CALCULATION OF NO_x EMISSIONS REDUCTIONS FROM ENERGY EFFICIENT RESIDENTIAL BUILDING CONSTRUCTION IN TEXAS

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Summary. Four areas in Texas have been designated by the United States Environmental Protection Agency (EPA) as non-attainment areas because ozone pollution levels exceed the National Ambient Air Quality Standard (NAAQS) maximum allowable limits. These areas face severe sanctions if attainment is not reached by 2007. This paper provides an overview of the procedures that have been developed and used to calculate the electricity savings and NOx reductions from code-compliant residential construction in non-attainment and affected counties[1]. This paper reviews the calculation methods and presents results that show the 2003 annual electricity and natural gas savings and NOx reductions from implementation of the 2000 IECC to single-family and multi-family residences in 2003, which use a code-traceable DOE-2 simulation. A discussion of the development of a web-based emissions reductions calculator is also discussed[2].

Keywords: Code-traceable DOE-2 Simulation, emissions calculator, building codes, eGRID.

INTRODUCTION

In 1970 the Federal Clean Air Act authorized the United States Environmental Protection Agency (EPA) to establish the maximum allowable concentrations of pollutants that are known to endanger human health, harm the environment or cause property damage. In response to this act the EPA established NAAQS which describe the allowable maximum limits of the six primary pollutants[3]. In Texas, the Texas Commission on Environmental Quality (TCEQ) has the responsibility of measuring and reporting these emissions to the EPA, which includes ozone. Nationally, areas that exceed safe levels of ozone are carefully monitored by the EPA. Ozone is formed when oxides of nitrogen (NOx), volatile organic compounds (VOCs), and oxygen (O_2) combine in the presence of strong sunlight. Hence, controlling NOx emissions is the priority air pollution reduction program in Texas, and it is fast becoming a priority for many areas of the United States.

In 2001, the Texas State Legislature formulated and passed the Texas Emissions Reduction Plan (TERP), to further reduce ozone levels by encouraging the reduction of emissions of NOx by sources that are currently not regulated by the TNRCC (now the TCEQ), 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)[4]. 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 2000). In 2001, thirty-eight counties in Texas were designated by the EPA as either non-attainment or affected areas. These areas are shown on the map[5] in Figure 1. In 2003, three additional counties were classified as affected counties[6], bringing the total to forty-one counties (sixteen non-

[1] The procedures outlined in this paper were developed and used in the Laboratory's 2002 and 2003 Annual Report to the TCEQ to satisfy the requirements of the Senate Bill 5 Legislation.
[2] In 2003 the Laboratory was awarded a grant from the USEPA, which was administered through the TCEQ, to expand the development of these procedures into a web-based tool that would provide state and local authorities with accurate emissions reduction calculations for use in preparing State Implementation Plans (SIP).
[3] These pollutants currently are: carbon monoxide (CO -- 9 ppm, 8 hr avg.), lead (Pb -- 1.5 ppm, maximum quarterly average), oxides of nitrogen (NO2 -- 53 ppb annual average), Ozone (O3 -- 120 ppb, 1 hr, avg.), particulate matter (PM10-- 50 micrograms/m3 annual average), and sulfur dioxide (SO2 -- 30 ppb annual average).
[4] 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, these new bills strengthen the previous legislation, without reducing the stringency of the building code or the reporting procedures of the emissions reductions.
[5] 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.
[6] These counties are Henderson, Hood and Hunt counties in the Dallas-Fort Worth area.

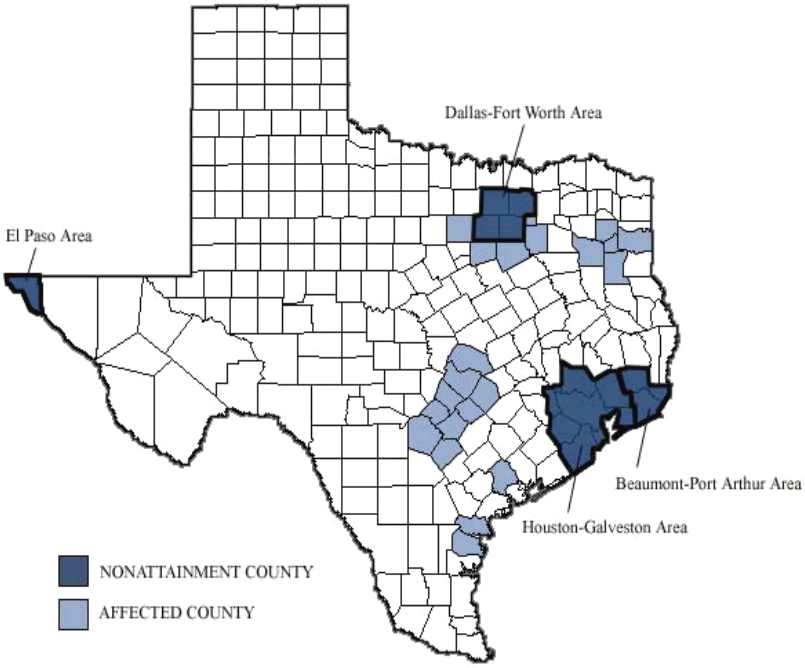


Figure 1: EPA Non-attainment (blue) and affected counties (light blue).

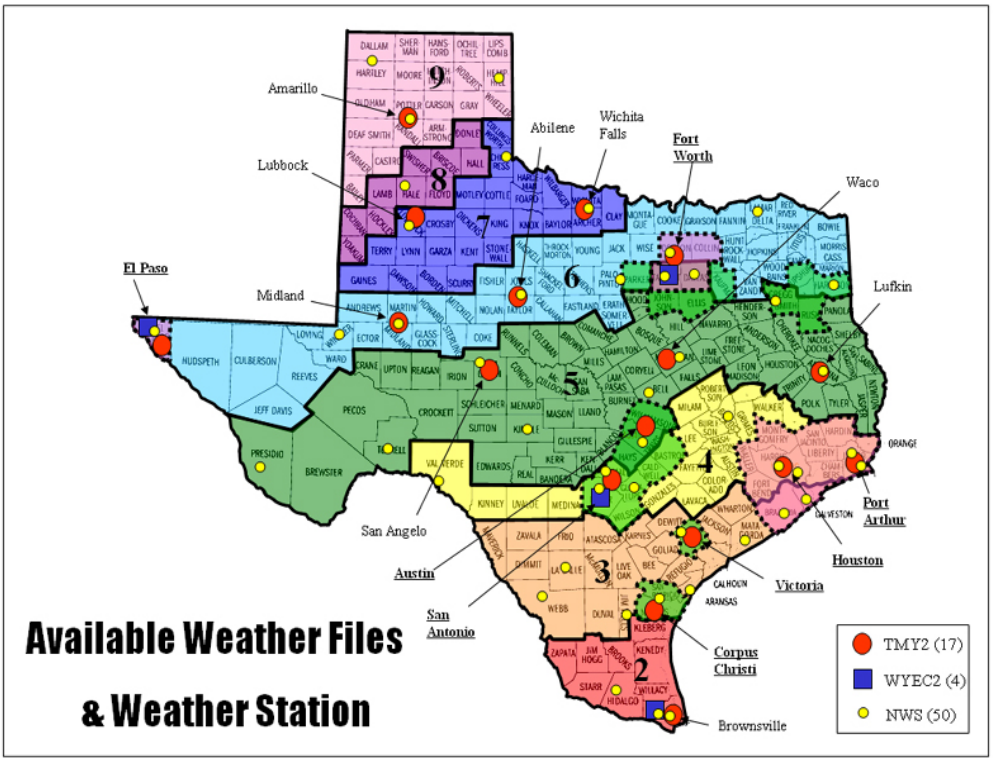


Figure 2: Available NWS, TMY2 and WYEC2 weather files compared to the 2000 IECC weather zones for Texas.

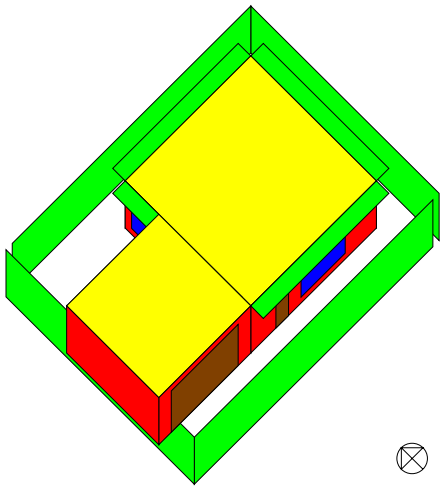


Figure 3: Architectural rendering[7] of the prototypical 2000 IECC, 1,000 ft^2 single-family residence.

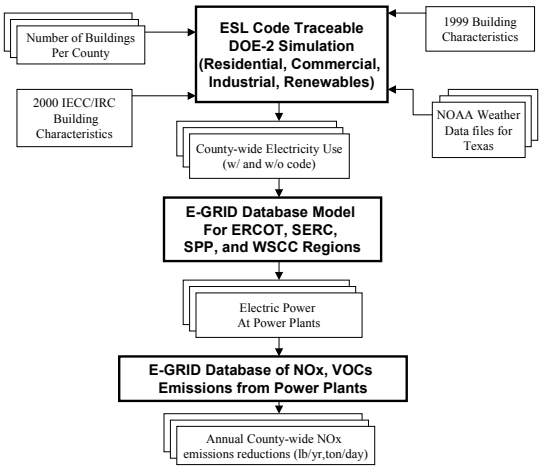


Figure 4: Overall flowchart for calculation of emission reductions from implementation of IECC/IRC 2001 in non-attainment and affected counties.

attainment and twenty-five affected counties). The analysis presented in this paper is based on the ESL's 2003 report to the TCEQ, which focused on the original 38 counties.

These counties represent different areas of the state that can be categorized into the different climate zones contained in Chapter 3 of the 2000 IECC as shown in Figure 2. Also shown in Figure 2 are the locations of the various weather data sources, including the seventeen Typical Meteorological Year (TMY2) (NREL 1995), and four Weather Year for Energy Calculations (WYEC2) weather stations (Stoffel 1995), as well as the forty-nine National Weather Service weather stations, (NWS) (NOAA 1993). To no surprise, these thirty-eight counties represent some of the most populated counties in the state, and contained 13.9 million residents in 1999, which represents 69.5% of the state's 20.0 million total population (U.S. Census 1999). Three of these non-attainment counties (i.e., Harris, Dallas, and Tarrant), and Bexar county, an affected county, contain 8.0 million residents, or 40.0% of the state's total population. In the rankings of the remaining counties it is clear to see that the most populated counties also represent the majority of the non-attainment regions.

The total housing units in the non-attainment and affected counties closely follow the county populations, with Harris, Dallas, Tarrant, and Bexar counties containing 3.2 million housing units, or 40.0% of the state's total 8.0 million households (U.S. Census 1999). The most building activity occurred in Harris county (25,862 units), followed by significantly less construction (i.e., 10,000 to 15,000 units) in Dallas, Travis, Bexar, Collin and Tarrant counties. These six counties represented 88,833 housing starts, or 71% of the total 125,100 residential building permits in the 38 counties classified as non-attainment or affected by the EPA. Also of interest is the significant number of new multi-family units in the counties with the largest number of building permits . In the six largest counties (i.e., Harris, Dallas, Travis, Bexar, Collin and Tarrant) there were 34,038 new multi-family units, or 38% of the 88,833 housing starts in these counties.

METHODOLOGY

The TCEQ is currently working with the EPA, through the Texas Emissions Reduction Plan (TERP) to determine how the State Implementation Plan (SIP) emissions reduction credits can be obtained from the reductions in electricity use from energy efficiency and renewable energy (EE/RE) projects, with an emphasis on peak summertime electric demand[8], that are attributable to the adoption of the International Energy Conservation Code (IECC 2000) in non-attainment and affected counties. In order for the TCEQ to

[7] These images were rendered with DrawBDL (Huang 2002).
[8] The peak day for the 2002 and 2003 Annual reports were determined from the nearest TMY2 weather files that were used for the simulations. The same peak days were used for the 2002 and 2003 simulations. Current work for the EPA includes the modification to the methodology to use actual 1999 NOAA weather data for the ozone episode period that occurred during August-September of 1999 (peak day August 19th,1999), combined with solar data recorded by the National Renewable Energy Laboratory (NREL).

accomplish this, county-wide reductions in electricity use must be calculated by the Energy Systems Laboratory (ESL) and presented to the TCEQ in a suitable format for calculating emissions reductions using the EPA's Emissions and Generation Resource Integrated Database (eGRID)[9]. An overview of the methodology to accomplish this for residential buildings is presented in this paper, additional detailed information can be found in Haberl et al. (2002a, 2002b, 2003a, 2003b, 2003c, 2004a, 2004b) and Im (2003). This methodology is composed of several procedures that calculate and verify savings using different sources of information. These procedures include:

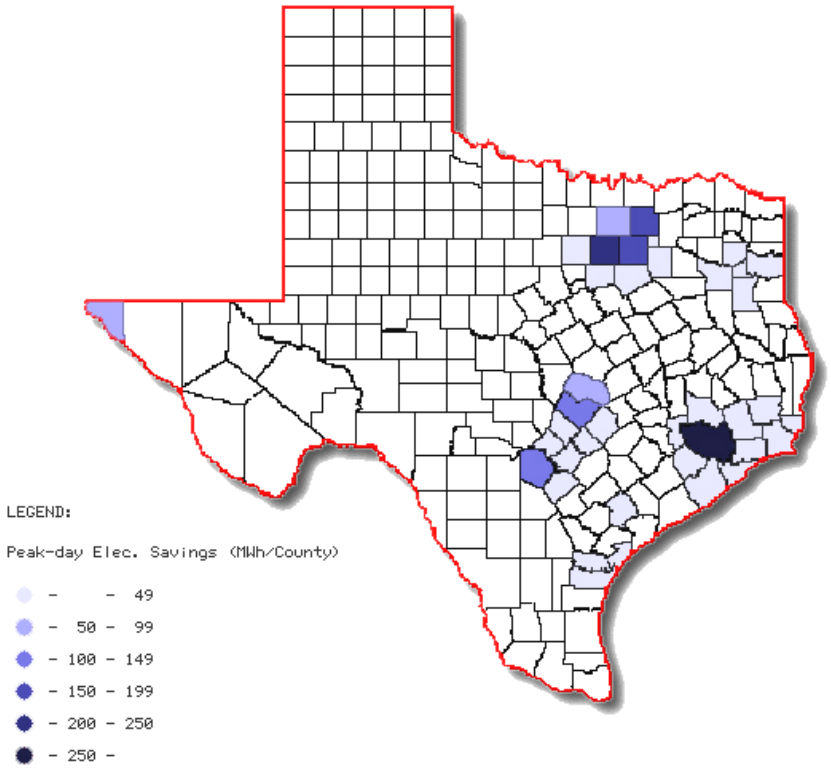
1. The calculation of electricity and natural gas savings and peak-day electricity and natural gas use reductions from the implementation of the IECC 2000 in new single-family and multi-family residences in non-attainment and affected counties as compared against 1999 single-family and multi-family housing characteristics using a code-traceable, calibrated DOE-2 simulation.
2. A cross-check of electricity and natural gas savings using a utility billing analysis method.
3. A cross-check of pre-code and post-code construction data using on-site visits.
4. A cross-check of the simulation accuracy using measured 15-minute data from a closely monitored house in Bryan-College Station.

Calculation of NOx Emissions Reductions. For each county, 1999 and 2003 residential housing characteristics for single and multifamily homes were then entered into the DOE-2 simulation to calculate the annual energy use of four average-sized residences, two representing a prototypical single-family and multi-family house with the average 1999 characteristics, and two representing the same houses with specific new energy-conserving characteristics from the 2000 IECC. For each county, the 1999 single-family and multi-family residential housing characteristics were obtained from the annual builder's survey of the National Association of Home Builders[10] (NAHB 2002). The average 1999 air-conditioner efficiencies (i.e., SEER 11) were obtained from the American Refrigeration Institute (ARI) state-wide sales data for Texas (ARI 2002). Average furnace efficiencies and domestic water heater efficiencies were assumed to meet the Federal Standards of 80% and 76%, respectively. The 2000 IECC code-compliant housing characteristics were then determined for a house with an equivalent floor area and an equivalent window-to-wall area. In this analysis, it was assumed that all houses have air conditioning, natural gas heating and DHW, which represents the most common single-family house according to the 1999 NAHB survey. All other characteristics in the simulation were carefully chosen to match the requirements of Chapter 4 of the 2000 IECC. To accommodate the simulation of varying floor areas, a scaleable simulation file was created as shown in Figure 3, which shows a 1,000 ft^2 house[11].

The procedure for linking the county-wide electricity reductions calculated with the DOE-2 simulations to the EPA's eGRID program (E-GRID 2002) are shown in Figure 4, additional details can be found in Haberl et al. (2003c). In this procedure, the code-traceable DOE-2 simulation is used to calculate the annual electricity savings (kWh/yr) and peak-day electricity savings (kWh/day) from the implementation of the 2000 IECC for all houses built in a county. The utility supplier for each county is then assigned according to data published by the Texas Public Utilities Commission (TPUC 2003, Haberl et al. 2003c). For each utility supplier eGRID then calculates, on average, which utility plant supplied electricity including the counties those plants were located in, and the associated NOx, SO_2, CO_2 and mercury emissions. The emissions from the different power plants in each county are then totaled to give the total county-wide emissions.

Results: 2003 Emissions Reductions From the Implementation of the 2000 IECC to Single-family and Multi-family Residential. In Figure 5 the peak-day electricity savings are shown for the combined single-family and multi-family savings. Figure 6 presents the combined total NOx reductions from electricity and natural gas savings in single-family and multi-family households in the 38 non-attainment and affected counties, and those counties calculated by eGRID to have electricity power production facilities. The total

[9] The use of the eGRID database, which includes a simplified utility grid model based on annual sales of electricity data, was proposed by the TNRCC for use in calculating the emissions reductions from energy efficiency and renewable energy projects in 2001. Although this method is not as accurate as more sophisticated electricity dispatch models, its use is acceptable to the EPA because it is based on public domain data, and uses procedures that were developed and the database maintained for this purpose by the EPA.
[10] In 2004 these characteristics will be expanded to include a diversified building stock that more closely tracks the NAHB survey data.
[11] The 2003 version of the DOE-2 simulation (LBNL 2000) includes a single-story residential simulation with slab-on-grade construction. In 2004 the simulation is being expanded to accommodate the simulation of fuel-neutral (i.e., electric, natural gas or heat pump heating, air-conditioning, and electric or natural gas DHW), 1 or 2 story residence with varying floor types (i.e., crawlspace, slab).



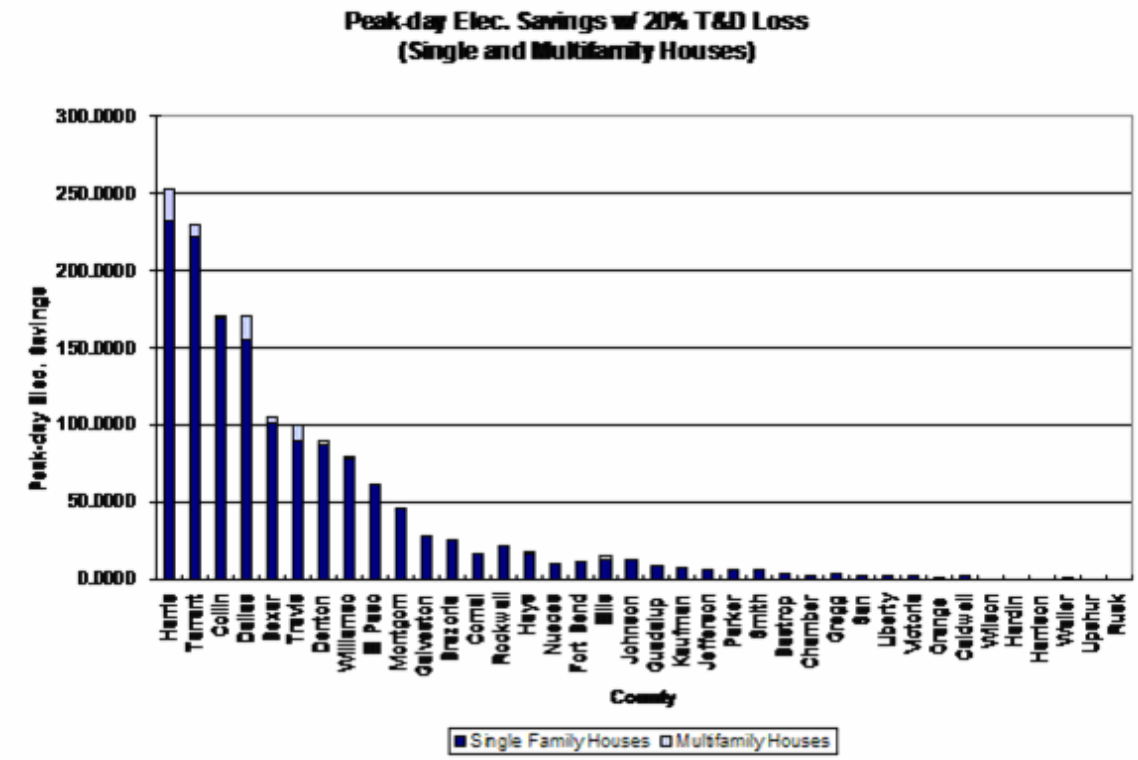
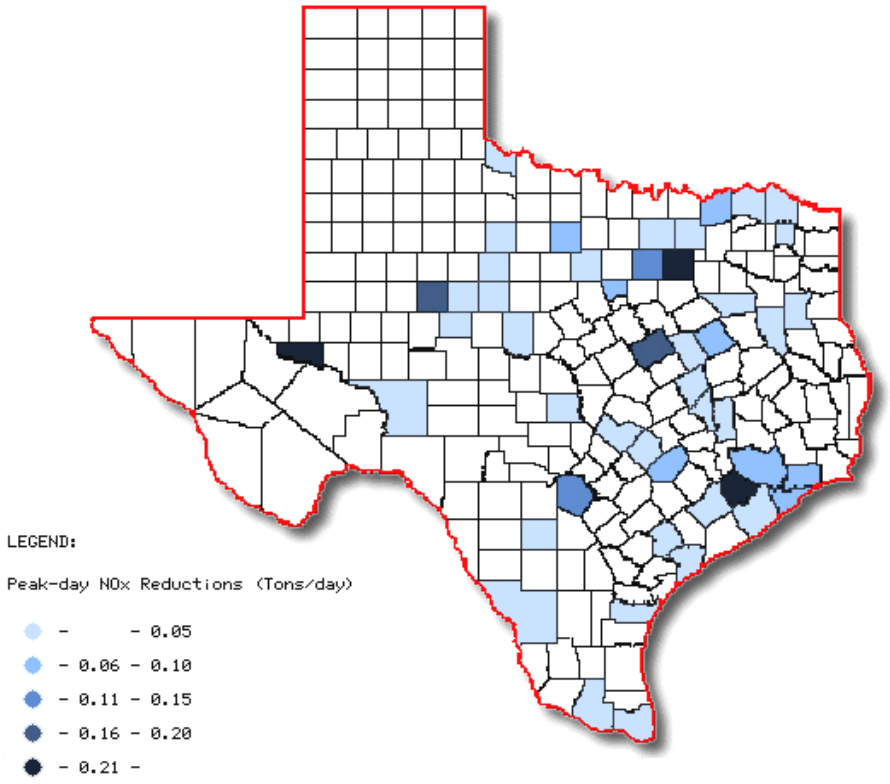


Figure 5: 2003 Peak-day electricity reductions (MWh/day) from 2000 IECC by PCA for single-family and multi-family residences by county using eGRID.



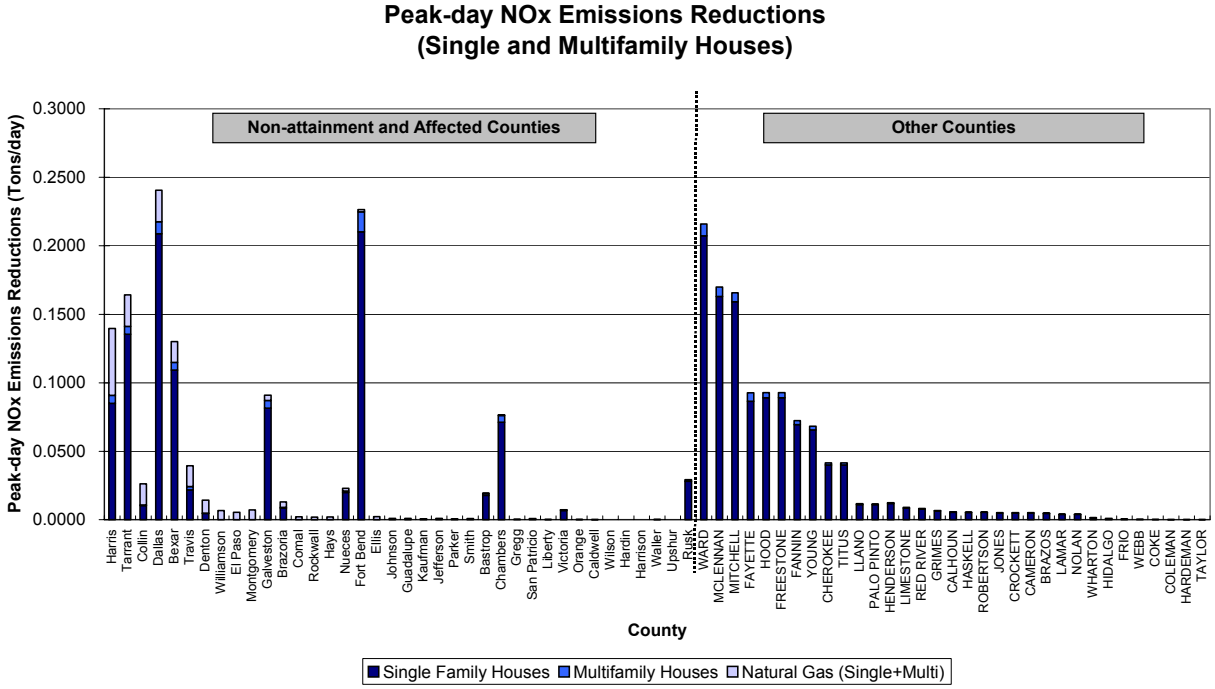


Figure 6: 2003 peak day NOx reductions from electricity and natural gas savings due to the 2000 IECC for single-family and multi-family residences by county.

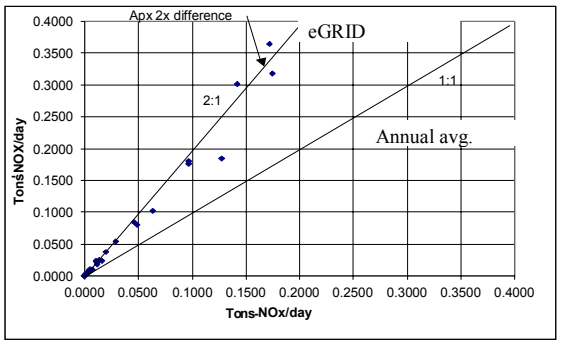


Figure 7: Comparison of peak day versus average daily NOx reductions from electricity savings for the 38 non-attainment and affected Counties.

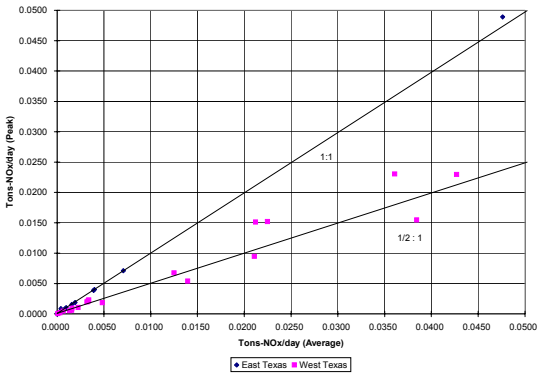


Figure 8: Comparison of peak day versus average daily NOx reductions from natural gas savings for the 38 non-attainment and affected counties.

annual electricity savings is 252,238 MWh/yr[12], which is comprised of 236,965 MWh/yr (93.9%) from single-family residences, and 15,272 MWh/yr (6.1%) from multi-family residences. The total peak-day electricity savings from all counties is calculated to be 1,526 MWh/day, which is comprised of 1,452 MWh/peak-day (95.2%) from single-family and 73.73 MWh/peak-day (4.8%) from multi-family. Natural Gas savings are calculated to be 8,875,694 therms/year (i.e., 887,569 MMBtu/yr) from single-family and multi-family residences and 15,965 therms/peak-day[13] (i.e., 1,596.5 MMBtu/peak-day). A comparison of Figure 5 with Figure 6 shows the importance of the use of the eGRID database for determining the location of the county in which the power generation facility is located. In Figure 5 the counties with the largest electricity savings are primarily non-attainment and affected counties with the largest housing growths. In comparison, in Figure 6 some of the counties with the largest NOx emissions reductions are not non-attainment or affected counties, but instead represent rural counties with large power generation facilities.

The importance of the use of peak-day electricity savings for calculating NOx emissions is made clear in Figure 7 , which shows a 2:1 increase in NOx reductions calculated using peak-day electricity savings[14] versus NOx reductions calculated with average daily values[15]. The reason for this difference is due to the fact that the electricity use is reduced most during the peak cooling periods of the year, which is not reflected by an average daily calculation. In contrast to this, Figure 8 shows an opposite 1:2 ratio when one compares the NOx reductions from peak cooling use of natural gas versus NOx reductions calculated from average daily natural gas use[16]. This 1:2 ratio is indicating the equal importance of properly accounting for the peak cooling day natural gas use in a residence, which primarily represents the gas use by the domestic water heating and any pilot lights.

Development of a web-based emissions reductions calculator. The ESL is working with the TCEQ to develop a web-based, emissions reduction calculator through funding provided by the EPA and the Texas Legislature. This calculator is scheduled to be operational in that fall of 2004, and will include EPA-approved calculation procedures for emissions reductions from code-compliant residential and commercial new construction, and energy conservation retrofits to municipal buildings, street lights, traffic lights, and water/waste water facilities, as well as emissions reductions from the installation of solar thermal, solar photovoltaic and wind energy installations. Figure 9 is an image of one of the opening screens of the emissions calculator (eCALC). Figure 10 contains a block diagram of the calculations performed by the eCALC[17]. In the upper-left corner of Figure 10, the user interacts with the eCALC through the web-interface using XML commands to the main calculation engine (i.e., the CE Frame Pitcher). Depending upon the model selected, the calculation engine first

[12] This includes an estimated 20% transmission and distribution loss.
[13] This is the summer-time peak day for electricity use.
[14] Peak day NOx reductions are calculated using the peak day savings with the DOE-2 simulation of the 1999 and code-compliant house characteristics.
[15] The average daily NOx reductions for electricity use are calculated by dividing the total annual NOx reductions by 365, which is indicated as "annual avg.". The values indicated as "eGRID" are the peak day simulations from DOE-2 for each county.
[16] NOx reductions from average daily values are calculated by dividing the annual natural gas use by 365. The west Texas data points are for those houses classified by the NAHB as being located roughly west of I-35. These show that peak day calculated from averaging the annual gas savings overstates the summertime gas reductions, which mostly include the elimination of the pilot lights in the new code-compliant furnaces.
[17] The eCALC website can be found at "ecalc.tamu.edu".

Figure 9: Screen-image from web-based emissions-reduction calculator (eCALC).

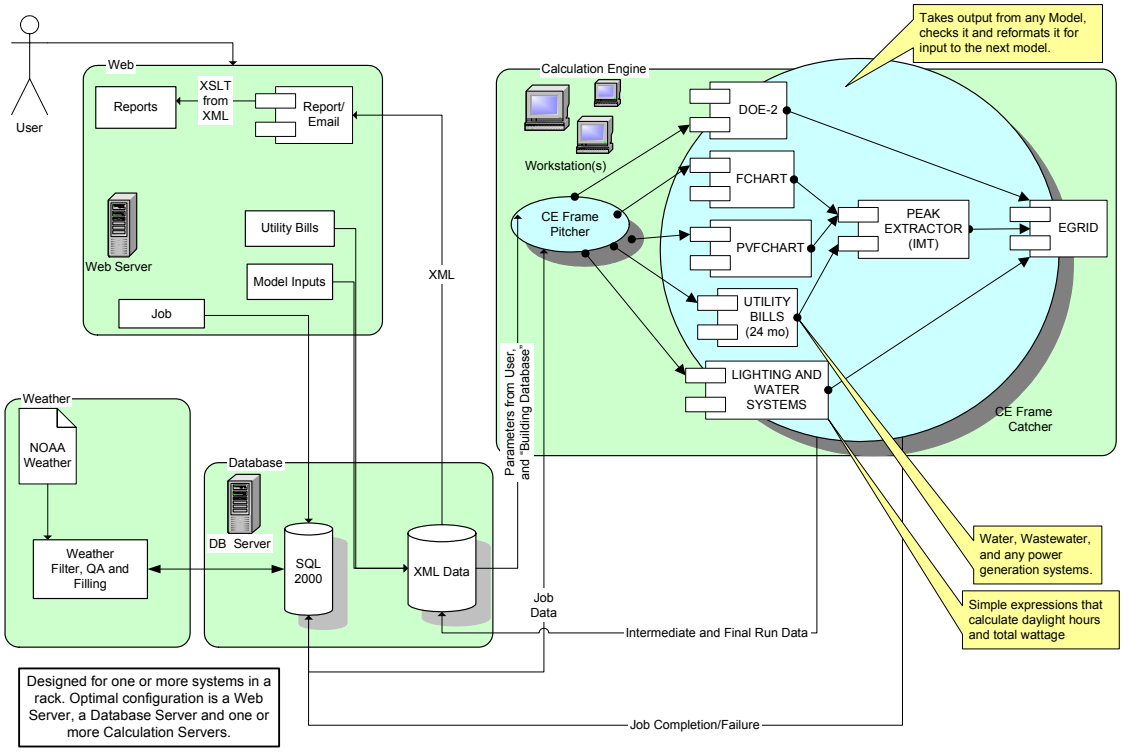


Figure 10 Block-diagram showing interactive-functionality of the emissions reduction calculator.

checks the user input, then reformats the input to the proper format for use by one of several legacy models, including:

- *DOE-2 for modeling the energy use of new residential and commercial construction (LBNL 2000).* These models consist of single-family, multi-family residential models and several commercial building models (i.e., office and retail). Each run consists of a code-compliant simulation, pre-code simulation, and a simulation using the current user inputs[18].
- *FCHART and PVFCHART for analyzing the energy savings from solar and solar photovoltaic systems (FCHART 1985, PVFCHART 2001).* The FCHART analysis consists of two system types: a flat-plate system for heating domestic hot water, and a flat-plate system for heating an outdoor pool.
- *ASHRAE's Inverse Model Toolkit (IMT) for analyzing monthly utility bills, street lights, traffic lights, water/waste-water, and wind energy systems (Kissock et al. 2003a, 2003b).* The IMT analyzes the monthly weather-dependency and system performance using linear, change-point linear, and multi-variable regression models.
- *eGRID for calculating the NOx, SOx, and CO2 from power plant emissions.* The electricity and natural gas savings from the above models is then passed into the EPA's eGRID database to determine which power plant supplied the electricity, and the amount of air pollution associated with the electricity use and natural gas consumption[19].

SUMMARY

This paper has presented procedures that have been used to calculate the electricity savings from residential construction in non-attainment and affected counties. Results are presented that show the annual electricity and natural gas savings and NOx reductions from implementation of the 2000 IECC to single and multi family residences in 2003, which use the DOE-2 simulation program. Energy savings from energy code-compliant new residential construction in 2003 were 252,238 MWh/year of electricity and 887,564 MBtu/year of natural gas in the 38 original, non-attainment and affected counties. The resultant annual NO_x reductions were calculated to be 473 tons NO_x/year which include:

- 340 tons NO_x/year (72.0%) from single-family residential (236,965 MWh/year saved),
- 22 tons NO_x/year (4.7%) from multi-family residential (15,272 MWh/year saved), and
- 110 tons NO_x/year (23.3%) from natural gas savings from single-family and multi-family residential (887,564 MBtu/year saved).

On a peak summer day, the NOx reductions in 2003 are calculated to be 2.44 tons of NO_x/day, which represents:

- 2.13 tons NOx/day (87.3%) from single-family residential (1,452 MWh/day saved),
- 0.11 tons NOx/day (4.5%) from multi-family residential (73.73 MWh/day saved), and
- 0.20 tons NOx /day (8.2%) from natural gas savings from single-family and multi-family residential (1,595 MBtu/day saved).

The comparative magnitude of the annual and peak-day NO_x reductions from natural gas compared to the savings from electricity vary significantly. This is because the annualized savings include heating period NO_x reductions, and the peak-day (i.e., cooling season) natural gas savings include only those savings associated with the elimination of pilot lights. An overview of the web-based NOx emissions calculator has also been presented. Additional details of the analysis are reported in Haberl et al. (2003c). The calculator web site is "ecalc.tamu.edu".

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[18] For the residential models the National Association of Home Builder's Builder survey (NAHB 2002) was used for pre-code conditions, and the 2000 IECC was used for code-compliant construction (IRC 2000). For commercial buildings ASHRAE Standard 90.1-1989 (ASHRAE 1989) was used for pre-code and Standard 90.1-1999 was used for code-compliant construction (ASHRAE 1999).

[19] In this analysis eGRID Ver. 2 is used. This publicly available database can be found at www.epa.gov/airmarkets/egrid/. eGRID contains power generation and emissions data for all utility power production facilities in the United States, and provides measured NOx, SOx and CO2 data for a specific year by region. In Texas, eGRID was configured to include the power and emissions data for the Electric Reliability Council of Texas (ERCOT) region.

assistance with the DOE-2 programming. Ms. Betty Liu provided assistance with several of the calculation procedures. Mr. Malcolm Verdict and Dr. Dan Turner also provided useful comments on the work.

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