient than a code-complaint house.

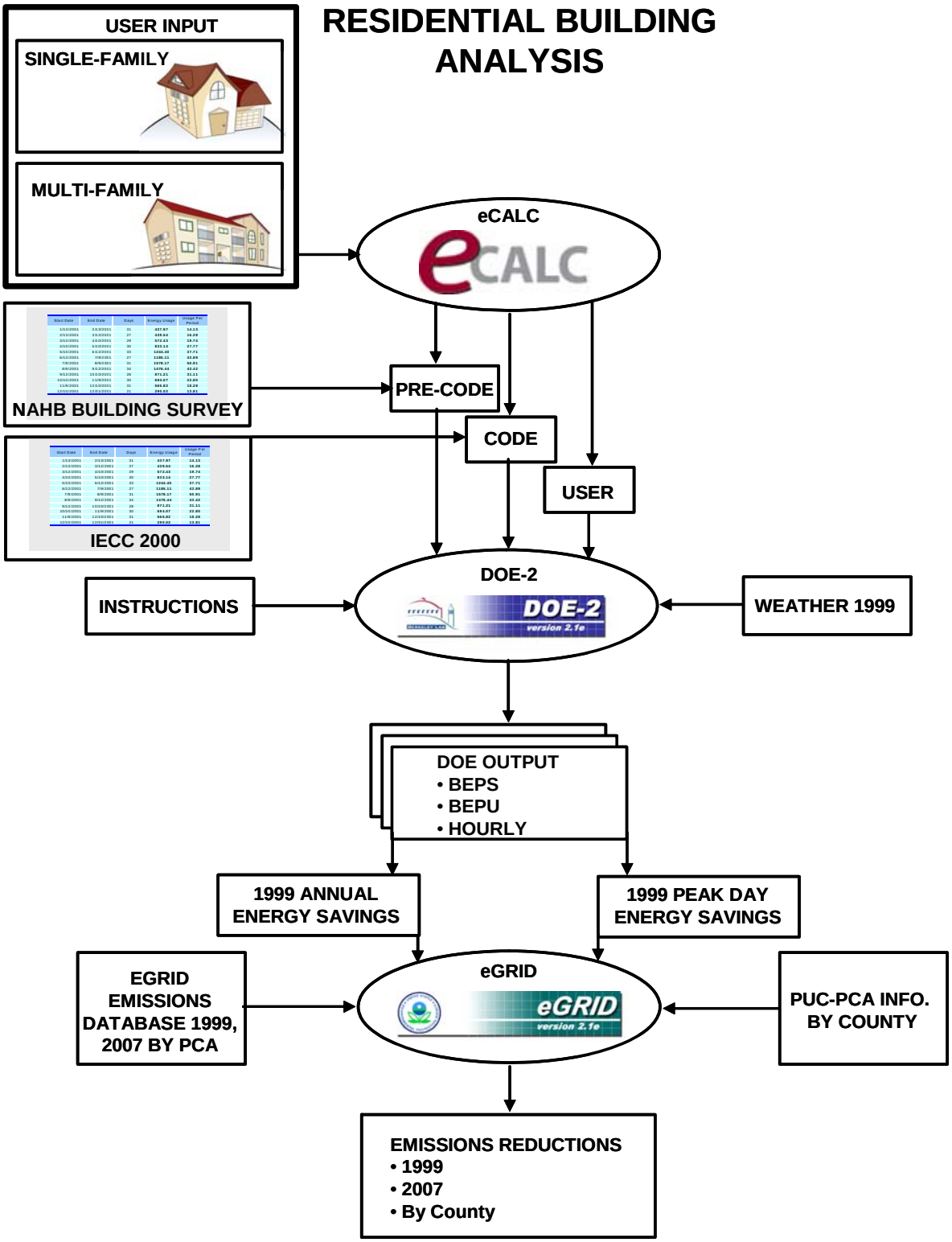

Figure 1: Single and Multi-family Analysis Flowchart

	Required Data	NAHB (East Texas)	NAHB (West Texas)
Year		1999	1999
Envelope	Floor Area (ft^2)	2,548	2,426
	Wall height(ft)	8.8	9.2
	Wall R-value	14 (Combined R)	14 (Combined R)
	Roof/Ceiling R-value	27	27
	Window area (%)	13.8% (16.4 units of windows)	20.6% (24.9 units of windows)
	Glazing U-factor	1.11	0.87
	SHGC	0.71	0.66
Building Mechanical Systems and Equipment	AFUE (Gas-fired or oil-fired furnace < 225,000 Btu/h)	80%	80%
	SEER (Air-cooled air conditioners and heat pumps cooling mode < 65,000	12	12

Table 1: NAHB residential characteristics for East and West Texas (Single-Family)

	Required Data	NAHB (West South Central)
Year		1999
Envelope	Floor Area (ft^2)	1,009
	Wall height(ft)	8.4 (1st floor) 8.3 (2nd floor)
	Wall R-value	21 (Combined R)
	Roof/Ceiling R-value	36
	Window area (%)	7.5%
	Glazing U-factor	0.75
	SHGC	0.61
Building Mechanical Systems and Equipment	AFUE (Gas-fired or oil-fired furnace < 225,000 Btu/h)	80%
	SEER (Air-cooled air conditioners and heat pumps cooling mode < 65,000	12

Table 2: NAHB residential characteristics for Texas (Multi-family)

County	**Building Characteristics**	**Glazing properties**		**Envelope properties**		**Minimum HVAC efficiencies**	
		U-factor	**SHGC**	**Wall U-value**	**Roof U-value**	**Cooling (SEER)**	**Heating (AFUE)**
Harris	**NAHB 1999**	1.11	0.71	14	27	12	80%
	IECC 2000/2001 Supplement	0.75	0.4	13	26	10	78%

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

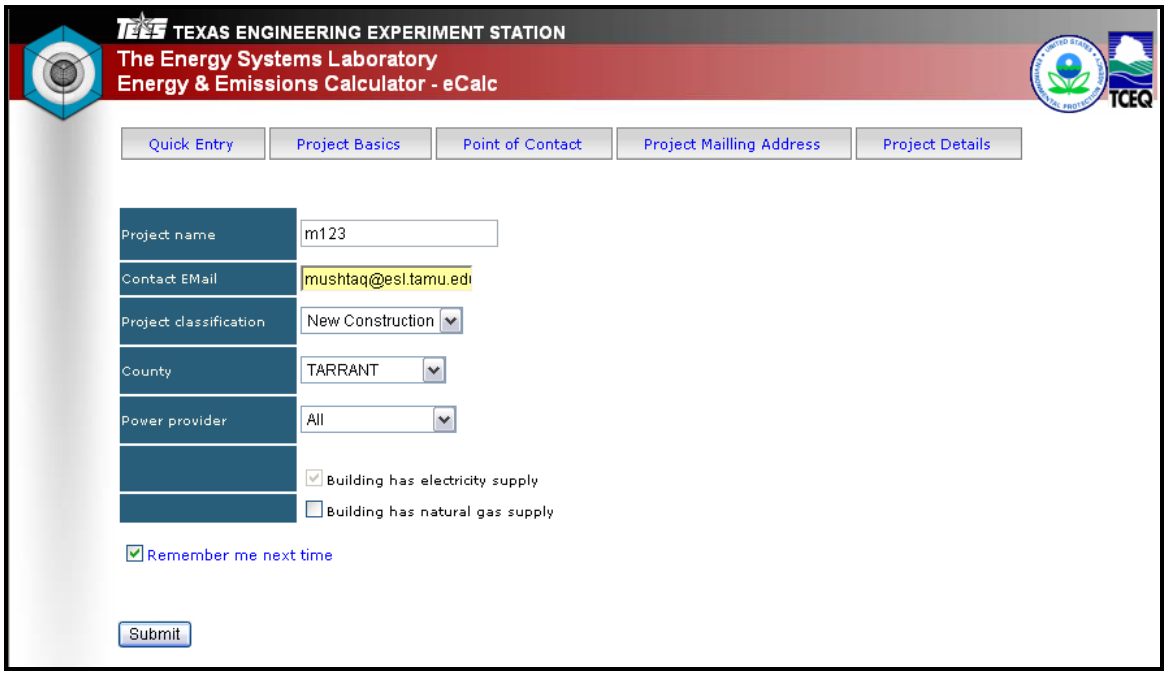

Figure 2: Multi-family input parameters screen

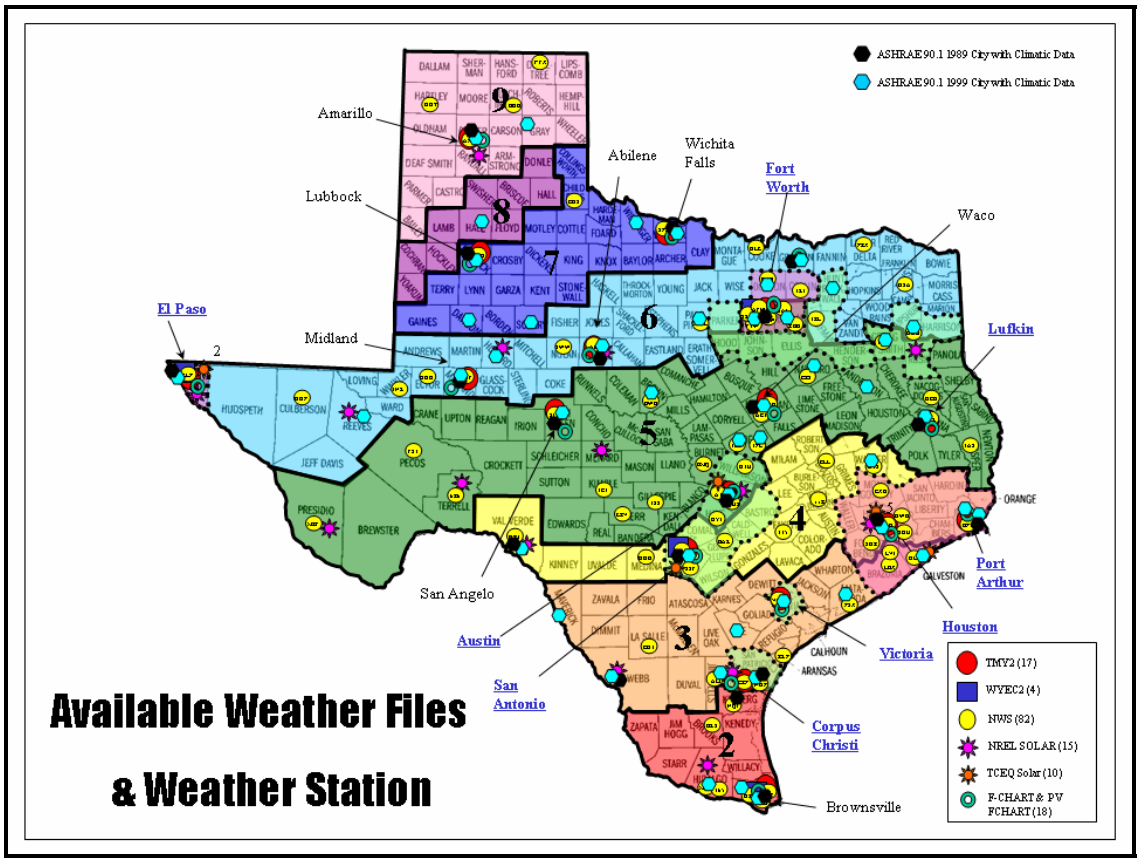

Figure 3: Available Weather Stations in Texas

code characteristics will be as shown in Table 3. If the pre-code characteristics, assigned to the county, are better than the code requirements then the pre-code numbers are used to simulate the code-compliant house. In Table 3 it can be seen that for Harris County only the 2000 IECC code glazing requirements are more stringent than the current characteristics[9].

Currently, the web-based emissions calculator[10] uses measured weather data for 1999 as the base year, which is packed into the TRY weather format for nine stations in Texas to perform the energy simulations. Figure 3 shows the available weather locations for Texas, which include TMY2 (17 stations), WYEC2 (4), NWS (82), NREL solar (15), TCEQ solar (10), and weather locations for FCHART and PVFCHART (18). Currently, weather files are assigned according to the counties chosen by the user. For Harris County, measured 1999 weather data from Houston's Bush Intercontinental Airport is used.

The three sets of inputs are then processed by DOE-2 to determine the energy consumption of the building. The values of interest from the DOE-2 output are the annual and peak day[11] electricity and gas consumption in kWh and therms, respectively. These results from the user's run are then compared with the results from the pre-code and code runs to determine the annual and peak day savings. These saving values are then further processed by eGRID to calculate the annual and peak day NOx emissions reduction number in lbs and tons of NOx for the power plant that supplied the electricity use[12].

Single-Family Input File:

Table 4 shows all the parameters used by the emissions calculator to generate a single-family simulation model. The parameters are divided into two major categories; loads and systems. 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.

The current simulation model has the provision of either one or two stories with a crawlspace or a slab on grade. The switch between quick (i.e., pre-calculated ASHRAE weighting factors) and thermal mass (i.e., DOE-2's custom weighting factors) mode is fixed at quick construction for the current version with the floor-weight equal to 11.5 lb/ft2, as required by Chapter 4 of the 2000 IECC[13].

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 option of changing the window areas for the different orientations. However for the code run, the window area will be fixed at 18% of conditioned floor area and is divided equally on the four cardinal directions, and by floors if needed. For the pre-code run, the total window area is either 13.8% or 20.6% of exterior wall area depending on the location of county in either east or west Texas, respectively.

For simulating residential buildings, according to 2000 IECC and 2001 Supplement, internal heat gains are fixed at 3,000 Btu/hr for a single-family dwelling, which limits the user's ability to change the lighting, occupancy and equipment gains. The space parameters are currently fixed at 2 occupants and 1 bedroom[14]. The number of bedrooms is used to calculate the daily domestic hot water consumption which in turn is used to size the domestic hot water heater according to section 420.1.3.7 of the 2000 IECC including the 2001 Supplement.

The system parameters include the type of systems, the system capacity and the efficiencies of the system selected. The user can choose from three kinds of systems; 1) gas heating, gas DHW and electric cooling, 2) electric heating, electric DHW and electric cooling, and 3) electric heat

[9] The input indicated in Figure 2 have been kept a simple as possible in order for builders and homeowners to use the calculator. The calculator also includes more detailed inputs for advanced users when the "switch to detail mode" button is selected. In the case of Figure 2 the user's email address is obtained so that the calculator can email the results back to the user. At the current time only the new construction mode is active. The option of the power provider allows the user to either use the existing utilities associated with their county, as provided by the Texas Public Utility Commission, or choose a different utility provider to see if there is a difference in emissions due to the choice of utility provider. The choice of natural gas and electric supplier (currently inactive) allows for the user to see the differences in emissions due to the choice of fuel type.

[10] The ESL's calculator can found at "http://ecalc.tamu.edu".

[11] For the 2004 analysis August 19th, 1999 was used as the peak day for the entire state of Texas.

[12] NOx emissions from natural gas use on-site are calculated with data from the EPA's AP-42 database.

[13] A future version will allow the user to change to the Custom Weighting Factor method, which is considered the most accurate DOE-2 simulation method.

[14] The future version of the code will allow the number of occupants and bedrooms to change automatically with the conditioned area.

PARAMETER NO:	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 (county name)	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	Width of building (ft)	50	User Defined	
b05	Depth of building (ft)	50	User Defined	
b06	Height of wall (ft)	8	User Defined	
b07	Door height (ft)	6.67	Fixed	Value from survey of manufactured doors
b08	Door width (ft)	3	Fixed	Value from survey of manufactured doors
b09	Run year	2000	User Defined	
b10	Option of second floor (1 or 2)	one floor (1)	User Defined	Controls activation/deactivation of one and two story portions of the BDL input
b11	Activation/ Deactivation of crawl (C or S)	Slab (S)	User Defined	Controls activation/deactivation of crawl space and slab on grade floor types for the residence
b12	Height of crawl space wall above ground(ft)	1.5	User Defined	
b13	Height of crawl space walll under ground(ft)	1	User Defined	
c01	Roof outside emissivity	0.89	User Defined	c01 and c02 are used to define "Roof color"
c02	Roof absorptance	0.45	User Defined	
c03	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
c04	Roof R-value (Hr-sq.ft-F/Btu)	R-26	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 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	Window option (S or D)	Same (S)	User Defined	Controls the input of same or different windows on individual orientation of the house
c11	U-Factor of glazing (Btu/hr-sq.ft-F)	0.75	User Defined	
c12	Solar Heat Gain Coefficient(SHGC)	0.4	User Defined	
c13	Number of panes of glazing	2	Fixed	
c14	Frame absorptance of glazing	0.7	Fixed	
c15	Frame type - A,B,C,D,E	Aluminium w/o thermal break (A)	User Defined	Allows user to select from 5 different frame types
c16		Void		
c17	Floor weight (lb/sq-ft)	11.5	Fixed	Value from IECC 2000
c18		Void		
c19	R-value of concrete slab (hr-sq.ft-F/Btu)	0.44	Fixed	
c20	Air film resistance (hr-sq.ft-F/Btu)	0.77	Fixed	
c21	Percentage of window area (%) for whole area or front side wall	15	User Defined	
c22	Percentage of window area (%) for back side wall	15	User Defined	
c23	Percentage of window area (%) for right side wall	15	User Defined	
c24	Percentage of window area (%) for left side wall	15	User Defined	
c25	Percentage of window area (%) for 2nd floor left side wall	15	User Defined	
c26	Floor R-Value (hr-sq.ft-F/Btu)	11	User Defined	
c27	Crawl space wall R-value (hr-sq.ft-F/Btu)	R-5 (F)	User Defined	Allows user to select from 13 different insulations
c28	Slab perimeter R-value and depth	R-0 (A)	User Defined	Allows user to select from 11 different insulation R-values and depths
sp01	Number of people	2	User Defined	
sp02	Number of bedroom	1	User Defined	
s01	Front eave shade (ft)	0	User Defined	
s02	Back eave shade (ft)	0	User Defined	
s03	Left eave shade (ft)	0	User Defined	
s04	Right eave shade (ft)	0	User Defined	
SYSTEM				
sy01	Mode of system: 1, 2, 3	Gas/Electric (1)	User Defined	Allows user to select all-electric, gas/electric or heatpump for HVAC
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)	10	User Defined	
sy05	ANNUAL FUEL UTILIZATION EFFICIENCY (AFUE)	0.8	User Defined	
sy06	HEATING SEASONAL PERFORMANCE FACTOR (HSPF)	6.8	User Defined	
sy07	The number of pilot lights of DHW	0	User Defined	
sy08	The number of pilot lights of Furnace	0	User Defined	
sy09	The number of pilot lights of others	0	User Defined	
sy10	Switch for Energy Factor for Domestic Hot Water consumption	Autosized (A)	User Defined	Allows user to input a DHW or let DOE-2 calculate the size and efficiency of the DHW
sy11	Energy Factor (%) for Domestic Hot Water	54	User Defined	Only applicable if the user chooses sy10 = S (EF is user defined)

Table 4. Single-Family input parameters

PARAMETER NO:	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	Width of unit (ft)	30	User Defined	
b05	Depth of unit (ft)	30	User Defined	
b06	Height of wall (ft)	8	User Defined	
b07	Door height (ft)	6.67	Fixed	Value from survey of manufactured doors
b08	Door width (ft)	3	Fixed	Value from survey of manufactured doors
b09	Run Period	2000	User Defined	
b10	Unit Configuration	1 floor 2 units (A)	User Defined	User can choose from 6 different configurations from 1 floor 2 units to 3 floors 12 units
b11	Activation/ Deactivation of crawl (C or S)	Slab (S)	Fixed	In Multifamily the crawl space is always deactivated
b12	Height of crawl space wall above ground(ft)	1.5	Fixed	Crawl space is deactivated
b13	Height of crawl space walll under ground(ft)	1	Fixed	Crawl space is deactivated
c01	Roof outside emissivity	0.89	User Defined	c01 and c02 are used to define "Roof color"
c02	Roof absorptance	0.45	User Defined	
c03	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
c04	Roof R-value (Hr-sq.ft-F/Btu)	R-19	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
c07	Wall outside emissivity	0.9	User Defined	c05 and c07 are used to define "wall color"
c08	Wall R-value (Hr-sq.ft-F/Btu)	R-11	User Defined	
c09	Ground reflectance	0.24	Fixed	This defines the fraction of sunlight reflected from the ground
c10	Window option (S or D)	Same (S)	User Defined	Controls the input of same or different windows on individual orientation of the house
c11	U-Factor of glazing (Btu/hr-sq.ft-F)	0.85	User Defined	
c12	Solar Heat Gain Coefficient(SHGC)	0.4	User Defined	
c13	Number of pane of glazing	2	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)	11.5	Fixed	Value from IECC 2000
c18	VOID			
c19	R-value of concrete slab (hr-sq.ft-F/Btu)	0.44	Fixed	
c20	Air film resistance (hr-sq.ft-F/Btu)	0.77	Fixed	
c21	Percentage of window area (%) for front side wall	20	User Defined	
c22	Percentage of window area (%) for back side wall	20	User Defined	
c23	Percentage of window area (%) for right side wall	20	User Defined	
c24	Percentage of window area (%) for left side wall	20	User Defined	
c25	Floor R-Value (hr-sq.ft-F/Btu)	11	User Defined	
c26	Crawl space wall R-value (hr-sq.ft-F/Btu)	R-5 (F)	Fixed	Crawl space is deactivated
c27	Slab perimeter R-value and depth	R-0 (A)	User Defined	Allows user to select from 11 different insulation R-values and depths
sp01	Number of people	2	User Defined	
sp02	Number of bedroom	1	User Defined	
s01	Front eave shade (ft)	0	User Defined	
s02	Back eave shade (ft)	0	User Defined	
s03	Left eave shade (ft)	0	User Defined	
s04	Right eave shade (ft)	0	User Defined	
SYSTEM				
sy01	Mode of system: 1, 2, 3	Gas/electric (1)	User Defined	Allows user to select all-electric, gas/electric or heatpump for HVAC
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)	10	User Defined	
sy05	ANNUAL FUEL UTILIZATION EFFICIENCY (AFUE)	0.8	User Defined	
sy06	HEATING SEASONAL PERFORMANCE FACTOR (HSPF)	6.8	User Defined	
sy07	The number of pilot lights of DHW	0	User Defined	
sy08	The number of pilot lights of Furnace	0	User Defined	
sy09	The number of pilot lights of others	0	User Defined	
sy10	Switch for Energy Factor for Domestic Hot Water consumption	Autosized (A)	User Defined	Allows user to input a DHW or let DOE-2 calculate the size and efficiency of the DHW
sy11	Energy Factor (%) for Domestic Hot Water	54	User Defined	Only applicable if the user chooses sy10 = S (EF is user defined)

Table 5. Multi-family input parameters

pump heating, electric DHW and electric cooling. For the pre-code configuration, one pilot light is being assumed for the DHW if gas is being used[15]. Currently, the heating and cooling system is auto-sized by DOE-2 according to the loads entered in DOE-2's LOADS sub-program. The user can define the system efficiencies according to the system type that is selected. For the code and pre-code runs the efficiencies will be according to the values in Table 3.

Multi-family Input File:

Table 5 describes the parameters that are required to generate the multi-family simulation models. The current multi-family model can be simulated with one, two or three stories and from 2 to 12 units[16]. The multi-family version has only a fixed slab on grade. In a similar fashion as the single-family simulations, the switch between quick and thermal mass mode is also fixed at quick construction for the current version.

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 putting in different window areas for the different orientations. However for the code run, the window area is fixed at 18% of conditioned floor area and is divided equally on the four cardinal directions. For the pre-code run, the total window area is fixed at 7.5% of the total exterior wall area per living unit[17].

For simulating multi-family residential buildings, according to 2000 IECC and 2001 Supplement, the internal heat gains are fixed at 1,500 Btu/hr, which is also fixed. The space parameters are fixed currently at 2 occupants and 1 bedroom per living unit. In a similar fashion as the single-family simulation, the number of bedrooms is used to calculate the daily domestic hot water consumption, which in turn is used to size the domestic hot water heater according to Section 420.1.3.7 of 2000 IECC and 2001 Supplement.

The system parameters include the type of systems, the system capacity and the efficiencies of the system selected. In a similar fashion as the single-family residential, the user can choose from: 1) gas heating, gas DHW and electric cooling, 2) electric heating, electric DHW and electric cooling, and 3) electric heat pump heating, electric DHW and electric cooling. Multi-family pilot lights are treated the same as single-family DHW, and in a similar fashion as the single family residential, heating and cooling systems are auto-sized by DOE-2. Code and pre-code efficiencies are shown in Table 3.

Running the web-based simulation:

Figure 4 shows the main menu of the web-interface. In addition to single and multi-family, simulation models for analyzing commercial buildings, lighting retrofits, water-waste water management, solar applications and wind energy are also available. For single and multi-family, the first input screens are shown in Figures 5 and 6, which show the "Express Calc" or quick input version of the simulation model that only requires 12 inputs to complete the comparison analysis of the user input with code compliant and pre-code characteristics. If the user has more detailed information[18] about the project, the web calculation can be switched to detailed mode by the tab at the bottom right of Figures 5 and 6.

Table 6 summarizes the results from the simulations conducted for Harris County for the single-family[19] and multi-family[20] residences, crawl space or slab-on-grade, with the different fuel options, and building layout (i.e., 1 story or 2 story). In order to run a complete set of fuel-neutral simulations for all NAHB options, 12 simulations are needed for single-family and 9 simulations are needed for multi-family for both code and pre-code configurations.

As discussed earlier, the major difference between the pre-code and code characteristics is in the window properties. Figure 7 and 8 graphically summarize the annual energy

[15] The energy use of this pilot light is fixed at 500 Btu/hr.

[16] This is accomplished with a switching scheme inside the DOE-2 input file, which turns on/off units and floors according to the user's choice. The choices are 2 units/2 story, 3 units/3 story, 4 units/2 story, 4 units/1 story, 8 units/2 story, 6 units/3 story, 8 units/2 story, 9 units/3 story, and 12 units/3 story. An analysis of these different configurations yielded small differences in the energy use, mostly due to window area, window placement, and apartment configuration. A maximum of 3 stories was chosen since this is the limit of the 2000 IECC definition of multifamily. Information and graphics displaying the models can be seen in the ESL's 2004 Annual report to the TCEQ.

[17] This 7.5% is the window area from the NAHB survey of homebuilders in Texas.

[18] In Figure 5 and 6 since the system selected is all electric, the user is not provided with an option for the efficiency of the electric resistance heating. The cooling system efficiency is listed as "code + 0%" versus SEER to avoid confusion.

[19] The single family example is a single story residence, 2,500 ft2, slab on grade construction with a 15% window to wall ratio on all orientations.

[20] The multi-family example is a two story complex with two 900 ft2 units, slab on grade construction with a 20% window to wall ratio on all orientations.

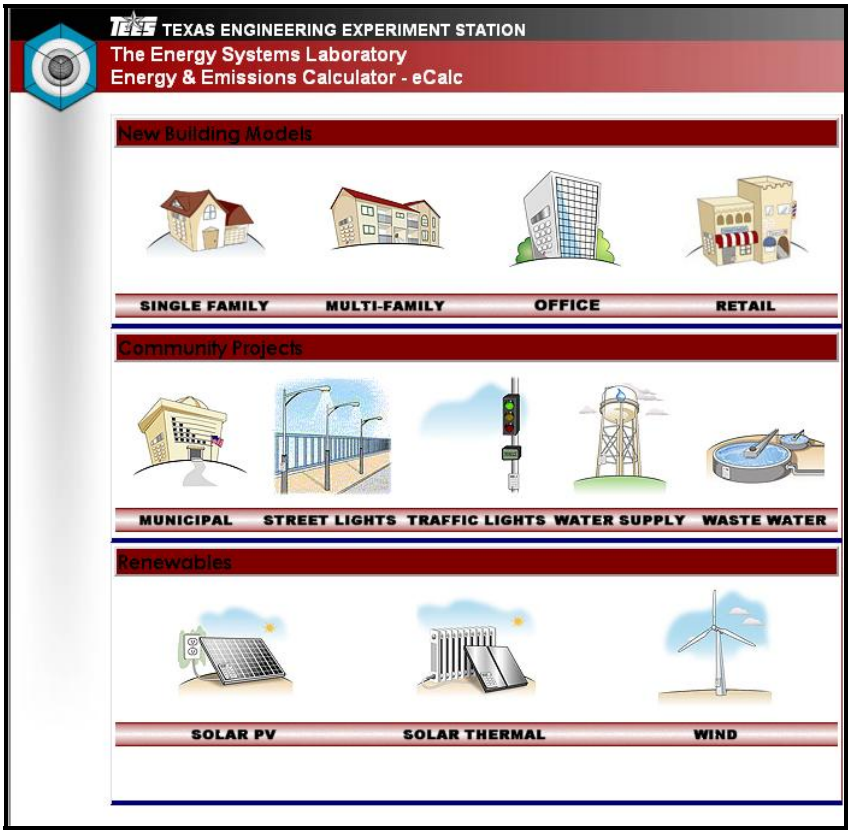

Figure 4: Main menu of the emissions calculator

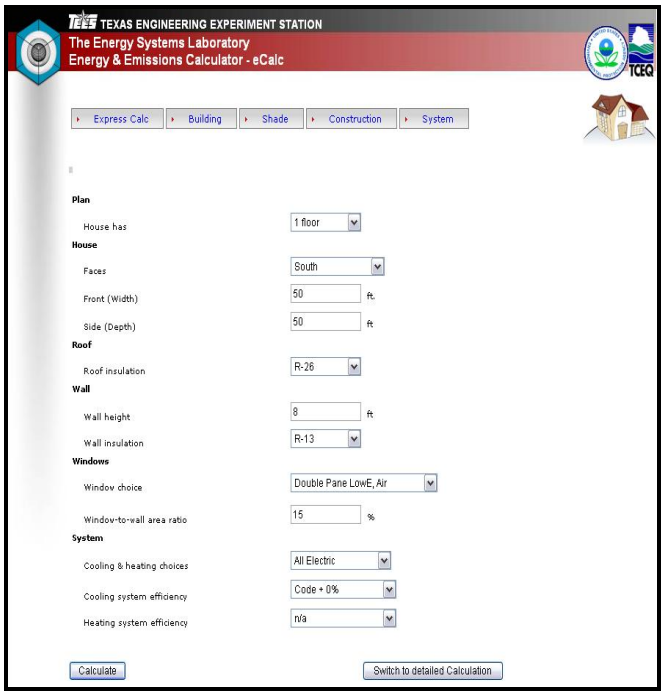

Figure 5: Single-family input parameters screen

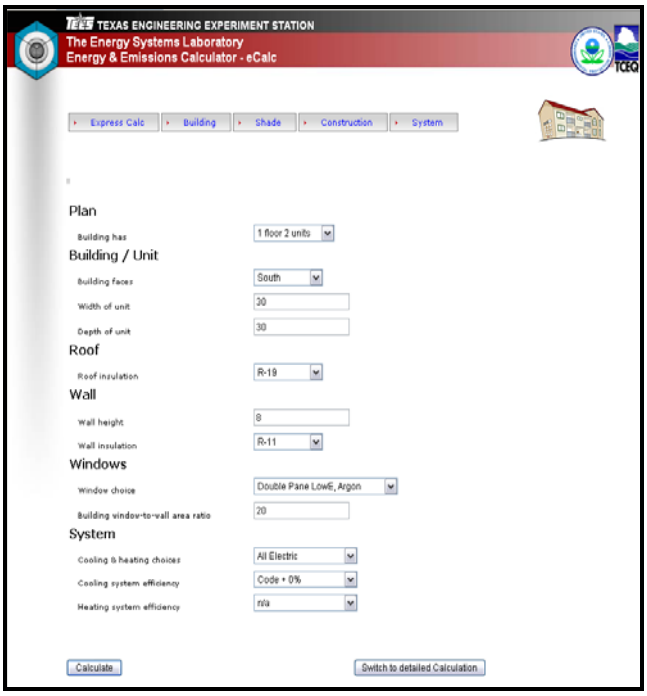

Figure 6: Multi-family input parameters screen

Table 6. Code and Pre-code Simulation Results for Individual Residence for Harris County (Single-Family and Multi-Family).

County	SF or MF	Precode or Code-compliant	Options			Simulation #	Annual Elec. (kWh/yr)	Annual NG (Therms/yr)	Peak-day Elec. (kWh/day) (Aug. 19)	Peak-day NG (Therm/day) (Aug. 19)	Total Annual (Elec. + NG) (MBtu)	Annual Elec.Savings (kWh/yr)	Annual NG Savings (Therms/yr)	Peak-day Elec. Savings (kWh/day) (Aug. 19)	Peak-day NG Savings (Therm/day) (Aug. 19)	Total Annual Savings (Elec. + NG) (MBtu)
Harris	SF	Precode	Slab-on-grade	Fuel Option 1	1-story	1	14265	293	67.383	0.585982	78.03					
					2-story	2	11942	291	56.781	0.585982	69.84					
				Fuel Option 2	1-story	3	19492	0	77.084	0	66.52					
					2-story	4	17105	0	66.482	0	58.38					
				Fuel Option 3	1-story	5	19313	0	77.084	0	65.91					
					2-story	6	16967	0	66.482	0	57.91					
			Crawl Space	Fuel Option 1	1-story	7	14932	283	68.014	0.585982	79.24					
					2-story	8	14315	272	63.89	0.585982	76.02					
				Fuel Option 2	1-story	9	19980	0	77.716	0	68.19					
					2-story	10	19154	0	73.591	0	65.37					
				Fuel Option 3	1-story	11	19843	0	77.716	0	67.72					
					2-story	12	19067	0	73.591	0	65.08					
		Code - Compliant	Slab-on-grade	Fuel Option 1	1-story	13	12544	246	59.036	0.465982	67.43	1,721	47	8.35	0.12	10.60
					2-story	14	11060	245	51.311	0.465982	62.29	882	46	5.47	0.12	7.55
				Fuel Option 2	1-story	15	17694	0	68.737	0	60.39	1,798	0	8.35	0.00	6.13
					2-story	16	16175	0	61.013	0	55.2	930	0	5.47	0.00	3.18
				Fuel Option 3	1-story	17	17572	0	68.737	0	59.97	1,741	0	8.35	0.00	5.94
					2-story	18	16077	0	61.013	0	54.87	890	0	5.47	0.00	3.04
			Crawl Space	Fuel Option 1	1-story	19	13231	235	59.722	0.465982	68.68	1,701	48	8.29	0.12	10.56
					2-story	20	12751	226	56.092	0.465982	66.08	1,564	46	7.80	0.12	9.94
				Fuel Option 2	1-story	21	18197	0	69.423	0	62.1	1,783	0	8.29	0.00	6.09
					2-story	22	17541	0	65.793	0	59.87	1,613	0	7.80	0.00	5.50
				Fuel Option 3	1-story	23	18109	0	69.423	0	61.81	1,734	0	8.29	0.00	5.91
					2-story	24	17484	0	65.793	0	59.67	1,583	0	7.80	0.00	5.41
	MF	Precode	Slab-on-grade	Fuel Option 1	1-story	1	6,346	243	27.09	0.59	45.97					
					2-story	2	6,230	242	25.40	0.59	45.42					
					3-story	3	6,274	241	25.07	0.59	45.54					
				Fuel Option 2	1-story	4	10,692	0	36.80	0.00	36.49					
					2-story	5	10,552	0	35.10	0.00	36.01					
					3-story	6	10,591	0	34.77	0.00	36.15					
				Fuel Option 3	1-story	7	10,691	0	36.80	0.00	36.49					
					2-story	8	10,553	0	35.10	0.00	36.02					
					3-story	9	10,592	0	34.77	0.00	36.15					
		Code - Compliant	Slab-on-grade	Fuel Option 1	1-story	10	5,929	203	25.61	0.47	40.46	417	41	1.48	0.12	5.51
					2-story	11	5,882	200	24.27	0.47	40.09	349	42	1.13	0.12	5.34
					3-story	12	5,927	200	23.99	0.47	40.18	347	42	1.08	0.12	5.36
				Fuel Option 2	1-story	13	10,324	0	35.31	0.00	35.24	368	0	1.48	0.00	1.26
					2-story	14	10,242	0	33.97	0.00	34.96	311	0	1.13	0.00	1.06
					3-story	15	10,278	0	33.69	0.00	35.08	313	0	1.08	0.00	1.07
				Fuel Option 3	1-story	16	10,320	0	35.31	0.00	35.22	371	0	1.48	0.00	1.27
					2-story	17	10,242	0	33.97	0.00	34.96	311	0	1.13	0.00	1.06
					3-story	18	10,277	0	33.69	0.00	35.07	315	0	1.08	0.00	1.08

consumption of single and multi-family residences for the different options for both code and pre-code runs, which were tabulated in Table 6. In Figure 7 and Table 6 it can be seen that for single-family residences, houses with heat pump heating and electric DHW and electric cooling have the lowest annual energy use, 2 story houses are less consumptive than 1 story houses[21], and slab-on-grade construction was less consumptive that houses with crawl spaces. In Figure 8 and Table 6 it can be seen that for multi-family residences, 2 story configurations are less consumptive than 3 story configurations, and units with heat pump heating are less consumptive than units with natural gas or electric resistance heating.

Of importance to the analysis of emissions reductions are the savings associated with the change in energy use of the different house types. These values can be seen in Table 6, and appear graphically in Figure 7 and 8 as the difference in the code and pre-code values for each house type. In general, for single-family residences, 1-story slab-on-grade houses have about the same savings as 1-story houses with crawl spaces. Houses with natural gas have more annual savings than houses with electric or heat pump systems because of the assumed elimination of the pilot light to meet the more stringent AFUE for furnaces that meet the 2000 IECC. Electric resistance houses show slightly more savings than heat pump houses due to the increased efficiency of the heat pump. 1-story houses have more savings than 2 –story houses because of increased roof area. The houses with the highest savings are 1-story houses with natural gas and slab-on-grade. The houses with the least savings are 2 story houses with electric or heat pump heating and slab-on-grade construction.

Figure 9 shows the percentage savings of the different fuel options for code and pre-code runs for single-family. For 1-story single-family, the annual percentage energy savings range from 13.6% for natural gas heating/DHW to 9% for houses with electric heat pump heating. More savings for natural gas heating/DHW occurs because of the elimination of the pilot light in the furnace, as mentioned previously. For 2-story single-family, the range is from 13% for natural gas heating/DHW and crawl space to 5% for electric heat pump and slab on grade.

Figure 10 shows the percentage savings of the different fuel options for code and pre-code runs for multi-family. In general, for multi-family residences, 1-story units have more savings than 2-story or 3-story units, and units with natural gas heating and DHW have more savings than units with electric or heat pump heating. Overall, savings are less for multi-family housing compared to single-family housing because of the reduced size of the dwelling unit, shared walls/roof, etc.

For multi-family, the saving range is from 12% for 1-story gas heating/DHW to 3% for 3-story with electric heat pump. The savings in Table 6 are per residence in Harris County. The total energy savings for Harris County from new construction according to the 2000 IECC and 2001 Supplement are obtained by the multiplying this number by the total number of building permits issued in a year. This final MWh value is then fed in the US EPA's eGRID to determine the NOx reductions for Harris County. A detailed description of this procedure is presented in Haberl et al. (2004a; 2004b; 2004c).

SUMMARY:

This paper explains in detail the residential simulation models that are used in the Energy Systems Laboratory's web-based emissions reduction calculator. To accomplish this, the DOE-2.1e simulation program was used to create pre-configured, single-family and multi-family simulation models. These models were then used to determine the fuel-neutral, annual and peak day energy savings attained by constructing code-complaint or above-code residences. These values are then processed through US EPA's eGRID to calculate the annual and peak NOx emissions reductions for the counties that contain the power plants that supplied the electricity to the households.

Future versions of the emissions calculator will include enhanced output capabilities that will allow for users to perform code-compliant calculations with results presented by end-use, thermal mass, use of the Windows 5 program, and a duct model. Finally, since the computation engine behind the calculator is DOE-2, which is driven by spreadsheet-assembled macros, a stand-alone batch mode has been developed that allows an analyst to quickly run 1,000s of

[21] In order to calculate this, the residence was assumed to have the same window area as a 1-story residence, only this window area was divided evenly between the first and second floors. This is not the case if one uses window-to-wall area to calculate the window area, since a 2 story house has more wall area than a 1 story house, and the energy use of the additional windows exceeds any savings from the reduced roof area of the 2-story house.

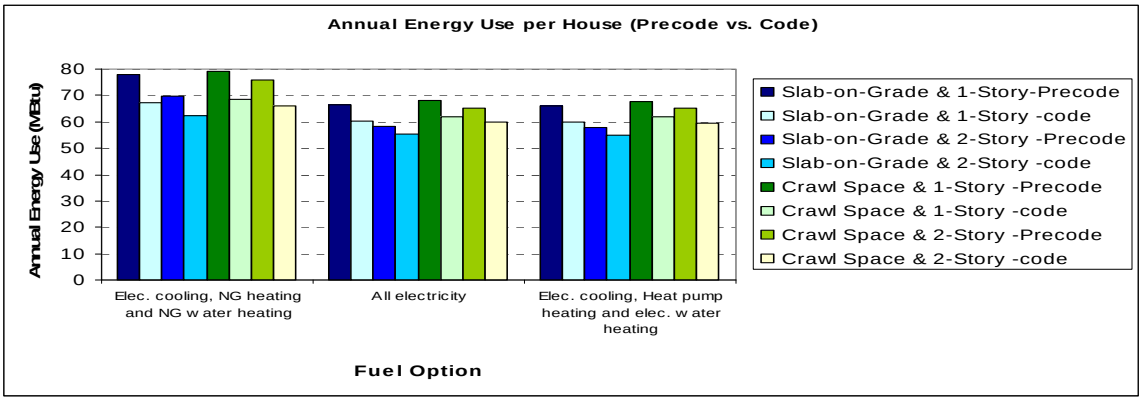

Figure 7: Comparison of code and pre-code energy consumption (Single-family)

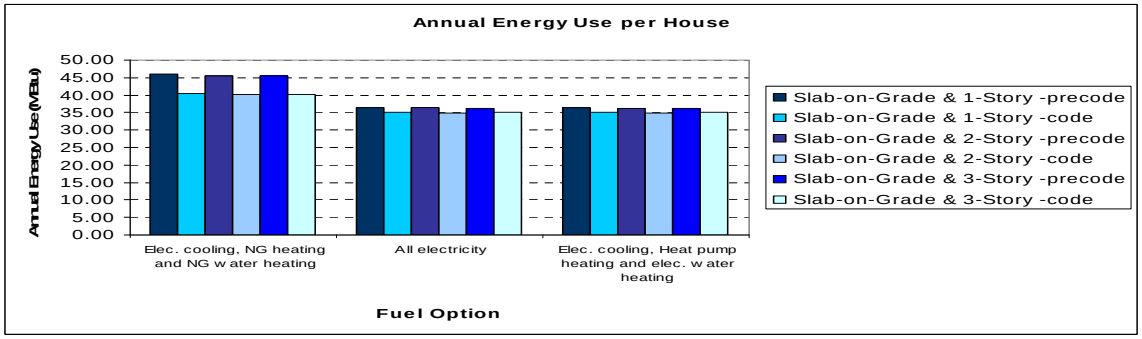

Figure 8: Comparison of code and pre-code energy consumption (Multi-family)

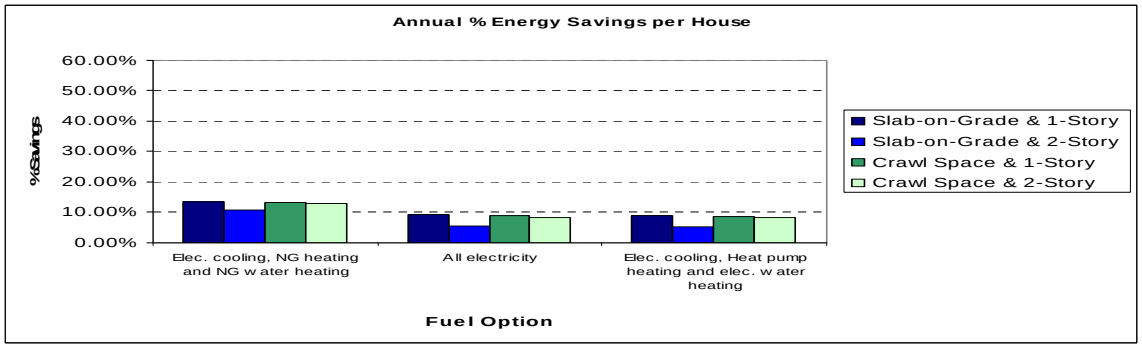

Figure 9: Annual percentage savings for code and pre-code energy consumption (Single-family)

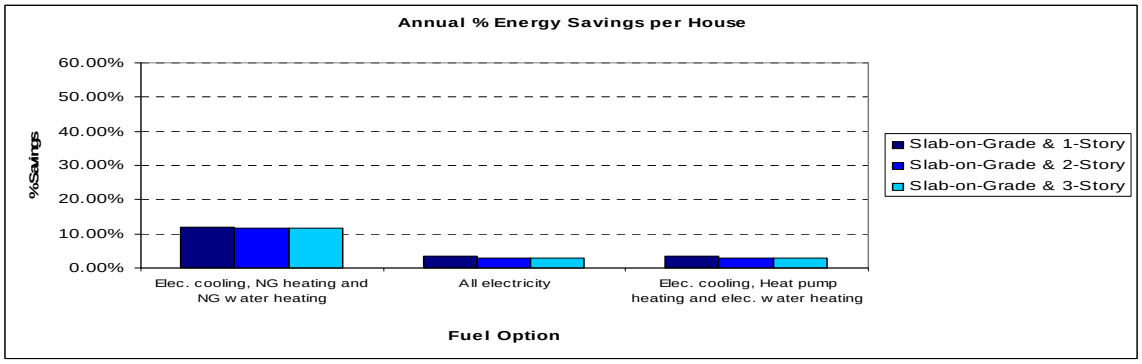

Figure 10: Annual percentage savings for code and pre-code energy consumption (Multi-family)

simulations to analyze emissions reductions scenarios as requested by the TCEQ and other state agencies.

Preliminary verifications of the accuracy of the energy calculations in the calculator can be found in Im (2003). Ongoing verification efforts include calibrated simulations with an instrumented Habitat for Humanity house in Bryan, Texas, and verification of whole-building reductions using utility bill comparisons.

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