A METHODOLOGY TO EVALUATE ENERGY SAVINGS AND NO_x EMISSIONS REDUCTIONS FROM THE ADOPTION OF THE 2000 INTERNATIONAL ENERGY CONSERVATION CODE (IECC) TO NEW RESIDENCES IN NON-ATTAINMENT AND AFFECTED COUNTIES IN TEXAS

A Thesis

by

PILJAE IM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2003

Major Subject: Architecture

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Approved as to style and content by:

Jeff S. Haberl (Chair of Committee)	David E. Claridge (Member)
Charles H. Culp (Member)	Phillip J. Tabb (Head of Department)

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ABSTRACT

A Methodology to Evaluate Energy Savings and NO_x Emissions Reductions from the Adoption of the 2000 International Energy Conservation Code (IECC) to New Residences in Non-attainment and Affected Counties in Texas. (December 2003)

Piljae Im, B.S., Hanyang University

Chair of Advisory Committee: Dr. Jeff S. Haberl

Currently, four areas of Texas have been designated by the United States Environmental Protection Agency (EPA) as non-attainment areas because they exceeded the national one-hour ground-level ozone standard of 0.12 parts-per-million (ppm). Ozone is formed in the atmosphere by the reaction of Volatile Organic Compounds (VOCs) and Nitrogen Oxides (NO_x) in the presence of heat and sunlight. In May 2002, The Texas State Legislature passed Senate Bill 5, the Texas Emissions Reduction Plan (TERP), to reduce the emissions of NO_x by several sources. As part of the 2001 building energy performance standards program which is one of the programs in the TERP, the Texas Legislature established the 2000 International Energy Conservation Code (IECC) as the state energy code. Since September 1, 2001, the 2000 IECC has been required for newly constructed single and multifamily houses in Texas. Therefore, this study develops and applies portions of a methodology to calculate the energy savings and NO_x emissions reductions from the adoption of the 2000 IECC to new single family houses in non-attainment and affected counties in Texas.

To accomplish the objectives of the research, six major tasks were developed: 1) baseline data collection, 2) development of the 2000 IECC standard building simulation, 3) projection of the number of building permits in 2002, 4) comparison of energy simulations, 5) validation and, 6) NO_x emissions reduction calculations. To begin, the 1999 standard residential building characteristics which are the baseline construction data were collected, and the 2000 IECC standard building characteristics were reviewed. Next, the annual and peak-day energy savings were calculated using the DOE-2 building energy simulation program. The building characteristics and the energy savings were then crosschecked using the data from previous studies, a site visit survey, and utility billing analysis. In this thesis, several case study houses are used to demonstrate the validation procedure. Finally, the calculated electricity savings (MWh/yr) were then converted into the NO_x emissions reductions (tons/yr) using the EPA's eGRID database. The results of the peak-day electricity savings and NO_x emissions reductions using this procedure are approximately twice the average day electricity savings and NO_x emissions reductions.

DEDICATION

To

My loving wife

ACKNOWLEDGMENTS

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CHAPTER I

INTRODUCTION

1.1. Background

Air pollution problems have existed for centuries primarily in areas where combustion by-products have exceeded the ambient air's ability to absorb and dissolve pollutants. In the last century and a half, these problems have become more severe because of increased urbanization, and rapid scientific and technological advances in combustion technology (NATO, 1982). Pollutants released into the atmosphere as a result of fuel combustion, industrial development, and the increased use of motor vehicles cause adverse effects on man's health, as well as on plants and exposed material surfaces, and other environmental media (U.S.E.P.A., 1998). To reduce such pollutants in the air, numerous efforts have concentrated on emissions controls from a variety of sources such as fuel combustion from on-road and non-road engines and vehicles (Wark et al., 1998). Generally, these control technologies include the process of evaluating and upgrading the effectiveness of air control practices as well as the application of specific hardware, fuels, and materials with low-emission potential (Mycock et al., 1995). Recently, however, in severe non-attainment areas such as Houston, reducing energy use from the building sector is being considered as a way of reducing air pollution. The main motivation for this strategy is therefore that the efficient use of energy in buildings will reduce demand for electric power generation, and this will reduce emissions from power plants that are one of the major sources of air pollution.

This thesis follows the style and format of the *ASHRAE Transactions.*

1.2. Problem Statements

Currently, four areas of Texas have been designated by the United States Environment Protection Agency (EPA) as non-attainment areas because they exceeded the national one-hour ground-level ozone standard of 0.12 parts-per-million (ppm) (TNRCC, 2002). These four areas include Beaumont-Port Arthur, El Paso, Dallas-Fort Worth, and the Houston-Galveston area (See Figure 1.1). These areas must meet the EPA's ozone standard by November 2007[1] or they will face sanctions including the withholding of federal highway funds which are valued at billions of dollars per year, or the withholding of EPA grants for state air pollution planning and control programs. Generally, ozone is readily formed in the atmosphere by the reaction of Volatile Organic Compounds (VOCs) and Nitrogen Oxides (NO_x) in the presence of heat and sunlight. To reduce air pollution, Texas has developed two major strategies. The first strategy of the Texas Natural Resource Conservation Commission (TNRCC)[2], which was approved by EPA to meet the national ozone standard in non-attainment areas in Texas, was to reduce VOCs from the stationary point sources such as refineries and chemical manufacturing plants. As a result, VOC emissions from such sources were reduced by over 50 percent during the 1990-1996 period for all areas (Holland, 2000). In spite of this reduction, the national ozone standard was not still achieved in the Houston-Galveston-Brazoria area nor in any of the other non-attainment areas. When the first strategy failed to achieve the EPA ozone standard, a second strategy was developed whereby the reduction of NO_x has now been targeted by TNRCC. In response to this new strategy, the Texas State Legislature passed Senate Bill 5 in May 2001, the Texas Emissions Reduction Plan (TERP) to reduce the emissions of NO_x by several sources. This plan includes a diesel emissions reduction incentive program, a motor vehicle purchase or lease incentive program, a new technology research and development

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[1] According to "SEC. 181. CLASSIFICATIONS AND ATTAINMENT DATES" of the 1990 Clean Air Act (EPA, 1990)
[2] The TNRCC is now the Texas Commission on Environmental Quality (TCEQ).

program, an energy efficiency grant program, and a building energy performance standards program.[3] As part of the 2001 building energy performance standards program, the Texas Legislature established the 2000 International Energy Conservation Code (IECC) as the state energy code (TNRCC, 2002). This code includes the regulation of new construction, including: the insulation level of ceilings, walls, floor/foundations and efficiencies of mechanical, lighting and power systems. Since September 1, 2001, the 2000 IECC has been required for newly constructed single and multifamily houses in Texas, as well as commercial buildings. This study develops and applies portions of a methodology to calculate the energy savings and emissions reductions from the implementation of the 2000 IECC to new single family houses in non-attainment and affected counties in Texas.

1.3. Objective and Scope

The primary objective of this research is to develop and test a methodology to calculate the energy savings and emissions reductions from adopting the 2000 IECC[4] to new single family houses in non-attainment and affected counties[5] in Texas. To achieve this objective, the following tasks have been defined:

1) Develop an overall procedure for calculating savings from the adoption of the 2000 IECC to commercial, residential and industrial buildings in Texas.

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[3] In 2003, the initial Texas Emissions Reduction Plan (TERP) was amended in response to the House Bill (HB) 1356, enacted by the 78th Texas Legislature. The HB 1356 includes the amendments of the surcharges and fees, and the addition of three counties (i.e., Henderson, Hood and Hunt) to the list of affected counties.

[4] This includes the 2001 Supplement to the 2000 IECC, which is published in 2001 by the International Code Council (International Code Council, 2001).

[5] Affected Counties are the counties that are on the borderline of being classified as non-attainment areas.

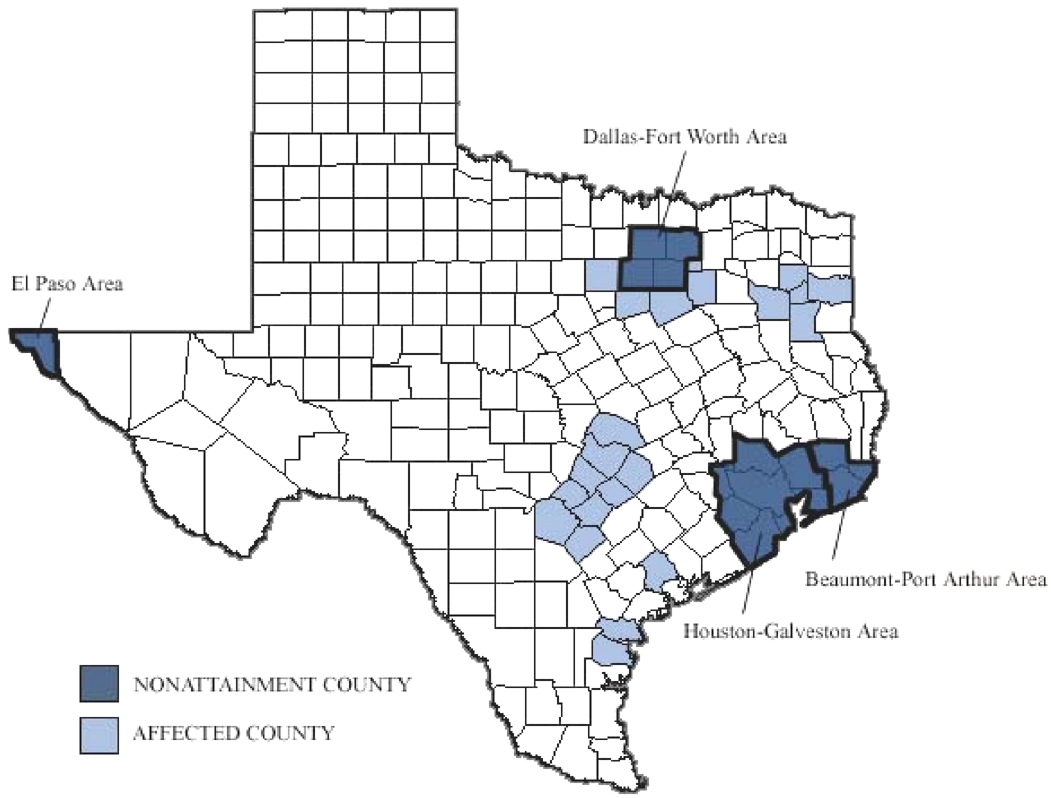

Figure 1.1 – Non-attainment and affected counties in Texas

2) Survey existing single family residential building characteristics that affect a building's energy use.

3) Develop typical characteristics of existing single family construction and code-compliant construction from the survey data.

4) Use the DOE-2 energy simulation program to compare the energy use of existing and code-compliant single family residential houses.

5) Develop and test procedures to crosscheck the data using site visits and utility billing analysis.

6) Calculate emissions reductions from the energy savings for the year 2002.

Although the target buildings of Senate Bill 5 include residential, commercial and industrial buildings, the scope of this research will be limited to the single family houses in non-attainment and affected counties in Texas. Each of the tasks is defined in the sections of that follow.

1) Baseline construction data collection

This includes collecting the average characteristics of single family houses built in 1999 from several sources such as the National Association of Home Builders (NAHB, 2000), the Air-Conditioning and Refrigeration Institute (ARI), Gas Appliance Manufacturers Association (GAMA) and other studies. Using the collected data, a typical house built in 1999 will be defined.

2) Development of the 2000 IECC standard building simulation

The 2000 IECC will be reviewed, and a code-compliant DOE-2 simulation of a single family standard house will be used to calculate code compliance for each IECC climate zone.

3) Projection of the number of building permits in 2002

To project the number of building permits of 2002, previous single family building permit data will be collected from the U.S. Census Bureau (U.S. Census Bureau, 1999) , the Real Estate Center at Texas A&M University (RECenter 2002), the data published F.W. Dodge company (F.W. Dodge), etc.

4) Comparison of energy simulations

The DOE-2.1e (ver. 119) building energy simulation program is used to calculate the annual and peak-day energy use of the baseline and the 2000 IECC compliant house. The energy savings per house will then be calculated as the difference between the baseline and

IECC-compliant house energy use. County-wide energy savings will then be calculated by multiplying the projected number of building permits by the savings per house.

5) Development of the Validation Procedure (Case Study)

A method to validate the building characteristics and simulated energy use for the baseline and the 2000 IECC compliant house is developed, which uses data from the previous studies and site visits to actual houses. For this phase, the following tasks will be defined: 1) Crosscheck from previous studies: the 1999 standard building characteristics defined in the base case study section, and the energy savings calculated in DOE-2 simulations is verified using a crosscheck from previous studies. 2) On-site visits: An overall methodology for the on-site visits is developed. In this study, a case study house is visited to test the methodology. Collected characteristics are compared against the 2000 IECC requirements. 3) Utility bill comparison: Overall methodology is developed to validate the simulated cooling and heating energy savings using utility billing analysis. In this study, utility bills from another case study house are used to demonstrate the procedure of the overall methodology.

6) NO_x emissions reduction calculation

To calculate NO_x emissions reduction by county, a method is developed to calculate energy savings by county, which is then categorized by the appropriate electricity provider or Power Control Area (PCA). Then, annual and peak-day NO_x emissions reductions by county are calculated using the EPA's eGRID program, which allow for the total NO_x emission reductions to be calculated by summing all NO_x reductions in non-attainment and affected counties in Texas.

1.4. Organization of the Thesis

This thesis is divided into 5 chapters. Chapter I is the introduction. This chapter provides the background of the research, the problem statement, objectives and the scope of the study, and the proposed research. Chapter II contains the literature review, which reviews the previous studies that are important to the proposed research, including: ozone pollution, NO_x emissions and electricity use, energy-savings technologies for residential buildings, an overview of existing residential energy codes, an evaluation of energy savings in residential buildings, previous calculations of emissions reduction from building energy conservation and a review of the sources of building characteristics data and sources of NO_x emissions rate. Chapter III presents the research methodology, and discusses the procedures used in this study, which include baseline construction data collection, development of the 2000 IECC standard building simulation, projection of the number of building permits in 2002, comparison of simulated energy use, demonstration of validation methodology, and NO_x emissions reduction calculations. In chapter IV, the results of the study are presented, which includes: the application of the methodology to new construction in the non-attainment and affected counties in 2002. Finally, chapter V contains the summary and future work for the research.

CHAPTER II

LITERATURE REVIEW

This chapter contains the relevant literature review for this study. The relevant literature review for this study includes: ozone pollution, NO_x emissions and electricity use, energy-savings technologies for residential buildings, an overview of existing residential energy codes, an evaluation of energy savings in residential buildings, previous calculations for emissions reduction and a review of the sources of building characteristics data and sources of NO_x emissions rate. To perform this literature review the following sources were reviewed: ASHRAE publications, the Journal of Energy and Building, the Journal of Solar Energy Engineering, the Proceedings of the American Council for an Energy Efficient Economy (ACEEE), and the Proceedings of the Symposium on Improving Building Systems in Hot and Humid Climates, reports from nationally-recognized laboratories such as the Lawrence Berkeley National Laboratory (LBNL), the Energy System Laboratory (ESL) at Texas A&M University, the Energy Information Administration (EIA), the U.S. Census Bureau, and other books related to the proposed research.

2.1. Ozone Pollution

The 1990 Federal Clean Air Act (CAA) sets forth air quality standards for six air pollutants: ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), respirable particulate matter (PM_{10}), and lead (Pb). Table 2.1 presents the EPA's National Ambient Air Quality Standards (NAAQS). When a geographic area in the United States does not meet the air quality standards for one of the six criteria pollutants the area may be classified

Table 2.1 - National ambient air quality standards

POLLUTANT	STANDARD VALUE	STANDARD TYPE
Carbon Monoxide (CO)		
8-hour Average	9 ppm (10 mg/m^3)	Primary
1-hour Average	35 ppm (40 mg/m^3)	Primary
Nitrogen Dioxide (NO_2)		
Annual Arithmetic Mean	0.053 ppm (100 µg/m^3)	Primary & Secondary
Ozone (O_3)		
1-hour Average	0.12 ppm (235 µg/m^3)	Primary & Secondary
8-hour Average **	0.08 ppm (157 µg/m^3)	Primary & Secondary
Lead (Pb)		
Quarterly Average	1.5 µg/m^3	Primary & Secondary
Particulate (PM 10) *Particles with diameters of 10 micrometers or less*		
Annual Arithmetic Mean	50 µg/m^3	Primary & Secondary
24-hour Average	150 µg/m^3	Primary & Secondary
Particulate (PM 2.5) *Particles with diameters of 2.5 micrometers or less*		
Annual Arithmetic Mean	15 µg/m^3	Primary & Secondary
24-hour Average	65 µg/m^3	Primary & Secondary
Sulfur Dioxide (SO_2)		
Annual Arithmetic Mean	0.03 ppm (80 µg/m^3)	Primary
24-hour Average	0.14 ppm (365 µg/m^3)	Primary
3-hour Average	0.50 ppm (1300 µg/m^3)	Secondary

*Source: U.S.E.P.A. (1998), Parenthetical value is an approximately equivalent concentration. ** The 8-hour ozone standard and the PM 2.5 standards are included for information only. A 1999 federal court ruling blocked implementation of these standards, which EPA proposed in 1997. EPA has asked the U.S. Supreme Court to reconsider that decision.*

as a non-attainment area. As of September 2000, there were a total of 114 non-attainment areas on the non-attainment list for the entire Unites States (U.S.E.P.A., 2001). Among these, 4 areas are in Texas; the Beamont-Port Arthur area, the El Paso area, the Dallas-Fort Worth area and the Houston-Galveston-Brazoria area. These four areas violate the one hour ground level ozone standards of 0.12 ppm. Parts of the El Paso area also violate the standards for particulate matter and carbon monoxide.

Ozone is recognized as a pervasive pollution problem in Texas. Generally, ozone is formed in the atmosphere by the reaction of VOCs and NO_x in the presence of heat and sunlight. VOCs are emitted from a variety of sources including: motor vehicles, chemical plants, refineries, factories, consumer and commercial products, other industries, and natural sources. NO_x are emitted from the combustion of fossil fuel in motor vehicles, power plants, and other sources as well as natural sources. Natural sources of NO_x include lightning, certain plants and biological processes in soil. Certain areas of Texas have shown increases in ground-level ozone over the last 10 years, due largely to increased NO_x emissions and weather conditions favorable to ozone formation (U.S.E.P.A., 2001). Unfortunately, ozone has clear, documented impacts on human health, crops, and ecosystems. Exposures to high levels of ozone can result in lung inflammation, and the aggravation of pre-existing respiratory diseases such as asthma[6]. Ozone also makes people more susceptible to respiratory infection (U.S.E.P.A., 2001).

[6] According to National Institutes of Health, the overall prevalence of asthma rose from 30.7 per 1,000 population in 1980 to a 2-year average of 53.8 per 1,000 in 1993-94. This represents an increase of 75 percent. (NIH, 1999)

2.2. NO_x Emissions from Electricity Use

"Nitrogen oxides, or NO_x, is the generic term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying amounts." (U.S.E.P.A., 1998, pp. 1). NO_x originates when fuel is burned at high temperatures, which is required in many highly-efficient combustion processes. The primary sources of NO_x are stationary point source, area source, on-road mobile source, and non-road mobile source. In general, stationary point source includes industrial and commercial boilers, electricity utility boilers, turbine engines, chemical and petroleum processing operations, etc. Area source includes the small insignificant point sources such as residential fuel combustion, forest fires, and light industrial/commercial sources which individually emit less than one ton per calendar year. On-Road mobile source includes all types of motor vehicles, trucks, cars, motorcycles, and light diesel-powered trucks. Non-road mobile source includes aircraft, locomotives, ships, barges, and small engines. According to the TNRCC (TNRCC, 2000), in the Houston-Galveston-Brazoria area, NO_x emissions are estimated to be Area (2%), Non-road Mobile (20%), On-road Mobile (25%) and Stationary Point sources (53%). In this region, chemical and petroleum refineries and electric utilities account for most of the emissions of the Stationary point sources. The NO_x emissions from electric utilities are influenced by their respective NO_x emission rates which are described by the pounds of NO_x emitted per MWh of electricity generated. Utilities can reduce their NO_x emissions by either reducing the NO_x emissions rate of their power plant or by reducing the demand for electricity from residential, commercial and industrial customers, or both.

While it is advantageous to reduce the demand for electricity to reduce NO_x emissions, the demand for electricity in the residential sector, which represents 36 percent of total demand for electricity in the Unites States, is increasing at a substantial rate (EIA, 2001). Figure 2.1 shows the residential primary energy consumption in Texas by fuel from 1960 to

1999. The total electricity consumption of the residential sector in Texas also increased from 82,548 MWh in 1990 to 108,591 MWh in 1999 (a 3.1 percent annual growth rate). During the same period, the annual growth rate of total housing units in Texas was only 1.4 percent (U.S. Census Bureau, 1999). Therefore, the average electricity use per house has increased during the 1990s[7]. Therefore, tracking both the electricity use per building and the number of new buildings in Texas each year is an important task of this thesis work.

2.3. Energy-Saving Technologies for Residential Buildings

Since the 1973 energy crisis, there have been remarkable developments in energy saving technologies for residential buildings. Generally, studies of energy saving technologies in residential buildings are conducted to verify the total energy savings in buildings. These

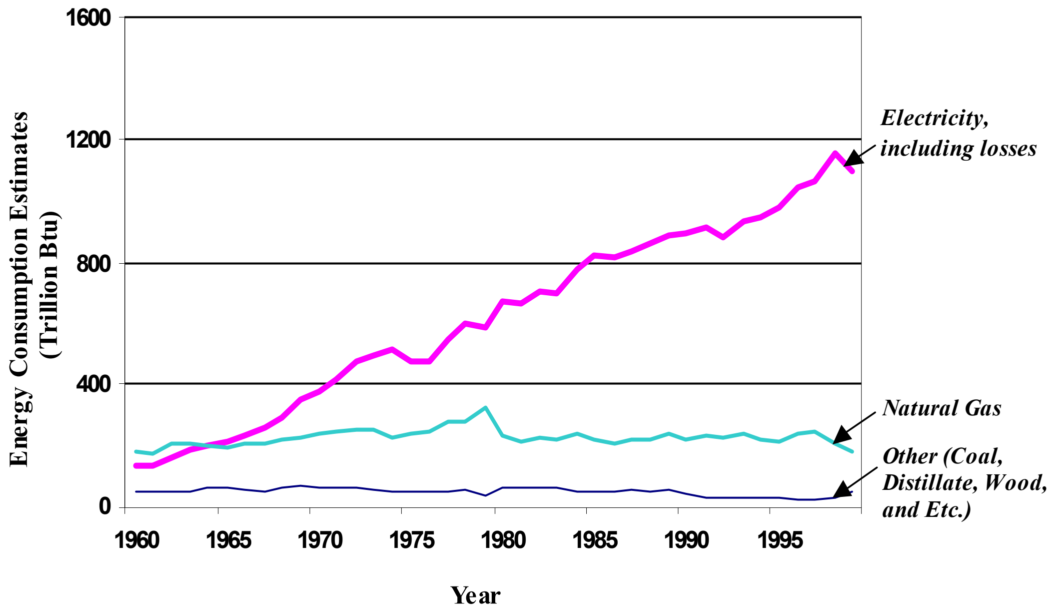

Figure 2.1 - Residential primary energy consumption in Texas by fuel, 1960-1999
(Source: Energy Information Administration, State Energy Data Report 1999, DOE/EIA-2014(99))

[7] Possible reasons for this increase include the increase number of the houses equipped with air-conditioning systems, and other energy consuming appliance such as swimming pools, personal computer systems, etc.

technologies include improved thermal insulation for walls, high efficiency windows such as low-e windows, energy efficient cooling and heating systems, energy efficient domestic hot water heaters, energy efficient lighting, and other energy efficient home appliances and construction practices. The following studies are most relevant to this thesis: Anello et al. (2000), Farrar-Nagy et al. (2000), and Schiller and Associates (2001).

Anello et al. (2000) conducted side-by-side tests to evaluate the impact of high performance windows on space cooling demand for two identical 2,122 square foot houses in Melbourne, Florida. In this study, double-pane, spectrally selective, thermally-broken windows were compared with single-pane windows without a thermal break in the metal frame. A detailed DOE-2 simulation was performed to compare the actual energy savings versus predicted savings. In this simulation, however, they did not consider the impact of internal or external building shades, which can be another energy saving measure. Use of a calibrated energy simulation showed that the annual cooling energy savings from the high performance windows was 937 kWh, or about $75/year at typical Florida electric rates of $0.08/kWh. The results of the Anello et al. study are useful because they can be used to compare the estimated energy and the resultant emissions savings from this thesis study by applying energy efficiency measures such as high-efficient windows.

Farrar-Nagy et al. (2000) evaluated the impact of shading and glazing combinations on a case-study building in Tucson, Arizona. Theoretically, solar heat gain can be reduced by spectrally selective windows, architectural shading and site shading from adjacent buildings. This study described the modeling and testing procedures used to evaluate the prototype house and summarized the relative impacts of several fenestration solar-gain control strategies. Building performance was modeled using the DOE-2 hourly energy simulation tool. The floor area of the test house was 1,170 square feet, and the house had 272 square feet of window area.

Four sliding glass doors facing an east patio made up about 80% of total window area. The Shading Coefficient (SC) for the spectrally selective windows was 0.37, and the center-of-glass U-factor was 0.296 Btu/hr-ft^2-F. The sliding glass doors had a SC of 0.57 and center-of-glass U-factor of 0.345. The results show that the use of high-performance glazing (i.e. low-e windows) reduced daily cooling energy use by 4.4 kWh/day (22%), and the combination of high-performance glazing and shading achieved a 0.4 kW (14%) reduction in peak demand and 12.4 kWh/day (30%) reduction in daily cooling energy compared to the same house with standard double-pane windows and no shading. For this thesis study, low-e windows as required by the 2000 IECC compliant house will be compared against regular double-pane windows. The resultant energy savings can be then compared to the results by Farrar-Nagy et al.

Schiller and Associates (2001) compared the energy use of a typical new house to the energy use of an ENERGY STAR compliant home. The ENERGY STAR labeled home is a national, voluntary program that promotes energy-efficient housing (EPA 2002). In the ENERGY STAR home, energy savings are achieved from various energy-efficient technologies and construction practices including: tight construction, sealed ducts, improved insulation, energy-efficient heating and cooling equipment, and high performance windows. In this study, the annual energy use and summer peak demand of typical and ENERGY STAR compliant houses in three areas, Houston, Dallas, and Amarillo, were simulated and analyzed. As the baseline average characteristics of typical house, the minimum requirements of the 1995 Model Energy Code (MEC) were used. The estimated savings were separated into three categories of floor area, which were: 1,250, 2,250, and 3,250 square feet. The results show that average annual energy savings for the Houston, Dallas, and Amarillo areas were 2,891 kWh/yr, 2,285 kWh/yr and 1,177 kWh/yr, respectively. The results also show that average peak demand savings for the Houston, Dallas, and Amarillo areas are 1.2 kW, 0.9 kW, and 1.1 kW, respectively. This study is very similar to this study except the study by Schiller and Associates did not calculate emissions reductions from energy savings. However, this study can use the results from Schiller's report to compare annual energy and peak demand savings from selected counties. Also, the average building characteristics of new houses in Schiller's report could be used to compare to the average building characteristics in this study.

2.4. Overview of Existing Residential Energy Codes

A properly applied energy code is considered one of the easiest and most cost-effective ways to help consumers reduce energy costs. In addition, energy codes improve air quality by reducing emissions such as NO_x, SO_2, CO_2 and particulates associated with electricity produced from the combustion of fossil fuels. In this section, the history and the status of residential building energy codes and several existing residential building energy codes will be reviewed. These codes include the California Title 24 program, the Model Energy Code, the International Energy Conservation Code, and ASHRAE Standard 90.2.

2.4.1. California Title 24

California Title 24, Energy Efficiency Standards for Residential and Non-residential Buildings, was one of the first state energy codes, which was established in 1978 in response to state legislation to reduce California's energy consumption. This code established building energy efficiency standards for new construction, including requirements for new buildings, additions, alterations, and in non-residential buildings, repairs. The requirements for residential buildings include insulation, glazing/fenestration, radiant barriers, thermal mass, space-conditioning systems, and water-heating systems. Title 24 provides two methods for complying with the code; a prescriptive package approach and computer performance methods. Title 24's prescriptive package approach is similar to Chapters 5 and 6 in the 2000 IECC (ICC, 1999), which define the minimum or maximum requirements for each individual component of the proposed building to meet a prescribed minimum energy requirement. To comply with the code using the prescriptive package approach, each building component must meet or exceed the energy conservation level specified in the prescriptive packages. The prescriptive package approach is the simplest but less flexible way to check compliance. The computer performance method provides a more flexible method to meet the standards compared to prescriptive packages. Using this method, the building designer can tradeoff the energy performance of different building components to achieve compliance. For performance methods, the California Energy Commission approved the use of specific computer programs to calculate the predicted energy usage for a proposed building. These programs include CALRES2 (California Energy Commission, 2001a), Energy Pro (EnergySoft, LLC, 2002), Micropas 6 (Enercomp, Inc, 2002), and Perform 2001 (California Energy Commission, 2001b). These computer programs automatically calculate the energy budget for space conditioning and water heating based on the standard design. The standard design is a building the same size as the proposed design, but uses all of the building components specified in the prescriptive packages. To comply with the code, the simulated energy use of the proposed design cannot exceed the energy budget of the standard design (California Energy Commission, 2001c). The compliance procedure of this code provides a detailed example for this thesis study.

2.4.2. Model Energy Code (MEC)

The Model Energy Code (MEC), which was developed jointly by the Building Officials and Code Administrators International (BOCA), the International Conference of

Building Officials (ICBO), the National Conference of States on Building Codes and Standards (NCSBCS) and the Southern Building Code Conference International (SBCCI), was the first official building energy code applicable to the entire United States (ICC, 1999). The first version of the MEC was developed in 1983, and has been updated every three years since its introduction. In December 1995, the Council of American Building Officials (CABO) assigned all rights and responsibilities of the Model Energy Code to the International Code Council (ICC). The first edition of the International Energy Conservation Code (IECC), issued by the ICC in 1998, replaced the 1995 CABO Model Energy Code (ICC, 1999). The most recent version of the IECC was published in 2000. New editions will be published at three-year intervals with supplements published annually. As of the fall of 2001, 39 states have adopted the MEC or an equivalent state code as their statewide residential energy code, which includes the 1992, 1993, and 1995 MEC or 2000 IECC. Some states have adopted these codes for all residential buildings. Others have adopted codes only for selected buildings such as multifamily houses (BCAP, 2002). Another 11 states have no statewide residential code or their residential code is not EPAct[8] compliant.

2.4.3. ASHRAE Standard 90.2

ASHRAE Standard 90.2-2001 *Energy Efficient Design for New Low-Rise Residential Buildings* (ASHRAE, 2001a) was developed by ASHRAE to provide minimum requirements for the energy-efficient design of residential buildings. This standard applies to the building envelope, heating equipment and systems, air-conditioning equipment and systems, domestic water-heating equipment and systems, and provisions for overall building design alternatives and trade-offs (ASHRAE, 2001a). This standard provides two paths for compliance: a

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[8] The Federal Energy Policy Act (EPAct) of 1992 requires state regulations of new building construction through building codes and standards that are equivalent to or exceed the 1992 MEC.

prescriptive path and an annual energy cost method. The prescriptive paths can be used when a rapid and easy compliance check is desired. The annual energy cost method should be used when the proposed design does not meet the prescriptive requirements or when more innovative design concepts are proposed.

2.4.4. The 2000 International Energy Conservation Code (IECC)

The 2000 IECC is a comprehensive energy conservation code that establishes minimum design and construction parameters for newly-built residential and commercial buildings to produce energy efficient buildings. As the successor of the ICC Model Energy Code (MEC) and the 1998 IECC, the 2000 IECC is similar to the previous codes and includes several new requirements. The most notable new feature in residential buildings is a new Chapter 6, which contains a prescriptive compliance approach. This chapter is basically the same as the International Residential Code (IRC)'s energy chapter, Chapter 11(ICC, 1999).

Chapter 6 defines the maximum glazing U-value and minimum exterior wall, ceiling, floor, basement wall, perimeter slab, and crawl space wall R-values. Chapter 6 is applicable only if glazing area does not exceed 15 percent of the gross area of the exterior walls for a single family house (Type A.1) and 25 percent for multifamily houses (Type A.2). If the glazing area of a house exceeds this, Chapter 5, should be used to design the building. The prescriptive tables in Chapter 5 define minimum R-value or maximum U-factor of each thermal envelope component for various window-to-wall area percentages for residential type A.1 (for the glazing areas of 8, 12, 15, 18, 20, and 25 percent of the gross area of exterior walls) and A.2 housing (for the glazing areas of 20, 25, and 30 percent of the gross area of exterior walls).

As another compliance approach, Chapter 4 provides a residential performance path. This approach uses the total annual energy usage for a building (i.e. the total building performance method) to assure compliance with the code. When Chapter 4 is used, the total annual energy use of a new building must be equal to or less than the energy use of an equivalent building built to the prescriptive specification of Chapter 5 or 6. The last two chapters of the 2000 IECC, Chapters 7 and 8 are dedicated to commercial buildings. Chapter 7 refers to ASHRAE 90.1 *Energy Code for Commercial and High-Rise Residential Buildings*. Since September 2001, compliance with the 2000 IECC, as amended by the 2001 Supplement, is required for all newly constructed buildings in Texas. This thesis study will therefore develop a methodology to calculate the energy savings and NO_x emissions reduction due to the 2000 IECC adoption.

2.5. Evaluation of Energy Savings in Residential Buildings

Energy savings from energy conservation measures in residential buildings have been calculated using many different methods. According to McDonald and Wassermann's 1989 study (McDonald and Wassermann, 1989), these methods include: 1) annual total energy and energy intensity comparisons, 2) linear regression models, 3) multiple regression models, 4) building simulation programs and, 5) dynamic thermal performance models. Annual total energy and energy intensity comparison is a simple and straightforward method to quantify and compare building energy use. However, this method is not sensitive to year-to-year changes in weather, occupancy, schedules, or building usage. Linear regression models have been successfully used to model residential heating and cooling energy use. In this method, energy use is divided into a constant monthly base consumption and a consumption component that is linearly proportional to either average monthly ambient temperature or heating degree days

(HDD). While linear regression models have only one variable such as ambient temperature, multiple regression models have also been used that have several factors that influence building energy use. When using multiple regression models, one must be careful to choose relevant, statistically significant independent variables to develop a successful model. Dynamic thermal performance models are usually required because of the limitations of simple steady state models. This method can provide peak load calculation, rapid diagnostics, and optimal control (Rabl, 1988).

Building simulation programs have also been used in the building design phase to model the predicted energy usage of the building. After the building was constructed, actual energy consumption can be compared against the simulated use to evaluate energy performance. This approach allows checking of certain complex interactions between systems. This method also can be used to evaluate the conservation potential in existing buildings. Of these methods, building simulation programs and linear and multiple regression models are reviewed for this thesis study. The first method considered, calibrated simulation, uses measured energy consumption data to calibrate or fine-tune the results of a computer simulation program such as the DOE-2 building energy simulation program (LBL 1993). Because the thesis study uses the DOE-2 building simulation program to calculate energy savings due to the code adoption, the detailed calibration procedure including the required information for calibration and several calibration methods will be important to this thesis study. The other method, the PRInceton Scorekeeping Method (PRISM) (Fels et al., 1986) and ASHRAE's Inverse Modeling Toolkit (IMT) (Kissock et al., 2001) use a change-point linear regression or variable-based degree-day model. As mentioned above, linear regression models have been successfully used to model residential heating and cooling energy use. In this thesis study, a change-point linear model is used to validate the simulated cooling and the heating energy use using the utility bills from a case study house.

2.5.1. Calibrated Simulation

During the past three decades, various hourly building energy simulation programs have been used to predict the energy consumption of a new building, design and properly size heating, ventilating and air-conditioning (HVAC) systems, and evaluate energy savings from energy conservation retrofits to existing buildings. Another important issue is how well the simulated model predictions fit measured data from a real building (Bou-Saada, 1994). A well-calibrated simulation can be used to evaluate retrofit strategies. During the last ten years, numerous studies about calibrated simulations have been reported. These studies include Hsieh (1988) who calibrated the DOE-2 model to two instrumented commercial building to track performance, Subbarao et al. (1990) who studied the problem of matching simulated data to measured data in buildings, Kaplan et al. (1990, 1992) who showed the general procedure for calibrated simulation, Bronson et al. (1992) who presented a procedure for calibrating DOE-2 to non-weather-dependent loads, Bou-Saada (1994) who showed an improved procedure for developing a calibrated hourly simulation model to weather-dependent loads, Soebarto(1996) who presented a calibration methodology using only two to four weeks of hourly monitored and monthly utility bills, Haberl et al. (1998) who used calibrated simulation to analyze energy conservation measures in two identical Habitat for Humanity houses, Haberl and Bou-Saada (1998) who reviewed the previous literature about calibration techniques and presented several new calibration methods, and Sylvester et al. (2002) who presented a method for verifying the energy savings of a newly constructed commercial building using a baseline simulation model calibrated to the measured whole-building energy consumption. Of these, the following studies are the most relevant for this thesis study.

Hsieh (1988) calibrated the DOE-2 model to two commercial buildings to track performance. This study is one of the first studies to show a general procedure for calibrated simulation. The results of Hsieh study showed that calibration at the hourly level to measured data provided the best alignment between the simulation and the measured data. The results also showed that an 18-20% difference in envelope heat loss between the measured data and the design stage predictions. This research provided this thesis the general procedure of calibration.

Kaplan et al. (1990) calibrated a DOE-2.1c model to monitored data from a small office building. This study is also one of the first studies to show a general procedure for calibrated simulation. Monitored data were used both to generate DOE-2 inputs and to verify DOE-2 outputs. Then, a series of iterations are made until the modeled output was within a certain tolerance band of the monitored data. The result shows that nine major changes were required to tune the DOE-2 model within the tolerance band. Although the target of this study was a commercial building, the general procedure of calibration is helpful for this thesis study.

Haberl et al. (1998) used calibrated simulation to analyze energy conservation measures in two identical Habitat for Humanity houses. After developing a base model, they tuned the input data until the simulated results matched measured data to within an acceptable range (i.e., 5 to 10 %). Then, the calibrated simulation was used to analyze the energy savings from applying several energy conservation measures to the Habitat for Humanity houses. This research is important to the current work because the study provided a detailed procedure for evaluating individual and combined energy savings features in residential buildings.

Haberl and Bou-Saada (1998) reviewed previous literature about calibration techniques and presented several new calibration methods including graphical procedures and statistical goodness-of-fit parameters for quantitatively comparing simulated data to measured data. Haberl and Bou-Saada's calibration methods were applied to a case study building which is a four zone, single-story electrically heated and cooled building. The results showed that the new calibration procedures were able to produce an hourly mean bias error (MBE) of -0.7% and an hourly coefficient of variation of the root mean squared error (CV(RMSE)) of 23.1 % which is acceptable compared with the most accurate hourly neural network models (Kreider and Haberl, 1994, and Haberl and Thamilseran, 1998). This research is useful for the current work because it provides a detailed calibration procedures including required information for calibrating DOE-2, graphical methods for improving a calibration, and statistical calibration methods.

2.5.2. PRInceton Scorekeeping Method (PRISM) and ASHRAE's Inverse Modeling Toolkit (IMT)

PRISM is a variable-based degree-day regression method which was developed to calculate residential energy savings from energy conservation retrofits (Fels et al., 1986). PRISM was developed in the 1980's to satisfy the need for a reliable scorekeeping method in residential energy conservation programs. PRISM uses monthly utility bills and at least ten years of average daily temperatures from a nearby weather station as data sources. The final product, the Normalized Annual Consumption (NAC) index provides a measure of what energy consumption would be during long-term, average weather conditions. Total energy savings are calculated as the difference between the NAC in the pre- and post-retrofit periods. Many studies about the evaluation of energy conservation retrofits in residential buildings have been performed using PRISM. These studies include Rodberg (1986) who used PRISM to analyze the results of energy conservation measures applied to a sample of low-income homes in New York City, Goldberg (1986) who applied the PRISM to an evaluation of a low-income weatherization program,, Goldman et al. (1986) who used PRISM to analyze the energy savings due to the energy retrofit for five multifamily houses, and Wang et al.(1996) who shows the detailed procedures for energy savings calculation in a large sample of residential buildings. Of these studies, the study of Wang et al.(1996) is the most relevant for this thesis study.

Wang et al.(1996) reviewed the various parameters that are required to develop a proper baseline model, and the methodology used to calculate energy savings from retrofits to low-income housing. In addition, Wang et al. explained the importance of using a weather normalized comparison instead of a direct utility bill comparison. Although there are usually consistent outdoor temperatures over several years, weather correction is absolutely required to obtain reliable estimates of retrofit energy savings. This study provides useful procedures for energy savings calculation in a large sample of residential buildings including selection procedures to obtain more reliable PRISM results.

ASHRAE's Inverse Model Toolkit (IMT) is a FORTRAN 90 application for regression modeling of building energy use (Kissock et al., 2001). This toolkit can identify best-fit regression models for measuring retrofit savings in buildings. The IMT includes PRISM's variable-based degree-day algorithms, and it includes traditional linear, least squares regression models, change-point linear models, multi-linear regression models, and combined models. Therefore, for this thesis study, the IMT toolkit will be used to compare the normalized energy use before and after code adoption.

2.6. Calculations for Emissions Reduction

As mentioned above, energy conservation in buildings is being considered by the U.S.E.P.A. for reducing air pollution from power plants. Several studies about emissions reductions from energy conservation have been previously reported. In this section, these studies will be discussed to review the procedures for calculation of emissions reduction. These studies include XENERGY (2001), Henwood Energy Services (2000), and Meisegeier et al. (2002).

XENERGY (2001) analyzed the energy savings and emissions reduction impact of the 1998 Massachusetts residential energy code. This study addressed the overall effects of the new code, including energy and emission savings. They determined current construction practices from previous documents and onsite surveys. Then, they used MAS*check*[9] to assess the level of code compliance of current construction. Finally, they simulated the energy use and used these results to estimate the savings for both complying and non-complying houses using the DOE-2.1 building simulation program. XENERGY also calculated the annual emissions reductions from energy savings on a per house basis. Based on this study, which used MAS*check,* they found that only 46.4 % of the new houses complied with the overall thermal envelope performance (UA) requirements of the code. Comparison of the characteristics of compliant and non-compliant houses found that non-compliant houses typically had less insulation in wall cavities, less efficient heating equipment, and poor duct sealing. The simulation results showed that energy savings occurred for both houses, but the space heating and cooling energy savings from code-compliant houses were about 50% larger than for non-compliant houses. The analysis of emissions reductions was performed using average

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[9] MAScheck is a specially modified version of MEC*Check*. MEC*Check* (U.S.DOE, 1995) was developed by Pacific Northwest National Laboratory (PNNL) to demonstrate compliance with the insulation and window requirements of the Council of American Building Officials (CABO) Model Energy Code (MEC).

emissions rates per unit of energy type multiplied by the amount of energy saved. For example, 2.6 lbs/MWh of NOx rate was used to calculate the NO_x reduction. The calculation showed that annual reduction of 24.5 tons of NO_x, 30.4 tons of SOx and 26,600 tons of CO_2 could be reduced attributed to energy savings from the l 14,442 new houses constructed under the revised code in 2000. In the XENERGY study, they presented the detailed description of how they inspected and measured existing house components, and what kind of instrumentation was used for the site visit. Although the site survey in this thesis targeted a house under construction instead of existing house, the XENERGY site check method can provide a guideline when conducting the site survey for this thesis. The XENERGY study also includes procedures for the calculation of energy savings from energy code adoption and calculation of emissions reductions from the energy savings. This thesis will improve on the XENERGY study since they used an average annual emissions rate to calculate emissions reductions. For this thesis, a detailed grid model contained in the U.S. EPA's eGRID database of Texas will be used to provide a more accurate annual and peak-day emission reductions.

Henwood Energy Services (2000) assessed NOx reductions from the penetration of higher Seasonal Energy Efficiency Ratio (SEER) Standards for air-conditioning units in the Houston/Galveston area within the service territory of Reliant Energy HL&P. Energy savings from the penetration of higher SEER units were calculated from three groups: single family residences, multifamily residences and commercial units. To calculate the maximum energy reduction (MW) in the peak load hour, they first calculated the peak load difference between SEER 10 and SEER 12 units. The difference was then multiplied by the estimated number of high SEER units in 2007. Then, they estimated the total energy reductions in MWh by multiplying the previously calculated peak one hour savings by total run time hours for the cooling season. The estimated total energy reduction (MWh) and peak electricity reduction

(MW) accomplished by the replacement of 10 SEER units with 12 SEER units over the cooling season in Texas in the year 2007 was calculated to be 2,420,748 MWh and 1,100.3 MW, respectively. For the calculation of NO_x reductions, Henwood's Electric Reliability Council of Texas (ERCOT) market simulation model was used. This proprietary software package conducts an hourly auction that determines each electric utility generation loading level based upon the economics of each power plant. The calculation results showed that NO_x emissions reductions in the ERCOT area as a result of the AC program were the largest in July at 560 tons and total 1,680 tons by the year 2007. The Henwood study provides a useful comparison for the current study in regard to AC savings. This thesis study will be an improvement over the Henwood study because it will calculate peak daily electricity savings using the DOE-2 program for a typical house and the eGRID database to calculate the annual and peak-day NO_x emissions

Meisegeier et al. (2002) analyzed the potential emissions reduction impacts of energy efficiency upgrades in new homes. These impacts include: avoided peak demand (kW), electricity consumption (MWh/yr), and pollution (lbs/year). This analysis was conducted using the DOE-2 energy simulation program and was limited to Houston, Texas. As a first step, they developed a number of prototypical base-case homes. Then, energy efficiency upgrades were selected and applied to the new homes. These upgrades included various individual upgrades and a package that includes several upgrades. The simulation results showed that the developed package saved 1.23 kW peak demand, and 1.6 MWh/yr (i.e., 1,600 kWh/yr) annual electricity use, which translates to 5.99 lbs/day of CO_2, 0.01 lbs/day of NO_x, and 0.01 lbs/day of SO_x per house. To calculate avoided pollution, they used the emission rates from Reliant HL&P for 1998 that were published in the EPA's Emissions and generation Resource Integrated Database (E-Grid) (EPA, 2001). In a similar fashion as the XENERGY study (XENERGY, 2001), Meisegeier et al. used simple emissions rates (lb-NOx/MWh) to calculate emission reduction. Nonetheless, the procedure used to calculate energy savings and the assessment of individual upgrades is useful since it can be compared to selected aspects of the procedure developed from this thesis.

2.7. Sources of Data

This section discusses the sources of construction characteristics data and the different sources of NOx emission rates. These sources include the National Association of Home Builders (NAHB, 2000), the Gas Appliance Manufacturers Association (GAMA), the Air-Conditioning and Refrigeration Institute (ARI), and EPA's eGRID Database (U.S.E.P.A., 2002).

The NAHB's Builder Practices Survey Reports (NAHB, 2000) present data on building material purchases based on responses from 2,800 U.S. home builders. This report is published annually, and targets areas including all 50 states, and 9 census divisions. The data set from the NAHB was for the average building characteristics for 1999 single family houses in Texas and Louisiana. In the NAHB survey, a total of 89 builders in Texas and Louisiana participated. The NAHB divided the region into two groups; west Texas and east Texas/Louisiana[10]. The report gives the average characteristics for each building element such as windows, HVAC equipment, insulation, exterior wall finishes, sheathing, roofing, wall height, floor area, number of stories, and garage. This report will be used in this thesis study to develop the average characteristics of a 1999 new single family house in Texas.

The GAMA provides data on shipments of gas furnaces in Texas during the period of 1995-2000. Although shipping a product to a state doesn't guarantee that product was installed

[10] The building characteristics in east Texas and Louisiana are defined the same according to the NAHB survey

in that state, these data are useful in determining the average Annual Fuel Utilization Efficiency (AFUE) of installed gas furnaces for the 1999 standard house in Texas. The ARI database contains annual 1999 manufacturer's shipments of unitary air-conditioners for residential use by Seasonal Energy Efficiency Ratio (SEER). These data will be used to decide the average SEER of installed unitary air-conditioners for the 1999 standard house in Texas. Finally, the EPA's eGRID provides emissions and resource mix data for all power plant and electric companies in the United States. eGRID NO_x emissions rates of each Power Control Area (PCA) and detailed grid model will be used to calculate NO_x emissions reductions from the estimated energy savings in residences.

2.8. Summary of Literature Review

In summary, this literature review has covered seven categories. For each of these categories the major features of interests are listed below:

1) Ground level ozone is a pervasive pollution problem in Texas. Of importance to this study in May 2001, the Texas state legislature passed Senate Bill 5 to reduce emissions of NO_x by various sources, including the implementation of the 2000 IECC in residential, commercial and industrial buildings.
2) The relationship between NO_x emissions and electricity use was also examined. From the previous studies it was clear that electricity utilities are one of the major sources of NO_x emissions, and utilities can reduce their NO_x emissions by reducing the demand for electricity from new residential, commercial and industrial buildings.
3) Three studies of energy-savings technologies for residential buildings were reviewed. The studies of Anello et al. showed that significant energy savings occur in residential buildings that use of high performance windows. Farrar-Nagy et al. evaluated the impact of

shading and high performance glazing combinations on a case-study building. Schiller and Associates compared the energy use of a typical new house to the energy use of an ENERGY STAR compliant home. All three provided valuable comparisons for the current study.

4) Several existing residential energy codes were reviewed. The codes reviewed included California Title 24, the MEC, the IECC, and ASHRAE Standard 90.2.2001. This code review provided valuable insights for this thesis study because it contained examples from other states where evaluation of codes had been successfully performed using simulation, which also provides valuable comparisons for the current study.
5) Several evaluation methods of energy savings in residences were also reviewed, including, PRISM, ASHRAE's IMT, and calibrated simulation. All three methods provided valuable procedures for this thesis study.
6) Three studies about the calculations for emissions reductions were reviewed. XENERGY, Henwood Energy Services and Meisegeier et al. All three studies calculated the expected NO_x emissions reductions from the estimated energy savings, which provides valuable comparisons for this thesis study. XENERGY and Meisegeier et al. used simple emissions rates to calculate emission reduction, whereas Henwood Energy Service used Henwood's Electric Reliability Council of Texas (ERCOT) market simulation software.
7) Finally, the sources of building characteristics data that are available for buildings in Texas were reviewed. These sources include the National Association of Home Builders (NAHB), the Gas Appliance Manufacturers Association (GAMA), and the Air-Conditioning and Refrigeration Institute (ARI). All these sources provide valuable data for this thesis study. EPA's eGRID was also reviewed for its relevance in the current study.

In summary, this thesis will develop procedures for calculating the annual and peak-day electricity savings from the implementation of the 2000 IECC in single family houses in non-attainment and affected counties in Texas using the DOE-2 building simulation program with building characteristics data provided by the appropriate sources. NO_x emissions reductions will also be calculated from the electricity savings using EPA's detailed eGRID database.

2.9. Significance of the Study

This research is expected to provide the following benefits:

1) A demonstrated procedure for the evaluation of the energy savings due to the impact of the application of the 2000 IECC to new single family residential buildings in Texas.
2) Calculations of annual and peak-day NO_x emission savings in Texas for single family residences for the year 2002.
3) A detailed procedure for the verifying the energy savings and NO_x emissions reduction using utility bill analysis and on-site surveys.

2.10. Limitation of the Study

The limitation of this study includes:

1) This study is limited to new one-story, single family residential housing in the 38 non-attainment and affected counties in Texas.
2) In this thesis, the thermal mass effects were considered indirectly in the DOE-2 simulations using a fixed floor wight.

3) The window's Shading Coefficient (SC) was used in the DOE-2 input file instead of a Solar Heat Gain Coefficient (SHGC), which requires the use of LBNL's Windows 5 program.
4) An electric air conditioning system, natural gas furnace, and natural gas domestic water heater were assumed to be installed in all new single family houses in the non-attainment and affected counties in Texas.
5) For the calculation of the underground surface heat transfer, the U-value of the floor surface was used. For a more accurate calculation, Winkelmann's U-EFFECTIVE method needs to be used instead of the U-value method (Winkelmann, 1998).
6) The DOE-2 input file used in this thesis did not consider the detailed behavior of a forced air distribution system including duct losses, and duct leakage.
7) Interior shading was not considered in the simulations.
8) For simulations, the air infiltration rate for all counties was fixed 0.57.
9) The energy savings from the adoption of the building components above code were not considered.
10) The counties included in SERC, WSCC and SPP NERC regions were excluded in the NO_x emissions reduction calculations in eGRID. Only the ERCOT region was used in eGRID.
11) To calculate the peak-day electricity savings, weather data from the TMY2 weather file was used instead of actual ozone episode day weather data for the peak-day period.

CHAPTER III

METHODOLOGY

This chapter discusses the methodology developed in this research to calculate energy savings and emissions reduction from the adoption of the 2000 IECC in new single family residences. The methodology can be divided into 6 major tasks: 1) Baseline construction data collection, 2) Development of the 2000 IECC standard building simulation, 3) Projection of building permits in 2002[1], 4) Comparison of energy simulations, 5) Demonstration of the validation procedure, and 6) NO_x emissions reduction calculations. The methodology discussed in this chapter has been developed to evaluate the energy savings and the NO_x emissions reductions from the implementation of the 2000 IECC to new residences in non-attainment and affected counties in Texas. Since the purpose of this thesis is to develop the methodology and to apply a "portion" of the methodology, some tasks were not fully performed as outlined in the methodology. These tasks include the validation from on-site visits and validation from utility billing analysis. For these tasks, a case study house was selected, and the methodology was applied to the house to demonstrate proof-of-concept. Figures 3.1, 3.2, 3.3 and 3.4 provide diagrams of these procedures.

3.1. Overview

Figure 3.1 shows the overall procedure for the calculation of 2002 NO_x emission reductions from the implementation of the 2000 IECC in non-attainment and affected counties

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[1] As of the year 2002, only annual building permits data before 2002 were available. Historical permit data was used to project the permit data for 2002. As of the year 2002, only annual building permits data before 2002 were available.

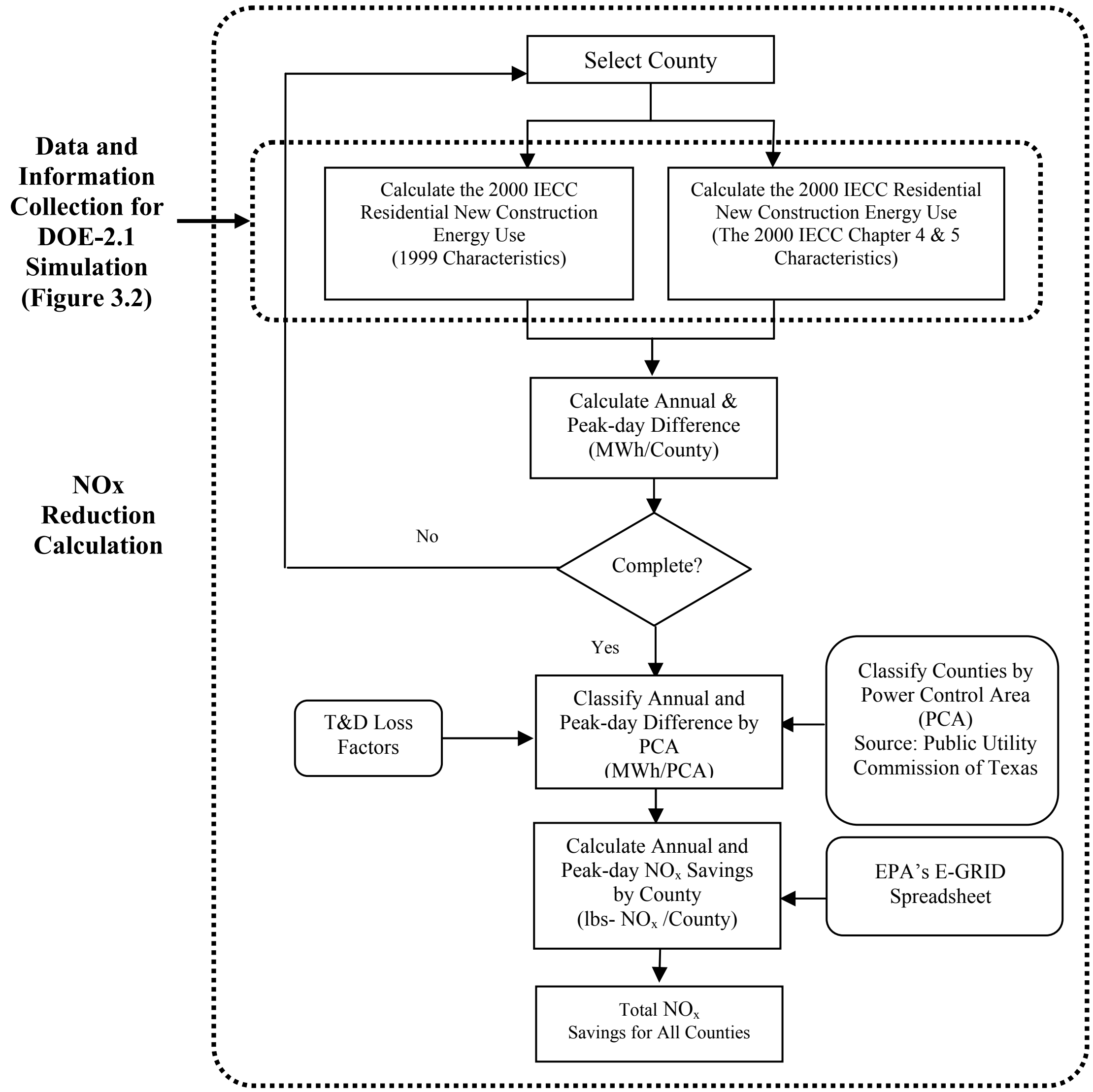

Figure 3.1 - Overall procedure for calculation of 2002 NO_x emission reductions from the implementation of the 2000 IECC in non-attainment & affected Counties in Texas

in Texas. To begin, a county is selected from the 38 non-attainment and affected counties. Then, in order to calculate energy use before and after the code adoption, the required data and information are collected. Using these data and information, two DOE-2 building energy simulations are performed. The first is for the annual and peak-day energy use consumed by new residential construction, which are built to 1999 average building characteristics. The second is for the annual and peak-day energy use consumed by new residential constructions, which are built to be compliant with the requirement in Chapter 4 and 5 of the 2000 IECC. The simulated energy use of a house built to average 1999 characteristics is assumed to be the energy use of an average house before code adoption. The energy use of the code-compliant house is assumed to be the energy use of an average house after code adoption. This energy calculation procedure will be described in further detail in Figure 3.2.

After these calculations are performed, the annual and peak-day energy difference for all houses in a county (MWh/county) is calculated. In this calculation, the energy differences represent the energy savings from the adoption of the 2000 IECC[2]. The calculation procedure up to this point is repeated for all 38 counties. After the calculation of the energy savings for each of the 38 counties is completed, the calculated energy savings are classified by the Power Control Area (PCA) to determine which utility provided the electricity for each county.

After classifying the calculated energy savings by PCA, NO_x emissions reductions (lbs- NO_x /County) were calculated using the EPA's eGRID table. Finally, the total NO_x emissions reductions from the energy savings in 38 counties were calculated.

As mentioned above, Figure 3.2 shows the detailed procedure of data collection and the simulations of energy use. To begin, the required data and information for the energy simulations is collected. The required data and information include: the average building characteristics for the year 1999; the projected number of building permits for the year 2002; the standard building characteristics in Chapter 4 and 5 of the 2000 IECC; the prescriptive tables in Chapter 5 of the 2000 IECC; and the appropriate weather file (TMY2) for each non-attainment and affected county in Texas. After collecting the data and information, a standard

[2] In this study, the 2000 IECC include the 2001 Supplement of the IECC

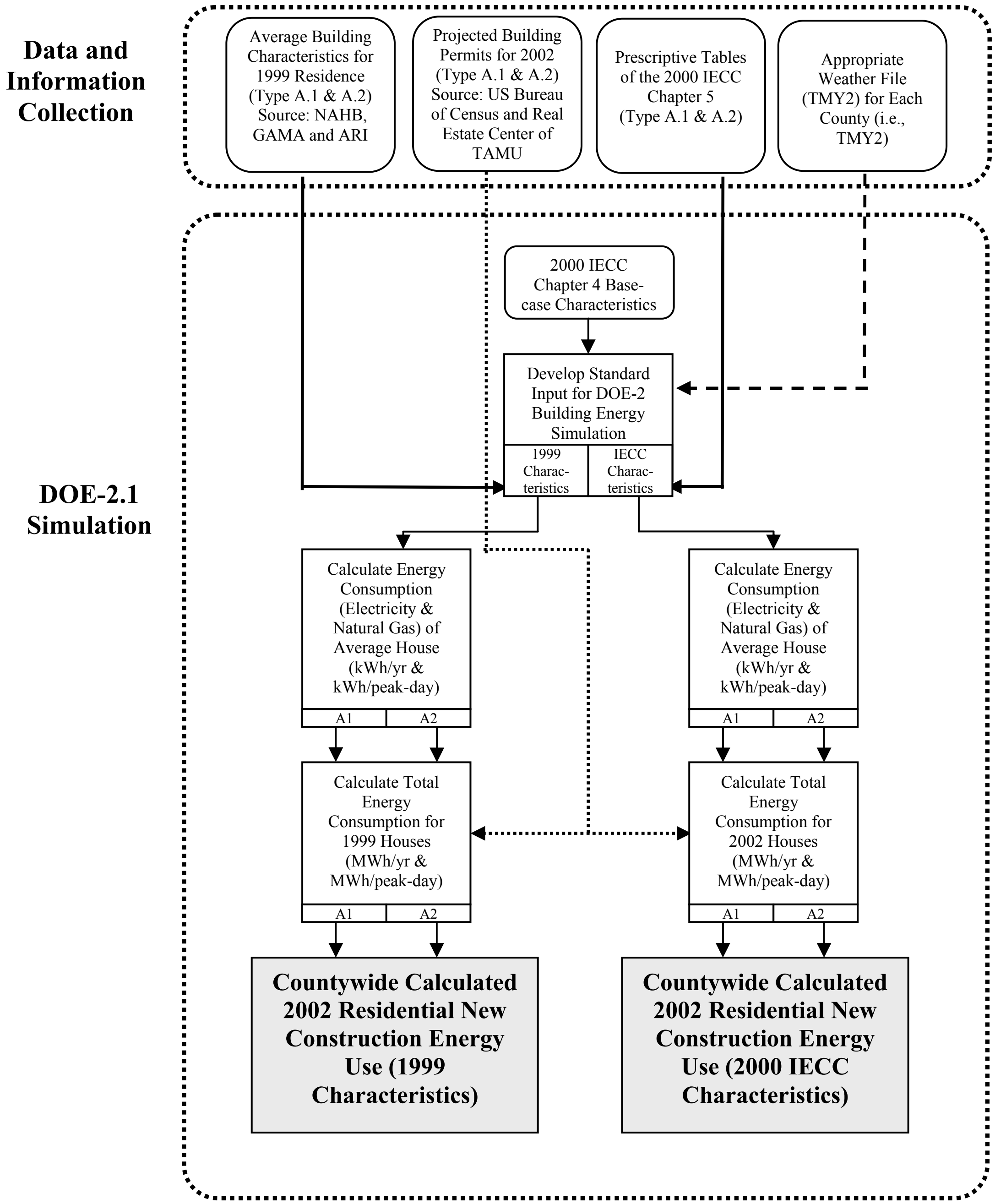

Figure 3.2 - Procedures for the preparation and calculation of countywide energy use for new single family houses before and after code adoption

DOE-2 input file is developed using the standard characteristics in Chapter 4 of the 2000 IECC. This standard input file uses PARAMETER commands to facilitate the rapid simulation of multiple houses. The PARAMETER command will be explained later in this chapter. Using the standard input file, the energy consumption per house before and after code adoption is calculated. The calculated energy use per house is then multiplied by the projected number of building permits for the specific county in the year of 2002. This county-wide energy use represents the total energy use consumed by the new residences in the county for 2002.

Figure 3.3 presents the procedure for the validation of residential housing characteristics using an on-site visit. This procedure was developed to verify average building characteristics for 1999 house built in 2002, which are supposed to be compliant with the 2000

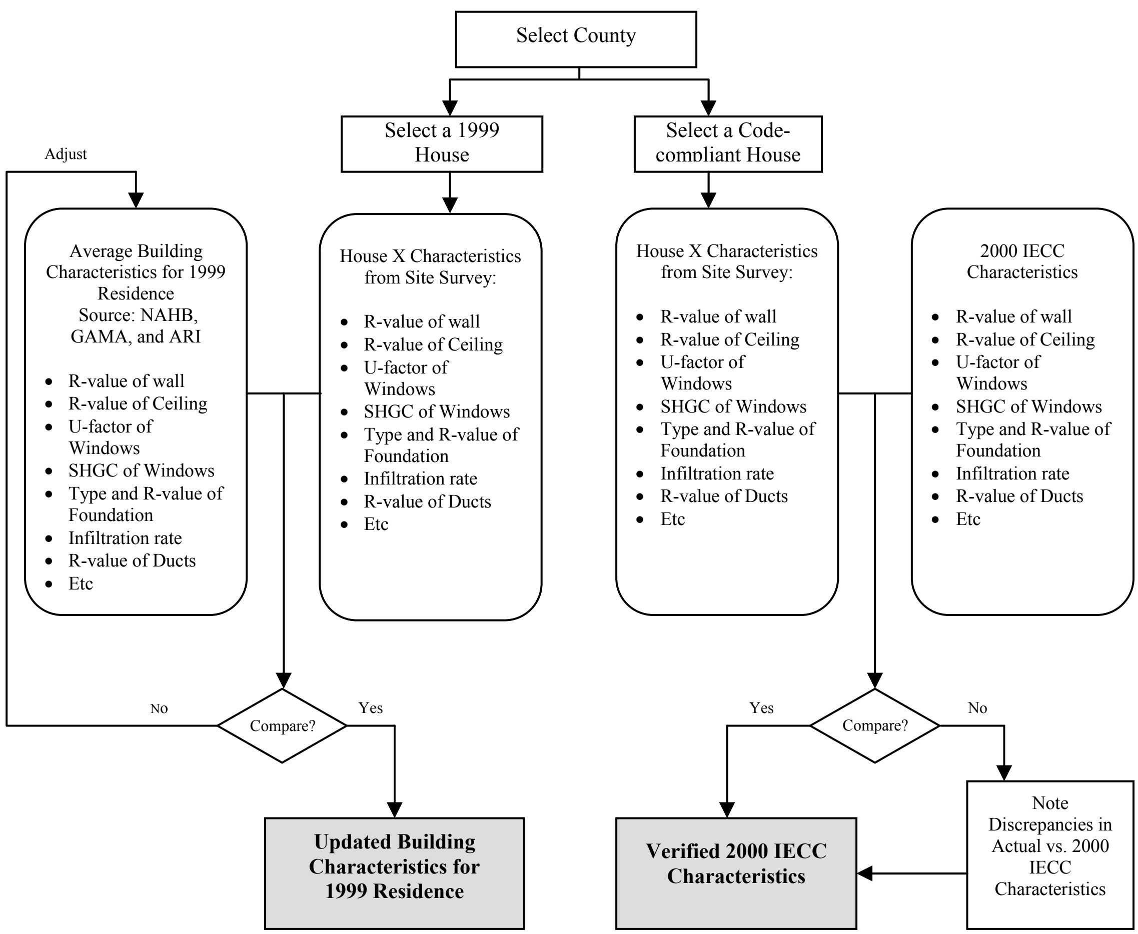

Figure 3.3 - Validation of residential housing characteristics using onsite visit

IECC. In this research, to demonstrate proof-of-concept, a 2002 house was selected as a case study house, and analyzed to develop the methodology for this procedure. Since the single-family houses built in 2002 were assumed to be built in accordance with the requirements of the 2000 IECC, the actual characteristics were compared against the building characteristics of the 2000 IECC.

To begin, a county is selected from the non-attainment and affected counties in Texas. Then, two houses, one built in 1999 and built after the code, are selected. The building characteristics for the two houses are then collected using on-site visits. These characteristics include the R-value of the exterior wall, the R-value of the ceiling, the U-factor and the Solar Heat Gain Coefficient (SHGC) of the windows, the type and the R-value of the foundation, the infiltration rate, the R-value of ducts, etc. Characteristics for 1999 house are then compared with the pre-defined average building characteristics for 1999 residences, and adjustments made as needed. The characteristics for the code-compliant house are also compared with the 2000 IECC characteristics and, in difference to the 1999 characteristics, discrepancies are noted for further analysis.

Figure 3.4 presents the procedure for the validation of the simulated annual energy use and savings using a utility billing analysis. The purpose of this procedure is to validate the simulated energy savings from the comparisons of the simulated energy use for 1999 and code-compliant houses against the annual energy uses for the actual 1999 and code-compliant houses. To obtain the annual energy use for actual 1999 and 2002 houses, monthly utility bills from the houses are obtained and analyzed using three-parameter change-point model. Figure 3.4 shows the overall procedure for this research, in this study, a case study house built before code adoption was selected, and the utility bills for the year 2000 and 2001 were obtained. Then, to demonstrate the analysis method, the utility bills for 2000 were assumed to be the bills

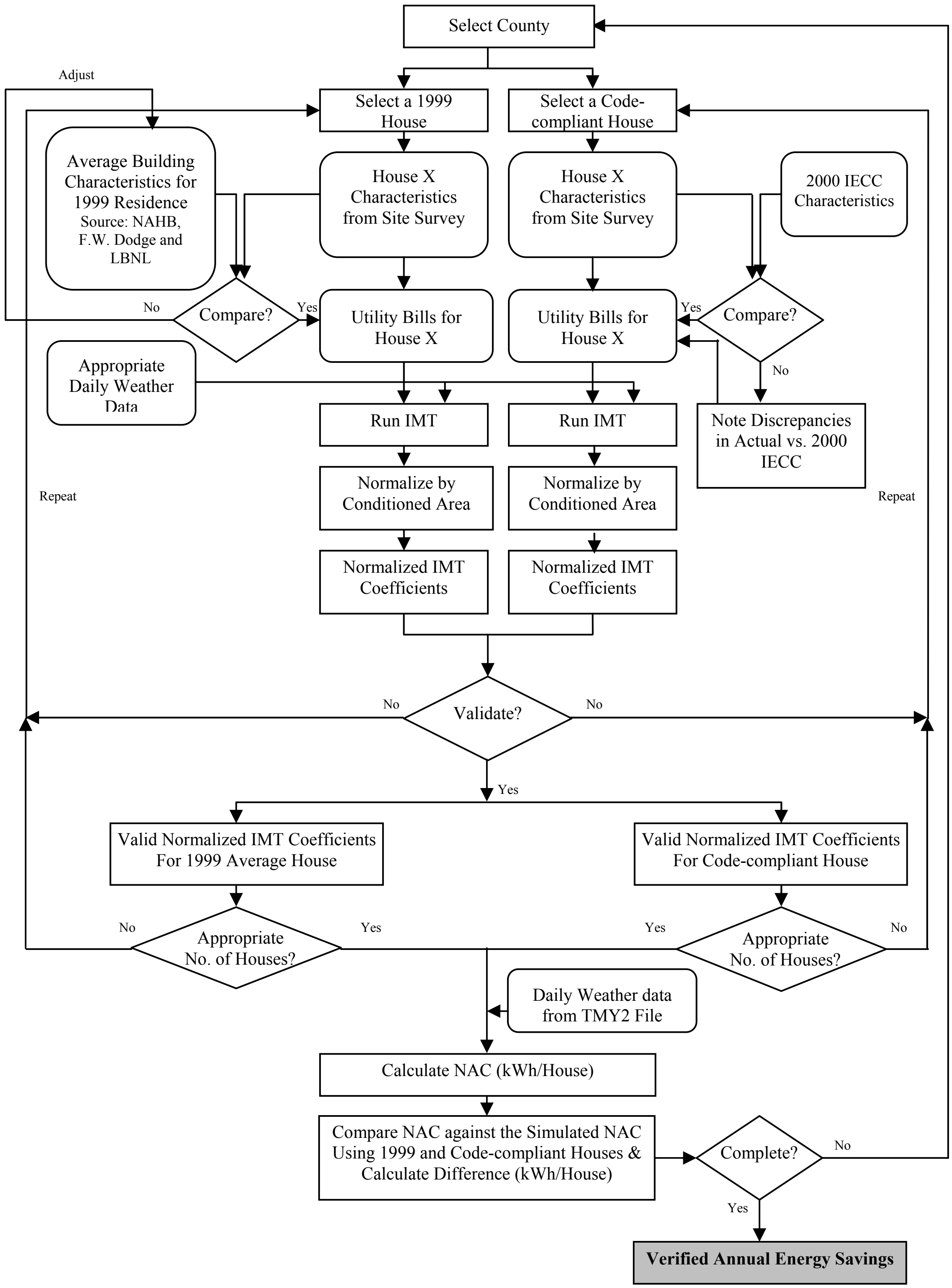

Figure 3.4 - Validation of the annual energy savings using utility bill analysis

from a house built in 1999, and the utility bills from a house built in 2002. Below is the description of the ultimate procedure of the utility billing analysis.

After validating of the residential housing characteristics using onsite visits, actual utility bills for 12 months from the selected 1999 and 2002 houses are obtained. Appropriate daily ambient temperatures for the 1999 and 2002 houses are also collected. The electricity and natural gas use from the utility bills are analyzed using the ASHRAE Inverse Model Toolkit (IMT) (Kissock et al. 2001). From the results of the IMT runs, the IMT coefficients and the Normalized Annual Consumption (NAC) for 1999 and 2002 houses are identified and compared. These procedures are repeated until the appropriated number of houses has been analyzed to represent a statistically significant portion of the total housing population for a county. Finally, the calculated energy savings from the utility billing analysis are compared to the differences in the simulated energy use of the 1999 and the 2002 house according to the procedure in Figure 3.2. Additional information about this procedure is provided in the section on validation.

3.2. Baseline Construction Data Collection

As one of the first steps of this research, it was necessary to determine the average characteristics of single family houses built before code adoption. These characteristics were used to simulate the building energy use of single family houses built before code adoption, and finally to estimate the energy effects of the code adoption. In this research, the single family houses built in 1999 were chosen as the houses built before the building energy code adoption. Two methods of data collection were used in this research. The first was the collection of data from previous similar studies, and the second method was the collection of data from personal communications with several institutes and research centers using emails and phone interviews.

3.2.1. The Data Level

Since the target buildings are single family houses in the 38 non-attainment and affected counties, county-level data would be the preferred data to correctly compare energy use before and after code adoption. If county-level data cannot be obtained, higher level data, such as east and west Texas or State level data, will be used to determine the average building characteristics for each county although the accuracy of data will be lower.

3.2.2. Required Data to Be Collected

Before collecting data, the list of required data was identified. The list of required data was developed based on the data that is required to simulate the standard house using the DOE-2 building simulation program. Although certain data were not used in the simulation procedure, those data were collected for general informative purposes. The data were divided into three categories; General Information, Building Envelope Data, and Building Mechanical Systems and Equipment Data.

3.2.2.1. General Information

General information includes the corresponding year of building characteristics, the number of household occupants, total internal load, etc. (See Appendix A).

3.2.2.2. Building Envelope Data

The building envelope data includes the total floor area, the average wall height, the average thermal performance of the building components, and the air leakage rate. The average thermal performance of the building components includes the R-value of the exterior wall, the roof/ceiling, and the floor R-values, the wall type (i.e., standard, steel frame or mass walls), the floor type, the U-factor of the windows, and the Solar Heat Gain Coefficient (SHGC) of the windows.

3.2.2.3. Building Mechanical Systems and Equipment Data

The building mechanical systems and equipment data includes the location of supply and return ducts, duct insulation level, duct leakage rate, and the efficiency of the cooling and heating systems.

3.3. The Characteristics of the 2000 IECC Standard Building

After collecting the required data for the standard 1999 single family house, the building characteristics required in the 2000 IECC were reviewed. In this research, single family houses built in 2002 were assumed to be built in accordance with the requirements of the 2000 IECC. From the requirements of the 2000 IECC, the appropriate building characteristics for each non-attainment or affected county were identified. The method of assigning building characteristics to a county is explained in Figure 3.5.

3.3.1. Climate Zones

Chapter 3 of the 2000 IECC presents the climate zones for the United States. In the 2000 IECC, climate zones were classified by Heating Degree Days (HDD). The building envelope requirements in the 2000 IECC are defined differently according to climate zones. As a first step of defining building characteristics for each county, therefore, 38 non-attainment and affected counties were assigned to the corresponding climate zones.

3.3.2. Prescriptive Building Envelope Requirements

Chapter 5 contains prescriptive tables to determine the building envelope requirements. To select a proper table for a selected house, the type of house (i.e., Type A-1 which is single family house, or Type A-2 which is multifamily house) should be identified. Then, the window-to-wall ratio should be identified for the selected house. Based on the house type and the window-to-wall ratio, the appropriate prescriptive table is selected, which contains the building envelope requirements according to the Heating Degree Days. HDDs are determined from the county that the selected house belongs to.

3.3.3. Building Mechanical Systems and Equipment

Chapter 5 also contains the requirements of the building mechanical systems and other equipment. In this chapter the minimum equipment performance for air-cooled heat pumps, furnaces, hot-water boilers, air conditioners, and domestic water heaters is defined. Minimum duct insulation requirements are also defined in Chapter 5.

3.3.4. Procedure to Determine Building Envelope Requirements

Figure 3.5 shows the procedure to determine the building envelope characteristics for the 2000 IECC-compliant new house by county. To begin, a county is selected from the non-attainment and affected counties. Then, from Chapter 3 of the 2000 IECC, the corresponding climate zone for the county was determined and, based on the selected climate zone, the

Heating Degree Days (HDD) for the climate zone are identified. Using this, the 1999 average building characteristics for the selected county are identified. The window-to-wall ratio is calculated from the 1999 building characteristics. This calculated window-to-wall ratio is required to select a proper prescriptive table from the 2000 IECC. From Chapter 5, a proper prescriptive table was selected and the required building envelope characteristics are determined.

3.4. Projection of Number of Building Permits in 2002

To calculate the energy savings per county from the adoption of the 2000 IECC, the number of building permits in 2002 was required. To accomplish this, in August 2002, the number of permits had to be projected using an average historical data. Various sources are available to collect the current population, the number of existing houses, and the number of building permits by Texas County. These sources include U.S. Census Bureau (U.S. Census Bureau 2002), the Real Estate Center at Texas A&M University (RECenter 2002), and the F.W. Dodge company.

3.4.1. Texas County Building Permit Activity

The Real Estate Center (RECenter) at Texas A&M University provides the building permit activity for residential and non-residential buildings by Texas County level. In this database, the residential buildings are divided into three categories: Single family building, 2-4 family buildings, and buildings with 5 families or more.

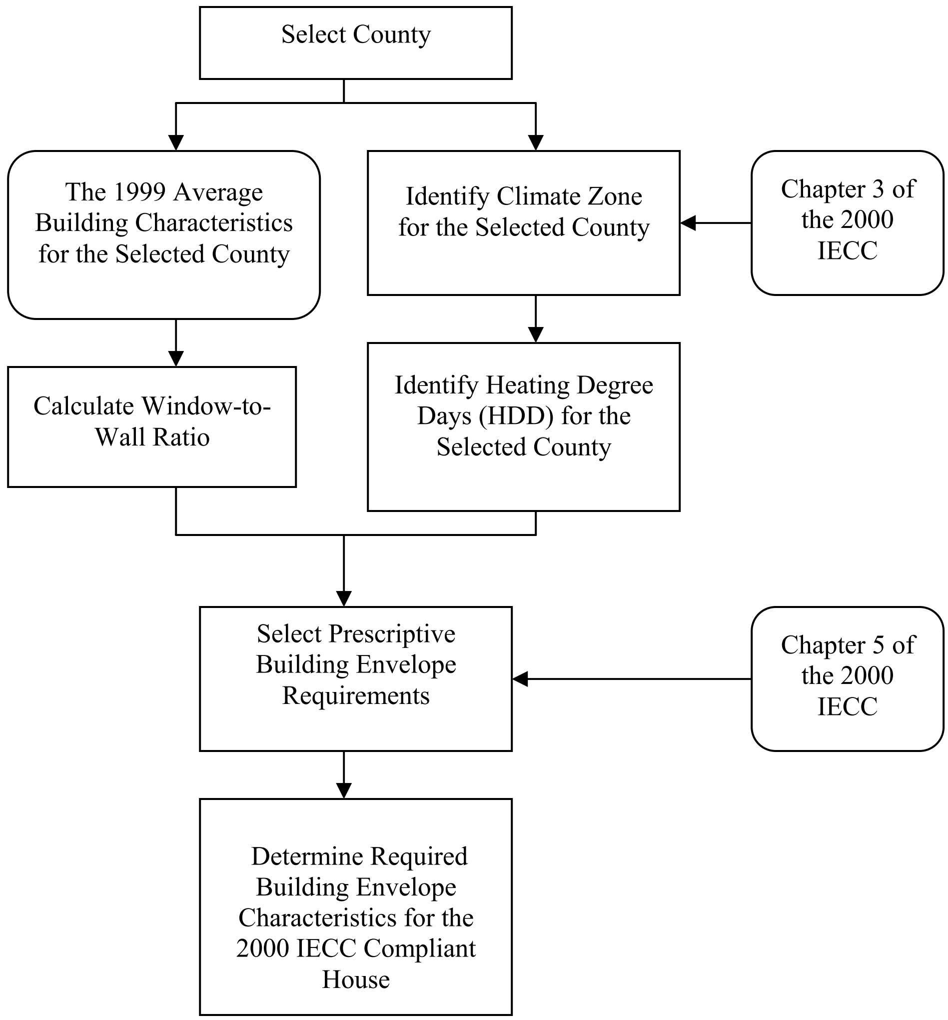

Figure 3.5 - Procedure to determine the building envelope characteristics for the 2000 IECC compliant new house in a county

3.4.2. Method to Project Building Permits in 2002

There are several methods to project the number of building permits in 2002. These methods include using the average number of historical permit data, using the same permit number of the last year, etc. In this thesis, the first method was used to project the number of building permit in 2002. The detailed projection method and the profiles of the historical data for each county during 1997 to 2002 are presented in Appendix B. Although the average number of historical permit data was used to project the building permit in this thesis, this method is only for estimation because the building permits are related to economy rather than previous years. A better method to project the number of permits would be the use of the last year's actual number of permits.

3.5. Comparisons of Energy Simulations

DOE-2 is a nationally recognized computer program that was used to simulate and analyze hourly energy consumption in residential or commercial buildings. This research used the DOE-2.1e (ver. 119) simulation program to simulate the energy uses for a 1999 and a 2002 standard house.[3]

3.5.1. The DOE-2 Building Simulation Program

The DOE-2 program can be divided into four sub-programs: LOADS, SYSTEMS, PLANTS, and ECONOMICS. Figure 3.6 presents the general procedure for using the DOE-2 simulation. To begin, the DOE-2 program requires three general inputs to run the Building Description Language (BDL) processors, which includes weather data, a materials library and the DOE-2 input file. Then, LOADS, SYSTEMS and PLANT are executed in sequence, with the output of LOADS becoming the input of SYSTEMS, followed by PLANTS and finally ECONOMICS. Each of the simulation subprograms produces printed reports of the results of its calculations.

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[3] Simulations were performed using the ESL's code-traceable DOE-2 input file (ver. IECC1100.inp) (Haberl et al. 2003)

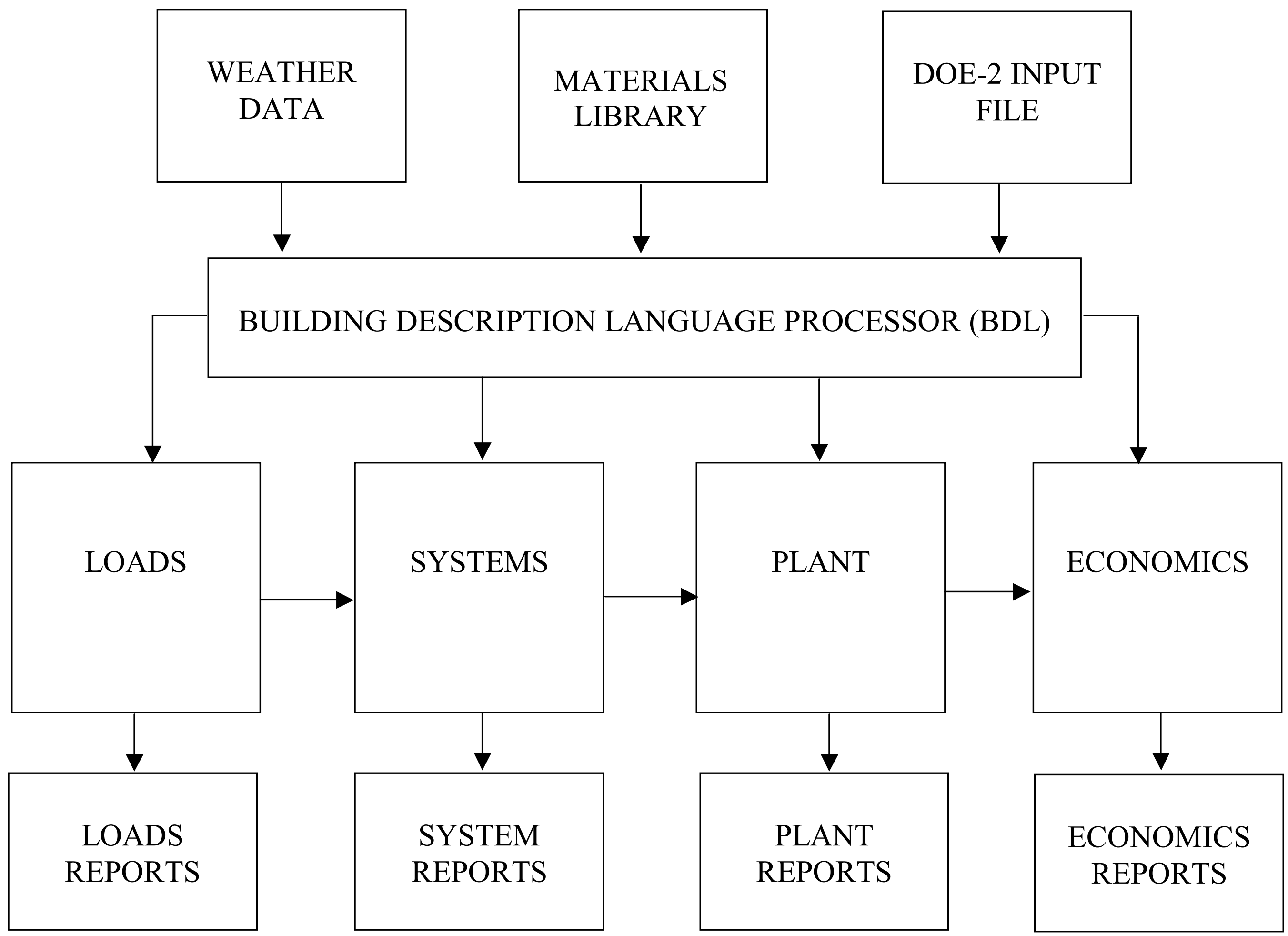

Figure 3.6 – Calculation Procedures of the DOE-2 simulation program (LBL 1981)

3.5.1.1. LOADS Subprogram

The LOADS simulation subprogram calculates the sensible and latent components of the hourly heating or cooling load for each space in the building. In the LOADS simulation, it is assumed that there is an ideal HVAC system and that each space remains at a pre-determined constant temperature. LOADS is responsive to weather conditions, schedules of people, lighting and equipment, infiltration loads, dynamic heat transfer through walls, roofs, and windows and includes the effect of building shades.

3.5.1.2. SYSTEMS Subprogram

The SYSTEMS subprogram simulates the operation of the air-side equipment and systems that distribute heating and cooling to the spaces. The SYSTEMS program receives a list of hourly loads for each space from the LOADS program.

3.5.1.3. PLANT Subprogram

The PLANT program simulates the primary equipment that uses energy to provide heating and cooling to the HVAC systems. PLANT receives a list of the hourly loads, as input, for the building from the SYSTEMS program. PLANT calculates the behavior of boilers, chillers, cooling towers, storage tanks that are required to deliver the secondary system's heating and cooling.

3.5.1.4. ECONOMICS Subprogram

The ECONOMICS subprogram calculates the cost of energy. It can also be used to compare the hourly cost-benefits of different building designs or to compare savings for retrofits to an existing building.

3.5.2. PARAMETER Command

To develop the standard input, the PARAMETER command (LBL 1981) was used. The PARAMETER command is one of the time saving DOE-2 commands, such as LIKE and SET-DEFAULT. For this research, one standard input file for all simulations was developed. Without the PARAMETER command, 76 input files would have been required to calculate energy consumption before and after code adoption for all 38 counties. Using the PARAMTER command only those variables that change from county to county were modified. For example, to calculate the energy use for a 1999 standard house in Harris County, only the parametric values for the wall and roof R-value, glazing U-value, glazing SHGC, and glazing area were changed to the average characteristics for Harris County in 1999. All other information about the house remained the same for all counties (floor area, orientation, etc.).

3.5.3. Conversion of the Window U-value and SHGC to Glass Conductance and Shading Coefficient

To input the windows properties into DOE-2, several pre-calculations were required. First, because the code-traceable input file assumes that there is one large window on each wall, the normal windows on each wall had to be combined into one window. This required that the glass area and equivalent frame width had to be calculated. Figure 3.7 shows the concept of the calculation of the equivalent glass area and equivalent frame width. Second, the window's U-value and the SHGC need to be converted to the appropriate glass conductance and the Shading Coefficient (SC) values required by the DOE-2 program, respectively. In the DOE-2.1e simulation, window properties can be input in three different ways. The first method is the traditional method that has been used in previous versions of DOE-2. Using this method, the user can input directly several window properties such as the Shading Coefficient (SC), the glass conductance, frame conductance, etc. In this method, the solar heat gain through windows is input as the Shading Coefficient by user. The second method is also a traditional method that has been used in previous versions of DOE-2. In difference to the first method, the solar heat gain through windows is input as a DOE-2 glass-type-code, which contains the previously calculated information of the transmittance and absorption characteristics (LBL 1981). The third method is a new method introduced in the in the DOE-2.1e version. DOE-2.1e contains a new Window Library with approximately 200 entries covering commonly available glazing. In this method, DOE-2.1e adopted the procedure used in the WINDOW 4 computer program for calculating the thermal performance of windows, which is consistent with the National Fenestration Rating Council's U-value rating procedure 100-91. The calculations also account for the solar energy absorbed and transmitted inside by the window-framing elements. Therefore, the more detailed modeling of the thermal and optical properties of windows can be possible using this method. The pros and cons of the three difference methods are compared in Table 3.1. The three different window input methods are described below.

Method 1: Shading Coefficient

```
Username = GLASS-TYPE    SHADING-COEFF = value
                         PANES  = 1,2 or 3
                         GLASS-CONDUCTANCE = value
                         VIS-TRANS = value
                         FRAME-CONDUCTANCE = value
                         FRAME-ABS = value
```

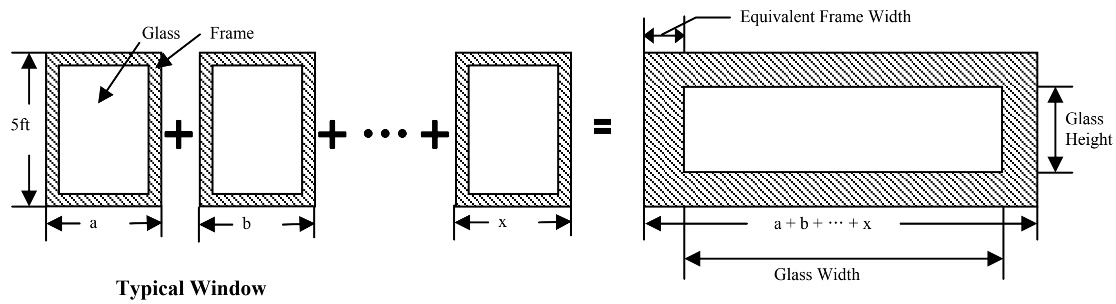

Figure 3.7 - Calculation of the equivalent frame width and glass area

Method 2: Glass-Type-Code ≤ 11

Username = GLASS-TYPE GLASS-TYPE-CODE = 1 to 11
PANES = 1,2, or 3
GLASS-CONDUCTANCE = value
VIS-TRANS = value
FRAME-CONDUCTANCE = value
FRAME-ABS = value

Method 3: Window Library (Glass-Type-Code ≥ 1000)

Username = GLASS-TYPE GLASS-TYPE-CODE = 1000 to 9999
FRAME-CONDUCTANCE = value
FRAME-ABS = value

Although the Window Library Method is the most accurate method for windows input, the first method, Shading Coefficient method, was used in this research because the original simulation for the IECC were performed prior to the release of the DOE-2.1e program, and

Table 3.1 - Comparison of methods for specifying window properties

Method	Pro	Con
1. Shading Coefficient	Convenient for conceptual design	Inaccurate angular dependence for multipane glazing
2. GLASS-TYPE-CODE $\leq$ 11	More accurate angular dependence	May not be good match to actual glazing
Window Library: 3. GLASS-TYPE-CODE $\geq$ 1000	Highly accurate angular dependence and conduction; user can expand library	50-100% increase in LOADS calculation time depending on number of windows

therefore it was felt that the traditional SC would best calculate the 2000 IECC window properties. Also, the DOE-2.1e libraries do not immediately allow for a calculation of varying SHGC and U-values, since this requires recalculating the window library file between each run. Therefore, in the current method, the window U-value and the SHGC are converted into glass conductance and SC before simulation. The detailed procedure for a calculation is presented in Figure 3.8. Preliminary information for this calculation includes house dimensions, glazing properties, and window-to-wall ratio.

3.5.3.1. Procedure for Glass Conductance Calculation

As a first step in the glass conductance calculation, the frame U-value was determined. The formula for this calculation was from DOE-2.1e Supplement Manual (LBL 1993)

$$F_u = \frac{1}{\frac{1}{F_c} + 0.197} \tag{3.1}$$

F_u = Frame U-value (Btu/ hr ft^2 °F)

F_c = Frame Conductance (Btu/ hr ft^2 °F)

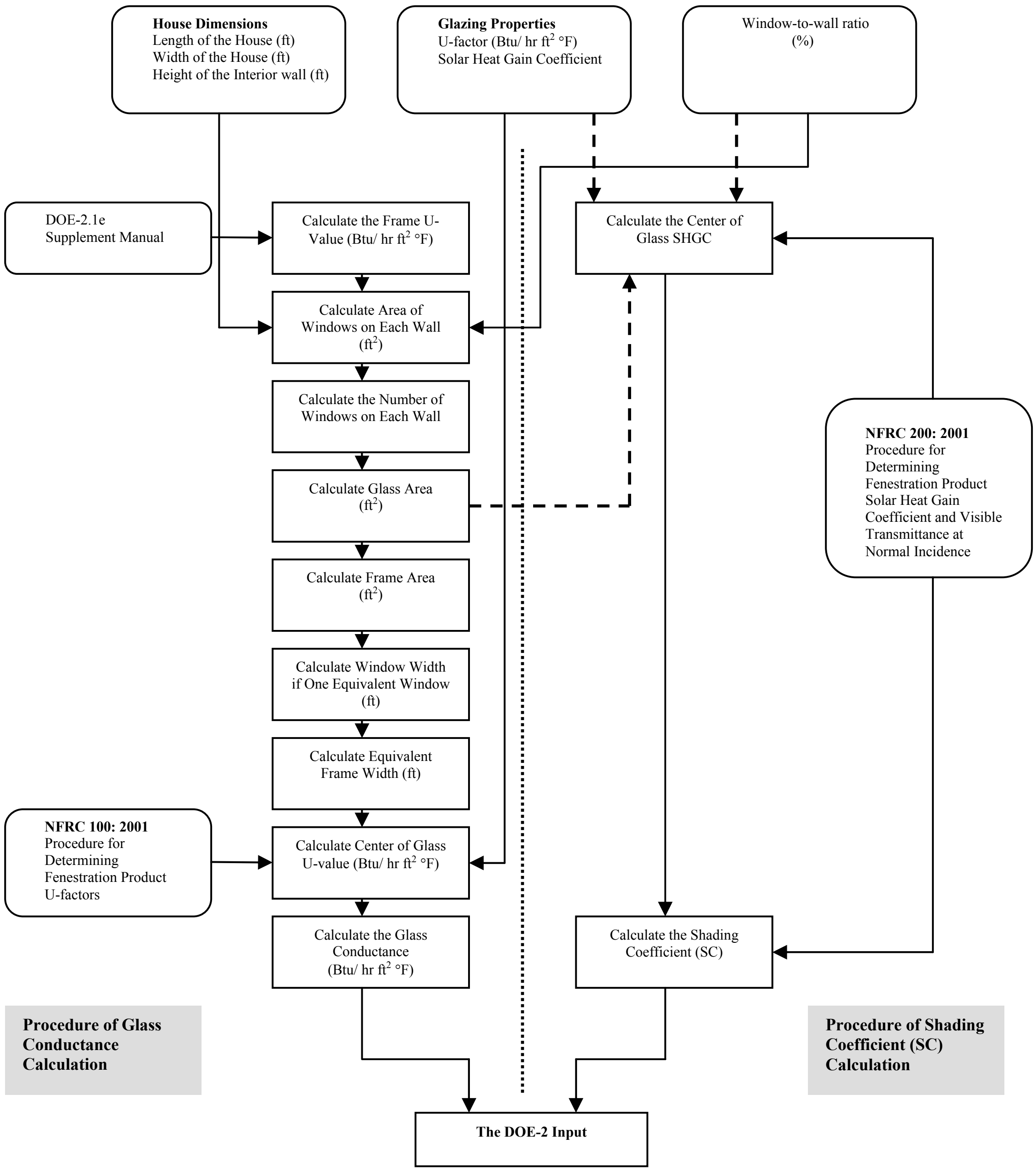

Figure 3.8 - Conversion procedure of window U-value to glass conductance and SHGF to shading coefficient

Next, the area of windows on each wall was calculated using the window-to-wall ratio. In this calculation, window area on all sides is assumed equal.

$$W_a = \frac{A_t \times Wr}{4} \tag{3.2}$$

W_a = Window area on each wall (ft^2)

A_t = Total wall area (ft^2)

W_r = Window-to-wall ratio (%)

In this study, the gross area of all windows is assumed to be 3ft x 5ft (i.e., 15 ft^2). Assuming this, the number of windows on each wall is calculated.

$$W_n = \frac{W_a}{15} \tag{3.3}$$

W_n = Number of Windows

Next, glass area was calculated. For this calculation, the frame width was assumed to be 0.125 ft (i.e., 1.5 inches).

$$G_a = (W_h - 2 \times F_w) \times (W_w - 2 \times F_w) \tag{3.4}$$

G_a = Glass area (ft^2)

W_h = Window height (ft)

W_w = Window width (ft)

F_w = Width of frame (ft)

After calculating the glass area, the frame area was calculated by subtracted the glass area from the gross window area.

$$F_a = W_a - G_a \tag{3.5}$$

F_a = Frame area (ft^2)

W_a = Gross window area on each wall (ft^2)

G_a = Glass area (ft^2)

For a square or rectangular house with one equivalent window on each side, the calculation becomes.

$$W_w = \frac{W_r \times A_t}{A_n \times W_h} \tag{3.6}$$

W_w = Window width (ft)

W_r = Window to wall ratio (%)

A_t = Total wall area (ft^2)

A_n = Number of walls

W_h = Window height (ft)

Next, the equivalent frame width is calculated, which also assumes there is one equivalent window instead several windows. For this calculation, the window height is assumed as 5 ft. The frame area calculated in (equation 3.5) is used to calculate the equivalent frame width.

$$F_a = \left(\left(W_w - 2 \times E_w\right) \times 2 \times E_w\right) + \left(W_h \times 2 \times E_w\right) \tag{3.7}$$

$$4E_w^{\;2} - 2\left(W_w + W_h\right)E_w + F_a = 0 \tag{3.8}$$

Since the above equation is a quadratic equation, the quadratic formula was used to solve it.

$$E_w = \frac{2(W_w + W_h) - \sqrt{(2(W_w + W_h))^2 - 4 \times 4 \times F_a}}{2 \times 4} \tag{3.9}$$

Where

E_w = Equivalent frame width (ft)

W_w = Window width (ft)

W_h = Window height (ft)

F_a = Frame area (ft^2)

As required by the 2000 IECC the National Fenestration Rating Council (NFRC) 100 should be used to calculate fenestration U-factors. This procedure was used in this study to calculate center of glass U-value. For the calculation in this thesis, the edge of glass U-value and dividers were neglected.

$$G_u = \frac{(W_u \times W_a) - (F_u \times F_a)}{G_a} \tag{3.10}$$

Where

G_u = Center of glass U-value (Btu/ hr ft^2 °F)

W_u = Total window U-value (Btu/ hr ft^2 °F)

W_a = Total window area (ft^2)

F_u = Frame U-value (Btu/ hr ft^2 °F)

F_a = Frame area (ft^2)

As a final step, glass conductance was calculated.

$$G_c = \frac{1}{\frac{1}{G_u} - 0.197} \tag{3.11}$$

G_c = Glass conductance (Btu/ hr ft^2 °F)

G_u = Center of glass U-value (Btu/ hr ft^2 °F)

Finally, the calculated glass conductance was input into the DOE-2 input file.

3.5.3.2. Procedure of Shading Coefficient Calculation

The first step of the procedure for the Shading Coefficient calculation is to calculate the center of glass SHGC. The required formula from NFRC 200 was used. In a similar fashion as the glass conductance calculation, the edge of glass and dividers were neglected. Also, the frame was assumed to have zero SHGC.

$$G_s = \frac{W_s \times W_a}{G_a} \tag{3.12}$$

Where

G_s = Center of glass SHGC

W_s = Window SHGC

W_a = Window area (ft^2)

G_a = Glass area (ft^2)

Finally, the shading coefficient was also calculated using the formula from the NFRC 200.

$$SC = \frac{G_s}{0.87} \tag{3.13}$$

SC = Shading Coefficient

G_s = Center of glass SHGC

Sample calculation for the window U-value and SHGC to glass conductance, and Shading Coefficient, and glazing U-value is provided in Chapter IV.

3.5.4. Energy Savings Calculation

This section describes the detailed procedures for performing the energy savings calculations. Figure 3.9 shows the overall procedure for performing the energy savings calculations. In the first step, the building characteristics for the 1999 and the code-compliant house were identified. The characteristics of the 1999 house were collected using the baseline construction data from the NAHB. The construction data were collected and used to fill-in the data collection form. Next, the building characteristics for the code-compliant house were defined by determining the building envelope characteristics for the 2000 IECC compliant new house for a particular County (Figure 3.5). For the 1999 and code-compliant data, the windows U-value and the SHGC were converted to the required glass conductance and the Shading Coefficient (SC) from the procedure defined in Figure 3.8. The 1999 and code-compliant building characteristics were then input separately into the standard DOE-2 input file as PARAMETERS. Two simulations, one for the 1999 house and one for the code-compliant houses were performed using the DOE-2.1e simulation program.

From the output files of the 1999 and the code-compliant houses, annual electricity, natural gas use, and peak-day electricity use were identified. To calculate annual electricity and

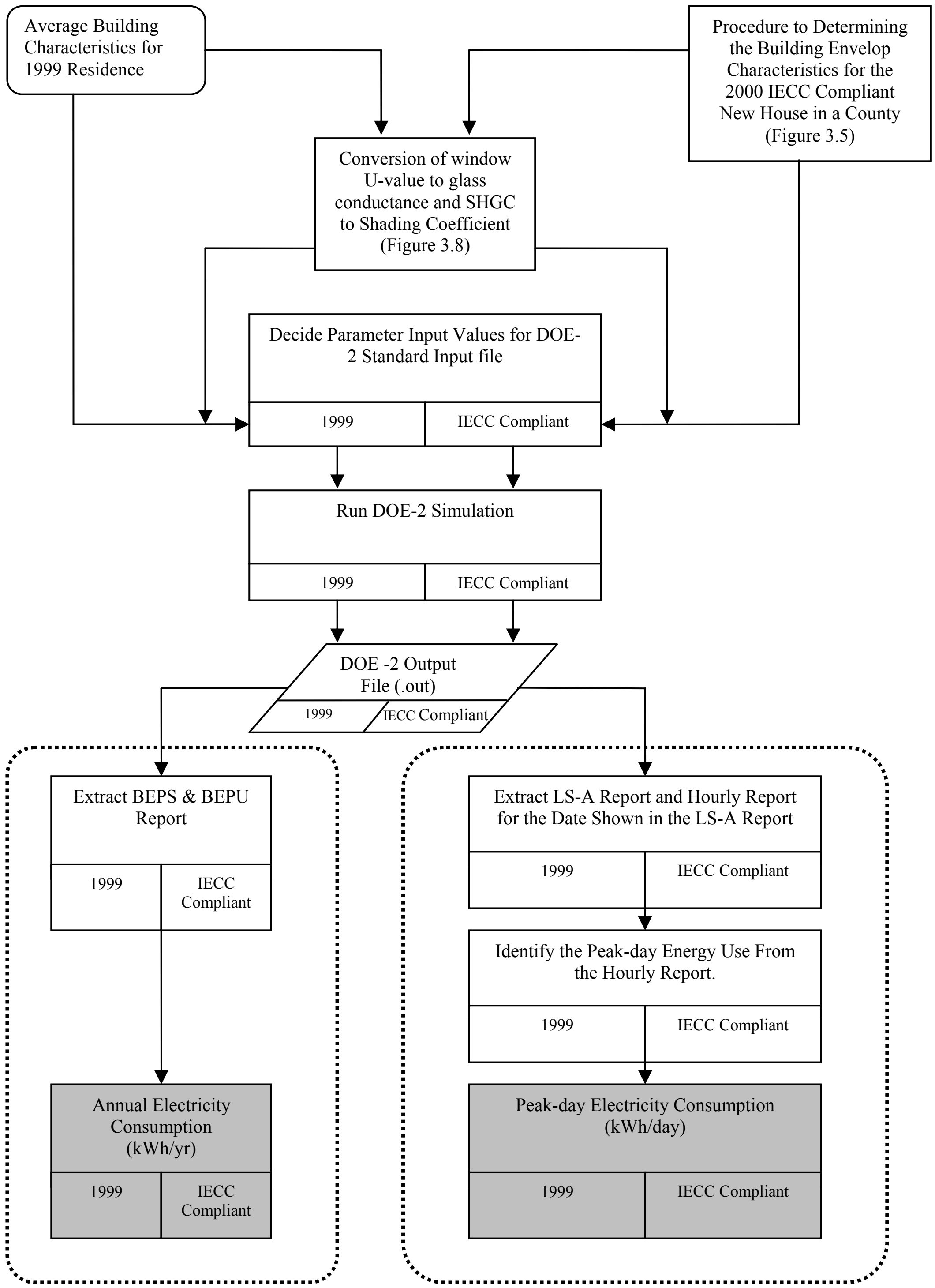

Figure 3.9 – Procedures for the annual and peak-day energy use calculations for 1999 residence and 2000 IECC complaint residences

natural gas savings, the BEPS and BEPU reports were extracted from the DOE-2.1e output files. The BEPS and BEPU reports present the simulated annual building energy performance summary. From these reports, the electricity and natural gas use were identified. Finally, the 1999 and code-compliant annual usage was compared and the savings calculated.

To calculate the peak-day electricity savings, another procedure was required. First, the report LS-A was extracted from the output files for 1999 and code-compliant. The LS-A report makes it possible to identify the time and date of the peak load. Unfortunately, DOE-2 sometimes identified different peak-days for the 1999 and code-compliant house in a given county. To avoid erroneous results, the same calendar day was used for each county for the 1999 and code-compliant simulations.

After identifying the peak date from the report LS-A, the electricity use of the 1999 and the code-compliant house for the peak-day was extracted from the hourly report. The peak-day electricity saving was then calculated.

3.5.4.1. The BEPS and BEPU Reports

The DOE-2 BEPS and BEPU reports present the simulated building energy performance summary. Figure 3.10 and 3.11 shows an example of the DOE-2 BEPS and BEPU reports. The information in this report was calculated and formatted to comply with the U.S. Department of Energy's Building Energy Performance Standard (LBL 1981). The BEPS report used MBTU (i.e., 1×10^6 Btu) as units, while the BEPU report used kWh for electricity use and Therms (i.e., 100,000 Btu) for natural gas use. These two reports show the building performance as a function of site energy used per unit floor area. In these reports, the electricity and natural gas use was also classified by seven categories of usage including lights, misc. equipment, space heat, space cool, pump & misc., vent fans, and domestic hot water.

3.5.4.2. The LS-A Report

The DOE-2 LS-A report provides the space peak load summary for the individual space peak sensible cooling load including the month, day and hour it occurred. The sum of the cooling loads for all the spaces is also reported, and the outside dry bulb and wet bulb temperatures are also reported for both the time of the peak load in each space, and for the building (LBL 1981). Figure 3.12 shows an example of the LS-A report.

3.5.4.3. Hourly Report

There are two types of reports that are available in the DOE-2 programs: Standard output reports and hourly reports. Standard output reports are available for each of the four programs, LOADS, SYSTEMS, PLANT, and ECONOMICS. The BEPS, BEPU reports and LS-A report that were previously described are standard output reports. Hourly reports that print or plot the values of user-selected variables for particular hours of the year are also available for the LOADS, SYSTEMS, and PLANT programs. To generate an hourly report in the DOE-2 output file, the user must define several instructions in the input file. First, using the SCHEDULE instruction, the user designates the hours to be printed or plotted. Then, using the REPORT-BLOCK instruction, the user chooses the variables to be reported. Finally, the HOURLY-REPORT instruction is used to connect the REPORT-BLOCK instructions with the SCHEDULE instructions.

In this research, an hourly report was used to identify the peak-day electricity use. As mentioned above, the peak date was identified from the report LS-A, then, the electricity use for the peak-day was identified from the hourly report for that day. To identify the hourly and

```
EPORT- BEPS  BUILDING ENERGY PERFORMANCE SUMMARY                    WEATHER FILE- HOUSTON  TX TMY2
 ---------------------------------------------------------------------------------------------------

                                   ENERGY TYPE:   ELECTRICITY   NATURAL-GAS
                                   UNITS: MBTU

                                CATEGORY OF USE
                                ---------------

                                    AREA LIGHTS         13.2          0.0

                                   MISC EQUIPMT         13.2          0.0

                                     SPACE HEAT          0.0          7.6

                                     SPACE COOL         17.0          0.0

                                   PUMPS & MISC          0.2          0.0

                                      VENT FANS          2.5          0.0

                                   DOMHOT WATER          0.0         16.3
                                                  ----------   ----------

                                          TOTAL         45.9         23.9


TOTAL SITE ENERGY        69.86 MBTU     27.9 KBTU/SQFT-YR GROSS-AREA     23.4 KBTU/SQFT-YR NET-AREA
TOTAL SOURCE ENERGY     161.75 MBTU     64.7 KBTU/SQFT-YR GROSS-AREA     54.2 KBTU/SQFT-YR NET-AREA

                    PERCENT OF HOURS ANY SYSTEM ZONE OUTSIDE OF THROTTLING RANGE =  0.0
                    PERCENT OF HOURS ANY PLANT LOAD NOT SATISFIED                =  0.0
```

Figure 3.10 – DOE-2 BEPS report

```
REPORT- BEPU  BUILDING ENERGY PERFORMANCE SUMMARY (UTILITY UNITS)    WEATHER FILE- HOUSTON  TX TMY2
 ---------------------------------------------------------------------------------------------------


                                   ENERGY TYPE:   ELECTRICITY   NATURAL-GAS
                                    SITE UNITS:       KWH          THERM

                                CATEGORY OF USE
                                ---------------

                                    AREA LIGHTS        3854.           0.

                                   MISC EQUIPMT        3854.           0.

                                     SPACE HEAT           0.          76.

                                     SPACE COOL        4967.           0.

                                   PUMPS & MISC          65.           0.

                                      VENT FANS         721.           0.

                                   DOMHOT WATER           0.         163.
                                                  ----------   ----------

                                          TOTAL       13460.         239.

TOTAL ELECTRICITY    13460. KWH    5.384 KWH /SQFT-YR GROSS-AREA    4.511 KWH     /SQFT-YR NET-AREA
TOTAL NATURAL-GAS    239. THERM   0.096 THERM /SQFT-YR GROSS-AREA   0.080 THERM   /SQFT-YR NET-AREA

                   PERCENT OF HOURS ANY SYSTEM ZONE OUTSIDE OF THROTTLING RANGE =  0.0
                   PERCENT OF HOURS ANY PLANT LOAD NOT SATISFIED                =  0.0
```

Figure 3.11 – DOE-2 BEPU report

```
REPORT- LS-A SPACE PEAK LOADS SUMMARY                             WEATHER FILE- HOUSTON  TX TMY2
 ---------------------------------------------------------------------------------------------------


            MULTIPLIER  COOLING LOAD   TIME OF    DRY-  WET-  HEATING LOAD   TIME OF    DRY- WET-
 SPACE NAME SPACE  FLOOR    (KBTU/HR)       PEAK   BULB  BULB     (KBTU/HR)      PEAK   BULB BULB

 RM-1          1.     1.      26.312   JUL 29 2 PM  95.F  76.F     -21.432   JAN 11 4 AM   18.F  15.F
 GARAGE-1      1.     1.      38.593   JUL 30 2 PM  97.F  78.F     -48.068   JAN 11 4 AM   18.F  15.F
                             ---------                            ---------
 SUM                          64.905                               -69.501


 BUILDING PEAK                63.659   JUL 30 2 PM  97.F  78.F     -69.501   JAN 11 4 AM   18.F  15.F
```

Figure 3.12 – DOE-2 LS-A report

```
REP-4            = HOURLY-REPORT
PAGE363 -  1
---------------------------------------------------------------------------------------------------
                   PLANT

                   TOTAL
                   ELECTRIC
                   KW

                   ----(10)
 730 1               0.880
  730 2              0.880
  730 3              0.880
  730 4              0.880
  730 5              0.880
  730 6              0.880
  730 7              1.360
  730 8              1.842
  730 9              2.073
  73010              2.665
  73011              3.313
  73012              3.449
  73013              3.732
  73014              3.851
  73015              3.831
  73016              3.872
  73017              3.428
  73018              3.058
  73019              2.501
  73020              2.034
  73021              1.696
  73022              1.535
  73023              1.376
  73024              1.289
0 DAILY SUMMARY (JUL 30)
     MN              0.880
     MX              3.872
     SM             52.184
     AV              2.174
```

Figure 3.13 – DOE-2 hourly report for one day

daily electricity use, the hourly report for PLANT, VARIABLE-TYPE = PLANT, and Variable list number = 10 were used. The variable number, 10 is designated as the Total Electric Load in PLANT (KW) (LBL 1981, page V.107). In each hourly report for the day a daily summary is included at the bottom of the report. The electricity use for the day was extracted from the daily summary. Figure 3.13 shows an example of an hourly report of hourly electricity uses for a day.

3.6. Demonstration of Selected Portions of the Validation Procedure

This section discusses the procedures for validation and the demonstration of selected portions of the validation procedure. In the original procedure, the building characteristics and the simulated energy savings were validated using data from several existing houses. The validation can be divided into three parts: 1) Crosschecks from previous studies, 2) On-site visit survey, and 3) Utility billing analysis. The crosschecks from previous studies were conducted to verify the 1999 standard building characteristics defined in base case study section, and to verify the calculated energy savings. For this crosscheck, several previous studies were reviewed, and the results of those studies were compared with the results of this research. An on-site visit survey was conducted to demonstrate the procedure to validate the building characteristics used in the building energy simulations. In this thesis, a house under construction in 2003 was selected and used as a case study house. In the original procedure, a utility billing analysis of the code-compliant versus pre-code house should also be conducted to validate the simulated energy savings. However, as mentioned previously, several years of utility bills from one case study house were used to demonstrate the utility billing analysis procedure.

3.6.1. Crosscheck from Previous Studies

In this validation procedure, the 1999 standard building characteristics defined in the base case study section, and the energy savings calculated in DOE-2 simulations were validated using crosschecks from the previous studies.

Table 3.2 – Crosscheck form for the 1999 average single-family house characteristics

Required Data			Source of Information			
			Current 1999 Data			
Year						
Weather Data	TMY2					
Household Occupants						
Internal Loads (Btu/hr)						
Envelope	Floor Area (ft2)					
	Wall height (ft)					
	Wall R-value (hr-ft^2-^{o}F/Btu)	Standard				
		Steel Frame (Steel frame wall cavity and sheathing R-value)				
		Mass Wall (Exterior or Integral Insulation)				
		Mass Wall (Other)				
	Roof/Ceiling R-value (hr-ft^2-^{o}F/Btu)					
	Floor R-value (hr-ft^2-^{o}F/Btu)					
	Basement wall R-value (hr-ft^2-^{o}F/Btu)					
	Slab perimeter R-value (hr-ft^2-^{o}F/Btu)					
	Slab perimeter depth (ft)					
	Crawlspace Wall R-value (hr-ft^2-^{o}F/Btu)					
	Air Leakage (cfm per square foot)					
	ACH (=Normalized Leakage X Weather Factor)					
	Window area (ft2)					
	Glazing U-factor (Btu/hr-ft^2-^{o}F)					
	SHGC					
Building Mechanical Systems and Equipment	Duct Insulation (hr-ft^2-^{o}F/Btu)	Unconditioned attic or Outside (Supply)				
		Unconditioned attic or Outside (Return)				
		Other Unconditioned (Supply)				
		Other Unconditioned (Return)				
	HSPF (Air-cooled heat pumps heating mode < 65,000 Btu/h cooling capacity)	Split systems				
		Single Package				
	AFUE (Gas-fired or oil-fired furnace < 225,000 Btu/h)					
	AFUE (Gas-fired or oil-fired steam and hot-water boilers < 300,000 Btu/h)					
	SEER (Air-cooled air conditioners and heat pumps cooling mode < 65,000 Btu/h cooling capacity)	Split systems				
		Single Package				
	Water Heater (EF)					
	Existence of Pilot Lights					

3.6.1.1. Crosscheck of the Base Case Study

The building characteristics of the 1999 Standard house were defined using the NAHB's survey report, and data from GAMA and ARI. These characteristics also need to be crosschecked to validate the data. To accomplish this, several previous studies were used. These studies include Henwood Energy Service (2000), Brown et al. (1998), Schiller and Associates (2001), and Meisegeier et al. (2002). All of these studies presented the building characteristics of base case house and the energy efficient house. After reviewing the base case characteristics from those studies, the identified data was entered into Table 3.2, and then compared to the 1999 standard building characteristics used in this research. The results of this crosscheck are discussed in Chapter IV.

3.6.1.2. Crosscheck of the Energy Savings

The annual electricity savings calculated in this research were compared to the electricity savings from previous similar studies. The studies include Schiller and Associates (2001), and Meisegeier et al. (2002). Although the building characteristics of the base case house and the energy efficient house from the two studies are different than the characteristics from this research, the annual electricity savings can be compared each other to show the overall electricity savings from the code or energy efficient package adoption. The annual energy savings from each studies and current research were divided by total floor area (square foot), and then compared each other. The results of this crosscheck are also presented in Chapter IV.

3.6.2. Demonstration of Onsite Visit Survey

In this research, the building characteristics of single family houses built in 1999 and 2002 were defined to simulate the annual and peak-day energy use for the houses. The purpose of the on-site visit was to verify those building characteristics for both houses. Ultimately, a statistically significant sample should be chosen and analyzed. In this research, to demonstrate proof-of-concept, a house under construction in 2003 house was visited and analyzed to demonstrate the methodology for this procedure. Since the single-family houses built in 2003 were assumed to be built in accordance with the requirements of the 2000 IECC, the actual characteristics were compared against the building characteristics of the 2000 IECC. Figure 3.14 shows the detailed procedure for the onsite visit survey for the house.

To begin, before the on-site visit, an on-site survey checklist was developed. This checklist was developed based on the requirements of the 2000 IECC and several previous studies such as XENERGY (XENERGY 2001). Appendix A shows the completed checklist.[4] Available building characteristics were collected from the on-site visit. The collected building characteristics were then used to fill-in the compliance form (Figure 3.15). The procedure to identify the building characteristics of the IECC-compliant house, which is compared against the actual house, is similar to the procedure shown in Figure 3.5. To compare the actual building characteristics against the requirements of the 2000 IECC, first the window-to-wall ratio and climate zone for the selected house were identified. Then, using the 2000 IECC Chapter 5 prescriptive table, the corresponding code requirements were identified, and the compliance for each feature was checked.

As another compliance check, a simulated energy use comparison was conducted. From the on-site visit, the actual building characteristics were collected. Using the collected

[4] The checklist is filled in using the data from the on-site visit which is described in Chapter IV.

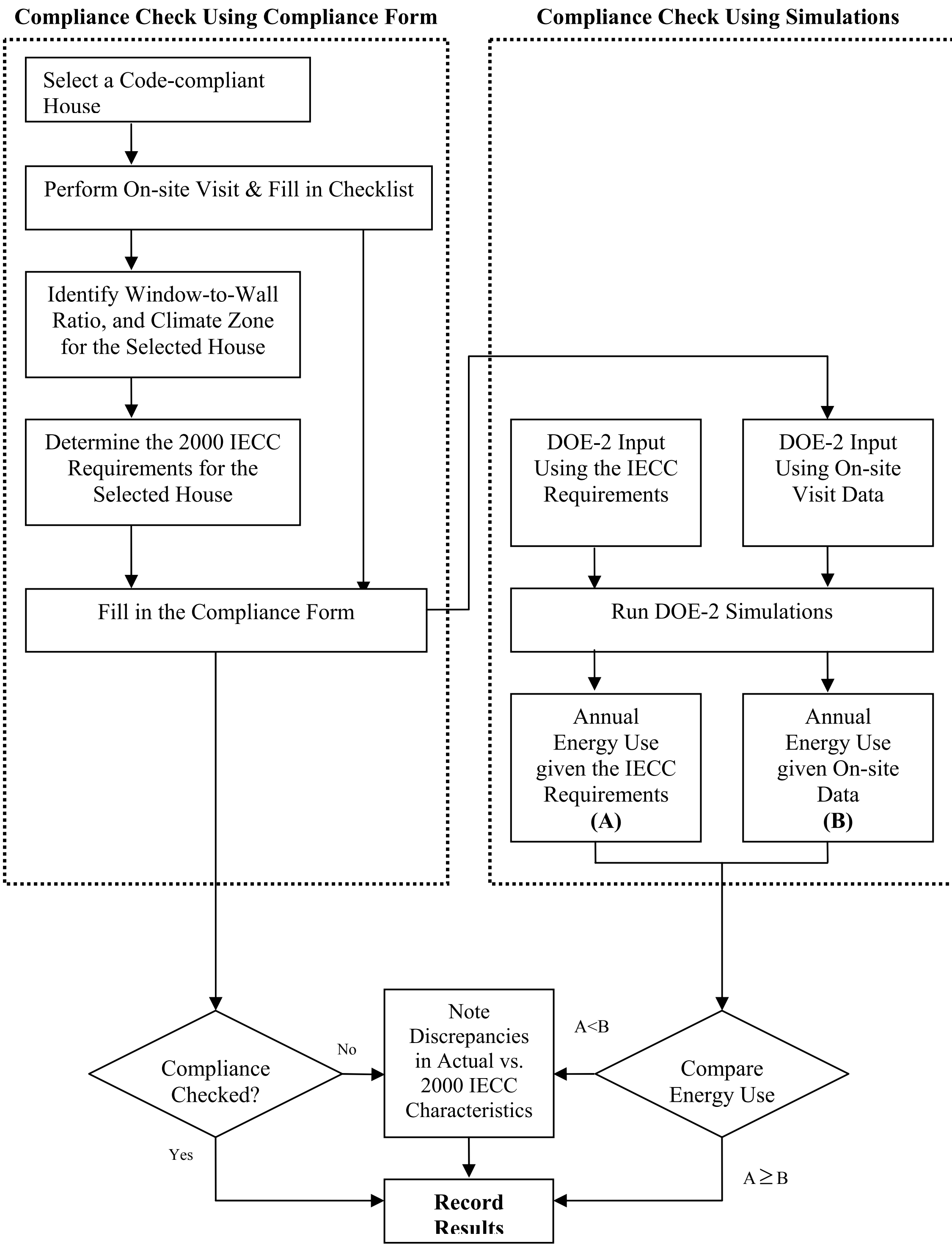

Figure 3.14 - Validation from on-site visit

Component			Onsite Visit	IECC Requirement		Compliance Check
			Installed Value	Maximum Value	Minimum Value	
Envelop	Window to Wall Ratio					
Envelop	Exterior Wall	Wall Color (Light, Med., Dark)				
Envelop	Exterior Wall	Gross Area (ft^2)				
Envelop	Exterior Wall	Average Wall Height (ft)				
Envelop	Exterior Wall	Insulation R-value (hr-ft^2-°F/Btu)				
Envelop	Exterior Wall	Stud Spacing (in.)				
Envelop	Windows	Gross Area (ft2)				
Envelop	Windows	Glazing Type				
Envelop	Windows	Frame type				
Envelop	Windows	U-value of windows (Btu/hr-ft^2-°F)				
Envelop	Windows	SHGC of windows				
Envelop	Door	Gross Area (ft2)				
Envelop	Door	Door type				
Envelop	Door	Door U-value (Btu/hr-ft^2-°F)				
Envelop	Roof/Attic	Roof Color (Light, Med., Dark)				
Envelop	Roof/Attic	Ceiling Type				
Envelop	Roof/Attic	Gross Area (ft2)				
Envelop	Roof/Attic	Insulation R-value (hr-ft^2-°F/Btu)				
Envelop	Slab Floor	Gross Area (ft2)				
Envelop	Slab Floor	Slab perimeter R-value (hr-ft^2-°F/Btu)				
Heating and Cooling Systems	Heating System	Fuel				
Heating and Cooling Systems	Heating System	Systems Type				
Heating and Cooling Systems	Heating System	System efficiency (AFUE or HSPF)				
Heating and Cooling Systems	Heating System	Manufacturer				
Heating and Cooling Systems	Heating System	System Location				
Heating and Cooling Systems	Cooling System	Systems Type				
Heating and Cooling Systems	Cooling System	System efficiency (SEER)				
Heating and Cooling Systems	Cooling System	Manufacturer				
Heating and Cooling Systems	Cooling System	System Location				
Duct		Duct location				
Duct		Duct diameter (in.)				
Duct		Duct type				
Duct		Duct insulation R-value (hr-ft^2-°F/Btu)				
Domestic Water Heater		NAECA-covered water heating equipment (yes, no)				
Domestic Water Heater		Fuel				
Domestic Water Heater		Capacity				
Domestic Water Heater		Energy Factor				
Domestic Water Heater		Type				
Domestic Water Heater		Tank location				
Domestic Water Heater		Manufacturer				
Infiltration		ACH				

Figure 3.15 - The 2000 IECC compliance form for on-site visit

characteristics, the PARAMETERs of the standard DOE-2 input file were modified. At the same time, the standard DOE-2 input file was modified using the identified requirements of the 2000 IECC. Then, the DOE-2 simulations were performed for both of the input files. From the BEPS and BEPU reports, the annual energy uses for both simulations were compared. If the simulated energy use using the actual building characteristics were less than or equal to the energy use using the requirements of the 2000 IECC, the visited house was considered code compliant. If not, the discrepancies and the resultant annual energy use difference were noted.

3.6.3. Demonstration of the Utility Billing Analysis

An example utility billing analysis was conducted using a three-parameter, change-point model to demonstrate the procedure for the validation of the simulated energy use and energy savings. In the original procedure, to validate the simulated energy use and energy savings, a statistically significant sample of houses built before and after code adoption was required to be analyzed. In this research, however, one case study house built before code adoption was selected, and the utility bills for the years 2000 and 2001 were obtained. Then, to demonstrate the analysis method, the utility bills for 2000 were assumed to be the bills from a house built in 1999, and the utility bills for 2001 were assumed to be the bills from a house built in 2002.

3.6.3.1. ASHRAE Inverse Modeling Toolkit (IMT)

As reviewed in Chapter II, ASHRAE's Inverse Model Toolkit (IMT) is a well-documented public domain toolkit for regression modeling of building energy use (Kissock et al., 2001). For validation of the simulated energy use and savings, the IMT toolkit was used to compare the normalized energy use before and after code adoption.

3.6.3.1.1. IMT Input Files

To run the IMT, two input files are required: a data file and an instruction file. The IMT comes with two sample data files. The first is a uniform time-scale data file called DAILY2.DAT. This data file contains uniform daily ambient temperatures and energy consumption data from a building. The DAILY2.DAT can be used to run mean, two-parameter change-point (2P), three-parameter change-point (3P), four-parameter change-point (4P), five-parameter change-point (5P) and Multiple Variable Regression (MVR) models. The second file is a non-uniform timescale data file called NONUNIPP.DAT. This file contains monthly energy use, and monthly occupancy data, and daily ambient temperatures. This file can be used to process the weather data for 2P, 3P, 4P, 5P or MVR models or it can be used to directly run VBDD models. Figure 3.16 shows an example of a non-uniform data file.

Using the IMT instruction file, the user identifies the input data file, and the desired fields and records in the input data file, and selects the proper regression model. Figure 3.17 shows an example of an instruction file to generate a Cooling Degree Day (CDD) model. The instruction file consists of 14 lines of a single field each. The first line is for the path and name of the input data file. The second line is for the value of the no-data flag. This value is used if there are missing data values for one or more fields in a data record. The user can select any numeric value for the no-data flag. In this sample file, "-99" was used for the no-data flag. The third and fourth line is for the column number of group field and the value of valid group field, respectively. There are included because the IMT input file may contain records that the user does not want to include in the model. Therefore, the user inputs the same numeric value (i.e., the value of valid group field) in each record that the user wants to be included in the model. In this example, if the user wants to include a specific record in the model, the value "1" will be input in the fifth column of the each record in input file. The fifth line is for residual file. If the user needs the residual file, this option will be input as 1. From the sixth line, the appropriate model is selected from the list shown. In this sample file, the CDD model is selected. The seventh line is for the column number of dependent variable Y. The value in this record indicates the column number for the dependent variable such as the cooling or heating energy consumption. The eighth line indicates the number of independent variables. In this sample file, one independent variable is used. The corresponding column numbers of independent variables are indicated from the ninth to the fourteenth lines. Since this sample file has one independent variable, the ninth line shows the corresponding column number, which is 9.

The IMT can also be run from a command-line input. The IMT provides the user with prompts asking for the appropriate information which is the same as the information in the instruction file.

3.6.3.1.2. IMT Output Files

IMT model coefficients and goodness-of-fit parameters are reported in the output file IMT.OUT. This output file can be viewed using any text editor. Figure 3.18 shows an example of an IMT.OUT file viewed from a text editor. If instructed to, IMT also creates a residual file that includes all of the input data, the predicted values of the dependent variable, and the difference between the predicted and measured values of the dependent variable. The file name of this output file is IMT.RES. This file can also be used to create plots using the Microsoft EXCEL program. It is also used to calculate average billing-period temperatures as a preprocessor to linear and change-point linear models, which are run with monthly utility billing data. Figure 3.19 shows an example of a residual file from a non-uniform timescale data input file.

12	1	1996	-99	-99	-99	-99	-99	26
12	2	1996	-99	-99	-99	-99	-99	36
12	3	1996	-99	-99	-99	-99	-99	38
12	4	1996	-99	-99	-99	-99	-99	31
12	5	1996	-99	-99	-99	-99	-99	32
12	6	1996	-99	-99	-99	-99	-99	36
12	7	1996	-99	-99	-99	-99	-99	40
12	8	1996	-99	-99	-99	-99	-99	32
12	9	1996	-99	-99	-99	-99	-99	30
12	10	1996	-99	-99	-99	-99	-99	41
12	11	1996	-99	-99	-99	-99	-99	56
12	12	1996	-99	-99	-99	-99	-99	42
12	13	1996	-99	-99	-99	-99	-99	38
12	14	1996	-99	-99	-99	-99	-99	37
12	15	1996	-99	-99	-99	-99	-99	43
12	16	1996	-99	-99	-99	-99	-99	38
12	17	1996	-99	-99	-99	-99	-99	36
12	18	1996	-99	-99	-99	-99	-99	22
12	19	1996	-99	-99	-99	-99	-99	13
12	20	1996	-99	-99	-99	-99	-99	-99
12	21	1996	-99	-99	-99	-99	-99	-99
12	22	1996	-99	-99	-99	-99	-99	-99
12	23	1996	-99	-99	-99	-99	-99	45
12	24	1996	-99	-99	-99	-99	-99	43
12	25	1996	-99	-99	-99	-99	-99	22
12	26	1996	-99	-99	-99	-99	-99	29
12	27	1996	-99	-99	-99	-99	-99	37
12	28	1996	-99	-99	-99	-99	-99	52
12	29	1996	-99	-99	-99	-99	-99	50
12	30	1996	-99	-99	-99	-99	-99	-99
12	31	1996	-99	-99	-99	-99	-99	44
1	1	1997	215	1	30	20	5	41
1	2	1997	-99	-99	-99	-99	-99	52
1	3	1997	-99	-99	-99	-99	-99	57

Figure 3.16 - First 34 records of a non-uniform timescale data file
(The fields are month, day, year, monthly electricity use and daily temperature)

3.6.3.1.3. Variable-Base Degree-Day (VBDD) Models

In this analysis, the Variable-Base Degree-Day (VBDD) model was used to calculate the daily average ambient temperature during the monthly billing periods. Since the billing period is not exactly one month, and the starting and the ending dates are not same as the starting and ending dates for the month, the average ambient temperature during each billing period need to be calculated for each analysis. To obtain the average ambient temperature for 12 billing periods, the utility bills for 13 months are required. The average daily ambient temperatures for those periods are also required. As mentioned above, a non-uniform timescale data file was used to run the VBDD model. From the output file IMT.RES, the average ambient temperature for each 12 billing period were identified, and then used in a second IMT analysis.

```
Line 1: Path and name of input data file = nonunipp.dat
Line 2: Value of no-data flag = -99
Line 3: Column number of group field = 5
Line 4: Value of valid group field = 1
Line 5: Residual file needed (1 yes, 0 no) = 1
Line 6: Model (1:Mean,2:2p,3:3pc,4:3ph,5:4p,6:5p,7:MVR,8:HDD,9:CDD) = 9
Line 7: Column number of dependent variable Y = 4
Line 8: Number of independent variables (0 to 6)  = 1
Line 9: Column number of independent variable X1 = 9
Line 10: Column number of independent variable X2 = 0
Line 11: Column number of independent variable X3 = 0
Line 12: Column number of independent variable X4 = 0
Line 13: Column number of independent variable X5 = 0
Line 14: Column number of independent variable X6 = 0
```

Figure 3.17 - Sample instruction file to generate a Cooling Degree Day (CDD) model

```
********************************************
 ASHRAE INVERSE MODELING TOOLKIT (1.9)
********************************************
  Output file name = IMT.Out
********************************************
  Input data file name =  nonunipp.dat
  Model type =          CDD
  Grouping column No =    5
  Value for grouping =    1
  Residual mode =         1
  # of X(Indep.) Var =    1
  Y1 column number =      4
  X1 column number =   9
  X2 column number =   0 (unused)
  X3 column number =   0 (unused)
  X4 column number =   0 (unused)
  X5 column number =   0 (unused)
  X6 column number =   0 (unused)
********************************************
  Regression Results
  --------------------------------------
        N =     11
  --------------------------------------
       R2 =     0.788
  --------------------------------------
    AdjR2 =     0.788
  --------------------------------------
     RMSE =    360.3786
  --------------------------------------
  CV-RMSE =    23.461%
  --------------------------------------
        p =     0.418
  --------------------------------------
       DW =     1.012 (p>0)
  --------------------------------------
  DD Base =      76
  --------------------------------------
        A =  1147.7827 (    127.6882)
  --------------------------------------
       X1 =   46.9383 (      8.1067)
  --------------------------------------
```

Figure 3.18 - Sample output file

2.00	1.00	1997.00	268.00	1.00	35.00	30.00	3.00	26.03	58.00	269.64	-1.64
3.00	1.00	1997.00	270.00	1.00	40.00	25.00	-5.00	40.00	76.00	273.23	-3.23
4.00	1.00	1997.00	321.00	1.00	45.00	30.00	6.00	42.48	88.00	275.62	45.38
5.00	1.00	1997.00	357.00	1.00	55.00	30.00	-8.00	48.69	231.00	304.11	52.89
6.00	1.00	1997.00	367.00	1.00	65.00	15.00	-3.00	57.26	504.00	358.51	8.49
7.00	1.00	1997.00	435.00	1.00	75.00	20.00	0.00	69.52	770.00	411.51	23.49
8.00	1.00	1997.00	447.00	1.00	75.00	20.00	12.00	73.71	785.00	414.50	32.50
9.00	1.00	1997.00	396.00	1.00	65.00	25.00	-4.00	70.43	883.00	434.03	-38.03
10.00	1.00	1997.00	373.00	1.00	55.00	30.00	8.00	64.93	718.00	401.15	-28.15
11.00	1.00	1997.00	324.00	1.00	45.00	30.00	9.00	54.61	435.00	344.76	-20.76
12.00	1.00	1997.00	235.00	1.00	35.00	25.00	-15.00	36.94	21.00	262.27	-27.27
1.00	1.00	1998.00	216.00	1.00	30.00	20.00	6.00	33.30	8.00	259.68	-43.68

Figure 3.19 - Example residual file from a non-uniform timescale data input file

3.6.3.1.4. Three Parameter Change-Point Models

In general, 3P models are used for modeling residential building energy use that is constant over one portion of the temperature range and varies linearly with temperature over the other portion (Kissock et al. 2001). For this research, two 3P models were defined: 3PC for cooling and 3PH for heating. The 3PC model uses ambient temperature as the independent variable and cooling energy use as the dependent variable above a certain change-point. Similarly, the 3PH model uses ambient temperature as the independent variable and heating energy use as the dependent variable below a certain change-point. After running the IMT for the 3PC and 3PH models, weather-normalized IMT coefficients were identified from the IMT.OUT, which includes a constant term, a slope, and a change point. Below is the typical three-parameter change-point model.

$$Y_c = \beta_1 + \beta_2 (X_1 - \beta_3)^+ \quad (3.14)$$

$$Y_h = \beta_1 + \beta_2 (\beta_3 - X_1)^+ \quad (3.15)$$

Where, β_1 is the constant term, β_2 is the slope term, and β_3 is the change point. The $( )^+$ indicates that the values of the parenthetic term should be set to zero when they are negative, respectively. Figure 3.20 shows the three parameter change-point models.

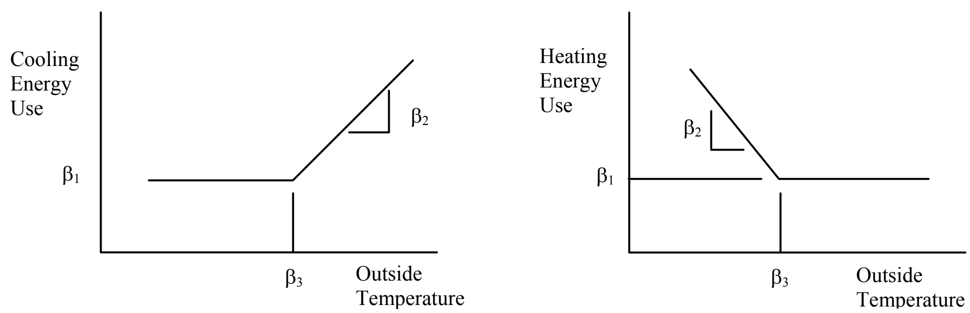

Figure 3.20 – IMT three parameter change-point models

3.6.3.2. Validation Procedure

The detailed procedure to validate the simulated cooling and heating energy savings is shown in Figure 3.21. The purpose of this procedure is to validate the simulated energy savings by comparing it with the normalized energy savings calculated from a utility billing analysis. As mentioned above, in this research, one house was selected as a case study house. Then, the utility bills for 2000 were assumed the bills from a 1999 house, and the utility bills for 2001 were assumed the bills from a 2002 house. To begin the full procedure, a county from the 38 non-attainment and affected counties would normally be selected. Then, a 1999 and a code-compliant house in the county would be selected. Twelve monthly utility bills from both houses are collected. As mentioned above, the IMT's variable-base degree-day (VBDD) procedure is used to calculate the average daily ambient temperatures for each billing period. For this calculation, the appropriate daily outdoor temperatures during the utility billing period are obtained from available sources. Using the monthly utility bills and daily temperatures, an

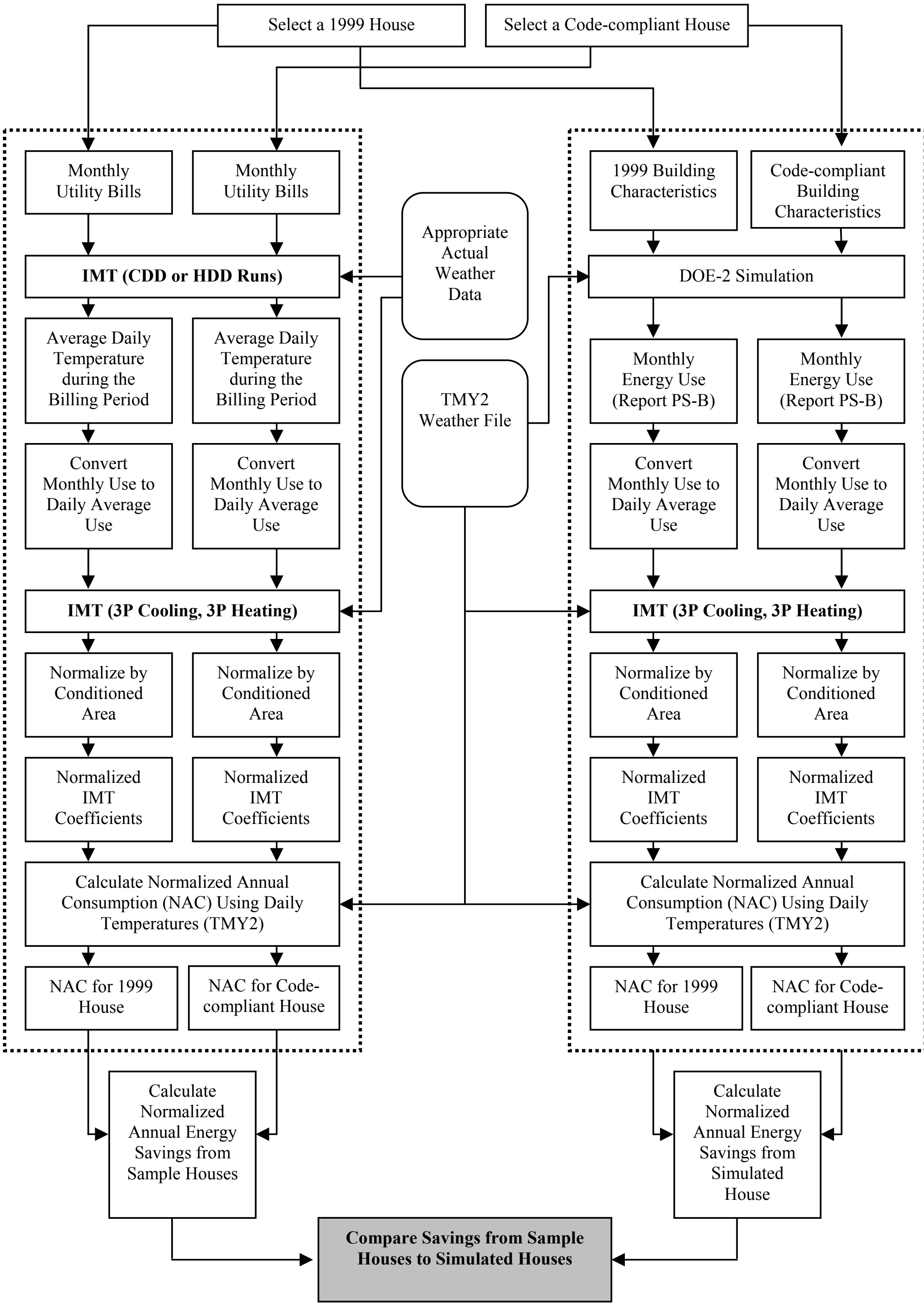

Figure 3.21 - Validation using utility billing analysis

IMT input file for the VBDD procedure is developed. After running the IMT using the VBDD models, daily average temperatures for each billing period are identified from the IMT.RES file. Then, monthly electricity and natural gas use are converted to daily use by dividing the monthly use by the number of days in each billing period. Using the calculated daily energy use and corresponding daily average temperature, the input files for the 3PC model and the 3PH models are developed. After running IMT for the 3PC and the 3PH models, the IMT coefficients for each model are identified. Using daily ambient temperatures from the appropriate TMY2 weather file and the 3PC and 3PH model results, the Normalized Annual Consumption (NAC) for the 1999 and code-compliant house were calculated. The difference between NAC for 1999 and code-compliant house is calculated to compare the normalized energy savings.

In a similar way, the simulated energy use for 1999 and code-compliant house were also analyzed using the IMT to compare against the results of the sample house. The building characteristics from the selected 1999 and code-compliant house were collected. Then, using the code-traceable standard DOE-2 input file, the energy consumption for the 1999 and code-compliant characteristics were simulated. From the PS-B report: Monthly Utility and Fuel Use Summary, the monthly electricity and natural gas use were identified for each house. The monthly energy use of each was then divided by the number of days in the month to obtain the average daily use. Using the calculated daily energy use and daily temperature from the TMY2 weather file, the input files for the simulate 3PC model and 3PH model were developed. After running IMT for simulated the 3PC and 3PH models, the IMT coefficients for each model were identified. Using daily ambient temperatures from the same TMY2 weather file which was used in the sample house analysis and the developed 3PC and 3PH models, Normalized Annual Consumptions (NAC) for the 1999 and the code-compliant house were then calculated. The difference between the NAC for the 1999 and for the code-compliant house was calculated to obtain the normalized energy savings. Finally, the normalized energy savings from real houses and simulated houses were compared to validate the simulated energy savings. The results of this demonstration of the crosscheck are discussed in Chapter IV.

3.7. NO_x Emissions Reduction Calculation

As a final task of this research, the NO_x emission reductions from energy savings were calculated. As mentioned in the literature review, previous calculation of NO_x emissions reduction from energy savings has been reported. However, all the previous studies suffered from over-simplification because they used a simple method such as multiplication times an average emission rate to calculate the NO_x emissions reductions from electricity savings. If average amounts of NO_x emissions reduction are required, then a simple method such as multiplication times an average emission rate could be used. However, since the purpose of this research is to calculate accurate NO_x emissions reduction by the 38 non-attainment and affected counties, a more accurate method needed to be developed. For this research, EPA's eGRID was chosen for use, because it is a widely-used, publically-funded data base of NO_x emissions for the power plants which serve the affected Texas counties.

3.7.1. Limitation of Methodology

Although this study used a detailed grid model to calculate the NO_x emissions reductions by county, there are several limitations in this calculation method.

1) This calculation method is as not precise method based on dispatch or forecasting modeling. Such models provide more realistic NO_x /MWh rates that represent variations in plant operation.

2) For T&D loss, a fixed loss rate (i.e., 20%) was used. In actuality, T&D losses vary according to the path the electricity takes from the power plant to the substation, and by various environmental factors such as temperature, wind, etc.

3.7.2. EPA's eGRID

eGRID is a comprehensive database of environmental pollution from electric power plants. eGRID is based on measured plant-specific data for all U.S. electricity generating plants that provide power and report data to the U.S. government. Data reported for each power generator includes electricity generation (in MWh), resource mix (i.e., renewables and non-renewables), emissions (in tons for NO_x, SO_2, and CO_2; and in pounds of mercury), emission rates (in both pounds per megawatt-hour [lbs/MWh] and pounds per million Btu [lbs/MMBtu] for NO_x, SO_2, and CO_2; and in both pounds per gigawatt-hour [lbs/GWh] and pounds per billion Btu [lbs/BBtu] for mercury), heat input (in MMBtu), and capacity (in MW). eGRID also reports changes in ownership and industry structure as well as power flows between states and grid regions.

3.7.3. eGRID Table

Table 3.3 shows the county-wide NO_x production per MWh of electricity listed by Power Control Area (PCA). The column headings indicate each PCA in the ERCOT region. The first column shows Federal Implementation Plan (FIP) code for each county, and the second column gives the corresponding county in the ERCOT region having electric generators that could be affected by the energy savings. The next ten columns give the NO_x production by PCA for one megawatt of electricity produced.

In Table 3.3, fifty counties have electric generating plants that would be affected by energy savings based on the application of the methodology in the ERCOT region. Each cell shows the annual average amount of NO_x (in pounds) that could be reduced by electric generators in that county if one megaWatt-hour of electricity reduction (i.e., savings) is realized within the PCA for that column. Counties that do not have NO_x values do not contain electric power generating plants (in the eGRID database) that would be affected by energy savings realized within the PCAs shown in the column. The total values shown at the bottom of each column represent the total NO_x produced to generate by one megaWatt-hour.

Table 3.4 presents an expanded version of Table 3.3. The shaded county rows do not have an electricity-generating plant that would be affected by energy savings according to the eGRID database, or are not in the ERCOT region analyzed by eGRID. Seventy-one (71) county names are shown in Table 3.4. Of the thirty-eight (38) non-attainment or affected counties, there are five (5) counties that do not have electricity-generating plants owned by PCAs that reported to eGRID in the ERCOT region. Eleven (11) counties are not in the ERCOT region.

To calculate the NO_x emissions reductions by county, energy savings in a PCA should be input into the bottom row of Table 3.4. For this, Table 3.5 was used to assign the simulated energy savings to each corresponding PCA. In Table 3.5, the first column gives the list of 38 non-attainment and affected counties. The second and third column shows the corresponding electric retail service area and PCA for the county, respectively. The forth column shows the corresponding NERC region for the county. To calculate the energy savings by PCA the MWh savings per county are entered into column five, and the total for each PCA is accumulated in column six.

3.7.4. Calculation of Annual NO_x Emissions Reductions

Figure 3.22 shows the detailed procedure of annual and peak-day NOx emission reductions calculation. As shown in the EPA's eGRID table (See Table 3.3), the electricity savings from a PCA cause NO_x emission reductions in other counties where the power plants are located. In the first step of the NO_x reduction calculation, the electricity savings for each county were classified by PCA. To assign a PCA to a county in this thesis, the Electric Retail Service Area Map (Figure 3.23) was used. Using this color coded map, the 38 non-attainment and affected counties were assigned to the corresponding PCA. The results of this assignment are shown in Table 3.5. Because this assignment was performed using a graphical method, the accuracy of assignment was not a good as it could be with detailed data. To improve of the assignment, a detailed list of Texas electric provider for counties from PUCT will be used for future work. Since the EPA's eGRID table was developed only for the ERCOT Region, the counties included in the other NERC regions such as SERC, WSCC and SPP were excluded in the calculation for this thesis. This should also be expanded in future efforts. As the next step of the calculation, the annual electricity savings (MWh/yr) for each PCA were entered into the last row of the corresponding column in Table 3.4. Then, the NO_x emissions reductions due to the energy savings by county were calculated. After repeating this calculation for all counties and all PCAs, the NO_x emissions reductions for each county were calculated by summing all values for the county across the row.

3.7.5. Calculation of peak-day NO_x Emissions Reductions

This calculation procedure is nearly identical to the previous calculation for annual NO_x reduction. As a first step of the calculation, the peak-day energy savings (MWh/day) for each PCA were entered into the last row of the corresponding column in Table 3.4. Then, the

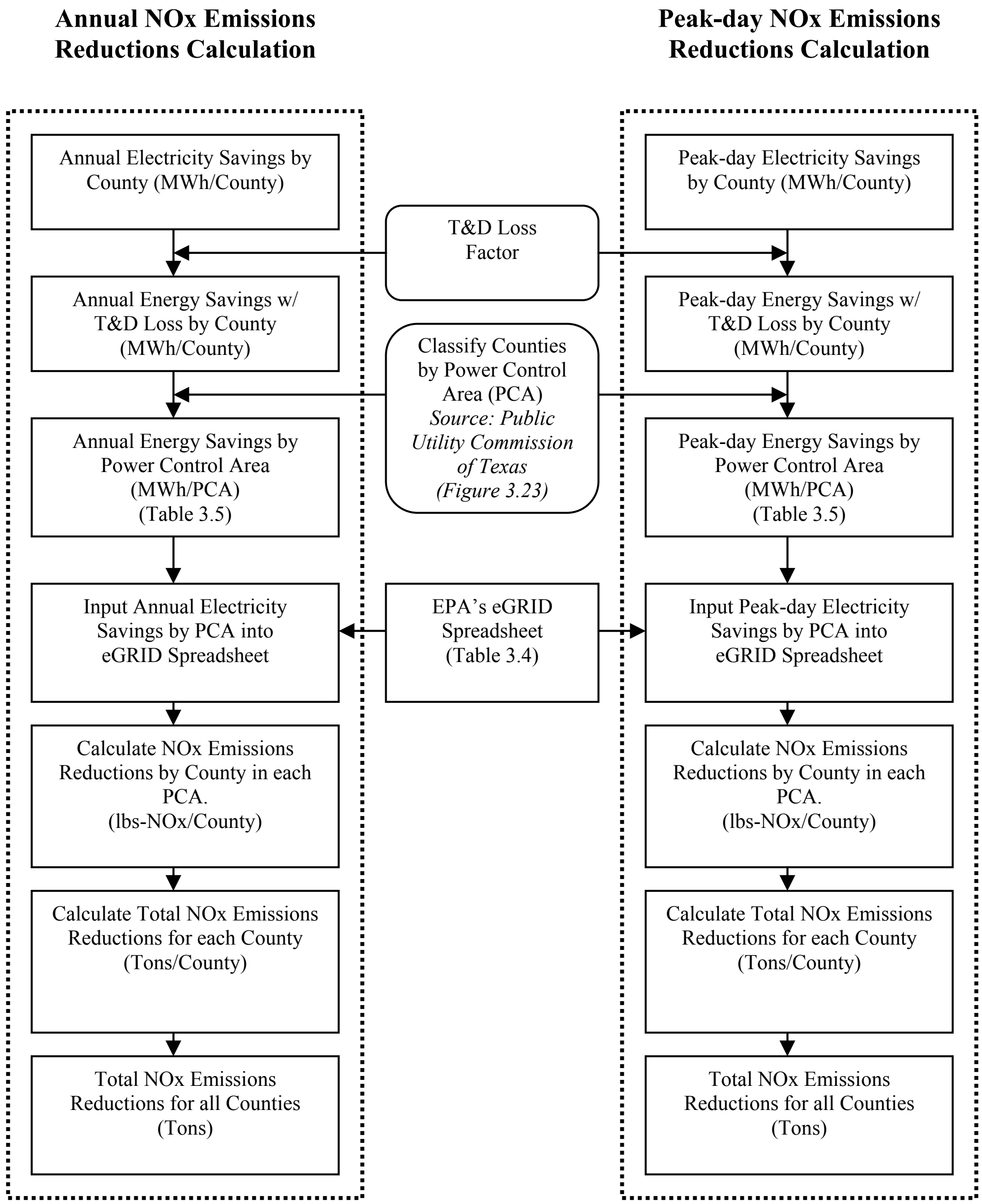

Figure 3.22 - Annual and peak-day NO_x emission reductions calculation

NO_x emissions reductions due to the energy savings by county were calculated as shown in the corresponding cells. After repeating this calculation for all counties and all PCAs, the NO_x emissions reductions for each county were calculated by adding all of the values for the county across the row.

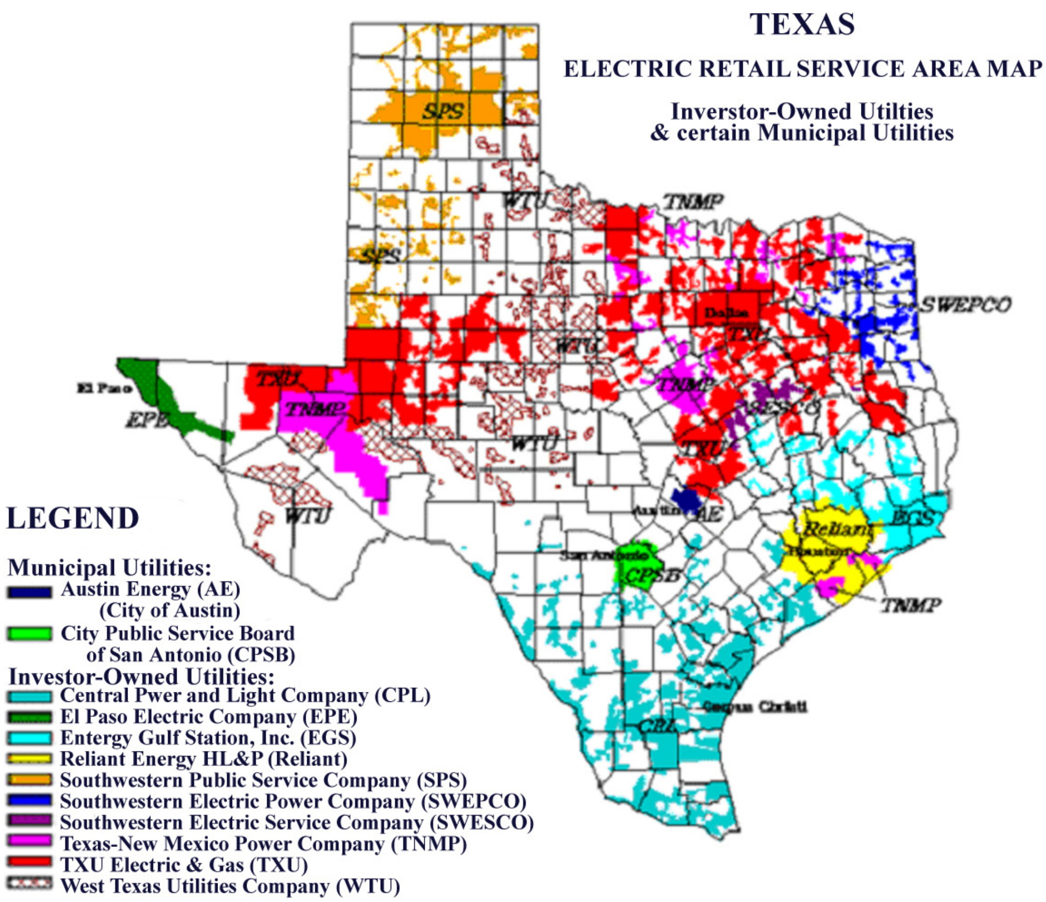

Figure 3.23 - Texas electric retail service area map
(Source: Public Utility Commissions of Texas)

Table 3.3 - EPA's eGRID table: county-wide NO_x productions in pounds per MWh in each listed PCA (received from U.S. E.P.A. at November 2002)

		County-wide NOx Reductions in pounds per MWh for EE/RE implemented in each listed PCA									
Cnty_FIP	County	AMERICAN ELECTRIC POWER-WEST (ERCOT) /PCA	AUSTIN-ENERGY /PCA	BROWNSVILLE PUBLIC UTILS BOARD /PCA	LOWER COLORADO RIVER AUTHORITY /PCA	RELIANT ENERGY HL&P /PCA	SAN ANTONIO PUBLIC SERVICE BD /PCA	SOUTH TEXAS ELECTRIC COOP INC. /PCA	TEXAS MUNICIPAL POWER POOL /PCA	TEXAS-NEW MEXICO POWER CO /PCA	TXU ELECTRIC /PCA
48021	BASTROP	0.01	0.20		0.34		0.01				
48029	BEXAR	0.06	0.09	0.04	0.16		2.00	0.08	0.01		
48039	BRAZORIA	0.01	0.01			0.05	0.01				
48041	BRAZOS		0.01		0.01			0.03	0.11		0.01
48057	CALHOUN	0.19		0.14	0.01			0.04	0.01		0.01
48061	CAMERON	0.14		0.20				0.03			0.01
48071	CHAMBERS	0.05	0.06	0.03	0.02	0.35	0.08	0.03	0.02	0.02	0.03
48073	CHEROKEE	0.01	0.01	0.01	0.02			0.02	0.06	0.02	0.10
48081	COKE	0.03		0.02				0.01			
48083	COLEMAN	0.02		0.01							
48085	COLLIN	0.01	0.01		0.02	0.01		0.05	0.19		0.02
48105	CROCKETT	0.14		0.11				0.03			0.01
48113	DALLAS	0.06	0.06	0.04	0.09	0.03	0.01	0.09	0.30	0.09	0.51
48121	DENTON		0.01		0.01			0.04	0.15		0.01
48147	FANNIN	0.02	0.02	0.01	0.03	0.01		0.03	0.09	0.03	0.17
48149	FAYETTE	0.02	0.86	0.02	1.51	0.01	0.04	0.01	0.02		0.02
48157	FORT BEND	0.13	0.17	0.10	0.06	1.01	0.23	0.09	0.06	0.07	0.10
48161	FREESTONE	0.02	0.02	0.02	0.04	0.01		0.03	0.12	0.04	0.22
48163	FRIO	0.05		0.04	0.01			1.15	0.07		
48167	GALVESTON	0.05	0.06	0.04	0.02	0.39	0.09	0.04	0.03	0.42	0.04
48185	GRIMES	0.01	0.01		0.02	0.01		0.06	0.23		0.01
48197	HARDEMAN	0.01		0.01							
48201	HARRIS	0.05	0.07	0.04	0.02	0.41	0.09	0.04	0.02	0.03	0.04
48207	HASKELL	0.16		0.12	0.01			0.03	0.01		0.01
48213	HENDERSON				0.01				0.02	0.01	0.03
48215	HIDALGO	0.13		0.10				0.03			

Table 3.3 - Continued

		County-wide NOx Reductions in pounds per MWh for EE/RE implemented in each listed PCA									
Cnty_FIP	County	AMERICAN ELECTRIC POWER-WEST (ERCOT) /PCA	AUSTIN-ENERGY /PCA	BROWNSVILLE PUBLIC UTILS BOARD /PCA	LOWER COLORADO RIVER AUTHORITY /PCA	RELIANT ENERGY HL&P /PCA	SAN ANTONIO PUBLIC SERVICE BD /PCA	SOUTH TEXAS ELECTRIC COOP INC. /PCA	TEXAS MUNICIPAL POWER POOL /PCA	TEXAS-NEW MEXICO POWER CO /PCA	TXU ELECTRIC /PCA
48221	HOOD	0.02	0.02	0.02	0.04	0.01		0.03	0.12	0.04	0.22
48251	JOHNSON								0.01		
48253	JONES	0.14		0.11				0.03			0.01
48277	LAMAR										0.01
48293	LIMESTONE	0.01	0.01			0.05	0.01				
48299	LLANO		0.12		0.21		0.01				
48309	MCLENNAN	0.04	0.04	0.03	0.07	0.02	0.01	0.06	0.22	0.07	0.40
48335	MITCHELL	0.04	0.04	0.03	0.07	0.02	0.01	0.06	0.21	0.07	0.39
48353	NOLAN										0.01
48355	NUECES	0.74	0.01	0.55	0.02	0.01	0.01	0.15	0.02	0.01	0.03
48363	PALO PINTO	0.01	0.02	0.01	0.03	0.01		0.09	0.36		0.02
48367	PARKER							0.01	0.03		
48387	RED RIVER								0.01		0.02
48395	ROBERTSON					0.01				0.40	0.01
48401	RUSK	0.01	0.01	0.01	0.01			0.01	0.04	0.01	0.07
48439	TARRANT	0.04	0.04	0.03	0.06	0.02	0.01	0.05	0.18	0.06	0.33
48441	TAYLOR	0.01									
48449	TITUS	0.01	0.01	0.01	0.02			0.02	0.05	0.02	0.10
48453	TRAVIS		0.46		0.05						
48469	VICTORIA	0.30	0.01	0.22	0.01			0.68	0.05		0.01
48475	WARD	0.06	0.06	0.04	0.09	0.02	0.01	0.08	0.28	0.10	0.51
48479	WEBB	0.06		0.05				0.01			
48481	WHARTON					0.01					
48503	YOUNG	0.02	0.02	0.01	0.03	0.01		0.03	0.09	0.03	0.16
	TOTAL	**2.90**	**2.56**	***2.24***	***3.16***	**2.50**	**2.65**	**3.28**	**3.22**	***1.59***	**3.66**

Table 3.4 - Expanded eGRID table

AREA	COUNTY	AMERICAN ELECTRIC POWER-WEST (ERCOT) /PCA	NOx REDUCT-IONS (LBS)	AUSTIN-ENERGY /PCA	NOx REDUCT-IONS (LBS)	BROWNSVILLE PUBLIC UTILS BOARD /PCA	NOx REDUCT-IONS (LBS)	LOWER COLORADO RIVER AUTHORITY /PCA	NOx REDUCT-IONS (LBS)	RELIANT ENERGY HL&P /PCA	NOx REDUCT-IONS (LBS)	SAN ANTONIO PUBLIC SERVICE BD /PCA	NOx REDUCT-IONS (LBS)	SOUTH TEXAS ELECTRIC COOP INC. /PCA	NOx REDUCT-IONS (LBS)	TEXAS MUNICIPAL POWER POOL /PCA	NOx REDUCT-IONS (LBS)	TEXAS-NEW MEXICO POWER CO /PCA	NOx REDUCT-IONS (LBS)	TXU ELECTRIC /PCA	NOx REDUCT-IONS (LBS)	TOTAL NOx REDUCTIONS (TONS)
AUSTIN-SAN ANTONIO AREA	BASTROP	0.01	0.00	0.20	0.00		0.00	0.34	0.00		0.00	0.01	0.00		0.00		0.00		0.00		0.00	0.00
	BEXAR	0.06	0.00	0.09	0.00	0.04	0.00	0.16	0.00		0.00	2.00	0.00	0.08	0.00	0.01	0.00		0.00		0.00	0.00
	TRAVIS		0.00	0.46	0.00		0.00	0.05	0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	FAYETTE	0.02	0.00	0.86	0.00	0.02	0.00	1.51	0.00	0.01	0.00	0.04	0.00	0.01	0.00	0.02	0.00		0.00	0.02	0.00	0.00
	LLANO		0.00	0.12	0.00		0.00	0.21	0.00		0.00	0.01	0.00		0.00		0.00		0.00		0.00	0.00
	CALDWELL		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	COMAL		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	GUADALUPE		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	HAYS		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	WILLIAMSON		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	WILSON		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
DALLAS-FORT WORTH AREA	COLLIN	0.01	0.00	0.01	0.00		0.00	0.02	0.00	0.01	0.00		0.00	0.05	0.00	0.19	0.00		0.00	0.02	0.00	0.00
	DALLAS	0.06	0.00	0.06	0.00	0.04	0.00	0.09	0.00	0.03	0.00	0.01	0.00	0.09	0.00	0.30	0.00	0.09	0.00	0.51	0.00	0.00
	DENTON		0.00	0.01	0.00		0.00	0.01	0.00		0.00		0.00	0.04	0.00	0.15	0.00		0.00	0.01	0.00	0.00
	JOHNSON		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01	0.00		0.00		0.00	0.00
	PARKER		0.00		0.00		0.00		0.00		0.00		0.00	0.01	0.00	0.03	0.00		0.00		0.00	0.00
	CHEROKEE	0.01	0.00	0.01	0.00	0.01	0.00	0.02	0.00		0.00		0.00	0.02	0.00	0.06	0.00	0.02	0.00	0.10	0.00	0.00
	COKE	0.03	0.00		0.00	0.02	0.00		0.00		0.00		0.00	0.01	0.00		0.00		0.00		0.00	0.00
	COLEMAN	0.02	0.00		0.00	0.01	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	FANNIN	0.02	0.00	0.02	0.00	0.01	0.00	0.03	0.00	0.01	0.00		0.00	0.03	0.00	0.09	0.00	0.03	0.00	0.17	0.00	0.00
	FRIO	0.05	0.00		0.00	0.04	0.00	0.01	0.00		0.00		0.00	1.15	0.00	0.07	0.00		0.00		0.00	0.00
	HARDEMAN	0.01	0.00		0.00	0.01	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	HASKELL	0.16	0.00		0.00	0.12	0.00	0.01	0.00		0.00		0.00	0.03	0.00	0.01	0.00		0.00	0.01	0.00	0.00
	HENDERSON		0.00		0.00		0.00	0.01	0.00		0.00		0.00		0.00	0.02	0.00	0.01	0.00	0.03	0.00	0.00
	HOOD	0.02	0.00	0.02	0.00	0.02	0.00	0.04	0.00	0.01	0.00		0.00	0.03	0.00	0.12	0.00	0.04	0.00	0.22	0.00	0.00
	JONES	0.14	0.00		0.00	0.11	0.00		0.00		0.00		0.00	0.03	0.00		0.00		0.00	0.01	0.00	0.00
	LAMAR		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01	0.00	0.00
	LIMESTONE	0.01	0.00	0.01	0.00		0.00		0.00	0.05	0.00	0.01	0.00		0.00		0.00		0.00		0.00	0.00
	MCLENNAN	0.04	0.00	0.04	0.00	0.03	0.00	0.07	0.00	0.02	0.00	0.01	0.00	0.06	0.00	0.22	0.00	0.07	0.00	0.40	0.00	0.00
	MITCHELL	0.04	0.00	0.04	0.00	0.03	0.00	0.07	0.00	0.02	0.00	0.01	0.00	0.06	0.00	0.21	0.00	0.07	0.00	0.39	0.00	0.00
	NOLAN		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01	0.00	0.00
	PALO PINTO	0.01	0.00	0.02	0.00	0.01	0.00	0.03	0.00	0.01	0.00		0.00	0.09	0.00	0.36	0.00		0.00	0.02	0.00	0.00
	RED RIVER		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01	0.00		0.00	0.02	0.00	0.00
	TAYLOR	0.01	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	TITUS	0.01	0.00	0.01	0.00	0.01	0.00	0.02	0.00		0.00		0.00	0.02	0.00	0.05	0.00	0.02	0.00	0.10	0.00	0.00
	YOUNG	0.02	0.00	0.02	0.00	0.01	0.00	0.03	0.00	0.01	0.00		0.00	0.03	0.00	0.09	0.00	0.03	0.00	0.16	0.00	0.00
	TARRANT	0.04	0.00	0.04	0.00	0.03	0.00	0.06	0.00	0.02	0.00	0.01	0.00	0.05	0.00	0.18	0.00	0.06	0.00	0.33	0.00	0.00
	ELLIS		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	KAUFMAN		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	ROCKWALL		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00

Table 3.4 - Continued

AREA	COUNTY	AMERICAN ELECTRIC POWER-WEST (ERCOT) /PCA	NOx REDUCT-IONS (LBS)	AUSTIN-ENERGY /PCA	NOx REDUCT-IONS (LBS)	BROWNSVILLE PUBLIC UTILS BOARD /PCA	NOx REDUCT-IONS (LBS)	LOWER COLORADO RIVER AUTHORITY /PCA	NOx REDUCT-IONS (LBS)	RELIANT ENERGY HL&P /PCA	NOx REDUCT-IONS (LBS)	SAN ANTONIO PUBLIC SERVICE BD /PCA	NOx REDUCT-IONS (LBS)	SOUTH TEXAS ELECTRIC COOP INC. /PCA	NOx REDUCT-IONS (LBS)	TEXAS MUNICIPAL POWER POOL /PCA	NOx REDUCT-IONS (LBS)	TEXAS-NEW MEXICO POWER CO /PCA	NOx REDUCT-IONS (LBS)	TXU ELECTRIC /PCA	NOx REDUCT-IONS (LBS)	TOTAL NOx REDUCTIONS (TONS)
HOUSTON-GALVESTON AREA	BRAZORIA	0.01	0.00	0.01	0.00		0.00		0.00	0.05	0.00	0.01	0.00		0.00		0.00		0.00		0.00	0.00
	BRAZOS		0.00	0.01	0.00		0.00	0.01	0.00		0.00		0.00	0.03	0.00	0.11	0.00		0.00	0.01	0.00	0.00
	GRIMES	0.01	0.00	0.01	0.00		0.00	0.02	0.00	0.01	0.00		0.00	0.06	0.00	0.23	0.00		0.00	0.01	0.00	0.00
	WHARTON		0.00		0.00		0.00		0.00	0.01	0.00		0.00		0.00		0.00		0.00		0.00	0.00
	CHAMBERS	0.05	0.00	0.06	0.00	0.03	0.00	0.02	0.00	0.35	0.00	0.08	0.00	0.03	0.00	0.02	0.00	0.02	0.00	0.03	0.00	0.00
	FORT BEND	0.13	0.00	0.17	0.00	0.10	0.00	0.06	0.00	1.01	0.00	0.23	0.00	0.09	0.00	0.06	0.00	0.07	0.00	0.10	0.00	0.00
	GALVESTON	0.05	0.00	0.06	0.00	0.04	0.00	0.02	0.00	0.39	0.00	0.09	0.00	0.04	0.00	0.03	0.00	0.42	0.00	0.04	0.00	0.00
	ROBERTSON		0.00		0.00		0.00		0.00	0.01	0.00		0.00		0.00		0.00	0.40	0.00	0.01	0.00	0.00
	HARRIS	0.05	0.00	0.07	0.00	0.04	0.00	0.02	0.00	0.41	0.00	0.09	0.00	0.04	0.00	0.02	0.00	0.03	0.00	0.04	0.00	0.00
	HARDIN		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	JEFFERSON		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	LIBERTY		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	MONTGOMERY		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	ORANGE		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	WALLER		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
EL PASO AREA	EL PASO		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
OTHERS	RUSK	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00		0.00		0.00	0.01	0.00	0.04	0.00	0.01	0.00	0.07	0.00	0.00
	CROCKETT	0.14	0.00		0.00	0.11	0.00		0.00		0.00		0.00	0.03	0.00		0.00		0.00	0.01	0.00	0.00
	FREESTONE	0.02	0.00	0.02	0.00	0.02	0.00	0.04	0.00	0.01	0.00		0.00	0.03	0.00	0.12	0.00	0.04	0.00	0.22	0.00	0.00
	CALHOUN	0.19	0.00		0.00	0.14	0.00	0.01	0.00		0.00		0.00	0.04	0.00	0.01	0.00		0.00	0.01	0.00	0.00
	HIDALGO	0.13	0.00		0.00	0.10	0.00		0.00		0.00		0.00	0.03	0.00		0.00		0.00		0.00	0.00
	CAMERON	0.14	0.00		0.00	0.20	0.00		0.00		0.00		0.00	0.03	0.00		0.00		0.00	0.01	0.00	0.00
	WARD	0.06	0.00	0.06	0.00	0.04	0.00	0.09	0.00	0.02	0.00	0.01	0.00	0.08	0.00	0.28	0.00	0.10	0.00	0.51	0.00	0.00
	WEBB	0.06	0.00		0.00	0.05	0.00		0.00		0.00		0.00	0.01	0.00		0.00		0.00		0.00	0.00
	NUECES	0.74	0.00	0.01	0.00	0.55	0.00	0.02	0.00	0.01	0.00	0.01	0.00	0.15	0.00	0.02	0.00	0.01	0.00	0.03	0.00	0.00
	VICTORIA	0.30	0.00	0.01	0.00	0.22	0.00	0.01	0.00		0.00		0.00	0.68	0.00	0.05	0.00		0.00	0.01	0.00	0.00
	GREGG		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	HARRISON		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	SMITH		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	UPSHUR		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	SAN PATRICIO		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	TOTAL	**2.89**		**2.54**		**2.22**		**3.12**		**2.48**		**2.63**		**3.27**		**3.19**		**1.54**		**3.65**		0.00
Energy Savings by PCA																						

Table 3.5 - Calculation table for energy use by PCA

Nonattainment and Affected Counties	Electric Retail Service Area	Power Control Area	NERC Region	Total Energy Savings by County (MWh)	Total Energy Savings by PCA (MWh)
Travis	Austin Energy	Austin Energy/PCA	ERCOT		
		Austin Energy/PCA			
Nueces	CRI	American Electric Power West (ERCOT)/PCA	ERCOT		
San Patricio	CRI	American Electric Power West (ERCOT)/PCA	ERCOT		
Victoria	CRI	American Electric Power West (ERCOT)/PCA	ERCOT		
		American Electric Power West (ERCOT)/PCA			
Bastrop		Lower Colorado River Authority/PCA	ERCOT		
Caldwell		Lower Colorado River Authority/PCA	ERCOT		
Comal		Lower Colorado River Authority/PCA	ERCOT		
Guadalupe		Lower Colorado River Authority/PCA	ERCOT		
Hays		Lower Colorado River Authority/PCA	ERCOT		
Wilson		Lower Colorado River Authority/PCA	ERCOT		
		Lower Colorado River Authority/PCA			
Brazoria	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT		
Fort Bend	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT		
Galveston	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT		
Harris	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT		
Waller	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT		
		Reliant Energy HL&P/PCA			
Bexar	San Antonio Public Service Bd	San Antonio Public Service Bd/PCA	ERCOT		
		San Antonio Public Service Bd/PCA			
Ellis	TXU	TXU Electric/PCA	ERCOT		
Johnson	TXU	TXU Electric/PCA	ERCOT		
Kaufman	TXU	TXU Electric/PCA	ERCOT		
Parker	TXU	TXU Electric/PCA	ERCOT		
Rockwall	TXU	TXU Electric/PCA	ERCOT		
Smith	TXU	TXU Electric/PCA	ERCOT		
Williamson	TXU	TXU Electric/PCA	ERCOT		
Collin	TXU	TXU Electric/PCA	ERCOT		
Dallas	TXU	TXU Electric/PCA	ERCOT		
Denton	TXU	TXU Electric/PCA	ERCOT		
Tarrant	TXU	TXU Electric/PCA	ERCOT		
		TXU Electric/PCA			
Chambers	EGS	Entergy Electric System/PCA	SERC		
Hardin	EGS	Entergy Electric System/PCA	SERC		
Jefferson	EGS	Entergy Electric System/PCA	SERC		
Liberty	EGS	Entergy Electric System/PCA	SERC		
Montgomery	EGS	Entergy Electric System/PCA	SERC		
Orange	EGS	Entergy Electric System/PCA	SERC		
		Entergy Electric System/PCA			
El Paso	EL PASO Electric Company	El Paso Electric Co/PCA	WSCC		
		El Paso Electric Co/PCA			
Gregg	SWEPCO	Southwestern Public Service Co/PCA	SPP		
Harrison	SWEPCO	Southwestern Public Service Co/PCA	SPP		
Rusk	SWEPCO	Southwestern Public Service Co/PCA	SPP		
Upshur	SWEPCO	Southwestern Public Service Co/PCA	SPP		
		Southwestern Public Service Co/PCA			
Total					

3.8. Summary

This chapter discussed the methodology developed in this research that was used to calculate energy savings and emissions reduction from the adoption of the 2000 IECC in new single family residences. The detailed procedures for 6 major tasks including: 1) Baseline construction data collection, 2) Development of the 2000 IECC standard building simulation, 3) Projection of building permits in 2002, 4) Comparison of energy simulation, 5) Demonstration of validation procedure, and 6) NO_x emissions reduction calculation, were described. The next chapter will present the results of the research performed using the methodology developed in this chapter.

CHAPTER IV

RESULTS

This chapter discusses the results the application of the research methodology that was defined in Chapter III. In a similar fashion as the methodology chapter, this chapter is divided into six sections. The first section presents the result of the base case study. The results of the base case study include the data collection process and the building characteristics of the base case house. The second section describes the standard building characteristics required in the 2000 IECC. After reviewing the 2000 IECC, the required building characteristics for each county were defined according to the corresponding climate zones. The third section presents the projected number of building permits in 2002. The fourth section is the result of the DOE-2 simulations for each county and the analysis of the energy savings due to the code adoption. In this section, using the standard input file for DOE-2 simulation and the defined building characteristics in the first and second section, several DOE-2 simulations were performed, and the annual and peak-day energy savings were calculated. In the fifth section, the validation procedure and results of testing the validation are presented. Using several previous studies, the 1999 building characteristics and the calculated energy savings were crosschecked. Then, using actual case study houses, the onsite visit analysis and the utility billing analysis were performed as a demonstration of the validation procedure, and the results were presented. Finally, in the sixth section, the NO_x emissions reductions due to the electricity savings calculated in the third section were calculated.

4.1. Results of Base Case Study

This section discusses the basic information gathered for the study, the data collection process, and the characteristics of the base case house. The basic information includes the 1999 Texas county population, the number of housing units in Texas counties, and the residential building permit activity by county. The data collection process presents the data sources, the available data from each source, and several personal communications. Finally, the developed building characteristics for the 1999 base case house are presented.

4.1.1. Population, Number of Housing Units and Building Permit Activity

To understand regional characteristics, several sources of data were collected before developing the base case house. These data include Texas county population, the number of existing housing units, and the residential building permit activity by county. This information can be used to understand not only the regional characteristics of each county and to predict the selected of data for the year 2002.

4.1.1.1. Population of 38 Non-attainment and Affected Counties

U.S. Census Bureau provides the population of Texas and its county from 1970 to the present (U.S. Census Bureau, 1999). Figure 4.1 shows the general distribution of the population of Texas counties for the year 2000. From this figure, one can clearly see that most of population is concentrated in the eastern portion of Texas and in cities such as Houston, Dallas, Fort Worth, Austin, San Antonio and El Paso. Not surprisingly, these populated cities are generally included in either non-attainment or affected counties. The population of the thirty-eight non-attainment and affected counties is 13.9 million in 1999, which represents 68 percent of the state's 20 million total populations. Table 4.1 and Figure 4.2 show the 1999 population of the thirty-eight non-attainment and affected in descending order. The total population of the first four counties makes up 40% of all thirty-eight counties' population. Among these four counties, the first three, Harris, Dallas and Tarrant were classified as non-attainment counties and the fourth Bexar County was classified as an affected county. Generally, non-attainment counties represent the majority of population in this graph. The population of the non-attainment counties makes up 71 percent of the total thirty eight counties population, and 49 percent of the total state population.

4.1.1.2. Number of Housing Units

The U.S. Census Bureau and Texas State Real Estate Center provide statistics about the existing number of housing units. In general, this number is similar to the population in each county (See Table 4.1 and Figure 4.3). In a similar fashion as the county's population

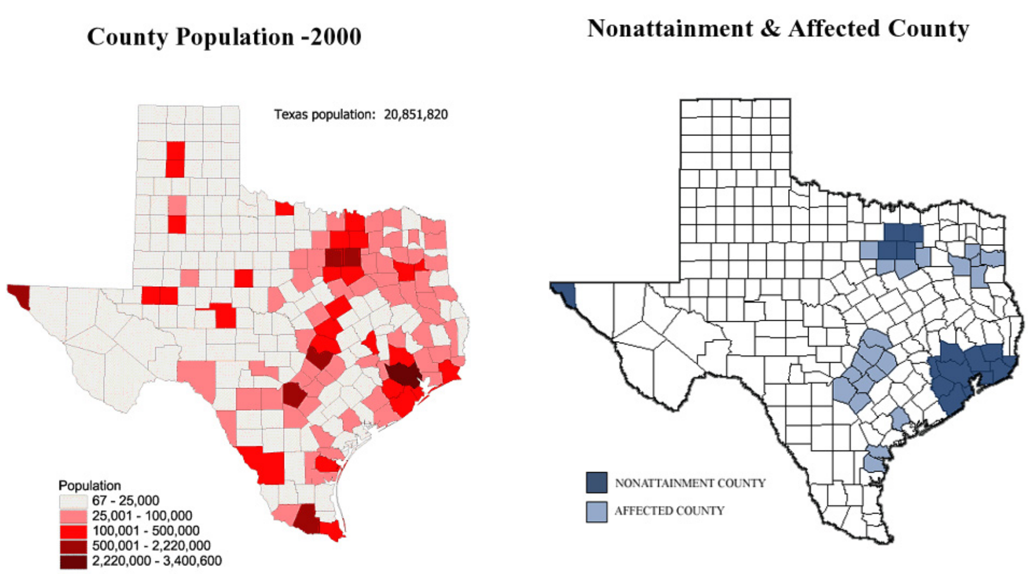

Figure 4.1 - Texas county populations (year 2000)
(Source: U.S. Census Bureau and TNRCC)

Table 4.1 - Population, housing units, and building permit activity in 1999
(Source: U.S. Census Bureau, RECenter at TAMU)

County	Population	Housing Unit	Building Permit Activity (Single Family House)
Harris	**3,250,404**	**1,273,565**	**16,055**
Dallas	**2,062,100**	**840,374**	**8,392**
Tarrant	**1,382,442**	**554,145**	**8,785**
Bexar	1,372,867	512,381	7,117
Travis	727,022	321,612	6,742
El Paso	**701,908**	**221,244**	**3,472**
Collin	**456,612**	**184,781**	**7,704**
Denton	**404,074**	**162,280**	**5,222**
Fort Bend	**353,697**	**114,678**	**1,148**
Nueces	315,469	122,102	694
Montgomery	**287,644**	**108,573**	**4,493**
Galveston	**248,469**	**108,802**	**1,627**
Jefferson	**241,332**	**101,465**	**581**
Williamson	240,892	84,634	3,984
Brazoria	**234,303**	**88,543**	**1,717**
Smith	169,693	71,158	440
Johnson	122,594	45,604	514
Gregg	113,155	46,189	194
Ellis	107,580	38,095	481
Hays	92,755	33,919	754
Parker	85,427	33,802	242
Orange	**85,240**	**34,607**	**218**
Guadalupe	82,808	33,112	628
Victoria	82,087	32,778	196
Comal	76,770	31,586	926
San Patricio	71,636	24,369	248
Kaufman	68,065	25,803	178
Liberty	**67,161**	**26,146**	**310**
Harrison	59,797	26,243	22
Bastrop	52,561	22,106	143
Hardin	**49,684**	**19,815**	**33**
Rusk	45,819	19,854	18
Rockwall	39,489	14,396	761
Upshur	36,541	14,917	14
Caldwell	32,820	11,844	81
Wilson	32,504	12,099	7
Waller	**28,070**	**11,668**	**29**
Chambers	**23,993**	**10,027**	**213**
Total	13,905,484	5,439,316	84,383

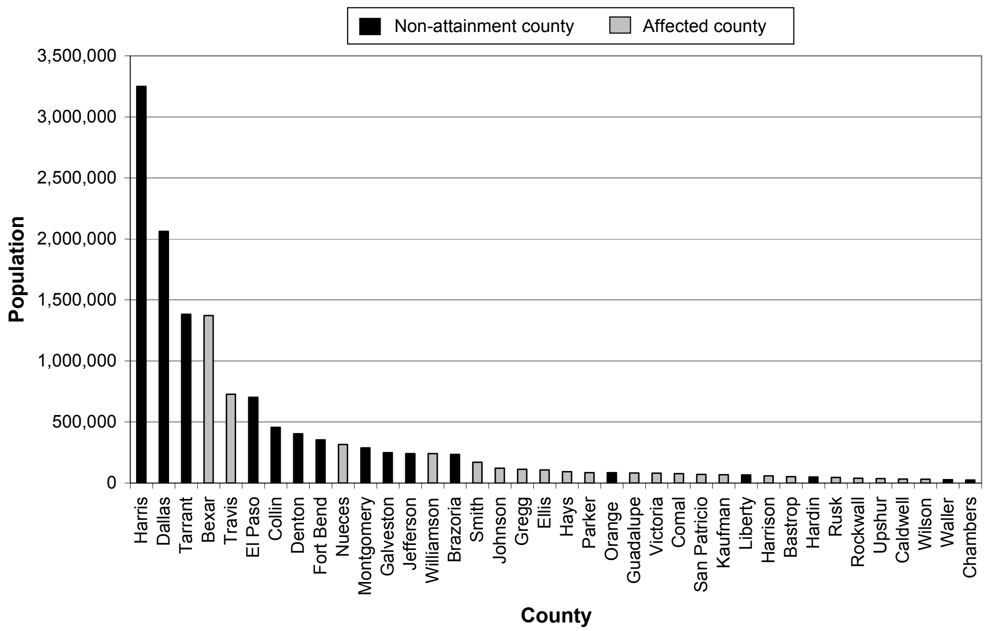

Figure 4.2 - Population in the 38 non-attainment and affected counties in Texas in 1999

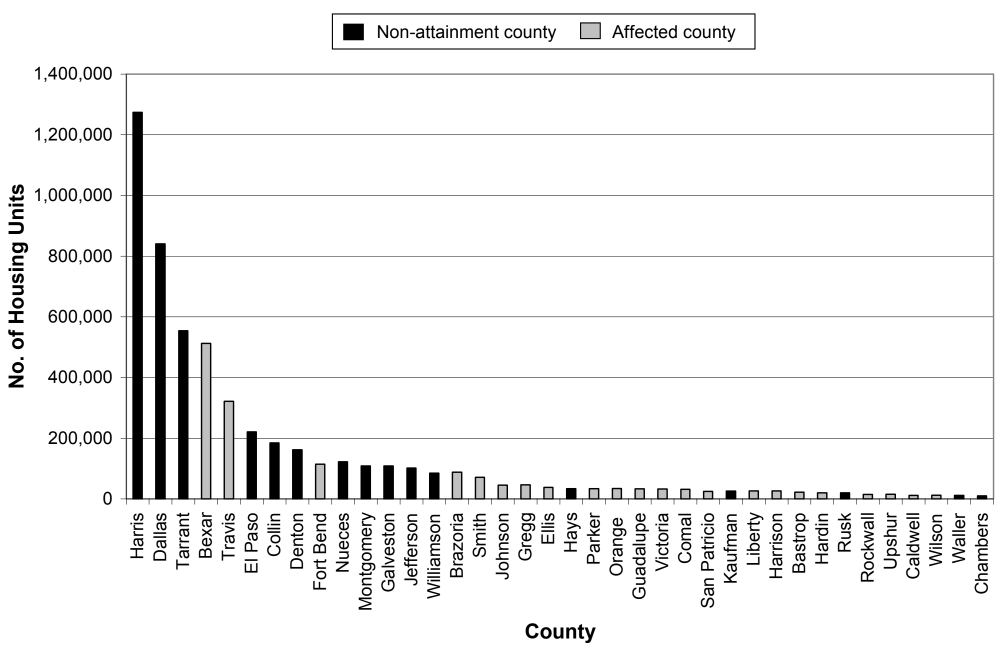

Figure 4.3 - Number of housing units in the non-attainment and affected counties in Texas in 1999

trends, the number housing units in the four most populated counties (i.e., Harris, Dallas, Tarrant, and Bexar) represent 59 percent of the number of total thirty eight counties housing units, and 47 percent of the total state's housing units.

4.1.1.3. Number of Building Permits

The building permit activities in 1999 show a slightly different trend compared with the trend of the population and the number of housing units. Figure 4.4 shows the ranking of single family residential building permit activity in 1999. In this graph, the county order is the same as the order of the graphs for population and number of housing units. From this graph, one can see that the county permit activity is not exactly matched with the population and the number of housing units. In a similar fashion as the population (Figure 4.2) and the housing unit trends (Figure 4.3), most permit activity is in Harris County with 16,055 units. However,

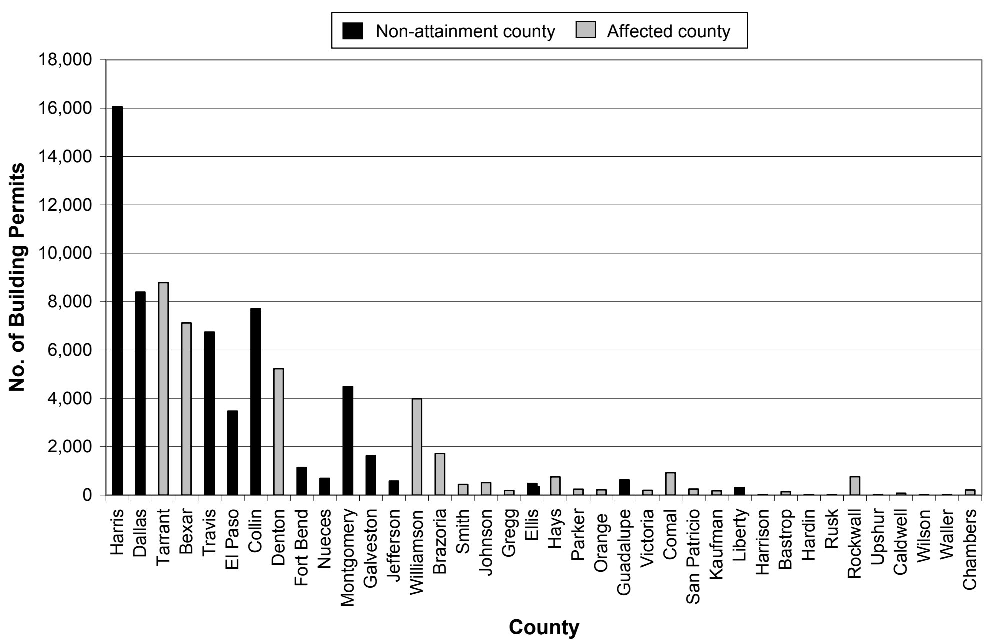

Figure 4.4 - 1999 single family residential building permit activities

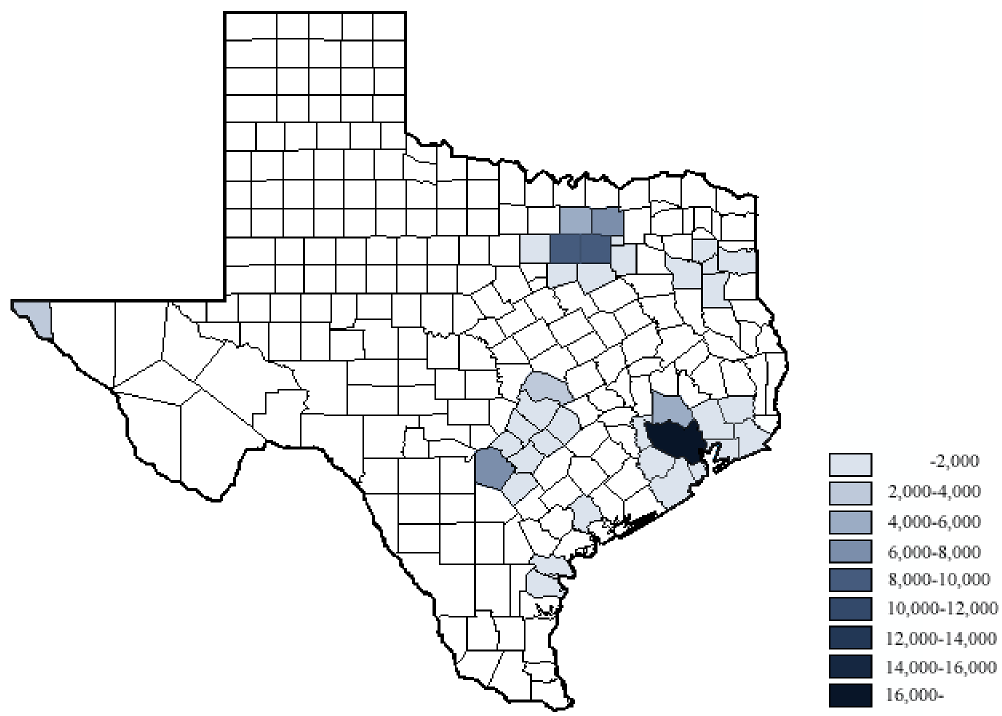

Figure 4.5 - 1999 Texas single family residential building permit activity by county

the second most active county, Tarrant, has only half the permit activity (8,785 units). The first six counties represent 54,795 permits, or 65 percent of the total 84,383 permits in the 38 counties. Figure 4.5 shows the residential permit activity distribution in 38 counties.

4.1.2. Base-Case Building Characteristics

This section presents the detailed descriptions of the process of the data collection, including: Data Sources and collection process, the description of the data from the NAHB's Builder Practices Survey, the ARI and the GAMA.

4.1.2.1. Data Sources and Collection Process

To develop the standard house which was built in 1999, all available data from previously published sources were collected. The primary source of the building characteristics is the National Home Builder Association (NAHB)'s Builder Practice Survey Reports (NAHB Research Center, 2000). The data for the heating and cooling system characteristics were collected from the Air-Conditioning and Refrigeration Institute (ARI), Gas Appliance Manufacturers Association (GAMA) by personal communications with Mr. Richard E. Cawley from the Trane, Co. and Mr. Mark Kendell from GAMA.

4.1.2.2. National Association of Home Builder (NAHB)'s Builder Practices Survey

4.1.2.2.1. Background

The *Builder Practices Survey Reports* present data about building material purchases based on a survey from 2,800 U.S. home builders. This report is published annually, with target areas including each of the 50 States, the 9 Census Divisions and the total U.S. To obtain the characteristics for single family houses that were built in 1999, the NAHB Research Center was contacted, and a set of reports was purchased, which presents the average building characteristics for the 1999 single family houses in Texas. All values in these data sheets are for new single family houses built in 1999. For the NAHB survey in Texas and Louisiana, a total of 89 builders in Texas and Louisiana participated. The survey area was divided into two groups; west Texas and east Texas & Louisiana[1]. Figure 4.6 shows the boundary line for the east and west Texas division. This set of reports includes several data sheets that show the average characteristics for each element of the building. The list of data sheets and the summarized information is presented in Table 4.2.

[1] The building characteristics for east Texas and Louisiana were defined the same in the NAHB's survey.

Table 4.2 – The list of data sheets from NAHB's builder practices survey

List of Data	
Windows	Exterior Wall Sheathing
HVAC Duct	Roofing
HVAC Equipment	Average Wall Height
Insulation	Average Floor Area
Exterior Wall Finishes	Number of Stories
Wall Type (Structural Materials)	Garage

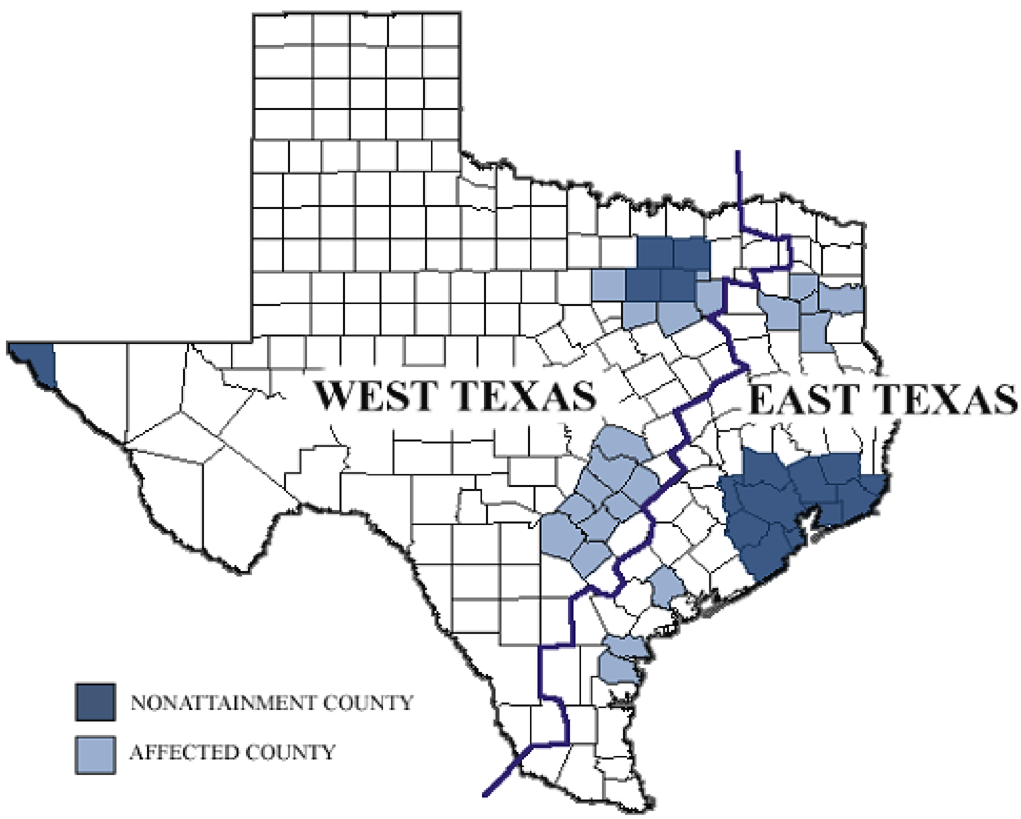

Figure 4.6 – Division of NAHB builder practices survey for Texas

4.1.2.2.2. Windows

This information includes the window frame material, the glass type, and the number of panes of windows. According to the survey, the number of windows in the standard house was 16.5 for east Texas, 25 for west Texas. Aluminum was the predominant window frame for both east and west Texas (83.7% for east Texas and 92.3% for west Texas). The glass type for both division of Texas in 1999 was mainly composed of clear glass (82.9% for east Texas and 86.8% for west Texas) and small percentage of the Low-E (9.9% for east Texas and 11.6% for west Texas), and tinted glass (7.2% for east Texas and 1.6% for west Texas %). For east Texas, the main glazing type was single pane glass (60%). The remaining glazing was double pane glass. For west Texas, most windows were composed of double pane glass except about 8 percent, which had single pane glass.

4.1.2.2.3. HVAC Equipment

According to the NAHB report, most of the single family houses in Texas had at least one heating and cooling system. The major type of heating equipment was a gas furnace (76.1% for east Texas and 84.1% for west Texas), with a small number of electric furnace (22.6% for east Texas and 15.9% for west Texas). The major type of cooling system was the central air conditioner (spilt systems) for both divisions of Texas (89.4% for east Texas and 68.6% for west Texas). The SEER ratings for cooling equipment varied from 10 to 13, with 12 and 12.9 the majority for east Texas, but for west Texas, less than 10 and between 12 and 12.9 was the majority. In this thesis, however, the efficiencies for the heating and the cooling systems in the 1999 standard house were defined using the data from GAMA and ARI. More detailed data for this is described in Section 4.1.3.2 of this Chapter.

4.1.2.2.4. Insulation

The NAHB report contains the information about insulation, including the material and the R-value for the foundation, the exterior wall, the ceiling and the interior wall. The type of foundation in Texas was mostly slab-on-grade with no insulation (98.9% for east Texas and 73.6% for west Texas). The main material for the exterior wall cavity insulation was fiberglass batt insulation for both areas (91.4% for east Texas and 96.8% for west Texas). The average R-value of the continuous exterior walls for east Texas was 13.99 (hr ft^2 °F/Btu) and for west Texas was 14.29 (hr ft^2 °F/Btu). The main type of the ceiling insulation was fiberglass batt and blown-in fiberglass. The average R-value of the ceiling for east Texas was 27.08 (hr ft^2 °F/Btu) and for west Texas was 26.75 (hr ft^2 °F/Btu).

4.1.2.2.5. Average Wall Height

The average wall height for east Texas was 8.8 ft and for west Texas, 9.2 feet for the first story. For the second story, average wall height for east Texas was 8.8 feet and west Texas was 8.8 feet. In this thesis, however, an 8 feet of height was used for both division of Texas, due to observation of local practices and discussions with builders.

4.1.2.2.6. Average Floor Area

The average floor area of finished floor for east Texas was 2,548 square feet and for west Texas was 2,426 square feet.

4.1.2.2.7. Number of Stories

The number of stories in both east and west Texas were mostly one story with a lesser amount of two story houses. In general, the rates of one and two story houses were similar in east and west Texas. In east Texas, the number of one story houses was higher than two story house (58.8% of one story and 36.6% of two stories). On the contrary, in west Texas, the number of two story houses was little bit higher than one story house (45.4% of one story and 54.5% of two stories). For the purposes of this thesis, a one story house was used for all simulations. This is due to the fact that the ESL's code-traceable simulation only contains one story. A two story simulation was under development at the time this thesis was being completed, but was not available for use in 2002 when the results of this thesis were completed.

4.1.2.2.8. Wall Type (Structural Material)

The main structural material for the exterior wall was either wood or masonry for east Texas. For east Texas, the houses with wood walls and masonry walls were 55 percent and 45 percent, respectively. However, in west Texas, exterior walls were constructed wood (90.7 %), and the remaining (9.3%) masonry.

4.1.2.2.9. Garage

In both Texas areas, a two car garage was the norm.. About 70 percent of total houses in east Texas had two car garages. In west Texas, 59 percent of total houses had two car garages.

4.1.3. 1999 Standard House

Using the house characteristics defined above, the average characteristics of the 1999 standard house for each county were defined. As previously mentioned, the building envelope characteristics were defined in the NAHB's report. The efficiencies of the furnace and air conditioning systems were defined using the data from GAMA (personal communication, April 11, 2002) and ARI (personal communication, March 29, 2002).

After the average characteristics data were collected, the next step was to prepare the data for the DOE-2 simulation. To accomplish this, some information was used as is, and other information required modification before it could be used in the input file of the DOE-2 simulation. Sometimes, additional assumptions were needed to modify the original data. The detailed procedure of developing the 1999 average building characteristics for single family houses is presented below.

4.1.3.1 Building Envelope

Of the building envelope data from NAHB, the floor area, the wall height, the wall R-value, the roof/ceiling R-value, the AFUE and SEER were used as it is. However, since the window area, glazing U-factor and SHGC were not provided in NAHB's reports, several calculations and assumptions were required.

4.1.3.1.1. Average Window Area and Window-to-Wall Ratio

NAHB's Builder Practice Survey Reports provide the average number of window units per house for east and west Texas. From the reports, the number of window units for east Texas is 16.4 and for west Texas is 24.9. Since the window area and the window-to-wall ratio is required to input the house information into the DOE-2 input file, the number of window units needed to be converted into window area and the window-to-wall ratio. For this task, the average window size was identified from several sources. The sources include: a personal visit to the local Lowes building supply store (Lowes, 2002) and information obtained from the local Habitat for Humanity office (communication with Jim Davis 2003). Both of these sources clearly show that the average window size is 3ft x 5ft. Therefore, the window-to-wall ratio conversion calculation used this average window size. The average floor area for east and west Texas are based on the NHAB's report, and the average wall height[2] was assumed to be 8 ft. The shape of the house is assumed a square with the house oriented North, South, East, and West. The followings are the pre-calculations of the window-to-wall ratio.

Total window area for east Texas house: 3 x 5 x 16.4 =246 ft^2

Total wall area for east Texas house: 50.5 (length of house) x 4 x 8 (height of house) = 1,616 ft^2

Calculated window-to-wall ratio for east Texas: (246/1616) x 100 = 15.2 %

Total window area for west Texas house: 3x5x24.9 =373.5 ft^2

Total wall area for west Texas house: 49.3 (length of house) x 4 x 8 (height of house) = 1,578 ft^2

Calculated window-to-wall ratio for west Texas: (373.5/1577.6) x 100 = 23.68 %

4.1.3.1.2. U-Value and SHGC

NAHB's Builder Practice Survey Reports provide the types of the glass and the frame installed on the single family houses in Texas. Section 4.1.2.2.2 presented the detailed characteristics of the glass and the frame installed. Since those window characteristics must be converted into window U-value and SHGC to be input in the DOE-2 simulation, several pre-calculations were required.

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[2] According to the ESL' Report (ESL, 2002), the average wall height was assumed. As noted earlier, in the NAHB's report, the wall height for east and west Texas was 8.8 ft and 9.2 ft, respectively.

To begin, the U-value and the SHGC for the standard single pane window and the double pane window were identified from the 2001 ASHRAE Handbook of Fundamentals (ASHRAE, 2001b). Table 4.3 shows the U-value and SHGC of the single-glazed window (1/8 in. glass) and the double-glazed window (1/4 in. air space). After identifying the U-values and SHGCs, the weighted average values for east Texas were calculated. Since the houses in west Texas have 100 % double-pane glass, the U-value and SHGC of west Texas is the same as the U-value and SHGC of the double glazing.

The calculation for east Texas, which has 60% single pane and 40% double pane glass, is as following.

U-value: (0.6 X 1.27) + (0.4 X 0.87) = 1.11

SHGC: (0.6 X 0.75) + (0.4 X 0.66) = 0.714

Table 4.3 – Center-of-glass U-value and SHGC for single and double glazing
(Source: 2001 ASHRAE HANDBOOK OF FUNDAMENTALS)

	Aluminum Without Thermal Break	
	U-value (Btu/ hr ft^2 °F)	SHGC
Single Glazing (1/8 in glass)	1.27	0.75
Double Glazing (1/4 in air space)	0.87	0.66

4.1.3.2. Systems

As mentioned above, the major type of the heating and the cooling systems in east and west Texas is the gas furnace and electric air-conditioners (spilt systems), respectively. In this research, those two systems were assumed to be installed for all single family houses built in 1999 in Texas.

4.1.3.2.1. The Efficiency of Air-Conditioners

The Air-Conditioning and Refrigeration Institute (ARI) published the shipments of single-phase unitary products under 65,000 Btu by SEER for the residential sector of Texas in 1999. Figure 4.7 shows the distribution of the SEER according to the ARI. To calculate the most common SEER in residential sector of Texas, the weighted average of the unit efficiencies was calculated. In this calculation, the SEER <10, <11, <12, <13, and +13 were assumed as 9, 10, 11, 12, and 13, respectively. From the weighted calculation, the weighted SEER average of all units was 10.2 SEER. In this thesis, however, 11 SEER was used as the average efficiency value for the air-conditioner in the 1999 standard house.[3] Although 11 SEER was used as the average efficiency value for the typical air-conditioners, the calculated overall electricity savings is not be affected because the SEER for a 1999 standard house and the IECC-compliant house is 11, which is above the code requirement of 10.

4.1.3.2.2. The Efficiency of Gas Furnaces

The Gas Appliance Manufacturers Association (GAMA) published the shipments of gas furnaces in Texas during 1995 to 2000. Figure 4.8 shows the historical profile of the shipments of gas furnaces in Texas. The AFUE of the gas furnaces in Texas is divided into two categories: less than 88% and more than 88%. According to the GAMA, the vast majority of shipments below 88% AFUE intended for new site-built homes are 80% AFUE. In 1999, therefore, the most common AFUE of gas furnaces for new built house is 80% AFUE (99.1% of total). It is interesting to note that shipments of 88+ AFUE furnaces have dropped. Conservation with several manufacturers revealed this was due to the discontinuance of pulse combustion furnaces by one manufacturer, which was the predominant high efficiency furnace.

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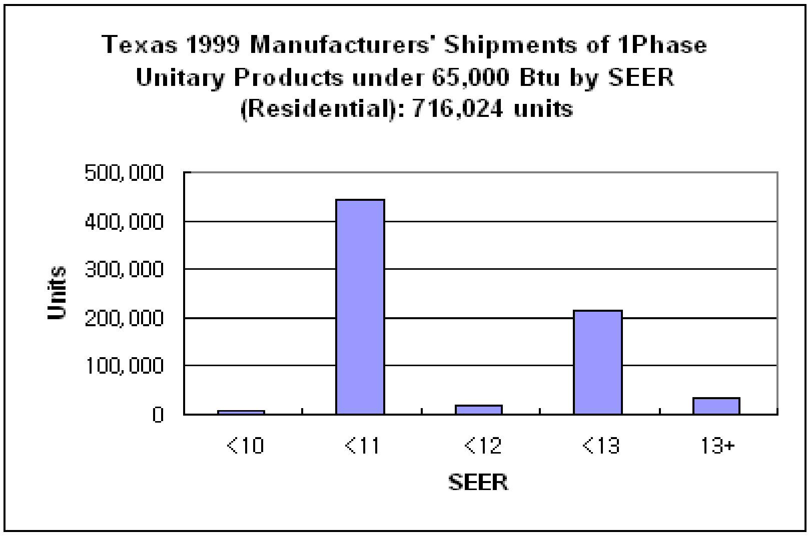
3 According to the ESL' Report (ESL, 2002), the average SEER for the standard 1999 house was assumed as 11 SEER.

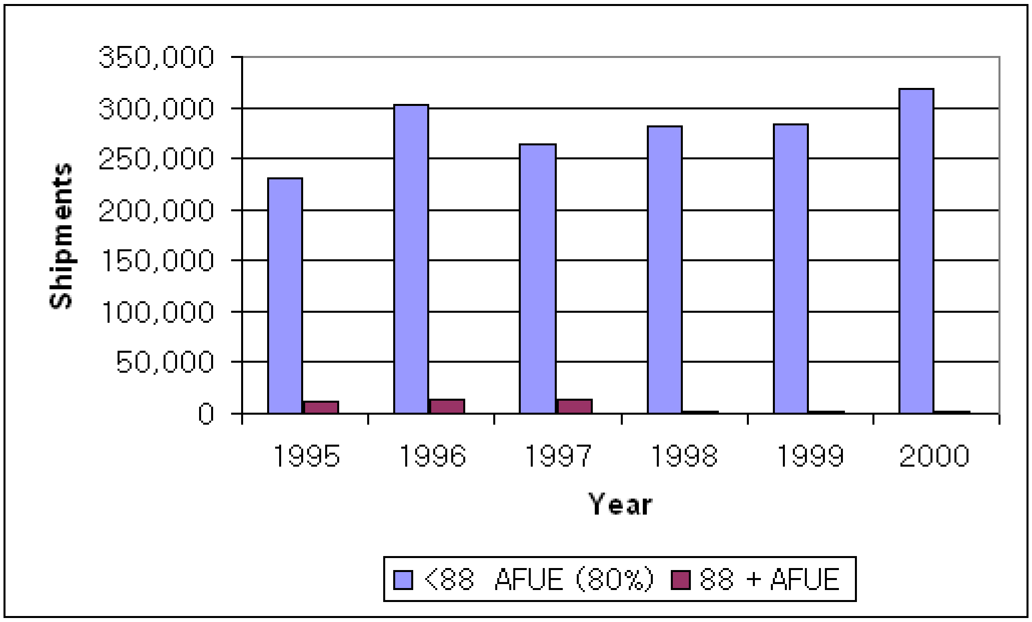


SEER	Units	Percentage
<10	6,757	0.90%
<11	445,116	62.20%
<12	17,556	2.50%
<13	213,344	29.80%
13+	33,251	4.60%
Total	716,024	

Figure 4.7 – Texas 1999 manufacturers' shipments of unitary products

4.1.3.3. The 1999 Standard House Building Characteristics

Table 4.4 shows the average building characteristics for the single family houses built in 1999. The building envelope characteristics were defined using the data from NAHB, and the efficiencies for the heating and cooling equipments were defined using the data from GAMA and ARI. From the Table, the floor area for east Texas (2,548 square feet) is little bit larger than the area for west Texas (2,464 square feet). As mentioned previously, for consistency, the average wall height was 8 ft., although the NAHB shows 8.8 ft. for east Texas and 9.2 ft. for west Texas. As for insulation, the wall R-value for east Texas (13.99) is lower than the R-value for west Texas (14.18), while the ceiling R-value for east Texas (27.08) is higher than the R-value for west Texas (26.75). The remaining envelope characteristics, the



AFUE	1995	1996	1997	1998	1999	2000
<88 AFUE (80%)	231,633	302,273	264,925	281,594	284,474	318,933
88 + AFUE	11,731	12,764	13,028	2,571	2,543	2,588

Source: Gas Appliance Manufacturers Association (April 10, 2002)

Figure 4.8 - Shipments of gas furnaces in Texas by AFUE

window area, glazing U-value and the SHGC were calculated from the NAHB's data. The window-to-wall ratio for east Texas is 15.2%, while the window-to-wall ratio for west Texas is 23.7%. Glazing U-value for east Texas is 1.11 and for west Texas is 0.87. SHGC for east Texas is 0.714 and for west Texas is 0.66. The same efficiencies for the furnace (80% AFUE) and the air-conditioner (11 SEER) were defined for both division of Texas.

Table 4.4 - Defined average characteristics for single family houses in 1999

	Required Data	East Texas	West Texas
Envelope	Floor Area (ft^2)	2,548	2,426
	Wall height(ft)	8	8
	Wall R-value	13.99 (Combined R)	14.18 (Combined R)
	Roof/Ceiling R-value	27.08	26.75
	Window area (%)[3]	15.2% (16.4 units of windows)	23.7% (24.9 units of windows)
	Glazing U-factor	1.11	0.87
	SHGC	0.714	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 Btu/h cooling capacity)	11	11

4.1.4. Summary of Base Case Study

The basic information for the study, the data collection process, and the characteristics of the base case house were discussed in this section. As basic information for this research, the 1999 Texas county population, the number of housing units in Texas counties, and the residential building permit activity by county were presented. From this information, it appears that most of the population and housing units were concentrated in the 38 non-attainment and affected counties. In addition, the non-attainment and affected counties show higher building permit activities than other counties in Texas.

To define the building characteristics for the 1999 standard single family house in Texas, several data from various sources were collected. The main sources for building envelope characteristics and the heating and cooling systems are NAHB Builder Practices Survey Report, GAMA and ARI. Using these data, the building characteristics for the 1999 base case house were presented.

4.2. Results of the 2000 IECC Standard House Study

This section discusses the description of the 2000 IECC standard house, which was used in this study. The discussion includes the overview of the 2000 IECC, and the 2000 IECC standard building characteristics. Although the 2000 IECC provides the requirements for single and multifamily house, and commercial buildings, in this study, the discussions are focused on the building characteristics required for single family houses.

4.2.1. The 2000 IECC

This research generally used Chapters 3, 4 and 5 of the 2000 IECC to define the standard 2000 IECC house. Chapter 3 provides the climate zones in Texas, and Chapter 4 and 5 present the standard building characteristics. The prescriptive tables in Chapter 5 provide the R-value of the exterior wall, the ceiling and the foundation, the U-value and the SHGC of the windows for each climate zone in Texas according to the window-to-wall ratio. In addition, the efficiency of the heating and cooling systems for all Texas areas was defined in this chapter. All other input values that were used in simulation tasks were obtained from Chapter 4.

4.2.2. Climate Zones of Texas (Chapter 3 of the 2000 IECC)

Before reviewing the requirement for building characteristics, the climate zone for each county was identified. The 2000 IECC divides the United States into climate zones by Heating Degree Day (HDD) base 65F^{o}. Texas climate zones include zones 2 to zones 9. The list of counties that are included in each climate zone is presented in chapter 3 of the 2000 IECC. Table 4.5 shows the climate zones for the 38 non-attainment and affected counties. Figure 4.9 shows the distribution of the climate zones in Texas.

4.2.3. IECC Standard Building Characteristics (Chapter 4 of the 2000 IECC)

Chapter 4: *Residential Building Design by Systems Analysis and Design of Buildings Utilizing Renewable Energy Sources* contains the standard building design to be used in a performance calculation. This chapter establishes the design criteria in terms of total energy use by a residential building, including all systems (ICC, 1999). The chapter defines two building designs: the Standard Design and the Proposed Design. A building whose envelope and energy-consuming systems is designed in accordance with Chapter 5 is defined as a "Standard Design". For a proposed alternate building design, which is defined as a "Proposed Design", to be considered similar to a "Standard Design", it should utilize Section 402.1.3,

Table 4.5 - Classification of climate zones for the 38 non-attainment and affected counties

Climate Zone	Heating Degree Day (HDD)	Non-attainment and Affected Counties
2	500-999	None
3	1,000-1,499	Victoria, San Patricio, Nueces, Brazoria, Galveston
4	1,500-1,999	Bexar, Wilson, Comal, Guadalupe, Caldwell, Bastrop, Fort Bend, Waller, Harris, Montgomery, Liberty, Chambers, Jefferson, Hardin, Orange
5	2,000-2,499	Hays, Travis, Williamson, Rusk, Smith, Tarrant, Dallas, Johnson, Ellis
6	2,500-2,999	El Paso, Parker, Denton, Collin, Kaufman, Rockwall, Upshur, Gregg, Harrison
7	3,000-3,499	None
8	3,500-3,999	None
9	4,000-4,499	None

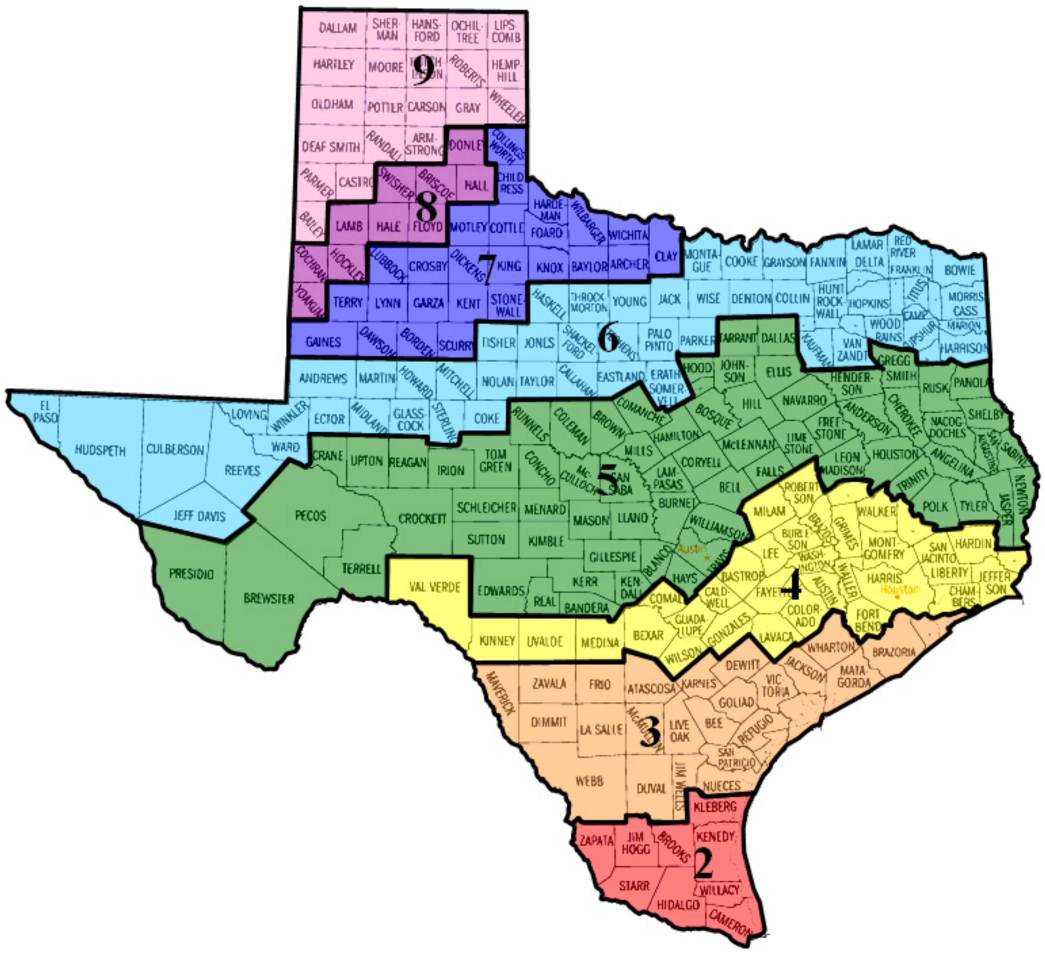


Figure 4.9 - Climate zones in Texas from the 2000 IECC

which presents the input values for the residential buildings. According to the IECC, section 402.1.3 (402.1.3.1 through 402.1.3.12) should be used in calculating the annual energy performance. Therefore, the input values in this section are reviewed and used to define the IECC standard house which was used in this research. The building characteristics described in the section 402.1.3.1 thorough 402.1.3.12 are explained below.

4.2.3.1. Glazing Systems

Section 402.1.3.1 *Glazing systems* defines the requirements for glazing systems. For the orientation of the house, equal areas of glazing on north, east, south, and west exposures were assumed (Section 402.1.3.1.1 as changed in the 2001 Supplement). According to this requirement, the standard house has equal exterior wall areas on north, east, south, and west exposures. In Chapter 4 the glazing areas in the standard building are not to be provided with exterior shadings such as roof overhangs (Section 402.1.3.1.3.). Therefore, no exterior shadings were defined for the standard house in this research. In the 2000 IECC, the Solar Heat Gain Coefficient (SHGC) of the glazing systems (inclusive of the frame, sash, and dividers) in the Standard design should be 0.4 or less for HDD<3,500 and 0.68 or less for HDD $\geq$ 3,500. Since the HDDs for all non-attainment and affected counties are less than 3,500, the SHGC is therefore 0.4.

4.2.3.2. Building Thermal Envelope-surface Areas and Volume

Section 402.1.3.4 defines the surface area of the building thermal envelope. According to this section, the Standard and the Proposed design should have the same area of the exterior walls, floors, ceilings and doors. The exterior door U-value of the Standard and Proposed Design is 0.2 Btu/h-ft^2-F (Section 402.1.3.4)

4.2.3.3. Heating and Cooling Controls

As changed in the 2001 Supplement, the heating and cooling thermostat should be set to the default settings in Table 4.6 defined in Section 402.1.3.5. Therefore, the setting values shown in Table 4.6 were used in the standard input file of the DOE-2 simulation. The DOE-2

Table 4.6 - Heating and cooling controls
(ICC, 2001)

Parameter	Standard design value	Proposed design value
Heating	68 F	68 F
Cooling	78 F	78 F
Set back/set up	5 F	5 F
Set back/set up duration	6 hours per day	6 hours per day
Number of set back/set up periods per unit	1 per unit per day	1 per unit per day
Maximum number of zones per unit	2	2
Number of thermostats per zone	1	1

input file used in this thesis has 1 unit and 1 zone house, which is code-compliant according to Table 4.6.

4.2.3.4. Internal Heat Gain

For a single family house (Type A-1 Residential building), a fixed internal heat gain of 3,000 Btu/hr per dwelling unit, should be used in calculating the annual energy performance, where the dwelling unit in the IECC is meant to be the thermal zone (Section 402.1.3.7)

4.2.3.5. Site Weather Data

As changed in the 2001 Supplement, typical meteorological year (TMY2), or its "Ersatz" equivalent from the National Oceanic and Atmospheric Administration (NOAA), or an approved equivalent, for the closest available location shall be used (Section 402.1.3.8). For this research, TMY2 weather data for specific Texas cities were used. The available TMY2 files and the assignment of TMY2 files to each county are discussed in Section 4.3 of this chapter.

4.2.3.6. Air Infiltration

In the 2000 IECC, annual average air changes per hour (ACH) for the standard design shall be determined using following equation.

$$ACH = Normalized\ Leakage\ X\ W$$

where: Normalized Leakage = 0.57, W = Weather Factors

The weather factor is determined in accordance with the weather factors (W) given by ASHRAE 136 (ASHRAE, 1993), as taken from the weather station nearest the building site. Table 4.7 shows the Air infiltration rate for Texas weather stations. However, in this research, the air infiltration rate was fixed 0.57 for all counties, which was considered acceptable since the purpose of this research was to perform a comparative analysis.

4.2.4. The IECC Standard Prescriptive Tables and System Efficiency (Chapter 5)

This chapter defines the prescriptive requirements of residential building designs by component. The requirements are divided into four categories, 1) Building envelope requirements, 2) Building mechanical systems and equipments, 3) Service water heating, and 4) Electrical power and lighting. For the building envelope requirements, this research used the prescriptive tables in Chapter 5 of the IECC. Section 502.2.4 provides several prescriptive tables that define the minimum required R-value of the exterior wall, ceiling and foundation, and the maximum glazing U-factor for Type A-1 (i.e., single family residential) buildings with a window-to-wall area less than or equal to 8 percent, 12 percent, 15 percent, 18 percent, 20 percent, or 25 percent.

Table 4.8 and 4.9 show the IECC prescriptive tables for the 38 non-attainment and affected counties. Since the window-to-wall ratio for the houses in east and west Texas is 15 percent and 25 percent, respectively, the tables for those ratios are shown here. The

Table 4.7 - Air infiltration rates for Texas cities
(ASHRAE, 1993)

City	*W* [ACH]	Source	ACH (0.57 x *W*)
Abilene	1.05	TMY	0.60
Amarillo	1.14	TMY	0.65
Austin	0.80	TMY	0.46
Brownsville	0.90	TMY	0.51
Corpus Christi	0.86	TMY	0.49
El Paso	0.76	TMY	0.43
Fort Worth	0.89	TMY	0.51
Houston	0.81	TMY	0.46
Kingsville	0.72	TMY	0.41
Laredo	0.91	TMY	0.52
Lubbock	1.00	TMY	0.57
Lufkin	0.64	TMY	0.36
Midland Odessa	0.96	TMY	0.55
Port Arthur	0.79	TMY	0.45
San Angelo	0.84	TMY	0.48
San Antonio	0.83	TMY	0.47
Sherman	0.80	TMY	0.46
Waco	0.92	TMY	0.52
Wichita Falls	0.99	TMY	0.56

Note: TMY2 was used in this study for DOE-2 simulation. ASHRAE Standard 136 used TMY.

requirements for mechanical systems and equipment are shown in Table 4.10. Table 4.10 provides the minimum equipment performance for several heating and cooling system (Section 503). For this research, an air-cooled, spilt system air conditioner (<65,000 Btu/h cooling capacity) is the cooling system, and a gas-fired furnace (<225,000 Btu/h) was assumed as the heating system. Therefore, the minimum efficiency of the air-cooled air conditioner (10 SEER) and the minimum efficiency of the gas-fired furnace (78% AFUE) were used in the 2000 IECC standard house.

Table 4.8 – The 2000 IECC building prescriptive envelope requirements for counties in east Texas (window-to-wall ratio 15 percent of the gross exterior wall area)

HEATING DEGREE DAYS	County	MAXIMUM	MINIMUM					
		Glazing U-factor	Ceiling R-value	Exterior wall R-value	Floor R-value	Basement wall R-value	Slab perimeter R-value and depth	Crawl space wall R-value
1,000-1,499	Victoria, San Patricio, Nueces, Brazoria, Galveston	0.75	R-19	R-11	R-11	R-0	R-0	R-5
1,500-1,999	Fort Bend, Waller, Harris, Montgomery, Liberty, Chambers, Jefferson, Hardin, Orange	0.75	R-26	R-13	R-11	R-5	R-0	R-5
2,000-2,499	Rusk, Smith	0.65	R-30	R-13	R-11	R-5	R-0	R-6
2,500-2,999	Upshur, Gregg, Harrison	0.60	R-30	R-13	R-19	R-6	R-0[4]	R-7

Table 4.9 - The 2000 IECC building prescriptive envelope requirements for counties in west Texas (window-to-wall ratio 25 percent of gross exterior wall area)

HEATING DEGREE DAYS	County	MAXIMUM	MINIMUM					
		Glazing U-factor	Ceiling R-value	Exterior wall R-value	Floor R-value	Basement wall R-value	Slab perimeter R-value and depth	Crawl space wall R-value
1,500-1,999	Caldwell, Bastrop, Bexar, Wilson, Comal, Guadalupe	0.52	R-30	R-13	R-13	R-6	R-0	R-6
2,000-2,499	Hays, Travis, Williamson, Tarrant, Dallas, Johnson, Ellis	0.50	R-38	R-13	R-19	R-8	R-0	R-10
2,500-2,999	El Paso, Parker, Denton, Collin, Kaufman, Rockwall,	0.46	R-38	R-16	R-19	R-6	R-0	R-7

[4] Although the 2000 IECC shows this value as R-4, 2ft, the ICC admitted that the correct value for this area should be R-0.

Table 4.10 – The 2000 IECC minimum equipment performance (Section 503.2)

EQUIPMENT CATEGORY	SUB-CATEGORY	REFERENCED STANDARD	MINIMUM PERFORMANCE
Air-cooled heat pumps heating mode < 65,000 Btu/h cooling capacity	Spilt systems Single package	ARI 210/240	6.8 HSPF 6.6 HSPF
Gas-fired or oil-fired furnace < 225,000 Btu/h	–	DOE 10 CFR Part 430, Subpart B, Appendix N	AFUE 78% Et 80%
Gas-fired or oil-fired steam and hot-water boilers < 300,000 Btu/h	–	DOE 10 CFR Part 430, Subpart B, Appendix N	AFUE 80%
Air-cooled air conditioners and heat pumps cooling mode < 65,000 Btu/h cooling capacity	Spilt systems Single package	ARI 210/240	10.0 SEER 9.7 SEER

Table 4.11 – Minimum duct insulation (Section 503.3.3.3)

ANNUAL HEATING DEGREE DAYS	Insulation R-value (hr ft^2 °F)/Btu			
	Ducts in unconditioned attics or outside building		Ducts in unconditioned basements, crawl spaces, garages, and other unconditioned spaces	
	Supply	Return	Supply	Return
Below 1,500	8	4	4	0
1,500 to 3,500	8	4	6	2
3,501 to 7,500	8	4	8	2
Above 7,500	11	6	11	2

Table 4.12 – The 2000 IECC minimum performance of water-heating equipment (Section 504.2)

CATEGORY	TYPE	FUEL	INPUT RATING	V_T [a] (gallons)	INPUT TO V_T RATIO (Btuh/gal)	TEST METHOD	ENERGY FACTOR [b] E_f	THERMAL EFFICIENCY E_t (percent)	STANDBY LOSS (percent/hour) [a]
NAECA-Covered water-heating equipment[c]	All	Electric	$\leq$ 12kW	All[e]	–	Note f	$\geq 0.93 - 0.00132V$	–	–
	Storage	Gas	$\leq$ 75,000 Btu/h	All[e]	–	Note f	$\geq 0.62 - 0.0019V$	–	–
	Instantaneous	Gas	$\leq$ 200,000 Btu/h	All	–	Note f	$\geq 0.62 - 0.0019V$	–	–
	Storage	Oil	$\leq$ 105,000 Btu/h	All	–	Note f	$\geq 0.59 - 0.0019V$	–	–
	Instantaneous	Oil	$\leq$ 210,000 Btu/h	All	–	Note f	$\geq 0.59 - 0.0019V$	–	–
	Pool heater	Gas/oil	All	All	–	Note g	–	$\geq$ 78%	–
Other water-heating equipment[d]	Storage	Electric	All	All	–	Note h	–	–	$\leq 0.30+27/V_T$
	Storage/ instantaneous	Gas/oil	$\leq$ 155,000 Btu/h	All	< 4,000	Note h	–	$\geq$ 78%	$\leq 1.3+114/V_T$
			> 155,000 Btu/h	All	< 4,000	Note h	–	$\geq$ 78%	$\leq 1.3+957/V_T$
				< 10 $\geq$ 10	$\geq$ 4,000 $\geq$ 4,000	Note h	–	$\geq$ 80% $\geq$ 77%	– $\leq 1.3+67/V_T$
Unfired storage tanks	–	–	–	All	–	–	–	–	$\leq$ 6.5Btuh/ft[2i]

a. V_T is the storage volume in gallons as measured during the standby loss test. For the purpose of estimating the standby loss requirement using the rated volume shon on the rating plate, V_T should be no less than 0.95V for electric water heaters.
b. V is rated storage volume in gallons as specified by the manufacturer.
c. Consistent with National Appliance Energy Conservation Act (NAECA) of 1987.
d. All except those water heaters covered by NAECA
e. DOE CFR 10; Part 430, Subpart B, Appendix E applies to electric and gas storage water heaters with rated volumes 20 gallons and gas instantaneous water heaters with input ratings of 50,000 to 200,000 Btu/h
f. DOE CFR 10; Part 430, Subpart B, Appendix E.
g. ANSI Z21.56.
h. ANSI Z21.10.3.
i. Heat loss of tank surface area (Btu/h-ft^2) based on 80°F water-air temperature difference.

In the 2001 Supplement, Section 503.3.3.3 presents the minimum duct insulation. According to this section, all supply and return-air duct and plenums installed as part of and HVAC air-distribution system shall be thermally insulated. The minimum duct insulation value is shown in Table 4.11. Although the code requires the duct insulation, a duct model was not simulated for all 1999 and code-compliant houses in this thesis since the current version of DOE-2.1e cannot simulate a duct model. For future work, a refined DOE-2 input file will be developed for a duct model. For water heaters, section 504.2 of the 2000 IECC presents the 2000 IECC minimum performance of water-heating equipment (See Table 4.12).

4.2.5. The 2000 IECC Standard House for Each County

From the study of the 2000 IECC, the requirements of the building envelope and the efficiency of the heating and cooling systems were identified. In the next step, using the requirements in the 2000 IECC, the 2000 IECC standard house for each county were defined. In this procedure, the 2000 IECC building requirements were compared against the building characteristics of the 1999 standard house. If the building characteristics of the 1999 standard house were superior to the building requirements of the 2000 IECC in terms of building thermal performance, then the building characteristics of the 1999 standard house were used for the 2000 IECC standard house (i.e., no extra credit was given since the current practice in 1888 is already above code). The detailed procedure and the completed assignment of the 1999 and IECC building characteristics to each county are described in the next section.

4.2.6. Summary of the 2000 IECC Standard House Study

The description of the 2000 IECC standard house, which was used in this study were presented in this section. From the study of the 2000 IECC and 2001 Supplement, the climate zones in Texas and the corresponding counties were identified. All non-attainment and affected counties are included in climate zones 3, 4, 5 and 6. The required building characteristics from Chapter 4 and 5 of the 2000 IECC then were reviewed. Finally, the prescriptive tables that defined the required building characteristics according to climate zones were presented for non-attainment and affected counties.

4.3. Results of the Projected Number of Building Permits in 2002

Using the methodology for the projection of the number of building permits, the numbers of building permits for non-attainment and affected counties in 2002 were projected. According to U.S. Census Bureau (U.S. Census Bureau 2002), the building permits represent the number of new housing units authorized by building permits in the United States. They exclude mobile homes (trailers), hotels, and motels. Table 4.13a and 4.13b show the projected number of building permits in 2002 for all counties. Appendix B shows the profiles of the historical data for each county during 1997 to 2001, the projected number for 2002, and contains a description of the projection method.

4.4. Results of the DOE-2 Simulations

4.4.1. Overview

Based on the results of the base case study and the 2000 IECC requirements, numerous simulations are performed.[5] In general, the simulations were performed twice for each county. One was for the simulation of 1999 standard house. The other was for the simulation of the 2000 IECC house. Since there are thirty-eight non-attainment and affected counties, seventy-

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[5] Simulations were performed using the ESL's code-traceable DOE-2 input file (ver. IECC1100.inp) (Haberl et al. 2003)

Table 4.13a - Number of building permits by county (non-attainment counties)

County	1997	1998	1999	2000	2001	2002 (Projected)
Brazoria	1,778	1,960	1,717	1,903	2,405	2,008
Chambers	128	171	213	309	326	318
Collin	7,198	8,031	7,704	9,621	9,657	9,639
Dallas	7,065	8,367	8,392	8,856	8,334	8,595
Denton	4,085	5,005	5,222	5,245	5,430	5,338
El Paso	2,316	3,039	3,472	2,879	3,317	3,098
Fort Bend	1,044	1,368	1,148	1,063	936	1,049
Galveston	1,112	1,684	1,627	2,235	2,441	2,338
Hardin	21	54	33	21	16	19
Harris	13,439	16,191	16,055	18,244	20,122	19,183
Jefferson	382	578	581	596	624	610
Liberty	195	317	310	213	212	213
Montgomery	3,110	3,674	4,493	4,067	3,997	4,032
Orange	200	225	218	174	170	172
Tarrant	6,470	8,521	8,785	9,505	11,210	10,358
Waller	20	22	29	21	17	22
Total (Non-attainment County)	48,563	59,207	59,999	64,952	69,214	66,992

Table 4.13b - Number of building permits by county (affected counties)

County	1997	1998	1999	2000	2001	2002 (Projected)
Bastrop	58	74	143	146	146	146
Bexar	5,238	6,993	7,117	6,873	7,462	7,168
Caldwell	51	25	81	57	145	101
Comal	841	865	926	1,050	1,172	1,111
Ellis	388	366	481	669	628	649
Gregg	215	193	194	160	227	194
Guadalupe	658	651	628	473	483	478
Harrison	35	44	22	28	38	33
Hays	157	363	754	727	746	737
Johnson	361	496	514	639	618	629
Kaufman	148	203	178	202	233	218
Nueces	889	991	694	737	945	841
Parker	233	277	242	282	321	302
Rockwall	391	495	761	955	1,267	1,111
Rusk	12	13	18	13	19	17
San Patricio	212	295	248	233	203	218
Smith	414	440	440	467	463	465
Travis	5,127	6,618	6,742	7,451	4,393	5,922
Upshur	13	21	14	13	24	17
Total (Affected County)	18,703	23,369	24,384	26,017	23,383	24,640
Grand Total (Non-attainment + Affected County)	**67,266**	**82,576**	**84,384**	**90,969**	**92,597**	**91,632**

six simulations needed to be performed to obtain the results. However, since several counties could be grouped according to the same conditions for simulation (i.e., the same weather file and the same building characteristics for 1999 and 2000 IECC standard house). Table 4.14 shows the grouped counties. From this table, 13 locations were the representative counties for all non-attainment and affected counties. Therefore, 26 simulations (13 for 1999 standard house, 13 for 2000 IECC standard house) were performed. The results of the simulations are followed by the results of the ESL's 2002 Report to the TNRCC (Haberl et al., 2002). Differences in the two values are discussed in this section.

4.4.2. Weather Files for Simulations

4.4.2.1. Typical Meteorological Years (TMY2) Weather File

TMY2 is an annual data set of average hourly values of solar radiation and meteorological elements. It consists of days of measured hourly weather day selected from individual years and concatenated to form a complete year. The intended use is for computer simulation of buildings and solar energy conversion systems.

Table 4.15 shows the available TMY2 files for Texas cities. The first column heading, WBAN number is the station Weather Bureau Army Navy (WBAN) identification number. From the location for the each city, the corresponding non-attainment and affected counties were assigned. Figure 4.10 shows the distribution of weather data files and non-attainment and affected counties. This figure also shows all available weather data files and the weather stations including TMY2, WYEC, and National Weather Service (NWS) Stations. From this figure, the nearest TMY2 weather file to each county was chosen. Table 4.16 shows the results of the chosen TMY2 files for each non-attainment and affected county.

Table 4.14 - Representative county for simulations

Climate Zone	Representative County	County	TMY2 Weather File	Division	Simulation Number
3	Nueces	Nueces	Corpus Christi	East	1
		San Patricio	Corpus Christi	East	
	Victoria	Victoria	Victoria	East	2
	Brazoria	Brazoria	Houston	East	3
		Galveston	Houston	East	
4	Bastrop	Bastrop	Austin	West	4
		Caldwell	Austin	West	
	Harris	Harris	Houston	East	5
		Fort Bend	Houston	East	
		Montgomery	Houston	East	
		Waller	Houston	East	
	Chambers	Chambers	Port Arthur	East	6
		Hardin	Port Arthur	East	
		Jefferson	Port Arthur	East	
		Liberty	Port Arthur	East	
		Orange	Port Arthur	East	
	Bexar	Bexar	San Antonio	West	7
		Comal	San Antonio	West	
		Guadalupe	San Antonio	West	
		Wilson	San Antonio	West	
5	Rusk	Rusk	Lufkin	East	8
		Smith	Lufkin	East	
	Hays	Hays	Austin	West	9
		Travis	Austin	West	
		Williamson	Austin	West	
	Dallas	Dallas	Fort Worth	West	10
		Johnson	Fort Worth	West	
		Tarrant	Fort Worth	West	
		Ellis	Fort Worth	West	
6	Gregg	Gregg	Lufkin	East	11
		Harrison	Lufkin	East	
		Upshur	Lufkin	East	
	El Paso	El Paso	El Paso	West	12
	Collin	Collin	Fort Worth	West	13
		Kaufman	Fort Worth	West	
		Parker	Fort Worth	West	
		Rockwall	Fort Worth	West	
		Denton	Fort Worth	West	

Table 4.15 - Available TMY2 files for Texas
Source: TMY2 User Manual

WBAN Number	City
13962	Abilene, TX
23047	Amarillo, TX
13958	Austin, TX
12919	Brownsville, TX
12924	Corpus Christi, TX
23044	El Paso, TX
3927	Fort Worth, TX
12960	Houston, TX
23042	Lubbock, TX
93987	Lufkin, TX
23023	Midland/Odessa, TX
12917	Port Arthur, TX
23034	San Angelo, TX
12921	San Antonio, TX
12912	Victoria, TX
13959	Waco, TX
13966	Wichita Falls, TX

4.4.3. NFRC Pre-calculation

As mentioned in Chapter III, the U-factor and SHGC of the windows cannot be input directly into the DOE-2 input file as is. Therefore, the U-factor and SHGC of windows for each county were converted into the center-of-glass conductance and Shading Coefficient (SC) using the method defined in Chapter III. Table 4.17 shows the results of those calculations. The table shows the classification of climate zone, NAHB division, selected building characteristics and the input parameters for DOE-2 simulation. An example of calculation is presented below.[6]

[6] The calculation method shown here is one of the known errors in ESL's 2002 report to the TNRCC. To correctly calculate, the equivalent frame width for a single window should be calculated using the equation (3.9) in Chapter III of this thesis.

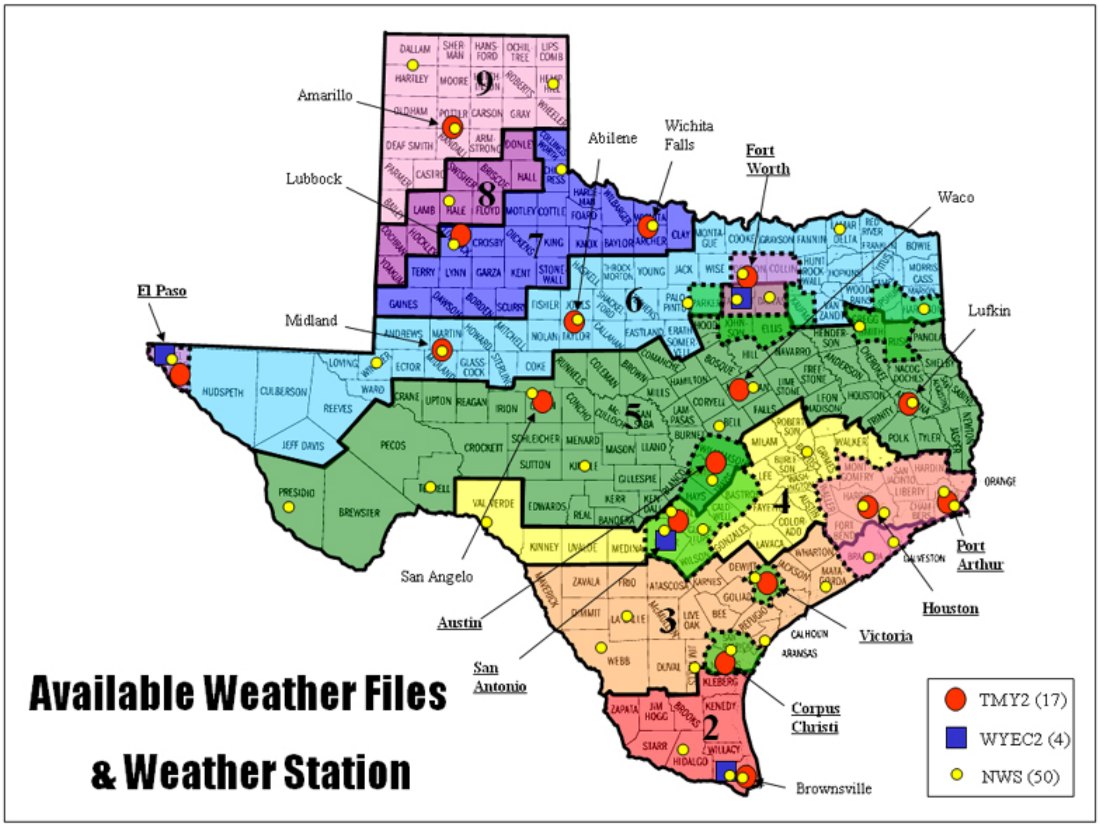

Figure 4.10 – Available weather data files for Texas

Example:

House dimensions:

Length = 50.48 ft.

Width = 50.48 ft.

Height of the interior wall = 8 ft

Window-to-wall ratio = 15.28%

Glazing Properties:

U-Factor = 0.75 Btu/ hr ft^2 °F

Solar Heat Gain Coefficient = 0.40

Aluminum frame thermal break

Table 4.16 - Assignments of TMY2 files for non-attainment and affected counties

Classification	County	TMY2 File
Affected County	Bastrop	Austin
	Bexar	San Antonio
	Caldwell	Austin
	Comal	San Antonio
	Ellis	Fort Worth
	Gregg	Lufkin
	Guadalupe	San Antonio
	Harrison	Lufkin
	Hays	Austin
	Johnson	Fort Worth
	Kaufman	Fort Worth
	Nueces	Corpus Christi
	Parker	Fort Worth
	Rockwall	Fort Worth
	Rusk	Lufkin
	San Patricio	Corpus Christi
	Smith	Lufkin
	Travis	Austin
	Upshur	Lufkin
	Victoria	Victoria
	Williamson	Austin
	Wilson	San Antonio
Non-attainment County	Brazoria	Houston
	Chambers	Port Arthur
	Collin	Fort Worth
	Dallas	Fort Worth
	Denton	Fort Worth
	El Paso	El Paso
	Fort Bend	Houston
	Galveston	Houston
	Hardin	Port Arthur
	Harris	Houston
	Jefferson	Port Arthur
	Liberty	Port Arthur
	Montgomery	Houston
	Orange	Port Arthur
	Tarrant	Fort Worth
	Waller	Houston

Table 4.17 - Calculation results for glass conductance and Shading Coefficient (SC)

Classification			Building Characteristics						DOE-2 Input Parameter Value					
Climate Zone	NAHB Division	Source of Characteristics	Floor Area (ft^2)	Area %	Gross Window Area (ft^2)	Number of 3x5 Windows	Window U-value (Btu/ hr ft^2 °F)	SHGC	Building Width & Depth (ft)	Window Width (ft)	Window Height (ft)	Equivalent Frame Width (ft)	Glass Conductance (Btu/ hr ft^2 °F)	Shading Coefficient
3	East	1999	2548	15.28	242	16	1.11	0.71	50.48	12.34	5	0.2286	1.2342	0.9372
		IECC	2548	15.28	242	16	0.75	0.40	50.48	12.34	5	0.2286	0.6541	0.5280
4	East	1999	2548	15.28	242	16	1.11	0.71	50.48	12.34	5	0.2286	1.2342	0.9372
		IECC	2548	15.28	242	16	0.75	0.40	50.48	12.34	5	0.2286	0.6541	0.5280
	West	1999	2426	23.69	373	25	0.87	0.66	49.25	18.67	5	0.2546	0.8352	0.8711
		IECC	2426	23.69	373	25	0.52	0.40	49.25	18.67	5	0.2546	0.3362	0.5280
5	East	1999	2548	15.28	242	16	1.11	0.71	50.48	12.34	5	0.2286	1.2342	0.9372
		IECC	2548	15.28	242	16	0.65	0.40	50.48	12.34	5	0.2286	0.5114	0.5280
	West	1999	2426	23.69	373	25	0.87	0.66	49.25	18.67	5	0.2546	0.8352	0.8711
		IECC	2426	23.69	373	25	0.5	0.40	49.25	18.67	5	0.2546	0.3102	0.5280
6	East	1999	2548	15.28	242	16	1.11	0.71	50.48	12.34	5	0.2286	1.2342	0.9372
		IECC	2548	15.28	242	16	0.6	0.40	50.48	12.34	5	0.2286	0.4427	0.5280
	West	1999	2426	23.69	373	25	0.87	0.66	49.25	18.67	5	0.2546	0.8352	0.8711
		IECC	2426	23.69	373	25	0.46	0.40	49.25	18.67	5	0.2546	0.2502	0.5280

Conductance of Aluminum without thermal break[7] = 3.037 Btu/ hr ft^2 °F

Frame U-value = [(frame conductance)$^{-1}$ + 0.197]$^{-1}$

= [(3.037)$^{-1}$ + 0.197]$^{-1}$

= 1.9 Btu/hr ft^2 °F

Frame-width = 0.125 ft

Total wall area = (2x width x height) + (2x length x height)

= (2 x 50.48 x 8) + (2 x 50.48 x 8)

= 1,615.36 ft^2

$$\text{Total area of a single window} = \frac{\text{Total wall area x Window-to-wall ratio (\%)}}{4}$$

$$= \frac{1615.36 \times 0.1528}{4}$$

= 61.70 ft^2

$$\text{Number of windows} = \frac{\text{Window area on each wall}}{\text{Area of one window (15 ft}^2\text{)}}$$

$$= \frac{61.70}{15}$$

= 4.11 windows

Glass area = [(Height of Window - 2x Width of frame) x (Width of Window – 2x Width of frame)] x Number of Windows

= [(5 – 2 x 0.125) x (3 – 2 x 0.125)] x 4.11

= 53.69 ft^2

Frame area[8] = (Window area on each wall) – (Glass Area)

= 61.70 – 53.69

= 8.01 ft^2

---

[7] The frame conductance value of aluminum without thermal break was referred to the DOE-2.1E Supplement manual (LBL 1993)

[8] Figure 3.7 (Chapter III) shows how the frame area can be calculated.

$$\text{Equivalent width of a single window} = \frac{\text{Window-to-wall ratio (\%)} \times \text{Total wall area}}{\text{(No. of exterior walls)} \times \text{(window height)}}$$

$$= \frac{0.1528 \times 1615.36}{4.11 \times 5}$$

$$= 12.01 \text{ ft.}$$

Equivalent frame width for a single window

$$= \frac{\text{Frame area}}{2\text{x (equiv. Window width + window height)}}$$

$$= 8.01/ [2 \times (12.01 + 5)]$$

$$= 0.235 \text{ ft.}$$

$$\text{Center of glass U-value} = \frac{\text{(Total U-value x Total area)} - \text{(Frame U-value x Frame area)}}{\text{Glass Area}}$$

$$= \frac{(0.75 \times 61.70) - (1.9 \times 8.01)}{53.69}$$

$$= 0.58 \text{ Btu/ hr ft}^2\ °\text{F}$$

$$\text{Glass conductance} = [(\text{Center of glass U-value})^{-1} - 0.197]^{-1}$$

$$= [(0.58)^{-1} - 0.197]^{-1}$$

$$= 0.65 \text{ Btu/ hr ft}^2\ °\text{F}$$

The second part of the spreadsheet is similar to the first one except for the following:

$$\text{Center of glass SHGC} = \frac{\text{Total SHGC x Total Area}}{\text{Area of Glass}}$$

$$= \frac{0.4 \times 60}{52.25}$$

$$= 0.459$$

Shading Coefficient = Center of glass SHGC/ 0.87

$= 0.459/0.87$
$= 0.528$

4.4.4. Input Parameters

After calculating the glass conductance and Shading Coefficient for each county, the parameter values for the 26 simulations were input into the standard DOE-2 input file. Table 4.18 shows the list of input parameters and the default value. The default value will be replaced according to the defined parameter for each county.

4.4.5. Simulations Results

The simulations were performed using the defined parameter values for each county. Figure 4.11a and Figure 4.11b summarize all input value for the 38 non-attainment and affected counties according to climate zones. In addition, Table 4.19a and Table 4.19b summarize all simulation inputs for the 38 non-attainment and affected counties.

4.4.5.1. Annual Energy Savings by County

According to the procedure defined in Chapter III, the annual energy savings by county were calculated next. These annual energy savings were then divided into two categories: annual electricity savings and annual natural gas savings. The gas and electricity savings were calculated by comparing the IECC-compliant house against the 1999 standard house. The annual electricity use and natural gas use were identified from the Report BEPS and BEPU of the DOE-2 output file. Appendix D presents the BEPS and BEPU reports for the 38 non-attainment and affected counties. Since the annual electricity savings was used in the

Table 4.18 - Parameter for standard input

CLASSIFICATION	PARAMETER	DESCRIPTION	Default Value
Building	P-AREA	Floor area (P-BUILDINGWIDTH x P-BUILDINGAZIMUTH) (ft^2)	2500
	P-AREA1	Perimeter (ft)	200
	P-VOLUME	P-AREA times P-WALLHEIGHT (ft^3)	20000
	P-LATITUDE	From Weather file (Degree)	29.98
	P-LONGITUDE	From Weather file (Degree)	95.37
	P-TIME-ZONE		6
	P-ALTITUDE	From Weather file (ft)	108
	P-BUILDINGWIDTH	Building Width (ft)	50
	P-BUILDINGLENGTH	Building Length (ft)	50
	P-BUILDINGAZIMUTH	Building Azimuth (Degree)	0
	P-OCCUPANCY	Number of Occupants	2
ROOF	P-ROOFOUTEMISS	Outside Emissivity for Roof	0.9
	P-ROOFABSORPTANCE	Roof Absorptance	0.5
	P-ROOFROUGHNESS	Roof Roughness	1
	P-ROOFUVALUE	Roof U value (Btu/hr-ft^2-F)	0.8
WALL	P-WALLABSORPTANCE	Wall Absorptance	0.55
	P-WALLROUGHNESS	Wall Roughness	2
	P-WALLHEIGHT	Average Wall Height (ft)	8.0
	P-WALLOUTEMISS	Outside Emissivity for Wall	0.9
	P-GND-REFLECTANCE	Ground Reflectance	0.24
	P-WALLUVALUE	Wall U-value (Btu/hr-ft^2-F)	0.077
CEILING	P-CLNGUVALUE	Ceiling U-value (Btu/hr-ft^2-F)	0.0263
DOOR	P-DOORHEIGHT	Average Door Height (ft)	6.67
	P-DOORWIDTH	Average Door Width (ft)	3.0
WINDOW	P-WINDOWHEIGHT	Average Window Height (ft)	5.0
	P-WINDOWWIDTH	Equivalent Window Width If one window is assumed on all sides (ft)	10.56
	P-SHADINGCOEFFICIENT	Shading Coefficient	0.528
	P-FRAMEWIDTH	Frame Width (ft)	0.22
	P-GLASSCONDUCTANCE	Glass Conductance (Btu/hr-ft^2-F)	0.65
	P-FRAMECONDUCTANCE	Frame Conductance (Btu/hr-ft^2-F)	3.307
	P-FRAMEABSORPTANCE	Frame Absorptance	0.7
	P-PANES	Number of Panes	2
FLOOR	P-FLOORWEIGHT	Floor Weight (lbs/sq.ft)	11.5
SHADES	P-SHADEWIDTHF	Front Shade Width (ft)	3
	P-SHADEWIDTHR	Right Shade Width (ft)	3
	P-SHADEWIDTHL	Left Shade Width (ft)	3
	P-SHADEWIDTHB	Bottom Shade Width (ft)	3

Climate Zone 3

County Name	TMY2	Division
Nueces	Corpus Christi	East
San Patricio	Corpus Christi	East
Victoria	Victoria	East
Brazoria	Houston	East
Galveston	Houston	East

	1999 East	2000 IECC	1999 West	2000 IECC
Area %	15.28	15.28	23.69	23.69
Floor Area	2548	2548	2426	2426
Glazing U value	1.11	0.75	0.87	0.55
SHGC	0.72	0.4	0.66	0.4
Roof Insulation	27	27	26.75	30
Wall Insulation	13.99	13.99	14.18	14.18
AFUE	80	80	80	80
SEER	11	11	11	11

Climate Zone 4

County Name	TMY2	Division
Bastrop	Austin	West
Caldwell	Austin	West
Fort Bend	Houston	East
Harris	Houston	East
Montgomery	Houston	East
Waller	Houston	East
Chambers	Port Arthur	East
Hardin	Port Arthur	East
Jefferson	Port Arthur	East
Liberty	Port Arthur	East
Orange	Port Arthur	East
Bexar	San Antonio	West
Comal	San Antonio	West
Guadalupe	San Antonio	West
Wilson	San Antonio	West

	1999 East	2000 IECC	1999 West	2000 IECC
Area %	15.28	15.28	23.69	23.69
Floor Area	2548	2548	2426	2426
Glazing U value	1.11	0.75	0.87	0.52
SHGC	0.714	0.4	0.66	0.4
Roof Insulation	27.08	27.08	26.75	30
Wall Insulation	13.99	13.99	14.18	14.18
AFUE	80	80	80	80
SEER	11	11	11	11

Figure 4.11a - Input definition for climate zone 3, 4

Climate Zone 5

County Name	TMY2	Division
Rusk	Lufkin	East
Smith	Lufkin	East
Hays	Austin	West
Travis	Austin	West
Williamson	Austin	West
Ellis	Fort Worth	West
Johnson	Fort Worth	West
Tarrant	Fort Worth	West
Dallas	Fort Worth	West

	1999 East	2000 IECC	1999 West	2000 IECC
Area %	15.28	15.28	23.69	23.69
Floor Area	2548	2548	2426	2426
Glazing U value	1.11	0.65	0.87	0.5
SHGC	0.714	0.4	0.66	0.4
Roof Insulation	27.08	30	26.75	38
Wall Insulation	13.99	13.99	14.18	14.18
AFUE	80	80	80	80
SEER	11	11	11	11

Climate Zone 6

County Name	TMY2	Division
Gregg	Lufkin	East
Harrison	Lufkin	East
Upshur	Lufkin	East
El Paso	El Paso	West
Collin	Fort Worth	West
Kaufman	Fort Worth	West
Parker	Fort Worth	West
Rockwall	Fort Worth	West
Denton	Fort Worth	West

	1999 East	2000 IECC	1999 West	2000 IECC
Area %	15.28	15.28	23.69	23.69
Floor Area	2548	2548	2426	2426
Glazing U value	1.11	0.6	0.87	0.46
SHGC	0.714	0.4	0.66	0.4
Roof Insulation	27.08	30	26.75	38
Wall Insulation	13.99	13.99	14.18	16
AFUE	80	80	80	80
SEER	11	11	11	11

Figure 4.11b - Input definition for climate zone 5, 6

Table 4.19a – Simulation inputs for affected counties

	County	TMY2	Division (East or West)	1999 Average					2000 IECC				
				Area %	Glazing U-value	SHGC	Roof Insulation	Wall Insulation	Area %	Glazing U-value	SHGC	Roof Insulation	Wall Insulation
Affected County	Bastrop	Austin	West	23.69	0.87	0.66	26.75	14.18	23.69	0.52	0.40	30.00	14.18
	Bexar	San Antonio	West	23.69	0.87	0.66	26.75	14.18	23.69	0.52	0.40	30.00	14.18
	Caldwell	Austin	West	23.69	0.87	0.66	26.75	14.18	23.69	0.52	0.40	30.00	14.18
	Comal	San Antonio	West	23.69	0.87	0.66	26.75	14.18	23.69	0.52	0.40	30.00	14.18
	Ellis	Fort Worth	West	23.69	0.87	0.66	26.75	14.18	23.69	0.50	0.40	38.00	14.18
	Gregg	Lufkin	East	15.28	1.11	0.71	27.08	13.99	15.28	0.60	0.40	30.00	13.99
	Guadalupe	San Antonio	West	23.69	0.87	0.66	26.75	14.18	23.69	0.52	0.40	30.00	14.18
	Harrison	Lufkin	East	15.28	1.11	0.71	27.08	13.99	15.28	0.60	0.40	30.00	13.99
	Hays	Austin	West	23.69	0.87	0.66	26.75	14.18	23.69	0.50	0.40	38.00	14.18
	Johnson	Fort Worth	West	23.69	0.87	0.66	26.75	14.18	23.69	0.50	0.40	38.00	14.18
	Kaufman	Fort Worth	West	23.69	0.87	0.66	26.75	14.18	23.69	0.46	0.40	38.00	16.00
	Nueces	Corpus Christi	East	15.28	1.11	0.71	27.08	14.18	15.28	0.75	0.40	27.08	14.18
	Parker	Fort Worth	West	23.69	0.87	0.66	26.75	14.18	23.69	0.46	0.40	38.00	16.00
	Rockwall	Fort Worth	West	23.69	0.87	0.66	26.75	14.18	23.69	0.46	0.40	38.00	16.00
	Rusk	Lufkin	East	15.28	1.11	0.71	27.08	13.99	15.28	0.65	0.40	30.00	13.99
	San Patricio	Corpus Christi	East	15.28	1.11	0.71	27.08	14.18	15.28	0.75	0.40	27.08	14.18
	Smith	Lufkin	East	15.28	1.11	0.71	27.08	13.99	15.28	0.65	0.40	30.00	13.99
	Travis	Austin	West	23.69	0.87	0.66	26.75	14.18	23.69	0.50	0.40	38.00	14.18
	Upshur	Lufkin	East	15.28	1.11	0.71	27.08	13.99	15.28	0.60	0.40	30.00	13.99
	Victoria	Victoria	East	15.28	1.11	0.71	27.08	14.18	15.28	0.75	0.40	27.08	14.18
	Williamson	Austin	West	23.69	0.87	0.66	26.75	14.18	23.69	0.50	0.40	38.00	14.18
	Wilson	San Antonio	West	23.69	0.87	0.66	26.75	14.18	23.69	0.52	0.40	30.00	14.18

Table 4.19b – Simulation inputs for non-attainment counties

	County	TMY2	Division (East or West)	1999 Average					2000 IECC				
				Area %	Glazing U-value	SHGC	Roof Insulation	Wall Insulation	Area %	Glazing U-value	SHGC	Roof Insulation	Wall Insulation
Non-attainment County	**Brazoria**	Houston	East	15.28	1.11	0.71	27.08	13.99	15.28	0.75	0.40	27.08	14.18
	Chambers	Port Arthur	East	15.28	1.11	0.71	27.08	13.99	15.28	0.75	0.40	27.08	13.99
	Collin	Fort Worth	West	23.69	0.87	0.66	26.75	14.18	23.69	0.46	0.40	38.00	16.00
	Dallas	Fort Worth	West	23.69	0.87	0.66	26.75	14.18	23.69	0.50	0.40	38.00	14.18
	Denton	Fort Worth	West	23.69	0.87	0.66	26.75	14.18	23.69	0.46	0.40	38.00	16.00
	El Paso	El Paso	West	23.69	0.87	0.66	26.75	14.18	23.69	0.46	0.40	38.00	16.00
	Fort Bend	Houston	East	15.28	1.11	0.71	27.08	13.99	15.28	0.75	0.40	27.08	13.99
	Galveston	Houston	East	15.28	1.11	0.71	27.08	13.99	15.28	0.75	0.40	27.08	14.18
	Hardin	Port Arthur	East	15.28	1.11	0.71	27.08	13.99	15.28	0.75	0.40	27.08	13.99
	Harris	Houston	East	15.28	1.11	0.71	27.08	13.99	15.28	0.75	0.40	27.08	13.99
	Jefferson	Port Arthur	East	15.28	1.11	0.71	27.08	13.99	15.28	0.75	0.40	27.08	13.99
	Liberty	Port Arthur	East	15.28	1.11	0.71	27.08	13.99	15.28	0.75	0.40	27.08	13.99
	Montgomery	Houston	East	15.28	1.11	0.71	27.08	13.99	15.28	0.75	0.40	27.08	13.99
	Orange	Port Arthur	East	15.28	1.11	0.71	27.08	13.99	15.28	0.75	0.40	27.08	13.99
	Tarrant	Fort Worth	West	23.69	0.87	0.66	26.75	14.18	23.69	0.50	0.40	38.00	14.18
	Waller	Houston	East	15.28	1.11	0.71	27.08	13.99	15.28	0.75	0.40	27.08	13.99

calculations of the NO_x emissions reductions, in this research, only the annual and peak-day electricity savings were considered for the NO_x reductions. Table 4.20a and 4.20b show the annual electricity savings for each county. Figure 4.12 shows the graph of the annual electricity savings by county. As shown in this table and figure, the total annual electricity savings in affected counties are 80,576.50 MWh, and the total annual electricity savings in non-attainment counties are 167,057.10 MWh. The total annual electricity savings for both the non-attainment and affected counties are 247,633.60 MWh. The average annual electricity use reduction from the code adoption is 11 %to 20%. The largest savings are in Collin County with 31,866.53 MWh. To no surprise, of the ten counties with the largest savings, seven are non-attainment counties.

4.4.5.2. Peak-day Electricity Savings by County

To calculated peak-day electricity savings, first, the same peak date for each county was determined by DOE-2. Since the same peak date is required in this study, the most frequently shown peak date was chosen from the list of peak dates. As a result, July 29 was chosen as the peak date for the peak-day NO_x reductions. Then, the peak-day electricity uses for all counties were identified from the hourly report in DOE-2 output file for this day. The peak electricity use for the 1999 standard house and the IECC standard house are shown in Table 4.20a and 4.20b. From the results, the total peak-day electricity savings in affected counties are 439.92 MWh, and the total peak-day electricity savings in non-attainment counties are 1,078.72 MWh. The total peak-day electricity savings for both the non-attainment and affected counties are 1,518.64 MWh. The results show the peak-day electricity use is reduced about 11% to 26% from the code adoption. If the average daily electricity savings by county was calculated by dividing the annual electricity savings by 365, then the peak-day electricity use is approximately the two times the average day electricity use. Figure 4.13 and Figure 4.14 shows the comparison of peak-day versus average daily electricity savings for the non-attainment and affected counties.

For future work, an improved method should be developed to calculate a peak-day electricity savings that is more representative of an ozone episode day. For target counties, actual ozone episode day weather data for peak-day period would be obtained. Using this weather data, the peak-day electricity savings for each county would be simulated using DOE-2 across all counties. The results from this simulation would more accurately represent the actual peak-day of the counties instead of weather data from the TMY2 weather file.

4.4.6. Summary of the DOE-2 Simulations

To calculate the annual and peak-day electricity savings from code adoption, several simulations were performed. The energy savings were calculated by subtracting the simulated energy use of the IECC standard house from the simulated energy use of the 1999 house, which was presented as annual electricity savings and the peak-day electricity savings. These calculated savings will be used to calculate the NO_x emissions reductions from the electricity savings in the next chapter. The results showed that the total annual electricity savings in affected counties are 80,576.50 MWh, and the total annual electricity savings in non-attainment counties are 167,057.10 MWh. The total annual electricity savings for both the non-attainment and affected counties are 247,633.60 MWh. The average county-wide annual electricity use reductions from the code adoption are 11 % to 20%. The results also showed that the total peak-day electricity savings in affected counties are 439.92 MWh, and the total annual electricity savings in non-attainment counties are 1,078.72 MWh. The total peak-day electricity savings for both the non-attainment and affected counties are 1,518.64 MWh. The

Table 4.20a – Simulated electricity savings for affected counties

	County	Climate Zone	No. of projected units	Floor Area (ft2)	1999 Average Energy Use (KWh)	IECC Energy Use (KWh)	Actual Peak Date	Fixed Peak Date	1999 Peak-day (KWH /House)	IECC Peak-day (KWH /House)	Annual Savings per house (kWh)	Peak-day Savings per house (kWh)	Total Savings (MWh) 1999-IECC	Peak-day Savings (MWh) 1999-IECC
Affected County	Bastrop	4	146	2,426	16,545	13,310	31-Jul	29-Jul	77.98	59.56	3,235	18.42	472.31	2.69
	Bexar	4	7,168	2,426	16,681	13,332	28-Aug	29-Jul	77.03	58.49	3,349	18.53	24,005.63	132.84
	Caldwell	4	101	2,426	16,545	13,310	31-Jul	29-Jul	77.98	59.56	3,235	18.42	326.74	1.86
	Comal	4	1,111	2,426	16,681	13,332	28-Aug	29-Jul	77.03	58.49	3,349	18.53	3,720.74	20.59
	Ellis	5	649	2,426	15,465	12,448	29-Jul	29-Jul	82.47	61.45	3,017	21.02	1,958.03	13.64
	Gregg	6	194	2,548	13,139	11,258	22-Jul	29-Jul	57.40	46.92	1,881	10.48	364.91	2.03
	Guadalupe	4	478	2,426	16,681	13,332	28-Aug	29-Jul	77.03	58.49	3,349	18.53	1,600.82	8.86
	Harrison	6	33	2,548	13,139	11,258	22-Jul	29-Jul	57.40	46.92	1,881	10.48	62.07	0.35
	Hays	5	737	2,426	16,662	13,160	31-Jul	29-Jul	74.44	56.49	3,502	17.95	2,580.97	13.23
	Johnson	5	629	2,426	15,465	12,448	29-Jul	29-Jul	82.47	61.45	3,017	21.02	1,897.69	13.22
	Kaufman	6	218	2,426	15,725	12,419	19-Aug	29-Jul	82.47	60.27	3,306	22.19	720.71	4.84
	Nueces	3	841	2,548	14,354	12,651	18-Aug	29-Jul	58.87	51.59	1,703	7.28	1,432.22	6.12
	Parker	6	302	2,426	15,725	12,419	19-Aug	29-Jul	82.47	60.27	3,306	22.19	998.41	6.70
	Rockwall	6	1,111	2,426	15,725	12,419	19-Aug	29-Jul	82.47	60.27	3,306	22.19	3,672.97	24.66
	Rusk	5	17	2,548	13,139	11,253	22-Jul	29-Jul	57.40	47.06	1,886	10.34	32.06	0.18
	San Patricio	3	218	2,548	14,354	12,651	18-Aug	29-Jul	58.87	51.59	1,703	7.28	371.25	1.59
	Smith	5	465	2,548	13,139	11,253	22-Jul	29-Jul	57.40	47.06	1,886	10.34	876.99	4.81
	Travis	5	5,922	2,426	16,662	13,160	31-Jul	29-Jul	74.44	56.49	3,502	17.95	20,738.84	106.30
	Upshur	6	17	2,548	13,139	11,258	22-Jul	29-Jul	57.40	46.92	1,881	10.48	31.98	0.18
	Victoria	3	156	2,548	13,923	12,251	2-Sep	29-Jul	62.17	54.85	1,672	7.33	260.83	1.14
	Williamson	5	4,111	2,426	16,662	13,160	31-Jul	29-Jul	74.44	56.49	3,502	17.95	14,396.72	73.79
	Wilson	4	16	2,426	16,681	13,332	28-Aug	29-Jul	77.03	58.49	3,349	18.53	53.58	0.30
	Total												80,576.50	439.92

Table 4.20b - Simulated electricity savings for non-attainment counties

	County	Climate Zone	No. of projected units	Floor Area (ft2)	1999 Average Energy Use (KWh)	IECC Energy Use (KWh)	Actual Peak Date	Peak Date	1999 Peak-day (KWH /House)	IECC Peak-day (KWH /House)	Annual Savings per house (kWh)	Peak-day Savings per house (kWh)	Total Savings (MWh) 1999-IECC	Peak-day Savings (MWh) 1999-IECC
Non-attainment County	**Brazoria**	3	2,008	2,548	13,740	11,859	29-Jul	29-Jul	66.52	55.57	1,881	10.95	3,777.05	21.99
	Chambers	4	318	2,548	12,913	11,297	1-Sep	29-Jul	53.74	45.52	1,616	8.22	513.89	2.61
	Collin	5	9,639	2,426	15,725	12,419	19-Aug	29-Jul	82.47	60.27	3,306	22.19	31,866.53	213.92
	Dallas	5	8,595	2,426	15,465	12,448	29-Jul	29-Jul	82.47	61.45	3,017	21.02	25,931.12	180.67
	Denton	6	5,338	2,426	15,725	12,419	19-Aug	29-Jul	82.47	60.27	3,306	22.19	17,647.43	118.47
	El Paso	6	3,098	2,426	16,085	12,684	12-Jul	29-Jul	63.13	47.77	3,401	15.37	10,536.30	47.61
	Fort Bend	4	1,049	2,548	13,093	11,467	29-Jul	29-Jul	61.75	51.80	1,626	9.96	1,705.67	10.44
	Galveston	3	2,338	2,548	13,740	11,859	29-Jul	29-Jul	66.52	55.57	1,881	10.95	4,397.78	25.61
	Hardin	4	19	2,548	12,913	11,297	1-Sep	29-Jul	53.74	45.52	1,616	8.22	30.70	0.16
	Harris	4	19,183	2,548	13,093	11,467	29-Jul	29-Jul	61.75	51.80	1,626	9.96	31,191.56	190.99
	Jefferson	4	610	2,548	12,913	11,297	1-Sep	29-Jul	53.74	45.52	1,616	8.22	985.76	5.01
	Liberty	4	213	2,548	12,913	11,297	1-Sep	29-Jul	53.74	45.52	1,616	8.22	344.21	1.75
	Montgomery	4	4,032	2,548	13,093	11,467	29-Jul	29-Jul	61.75	51.80	1,626	9.96	6,556.03	40.14
	Orange	4	172	2,548	12,913	11,297	1-Sep	29-Jul	53.74	45.52	1,616	8.22	277.95	1.41
	Tarrant	5	10,358	2,426	15,465	12,448	29-Jul	29-Jul	82.47	61.45	3,017	21.02	31,250.09	217.73
	Waller	4	22	2,548	13,093	11,467	29-Jul	29-Jul	61.75	51.80	2,047	9.96	45.03	0.22
	Total												167,057.10	1,078.72
	Grand Total												**247,633.60**	**1,518.64**

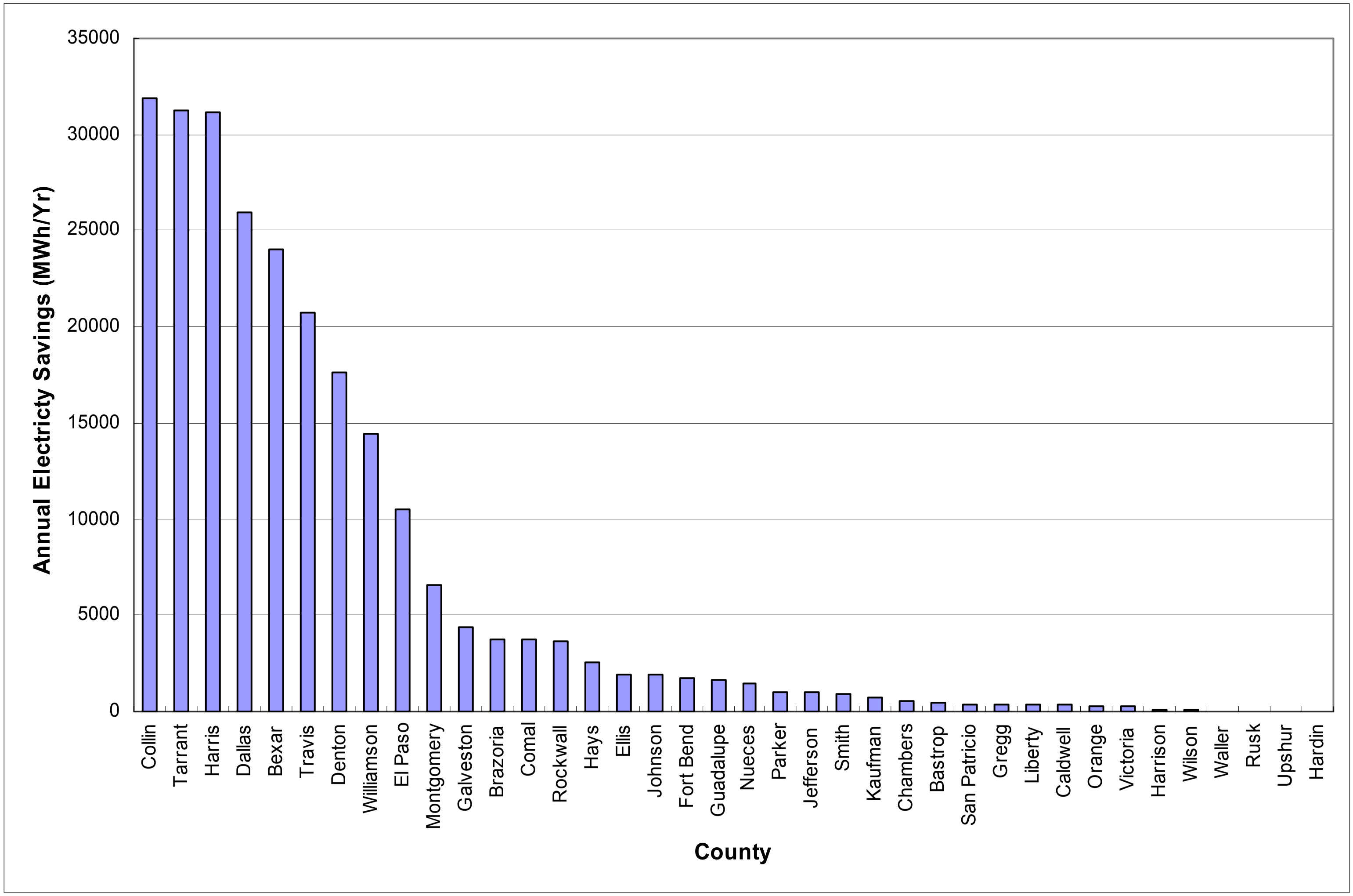

Figure 4.12 - Annual electricity savings by county

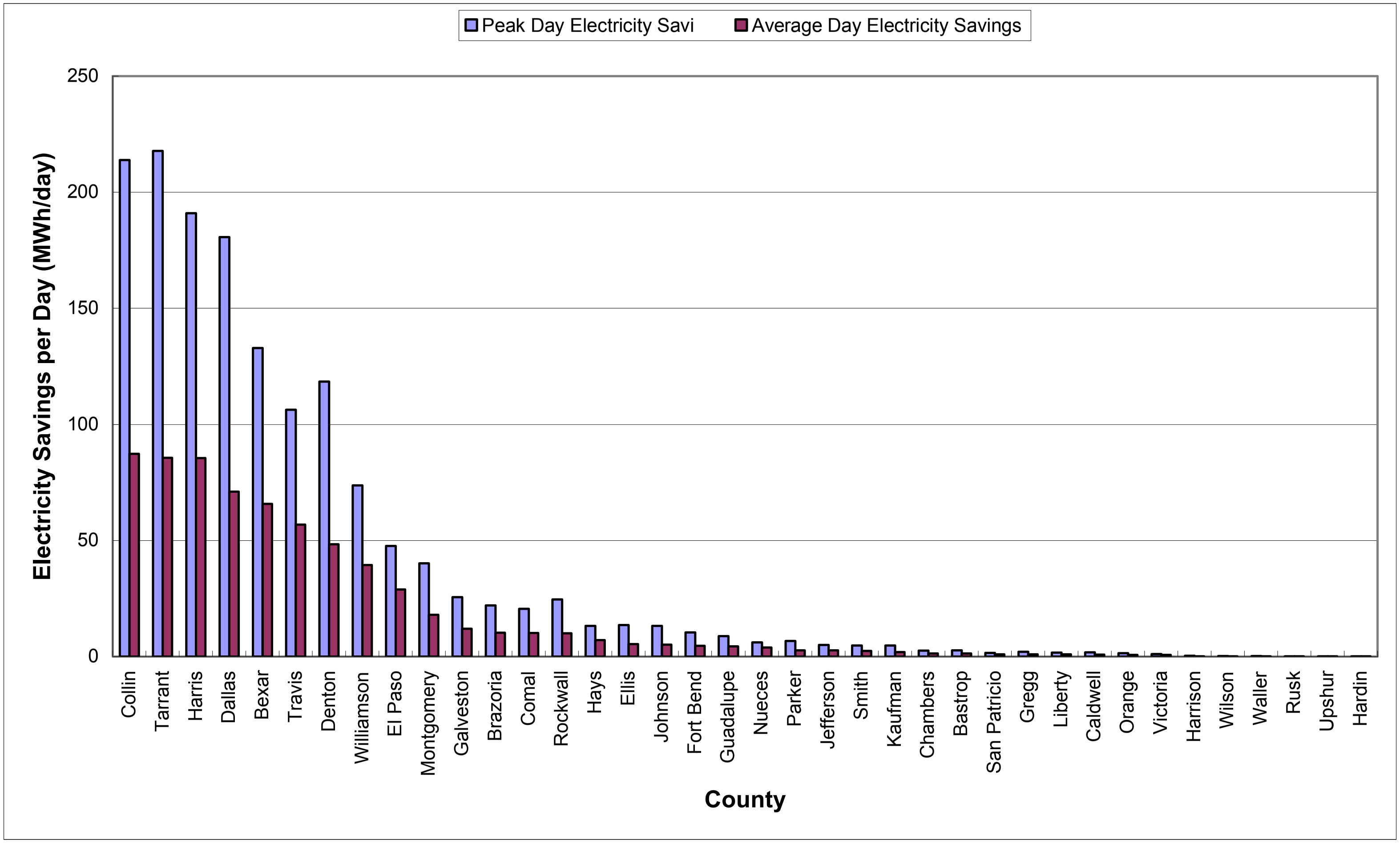

Figure 4.13 - Peak-day electricity savings vs. average day electricity savings by county

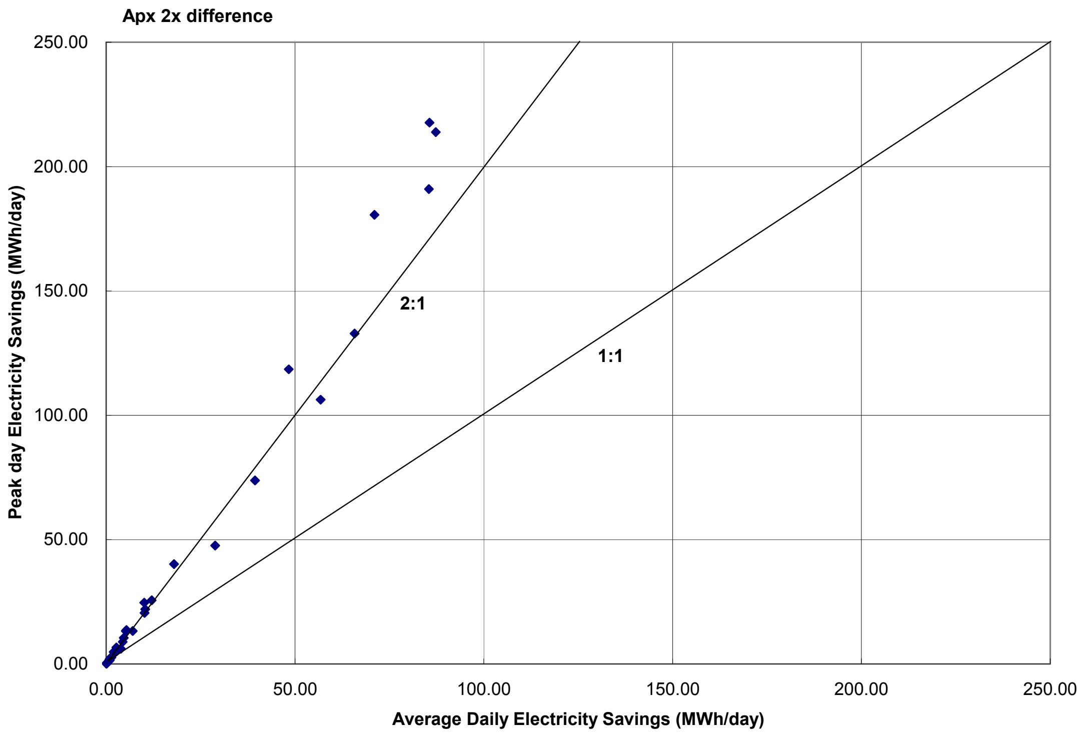

Figure 4.14 – Comparison of peak-day versus average daily electricity savings for the 38 non-attainment and affected counties

peak-day electricity use is reduced about 11% to 26% from the code adoption. Finally, if the average daily electricity savings by county was calculated by dividing the annual electricity savings by 365, the peak-day electricity savings is approximately the two times as the average day electricity savings.

4.5. Results of Demonstration of Validation Procedure

4.5.1. Overview

The results of base case study, the 2000 IECC standard house study, and DOE-2 simulations were crosschecked using the previous studies, an onsite visit and utility billing analysis. For the crosschecks, several previous studies were reviewed, and the results of those studies were compared with the results of this research. The crosschecked results include the 1999 Standard house building characteristics, the energy savings from the code adoption.

For a demonstration of the procedure of the onsite survey, a Habitat for Humanity house in Bryan, Texas was chosen. Since the objective of this procedure will to develop the methodology for the validation from the onsite visit, a sample house was chosen to present the validation procedure. The results of the onsite survey from a case study house include the completed onsite survey checklist, the completed compliance forms, the results of the compliance check using the comparisons of the building characteristics and the building energy simulations. The results of this task provide useful information about the detailed onsite visit survey procedure.

As another demonstration, the validation procedure using the utility billing analysis was conducted. For this procedure, ideally, two houses that were built, one before and one after the 2000 IECC code adoption should be chosen, and 12 months of utility bills for the houses should be obtained. However, utility bills for the Habitat for Humanity house used in the onsite survey were not available because the house was still under construction. Therefore, several years of utility bills of another sample house that was built before code adoption were obtained for the years 2000, and 2001 to demonstrate how the procedure works. In this study, the utility bills in 2000 and 2001 were considered as the utility bills from the houses before and after code adoption, respectively.

4.5.2. Crosscheck from Previous Studies

4.5.2.1. Crosscheck of the Base Case Study

In the base case study, the 1999 Standard single family house building characteristics were defined using NAHB's Builder Practices Survey Report, data from GAMA, and ARI.

Those characteristics were crosschecked from several previous studies. Table 4.21 shows the studies and the characteristics from the studies. The studies include the Henwood Energy Service study (2000), Brown et al. (1998), Schiller and Associates (2001), and Meisegeier et al. (2002). The first column shows the 2000 IECC data required for comparison. The next four columns show the building characteristics from the IECC, NAHB, ARI, and GAMA to be compared to the characteristics from the previous studies. Most of the data sources except Henwood's study provided the overall building characteristics such as the total floor area, the R-value of the wall, ceiling and floor, the efficiency of the air-conditioner and furnace, etc.

4.5.2.1.1. Base Year

The base year chosen in this research is the year 1999. If some previous studies that chose the year 1999 as base year are available, those studies could be the most appropriate for crosscheck. Although the four studies mentioned above did not chose the year 1999 as base year, the chosen base years are close to the year 1999 (1995 to 2001).

4.5.2.1.2. Location

The location of the base case house from NAHB is east Texas and west Texas.

4.5.2.1.3. Internal Load

One previous study mentioned the internal load for the base case house. Meisegeier et al. defined the 3,600 Btu/hr as the internal load. Compared to the 3,000 Btu/hr defined in the 2000 IECC, this number is 20% larger. This could be one reason that the base case house of Meisegeier et al. study uses more cooling energy use than the code house.

Table 4.21 – Crosscheck of building characteristics from previous studies

Required Data			IECC 2000 Requirement	Data Used for 1999 Standard House				Crosscheck from Previouse Studies				
				NAHB		ARI	GAMA	Henwood	Meisegeier et al.	Schiller and Associates		Brown et al.
Year			2001	1999	1999	1999	1999		Before 2001	1995 (1995 MEC)	1995 (1995 MEC)	Before 1998
Location			Houston	East Texas	West Texas	Texas	Texas	Texas	Houston	Houston	Dallas	Dallas
Weather Data	TMY2		houstontmy2.bin									
Household Occupants												
Internal Loads			3,000 Btu/hr						3,6000 Btu/hr			
Envelope	Floor Area (ft2)			2548.01	2426.43				1250, 1750, 2500, 3000, 5000	2250	2250	2000, 3000
	Wall height			8.8	9.2							
	Wall R-value	Standard	R-13	13.99	14.18				11	4.7 (Wall + Window)	5.5 (Wall + Window)	13
		Steel Frame (Steel frame wall cavity and sheathing R-value)	R-11+R-5,R-15+R4 ,R-21+R-3									
		Mass Wall (Exterior or Integral Insulation)	R-8.1									
		Mass Wall (Other)	R-10.8									
	Roof/Ceiling R-value		R-26	27.08	26.75				22	24	27	19
	Floor R-value		R-11									
	Basement wall R-value		R-5									
	Slab perimeter R-value		R-0	R-0	R-0					R-0	R-0	R-0
	Slab perimeter depth											
	Crawlspace Wall R-value		R-5									
	Air Leakage (cfm per square foot)											
	ACH (=Normalized Leakage X Weather Factor)		0.4617						0.46	0.45	0.5	
	Window area (Window-to-Wall or Window-to-Floor)		15%	15%	24%				15%, 18%,21% (Window-to-Floor)	18% (Window-to-Floor)	18% (Window-to-Floor)	20%, 25% (Window-to-Floor)
	Glazing U-factor		0.75	1.1	0.75				0.47	0.75 (Double Pane Clear)	0.75 (Double Pane Clear)	0.75 (Double Pane Clear)
	SHGC		0.4	0.72	0.67				0.4	0.67	0.67	0.67
Building Mechanical Systems and Equipment	Duct Insulation	Unconditioned attic or Outside (Supply)	8						6			4.2
		Unconditioned attic or Outside (Return)	4						6			4.2
		Other Unconditoned (Supply)	6									
		Other Unconditoned (Return)	2									
	HSPF (Air-cooled heat pumps heating mode < 65,000 Btu/h cooling capacity)	Split systms	6.8									6.8
		Single Package	6.8									
	AFUE (Gas-fired or oil-fired furnace < 225,000 Btu/h)		78%	80%	80%		80%		78%	78%	78%	78%
	AFUE (Gas-fired or oil-fired steam and hot-water boilers < 300,000 Btu/h)		80%									
	SEER (Air-cooled air conditioners and heat pumps cooling mode < 65,000 Btu/h cooling capacity)	Split systems	10 SEER	12 SEER	12SEER	11 SEER		10 SEER	10 SEER	10 SEER	10 SEER	10 SEER
		Single Package	9.7 SEER									
	Water Heater (EF)		>= 0.62-0.0019V*							0.54 (Gas)	0.54 (Gas)	

4.5.2.1.4. Floor Area

While the NAHB's report shows the one average floor area (2,500 square foot), most of the other studies show multiple floor areas such as 1250, 2250, 3000 square feet, etc. In the case of single family housing in Texas, it appears that 2,500 square foot of floor area for 1999 is the average floor area.

4.5.2.1.5. Insulation

Previous studies show R-11 and R-13 as the predominant exterior wall insulation for houses in Texas. This value is for the insulation-only, while the NAHB's report provides the continuous R-value for the whole wall. Since Schiller and Associates provided the overall wall U-value which combines the U-value of wall and windows, it cannot be compared directly to the wall R-value from NAHB without additional information. From the comparison, it appears that the wall R-value from NAHB is little larger than the R-value from previous studies (i.e., Meisegeier et al. and Brown et al.). Therefore, if the lower wall R-value from previous study were used for the 1999 standard house in this thesis, this could overstate the energy savings from adopting the energy code.

The R-value for ceilings from the previous studies is varied from 19 to 27. The overall ceiling R-value is slightly lower than the R-value from the NAHB's Report. If the lower ceiling R-value from previous study were used for the 1999 standard house in this thesis, this could also overstate the energy savings from adopting the energy code.

Three of the previous studies show that the slab-perimeter R-value is zero, and this value agrees with the value from NAHB.

4.5.2.1.6. Windows

All of previous studies except the Meisegeier et al. study define the type of windows in Texas as the double pane, clear glazing with aluminum frame. NAHB defines a mixture of single and double pane clear glazing with aluminum frames for east Texas (i.e.,Houston), and double pane, clear glazing with aluminum frames for west Texas (i.e., Dallas). Therefore, in the current study, a mixture of single and double pane clear glazing with aluminum frames for east Texas and double pane, clear glazing with aluminum frames for west Texas were used to define the 1999 standard house. If the double pane clear glazing with aluminum frame were used for the 1999 standard house in east Texas instead of the NAHB's data (i.e., a mixture of single and double pane clear glazing with aluminum frames), the energy savings from code adoption could be understated. In addition, none of the previous studies exactly how thy simulated the windows with DOE-2 simulation program.

4.5.2.1.7. Duct Insulation

The location and the insulation value for duct were not used to simulate the energy use in this research since currently a duct model is not available with DOE-2.1e program. Several previous studies show the duct insulation value. For the simulation of duct model, Meisegeier et al. used Jeff Hirsch's DOE-2.2 Vol. 121 which has undocumented duct model. While the 2000 IECC defines the different insulation value for the supply and the return duct, the previous study shows the same value for the supply and the return duct insulation.

4.5.2.1.8. Efficiency of the Heating and Cooling System

The Efficiency of the Heating and Cooling System from the previous studies are lower than the actual sales data from GAMA and ARI, which is 11 SEER and 80% AFUE (See

Figure 4.7 and 4.8). All the studies used a 10 SEER for the air-conditioner and 78% AFUE for gas furnace efficiency for Texas. These efficiency values for the air-conditioner and the gas furnace are the same to the minimum values required in the 2000 IECC. Therefore, there should have been no expected energy savings due to the air-conditioner and gas furnace when using the efficiency values from previous studies. Current study used the actual sales data from AIR and GAMA which 11 SEER and 80% AFUE.

4.5.2.1.9. Water Heater

Of the four previous studies, Schiller and Associates' study defines the Energy Factor (EF) of the water heater for base case house. The defined EF for both Houston and Dallas is 0.54. When 40 gallons of water tank was assumed for the water heater installed in the base case house, the 0.54 should be calculated[9] as the minimum EF required in the 2000 IECC. Therefore, there should be also no expected energy savings due to water heater when using the EF values from the Schiller and Associates' study.

4.5.2.2. Crosscheck of the Energy Savings

As previously explained, the electricity savings were calculated using the DOE-2 simulation. As a crosscheck, these simulated annual electricity savings are compared to the electricity savings from the previous studies. The studies include Schiller and Associates (2001) and Meisegeier et al. (2002). Both studies defined the single family house in Houston, Texas as the target building. The study of Schiller and Associates used the 1995 MEC to define the base case house and the USEPA's ENERGY STAR program to define the energy efficient

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[9] The 2000 IECC presented the equation to calculate the minimum EF.
Minimum EF = 0.62 – 0.0019 x V, where V= capacity of water tank

Table 4.22 - Upgrade package components from the study of Meisegeier et al.

Upgrade Type	Base Case	Upgrade
Thermal	R-11 wall ins.	R-13 wall ins.
	R-22 attic ins.	R-30 attic ins.
HVAC System	10 SEER	12 SEER
Window	0.47 U-value 0.40 SHGC	0.35 U-value 0.35 SHGC
Infiltration	0.46 ACH	0.35 ACH

Table 4.23 - Electricity use for base case house and code house

1. Schiller and Associates

Location	Floor Area (ft2)	Base Case Elec. Use (kWh/yr)	Base Case Elec. Use (kWh/ft2/yr)	Energy Star Elec. Use (kWh/yr)	Energy Star Elec. Use (kWh/ft2/yr)	Elec. Savings (kWh/yr/house)	Elec. Savings (kWh/ft2/yr)
Houston	1250	15954	12.76	13535	10.83	2419	1.94
	2250	17752	7.89	14914	6.63	2838	1.26
	3250	19850	6.11	16433	5.06	3417	1.05

2. Meisegeier et al.[1]

Location	Floor Area (ft2)	Base Case Elec. Use (kWh/yr)	Base Case Elec. Use (kWh/ft2/yr)	Upgrade Elec. Use (kWh/yr)	Upgrade Elec. Use (kWh/ft2/yr)	Elec. Savings (kWh/yr/house)	Elec. Savings (kWh/ft2/yr)
Houston	1250	3181	2.54	2328	1.86	853	0.68
	2500	5466	2.19	3980	1.59	1486	0.59
	3500	7466	2.13	5415	1.55	2051	0.59

1. The electricity use in this study is only for cooling and ventilating.

3. Current Research

Location	Floor Area (ft2)	Base Case Elec. Use (kWh/yr)	Base Case Elec. Use (kWh/ft2/yr)	IECC Elec. Use (kWh/yr)	IECC Elec. Use (kWh/ft2/yr)	Elec. Savings (kWh/yr/house)	Elec. Savings (kWh/ft2/yr)
Houston	2548	13093	5.14	11467	4.50	1626	0.64

house. The study by Meisegeier et al. defined the base-case house as the 2000 IECC house, and the energy efficient house using several energy efficient upgrade package components. The upgrade package components are shown in Table 4.22. Although the building characteristics of the base-case house and energy efficient house from the two studies are different than the characteristics from this research, the annual electricity savings can be compared to show the electricity savings from the code or energy efficient package adoption. Table 4.23 shows the annual electricity use for base-case house and the energy efficient house, and the electricity savings. From the table, it can be seen that the smaller house realized more electricity savings per square foot than the bigger house. Overall annual electricity savings per square foot (kWh/ft2/yr) from the previous studies are from 0.6 to 1.94 kWh/ft^2-yr. The annual electricity savings by square foot (kWh/ft2-yr) from this research is 0.64 kWh/ft^2-yr, which indicates a conservative estimate when compared to the previous studies.

Schiller and Associates' study shows over 2 times electricity savings rather than the electricity savings calculated from this research. This difference shows that the ENERGY STAR house is more efficient than the 2000 IECC code house.

4.5.3. Sample Study for Onsite Visit

As mentioned in Chapter III, the purpose of the onsite visit is to verify the building characteristics for both houses before and after code adoption. In this study, however, only one house after code adoption was chosen to demonstrate the procedure to be use.

4.5.3.1. Case Study House: Habitat for Humanity

In March 2003, several new Habitat for Humanity houses were being built in Bryan, Texas (Habitat for Humanity in Bryan, 2003). One of the houses was randomly chosen, and visited to collect the required information to verify the code-compliant house. Figure 4.15

through Figure 4.19 are the photos of site. The house is a single story and has 1,076 square feet of conditioned floor area. The house has one living room, a dining room, a kitchen, a utility area, 3 bedrooms, and 1- ½ bathrooms. In general, the building characteristics of this house show similar patterns to other Habitat for Humanity houses discussed in the previous research (Haberl et al., 1998). Compared with the Habitat for Humanity houses which were built before code adoption, the case study house has low-E windows (i.e., SHGC<0.40) and an air conditioner with a higher SEER. The 2000 IECC requires the installment of low-E windows for all new houses in Texas. As shown in the results of the base-case study, almost all building characteristics of the 1999 Standard house already meet or exceed the requirements of the 2000 IECC. The only characteristic that did not meet the 2000 IECC in the 1999 Standard house is the U-value and SHGC of windows. In general, the average standard 1999 house in Texas area has double pane clear glazing or mixed double pane and single pane clear glazing. Appendix A shows the completed onsite checklist from the sample house. The checklist shows the detailed building characteristics, simple drawings of the house, etc.

4.5.3.1.1. Site Component Inspection Method

During the onsite visit, building components were checked through visual inspection and measurement. In general, the inspection method is similar to the method used in the XENERGY (2001) study. Since the target houses of the XENERGY study are existing houses, while the case study house of this research is still under construction, some inspection methods can be applied to this research, while others not. Table 4.24 shows the comparison of the inspection methods used in XENERGY study and this research.

Figure 4.15 – Case study house: Habitat for Humanity, Bryan, Texas

Figure 4.16 – Case study house (orientation – southwest)

Figure 4.17 – Case study house (orientation – southeast)

Figure 4.18 – Case study house (orientation – northeast)

Figure 4.19 – Case study house (orientation – northwest)

For future study, it is recommended to produce a list of the building components required to be inspected for existing and new construction, separately. In addition, it is necessary to identify specific inspection instruments for each of the building components and procedures for using the equipment.

4.5.3.1.2. R-value of the Exterior Wall and the Ceiling

During the onsite visit, some building characteristics could be identified by inspection. Others could not because portions of house were already completed. The R-value of the exterior wall could not be identified directly since the construction of the exterior wall was already completed. Therefore, the R-value of the wall was identified by interviewing the builder of the house. According to the builder, the exterior walls are on 2 X 4" stud

Table 4. 24 – Building component inspection methods used in XENERGY vs. this study

Building Components	XENERGY	This Study
Attic	Accessed and thoroughly inspected	Same as XENERGY
Wall	Checked with wire probes at the edge of electrical boxes	Type of insulation was checked by interviewing with the builder. Calculated from the depth of wall
Windows	Checked for the presence of low-E coatings with specialized meters	Checked from NFRC windows label, Checked for the presence of low-E coatings with flame test
Equipment	Nameplate data were recorded	Same as XENERGY
Air exchange rate	Blower door test	None
Duct	Visually inspected	Same as XENERGY

construction set at 16” centers with blown in treated cellulose insulation. Therefore, the R-value of the exterior wall was calculated to be R-13. Although the R-value of the exterior walls was identified by interviewing and a simple calculation, for future work, it is necessary to inspect whether the insulation was correctly installed or not. On the other hand, measuring the depth of the insulation in the attic allowed for the verification of the R-value of the ceiling. Figure 4.20 shows the attic insulation installed on the case study building. Figure 4.21 shows the measuring of the attic insulation. Although there were some variations in the depth of the insulation, the average depth of the insulation was about 8.5 inches. The type of insulation in the attic is also cellulose insulation. According to the DOE-2.1 Manual (LBL 1981), this depth of the insulation corresponds to about R- 28.

4.5.3.1.3. U-value and SHGC of Windows

The National Fenestration Rating Council (NFRC) Energy Performance Label is required to provide consumers, builders, and code officials with a consistent energy performance ratings. The label shows that the product is NFRC-certified, provides a brief

Figure 4.20 – Attic insulation

Figure 4.21 – Measuring the depth of the attic insulation

description of the product, and shows the product's U-factor, solar heat gain coefficient (SHGC) and visible transmittance ratings for two standard sizes, "residential" and "non-residential". As of January 1, 2001, all window used in Texas must include all three of these ratings on their labels. This label must be affixed by the window manufacturer prior to purchase and must remain on the window until the code inspector completes the final on-site verification. The window characteristics of the case study house were easily identified from the NFRC label. Figure 4.22 shows the NFRC label at the case study house. All windows in this house had the same NFRC label. According to this label, the U-factor and SHGC of the windows are 0.40 and 0.28, respectively. Compared with the required U-factor and SHGC in the 2000 IECC for this area, these values are significantly more efficient than the required value. To crosscheck the windows characteristics of the case study house, the NFRC product Certification Authorization Report was obtained from the NFRC by personal communication (D. Wise, personal communication, May 16, 2003). This report provides the detailed window energy performance characteristics for this particular manufacturer. Figure 4.23 shows the report, which gives the energy performance characteristics of the window in the case study house. The U-factor and SHGC from this report are identical with the values showing on the NFRC label. Besides the U-factor and SHGC, this report provides the type of spacer systems, the emissivity value for the Low-e coating, the SHGC and Visible Transmittance of the dividers, and etc. The fifth column of this table shows the emissivity value for Low-E or internal film, which is 0.036 for this window. The information in parentheses indicates the glazing layer surface that contains the low-e or internal film. For the windows of this case study house, the surface number 2 which is the second surface from the outside surface contains the Low-e film, which is the current placement for window in the south. Figure 4.24 shows the section of the windows. The seventh column is for the spacer type. For this product,

Figure 4.22 – National Fenestration Rating Council (NFRC) certificate label

2003 NFRC Certified Products Directory · 1

Manufacturer - ProductName

CPD Number	Mfr Product Code	Frame/Sash Type	Glazing Layers	Low-E/ Internal Film (Surface)	Gap Width(s)	Spacer	Gap Fill	Grids	Dividers	Tint	U-Factor Res/Non/Gen	SHGC Res/Non/Gen	VT Res/Non/Gen
Reliant Building Products, Inc. - 1110 Single Hung													
ALE-M-22-00001		Vinyl/ Vinyl w/ All Members Reinforced	2		0.3900	S4-D	Air	N		CL	0.53/0.53/	0.60/0.59/	0.62/0.63/
ALE-M-22-00002		Vinyl/ Vinyl w/ All Members Reinforced	2		0.4510	S4-D	Air	N		CL	0.53/0.53/	0.60/0.59/	0.62/0.63/
ALE-M-22-00003		Vinyl/ Vinyl w/ All Members Reinforced	2	0.036 (2)	0.3900	S4-D	Air	N		LE	0.39/0.38/	0.30/0.30/	0.54/0.54/
ALE-M-22-00004		Vinyl/ Vinyl w/ All Members Reinforced	2	0.036 (2)	0.4510	S4-D	Air	N		LE	0.39/0.38/	0.30/0.30/	0.54/0.54/
ALE-M-22-00005		Vinyl/ Vinyl w/ All Members Reinforced	2		0.3900	S4-D	Air	G	1.50	CL	0.53/0.53/	0.50/0.49/	0.50/0.51/
ALE-M-22-00006		Vinyl/ Vinyl w/ All Members Reinforced	2		0.4510	S4-D	Air	G	1.50	CL	0.53/0.53/	0.50/0.49/	0.50/0.51/
ALE-M-22-00007		Vinyl/ Vinyl w/ All Members Reinforced	2	0.036 (2)	0.3900	S4-D	Air	G	1.50	LE	0.41/0.39/	0.26/0.26/	0.43/0.44/
ALE-M-22-00008		Vinyl/ Vinyl w/ All Members Reinforced	2	0.036 (2)	0.4510	S4-D	Air	G	1.50	LE	0.41/0.39/	0.26/0.26/	0.43/0.44/

Figure 4.23 – NFRC product certification authorization report

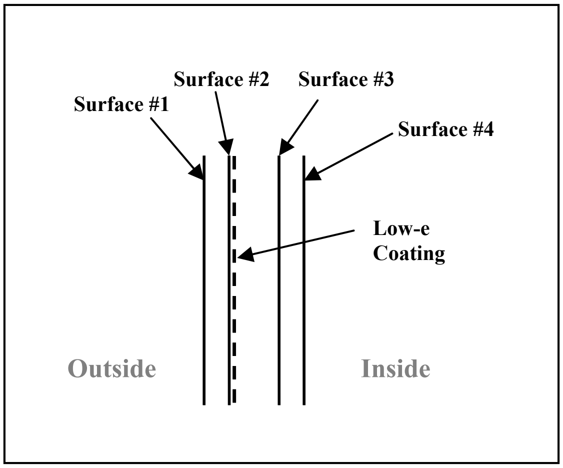


Figure 4.24 – Section of the windows for the case study house

the S4 code for the spacer system means 'steel/U-shaped'. The D means that the spacer system is dual-sealed.

4.5.3.1.4. AFUE and SEER

The efficiency of the cooling and heating systems were identified. The type of the heating system was a gas-fired furnace. The furnace of this house was located in the attic. Figure 4.25 shows the installed furnace in the attic. Details about the furnace were obtained from the manufacturer. According to the manufacturer, the AFUE of this furnace is 80% which exceeds the 2000 IECC requirement of 78% AFUE. The efficiency of the cooling system was also identified. Unfortunately, during the onsite visit, the cooling system of the house had not been installed yet. Fortunately, according to Habitat, the case study house had the same cooling system as house next door. Therefore, the cooling system of neighboring Habitat for Humanity house was used to identify the efficiency of the cooling system. Figure 4.26 shows the installed cooling system of the house next door. The air conditioner's condenser was located outside of the house. In a similar fashion as the furnace, details about the characteristics

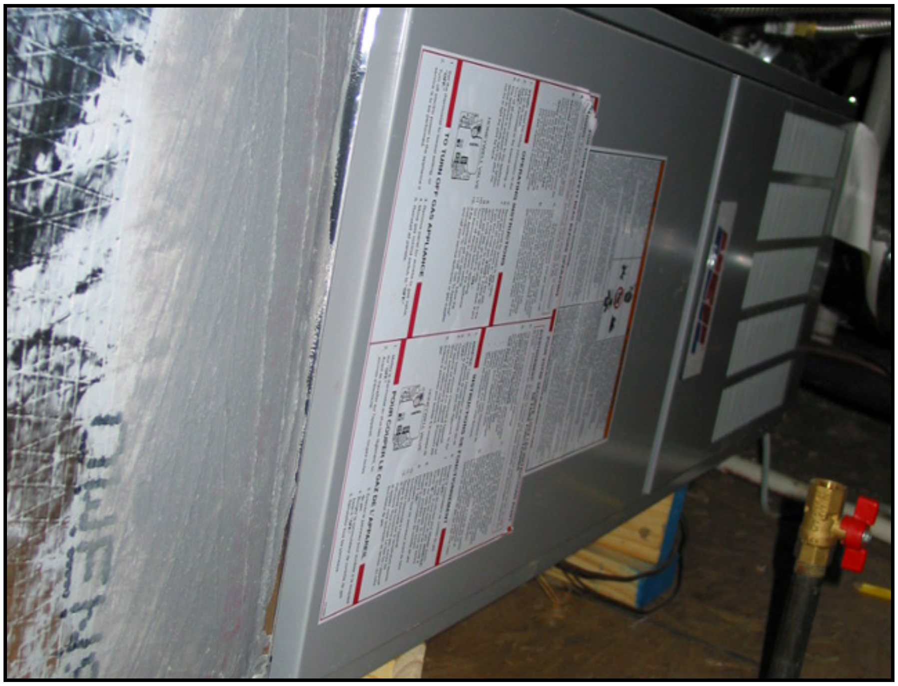


Figure 4.25– Installed furnace in the attic

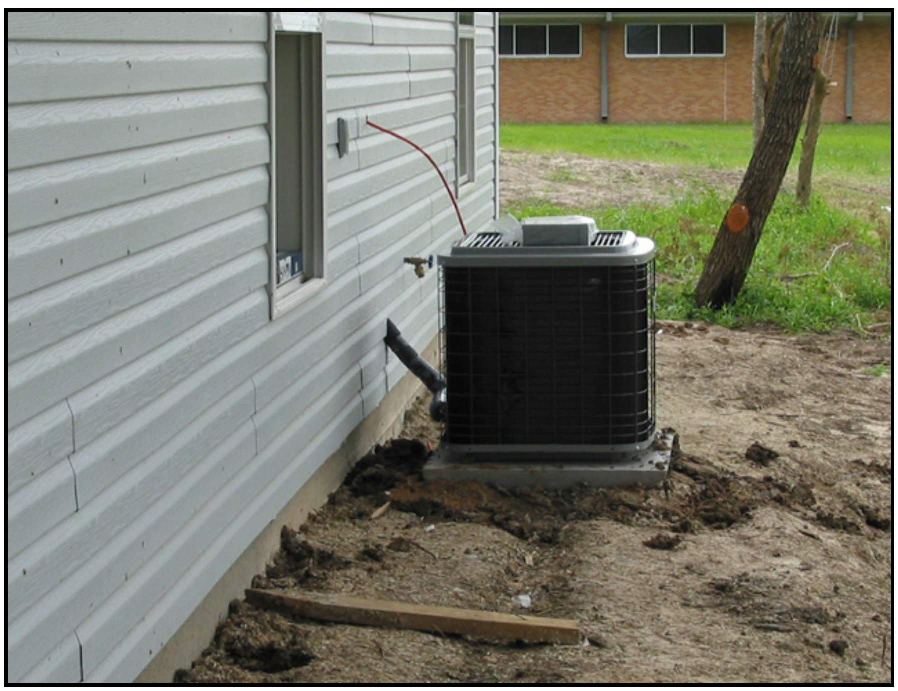


Figure 4.26 – Installed cooling system outside of the house

of the cooling system were obtained from the manufacturer. According to the manufacturer, the cooling system is the air conditioner was a SEER 12 which exceeds the 2000 IECC requirement of SEER 10.

4.5.3.1.5. Water Heater

In a similar fashion as the air conditioning system, the water heater of the house had not been installed prior to the site visit. Therefore, the information for the water heater was also obtained from the same neighboring house. Figure 4.27 shows the installed water heater in the neighboring house. The type in water heater of the house is a natural gas 40 gallon water heater, with an Energy Factor (EF) is 0.55. Since this water heater is a NAECA-covered water heating equipment according to the manufacturer, the minimum required EF for storage type gas water heater from the NAECA-covered water-heating equipment category was used to check the compliance (see Table 4.12). The minimum required EF was calculated using following equation.

$$\geq 0.62 - 0.0019V$$

where V is rated storage volume in gallons as specified by the manufacturer.

For this water heater, V is 40. Therefore, the calculated minimum EF is 0.544. Since the EF of this water heater is over 0.544, this water heater exceeds the minimum efficiency of the 2000 IECC.

Figure 4.27 – Installed water heater

4.5.3.2. Compliance Check by Components

Based on the completed checklist, a compliance check by component was conducted. Using the table developed for the compliance check in Chapter III, the building characteristics of the case study house were entered into the table. Then, the corresponding requirements of the 2000 IECC were identified and input into the next column. Since the case study house is located in the Climate Zone 4, and the window-to-wall ratio is 15%, and the prescriptive table for this climate zone and window-to-wall ratio was used to complete the form. Finally, the compliance check was performed by comparing the case study house and the requirements of the 2000 IECC. Table 4.25 shows the completed table for the compliance check.

According to Table 4.25, the R-value of the exterior wall, the door, and the slab perimeter, the Energy Factor (EF) of the water heater meet the 2000 IECC. The U-factor and the SHGC of the windows, the AFUE of the furnace, the SEER of the air conditioning system, the ceiling R-value exceed the 2000 IECC. In conclusion, the building characteristics of the case study house meet or exceed the all requirements of the 2000 IECC.

4.5.3.3. Compliance Check by Whole-building Performance

In the procedures outlined in Chapter 4 of the 2000 IECC, a compliance check by whole-building performance was to be used as another crosscheck of the house's performance.

As defined in Chapter III, the standard DOE-2 input file was used to check the compliance in this procedure. For the compliance check, two simulations were performed. One is simulated using the actual characteristics from the on-site visits. The other simulation was performed using the corresponding the 2000 IECC requirements. The 2000 IECC-compliant house has same floor area and window-to-wall ratio as the case study house, with the energy saving features of the 2000 IECC (i.e., R-values, SHGC, etc). To begin, the input file for the case study house was created using PARAMETER inputs. Next, the U-factor and SHCG of the windows is converted into the glass conductance and Shading Coefficient (SC). Using the same method, the input file for the corresponding 2000 IECC requirements was created. Table 4.26 shows the simulated annual electricity use and natural gas use for the two houses. The results show the case study house used 11,684 kWh of electricity annually while the corresponding IECC-compliant house used 12,730 kWh of electricity annually, which means the case study house is 8.9 percent more efficient than the 2000 IECC house electricity use. The case study house used 182 therms of natural gas annually, while the IECC compliant house used 201 therms of natural gas annually. Therefore, the case study house is 10.4 percent more efficient than the IECC-compliant house in natural gas use. As for total annual energy use, the case study house used 58.08 MBtu annually while the corresponding IECC-compliant house used 63.56 MBtu annually. Therefore, the case study house is 9.4 percent more efficient than the 2000 IECC house in total energy use.

In general, this procedure of the compliance check which uses a whole-building performance check can be used to check for overall compliance. In addition, in this study, several more simulations were performed to examine which energy saving features in the case study house contributed the most to the savings. The energy saving features of the case study house are the higher air-conditioning SEER, the higher furnace AFUE, and the more efficient windows. For this task, five simulations were performed: 1) the IECC compliant house, 2) the IECC compliant house with the case study house glazing, 3) the IECC compliant house with the 12 SEER air-conditioner, 4) the IECC compliant house with the 80 AFUE furnace, and 5) the case study house. The simulation results shows on the Table 4.27 and Figure 4.28. As shown in the table and the figure, the improved house glazing (i.e., a lower U-factor and SHGC) contributes to the annual heating and cooling savings. Likewise, as expected, the higher AFUE contributes only to the annual heating energy savings while the higher SEER contributes only the annual cooling energy savings. Finally, the glazing of the case study house and the higher SEER (i.e., 12 SEER) contributed to 6.29 % and 8.75 % peak-day electricity savings compared to the IECC-compliant house, and the combination of the glazing, AFUE, and SEER contributed to 14.40 % peak-day electricity savings.

4.5.4. Sample Study for Utility Billing Crosscheck Analysis

To demonstrate, the utility billing crosscheck analysis, the utility bills from another house in College Station, Texas during 1999 and 2000 were obtained. The building

Table 4.25 - Compliance check by components

Component			Onsite Visit	IECC Requirement		Compliance Check
			Installed Value	Maximum Value	Minimum Value	
Envelop		Window to Wall Ratio	15%			
Envelop	Exterior Wall	Wall Color (Light, Med., Dark)	N/A			
Envelop	Exterior Wall	Gross Area (ft^2)	1104 square feet			
Envelop	Exterior Wall	Average Wall Height (ft)	8ft			
Envelop	Exterior Wall	Insulation R-value	R-13		R-13	Meet
Envelop	Exterior Wall	Stud Spacing (in.)	16"			
Envelop	Windows	Gross Area (ft^2)	171 square feet			
Envelop	Windows	Glazing Type	Low-E			
Envelop	Windows	Frame type	Vinyl			
Envelop	Windows	U-value of windows	0.4	0.75		Exceed
Envelop	Windows	SHGC of windows	0.28	0.4		Exceed
Envelop	Door	Gross Area (ft^2)	40			
Envelop	Door	Door type	Steel Door			
Envelop	Door	Door U-value	0.35	0.35		Meet
Envelop	Roof/Attic	Roof Color (Light, Med., Dark)	Med.			
Envelop	Roof/Attic	Ceiling Type	Ceiling with attic above			
Envelop	Roof/Attic	Gross Area (ft^2)	1134			
Envelop	Roof/Attic	Insulation R-value	R-28 (7 ~8")		R-26	Exceed
Envelop	Slab Floor	Gross Area (ft^2)	1134			
Envelop	Slab Floor	Slab R-	R-0		R-0	Meet
Heating and Cooling Systems	Heating System	Fuel	Natural Gas			
Heating and Cooling Systems	Heating System	Systems Type	Furnace			
Heating and Cooling Systems	Heating System	System efficiency (AFUE or HSPF)	80% AFUE		78% AFUE	Exceed
Heating and Cooling Systems	Heating System	Manufacturer	HEIL			
Heating and Cooling Systems	Heating System	System Location	Attic			
Heating and Cooling Systems	Cooling System	Systems Type				
Heating and Cooling Systems	Cooling System	System efficiency (SEER)	12 SEER		10 SEER	Exceed
Heating and Cooling Systems	Cooling System	Manufacturer	HEIL			
Heating and Cooling Systems	Cooling System	System Location	Unconditioned area			
Duct		Duct location	Attic			
Duct		Duct diameter (in.)	6"			
Duct		Duct type	Round flexible			
Duct		Duct insulation R-value	R-6		Supply 8, Return 4	
Domestic Water Heater		NAECA-covered water heating equipment (yes, no)	Yes			
Domestic Water Heater		Fuel	Gas			
Domestic Water Heater		Capacity	40 gallon			
Domestic Water Heater		Energy Factor	0.55		0.54 (>_ 0.62-0.0019V)	Exceed
Domestic Water Heater		Type	Storage			
Domestic Water Heater		Tank location	Unconditioned area			
Domestic Water Heater		Manufacturer	Rheem			
Infiltration		ACH	N/A		0.57 x weather factor (402.1.3.10)	

Table 4.26 - Compliance check by whole building performance

	Case Study House (Habitat for Humanity)	IECC Compliant House (w/ same floor, windows area of Case Study House)	Compliance Check (Meet, Exceeds)
Electricity (kWh)	11,684	12,730	Exceeds (8.9%)
Natural Gas (THERM)	182	201	Exceeds (10.4%)
Total (MBtu)	58.08	63.56	Exceeds (9.4%)

characteristics of the house were also obtained to simulate the annual energy use of this house, and run the ASHRAE Inverse Model Toolkit (IMT) weather normalization analysis on the resultant simulations. According to the methodology defined in Chapter III, the utility bills from two houses that are built before code adoption and after code adoption should be obtained to be compared. In this study, to demonstrate the analysis method, the utility bills from the year 2000 were assumed to be the bills from the house "before code" adoption, and the utility bills from the year 2001 were assumed to be the bills from the house "after code" adoption. To demonstrate the method, these "before" and "after" utility bills were analyzed with the IMT program to develop the NAC, cooling, heating and base line use. There were then compared against the DOE-2 simulated 1999 and 2000 IECC-compliant house.

4.5.4.1. Case Study House

The case study house for this task is a single story house located in College Station, Texas. Figure 4.29 through Figure 4.32 are the photos of the case study house. To obtain the building characteristics for this house, the list of required information was given to the owner of the house. The owner provided the required building characteristics, and several photos of the house. Based on the information, Table 4.28 was developed. In this table, two values for

Table 4.27 - Energy consumptions with each energy saving feature

	Annual Electricity (kWh)	Annual Electricity % Difference vs. IECC	Annual Gas (Therm)	Annual Gas % Difference vs. IECC	Total Annual Use (MBtu)	Total Annual % Difference vs. IECC	Peak-day Electricity (kWh)	Peak-Day Electricity % Difference vs. IECC
IECC compliant	12,730	-	201	-	63.53	-	52.14	-
IECC compliant w/ the case study house glazing	12,363	2.88%	184	8.46%	60.54	4.71%	48.86	6.29%
IECC compliant w/ AFUE (78%->80%)	12,730	0.00%	200	0.50%	63.47	0.09%	52.14	0.00%
IECC compliant w/ SEER (10->12)	12,006	5.69%	201	0.00%	61.08	3.86%	47.58	8.75%
IECC compliant w/ glazing, AFUE and SEER	11,684	8.22%	182	9.45%	58.08	8.58%	44.63	14.40%

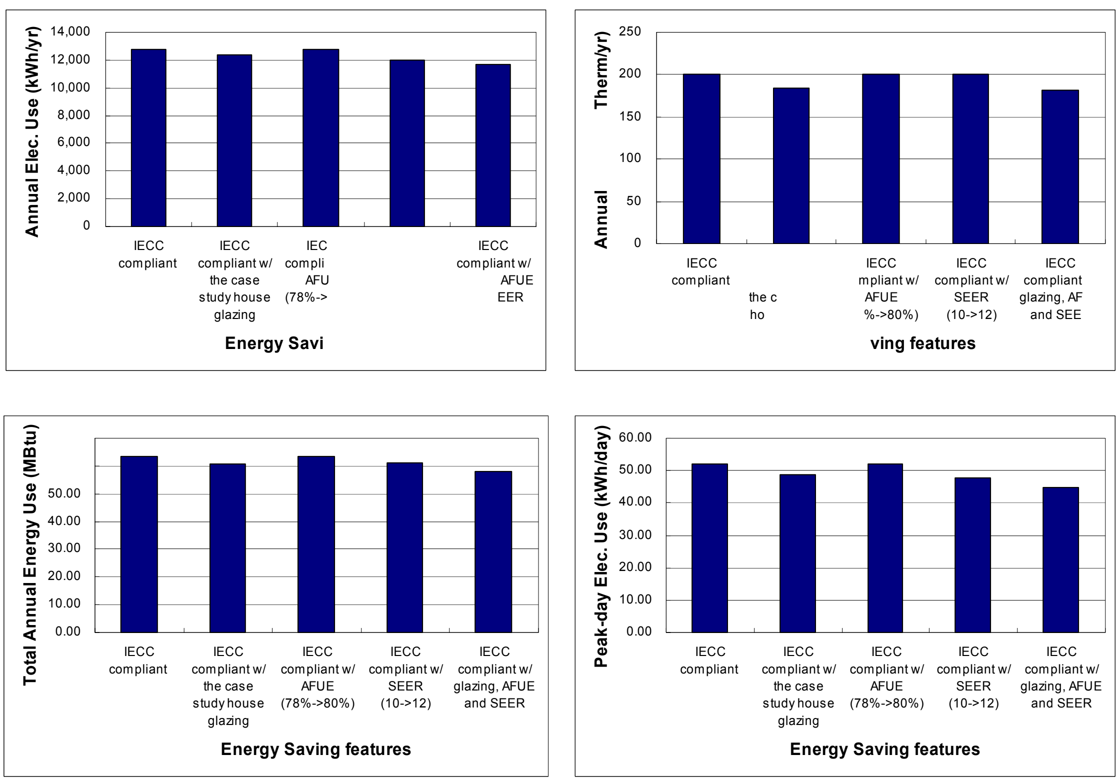


Figure 4.28 - Energy consumptions with each energy saving feature in the Habitat for Humanity

Table 4.28 – Building characteristics of the case study house: as it is built vs. with the 2000 IECC characteristics

Component			**Value**	
			As it is built	**With the 2000 IECC characteristics**
Envelope	Window to Wall Ratio		18.8%	18.8%
	Exterior Wall	Wall Color	Dark	Dark
		Gross Area	1,564 Square feet	1,564 Square feet
		Average Wall Height	8 ft	8 ft
		Insulation R-value	R-13	R-13
		Stud Spacing	16”	16”
	Windows	Gross Area	295 Square feet	295 Square feet
		Glazing Type	Clear Double Pane	Low-E glass
		Frame Type	Aluminum	Aluminum
		U-value	0.87	0.60
		SHGC	0.66	0.40
	Roof/Attic	Roof Color	Dark	Dark
		Ceiling Type	Ceiling with attic above	Ceiling with attic above
		Gross Area	2,391 Square feet	2,391 Square feet
		Insulation R-value	R-29.6 (8” insulation depth)	R-30
	Slab Floor	Gross Area	2,391 Square feet	2,391 Square feet
		Slab perimeter R-value	R-0	R-0
Equipments	Heating System	Fuel	Natural Gas	Natural Gas
		System Type	Furnace	Furnace
		Efficiency (AFUE or HSPF)	66 %	78 %
		Manufacturer	Lennox	-
		System Location	Attic	-
	Cooling System	System Type	Air conditioner, air cooled	Air conditioner, air cooled
		Efficiency (SEER)	10 (9.9 ~ 10.7)	10
		Manufacturer	Lennox	-
		System Location	Unconditioned Area	-
	Domestic Water Heater	NAECA-covered water heating equipment (yes, no)	Yes	Yes
		Fuel	Gas	Gas
		Capacity	50 Gallon	-
		Energy Factor		-
		Type	Storage	-
		Tank Location	Unconditioned Area	-
		Manufacturer	Rheem	-
Infiltration		ACH	N/A	0.46

Figure 4.29 – Front view of the case study house (southeast)

Figure 4.30 – Back view of the case study house (northwest)

Figure 4.31 – Side of the case study house (southwest)

Figure 4.32 – Side of the case study house (northeast)

each component of the building are shown. One is the value as it is built, the second is the value with the 2000 IECC characteristics. The two sets of building characteristics were then used to simulate the energy use of the house with and without the 2000 IECC characteristics. The monthly utility bills during 1999 to 2001 were also obtained from the owner to demonstrate how the IMT three-parameter can be used. The utility bills include both the electricity and natural gas use.

4.5.4.2. Calculation of the Daily Average Temperatures

Before performing the three-parameter, weather normalization (i.e., change-point linear regression), the monthly electricity and natural gas utility billing data were converted into average daily use before modeling. At the same time, the average daily ambient temperature was also calculated for the billing period. To calculate the daily average ambient temperature during the billing periods, the IMT VBDD model was run and the residual file was calculated daily electricity and natural gas usage and the corresponding daily average ambient temperatures. Table 4.29 and Table 4.30 show the calculated daily average temperature and electric usage, the calculated daily average temperature and natural gas usage, respectively.

4.5.4.3. Three-parameter Change-point Cooling Model (Utility Bills)

To calculate the Normalized Annual Consumption for Cooling, a three-parameter change-point (3P) cooling model was developed using ASHRAE IMT. The detailed modeling procedure for this task was described in Chapter III. Table 4.31 shows the output files of 3P cooling model for the 2000 and 2001 years. The output file shows the IMT coefficients and other information. From this output, the adjusted R^2 values for the 2000 and 2001 years are 89.5% and 85.2% respectively, which are statically desirable The CV-RMSE values for the 2000 and 2001 are 16.2% and 16.38%, respectively, which are statistically acceptable. The Ycp is the baseline cooling energy use below the change point, RS is the slope of the model, and Xcp is the change point of the model. As shown, the baseline use of 2001 is slightly higher than the use of 2000 (0.8853 kWh), while the slope of 2001 is lower than the slope of 2000 (0.8228). The change point temperature of 2000 and 2001 is 65.84 F and 61.69 F, respectively. Using the IMT coefficients, the model can be plotted as shown in Figure 4.33. In this figure, the monthly daily-average cooling use is also shown.

4.5.4.4. Three-parameter Change-point Heating Model (Utility Bills)

A similar procedure was used to model the natural gas use for 2000 and 2001 years. Table 4.32 shows the output file of the 3P heating model. The results shows the baseline use of 2001 is slightly higher than the use of 2000 (0.0167 MBtu), while the slope of 2001 is lower than the slope of 2000 (0.8228), which indicates slightly more gas use in 2000 verses 2001. The change point temperature of 2000 and 2001 is 75.41 F and 67.84 F, respectively. Using the IMT coefficients, the model can be plotted as shown in Figure 4.34. In this figure, the monthly daily-average heating use is also shown.

4.5.4.5. Three-parameter Change-point Cooling Model & Three-parameter Change-point Heating Model (DOE-2 Simulation)

To compare the NAC from the utility bills to the results of the DOE-2 simulations, several tasks were performed. Using the values in Table 4.28, two simulations were performed. From the DOE-2 output file, the monthly electricity use and natural gas use were converted into the daily average electricity use and natural gas use to be input the input file of IMT. Daily average temperatures for each month were identified from the hourly report of the DOE-2 simulation (i.e., TMY2 weather file). Table 4.33 shows the calculated average daily electricity and natural gas use and average temperature. Based on those data, the 3P cooling model and 3P heating model for a house without the IECC characteristics, and a house with the IECC characteristics were developed using the IMT. Table 4.34 and 4.35 present the output files, and Figure 4.35 and 4.36 show the residual data, and plotted graph.

4.5.4.6. Normalized Annual Consumption and Savings Comparison

After completing all IMT runs to develop the 3P cooling and heating models, the Normalized Annual Consumptions (NAC) were calculated. Figure 4.37 shows the coefficients of the 3P cooling and heating models for 2000 and 2001 years. The tables present the model developed using the actual utility billing analysis and the simulated energy use. To calculate the NACs, the daily temperatures for one year were obtained. For this procedure, the Houston

Table 4.29 – Calculated daily average temperatures and electricity use

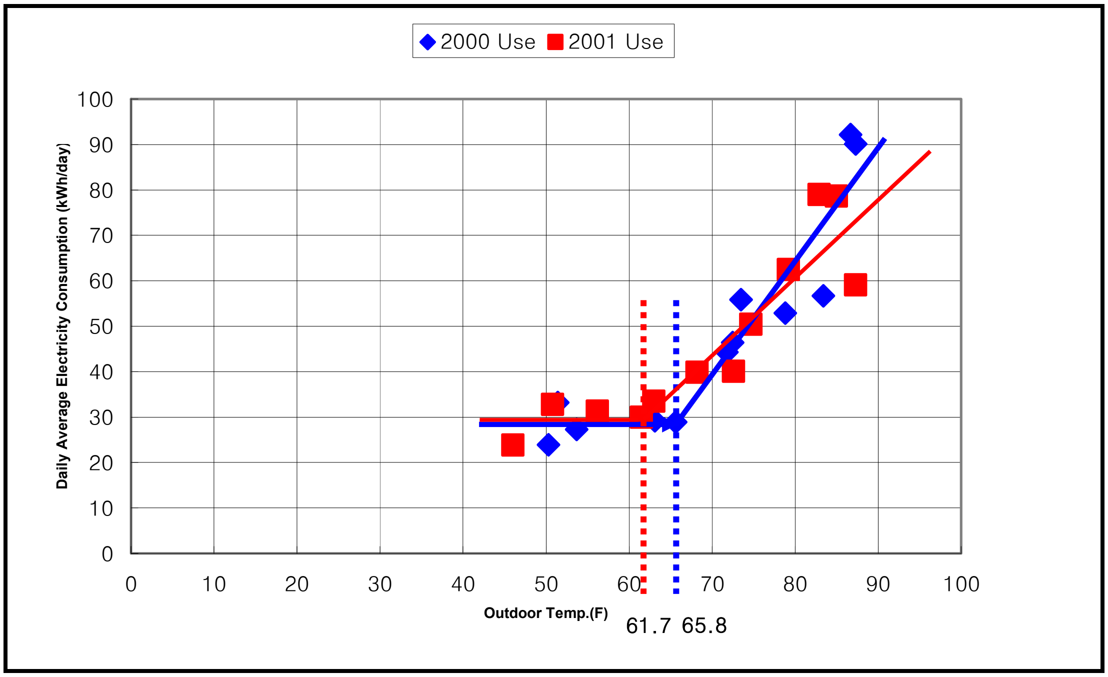
Billing Period		Days in Billing Cycles	Average Temperature from the VBDD IMT Runs	Monthly Electric Usage (kWh)	Calculated Daily Electric Usage (kWh)
Start Date	End Date				
12/10/1999	1/11/2000	33	50.3	788	23.88
1/12/2000	2/9/2000	29	53.7	792	27.31
2/10/2000	3/10/2000	30	65.6	868	28.93
3/11/2000	4/10/2000	31	63.1	906	29.23
4/11/2000	5/9/2000	29	72.5	1,345	46.38
5/10/2000	6/9/2000	31	78.8	1,639	52.87
6/10/2000	7/11/2000	32	83.4	1,815	56.72
7/12/2000	8/11/2000	31	86.7	2,858	92.19
8/12/2000	9/12/2000	32	87.3	2,884	90.13
9/13/2000	10/10/2000	28	73.5	1,563	55.82
10/11/2000	11/8/2000	29	71.5	1,284	44.28
11/9/2000	12/8/2000	30	51.4	996	33.20
12/9/2000	1/10/2001	31	46	740	23.87
1/11/2001	2/8/2001	29	50.8	951	32.79
2/9/2001	3/9/2001	29	56.2	908	31.31
3/10/2001	4/9/2001	31	61.5	930	30.00
4/10/2001	5/9/2001	30	72.6	1,201	40.03
5/10/2001	6/11/2001	33	79.2	2,062	62.48
6/12/2001	7/10/2001	29	82.9	2,290	78.97
7/11/2001	8/9/2001	30	87.3	1,772	59.07
8/10/2001	9/10/2001	32	85	2,516	78.63
9/11/2001	10/9/2001	29	74.7	1,463	50.45
10/10/2001	11/7/2001	29	68.2	1,156	39.86
11/8/2001	12/7/2001	30	63	1,005	33.50

Table 4.30 – Calculated daily average temperatures and natural gas use

Billing Period		Days in Billing Cycles	Average Temp.	Monthly N.G. Usage (MCF)	Monthly N.G. Usage (MBtu)	Calculated Daily N.G. Usage (MBtu)
Start Date	End Date					
12/15/1999	1/15/2000	32	53	5.6	5.7	0.180
1/16/2000	2/15/2000	31	54.5	7.1	7.3	0.235
2/16/2000	3/15/2000	29	64.3	3.5	3.6	0.124
3/16/2000	4/13/2000	29	64.6	3.2	3.3	0.113
4/14/2000	5/15/2000	32	73.8	2.9	3.0	0.093
5/16/2000	6/15/2000	31	79.6	1.7	1.7	0.056
6/16/2000	7/17/2000	32	84.8	1.5	1.5	0.048
7/18/2000	8/15/2000	29	86.7	1.7	1.7	0.060
8/16/2000	9/14/2000	30	86.9	1.9	1.9	0.065
9/15/2000	10/12/2000	28	72.6	2.2	2.3	0.081
10/13/2000	11/13/2000	32	68.9	2.6	2.7	0.083
11/14/2000	12/12/2000	29	51	6.7	6.9	0.237
12/13/2000	1/15/2001	34	44.4	11.4	11.7	0.344
1/16/2001	2/12/2001	28	50.9	7.7	7.9	0.282
2/13/2001	3/14/2001	30	58.1	4.8	4.9	0.164
3/15/2001	4/12/2001	29	63.1	4.2	4.3	0.149
4/13/2001	5/14/2001	32	73	2.9	3.0	0.093
5/15/2001	6/14/2001	31	80.3	2.5	2.6	0.083
6/15/2001	7/16/2001	32	83.3	2.3	2.4	0.074
7/17/2001	8/14/2001	29	87.8	1.2	1.2	0.042
8/15/2001	9/13/2001	30	83.7	2.0	2.1	0.068
9/14/2001	10/12/2001	29	74.2	2.3	2.4	0.081
10/13/2001	11/12/2001	31	67.3	2.6	2.7	0.086
11/13/2001	12/13/2001	31	60.4	4.5	4.6	0.149

Table 4.31 – Three-parameter change-point electricity models for 2000 and 2001

2000	2001
***	***
ASHRAE INVERSE MODELING TOOLKIT (1.9)	ASHRAE INVERSE MODELING TOOLKIT (1.9)
***	***
Output file name = IMT.Out	Output file name = IMT.Out
***	***
Input data file name = 2000.dat	Input data file name = 2001.dat
Model type = 3P Cooling	Model type = 3P Cooling
Grouping column No = 5	Grouping column No = 5
Value for grouping = 1	Value for grouping = 1
Residual mode = 1	Residual mode = 1
# of X(Indep.) Var = 1	# of X(Indep.) Var = 1
Y1 column number = 4	Y1 column number = 4
X1 column number = 9	X1 column number = 9
X2 column number = 0 (unused)	X2 column number = 0 (unused)
X3 column number = 0 (unused)	X3 column number = 0 (unused)
X4 column number = 0 (unused)	X4 column number = 0 (unused)
X5 column number = 0 (unused)	X5 column number = 0 (unused)
X6 column number = 0 (unused)	X6 column number = 0 (unused)
***	***
Regression Results	Regression Results
--	--
N = 12	N = 12
--	--
R2 = 0.895	R2 = 0.852
--	--
AdjR2 = 0.895	AdjR2 = 0.852
--	--
RMSE = 7.8355	RMSE = 7.6573
--	--
CV-RMSE = 16.185%	CV-RMSE = 16.380%
--	--
p = 0.168	p = -0.606
--	--
DW = 1.604 (p>0)	DW = 3.095 (p>0)
--	--
N1 = 5	N1 = 4
--	--
N2 = 7	N2 = 8
--	--
Ycp = 28.4115 (3.1318)	Ycp = 29.2968 (3.1872)
--	--
LS = 0.0000 (0.0000)	LS = 0.0000 (0.0000)
--	--
RS = 2.5773 (0.2791)	RS = 1.7545 (0.2309)
--	--
Xcp = 65.8400 (0.7400)	Xcp = 61.6940 (0.8260)
--	--

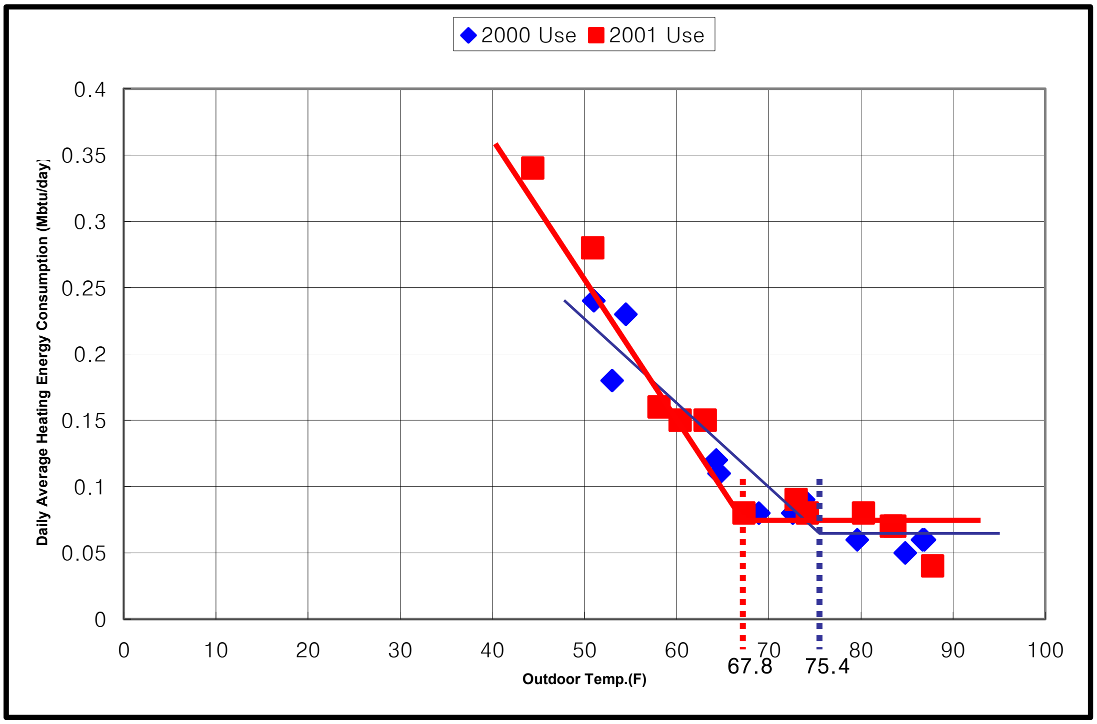


Month	Day	Year	Actual Daily Use (kWh)	Daily Average Temperature (F)	Modeled Use (kWh)	Residual
1	11	2000	23.88	50.3	28.41	-4.53
2	9	2000	27.31	53.7	28.41	-1.1
3	10	2000	28.93	65.6	28.41	0.52
4	10	2000	29.23	63.1	28.41	0.82
5	9	2000	46.38	72.5	45.58	0.8
6	9	2000	52.87	78.8	61.81	-8.94
7	11	2000	56.72	83.4	73.67	-16.95
8	11	2000	92.19	86.7	82.17	10.02
9	12	2000	90.13	87.3	83.72	6.41
10	10	2000	55.82	73.5	48.15	7.67
11	8	2000	44.28	71.8	43.77	0.51
12	8	2000	33.2	51.4	28.41	4.79
1	10	2001	23.87	46	29.3	-5.43
2	8	2001	32.79	50.8	29.3	3.49
3	9	2001	31.31	56.2	29.3	2.01
4	9	2001	30	61.5	29.3	0.7
5	9	2001	40.03	72.6	48.43	-8.4
6	11	2001	62.48	79.2	60.01	2.47
7	10	2001	78.97	82.9	66.5	12.47
8	9	2001	59.07	87.3	74.22	-15.15
9	10	2001	78.63	85	70.19	8.44
10	9	2001	50.45	74.7	52.12	-1.67
11	7	2001	39.86	68.2	40.71	-0.85
12	7	2001	33.5	63	31.59	1.91

Figure 4.33– Three-parameter change-point electricity models for 2000 and 2001

Table 4.32 - Three-parameter change-point natural gas models for 2000 and 2001

2000	2001
***	***
ASHRAE INVERSE MODELING TOOLKIT (1.9)	ASHRAE INVERSE MODELING TOOLKIT (1.9)
***	***
Output file name = IMT.Out	Output file name = IMT.Out
***	***
Input data file name = 2000.dat	Input data file name = 2001.dat
Model type = 3P Heating	Model type = 3P Heating
Grouping column No = 5	Grouping column No = 5
Value for grouping = 1	Value for grouping = 1
Residual mode = 1	Residual mode = 1
# of X(Indep.) Var = 1	# of X(Indep.) Var = 1
Y1 column number = 4	Y1 column number = 4
X1 column number = 9	X1 column number = 9
X2 column number = 0 (unused)	X2 column number = 0 (unused)
X3 column number = 0 (unused)	X3 column number = 0 (unused)
X4 column number = 0 (unused)	X4 column number = 0 (unused)
X5 column number = 0 (unused)	X5 column number = 0 (unused)
X6 column number = 0 (unused)	X6 column number = 0 (unused)
***	***
Regression Results	Regression Results
--------------------------------------	--------------------------------------
N = 12	N = 12
--------------------------------------	--------------------------------------
R2 = 0.922	R2 = 0.970
--------------------------------------	--------------------------------------
AdjR2 = 0.922	AdjR2 = 0.970
--------------------------------------	--------------------------------------
RMSE = 0.0196	RMSE = 0.0166
--------------------------------------	--------------------------------------
CV-RMSE = 17.141%	CV-RMSE = 12.352%
--------------------------------------	--------------------------------------
p = -0.674	p = -0.018
--------------------------------------	--------------------------------------
DW = 2.745 (p>0)	DW = 1.994 (p>0)
--------------------------------------	--------------------------------------
N1 = 8	N1 = 6
--------------------------------------	--------------------------------------
N2 = 4	N2 = 6
--------------------------------------	--------------------------------------
Ycp = 0.0574 (0.0077)	Ycp = 0.0741 (0.0058)
--------------------------------------	--------------------------------------
LS = -0.0068 (0.0006)	LS = -0.0115 (0.0006)
--------------------------------------	--------------------------------------
RS = 0.0000 (0.0000)	RS = 0.0000 (0.0000)
--------------------------------------	--------------------------------------
Xcp = 75.4120 (0.7180)	Xcp = 67.8360 (0.8680)
--------------------------------------	--------------------------------------



Month	Day	Year	Actual Daily Use (MBtu)	Daily Average Temperature (F)	Modeled Use (MBtu)	Residual
1	15	2000	0.18	53	0.21	−0.03
2	15	2000	0.23	54.5	0.2	0.03
3	15	2000	0.12	64.3	0.13	−0.01
4	13	2000	0.11	64.6	0.13	−0.02
5	15	2000	0.09	73.8	0.07	0.02
6	15	2000	0.06	79.6	0.06	0
7	17	2000	0.05	84.8	0.06	−0.01
8	15	2000	0.06	86.7	0.06	0
9	14	2000	0.06	86.9	0.06	0.01
10	12	2000	0.08	72.6	0.08	0
11	13	2000	0.08	68.9	0.1	−0.02
12	12	2000	0.24	51	0.22	0.01
1	15	2001	0.34	44.4	0.34	0
2	12	2001	0.28	50.9	0.27	0.01
3	14	2001	0.16	58.1	0.19	−0.02
4	12	2001	0.15	63.1	0.13	0.02
5	14	2001	0.09	73	0.07	0.02
6	14	2001	0.08	80.3	0.07	0.01
7	16	2001	0.07	83.3	0.07	0
8	14	2001	0.04	87.8	0.07	−0.03
9	13	2001	0.07	83.7	0.07	−0.01
10	12	2001	0.08	74.2	0.07	0.01
11	12	2001	0.08	67.3	0.08	0
12	13	2001	0.15	60.4	0.16	−0.01

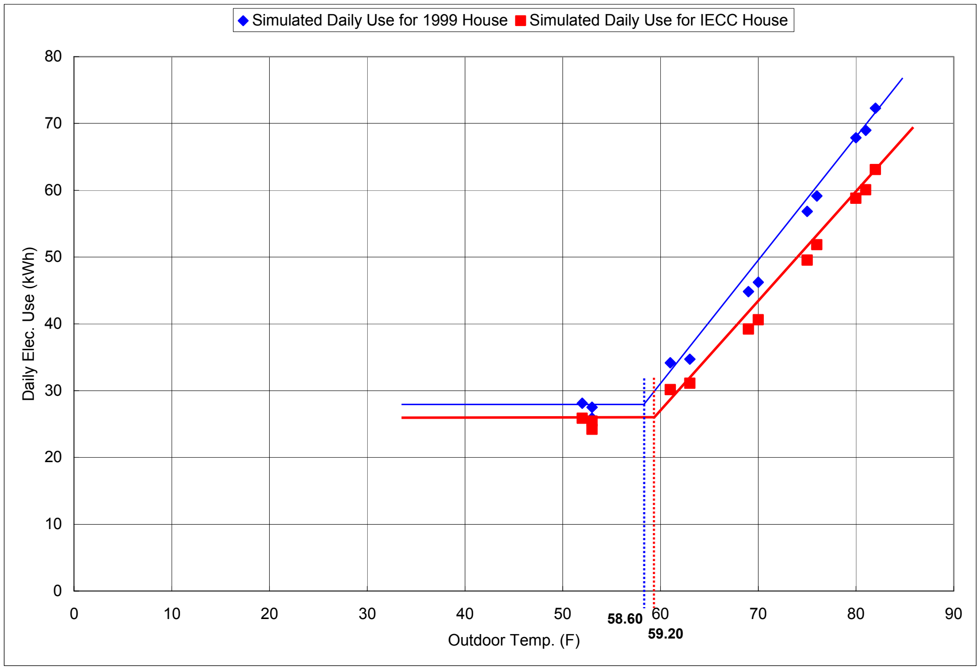
Figure 4.34– Three-parameter change-point natural gas models for 2000 and 2001

Table 4.33 – Calculated daily average temperature and average daily energy use (DOE-2 simulations)

Month	Daily temperature (F)	Calculated Average Daily Use			
		Without IECC		With IECC	
		kWh	MBtu	kWh	MBtu
Jan	53	27.52	0.17	25.45	0.13
Feb	52	28.11	0.16	25.86	0.12
Mar	61	34.16	0.08	30.16	0.06
Apr	69	44.83	0.07	39.20	0.05
May	75	56.84	0.06	49.55	0.05
Jun	80	67.87	0.06	58.80	0.04
Jul	82	72.29	0.06	63.10	0.04
Aug	81	68.97	0.06	60.06	0.04
Sep	76	59.13	0.06	51.83	0.04
Oct	70	46.23	0.06	40.61	0.04
Nov	63	34.70	0.07	31.10	0.05
Dec	53	25.87	0.14	24.19	0.10

Table 4.34 - Three-parameter change-point electricity models for 1999 and IECC (DOE-2)

1999	IECC
***	***
ASHRAE INVERSE MODELING TOOLKIT (1.9)	ASHRAE INVERSE MODELING TOOLKIT (1.9)
***	***
Output file name = IMT.Out	Output file name = IMT.Out
***	***
Input data file name = 1999.dat	Input data file name = IECCC.dat
Model type = 3P Cooling	Model type = 3P Cooling
Grouping column No = 5	Grouping column No = 5
Value for grouping = 1	Value for grouping = 1
Residual mode = 1	Residual mode = 1
# of X(Indep.) Var = 1	# of X(Indep.) Var = 1
Y1 column number = 4	Y1 column number = 4
X1 column number = 9	X1 column number = 9
X2 column number = 0 (unused)	X2 column number = 0 (unused)
X3 column number = 0 (unused)	X3 column number = 0 (unused)
X4 column number = 0 (unused)	X4 column number = 0 (unused)
X5 column number = 0 (unused)	X5 column number = 0 (unused)
X6 column number = 0 (unused)	X6 column number = 0 (unused)
***	***
Regression Results	Regression Results
N = 12	N = 12
R2 = 0.994	R2 = 0.994
AdjR2 = 0.994	AdjR2 = 0.994
RMSE = 1.4524	RMSE = 1.2296
CV-RMSE = 3.076%	CV-RMSE = 2.952%
p = 0.182	p = 0.045
DW = 1.564 (p>0)	DW = 1.847 (p>0)
N1 = 3	N1 = 3
N2 = 9	N2 = 9
Ycp = 27.0497 (0.6609)	Ycp = 25.1149 (0.5523)
LS = 0.0000 (0.0000)	LS = 0.0000 (0.0000)
RS = 1.8667 (0.0473)	RS = 1.5985 (0.0409)
Xcp = 58.6000 (0.6000)	Xcp = 59.2000 (0.6000)

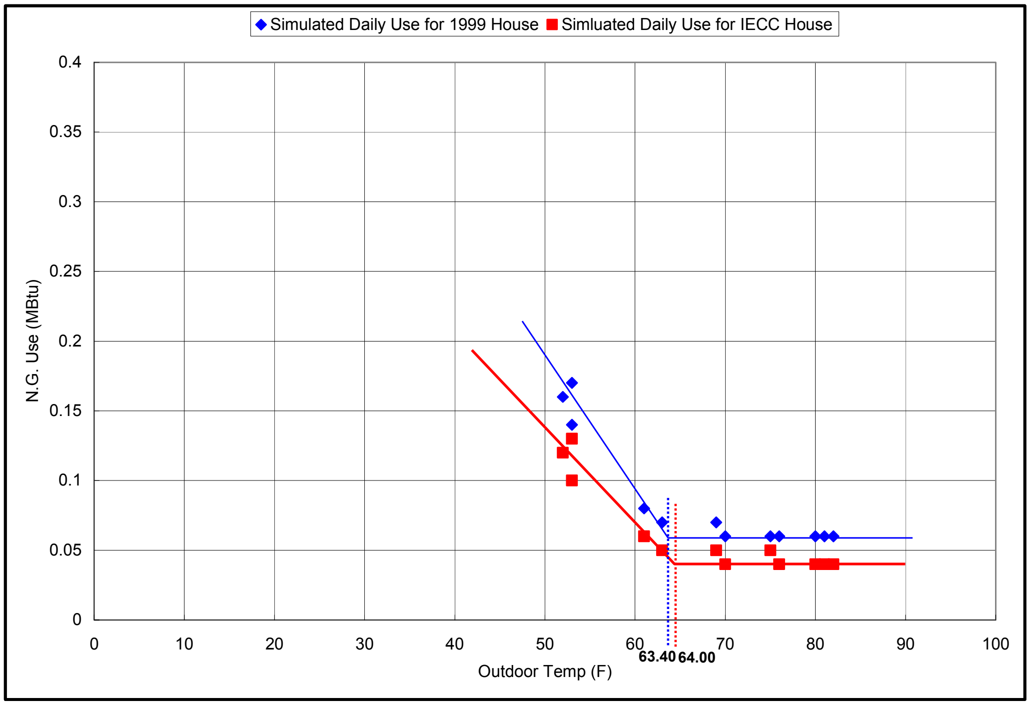


Month	Day	Year	Actual Daily Use (kWh)	Daily Average Temperature (F)	Modeled Use (kWh)	Residual
1	1	1999	27.52	53	27.05	0.47
2	1	1999	28.11	52	27.05	1.06
3	1	1999	34.16	61	31.53	2.63
4	1	1999	44.83	69	46.46	-1.63
5	1	1999	56.84	75	57.66	-0.82
6	1	1999	67.87	80	67	0.87
7	1	1999	72.29	82	70.73	1.56
8	1	1999	68.97	81	68.86	0.11
9	1	1999	59.13	76	59.53	-0.4
10	1	1999	46.23	70	48.33	-2.1
11	1	1999	34.7	63	35.26	-0.56
12	1	1999	25.87	53	27.05	-1.18
1	1	2002	25.45	53	25.11	0.34
2	1	2002	25.86	52	25.11	0.75
3	1	2002	30.16	61	27.99	2.17
4	1	2002	39.2	69	40.78	-1.58
5	1	2002	49.55	75	50.37	-0.82
6	1	2002	58.8	80	58.36	0.44
7	1	2002	63.1	82	61.56	1.54
8	1	2002	60.06	81	59.96	0.1
9	1	2002	51.83	76	51.97	-0.14
10	1	2002	40.61	70	42.38	-1.77
11	1	2002	31.1	63	31.19	-0.09
12	1	2002	24.19	53	25.11	-0.92

Figure 4.35 – Three-parameter change-point electricity models for 1999 and IECC (DOE-2)

Table 4.35- Three-parameter change-point natural gas models for 1999 and IECC (DOE-2)

1999	IECC
**	**
ASHRAE INVERSE MODELING TOOLKIT (1.9)	ASHRAE INVERSE MODELING TOOLKIT (1.9)
**	**
Output file name = IMT.Out	Output file name = IMT.Out
**	**
Input data file name = 1999.dat	Input data file name = IECCH.dat
Model type = 3P Heating	Model type = 3P Heating
Grouping column No = 5	Grouping column No = 5
Value for grouping = 1	Value for grouping = 1
Residual mode = 1	Residual mode = 1
# of X(Indep.) Var = 1	# of X(Indep.) Var = 1
Y1 column number = 4	Y1 column number = 4
X1 column number = 9	X1 column number = 9
X2 column number = 0 (unused)	X2 column number = 0 (unused)
X3 column number = 0 (unused)	X3 column number = 0 (unused)
X4 column number = 0 (unused)	X4 column number = 0 (unused)
X5 column number = 0 (unused)	X5 column number = 0 (unused)
X6 column number = 0 (unused)	X6 column number = 0 (unused)
**	**
Regression Results	Regression Results
N = 12	N = 12
R2 = 0.971	R2 = 0.969
AdjR2 = 0.971	AdjR2 = 0.969
RMSE = 0.0076	RMSE = 0.0060
CV-RMSE = 8.682%	CV-RMSE = 9.545%
p = -0.413	p = -0.080
DW = 1.649 (p>0)	DW = 1.372 (p>0)
N1 = 5	N1 = 5
N2 = 7	N2 = 7
Ycp = 0.0618 (0.0026)	Ycp = 0.0427 (0.0021)
LS = -0.0088 (0.0005)	LS = -0.0064 (0.0004)
RS = 0.0000 (0.0000)	RS = 0.0000 (0.0000)
Xcp = 63.4000 (0.6000)	Xcp = 64.0000 (0.6000)



Month	Day	Year	Actual Daily Use (MBtu)	Daily Average Temperature (F)	Modeled Use (MBtu)	Residual
1	1	1999	0.17	53	0.15	0.02
2	1	1999	0.16	52	0.16	0
3	1	1999	0.08	61	0.08	0
4	1	1999	0.07	69	0.06	0.01
5	1	1999	0.06	75	0.06	0
6	1	1999	0.06	80	0.06	0
7	1	1999	0.06	82	0.06	0
8	1	1999	0.06	81	0.06	0
9	1	1999	0.06	76	0.06	0
10	1	1999	0.06	70	0.06	0
11	1	1999	0.07	63	0.07	0
12	1	1999	0.14	53	0.15	-0.01
1	1	2002	0.13	53	0.11	0.02
2	1	2002	0.12	52	0.12	0.00
3	1	2002	0.06	61	0.06	0.00
4	1	2002	0.05	69	0.04	0.01
5	1	2002	0.05	75	0.04	0.01
6	1	2002	0.04	80	0.04	0.00
7	1	2002	0.04	82	0.04	0.00
8	1	2002	0.04	81	0.04	0.00
9	1	2002	0.04	76	0.04	0.00
10	1	2002	0.04	70	0.04	0.00
11	1	2002	0.05	63	0.05	0.00
12	1	2002	0.10	53	0.11	-0.01

Figure 4.36 – Three-parameter change-point natural gas models for 1999 and IECC (DOE-2)

IMT results for Case Study House

Three-Parameter Cooling Models

Year	Constant term	Slope term	Change point	
2000	28.41	2.58	65.84	(Y = 28.41 + 2.58 x (T - 65.84)+)
2001	29.2968	1.7545	61.694	(Y = 29.2968 + 1.7545 x (T - 61.6940)+)

Three-Parameter Heating Models.

Year	Constant term	Slope term	Change point	
2000	0.0574	-0.0068	75.4120	(Y = 0.0574 - 0.0068 (T - 75.4120)-)
2001	0.0741	-0.0115	67.8360	(Y = 0.0741 - 0.0115 (T - 67.8360)-)

IMT results for Case Study House (DOE-2)

Three-Parameter Cooling Models

Year	Constant term	Slope term	Change point	
w/o IECC	27.0497	1.8667	58.6	(Y = 27.0497 + 1.8667 x (T - 58.6)+)
w/ IECC	25.1149	1.5985	59.2	(Y = 25.1149 + 1.5985 x (T – 59.2)+)

Three-Parameter Heating Models.

Year	Constant term	Slope term	Change point	
w/o IECC	0.0618	-0.0088	63.4	(Y = 0.0618 - 0.0088 (T -63.4)-)
w/ IECC	0.0427	-0.0064	64.0	(Y = 0.0427 - 0.0064 (T – 64.0)-)

Figure 4.37 - Developed three-parameter cooling and heating model (utility bills & DOE-2 simulations)

TMY2 data was used. The daily temperatures from the Houston TMY2 were extracted from the hourly report of DOE-2 simulation. Then, using the developed model equations from Figure 4.37, eight NACs (Four for cooling use, four for heating use) were calculated. The results of the NAC and the differences of NAC are shown in Table 4.36 and 4.37. In Table 4.36, the results show the 2001 NAC had a 5.58% increase over the 2000 NAC. In Table 4.37, the results show the code compliant house was 21.7% less consumption than the non-code houses. This difference is consistent with the results from section 4.4. Figure 4.38 and 4.39 show the NAC comparison between 2000 and 2001 from utility billing analysis, and between 1999 and

Table 4.36 – Normalized Annual Consumption (NAC) for case study house (utility billing analysis)

Year	Cooling (kWh)	Cooling (MBtu)	Difference (kWh)	Difference (%)	Heating (MBtu)	Difference (MBtu)	Difference (%)	Total (MBtu)	Difference (%)
2000	16768	57	_	_	43.72	-	-	100.93	-
2001	16872	58	104.6	0.62%	49.33	5.6	11.37%	106.90	5.58%

Table 4.37 – Normalized Annual Consumption (NAC) for case study house (DOE-2 Simulations)

	Cooling (kWh)	Cooling (MBtu)	Difference (kWh)	Difference (%)	Heating (MBtu)	Difference (MBtu)	Difference (%)	Total (MBtu)	Difference (%)
W/O IECC	18018	61.48	-	-	34.65	-	-	96.13	-
W/ IECC	15875	54.17	-2,143	-13.5%	24.81	-9.84	-39.7%	78.98	-21.7%

IECC from DOE-2 simulation results, respectively. Had the utility billing results been for a code-compliant and non-code compliant house, they could have been compared to the DOE-2 simulation to serve as a crosscheck for code compliance.

4.5.5. Summary of Demonstration of Validation Procedure

For validation of this research, a crosscheck from the previous studies, an onsite visit survey, and a utility billing analysis were conducted. The crosscheck from the previous studies compared the 1999 building characteristics and the calculated annual electricity savings in this research against the results from the previous studies.

From the site visit, a case study house in Bryan, Texas, was used to determine the characteristics of a code-compliant house. The observed characteristics then compared with the requirements from the 2000 IECC. As another compliance check, a whole building performance check was performed using the standard input and DOE-2 simulation program.

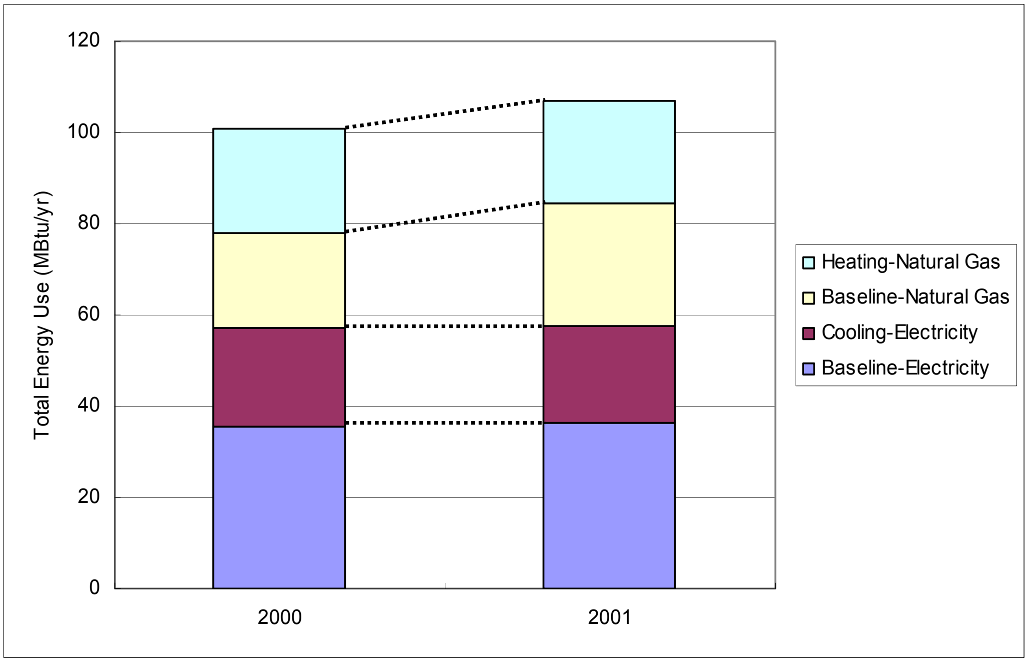


Figure 4.38 - NAC comparison between 2000 and 2001 from utility billing analysis

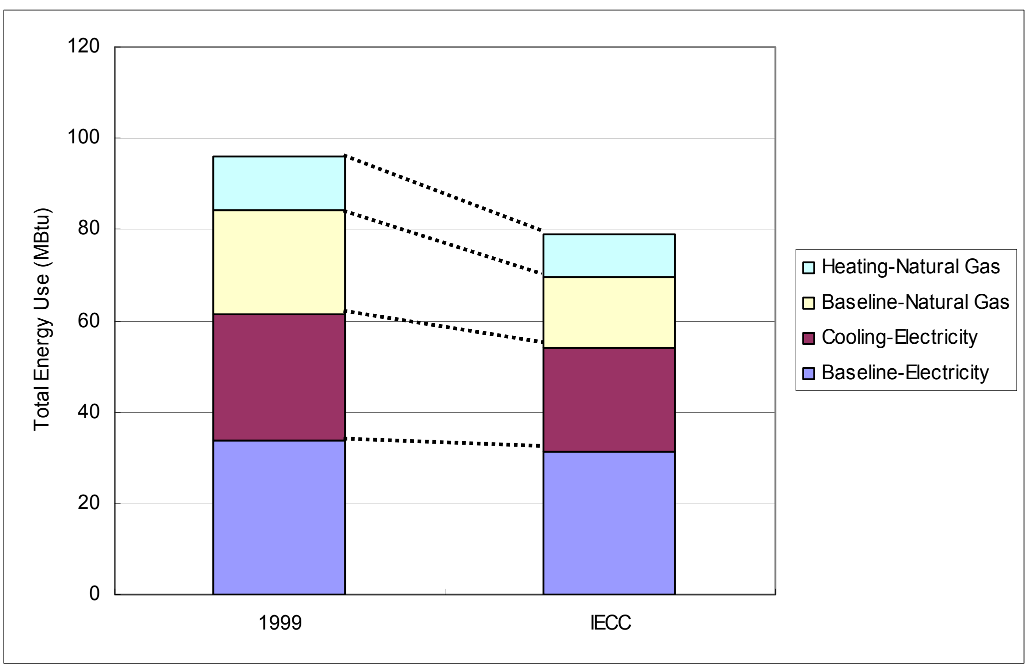


Figure 4.39 - NAC comparison between 1999 and IECC from DOE-2 simulation results

The results showed that the elements of the case study house met or exceeded the requirements of the 2000 IECC. The annual energy use (electricity + natural gas) of the case house is 7.8 percent smaller than the energy use of the 2000 IECC house.

Another case study house was chosen for the validation of the calculated energy savings using utility billing analysis. For this house, the utility bills for 2000 and 2001 were obtained, and weather-dependent models using a three-parameter change-point model were developed. The results of the utility bills analysis were compared with the results of the DOE-2 simulated energy savings. The results from the case study house analysis showed the 2001 NAC had a 5.58 % increase over the 2000 NAC. The results from DOE-2 simulation analysis showed the code-compliant house was 21.7 % less consumption than the non-code houses. Although one case study house was used instead of two houses before and after code adoption, the procedure and analysis method can be referenced for future study.

4.6 Results of NO_x Emissions Reduction Calculation

As a final task of this research, the NO_x emissions reductions from the electricity savings calculated using DOE-2 simulations were calculated. In this procedure, the EPA's eGRID database was used to calculate NO_x emissions that were reduced at the power plants of each county in Texas. The results include the detailed procedure of this task, the annual and the peak-day electricity savings by PCA, and the calculated NO_x emissions reductions for each county.

4.6.1 Annual and Peak-day Electricity Savings by PCA

In the DOE-2 simulation procedure, the electricity savings by county were simulated using DOE-2. Since the EPA's eGRID spreadsheet requires the electricity savings by PCA, the electricity savings by county were converted to PCA. Table 4.38and 4.39 show the electricity savings by PCA. The electricity savings include the annual and the peak-day savings. From the table, the largest annual electricity savings occurred in the TXU/Electric Power Control Area (157,460 MWh), while the smallest savings occurred in the Southwestern Public Service Co. PCA (589 MWh). In a similar fashion as the annual savings, the largest peak-day savings occurred in the TXU/Electric PCA (1,046.9 MWh), and the smallest savings occurred in the Southwestern Public Service Co. PCA (3.3 MWh).

4.6.2 Calculation of Annual and Peak-day NO_x Emissions Reductions

After calculating the annual and the peak-day electricity savings by PCA, the calculated savings were input into the eGRID spreadsheet. For this calculation, the annual and the peak-day electricity savings (MWh/yr) for each PCA were entered into the last row of the corresponding column in Table 4.40 and 4.41. Then, the NO_x emissions reductions due to the energy savings by county were calculated. After repeating this calculation for all counties and all PCAs, the NO_x emissions reductions for each county were calculated by summing all values for the county across the row. Table 4.40 and 4.41 show the calculated annual and peak-day NO_x emissions reductions by county. The last column of the table shows the calculated NO_x emissions reductions by county. In annual NO_x emissions reductions, the total annual NO_x reductions in ERCOT region are 438 tons per year. The largest NO_x emissions reductions are realized in Dallas County (42.33 tons per year) which is a non-attainment county, and the next largest NO_x reductions are realized in Ward County (42.08 tons per year). In peak NO_x emissions reductions, the total peak-day NO_x reductions in ERCOT region is 2.76 tons per day. The largest NO_x emissions reductions are also realized in Dallas County (0.28 tons per day). If the average daily NO_x reduction was calculated by dividing the annual NO_x reduction by 365,

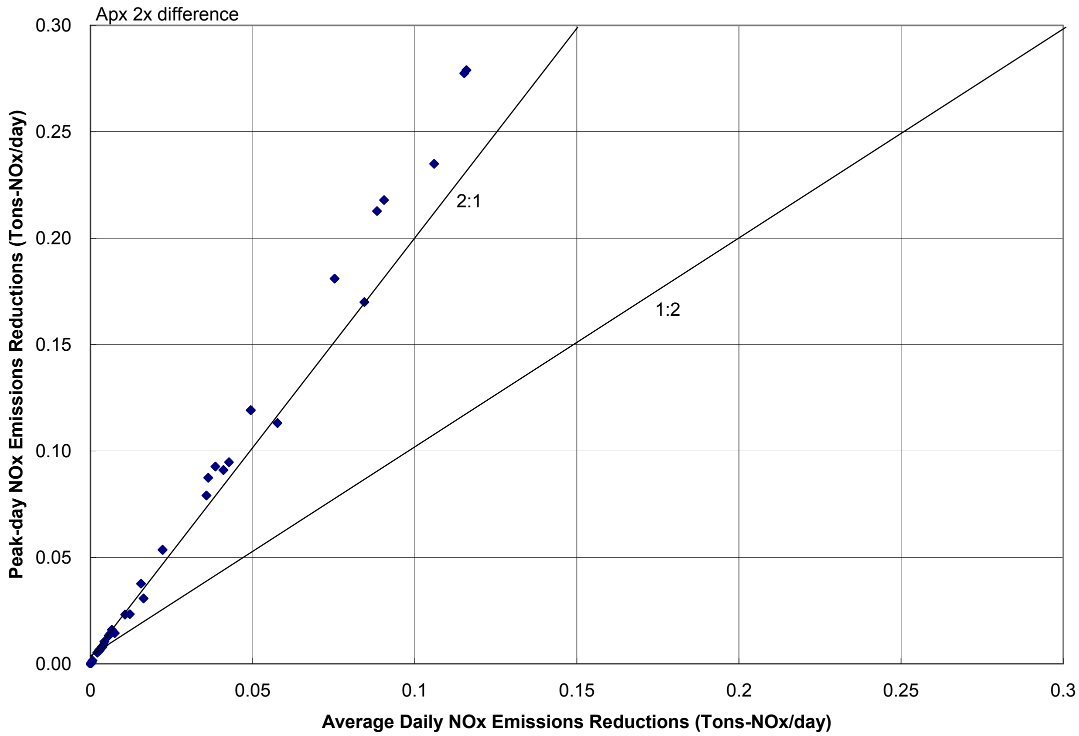


Figure 4.40 – Comparison of peak-day versus average daily NO_x emissions reductions

the peak-day NO_x reduction is approximately the two times as the average day NO_x reduction. Figure 4.40 shows that the comparison of peak-day versus average daily NOx emissions reductions.

Based on the calculation results, a distribution map and graph were created. Figure 4.41 and 4.42 show the map and graph for annual NO_x emissions reductions. The order of county name follows the descending order of magnitude of the annual electricity savings by county. The order of the NO_x emissions reductions is determined by the presence of power plants in the county. As can be seen in Figure 4.41 and 4.42, some of the counties that will realize the largest NO_x reductions are in counties that are not classified as non-attainment or affected counties, because there counties have large electric utility power plant. Figure 4.43 and 4.44 show the map and graph for the peak-day NO_x emissions reductions.

As mentioned in Chapter III, the EPA's eGRID table was developed only for the ERCOT region, and the counties included in the other NERC regions such as SERC, WSCC and SPP were excluded in the calculations for this thesis. Although, the electricity savings in the SERC, WSCC and SPP regions were relatively small (i.e., 8% of total savings), to refine the calculation, similar eGRID tables for SERC, WSCC and SPP regions would be used to calculate the NO_x emissions reductions for future work. Additionally, it is necessary to observe the actual NO_x peak-day and the actual weather peak-day in order to verify the relationship between the NO_x peak-day and the weather peak-day.

4.6.2.1 Comparison of the eGRID Method to the Simple Emission Rate Method

From the literature review, several previous studies were reviewed (XENERGY, 2001; Meisegeier et al., 2002), that calculated the NO_x emissions reductions from the energy savings. Most of the studies used a simple Emission Rate (lb- NO_x/MWh) method to calculate the expected NO_x emission reductions. To calculate the NO_x emissions reductions using simple emission rate method, the estimated electricity savings are multiplied by an average NO_x emission rate (lb- NO_x/MWh). This method does not consider the interaction among the power plants in different areas and it does not accurately reflect the emissions of a specific plant. In this section, the calculated NO_x emissions reductions from this study were compared the NO_x emissions reductions calculated using the simple emission rate method. According to eGRID (EPA 2002), the average NO_x emission rate for Texas is 2.69 lb- NO_x/MWh. This number was simply multiplied by the annual and peak-day electricity savings calculated in the DOE-2 simulations. Table 4.42, Figure 4.45 and 4.46 show the results of this calculation. As shown,

Table 4.38 - Total annual electricity savings due to the 2000 IECC by Power Control Area

Nonattainment and Affected Counties	Electric Retail Service Area	Power Control Area	NERC Region	Total Energy Savings by County (MWh)	Total Energy Savings by PCA (MWh)
Travis	Austin Energy	Austin Energy/PCA	ERCOT	24,886.6	
		Austin Energy/PCA			24,886.6
Nueces	CRI	American Electric Power West (ERCOT)/PCA	ERCOT	1,718.7	
San Patricio	CRI	American Electric Power West (ERCOT)/PCA	ERCOT	445.5	
Victoria	CRI	American Electric Power West (ERCOT)/PCA	ERCOT	313.0	
		American Electric Power West (ERCOT)/PCA			2,477.2
Bastrop		Lower Colorado River Authority/PCA	ERCOT	566.8	
Caldwell		Lower Colorado River Authority/PCA	ERCOT	392.1	
Comal		Lower Colorado River Authority/PCA	ERCOT	4,464.9	
Guadalupe		Lower Colorado River Authority/PCA	ERCOT	1,921.0	
Hays		Lower Colorado River Authority/PCA	ERCOT	3,097.2	
Wilson		Lower Colorado River Authority/PCA	ERCOT	64.3	
		Lower Colorado River Authority/PCA			10,506.2
Brazoria	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT	4,532.5	
Fort Bend	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT	2,046.8	
Galveston	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT	5,277.3	
Harris	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT	37,429.9	
Waller	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT	54.0	
		Reliant Energy HL&P/PCA			49,340.5
Bexar	San Antonio Public Service Bd	San Antonio Public Service Bd/PCA	ERCOT	28,806.8	
		San Antonio Public Service Bd/PCA			28,806.8
Ellis	TXU	TXU Electric/PCA	ERCOT	2,349.6	
Johnson	TXU	TXU Electric/PCA	ERCOT	2,277.2	
Kaufman	TXU	TXU Electric/PCA	ERCOT	864.9	
Parker	TXU	TXU Electric/PCA	ERCOT	1,198.1	
Rockwall	TXU	TXU Electric/PCA	ERCOT	4,407.6	
Smith	TXU	TXU Electric/PCA	ERCOT	1,052.4	
Williamson	TXU	TXU Electric/PCA	ERCOT	17,276.1	
Collin	TXU	TXU Electric/PCA	ERCOT	38,239.8	
Dallas	TXU	TXU Electric/PCA	ERCOT	31,117.3	
Denton	TXU	TXU Electric/PCA	ERCOT	21,176.9	
Tarrant	TXU	TXU Electric/PCA	ERCOT	37,500.1	
		TXU Electric/PCA			157,460.0
Chambers	EGS	Entergy Electric System/PCA	SERC	616.7	
Hardin	EGS	Entergy Electric System/PCA	SERC	36.8	
Jefferson	EGS	Entergy Electric System/PCA	SERC	1,182.9	
Liberty	EGS	Entergy Electric System/PCA	SERC	413.1	
Montgomery	EGS	Entergy Electric System/PCA	SERC	7,867.2	
Orange	EGS	Entergy Electric System/PCA	SERC	333.5	
		Entergy Electric System/PCA			10,450.2
El Paso	EL PASO Electric Company	El Paso Electric Co/PCA	WSCC	12,643.6	
		El Paso Electric Co/PCA			12,643.6
Gregg	SWEPCO	Southwestern Public Service Co/PCA	SPP	437.9	
Harrison	SWEPCO	Southwestern Public Service Co/PCA	SPP	74.5	
Rusk	SWEPCO	Southwestern Public Service Co/PCA	SPP	38.5	
Upshur	SWEPCO	Southwestern Public Service Co/PCA	SPP	38.4	
		Southwestern Public Service Co/PCA			589.2
Total					297,160.3

Table 4.39 - Peak-day electricity savings due to the 2000 IECC by Power Control Area

Nonattainment and Affected Counties	Electric Retail Service Area	Power Control Area	NERC Region	Total Energy Savings by County (MWh)	Total Energy Savings by PCA (MWh)
Travis	Austin Energy	Austin Energy/PCA	ERCOT	127.6	
		Austin Energy/PCA			127.6
Nueces	CRI	American Electric Power West (ERCOT)/PCA	ERCOT	7.3	
San Patricio	CRI	American Electric Power West (ERCOT)/PCA	ERCOT	1.9	
Victoria	CRI	American Electric Power West (ERCOT)/PCA	ERCOT	1.4	
		American Electric Power West (ERCOT)/PCA			10.6
Bastrop		Lower Colorado River Authority/PCA	ERCOT	3.2	
Caldwell		Lower Colorado River Authority/PCA	ERCOT	2.2	
Comal		Lower Colorado River Authority/PCA	ERCOT	24.7	
Guadalupe		Lower Colorado River Authority/PCA	ERCOT	10.6	
Hays		Lower Colorado River Authority/PCA	ERCOT	15.9	
Wilson		Lower Colorado River Authority/PCA	ERCOT	0.4	
		Lower Colorado River Authority/PCA			57.0
Brazoria	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT	26.4	
Fort Bend	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT	12.5	
Galveston	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT	30.7	
Harris	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT	229.2	
Waller	Reliant Energy HL&P	Reliant Energy HL&P/PCA	ERCOT	0.3	
		Reliant Energy HL&P/PCA			299.1
Bexar	San Antonio Public Service Bd	San Antonio Public Service Bd/PCA	ERCOT	159.4	
		San Antonio Public Service Bd/PCA			159.4
Ellis	TXU	TXU Electric/PCA	ERCOT	16.4	
Johnson	TXU	TXU Electric/PCA	ERCOT	15.9	
Kaufman	TXU	TXU Electric/PCA	ERCOT	5.8	
Parker	TXU	TXU Electric/PCA	ERCOT	8.0	
Rockwall	TXU	TXU Electric/PCA	ERCOT	29.6	
Smith	TXU	TXU Electric/PCA	ERCOT	5.8	
Williamson	TXU	TXU Electric/PCA	ERCOT	88.5	
Collin	TXU	TXU Electric/PCA	ERCOT	256.7	
Dallas	TXU	TXU Electric/PCA	ERCOT	216.8	
Denton	TXU	TXU Electric/PCA	ERCOT	142.2	
Tarrant	TXU	TXU Electric/PCA	ERCOT	261.3	
		TXU Electric/PCA			1,046.9
Chambers	EGS	Entergy Electric System/PCA	SERC	3.1	
Hardin	EGS	Entergy Electric System/PCA	SERC	0.2	
Jefferson	EGS	Entergy Electric System/PCA	SERC	6.0	
Liberty	EGS	Entergy Electric System/PCA	SERC	2.1	
Montgomery	EGS	Entergy Electric System/PCA	SERC	48.2	
Orange	EGS	Entergy Electric System/PCA	SERC	1.7	
		Entergy Electric System/PCA			61.3
El Paso	EL PASO Electric Company	El Paso Electric Co/PCA	WSCC	57.1	
		El Paso Electric Co/PCA			57.1
Gregg	SWEPCO	Southwestern Public Service Co/PCA	SPP	2.4	
Harrison	SWEPCO	Southwestern Public Service Co/PCA	SPP	0.4	
Rusk	SWEPCO	Southwestern Public Service Co/PCA	SPP	0.2	
Upshur	SWEPCO	Southwestern Public Service Co/PCA	SPP	0.2	
		Southwestern Public Service Co/PCA			3.3
Total					1,822.4

Table 4.40 - Calculation for annual NO_x emissions reductions

AREA	COUNTY	AMERICAN ELECTRIC POWER-WEST (ERCOT) /PCA	NOx REDUCT-IONS (LBS)	AUSTIN-ENERGY /PCA	NOx REDUCT-IONS (LBS)	BROWNSVILLE PUBLIC UTILS BOARD /PCA	NOx REDUCT-IONS (LBS)	LOWER COLORADO RIVER AUTHORITY /PCA	NOx REDUCT-IONS (LBS)	RELIANT ENERGY HL&P /PCA	NOx REDUCT-IONS (LBS)	SAN ANTONIO PUBLIC SERVICE BD /PCA	NOx REDUCT-IONS (LBS)	SOUTH TEXAS ELECTRIC COOP INC. /PCA	NOx REDUCT-IONS (LBS)	TEXAS MUNICIPAL POWER POOL /PCA	NOx REDUCT-IONS (LBS)	TEXAS-NEW MEXICO POWER CO /PCA	NOx REDUCT-IONS (LBS)	TXU ELECTRIC /PCA	NOx REDUCT-IONS (LBS)	TOTAL NOx REDUCTIONS (TONS)
AUSTIN-SAN ANTONIO AREA	BASTROP	0.01	24.77	0.20	4977.32		0.00	0.34	3572.10		0.00	0.01	288.07		0.00		0.00		0.00		0.00	4.43
	BEXAR	0.06	148.63	0.09	2239.79	0.04	0.00	0.16	1680.99		0.00	2.00	57613.52	0.08	0.00	0.01	0.00		0.00		0.00	30.84
	TRAVIS		0.00	0.46	11447.84		0.00	0.05	525.31		0.00		0.00		0.00		0.00		0.00		0.00	5.99
	FAYETTE	0.02	49.54	0.86	21402.48	0.02	0.00	1.51	15864.35	0.01	493.41	0.04	1152.27	0.01	0.00	0.02	0.00		0.00	0.02	3149.20	21.06
	LLANO		0.00	0.12	2986.39		0.00	0.21	2206.30		0.00	0.01	288.07		0.00		0.00		0.00		0.00	2.74
	CALDWELL		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	COMAL		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	GUADALUPE		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	HAYS		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	WILLIAMSON		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	WILSON		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
DALLAS-FORT WORTH AREA	COLLIN	0.01	24.77	0.01	248.87		0.00	0.02	210.12	0.01	493.41		0.00	0.05	0.00	0.19	0.00		0.00	0.02	3149.20	2.06
	DALLAS	0.06	148.63	0.06	1493.20	0.04	0.00	0.09	945.56	0.03	1480.22	0.01	288.07	0.09	0.00	0.30	0.00	0.09	0.00	0.51	80304.62	42.33
	DENTON		0.00	0.01	248.87		0.00	0.01	105.06		0.00		0.00	0.04	0.00	0.15	0.00		0.00	0.01	1574.60	0.96
	JOHNSON		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01	0.00		0.00		0.00	0.00
	PARKER		0.00		0.00		0.00		0.00		0.00		0.00	0.01	0.00	0.03	0.00		0.00		0.00	0.00
	CHEROKEE	0.01	24.77	0.01	248.87	0.01	0.00	0.02	210.12		0.00		0.00	0.02	0.00	0.06	0.00	0.02	0.00	0.10	15746.00	8.11
	COKE	0.03	74.31		0.00	0.02	0.00		0.00		0.00		0.00	0.01	0.00		0.00		0.00		0.00	0.04
	COLEMAN	0.02	49.54		0.00	0.01	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.02
	FANNIN	0.02	49.54	0.02	497.73	0.01	0.00	0.03	315.19	0.01	493.41		0.00	0.03	0.00	0.09	0.00	0.03	0.00	0.17	26768.21	14.06
	FRIO	0.05	123.86		0.00	0.04	0.00	0.01	105.06		0.00		0.00	1.15	0.00	0.07	0.00		0.00		0.00	0.11
	HARDEMAN	0.01	24.77		0.00	0.01	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01
	HASKELL	0.16	396.35		0.00	0.12	0.00	0.01	105.06		0.00		0.00	0.03	0.00	0.01	0.00		0.00	0.01	1574.60	1.04
	HENDERSON		0.00		0.00		0.00	0.01	105.06		0.00		0.00		0.00	0.02	0.00	0.01	0.00	0.03	4723.80	2.41
	HOOD	0.02	49.54	0.02	497.73	0.02	0.00	0.04	420.25	0.01	493.41		0.00	0.03	0.00	0.12	0.00	0.04	0.00	0.22	34641.21	18.05
	JONES	0.14	346.80		0.00	0.11	0.00		0.00		0.00		0.00	0.03	0.00		0.00		0.00	0.01	1574.60	0.96
	LAMAR		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01	1574.60	0.79
	LIMESTONE	0.01	24.77	0.01	248.87		0.00		0.00	0.05	2467.03	0.01	288.07		0.00		0.00		0.00		0.00	1.51
	MCLENNAN	0.04	99.09	0.04	995.46	0.03	0.00	0.07	735.43	0.02	986.81	0.01	288.07	0.06	0.00	0.22	0.00	0.07	0.00	0.40	62984.01	33.04
	MITCHELL	0.04	99.09	0.04	995.46	0.03	0.00	0.07	735.43	0.02	986.81	0.01	288.07	0.06	0.00	0.21	0.00	0.07	0.00	0.39	61409.41	32.26
	NOLAN		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01	1574.60	0.79
	PALO PINTO	0.01	24.77	0.02	497.73	0.01	0.00	0.03	315.19	0.01	493.41		0.00	0.09	0.00	0.36	0.00		0.00	0.02	3149.20	2.24
	RED RIVER		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01	0.00		0.00	0.02	3149.20	1.57
	TAYLOR	0.01	24.77		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01
	TITUS	0.01	24.77	0.01	248.87	0.01	0.00	0.02	210.12		0.00		0.00	0.02	0.00	0.05	0.00	0.02	0.00	0.10	15746.00	8.11
	YOUNG	0.02	49.54	0.02	497.73	0.01	0.00	0.03	315.19	0.01	493.41		0.00	0.03	0.00	0.09	0.00	0.03	0.00	0.16	25193.60	13.27
	TARRANT	0.04	99.09	0.04	995.46	0.03	0.00	0.06	630.37	0.02	986.81	0.01	288.07	0.05	0.00	0.18	0.00	0.06	0.00	0.33	51961.81	27.48
	ELLIS		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	KAUFMAN		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	ROCKWALL		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00

Table 4.40 - Continued

AREA	COUNTY	AMERICAN ELECTRIC POWER-WEST (ERCOT) /PCA	NOx REDUCT-IONS (LBS)	AUSTIN-ENERGY /PCA	NOx REDUCT-IONS (LBS)	BROWNSVILLE PUBLIC UTILS BOARD /PCA	NOx REDUCT-IONS (LBS)	LOWER COLORADO RIVER AUTHORITY /PCA	NOx REDUCT-IONS (LBS)	RELIANT ENERGY HL&P /PCA	NOx REDUCT-IONS (LBS)	SAN ANTONIO PUBLIC SERVICE BD /PCA	NOx REDUCT-IONS (LBS)	SOUTH TEXAS ELECTRIC COOP INC. /PCA	NOx REDUCT-IONS (LBS)	TEXAS MUNICIPAL POWER POOL /PCA	NOx REDUCT-IONS (LBS)	TEXAS-NEW MEXICO POWER CO /PCA	NOx REDUCT-IONS (LBS)	TXU ELECTRIC /PCA	NOx REDUCT-IONS (LBS)	TOTAL NOx REDUCTIONS (TONS)
HOUSTON-GALVESTON AREA	BRAZORIA	0.01	24.77	0.01	248.87		0.00		0.00	0.05	2467.03	0.01	288.07		0.00		0.00		0.00		0.00	1.51
	BRAZOS		0.00	0.01	248.87		0.00	0.01	105.06		0.00		0.00	0.03	0.00	0.11	0.00		0.00	0.01	1574.60	0.96
	GRIMES	0.01	24.77	0.01	248.87		0.00	0.02	210.12	0.01	493.41		0.00	0.06	0.00	0.23	0.00		0.00	0.01	1574.60	1.28
	WHARTON		0.00		0.00		0.00		0.00	0.01	493.41		0.00		0.00		0.00		0.00		0.00	0.25
	CHAMBERS	0.05	123.86	0.06	1493.20	0.03	0.00	0.02	210.12	0.35	17269.18	0.08	2304.54	0.03	0.00	0.02	0.00	0.02	0.00	0.03	4723.80	13.06
	FORT BEND	0.13	322.03	0.17	4230.72	0.10	0.00	0.06	630.37	1.01	49833.92	0.23	6625.55	0.09	0.00	0.06	0.00	0.07	0.00	0.10	15746.00	38.69
	GALVESTON	0.05	123.86	0.06	1493.20	0.04	0.00	0.02	210.12	0.39	19242.80	0.09	2592.61	0.04	0.00	0.03	0.00	0.42	0.00	0.04	6298.40	14.98
	ROBERTSON		0.00		0.00		0.00		0.00	0.01	493.41		0.00		0.00		0.00	0.40	0.00	0.01	1574.60	1.03
	HARRIS	0.05	123.86	0.07	1742.06	0.04	0.00	0.02	210.12	0.41	20229.61	0.09	2592.61	0.04	0.00	0.02	0.00	0.03	0.00	0.04	6298.40	15.60
	HARDIN		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	JEFFERSON		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	LIBERTY		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	MONTGOMERY		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	ORANGE		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	WALLER		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
EL PASO AREA	EL PASO		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
OTHERS	RUSK	0.01	24.77	0.01	248.87	0.01	0.00	0.01	105.06		0.00		0.00	0.01	0.00	0.04	0.00	0.01	0.00	0.07	11022.20	5.70
	CROCKETT	0.14	346.80		0.00	0.11	0.00		0.00		0.00		0.00	0.03	0.00		0.00		0.00	0.01	1574.60	0.96
	FREESTONE	0.02	49.54	0.02	497.73	0.02	0.00	0.04	420.25	0.01	493.41		0.00	0.03	0.00	0.12	0.00	0.04	0.00	0.22	34641.21	18.05
	CALHOUN	0.19	470.66		0.00	0.14	0.00	0.01	105.06		0.00		0.00	0.04	0.00	0.01	0.00		0.00	0.01	1574.60	1.08
	HIDALGO	0.13	322.03		0.00	0.10	0.00		0.00		0.00		0.00	0.03	0.00		0.00		0.00		0.00	0.16
	CAMERON	0.14	346.80		0.00	0.20	0.00		0.00		0.00		0.00	0.03	0.00		0.00		0.00	0.01	1574.60	0.96
	WARD	0.06	148.63	0.06	1493.20	0.04	0.00	0.09	945.56	0.02	986.81	0.01	288.07	0.08	0.00	0.28	0.00	0.10	0.00	0.51	80304.62	42.08
	WEBB	0.06	148.63		0.00	0.05	0.00		0.00		0.00		0.00	0.01	0.00		0.00		0.00		0.00	0.07
	NUECES	0.74	1833.10	0.01	248.87	0.55	0.00	0.02	210.12	0.01	493.41	0.01	288.07	0.15	0.00	0.02	0.00	0.01	0.00	0.03	4723.80	3.90
	VICTORIA	0.30	743.15	0.01	248.87	0.22	0.00	0.01	105.06		0.00		0.00	0.68	0.00	0.05	0.00		0.00	0.01	1574.60	1.34
	GREGG		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	HARRISON		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	SMITH		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	UPSHUR		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	SAN PATRICIO		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	TOTAL	2.89		2.54		2.22		3.12		2.48		2.63		3.27		3.19		1.54		3.65		438.00
Energy Savings by PCA		2477.16		24886.61		0		10506.19		49340.51		28806.76		0		0		0		157460.03		

Table 4.41 - Calculation for peak-day NO_x emissions reductions

AREA	COUNTY	AMERICAN ELECTRIC POWER-WEST (ERCOT) /PCA	NOx REDUCT-IONS (LBS)	AUSTIN-ENERGY /PCA	NOx REDUCT-IONS (LBS)	BROWNSVILLE PUBLIC UTILS BOARD /PCA	NOx REDUCT-IONS (LBS)	LOWER COLORADO RIVER AUTHORITY /PCA	NOx REDUCT-IONS (LBS)	RELIANT ENERGY HL&P /PCA	NOx REDUCT-IONS (LBS)	SAN ANTONIO PUBLIC SERVICE BD /PCA	NOx REDUCT-IONS (LBS)	SOUTH TEXAS ELECTRIC COOP INC. /PCA	NOx REDUCT-IONS (LBS)	TEXAS MUNICIPAL POWER POOL /PCA	NOx REDUCT-IONS (LBS)	TEXAS-NEW MEXICO POWER CO /PCA	NOx REDUCT-IONS (LBS)	TXU ELECTRIC /PCA	NOx REDUCT-IONS (LBS)	TOTAL NOx REDUCTIONS (TONS)
AUSTIN-SAN ANTONIO AREA	BASTROP	0.01	0.11	0.20	25.51		0.00	0.34	19.39		0.00	0.01	1.59		0.00		0.00		0.00		0.00	0.02
	BEXAR	0.06	0.64	0.09	11.48	0.04	0.00	0.16	9.13		0.00	2.00	318.82	0.08	0.00	0.01	0.00		0.00		0.00	0.17
	TRAVIS		0.00	0.46	58.68		0.00	0.05	2.85		0.00		0.00		0.00		0.00		0.00		0.00	0.03
	FAYETTE	0.02	0.21	0.86	109.70	0.02	0.00	1.51	86.13	0.01	2.99	0.04	6.38	0.01	0.00	0.02	0.00		0.00	0.02	20.94	0.11
	LLANO		0.00	0.12	15.31		0.00	0.21	11.98		0.00	0.01	1.59		0.00		0.00		0.00		0.00	0.01
	CALDWELL		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	COMAL		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	GUADALUPE		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	HAYS		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	WILLIAMSON		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	WILSON		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
DALLAS-FORT WORTH AREA	COLLIN	0.01	0.11	0.01	1.28		0.00	0.02	1.14	0.01	2.99		0.00	0.05	0.00	0.19	0.00		0.00	0.02	20.94	0.01
	DALLAS	0.06	0.64	0.06	7.65	0.04	0.00	0.09	5.13	0.03	8.97	0.01	1.59	0.09	0.00	0.30	0.00	0.09	0.00	0.51	533.94	0.28
	DENTON		0.00	0.01	1.28		0.00	0.01	0.57		0.00		0.00	0.04	0.00	0.15	0.00		0.00	0.01	10.47	0.01
	JOHNSON		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01	0.00		0.00		0.00	0.00
	PARKER		0.00		0.00		0.00		0.00		0.00		0.00	0.01	0.00	0.03	0.00		0.00		0.00	0.00
	CHEROKEE	0.01	0.11	0.01	1.28	0.01	0.00	0.02	1.14		0.00		0.00	0.02	0.00	0.06	0.00	0.02	0.00	0.10	104.69	0.05
	COKE	0.03	0.32		0.00	0.02	0.00		0.00		0.00		0.00	0.01	0.00		0.00		0.00		0.00	0.00
	COLEMAN	0.02	0.21		0.00	0.01	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	FANNIN	0.02	0.21	0.02	2.55	0.01	0.00	0.03	1.71	0.01	2.99		0.00	0.03	0.00	0.09	0.00	0.03	0.00	0.17	177.98	0.09
	FRIO	0.05	0.53		0.00	0.04	0.00	0.01	0.57		0.00		0.00	1.15	0.00	0.07	0.00		0.00		0.00	0.00
	HARDEMAN	0.01	0.11		0.00	0.01	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	HASKELL	0.16	1.70		0.00	0.12	0.00	0.01	0.57		0.00		0.00	0.03	0.00	0.01	0.00		0.00	0.01	10.47	0.01
	HENDERSON		0.00		0.00		0.00	0.01	0.57		0.00		0.00		0.00	0.02	0.00	0.01	0.00	0.03	31.41	0.02
	HOOD	0.02	0.21	0.02	2.55	0.02	0.00	0.04	2.28	0.01	2.99		0.00	0.03	0.00	0.12	0.00	0.04	0.00	0.22	230.33	0.12
	JONES	0.14	1.49		0.00	0.11	0.00		0.00		0.00		0.00	0.03	0.00		0.00		0.00	0.01	10.47	0.01
	LAMAR		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01	10.47	0.01
	LIMESTONE	0.01	0.11	0.01	1.28		0.00		0.00	0.05	14.96	0.01	1.59		0.00		0.00		0.00		0.00	0.01
	MCLENNAN	0.04	0.42	0.04	5.10	0.03	0.00	0.07	3.99	0.02	5.98	0.01	1.59	0.06	0.00	0.22	0.00	0.07	0.00	0.40	418.78	0.22
	MITCHELL	0.04	0.42	0.04	5.10	0.03	0.00	0.07	3.99	0.02	5.98	0.01	1.59	0.06	0.00	0.21	0.00	0.07	0.00	0.39	408.31	0.21
	NOLAN		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01	10.47	0.01
	PALO PINTO	0.01	0.11	0.02	2.55	0.01	0.00	0.03	1.71	0.01	2.99		0.00	0.09	0.00	0.36	0.00		0.00	0.02	20.94	0.01
	RED RIVER		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.01	0.00		0.00	0.02	20.94	0.01
	TAYLOR	0.01	0.11		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	TITUS	0.01	0.11	0.01	1.28	0.01	0.00	0.02	1.14		0.00		0.00	0.02	0.00	0.05	0.00	0.02	0.00	0.10	104.69	0.05
	YOUNG	0.02	0.21	0.02	2.55	0.01	0.00	0.03	1.71	0.01	2.99		0.00	0.03	0.00	0.09	0.00	0.03	0.00	0.16	167.51	0.09
	TARRANT	0.04	0.42	0.04	5.10	0.03	0.00	0.06	3.42	0.02	5.98	0.01	1.59	0.05	0.00	0.18	0.00	0.06	0.00	0.33	345.49	0.18
	ELLIS		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	KAUFMAN		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	ROCKWALL		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00

Table 4.41 – Continued

AREA	COUNTY	AMERICAN ELECTRIC POWER-WEST (ERCOT) /PCA	NOx REDUCT-IONS (LBS)	AUSTIN-ENERGY /PCA	NOx REDUCT-IONS (LBS)	BROWNSVILLE PUBLIC UTILS BOARD /PCA	NOx REDUCT-IONS (LBS)	LOWER COLORADO RIVER AUTHORITY /PCA	NOx REDUCT-IONS (LBS)	RELIANT ENERGY HL&P /PCA	NOx REDUCT-IONS (LBS)	SAN ANTONIO PUBLIC SERVICE BD /PCA	NOx REDUCT-IONS (LBS)	SOUTH TEXAS ELECTRIC COOP INC. /PCA	NOx REDUCT-IONS (LBS)	TEXAS MUNICIPAL POWER POOL /PCA	NOx REDUCT-IONS (LBS)	TEXAS-NEW MEXICO POWER CO /PCA	NOx REDUCT-IONS (LBS)	TXU ELECTRIC /PCA	NOx REDUCT-IONS (LBS)	TOTAL NOx REDUCTIONS (TONS)
HOUSTON-GALVESTON AREA	BRAZORIA	0.01	0.11	0.01	1.28		0.00		0.00	0.05	14.96	0.01	1.59		0.00		0.00		0.00		0.00	0.01
	BRAZOS		0.00	0.01	1.28		0.00	0.01	0.57		0.00		0.00	0.03	0.00	0.11	0.00		0.00	0.01	10.47	0.01
	GRIMES	0.01	0.11	0.01	1.28		0.00	0.02	1.14	0.01	2.99		0.00	0.06	0.00	0.23	0.00		0.00	0.01	10.47	0.01
	WHARTON		0.00		0.00		0.00		0.00	0.01	2.99		0.00		0.00		0.00		0.00		0.00	0.00
	CHAMBERS	0.05	0.53	0.06	7.65	0.03	0.00	0.02	1.14	0.35	104.69	0.08	12.75	0.03	0.00	0.02	0.00	0.02	0.00	0.03	31.41	0.08
	FORT BEND	0.13	1.38	0.17	21.69	0.10	0.00	0.06	3.42	1.01	302.09	0.23	36.66	0.09	0.00	0.06	0.00	0.07	0.00	0.10	104.69	0.23
	GALVESTON	0.05	0.53	0.06	7.65	0.04	0.00	0.02	1.14	0.39	116.65	0.09	14.35	0.04	0.00	0.03	0.00	0.42	0.00	0.04	41.88	0.09
	ROBERTSON		0.00		0.00		0.00		0.00	0.01	2.99		0.00		0.00		0.00	0.40	0.00	0.01	10.47	0.01
	HARRIS	0.05	0.53	0.07	8.93	0.04	0.00	0.02	1.14	0.41	122.63	0.09	14.35	0.04	0.00	0.02	0.00	0.03	0.00	0.04	41.88	0.09
	HARDIN		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	JEFFERSON		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	LIBERTY		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	MONTGOMERY		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	ORANGE		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	WALLER		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
EL PASO AREA	EL PASO		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
OTHERS	RUSK	0.01	0.11	0.01	1.28	0.01	0.00	0.01	0.57		0.00		0.00	0.01	0.00	0.04	0.00	0.01	0.00	0.07	73.29	0.04
	CROCKETT	0.14	1.49		0.00	0.11	0.00		0.00		0.00		0.00	0.03	0.00		0.00		0.00	0.01	10.47	0.01
	FREESTONE	0.02	0.21	0.02	2.55	0.02	0.00	0.04	2.28	0.01	2.99		0.00	0.03	0.00	0.12	0.00	0.04	0.00	0.22	230.33	0.12
	CALHOUN	0.19	2.02		0.00	0.14	0.00	0.01	0.57		0.00		0.00	0.04	0.00	0.01	0.00		0.00	0.01	10.47	0.01
	HIDALGO	0.13	1.38		0.00	0.10	0.00		0.00		0.00		0.00	0.03	0.00		0.00		0.00		0.00	0.00
	CAMERON	0.14	1.49		0.00	0.20	0.00		0.00		0.00		0.00	0.03	0.00		0.00		0.00	0.01	10.47	0.01
	WARD	0.06	0.64	0.06	7.65	0.04	0.00	0.09	5.13	0.02	5.98	0.01	1.59	0.08	0.00	0.28	0.00	0.10	0.00	0.51	533.94	0.28
	WEBB	0.06	0.64		0.00	0.05	0.00		0.00		0.00		0.00	0.01	0.00		0.00		0.00		0.00	0.00
	NUECES	0.74	7.86	0.01	1.28	0.55	0.00	0.02	1.14	0.01	2.99	0.01	1.59	0.15	0.00	0.02	0.00	0.01	0.00	0.03	31.41	0.02
	VICTORIA	0.30	3.19	0.01	1.28	0.22	0.00	0.01	0.57		0.00		0.00	0.68	0.00	0.05	0.00		0.00	0.01	10.47	0.01
	GREGG		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	HARRISON		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	SMITH		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	UPSHUR		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	SAN PATRICIO		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	0.00
	TOTAL	2.89		2.54		2.22		3.12		2.48		2.63		3.27		3.19		1.54		3.65		2.76
Energy Savings by PCA		10.62		127.56		0.00		57.04		299.10		159.41		0.00		0.00		0.00		1046.94		

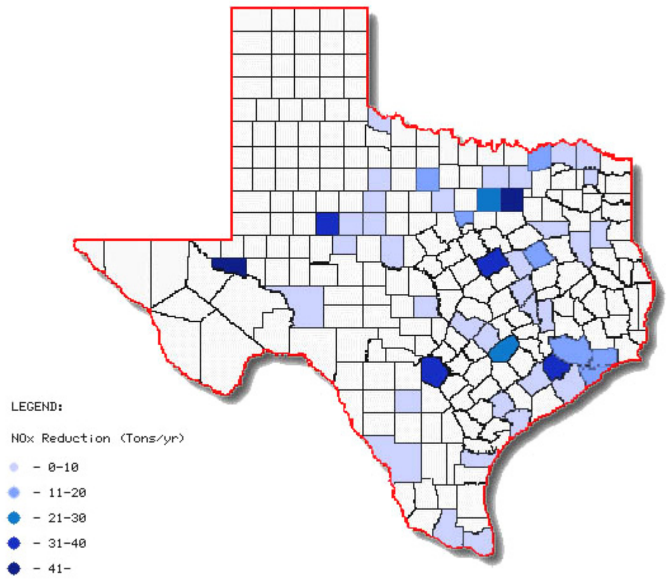


Figure 4.41 - Distribution of power plant annual NO_x reductions due to the 2000 IECC

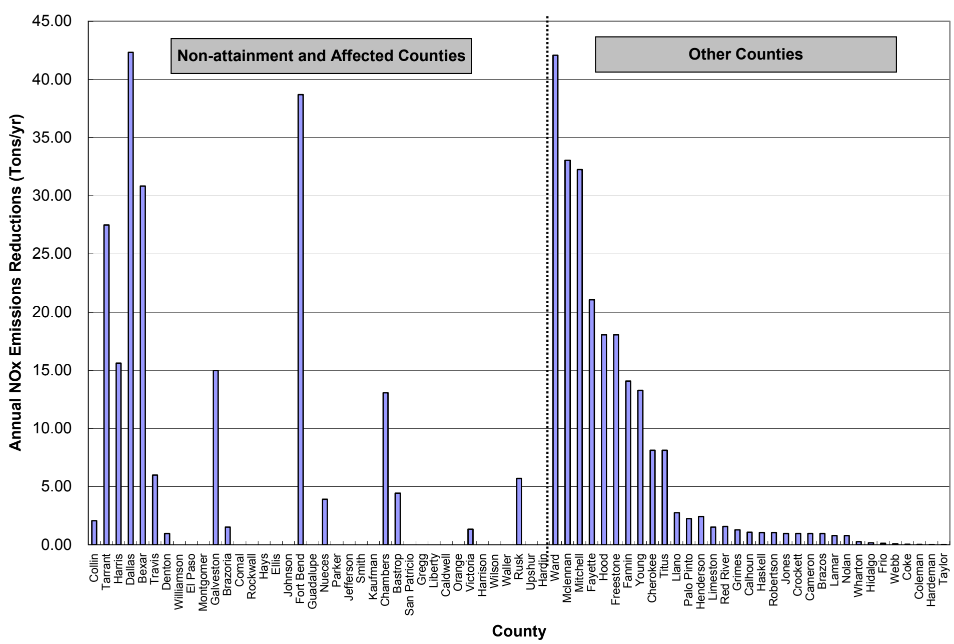


Figure 4.42- Power plant annual NO_x reductions due to the 2000 IECC

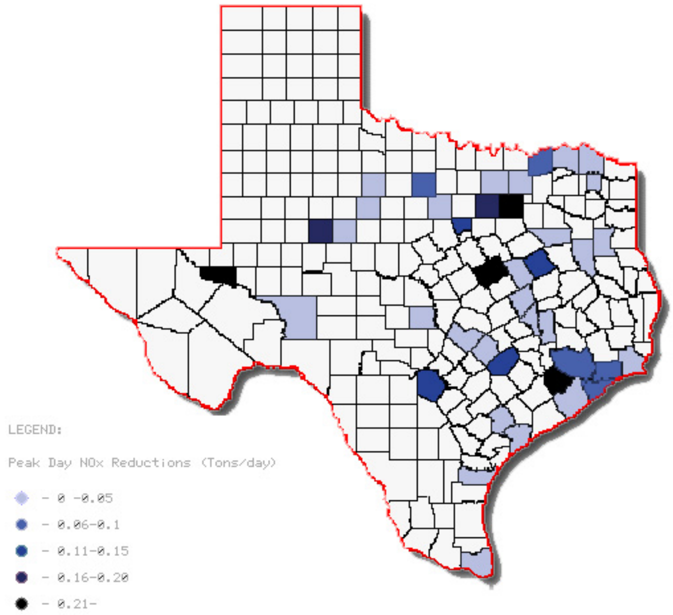


Figure 4.43 - Distribution of power plant peak-day NO_x reductions due to the 2000 IECC

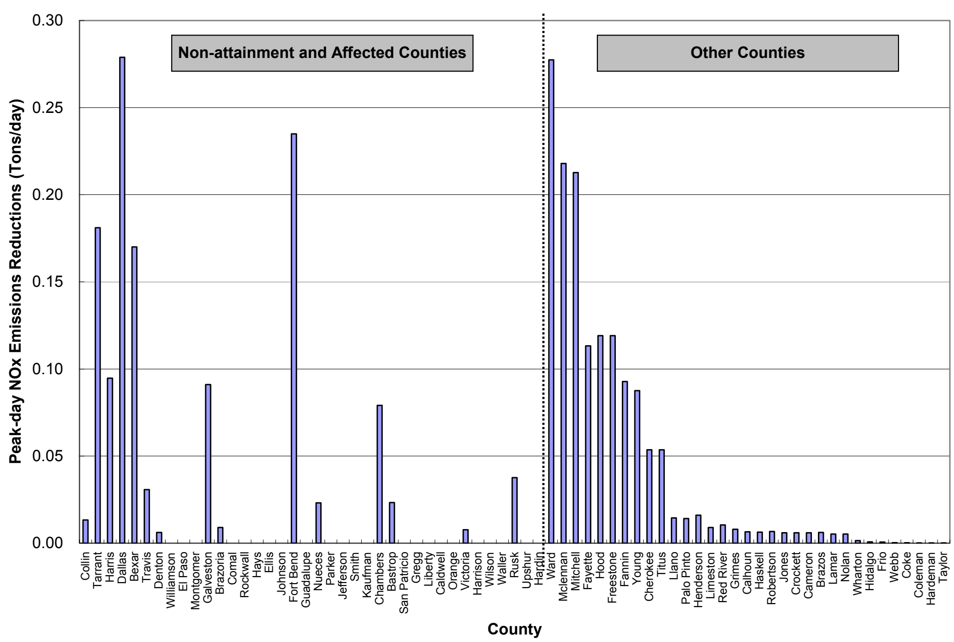


Figure 4.44 - Power plant peak-day NO_x reductions due to the 2000 IECC

Table 4.42 – Calculation of annual and peak-day NO_x emissions reductions using emission rate method

County	Annual Electricity Savings (MWh/yr)	Peak-day Electricity Savings (MWh/day)	NO_x Emission Rate (lb- NO_x /MWh)	Annual NO_x Emission Reductions (tons/yr)	Peak-day NO_x Emission Reductions (tons/day)
	(A)	*(B)*	*(C)*	*(A X C)*	*(B X C)*
Collin	38,239.84	256.7	2.69	51.43	0.35
Tarrant	37,500.10	261.27	2.69	50.44	0.35
Harris	37,429.87	229.18	2.69	50.34	0.31
Dallas	31,117.34	216.8	2.69	41.85	0.29
Bexar	28,806.76	159.41	2.69	38.75	0.21
Travis	24,886.61	127.56	2.69	33.47	0.17
Denton	21,176.91	142.16	2.69	28.48	0.19
Williamson	17,276.07	88.55	2.69	23.24	0.12
El Paso	12,643.56	57.13	2.69	17.01	0.08
Montgomery	7,867.24	48.17	2.69	10.58	0.06
Galveston	5,277.33	30.73	2.69	7.10	0.04
Brazoria	4,532.46	26.39	2.69	6.10	0.04
Comal	4,464.89	24.71	2.69	6.01	0.03
Rockwall	4,407.56	29.59	2.69	5.93	0.04
Hays	3,097.17	15.87	2.69	4.17	0.02
Ellis	2,349.64	16.37	2.69	3.16	0.02
Johnson	2,277.23	15.87	2.69	3.06	0.02
Fort Bend	2,046.81	12.53	2.69	2.75	0.02
Guadalupe	1,920.99	10.63	2.69	2.58	0.01
Nueces	1,718.67	7.35	2.69	2.31	0.01
Parker	1,198.09	8.04	2.69	1.61	0.01
Jefferson	1,182.91	6.02	2.69	1.59	0.01
Smith	1,052.39	5.77	2.69	1.42	0.01
Kaufman	864.85	5.81	2.69	1.16	0.01
Chambers	616.67	3.14	2.69	0.83	0.00
Bastrop	566.77	3.23	2.69	0.76	0.00
San Patricio	445.5	1.9	2.69	0.60	0.00
Gregg	437.9	2.44	2.69	0.59	0.00
Liberty	413.05	2.1	2.69	0.56	0.00
Caldwell	392.08	2.23	2.69	0.53	0.00
Orange	333.54	1.7	2.69	0.45	0.00
Victoria	313	1.37	2.69	0.42	0.00
Harrison	74.49	0.42	2.69	0.10	0.00
Wilson	64.3	0.36	2.69	0.09	0.00
Waller	54.04	0.26	2.69	0.07	0.00
Rusk	38.47	0.21	2.69	0.05	0.00
Upshur	38.37	0.21	2.69	0.05	0.00
Hardin	36.84	0.19	2.69	0.05	0.00
Total (Counties in ERCOT Region)				**367.83**	**2.29**
Total (All Counties)				**399.68**	**2.45**

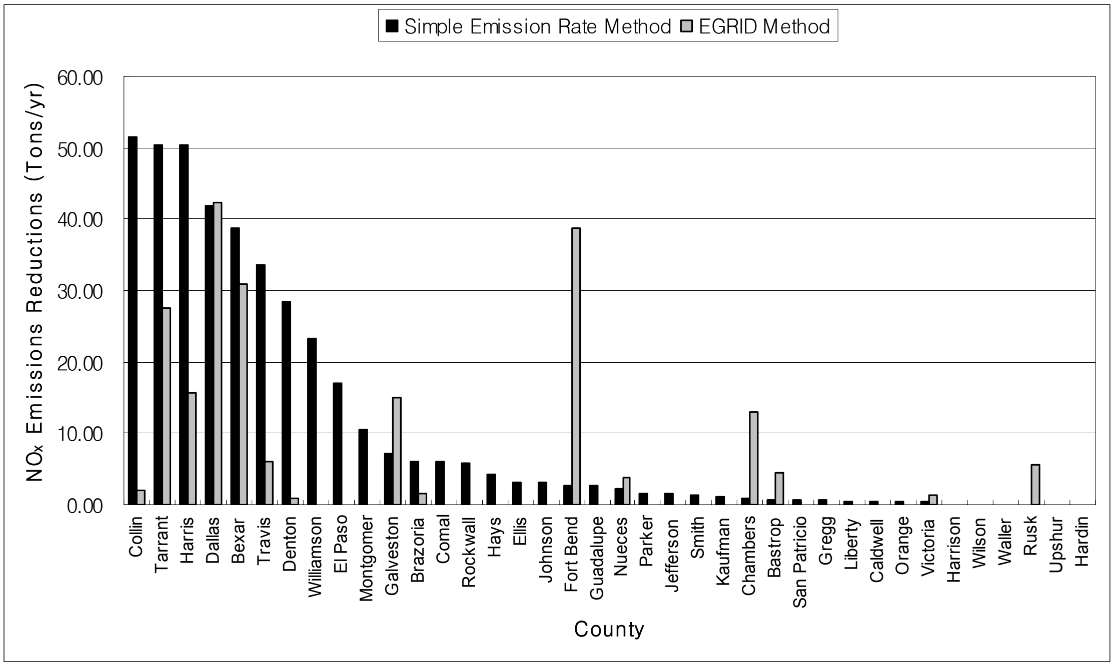


Figure 4.45 – Annual NO_x emissions reductions using eGRID method vs. emission rate method

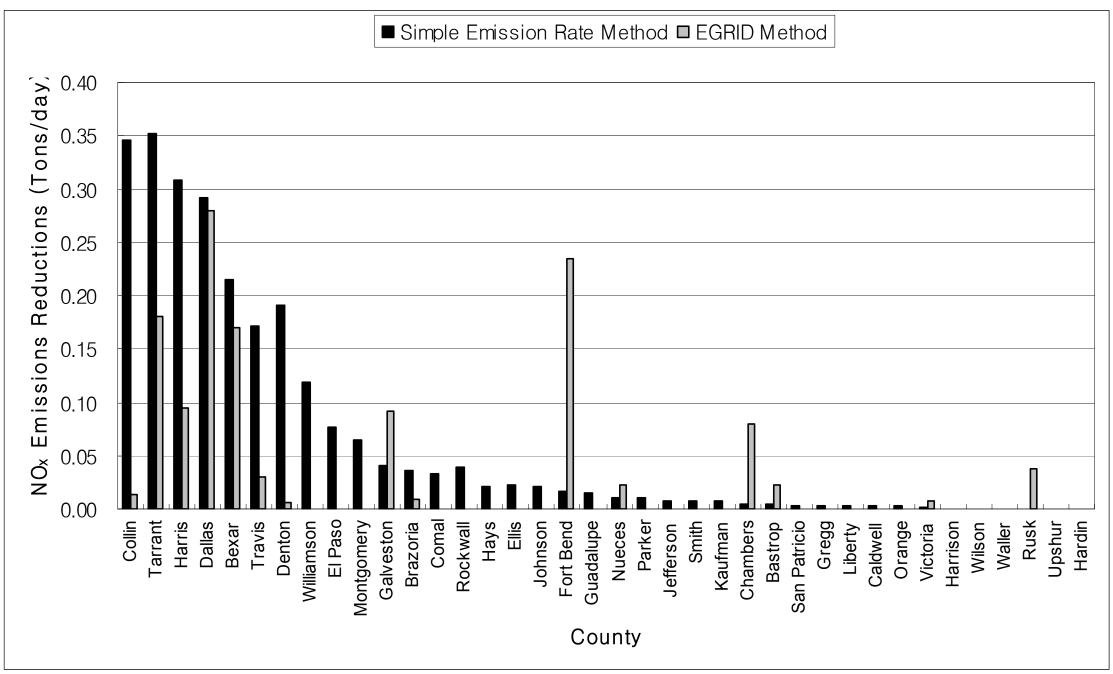


Figure 4.46 – Peak-day NO_x emissions reductions using eGRID method vs. emission rate method

the order of the NO_x emissions reductions is the same to the order of the electricity savings. The electricity savings from the counties in ERCOT region were used when calculating the NO_x emissions reductions using eGRID spreadsheet. From the table, the total annual and peak-day NO_x reductions except the NO_x reductions from the counties not in ERCOT region is 367.83 tons per year and 2.29 tons per day, respectively. Compared with the reductions of 438 tons per year and 2.76 tons per peak-day from the eGRID method, the total number from a simple emission rate method is 19 percent, 20.5 percent smaller than the reductions from eGRID method. But in eGRID method, the total NO_x emissions reductions in only non-attainment and affected counties are 208.88 tons per year and 1.28 tons per day. From this, the actual NO_x emissions reductions in non-attainment and affected counties are about 44 percent smaller than the estimated NO_x emissions reductions using simple emission rate method. In conclusion, the simple emission rate method is not a proper method if one needs to know in where and how much the NOx emissions were reduced due to electricity savings.

4.6.2.2 Comparison of the Results of This Thesis to the Results of the ESL's 2000 Report

As mentioned previously, the results in this thesis were calculated after the 2002 ESL's 2002 Annual report was submitted to the TNRCC (Haberl et al., 2002). The simulations in this thesis used version IECC1100.inp of the ESL's code-traceable DOE-2 simulations, which has used in the ESL' 2002 Annual report. The differences that in this thesis when compare to the 2002 result, are due to the followings:

1) **Peak-electricity savings**

   The ESL's 2002 report used various peak dates for each county, which were calculated by DOE-2. This thesis used one selected peak date, therefore the calculated peak-day electricity savings are different to the ESL's 2002 report.

(i.e., 1,477.74 MWh/day for the 2002 report versus 1,518.64 MWh/day for this thesis)

2) **Annual NO_x emissions reductions**

   The ESL's 2002 report used the TNRCC's published emissions rates for each PCA to calculate the annual NO_x emissions reductions. This thesis used the eGRID method. The results show that the total annual NO_x emissions reductions from the ESL's 2002 report are 417 tons per year, while the total annual NO_x emissions reductions from this thesis are 438 tons per year (ERCOT region only using eGRID).

3) **Peak-day NO_x emissions reductions**

   When calculating the peak-day NO_x emissions reductions in the ESL's 2002 report, the 20% T&D loss was not included in the peak-day electricity savings. Therefore, the calculated peak-day NO_x emissions reductions in the ESL's 2002 report are lower than the peak-day NO_x emissions reductions in this thesis (i.e., 2.09 tons per day for the ESL's 2002 report vs. 2.76 tons per day for this thesis).

4.6.3. Summary of NO_x Emissions Reduction Calculation

The NO_x emissions reductions from the electricity savings calculated using DOE-2 simulations were calculated in this section. In this procedure, the EPA's eGRID spreadsheet was used to calculate NO_x emissions reductions that were realized in the power plants of each county in Texas. The results showed that the electricity savings in a county could not guarantee the NO_x emissions reductions in the same county because the electricity used in the county was originated from several power plants that are located in several counties. In addition, the simple emission rate method which was frequently used in previous studies is not a proper method if one needs to know in where and how much the NO_x emissions were reduced due to electricity savings.

CHAPTER V

SUMMARY AND FUTURE WORK

This research has developed and demonstrated a methodology to calculate the energy savings and emissions reductions from adopting the 2000 IECC to new single family houses in non-attainment and affected counties in Texas. The literature review has covered NO_x -related problems in Texas, the relation between NO_x emissions and the electricity savings, the previous energy conservation research in the residential sector, the review of the energy code, and the previous research about the calculation of the NO_x emissions reductions. Six steps of the methodology to calculate the energy savings and NO_x emissions reductions were then proposed in Chapter III. The developed methodology includes: 1) A base case study, 2) The 2000 IECC standard house definition, 3) The projected number of the building permits in 2002, 4) The DOE-2 simulations, 5) the validation efforts, and 6) The NO_x emissions reductions calculation. This chapter discusses the summary of the methodology and the summary of the research results performed using the developed methodology.

5.1. Summary of the Methodology

As a first step of this research, the required data for the 1999 standard house for each county was collected. To begin, a county was selected from the 38 non-attainment and affected counties. Then, in order to calculate energy use before and after the code adoption, the required data and information are collected. Using these data and information, two DOE-2 building energy simulations are performed. The first is for the annual and peak day energy use consumed by new residential construction using 1999 average building characteristics. The second is for the annual and peak day energy use consumed by new residential constructions using the requirement in Chapter 4 and 5 of the 2000 IECC. The simulated energy use of the former is assumed to be the energy use of an average house before code adoption, and the energy use of the later is assumed to be the energy use of an average house after code adoption. After these calculations were performed, the annual and peak day energy difference (MWh/county) was calculated. In this calculation, the energy differences represent the energy savings from the adoption of the 2000 IECC. The calculation procedure up to this point was then repeated for all 38 counties. After the calculation of the energy savings for each of the 38 counties is completed, the calculated energy savings were classified by the Power Control Area (PCA) to determine which utility provided the electricity. After classifying the calculated energy savings by PCA, NO_x emissions reductions (lbs- NO_x /County) were calculated using the EPA's eGRID table. Finally, the total NO_x emissions reductions from the energy savings in 38 counties were calculated.

5.2. Summary of the Base Case Study

The 1999 built average building characteristics were collected from several sources to develop the baseline house as the house before code adoption. The sources used include the NAHB's Builders Report, as well as data from the Air-conditioning and Refrigeration Institute (ARI) and Gas Appliance Manufacturers Association (GAMA). The building envelope information used the NAHB's Builder Practice Survey Report, and the building systems information used the ARI and GAMA data.

The NAHB's Builder Practice Survey Report provided the detailed information for the windows, HVAC ducts, HVAC equipment, insulation, exterior wall finishes, exterior wall sheathing, roofing, average wall height, average floor area, number of stories, wall type (Structural Materials), and garage. Since the data were given for two areas of Texas (i.e., east

Texas and west Texas), the 38 non-attainment and affected counties were divided into those two areas, and the building characteristics for East Texas and West Texas were assigned to each county. From the defined 1999 building characteristics, the overall characteristics for East and West Texas are similar. The major differences between the NAHB's east and west Texas are the types of windows, and the window-to-wall ratio. For the type of windows, the house in east Texas area used both the single pane glass and the double pane glass, while the house in west Texas area used mostly double pane glass. From the major windows type, the U-value and SHGC were calculated using the ASHRAE Handbook of Fundamentals (ASHRAE, 2001). The window-to-wall ratio was calculated from the average number of window units. The calculated number shows that the window-to-wall ratio for east Texas is 15.2 % and for west Texas is 23.7 % (i.e., 16.4 units of windows for east Texas, 24.9 units of windows for west Texas)

The efficiency of the heating and cooling systems used the data from ARI and GAMA. ARI presented the Texas 1999 manufacturer's shipments for unitary products. The data shows that the major SEER was between 10 and 11 (62.2 %), between 12 and 13 (29.8 %). According to GAMA, in 1999, the AFUE of the 99.1% of the total shipments of gas furnace was 80%.

5.3. Summary of the 2000 IECC Standard House

From the review of the 2000 IECC, the required building characteristics for each county were identified. To begin, the 38 non-attainment and affected counties were assigned to corresponding climate zone from the 2000 IECC. The 2000 IECC divides the United States into climate zones by Heating Degree Day (HDD) 65^{o}F. All non-attainment and affected counties in Texas were included in climate zones 3, 4, 5 and 6.

Chapter 4 of the 2000 IECC contains the standard building design required in the 2000 IECC. The standard building design provides the input values for glazing systems, heat storage(thermal mass), building thermal envelope-surface area and volume, heating and cooling controls, internal heat gain, site weather data, forced-air distribution systems loss factors, air infiltration, and foundation wall insulation. Those input values were used to develop the standard input file for DOE-2 simulations.

Chapter 5 of the 2000 IECC presents the prescriptive tables that define the maximum U-value of windows and the minimum R-value of exterior wall, ceiling and foundations according to the window-to-wall ration and the climate zones. In the 2000 IECC, the Solar Heat Gain Coefficient (SHGC), inclusive of framed sash and glazing area, of the glazing systems should be 0.4 for HDD<3,500 and 0.68 for HDD$\geq$ 3,500. Since the HDDs for all non-attainment and affected counties are less than 3,500, the SHCG is therefore 0.4.

The input values from the proper prescriptive table for each county were used to input parameter values into the standard DOE-2 input file. Chapter 5 also provides the minimum equipment performance for several heating and cooling system. When defining the building characteristics for IECC house in each county, the 2000 IECC building requirements were compared against the building characteristics of the 1999 standard house. If the building characteristics of the 1999 standard house are superior to the building requirements of the 2000 IECC in terms of building thermal performance, then the building characteristics of the 1999 standard house were used for the 2000 IECC standard house (i.e., no savings credit was given). From the comparison between the base case house and the IECC house, the major difference between those two house was the window U-value and the SHGC. Except the windows properties, most of the other building characteristics of the 1999 standard house from NAHB's reports already meet or exceed the requirements of the 2000 IECC. Therefore, the largest expected energy savings due to the code adoption is the upgraded windows in the code compliant house.

5.4. Summary of the DOE-2 Simulations

To calculate the annual and peak day energy savings due to the code adoption, several simulations were performed. The energy savings were calculated by subtracting the simulated energy use of the IECC standard house from the simulated energy use of the 1999 house. Since only the electricity savings were used to calculate the NOx emissions reductions from the utility power plants that provided the electricity, the annual and peak day electricity savings were presented. The results show that the total annual electricity savings in the affected counties are 80,576.50 MWh, the total annual electricity saving in the non-attainment counties was 167,057.10 MWh, and the total annual electricity saving in the non-attainment and affected counties was 247,633.60MWh. The average county-wide annual electricity use reductions from the code adoption are 11 % to 20%. The most savings were realized in Collin County with 213.92 MWh. To no surprise, among the top ten counties with the most savings, seven counties are from non-attainment counties. The results also showed that the total peak day electricity savings in affected counties are 439.92 MWh, and the total annual electricity savings in non-attainment counties are 1,518.64 MWh. The peak day electricity use is reduced about 11% to 26% from the code adoption. Finally, the results show that if the average daily electricity savings by county was calculated by dividing the annual electricity savings by 365, the peak day electricity savings is approximately the two times as the average day electricity savings.

5.5. Summary of Demonstration of Validation Procedure

In this step of the research, three tasks for validation were performed. The validation includes the crosscheck from several previous studies, the onsite survey, and a utility billing analysis. The crosscheck from several previous studies was conducted to verify the defined

1999 standard building characteristics in the base case study in this research, and to compare the calculated energy savings from code adoption. For the crosscheck of the 1999 building characteristics, four similar studies (Henwood Energy Service (2000), Brown et al. (1998), Schiller and Associates (2001), and Meisegeier et al. (2002)) were reviewed, and the defined building characteristics from those studies were identified. The identified characteristics include the total floor area, the insulation value for wall, ceiling and foundation, the U-value and the SHGC of windows, and the efficiency of the cooling and the heating systems. According to the results of the crosscheck, the overall building characteristics for building envelope from previous studies showed a similar trends to the 1999 standard building characteristics defined in this study. All four studies defined the average SEER for air conditioner is 10 and the AFUE for gas furnace is 78 %, which is lower than the value GAMA (11 SEER) and ARI (80% AFUE) provided.

The crosscheck of the energy savings was conducted to verify the energy savings calculated in this research. Although the building characteristics of the base case house and energy efficient house from the two studies are different to the characteristics from this research, the annual electricity savings can be compared each other to show the overall electricity savings from the code or energy efficient package adoption. The results of the crosscheck show that the overall annual electricity savings by square foot (kWh/ ft^2-yr) from previous studies are from 0.6 to 2.0 kWh/ft^2-yr, while the annual electricity savings by square foot (kWh/ft2-yr) from this research were 0.64 kWh/ft^2-yr, and the peak day savings by square foot (W/ft^2) were 3.9 W/ft^2.

For the onsite survey, a house under construction in Bryan, Texas was chosen. From visiting a case study house, the building characteristics of the house were collected. The collected characteristics then were compared to the requirements from the 2000 IECC. As another compliance check, the whole building performance check was performed using the standard input and DOE-2 simulation program. The results show that the building elements of the case study house meet or exceed the requirements of the 2000 IECC. Specially, the U-value and the SHGC of the house is much lower than the maximum requirements of the 2000 IECC. The results of the whole-building performance check also showed that the annual energy use (electricity + natural gas) of the case house is 7.8 percent smaller than the energy use of the 2000 IECC house.

Another case study house in College Station, Texas was chosen for the demonstration of the procedure for the validation of the calculated energy savings using utility billing analysis. The utility bills during 2000 and 2001 from a case study house were obtained, and the energy use was analyzed using a three parameter change point analysis. The results of the utility bills analysis were compared to the results of the DOE-2 simulated energy savings. Although two years of data from one case study house was used instead of two houses (i.e., on before and after code adoption), the procedure and analysis method were demonstrated.

5.6. Summary of the NOx Emissions Reduction Calculation

The NO_x emissions reductions from the electricity savings calculated using DOE-2 simulations were calculated. In this procedure, the EPA's eGRID spreadsheet was used to calculate NO_x emissions that were reduced in the power plants of each county in Texas. The results showed that the NOx emissions reductions due to the estimated electricity savings in 38 counties results in an annual 438 tons NOx emissions reductions in 48 counties that have power plants. Of those 48 counties, 17 counties were included in non-attainment or affected counties, and 31 counties were included in other counties. This shows that the electricity savings in a county does not guarantee the NO_x emissions reductions in the same county because the electricity used in the county originates from power plants that are located in several different counties. The calculated NOx emissions reductions using eGRID method were compared to the calculated NOx emissions reductions using the simple emission rate method which were frequently used in previous studies. The results show that the NO_x emissions reductions in only the non-attainment and affected counties, which were calculated using the eGRID method are about 44 percent smaller than the NO_x emissions reductions calculated using simple emission rate method. This shows that the simple emission rate method is not the most accurate method to calculate the NO_x emissions reductions due to the electricity savings. .

5.7. Future Work

This section discusses the future work concerning to the calculation of the NO_x emissions reductions for all NERC regions, an improved method for the calculation of peak day electricity savings, the refined modeling of the code compliant house, and the expansion of the target buildings to multi-family houses and commercial buildings, etc.

5.7.1. Calculation of the NO_x Emissions Reductions for All NERC Regions

As mentioned in Chapter III, the EPA’s eGRID table used in this thesis was developed only for the ERCOT region. Therefore, the counties included in the other NERC regions such as SERC, WSCC and SPP were excluded in the calculation. For future work, the same eGRID tables for SERC, WSCC and SPP regions will need to be developed, and the total NO_x emissions reductions from the electricity savings for all 38 non-attainment and affected counties will need to be calculated. In 2003, the Texas State legislature added (3) new counties (i.e., Henderson, Hood, and Hunt) to the list of affected counties. Therefore, the NOx emissions reductions calculation will need to be expanded to include these new counties.

5.7.2. Improved Method for the Calculation of Peak-day Electricity Savings

For future work, an improved method will be developed to calculate a peak-day electricity savings that is more representative of an ozone episode day. For target counties, actual ozone episode day weather data for peak day period will be obtained. Using this weather data, the peak day electricity savings for each county will be simulated using DOE-2 across all counties. The results from this simulation will more accurately represent the actual peak day of the counties instead of weather data from the TMY2 weather file.

5.7.3. Residential Model

In this thesis, a code-traceable DOE-2 input file was used that include several assumptions and simplified methods to model the standard single family house. This limitations were described in Chapter II of this thesis. For future work, several updates are proposed here.

1) Multi-Story, Single Family Houses

This study is limited to one-story single family residential housing in the non-attainment and affected counties in Texas. For future work, the DOE-2 input file will need to be updated for two and three-story single family houses, that can have slab-on-grade or crawlspaces.

2) Various Shapes of Houses

The standard house simulated in this thesis is a square or rectangular shape house. For future work, various shapes of houses will need to be developed including L-shape, U-shape, etc.

3) Use of Solar Heat Gain Coefficient (SHGC) instead of Shading Coefficient (SC)

As described in Chapter III, in this thesis, the window's SHGC was converted to the Shading Coefficient (SC) to be entered into the DOE-2 simulations. Although the SC method is convenient for conceptual design of windows, for more accurate simulation of the angular dependence and conduction of windows, the window 5 library will need to be used to input the window properties in the DOE-2 simulations.

4) Different Systems

In this thesis, an electric air conditioning system, natural gas furnace, and natural gas water heater were assumed to be installed in all new single family houses in the non-attainment and affected counties in Texas. For future work, different systems will need to be added in the DOE-2 input file, which will allow the user will be able to choose the different set of fuels for each system. For example, 1) electricity can be chosen for cooling systems, 2) natural gas, electricity or heat pump can be chosen for heating system, and 3) natural gas or electricity can be chosen for domestic water heater.

5) Thermal Mass

In this thesis, the thermal mass effects were estimated using a fixed floor weight as defined by Chapter 4 of the 2000 IECC. For future work, instead of using the U-value of the wall and roof, a refined DOE-2 input file will need to be developed that will use real materials and layers of the structure to calculate the thermal mass effects.

6) Use of U-EFFECTIVE for UNDERGROUND-FLOOR

For the calculation of the underground surface heat transfer in this thesis, the U-value of the floor surface was used in this thesis. Since the DOE-2 program calculates the thermal mass of the underground surfaces, according to the use of custom weighting factors, by multiplying the U-value with the surface area and the temperature differences between zone temperature and ground temperature, the results of heat transfer can be overcalculated, when using TMY2 weather data. For more accurate calculation, Winkelmann (1998) reported the corrections and bug fixes for calculating the heat transfer through underground surfaces in DOE-2.1e. From this report, he suggested the use of U-EFFECTIVE procedure for determine the underground surface construction using the perimeter conduction factor. Therefore, the DOE-2 input file used in this thesis will need to be refined using the appropriate U-EFFECTIVE value to correct the calculation of the underground surface heat transfer.

7) Duct Models

The DOE-2 input file used in this thesis did not consider the detailed behavior of forced air distribution system including duct loss. Therefore, a refined DOE-2 input file will need to be developed to model the detailed behavior of forced air distribution system to calculate more accurate energy use in residential buildings.

8) Shadings

In this thesis, interior or exterior shading was not considered in the DOE-2 simulation. The 2000 IECC defined that the values used for interior shadings shall be 0.70 in summer, and 0.90 in winter. For future work, the values for interior shadings will need to be added the DOE-2 input file to simulate the prescribed effects of the shadings.

9) Air Infiltration

As mentioned in Chapter IV, in this thesis, the air infiltration rate (ACH) was fixed 0.57 for all counties. For future work, the different air infiltration rate by county will be applied for each simulation. The corresponding air infiltration rate will be calculated using following equation which is presented in ASHRAE 136 (ASHRAE, 1993).

$$ACH = Normalized\ Leakage\ X\ W$$

where: Normalized Leakage = 0.57, W = Weather Factors

10) Above Code Energy Savings

Although the purpose of this thesis was limited to the calculation of the energy savings from the code adoption, the potential energy savings from the adoption of the building components above code will need to be calculated for future work. Possible adoptions will include the higher R-values of wall, roof, higher U-value and lower SHGC of windows, and higher SEER, AFUE, etc.

5.7.4. Expansion of the Target Building Types

This thesis targeted new single family houses to calculate the energy savings and the NO_x emissions reductions from the code adoption. For future work, the energy savings from multifamily houses, commercial buildings, renewable energy technologies, and remodeling of the existing buildings will need to be accomplished to estimate the total county-wide annual and peak-day NO_x emissions reductions in power plants.

5.7.4.1. Multifamily Houses

In general, the overall procedure to calculate the energy savings for multi family houses is identical to the procedure for single family houses. To calculate the 1999 standard multifamily house, the most common type of multi family houses (i.e., 1, 2, or 3 story, the number of units in a building, etc.) and the average building characteristics will be identified from the NAHB's Builder Practices Survey and several other sources. The building permit activities for multifamily houses will be also obtained from RECenter at TAMU and U.S. Census Bureau. The remainder of the procedure is the same as the procedure for single family houses.

5.7.4.2. Commercial Buildings

The overall procedure to calculate the energy savings for commercial buildings are also similar to the procedure for single family houses. For each county, 1999 commercial building characteristics will need to be ascertained from several sources including the Commercial Buildings Energy Consumption Survey (CBECS). The Commercial Buildings Energy Consumption Survey (CBECS) is a national-level sample survey of commercial buildings and their energy suppliers conducted quadrennially by the Energy Information Administration (EIA). The commercial building characteristics will need to be defined according to the various types of commercial buildings classified in CBECS. Table 5.1 shows the list of the commercial building types from CBECS. The code-compliant commercial building characteristics will need to be ascertained from Chapters 4, 7, and 8 of the 2000 IECC. Using simulation, then, these characteristics are entered into the DOE-2 simulation to calculate the annual and peak day electricity use of two representative buildings, one representing the commercial building with the average 1999 characteristics, and one representing the appropriate characteristics from the 2000 IECC. The annual and peak day electricity savings will then be calculated by subtracting the annual and peak day electricity use of the code-compliant buildings from the electricity use of the 1999 standard buildings.

Table 5.1 – List of commercial building types from CBECS

List of commercial building types from CBECS
Education
Food Sales
Food Service
Health Care
Lodging
Mercantile and Service
Office
Public Assembly
Public Order and Safety
Religious Worship
Warehouse and Storage
Other
Vacant

5.7.4.3. Renewable Energy Technologies

The 2000 IECC addressed the application of renewable energy systems in buildings. For future work, the energy savings from the installation of renewable energy systems in buildings will be calculated. These renewable energy systems include solar thermal systems and solar photovoltaic systems. To calculate the energy savings, characteristics about each system will need to be collected, including: the type of system, area of the aperture, orientation, tilt, systems characteristics, etc. These characteristics will then be input into either the FCHART or PVFCHART Program, depending upon system type, and the annual energy use for the energy savings from these activities will be used to track the installation of projects that utilize renewables, according to the procedures in the 2000 IECC. Total county-wide energy use is the cumulative total energy production of all systems installed in a county.

5.7.4.4. Remodeling of the Existing Buildings

The 2000 IECC addresses additions, alterations, renovations and repairs to a building envelope, mechanical, service water-heating, electrical distribution or illumination systems. For future work, a procedure to calculate the energy savings from these activities will need to be developed and applied. Although the procedure will be similar to the procedure used for new construction, several different procedures can be applied for existing constructions, including:

- Tracking remodeling permit activity.
- Tracking the activity by the type of remodeling such as building envelope, mechanical, service water-heating, electrical distribution or illumination systems, etc.

The energy savings from this procedure will then need to be added to the energy savings from new constructions, and then the total energy savings (i.e., electricity savings) will be used to calculate the county-wide NO_x emissions reductions from power plants.

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APPENDIX A

RESIDENTIAL SINGLE FAMILY HOUSE ONSITE SURVEY CHECKLIST

This appendix presents the onsite survey checklist that was used to collect house characteristics of the case study building. These building characteristics were used to validate the building characteristics for the IECC house defined in Chapter IV of this research. The information required to be input in this checklist includes the general building information, the building envelope information, the mechanical system information, etc. The checklist is composed of several sections and each section is described by the section title.

After completing the check list from the onsite visit, the obtained building characteristics were compared to the requirements of the 2000 IECC, and used to be input into the standard DOE-2 input file for simulation. The simulated energy use was compared to the energy use of the simulated IECC standard house for compliance check.

SENATE BILL 5:
RESIDENTIAL SINGLE FAMILY HOUSE ONSITE SURVEY CHECKLIST

Piljae Im
Jeff S. Haberl, Ph.D., P.E.
Energy Systems Laboratory (ESL)
Texas A&M University System

March, 2003

ENERGY SYSTEMS LABORATORY

Texas Engineering Experiment Station
Texas A&M University System

ONSITE SURVEY CHECKLIST

AUDITOR NAME PILJAE IM

DATE SURVEYED March 20, 2003

1. GENERAL INFORMATION

1.1. Address: 1101 Faith Circle

1.2. City/State/Zip: Bryan, TX.

1.3. Building Permit Date: Month N/A Year N/A

1.4. Expected Completion Date: Month N/A Year N/A

1.5. Builder Name: Habitat for Humanity

1.6. Builder Phone Number: N/A

1.7. Electricity Provider: N/A

1.8. Natural Gas Provider: N/A

2. BUILDING INFORMATION

2.1. Number of Floors: ✓1-One 2-Two 3-Three 4-Over Four

2.2. Total Conditioned Area: 1,076 Square Feet

2.3. Number of Bedrooms: 3

2.4. Floor/Foundation Type: 1. Slab on Grade

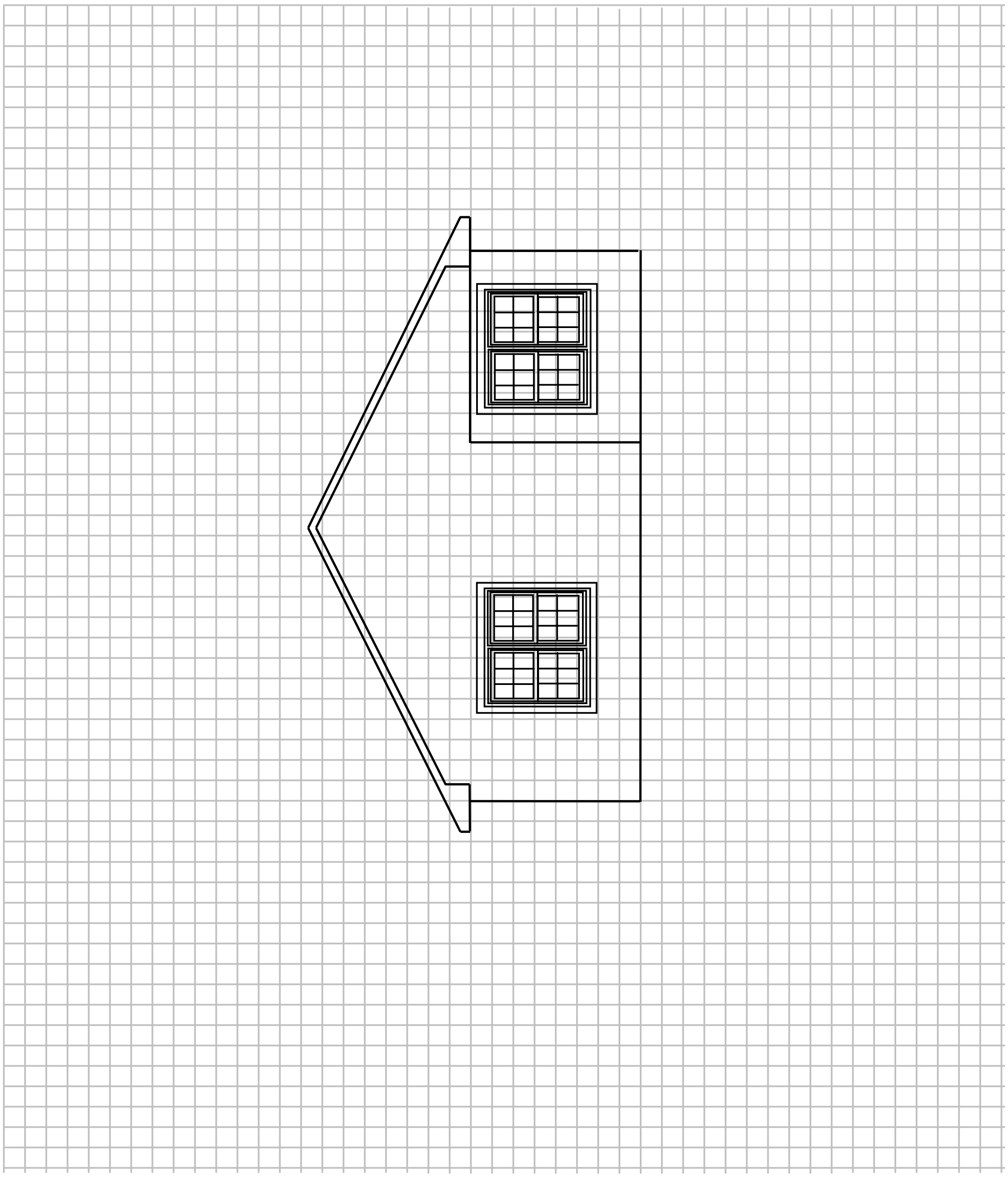
Floor #	1	2	3	4
Floor Area	1,076 ft^2	_	_	_
Wall Height	8ft	_	_	_

FOUNDATION
1. Slab on Grade
2. Vented Crawl
3. Unvented Crawl Space
4. Conditioned Basement
5. Unconditioned Basement
6. More than one type

3A. ENVELOPE – WALL, WINDOWS, AND DOOR

3A.1. Orientation Southwest

3A.2. Elevation



3A.3. Exterior Wall

- Length of wall: 27 Feet
- Average height of wall: 8 Feet
- Cavity wall insulation R-value: R - 13
- Cavity wall insulation thickness in inches: 3.5 Inches
- Continuous wall insulation R-value: R - N/A
- Continuous wall insulation thickness: N/A Inches
- Stud spacing: 16 in.
- Exterior wall color (1-light 2-med 3-dark): N/A

3A.4. Windows

a. Window #1
   - Height: 5 Feet
   - Width: 3x2 Feet
   - Shade (Projection Factor): N/A
   - Glazing Type: Double with Low-E
   - Frame Type: Vinyl
   - Window Screen (1-Bug 2-Solar 3-None): 3 (not yet installed)
   - U-value: 0.40
   - SHGC: 0.28

b. Window #2
   - Height: 5 Feet
   - Width: 3x2 Feet
   - Shade (Projection Factor): 0.9
   - Glazing Type: Double with Low-E
   - Frame Type: Vinyl
   - Window Screen (1-Bug 2-Solar 3-None): 3 (not yet installed)
   - U-value: 0.40
   - SHGC: 0.28

c. Window #3
   - Height: N/A Feet
   - Width: N/A Feet
   - Shade (Projection Factor): N/A

- Glazing Type N/A
- Frame Type N/A
- Window Screen (1-Bug 2-Solar 3-None) N/A
- U-value N/A
- SHGC N/A

d. Window #4

- Height N/A Feet
- Width N/A Feet
- Shade (Projection Factor) N/A
- Glazing Type N/A
- Frame Type N/A
- Window Screen (1-Bug 2-Solar 3-None) N/A
- U-value N/A
- SHGC N/A

e. Window #5

- Height N/A Feet
- Width N/A Feet
- Shade (Projection Factor) N/A
- Glazing Type N/A
- Frame Type N/A
- Window Screen (1-Bug 2-Solar 3-None) N/A
- U-value N/A
- SHGC N/A

3A.5. Door

a. Door #1

- Height N/A Feet
- Width N/A Feet
- Door Type N/A
- Door Glazing Type N/A
- Door Glazing SHGC N/A
- Door Glazing U-value N/A

- Door Glazing Area: N/A
- Door U-value: N/A

b. Door #2

- Height: N/A Feet
- Width: N/A Feet
- Door Type: N/A
- U-value: N/A

FRAME TYPE
1. Metal
2. Metal with break
3. Wood
4. Vinyl
5. Fiberglass

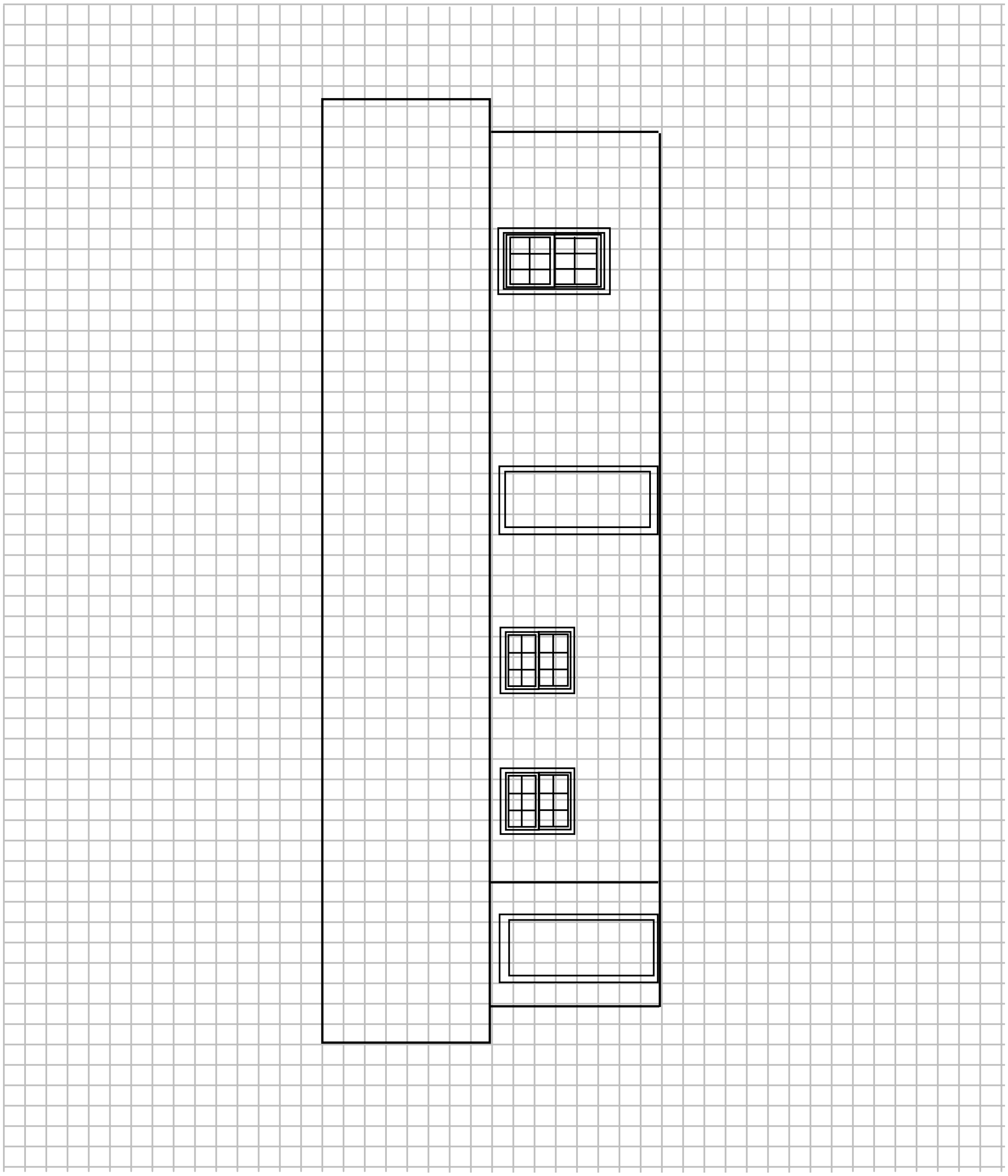
GLAZING TYPE
1.Single
2. Single with storm
3. Double
4. Triple
5. Double with Low-E
6. Double with Low-E and Argon
7. Heat Mirror 88
8. Double HM88 with Krypton
9. Double Low E with Krypton
10. Triple Low E with Argon
11. Triple Low E with Krypton
12. Other

DOOR TYPE
1. Steel with insulated core
2. Wood

3B. ENVELOPE – WALL, WINDOWS, AND DOOR

3B.1. Orientation Southeast

3B.2. Elevation



3B.3. Exterior Wall

- Length of wall: 42 Feet
- Average height of wall: 8 Feet
- Cavity wall insulation R-value: R - 13
- Cavity wall insulation thickness in inches: 3.5 Inches
- Continuous wall insulation R-value: R - N/A
- Continuous wall insulation thickness: N/A Inches
- Stud spacing: 16 in.
- Exterior wall color (1-light 2-med 3-dark): N/A

3B.4. Windows

a. Window #1
   - Height: 3 Feet
   - Width: 3 Feet
   - Shade (Projection Factor): N/A
   - Glazing Type: Double with Low-E
   - Frame Type: Vinyl
   - Window Screen (1-Bug 2-Solar 3-None): 3 (not yet installed)
   - U-value: 0.40
   - SHGC: 0.28

b. Window #2
   - Height: 3 Feet
   - Width: 3 Feet
   - Shade (Projection Factor): 0.9
   - Glazing Type: Double with Low-E
   - Frame Type: Vinyl
   - Window Screen (1-Bug 2-Solar 3-None): 3 (not yet installed)
   - U-value: 0.40
   - SHGC: 0.28

c. Window #3
   - Height: 6 Feet
   - Width: 3 Feet
   - Shade (Projection Factor): N/A

- Glazing Type: Double with Low-E
- Frame Type: Vinyl
- Window Screen (1-Bug 2-Solar 3-None): 3
- U-value: 0.4
- SHGC: 0.28

d. Window #4

- Height: N/A Feet
- Width: N/A Feet
- Shade (Projection Factor): N/A
- Glazing Type: N/A
- Frame Type: N/A
- Window Screen (1-Bug 2-Solar 3-None): N/A
- U-value: N/A
- SHGC: N/A

e. Window #5

- Height: N/A Feet
- Width: N/A Feet
- Shade (Projection Factor): N/A
- Glazing Type: N/A
- Frame Type: N/A
- Window Screen (1-Bug 2-Solar 3-None): N/A
- U-value: N/A
- SHGC: N/A

3B.5. Door

a. Door #1

- Height: 6.7 Feet
- Width: 3 Feet
- Door Type: Steel with insulated core
- Door Glazing Type: N/A
- Door Glazing SHGC: N/A
- Door Glazing U-value: N/A

- Door Glazing Area N/A
- Door U-value 0.35

b. Door #2

- Height 6.7 Feet
- Width 3 Feet
- Door Type Steel with insulated core
- U-value 0.35

FRAME TYPE
1. Metal
2. Metal with break
3. Wood
4. Vinyl
5. Fiberglass

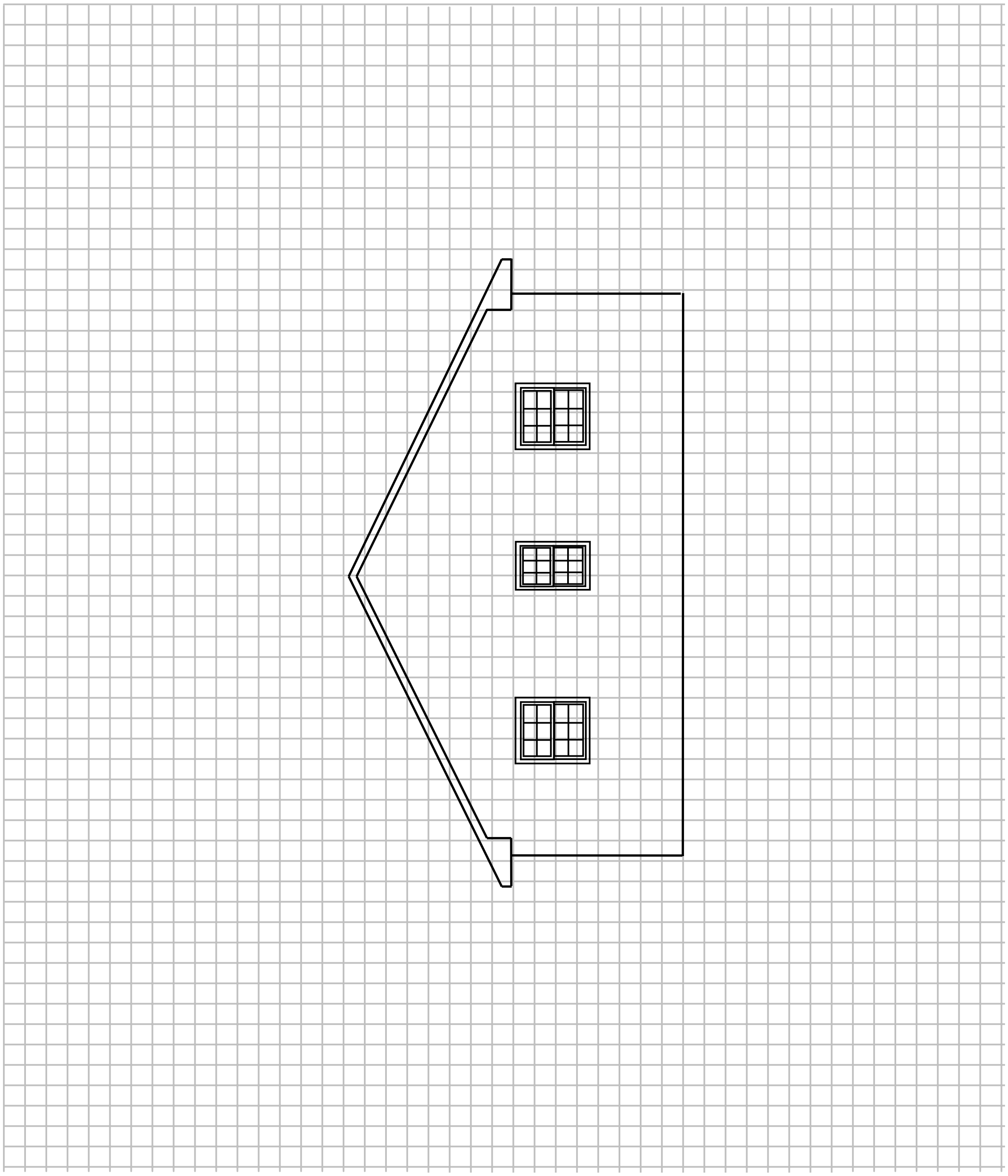
GLAZING TYPE
1.Single
2. Single with storm
3. Double
4. Triple
5. Double with Low-E
6. Double with Low-E and Argon
7. Heat Mirror 88
8. Double HM88 with Krypton
9. Double Low E with Krypton
10. Triple Low E with Argon
11. Triple Low E with Krypton
12. Other

DOOR TYPE
1. Steel with insulated core
2. Wood

3C. ENVELOPE – WALL, WINDOWS, AND DOOR

3C.1. Orientation Northeast

3C.2. Elevation



3C.3. Exterior Wall

- Length of wall — 27 Feet
- Average height of wall — 8 Feet
- Cavity wall insulation R-value — R - 13
- Cavity wall insulation thickness in inches — 3.5 Inches
- Continuous wall insulation R-value — R - N/A
- Continuous wall insulation thickness — N/A Inches
- Stud spacing — 16 in.
- Exterior wall color (1-light 2-med 3-dark) — N/A

3C.4. Windows

a. Window #1
   - Height — 3 Feet
   - Width — 3 Feet
   - Shade (Projection Factor) — N/A
   - Glazing Type — Double with Low-E
   - Frame Type — Vinyl
   - Window Screen (1-Bug 2-Solar 3-None) — 3 (not yet installed)
   - U-value — 0.40
   - SHGC — 0.28

b. Window #2
   - Height — 2 Feet
   - Width — 3 Feet
   - Shade (Projection Factor) — 0.9
   - Glazing Type — Double with Low-E
   - Frame Type — Vinyl
   - Window Screen (1-Bug 2-Solar 3-None) — 3 (not yet installed)
   - U-value — 0.40
   - SHGC — 0.28

c. Window #3
   - Height — 3 Feet
   - Width — 3 Feet
   - Shade (Projection Factor) — N/A

- Glazing Type — Double with Low-E
- Frame Type — Vinyl
- Window Screen (1-Bug 2-Solar 3-None) — 3
- U-value — 0.4
- SHGC — 0.28

d. Window #4

- Height — N/A Feet
- Width — N/A Feet
- Shade (Projection Factor) — N/A
- Glazing Type — N/A
- Frame Type — N/A
- Window Screen (1-Bug 2-Solar 3-None) — N/A
- U-value — N/A
- SHGC — N/A

e. Window #5

- Height — N/A Feet
- Width — N/A Feet
- Shade (Projection Factor) — N/A
- Glazing Type — N/A
- Frame Type — N/A
- Window Screen (1-Bug 2-Solar 3-None) — N/A
- U-value — N/A
- SHGC — N/A

3C.5. Door

a. Door #1

- Height — N/A Feet
- Width — N/A Feet
- Door Type — N/A
- Door Glazing Type — N/A
- Door Glazing SHGC — N/A
- Door Glazing U-value — N/A

- Door Glazing Area N/A
- Door U-value N/A

b. Door #2

- Height N/A Feet
- Width N/A Feet
- Door Type N/A
- U-value N/A

FRAME TYPE
1. Metal
2. Metal with break
3. Wood
4. Vinyl
5. Fiberglass

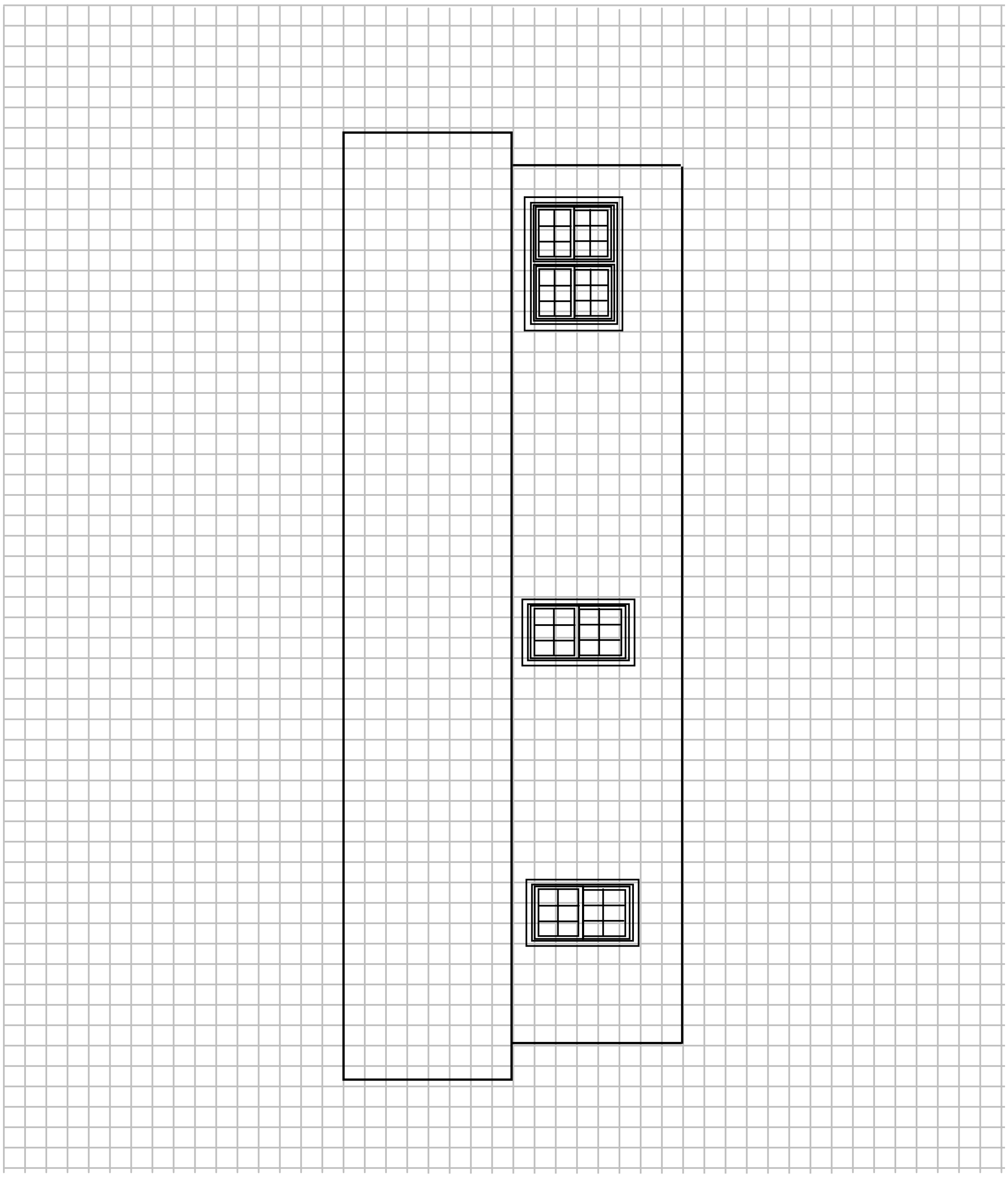
GLAZING TYPE
1.Single
2. Single with storm
3. Double
4. Triple
5. Double with Low-E
6. Double with Low-E and Argon
7. Heat Mirror 88
8. Double HM88 with Krypton
9. Double Low E with Krypton
10. Triple Low E with Argon
11. Triple Low E with Krypton
12. Other

DOOR TYPE
1. Steel with insulated core
2. Wood

3D. ENVELOPE – WALL, WINDOWS, AND DOOR

3D.1. Orientation Northwest

3D.2. Elevation



3D.3. Exterior Wall

- Length of wall: 42 Feet
- Average height of wall: 8 Feet
- Cavity wall insulation R-value: R - 13
- Cavity wall insulation thickness in inches: 3.5 Inches
- Continuous wall insulation R-value: R - N/A
- Continuous wall insulation thickness: N/A Inches
- Stud spacing: 16 in.
- Exterior wall color (1-light 2-med 3-dark): N/A

3D.4. Windows

a. Window #1

- Height: 6 Feet
- Width: 3 Feet
- Shade (Projection Factor): N/A
- Glazing Type: Double with Low-E
- Frame Type: Vinyl
- Window Screen (1-Bug 2-Solar 3-None): 3 (not yet installed)
- U-value: 0.40
- SHGC: 0.28

b. Window #2

- Height: 6 Feet
- Width: 3 Feet
- Shade (Projection Factor): N/A
- Glazing Type: Double with Low-E
- Frame Type: Vinyl
- Window Screen (1-Bug 2-Solar 3-None): 3 (not yet installed)
- U-value: 0.40
- SHGC: 0.28

c. Window #3

- Height: 5 Feet
- Width: 3x2 Feet
- Shade (Projection Factor): N/A

- Glazing Type: Double with Low-E
- Frame Type: Vinyl
- Window Screen (1-Bug 2-Solar 3-None): 3
- U-value: 0.4
- SHGC: 0.28

d. Window #4

- Height: N/A Feet
- Width: N/A Feet
- Shade (Projection Factor): N/A
- Glazing Type: N/A
- Frame Type: N/A
- Window Screen (1-Bug 2-Solar 3-None): N/A
- U-value: N/A
- SHGC: N/A

e. Window #5

- Height: N/A Feet
- Width: N/A Feet
- Shade (Projection Factor): N/A
- Glazing Type: N/A
- Frame Type: N/A
- Window Screen (1-Bug 2-Solar 3-None): N/A
- U-value: N/A
- SHGC: N/A

3D.5. Door

a. Door #1

- Height: N/A Feet
- Width: N/A Feet
- Door Type: N/A
- Door Glazing Type: N/A
- Door Glazing SHGC: N/A
- Door Glazing U-value: N/A

- Door Glazing Area: N/A
- Door U-value: N/A

b. Door #2

- Height: N/A Feet
- Width: N/A Feet
- Door Type: N/A
- U-value: N/A

FRAME TYPE
1. Metal
2. Metal with break
3. Wood
4. Vinyl
5. Fiberglass

GLAZING TYPE
1. Single
2. Single with storm
3. Double
4. Triple
5. Double with Low-E
6. Double with Low-E and Argon
7. Heat Mirror 88
8. Double HM88 with Krypton
9. Double Low E with Krypton
10. Triple Low E with Argon
11. Triple Low E with Krypton
12. Other

DOOR TYPE
1. Steel with insulated core
2. Wood

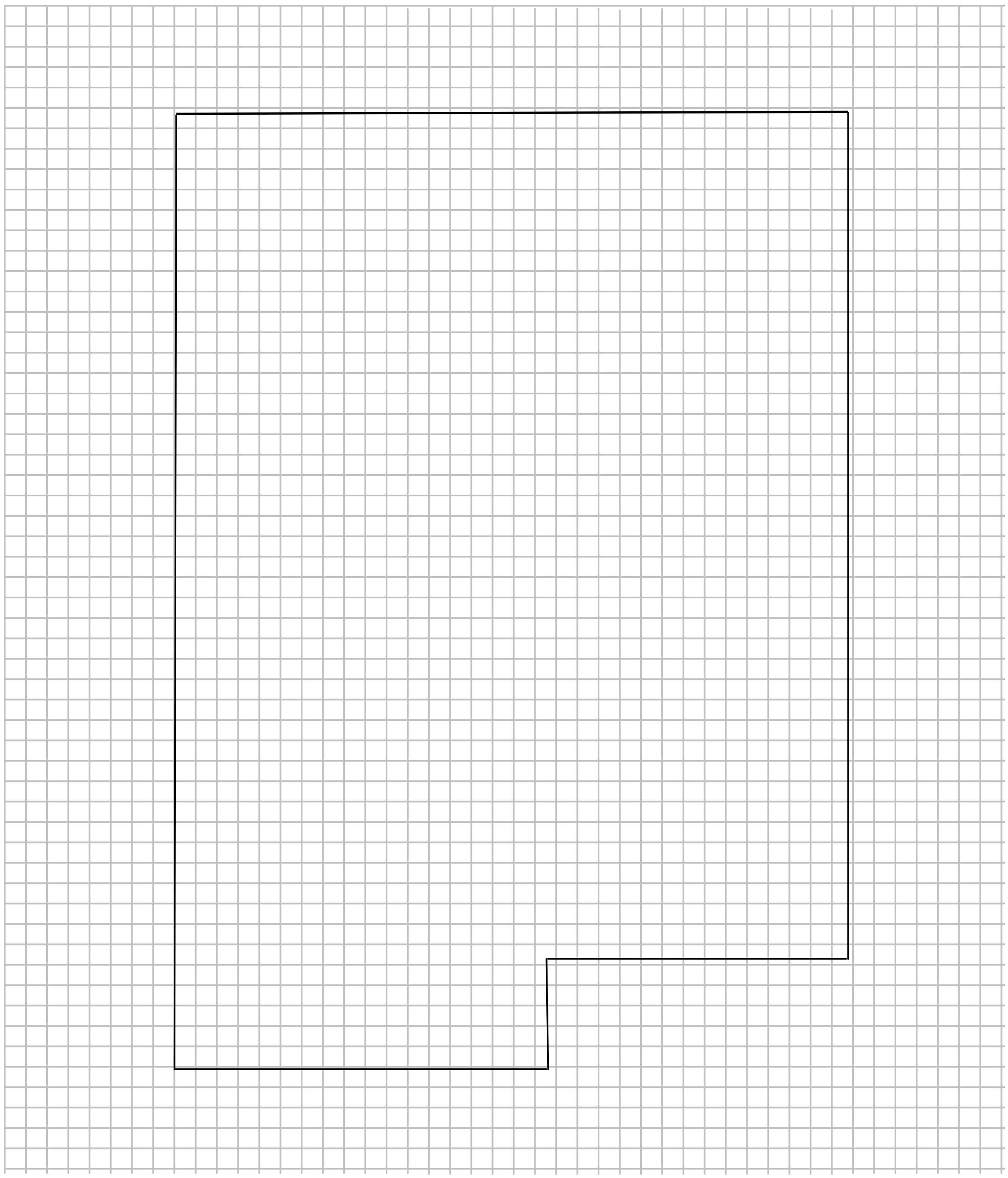
FRAME TYPE
1. Metal
2. Metal with break
3. Wood
4. Vinyl
5. Fiberglass

GLAZING TYPE
1. Single
2. Single with storm
3. Double
4. Triple
5. Double with Low-E
6. Double with Low-E and Argon
7. Heat Mirror 88
8. Double HM88 with Krypton
9. Double Low E with Krypton
10. Triple Low E with Argon
11. Triple Low E with Krypton
12. Other

DOOR TYPE
1. Steel with insulated core
2. Wood

4. ENVELOPE – FLOOR

4.1. Plan

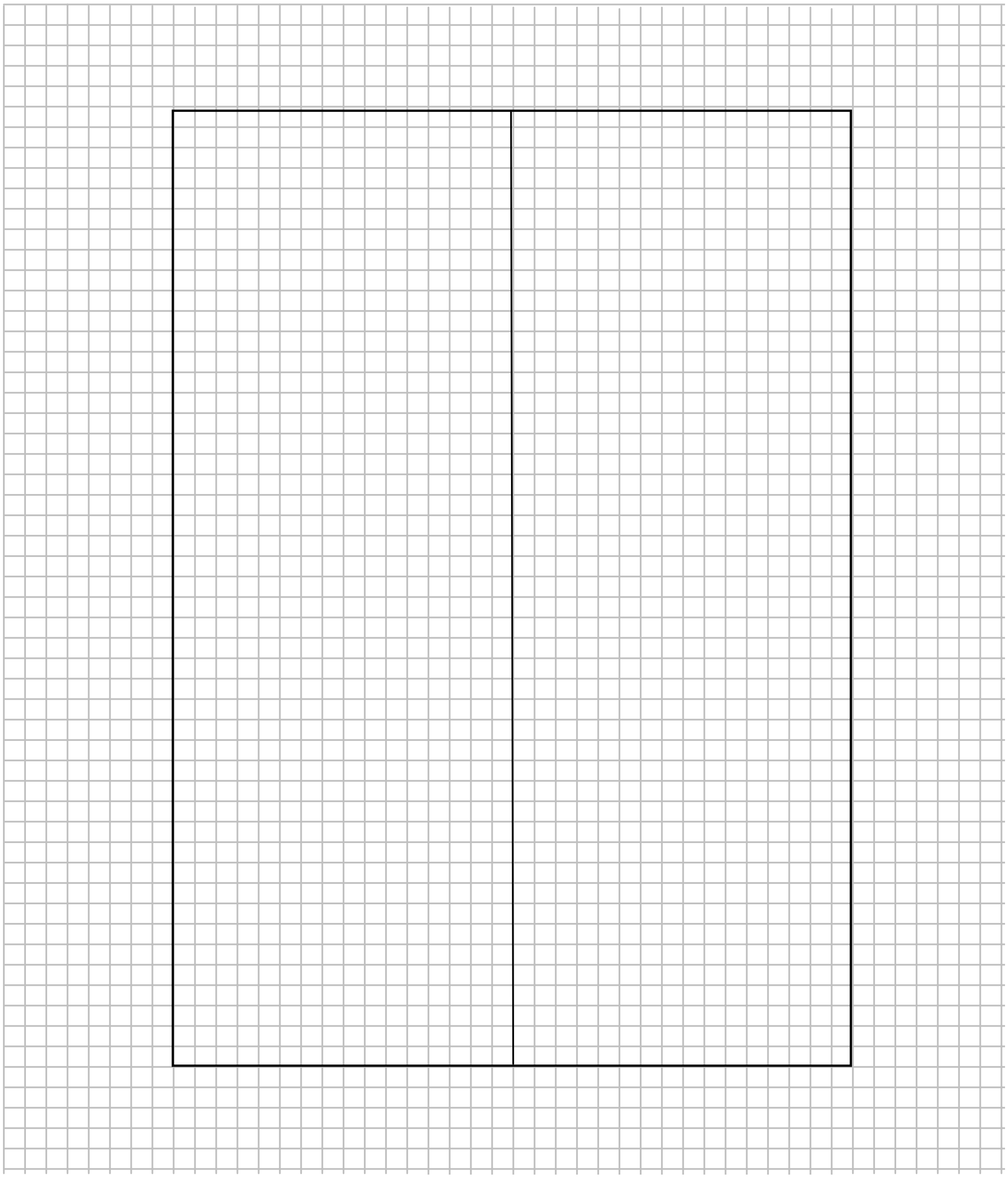


4.2. Type of Floor/foundation	Slab on Grade
4.3. Floor area	1,076 ft^2
4.4. Total perimeter	138 ft
4.5. Perimeter R-value	0
4.6. Depth below grade in feet	N/A
4.7. Insulation to top of slab? (1- yes 2-No 99 -don't know)	2
4.8. Floor covering	N/A

FOUNDATION
1. Slab on Grade
2. Vented Crawl
3. Unvented Crawl Space
4. Conditioned Basement
5. Unconditioned Basement
6. More than one type

5. ENVELOPE – CEILING/ROOF

5.1. Plan



5.2. Gross area	1,134ft^2
5.3. Ceiling type	Ceiling with attic above
5.4. Ceiling R-value	R-26
5.5. Roof Color (1-light 2-medium 3-dark)	2

CEILING TYPE
1. Ceiling with attic above
2. Cathedral ceiling / no attic
3. Flat roof

6. HVAC DATA – HEATING

6.1. Fuel (See below)	Gas
6.2. System Type (See below)	Force Air
6.3. Manufacturer	HEIL (NTCG Gas Furnace)
6.4. Model Number	N/A
6.5. Serial Number	N/A
6.6. System location (See below)	Unconditioned Space

FUEL	**SYSTEM TYPE**	**SYSTEM LOCATION**
1. Oil	1. Forced Air	1. Conditioned Space
2. Gas	2. Hot Water	2. Unconditioned Space
3. Propane	3. Steam	
4. Electric	4. Electric Baseboard	
5. Wood/Coal	5. Electric Radiant	
6. Other	6. Air to Air Heat Pump	
	7. Ground Source Heat Pump	
	8. Other	

7. HVAC DATA –COOLING

7.1. Manufacturer	HEIL
7.2. Model Number	HAC224AKA4
7.3. Serial Number	L022920519
7.4. System location	Unconditioned Space

SYSTEM LOCATION
1. Conditioned Space
2. Unconditioned Space

8. DUCT DATA

8.1. Duct location	Attic
8.2. Duct diameter	6 in.
8.3. Duct type	Round Flexible
8.4. Duct insulation R-value	R-8
8.5. Duct leakage	N/A

DUCT TYPE
1. Metal Duct
2. Flexible Duct

DUCT LOCATION
1. Attic
2. Crawl Space
3. Unconditioned Basement

9. DOMESTIC HOT WATER

9.1. Fuel (See below)	Gas
9.2. Type (See below)	Conventional Tank
9.3. Tank location (See below)	Unconditioned Space
9.4. Capacity (Gallons)	40 Gallons
9.5. Manufacturer	Rheem
9.6. Model Number	21V40-38N
9.7. Serial Number	RHLN 0802411566

FUEL	UNIT TYPE	SYSTEM LOCATION
1. Oil	1. Conventional tank	1. Conditioned Space
2. Gas	2. High efficiency tank	2. Unconditioned Space
4. Electric	4. Tankless coil	
5. Wood/Coal	5. Instantaneous	
6. Solar	6. Heat pump	
7. Other	7. Solar	
	8. Other	

10. PILOT LIGHTS

10.1. Domestic Hot Water System (1-yes 2-no)	1 - yes
10.2. Furnace (1-yes 2-no)	2 - no
10.3. Kitchen (1-yes 2-no)	N/A
10.4. Gas Dryer (1-yes 2-no)	N/A
10.5. B.B.Q. (1-yes 2-no)	N/A
10.6. Other	N/A
	N/A
	N/A
	N/A

11. GARAGE

11.1. Size (1 - One car 2- Two Car 3 - Three or more 4 - No garage) 4 – No garage

11.2. Attached or Detached N/A

12. Trees & Buildings surrounded

12.1. Plan

13. LIGHTING FIXTURES

13.1. Distribution and type of lighting fixtures

14. EXHAUST FAN

14.1. Distribution of Exhaust fan

15. THERMOSTAT

15.1. Distribution of Thermostat

15.2. Manufacturer N/A

15.3. Night Setback Function (1-Yes 2-No) N/A

APPENDIX B

HISTORICAL AND PROJECTED NUMBER OF BUILDING PERMITS BY TEXAS COUNTY

This appendix contains a description of the projection method, the profiles of the historical data for each county during 1997 to 2001, and the projected number of building permits in 2002. The detailed projection method and example is shown below.

To begin, one county was selected from the 38 non-attainment and affected counties. For this county, the published number of building permits for the county for the years of 1999, 2000, and 2001 were obtained. Then, for each year, the average numbers of building permits for the previous two, three and four years were calculated. For example, for 1999 the average number of the previous two years, 1998 and 1997, the previous three years, 1998, 1997, and 1996, and the previous four years, 1998, 1997, 1996, and 1995 were calculated. Then, the calculated average values were compared with the real number from 1999. The nearest value was chosen, and the averaging method of the chosen value was identified. After repeating this procedure for the three years, 2001, 2000, and 1999, the most appropriate averaging method was identified. The number of building permits for 2002 was projected using the chosen method. An example of projection of building permits in a county in 2002 is described below.

Example:

Selected County: Harris County

To begin, from the published number of the building permits (Table 3.1), the number of the building permits for 1999, 2000, and 2001 is obtained. Then, for each year, the average numbers of building permits for the previous two, three and four years were calculated. Table 3.2 shows the results of the calculation. From the calculation, the most appropriate averaging method was identified. For Harris County, the average number for previous two years is the closest number to the published number. Therefore, the projected number of building permit in 2002 for Harris County is the average number for 2001 and 2000, which is 19,183.

The profile of the historical number of building permits and the projected number of building permits in 2002 by County were presented from Figure B1 through B5. The shaded part of the graph presents the projected number of building permits in 2002.

Table B1 – Number of building permits for Harris County (1991~2001)

Year	Number of Dwelling Unit	
	Units	%Change
1991	9,018	11
1992	9,614	7
1993	10,065	5
1994	9,934	-1
1995	9,708	-2
1996	11,677	20
1997	13,439	15
1998	16,191	20
1999	16,055	-1
2000	18,244	14
2001	20,122	10

Table B2 - Projection method for Harris County

Year	Averaging Method	Building Permits	Selected Method
For 2001	Published Number	20,122	
	Average for Previous 2 Years (2000 and 1999)	17,150	x
	Average for Previous 3 Years (2000,1999 and1998)	16,830	
	Average for Previous 4 Years (2000,1999,1998 and 1997)	15,982	
For 2000	Published Number	18,244	
	Average for Previous 2 Years (1999 and 1998)	16,123	x
	Average for Previous 3 Years (1999, 1998 and 1997)	15,228	
	Average for Previous 4 Years (1999,1998,1997 and 1996)	14,341	
For 1999	Published Number	16,055	
	Average for Previous 2 Years (1998 and 1997)	14,815	x
	Average for Previous 3 Years (1998, 1997 and1996)	13,769	
	Average for Previous 4 Years (1998, 1997, 1996 and 1995)	12,754	

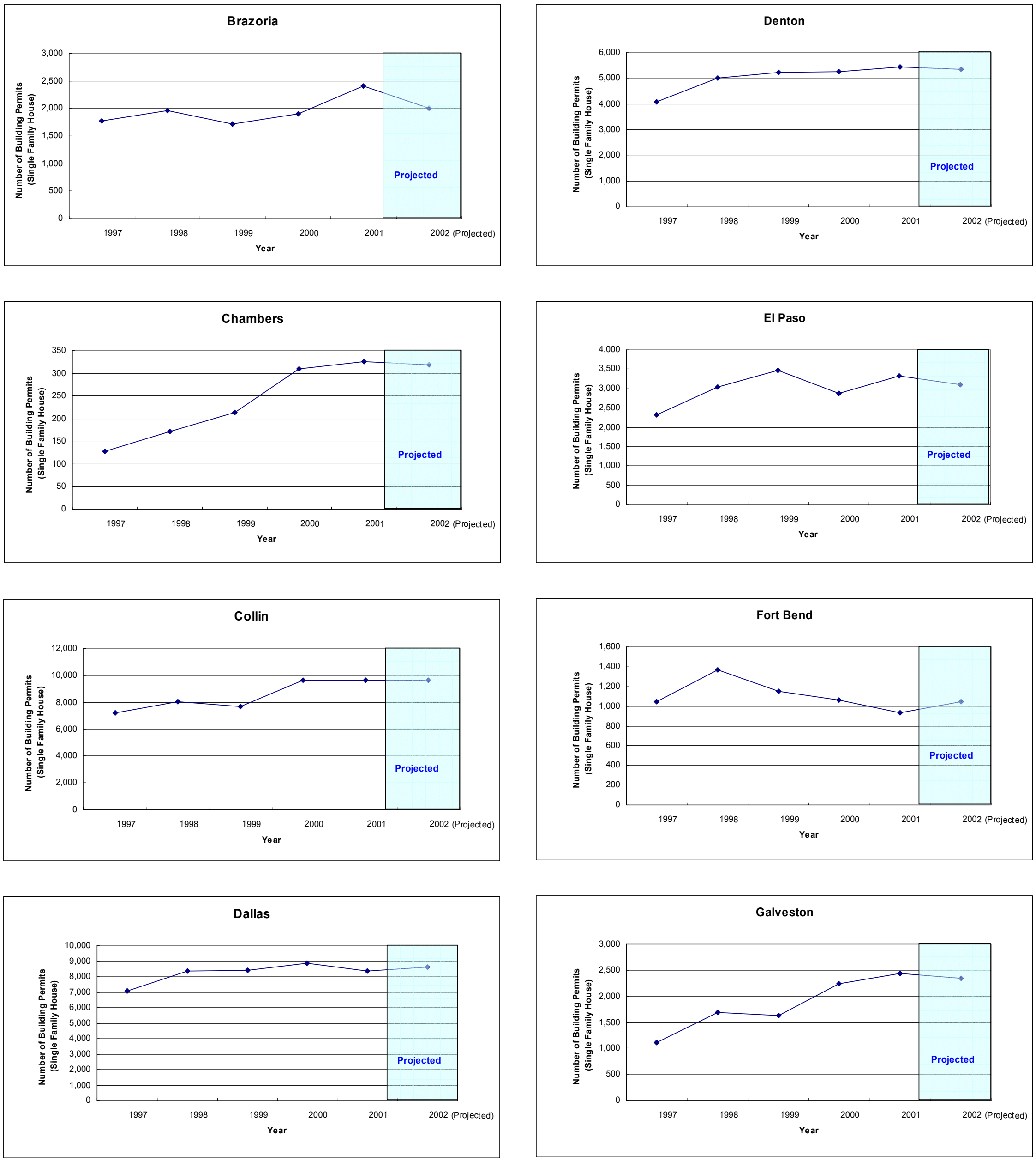


Figure B1 – Profile of the historical number of building permits by County

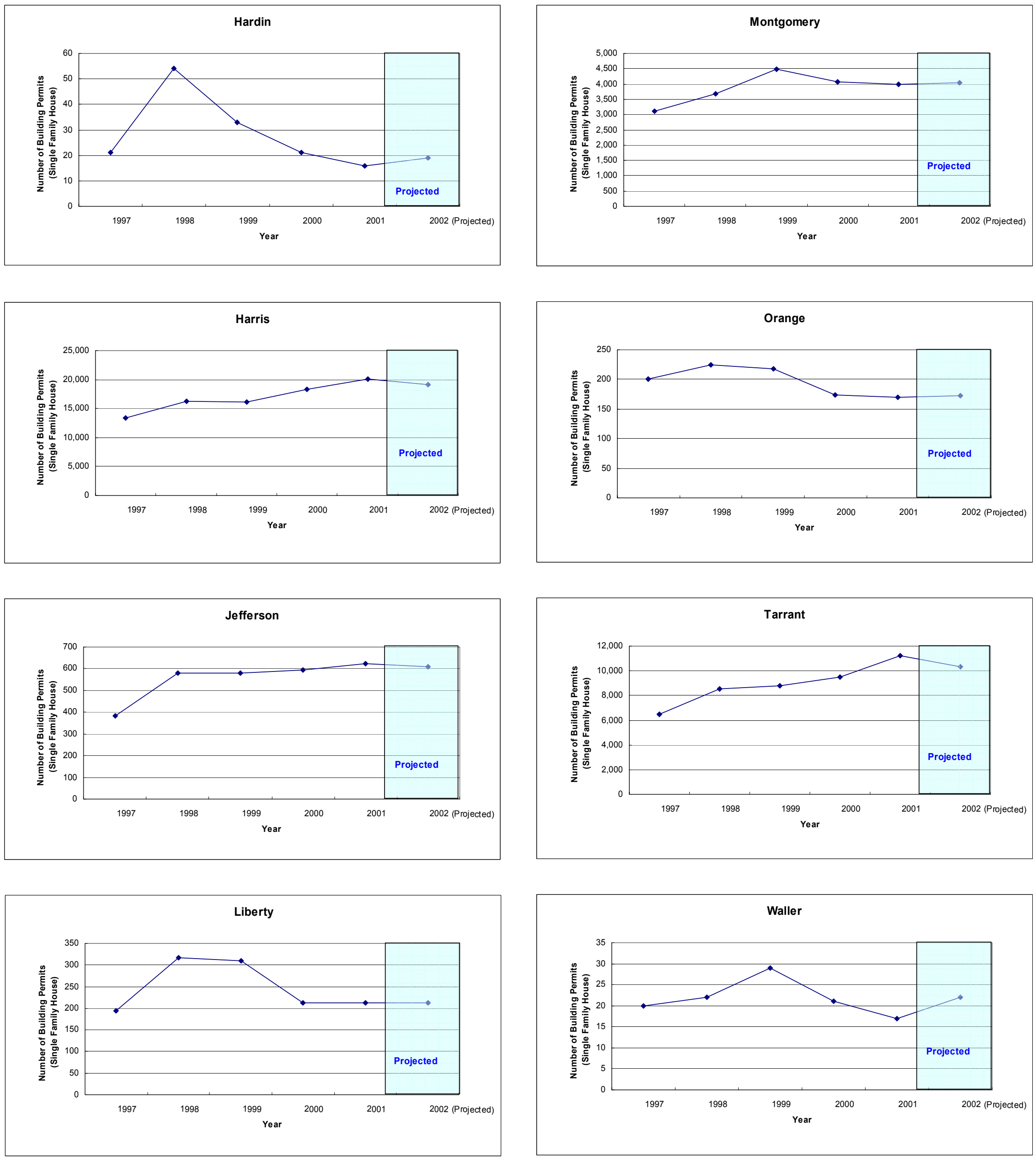


Figure B2 – Profile of the historical number of building permits by County

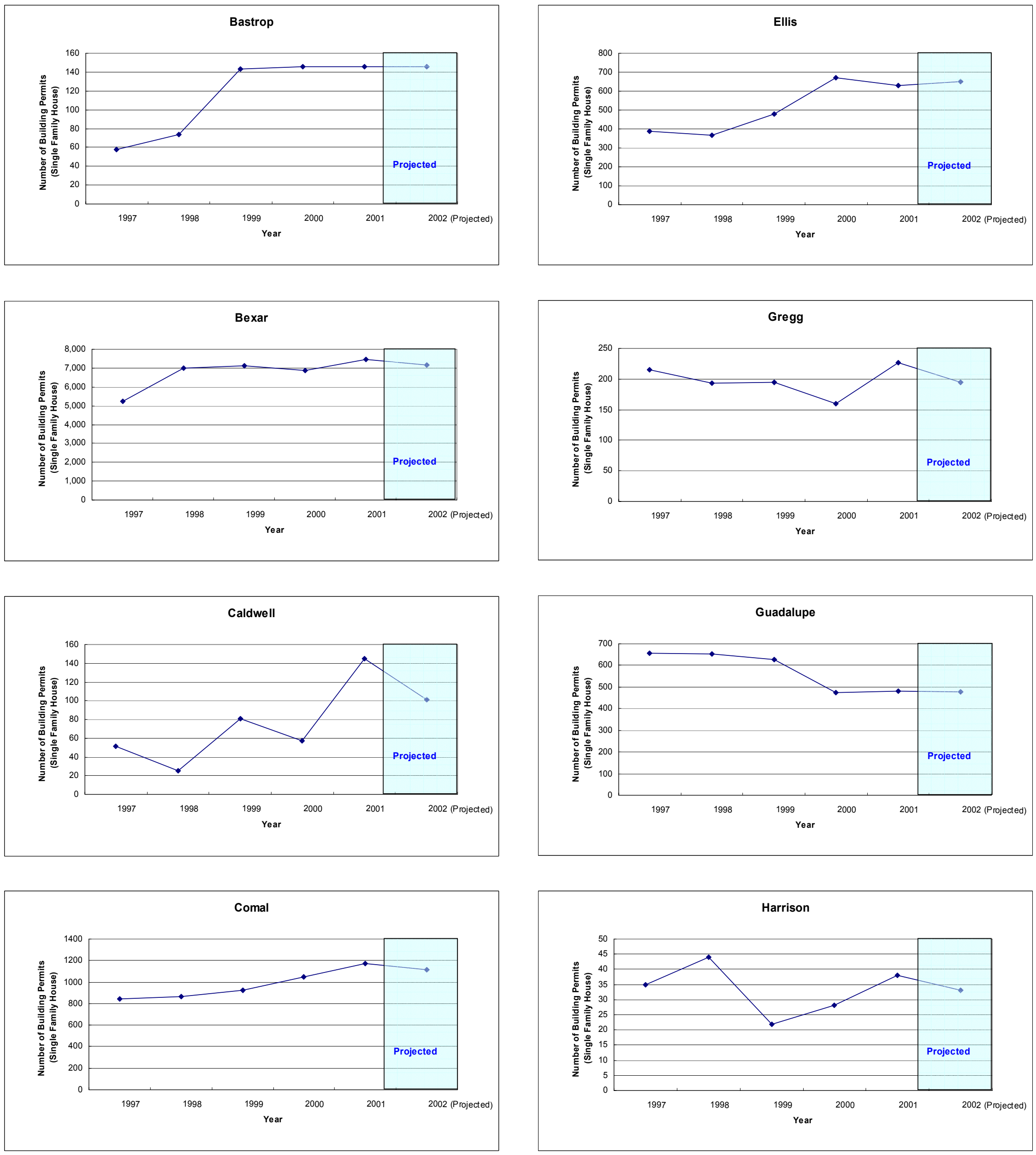


Figure B3 – Profile of the historical number of building permits by County

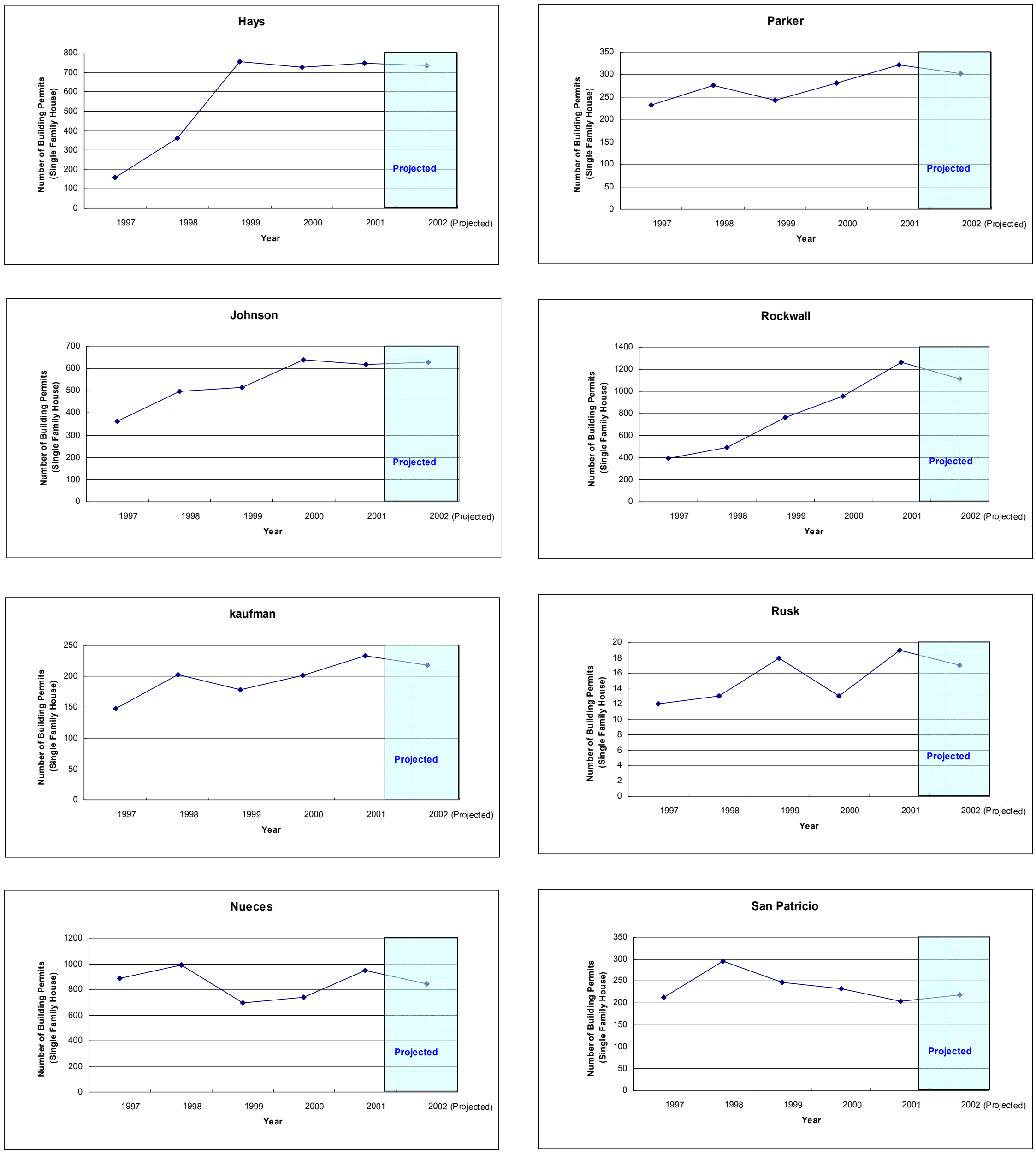
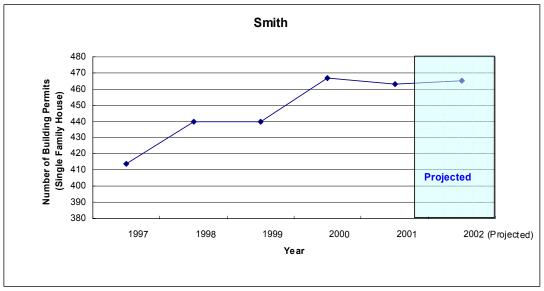
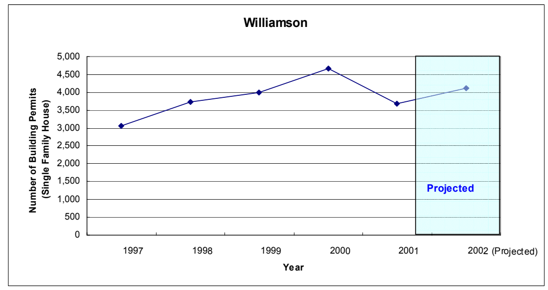
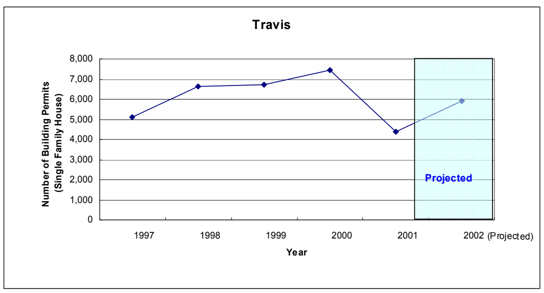
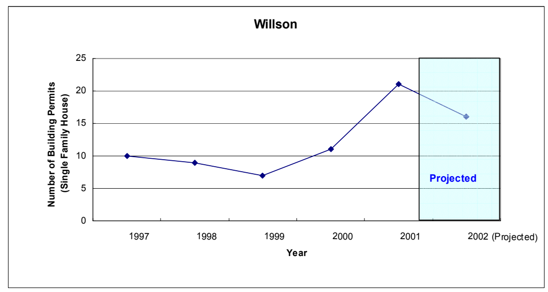


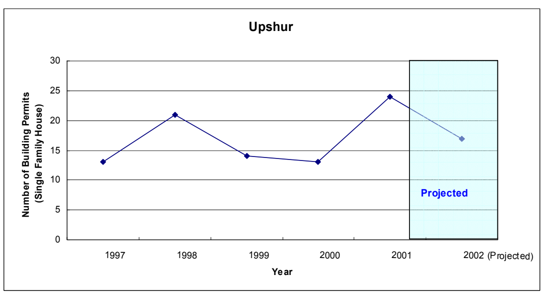
Figure B4 – Profile of the historical number of building permits by County











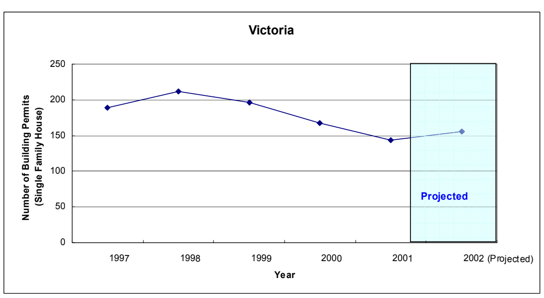


Figure B5 – Profile of the historical number of building permits by County

APPENDIX C

PARAMETER VALUES FOR 38 NON-ATTAINMENT AND AFFECTED COUNTIES

In this research, the PARAMETER command (LBL 1981) was used to input various building characteristics into the standard DOE-2 input file (ver. IECC1100.inp). The PARAMETER command is one of the time saving DOE-2 commands, such as LIKE and SET-DEFAULT. In this appendix, each page shows the corresponding county, the type of house (1999 standard house or IECC house), and the list of parameter values. Since there are known errors in the simulations, corrected values are also shown. In parameter summary table, the version 1 shows the parameter value as it was used in this thesis, and the version 2 shows the corrected value for future work. The main changes in version 2 are the corrected altitude values. In this thesis, the altitude values were input using the SI unit (i.e. meter), which should be IP unit (i.e., feet). Therefore, in the version 2, all altitude values are converted into IP units. Except the altitude error, there are several irregular errors in wall R-values and ceiling R-values for several counties. Those errors are also fixed in the version 2.

Table C1. The List of the DOE-2 Parameters for the 1999 Standard House (Version 1)

County	Nueces, San Patricio	Victoria	Brazorial, Galveston	Bastrop, Caldwell	Harris, Fort bend, Montgomery, Waller	Chambers, Hardin, Jefferson, Liberty, Orange	Bexar, Comal, Guadalupe, Wilson	Rusk, Smith	Hays, Travis, Williamson	Dallas, Johnson, Tarrant, Ellis	Gregg, Harrison, Upshur	El Paso	Collin, Kaufman, Parker, Rockwall, Denton,
BUILDING													
P-AREA	2548	2548	2548	2426	2548	2548	2426	2548	2426	2426	2548	2426	2426
P-AREA1	201.92	201.92	201.92	197	201.92	201.92	197	201.92	197	197	201.92	197	197
P-VOLUME	20384	20384	20384	19408	20384	20384	19408	20384	19408	19408	20384	19408	19408
P-LATITUDE	27.77	28.85	29.98	30.3	29.98	29.95	29.53	31.23	30.3	32.83	31.23	32.83	32.83
P-LONGTUDE	97.5	96.62	95.37	97.7	95.37	94.017	98.46	93.75	97.7	97.05	94.75	97.05	97.05
P-TIME-ZONE	6	6	6	6	6	6	6	6	6	6	6	6	6
P-ALTITUDE	13	13	108	189	108	7	242	96	189	164	96	164	164
P-BUILDINGWIDTH	50.48	50.48	50.48	49.25	50.48	50.48	49.25	50.48	49.25	49.25	50.48	49.25	49.25
P-BUILDINGLENGTH	50.48	50.48	50.48	49.25	50.48	50.48	49.25	50.48	49.25	49.25	50.48	49.25	49.25
P-BUILDINGAZIMUTH	0	0	0	0	0	0	0	0	0	0	0	0	0
P-OCCUPANCY	2	2	2	2	2	2	2	2	2	2	2	2	2
ROOF													
P-ROOFOUTEMISS	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
P-ROOFABSORPTANCE	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P-ROOFROUGHNESS	1	1	1	1	1	1	1	1	1	1	1	1	1
P-ROOFUVALUE	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
WALL													
P-WALLABSORPTANCE	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
P-WALLROUGHNESS	2	2	2	2	2	2	2	2	2	2	2	2	2
P-WALLHEIGHT	8	8	8	8	8	8	8	8	8	8	8	8	8
P-WALLOUTEMISS	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
P-GND-REFLECTANCE	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
P-WALLUVALUE	0.071	0.071	0.091	0.071	0.071	0.077	0.071	0.071	0.07	0.077	0.071	0.077	0.07
CEILING													
P-CLNGUVALUE	0.037	0.037	0.0526	0.037	0.037	0.0386	0.037	0.037	0.0374	0.0263	0.037	0.0263	0.0374
DOOR													
P-DOORHEIGHT	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67
P-DOORWIDTH	3	3	3	3	3	3	3	3	3	3	3	3	3
P-DOOREFFWIDTH	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WINDOW													
P-WINDOWHEIGHT	5	5	5	5	5	5	5	5	5	5	5	5	5
P-WINDOWWIDTH	12.34	12.34	12.34	18.67	12.34	12.34	18.67	12.34	18.67	18.67	12.34	18.67	18.67
P-WINDOWOUTEMISS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P-SHADINGCOEFFICIENT	0.95	0.95	0.95	0.95	0.887	0.887	0.95	0.95	0.95	0.95	0.95	0.95	0.95
P-FRAMEWIDTH	0.23	0.23	0.23	0.25	0.25	0.25	0.25	0.23	0.26	0.25	0.23	0.25	0.26
P-GLASSCONDUCTANCE	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	0.84	1.23	1.23	1.23	0.84
P-FRAMECONDUCTANCE	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037
P-FRAMEABSORPTANCE	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P-PANES	2	2	2	2	2	2	2	2	2	2	2	2	2
P-VISTRANSMITTENCE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P-SPACERCODE	2	2	2	2	2	2	2	2	2	2	2	2	2
FLOOR													
P-FLOORWEIGHT	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
SHADE													
P-SHADEWIDTHF	3	3	3	3	3	3	3	3	3	3	3	3	3
P-SHADEWIDTHR	3	3	3	3	3	3	3	3	3	3	3	3	3
P-SHADEWIDTHB	3	3	3	3	3	3	3	3	3	3	3	3	3
P-SHADEWIDTHL	3	3	3	3	3	3	3	3	3	3	3	3	3

Table C2. The List of the DOE-2 Parameters for the 1999 Standard House (Version 2)

County	Nueces, San Patricio	Victoria	Brazorial, Galveston	Bastrop, Caldwell	Harris, Fort bend, Montgomery, Waller	Chambers, Hardin, Jefferson, Liberty Orange	Bexar, Comal, Guadalupe, Wilson	Rusk, Smith	Hays, Travis, Williamson	Dallas, Johnson, Tarrant, Ellis	Gregg, Harrison, Upshur	El Paso	Collin, Kaufman, Parker, Rockwall, Denton,
BUILDING													
P-AREA	2548	2548	2548	2426	2548	2548	2426	2548	2426	2426	2548	2426	2426
P-AREA1	201.92	201.92	201.92	197	201.92	201.92	197	201.92	197	197	201.92	197	197
P-VOLUME	20384	20384	20384	19408	20384	20384	19408	20384	19408	19408	20384	19408	19408
P-LATITUDE	27.77	28.85	29.16916	30.3	29.98	29.95	29.44858	31.23	30.3	32.83	31.23	32.83	32.83
P-LONGTUDE	97.5	96.62	95.43529	97.7	95.37	94.017	98.51986	93.75	97.7	97.05	94.75	97.05	97.05
P-TIME-ZONE	6	6	6	6	6	6	6	6	6	6	6	6	6
P-ALTITUDE	43	105	108	620	108	23	794	315	620	538	315	3916	538
P-BUILDINGWIDTH	50.48	50.48	50.48	49.25	50.48	50.48	49.25	50.48	49.25	49.25	50.48	49.25	49.25
P-BUILDINGLENGTH	50.48	50.48	50.48	49.25	50.48	50.48	49.25	50.48	49.25	49.25	50.48	49.25	49.25
P-BUILDINGAZIMUTH	0	0	0	0	0	0	0	0	0	0	0	0	0
P-OCCUPANCY	2	2	2	2	2	2	2	2	2	2	2	2	2
ROOF													
P-ROOFOUTEMISS	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
P-ROOFABSORPTANCE	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P-ROOFROUGHNESS	1	1	1	1	1	1	1	1	1	1	1	1	1
P-ROOFUVALUE	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
WALL													
P-WALLABSORPTANCE	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
P-WALLROUGHNESS	2	2	2	2	2	2	2	2	2	2	2	2	2
P-WALLHEIGHT	8	8	8	8	8	8	8	8	8	8	8	8	8
P-WALLOUTEMISS	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
P-GND-REFLECTANCE	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
P-WALLUVALUE	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071
CEILING													
P-CLNGUVALUE	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
DOOR													
P-DOORHEIGHT	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67
P-DOORWIDTH	3	3	3	3	3	3	3	3	3	3	3	3	3
P-DOOREFFWIDTH	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WINDOW													
P-WINDOWHEIGHT	5	5	5	5	5	5	5	5	5	5	5	5	5
P-WINDOWWIDTH	12.34	12.34	12.34	18.67	12.34	12.34	18.67	12.34	18.67	18.67	12.34	18.67	18.67
P-WINDOWOUTEMISS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P-SHADINGCOEFFICIENT	0.95	0.95	0.95	0.95	0.887	0.887	0.95	0.95	0.95	0.95	0.95	0.95	0.95
P-FRAMEWIDTH	0.23	0.23	0.23	0.25	0.25	0.25	0.25	0.23	0.26	0.25	0.23	0.25	0.26
P-GLASSCONDUCTANCE	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	0.84	1.23	1.23	1.23	0.84
P-FRAMECONDUCTANCE	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037
P-FRAMEABSORPTANCE	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P-PANES	2	2	2	2	2	2	2	2	2	2	2	2	2
P-VISTRANSMITTENCE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P-SPACERCODE	2	2	2	2	2	2	2	2	2	2	2	2	2
FLOOR													
P-FLOORWEIGHT	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
SHADE													
P-SHADEWIDTHF	3	3	3	3	3	3	3	3	3	3	3	3	3
P-SHADEWIDTHR	3	3	3	3	3	3	3	3	3	3	3	3	3
P-SHADEWIDTHB	3	3	3	3	3	3	3	3	3	3	3	3	3
P-SHADEWIDTHL	3	3	3	3	3	3	3	3	3	3	3	3	3

Table C3. The List of the DOE-2 Parameters for the IECC House (Version 1)

County	Nueces, San Patricio	Victoria	Brazorial, Galveston	Bastrop, Caldwell	Harris, Fort bend, Montgomery, Waller	Chambers, Hardin, Jefferson, Liberty, Orange	Bexar, Comal, Guadalupe, Wilson	Rusk, Smith	Hays, Travis, Williamson	Dallas, Johnson, Tarrant, Ellis	Gregg, Harrison, Upshur	El Paso	Collin, Kaufman, Parker, Rockwall, Denton,
BUILDING													
P-AREA	2548	2548	2548	2426	2548	2548	2426	2548	2426	2426	2548	2426	2426
P-AREA1	201.92	201.92	201.92	197	201.92	201.92	197	201.92	197	197	201.92	197	197
P-VOLUME	20384	20384	20384	19408	20384	20384	19408	20384	19408	19408	20384	19408	19408
P-LATITUDE	27.77	28.85	29.98	30.3	29.98	29.95	29.53	27.77	29.53	32.83	31.23	31.8	32.83
P-LONGTUDE	97.5	96.62	95.37	97.7	95.37	94.017	98.46	97.5	98.46	97.05	94.75	106.4	97.05
P-TIME-ZONE	6	6	6	6	6	6	6	6	6	6	6	6	6
P-ALTITUDE	13	13	108	189	108	7	242	96	189	164	96	164	164
P-BUILDINGWIDTH	50.48	50.48	50.48	49.25	50.48	50.48	49.25	50.48	49.25	49.25	50.48	49.25	49.25
P-BUILDINGLENGTH	50.48	50.48	50.48	49.25	50.48	50.48	49.25	50.48	49.25	49.25	50.48	49.25	49.25
P-BUILDINGAZIMUTH	0	0	0	0	0	0	0	0	0	0	0	0	0
P-OCCUPANCY	2	2	2	2	2	2	2	2	2	2	2	2	2
ROOF													
P-ROOFOUTEMISS	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
P-ROOFABSORPTANCE	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P-ROOFROUGHNESS	1	1	1	1	1	1	1	1	1	1	1	1	1
P-ROOFUVALUE	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
WALL													
P-WALLABSORPTANCE	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
P-WALLROUGHNESS	2	2	2	2	2	2	2	2	2	2	2	2	2
P-WALLHEIGHT	8	8	8	8	8	8	8	8	8	8	8	8	8
P-WALLOUTEMISS	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
P-GND-REFLECTANCE	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
P-WALLUVALUE	0.091	0.091	0.091	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.0625	0.0625
CEILING													
P-CLNGUVALUE	0.0526	0.0526	0.0526	0.033	0.033	0.033	0.033	0.033	0.0263	0.0263	0.033	0.0263	0.0263
DOOR													
P-DOORHEIGHT	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67
P-DOORWIDTH	3	3	3	3	3	3	3	3	3	3	3	3	3
P-DOOREFFWIDTH	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WINDOW													
P-WINDOWHEIGHT	5	5	5	5	5	5	5	5	5	5	5	5	5
P-WINDOWWIDTH	12.34	12.34	12.34	18.67	12.34	12.34	18.67	12.34	18.67	18.67	12.34	18.67	18.67
P-WINDOWOUTEMISS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P-SHADINGCOEFFICIENT	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528
P-FRAMEWIDTH	0.23	0.23	0.23	0.25	0.22	0.22	0.25	0.23	0.25	0.25	0.23	0.25	0.25
P-GLASSCONDUCTANCE	0.65	0.62	0.65	0.34	0.65	0.65	0.34	0.51	0.31	0.31	0.44	0.26	0.26
P-FRAMECONDUCTANCE	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037
P-FRAMEABSORPTANCE	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P-PANES	2	2	2	2	2	2	2	2	2	2	2	2	2
P-VISTRANSMITTENCE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P-SPACERCODE	2	2	2	2	2	2	2	2	2	2	2	2	2
FLOOR													
P-FLOORWEIGHT	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
SHADE													
P-SHADEWIDTHF	3	3	3	3	3	3	3	3	3	3	3	3	3
P-SHADEWIDTHR	3	3	3	3	3	3	3	3	3	3	3	3	3
P-SHADEWIDTHB	3	3	3	3	3	3	3	3	3	3	3	3	3
P-SHADEWIDTHL	3	3	3	3	3	3	3	3	3	3	3	3	3

Table C4. The List of the DOE-2 Parameters for the IECC House (Version 2)

County	Nueces, San Patricio	Victoria	Brazorial, Galveston	Bastrop, Caldwell	Harris, Fort bend, Montgomery , Waller	Chambers, Hardin, Jefferson, Liberty, Orange	Bexar, Comal, Guadalupe, Wilson	Rusk, Smith	Hays, Travis, Williamson	Dallas, Johnson, Tarrant, Ellis	Gregg, Harrison, Upshur	El Paso	Collin, Kaufman, Parker, Rockwall, Denton,
BUILDING													
P-AREA	2548	2548	2548	2426	2548	2548	2426	2548	2426	2426	2548	2426	2426
P-AREA1	201.92	201.92	201.92	197	201.92	201.92	197	201.92	197	197	201.92	197	197
P-VOLUME	20384	20384	20384	19408	20384	20384	19408	20384	19408	19408	20384	19408	19408
P-LATITUDE	27.77	27.77	29.16916	30.3	29.98	29.95	29.44858	27.77	29.53	32.83	31.23	31.8	32.83
P-LONGTUDE	97.5	97.5	95.43529	97.7	95.37	94.017	98.51986	97.5	98.46	97.05	94.75	106.4	97.05
P-TIME-ZONE	6	6	6	6	6	6	6	6	6	6	6	6	6
P-ALTITUDE	43	105	108	620	108	23	794	315	620	538	315	3916	538
P-BUILDINGWIDTH	50.48	50.48	50.48	49.25	50.48	50.48	49.25	50.48	49.25	49.25	50.48	49.25	49.25
P-BUILDINGLENGTH	50.48	50.48	50.48	49.25	50.48	50.48	49.25	50.48	49.25	49.25	50.48	49.25	49.25
P-BUILDINGAZIMUTH	0	0	0	0	0	0	0	0	0	0	0	0	0
P-OCCUPANCY	2	2	2	2	2	2	2	2	2	2	2	2	2
ROOF													
P-ROOFOUTEMISS	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
P-ROOFABSORPTANCE	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
P-ROOFROUGHNESS	1	1	1	1	1	1	1	1	1	1	1	1	1
P-ROOFUVALUE	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
WALL													
P-WALLABSORPTANCE	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
P-WALLROUGHNESS	2	2	2	2	2	2	2	2	2	2	2	2	2
P-WALLHEIGHT	8	8	8	8	8	8	8	8	8	8	8	8	8
P-WALLOUTEMISS	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
P-GND-REFLECTANCE	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
P-WALLUVALUE	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071
CEILING													
P-CLNGUVALUE	0.037	0.037	0.037	0.033	0.037	0.037	0.033	0.033	0.0263	0.0263	0.037	0.0263	0.0263
DOOR													
P-DOORHEIGHT	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67	6.67
P-DOORWIDTH	3	3	3	3	3	3	3	3	3	3	3	3	3
P-DOOREFFWIDTH	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
WINDOW													
P-WINDOWHEIGHT	5	5	5	5	5	5	5	5	5	5	5	5	5
P-WINDOWWIDTH	12.34	12.34	12.34	18.67	12.34	12.34	18.67	12.34	18.67	18.67	12.34	18.67	18.67
P-WINDOWOUTEMISS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P-SHADINGCOEFFICIENT	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528	0.528
P-FRAMEWIDTH	0.23	0.23	0.23	0.25	0.22	0.22	0.25	0.23	0.25	0.25	0.23	0.25	0.25
P-GLASSCONDUCTANCE	0.65	0.62	0.65	0.34	0.65	0.65	0.34	0.51	0.31	0.31	0.44	0.26	0.26
P-FRAMECONDUCTANCE	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037	3.037
P-FRAMEABSORPTANCE	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
P-PANES	2	2	2	2	2	2	2	2	2	2	2	2	2
P-VISTRANSMITTENCE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
P-SPACERCODE	2	2	2	2	2	2	2	2	2	2	2	2	2
FLOOR													
P-FLOORWEIGHT	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
SHADE													
P-SHADEWIDTHF	3	3	3	3	3	3	3	3	3	3	3	3	3
P-SHADEWIDTHR	3	3	3	3	3	3	3	3	3	3	3	3	3
P-SHADEWIDTHB	3	3	3	3	3	3	3	3	3	3	3	3	3
P-SHADEWIDTHL	3	3	3	3	3	3	3	3	3	3	3	3	3

APPENDIX D

BEPS AND BEPU REPORT FOR 38 NON-ATTAINMENT AND AFFECTED COUNTIES

As results of the DOE-2 simulations, the report BEPS and BEPU were generated for each non-attainment or affected county. From the report BEPS and BEPU, the annual electricity and natural gas use[1] could be obtained. For each county, two sets of the report BEPS and BEPU were generated. One is for the 1999 standard house, and the other is for the IECC house. From identifying the annual energy use for each house, the annual electricity and natural gas savings can be calculated by subtracting the energy use of the IECC house from the energy use of the 1999 house.

In this appendix, the report BEPS and BEPU for 38 non-attainment and affected counties are presented. As mentioned in Chapter IV in this research, 13 counties were assigned as the representative counties for all non-attainment and affected counties. Therefore, 26 simulations (13 for 1999 standard house, 13 for 2000 IECC standard house) were performed.

[1] In this thesis, version IECC1100.inp was used to simulate the energy use. Please note that version IECC1100.inp includes double count of furnace. Therefore, the natural gas use needs to be half of the shown value.

Table C1 – Report BEPS from the 1999 Standard House Simulations

County	Nueces, San Patricio		Victoria		Brazoria, Galveston		Bastrop, Caldwell		Harris, Fort bend, Montgomery, Waller	
Energy Type	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas
Site Unit	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu
Category of Use										
AREA LIGHTS	13.2	0	13.2	0	13.2	0	13.2	0	13.2	0
MISC EQUIPMT	13.2	0	13.2	0	13.2	0	13.2	0	13.2	0
SPACE HEAT	0	9.9	0	11.6	0	19.4	0	20.5	0	17.1
SPACE COOL	19.7	0	18.3	0	17.6	0	26.1	0	15.7	0
PUMPS & MISC	0.1	0	0.2	0	0.2	0	0.2	0	0.2	0
VENT FANS	2.9	0	2.7	0	2.7	0	4	0	2.4	0
DOMHOT WATER	0	15.4	0	15.9	0	16.3	0	16.4	0	16.3
TOTAL	49	25.3	47.5	27.5	46.9	35.7	56.7	36.9	44.7	33.4
Total (Electricity + Natural-Gas)	74.3		75		82.6		93.6		78.1	

County	Chambers, Hardin, Jefferson, Liberty Orange		Bexar, Comal, Guadalupe, Wilson		Rusk, Smith		Hays, Travis, Williamson		Dallas, Johnson, Tarrant, Ellis	
Energy Type	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas
Site Unit	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu
Category of Use										
AREA LIGHTS	13.2	0	13.2	0	13.2	0	13.2	0	13.2	0
MISC EQUIPMT	13.2	0	13.2	0	13.2	0	13.2	0	13.2	0
SPACE HEAT	0	15.6	0	19.3	0	9.9	0	17.3	0	26.4
SPACE COOL	15.2	0	26.3	0	19.7	0	26.3	0	22.5	0
PUMPS & MISC	0.2	0	0.2	0	0.1	0	0.2	0	0.3	0
VENT FANS	2.3	0	4	0	2.9	0	4	0	3.6	0
DOMHOT WATER	0	16.4	0	16.4	0	15.4	0	16.4	0	17.4
TOTAL	44.1	32.1	56.9	35.7	49	25.3	56.9	33.7	52.8	43.8
Total (Electricity + Natural-Gas)	76.2		92.6		74.3		90.6		96.6	

County	Gregg, Harrison, Upshur		El Paso		Collin, Kaufman, Parker, Rockwall, Denton	
Energy Type	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas
Site Unit	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu
Category of Use						
AREA LIGHTS	13.2	0	13.2	0	13.2	0
MISC EQUIPMT	13.2	0	13.2	0	13.2	0
SPACE HEAT	0	19.8	0	26.4	0	23.3
SPACE COOL	15.8	0	22.5	0	23.4	0
PUMPS & MISC	0.3	0	0.3	0	0.3	0
VENT FANS	2.4	0	3.6	0	3.7	0
DOMHOT WATER	0	17	0	17.4	0	17.4
TOTAL	44.8	36.8	52.8	43.8	53.7	40.6
Total (Electricity + Natural-Gas)	81.6		96.6		94.3	

Table C2 – Report BEPU from the 1999 Standard House Simulations

County	Nueces, San Patricio		Victoria		Brazoria, Galveston		Bastrop, Caldwell		Harris, Fort bend, Montgomery, Waller	
Energy Type	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas
Site Unit	KWH	THERM	KWH	THERM	KWH	THERM	KWH	THERM	KWH	THERM
Category of Use										
AREA LIGHTS	3854	0	3854	0	3854	0	3854	0	3854	0
MISC EQUIPMT	3854	0	3854	0	3854	0	3854	0	3854	0
SPACE HEAT	0	99	0	116	0	194	0	205	0	171
SPACE COOL	5774	0	5376	0	5163	0	7650	0	4609	0
PUMPS & MISC	33	0	44	0	65	0	70	0	65	0
VENT FANS	839	0	795	0	805	0	1172	0	711	0
DOMHOT WATER	0	154	0	159	0	163	0	164	0	163
TOTAL	14354	253	13923	275	13740	357	16600	369	13093	334
Total (Electricity + Natural-Gas)	14607		14198		14097		16969		13427	

County	Chambers, Hardin, Jefferson, Liberty Orange		Bexar, Comal, Guadalupe, Wilson		Rusk, Smith		Hays, Travis, Williamson		Dallas, Johnson, Tarrant, Ellis	
Energy Type	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas
Site Unit	KWH	THERM	KWH	THERM	KWH	THERM	KWH	THERM	KWH	THERM
Category of Use										
AREA LIGHTS	3854	0	3854	0	3854	0	3854	0	3854	0
MISC EQUIPMT	3854	0	3854	0	3854	0	3854	0	3854	0
SPACE HEAT	0	156	0	193	0	99	0	173	0	264
SPACE COOL	4459	0	7718	0	5774	0	7719	0	6607	0
PUMPS & MISC	61	0	70	0	33	0	70	0	95	0
VENT FANS	684	0	1185	0	839	0	1166	0	1056	0
DOMHOT WATER	0	164	0	164	0	154	0	164	0	174
TOTAL	12913	321	16681	357	14354	253	16662	337	15465	438
Total (Electricity + Natural-Gas)	13234		17038		14607		16999		15903	

County	Gregg, Harrison, Upshur		El Paso		Collin, Kaufman, Parker, Rockwall, Denton	
Energy Type	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas
Site Unit	KWH	THERM	KWH	THERM	KWH	THERM
Category of Use						
AREA LIGHTS	3854	0	3854	0	3854	0
MISC EQUIPMT	3854	0	3854	0	3854	0
SPACE HEAT	0	198	0	264	0	233
SPACE COOL	4630	0	6607	0	6843	0
PUMPS & MISC	86	0	95	0	95	0
VENT FANS	715	0	1056	0	1079	0
DOMHOT WATER	0	170	0	174	0	174
TOTAL	13139	368	15465	438	15725	406
Total (Electricity + Natural-Gas)	13507		15903		16131	

Table C3 – Report BEPS from the IECC House Simulations

County	Nueces, San Patricio		Victoria		Brazoria, Galveston		Bastrop, Caldwell		Harris, Fort bend, Montgomery, Waller	
Energy Type	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas
Site Unit	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu
Category of Use										
AREA LIGHTS	13.2	0	13.2	0	13.2	0	13.2	0	13.2	0
MISC EQUIPMT	13.2	0	13.2	0	13.2	0	13.2	0	13.2	0
SPACE HEAT	0	10.9	0	13.3	0	19.2	0	14.7	0	16
SPACE COOL	14.6	0	13.4	0	12.1	0	16.4	0	10.9	0
PUMPS & MISC	0.1	0	0.2	0	0.2	0	0.2	0	0.2	0
VENT FANS	2.1	0	2	0	1.9	0	2.4	0	1.7	0
DOMHOT WATER	0	15.4	0	15.9	0	16.3	0	16.4	0	16.3
TOTAL	43.2	26.3	41.8	29.2	40.5	35.5	45.4	31	39.1	32.4
Total (Electricity + Natural-Gas)	69.5		71		76		76.4		71.5	

County	Chambers, Hardin, Jefferson, Liberty Orange		Bexar, Comal, Guadalupe, Wilson		Rusk, Smith		Hays, Travis, Williamson		Dallas, Johnson, Tarrant, Ellis	
Energy Type	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas
Site Unit	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu
Category of Use										
AREA LIGHTS	13.2	0	13.2	0	13.2	0	13.2	0	13.2	0
MISC EQUIPMT	13.2	0	13.2	0	13.2	0	13.2	0	13.2	0
SPACE HEAT	0	14.4	0	13.6	0	18.4	0	13.5	0	18.5
SPACE COOL	10.5	0	16.5	0	10.2	0	16	0	13.7	0
PUMPS & MISC	0.2	0	0.2	0	0.3	0	0.2	0	0.3	0
VENT FANS	1.6	0	2.5	0	1.6	0	2.4	0	2.1	0
DOMHOT WATER	0	16.4	0	16.4	0	17	0	16.4	0	17.4
TOTAL	38.6	30.8	45.5	30	38.4	35.4	44.9	29.9	42.5	35.9
Total (Electricity + Natural-Gas)	69.4		75.5		73.8		74.8		78.4	

County	Gregg, Harrison, Upshur		El Paso		Collin, Kaufman, Parker, Rockwall, Denton	
Energy Type	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas
Site Unit	MBtu	MBtu	MBtu	MBtu	MBtu	MBtu
Category of Use						
AREA LIGHTS	13.2	0	13.2	0	13.2	0
MISC EQUIPMT	13.2	0	13.2	0	13.2	0
SPACE HEAT	0	17.7	0	14.8	0	16.5
SPACE COOL	10.2	0	14.4	0	13.7	0
PUMPS & MISC	0.3	0	0.4	0	0.3	0
VENT FANS	1.6	0	2.2	0	2.1	0
DOMHOT WATER	0	17	0	17.7	0	17.4
TOTAL	38.4	34.7	43.3	32.5	42.4	33.9
Total (Electricity + Natural-Gas)	73.1		75.8		76.3	

Table C4 – Report BEPU from the IECC House Simulations

County	Nueces, San Patricio		Victoria		Brazoria, Galveston		Bastrop, Caldwell		Harris, Fort bend, Montgomery, Waller	
Energy Type	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas
Site Unit	KWH	THERM	KWH	THERM	KWH	THERM	KWH	THERM	KWH	THERM
Category of Use										
AREA LIGHTS	3854	0	3854	0	3854	0	3854	0	3854	0
MISC EQUIPMT	3854	0	3854	0	3854	0	3854	0	3854	0
SPACE HEAT	0	109	0	133	0	192	0	147	0	160
SPACE COOL	4283	0	3919	0	3535	0	4815	0	3203	0
PUMPS & MISC	33	0	44	0	65	0	70	0	65	0
VENT FANS	627	0	580	0	551	0	717	0	491	0
DOMHOT WATER	0	154	0	159	0	163	0	164	0	163
TOTAL	12651	263	12251	292	11859	355	13310	310	11467	324
Total (Electricity + Natural-Gas)	12914		12543		12214		13620		11791	

County	Chambers, Hardin, Jefferson, Liberty Orange		Bexar, Comal, Guadalupe, Wilson		Rusk, Smith		Hays, Travis, Williamson		Dallas, Johnson, Tarrant, Ellis	
Energy Type	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas
Site Unit	KWH	THERM	KWH	THERM	KWH	THERM	KWH	THERM	KWH	THERM
Category of Use										
AREA LIGHTS	3854	0	3854	0	3854	0	3854	0	3854	0
MISC EQUIPMT	3854	0	3854	0	3854	0	3854	0	3854	0
SPACE HEAT	0	144	0	136	0	184	0	135	0	185
SPACE COOL	3065	0	4824	0	2999	0	4685	0	4027	0
PUMPS & MISC	61	0	70	0	86	0	70	0	95	0
VENT FANS	463	0	731	0	460	0	696	0	617	0
DOMHOT WATER	0	164	0	164	0	170	0	164	0	174
TOTAL	11297	308	13332	300	11253	354	13160	299	12448	359
Total (Electricity + Natural-Gas)	11605		13632		11607		13459		12807	

County	Gregg, Harrison, Upshur		El Paso		Collin, Kaufman, Parker, Rockwall, Denton	
Energy Type	Electricity	Natural-Gas	Electricity	Natural-Gas	Electricity	Natural-Gas
Site Unit	KWH	THERM	KWH	THERM	KWH	THERM
Category of Use						
AREA LIGHTS	3854	0	3854	0	3854	0
MISC EQUIPMT	3854	0	3854	0	3854	0
SPACE HEAT	0	177	0	148	0	165
SPACE COOL	3000	0	4211	0	4008	0
PUMPS & MISC	86	0	108	0	95	0
VENT FANS	464	0	658	0	608	0
DOMHOT WATER	0	170	0	177	0	174
TOTAL	11258	347	12684	325	12419	339
Total (Electricity + Natural-Gas)	11605		13009		12758	

APPENDIX E

APPROVAL OF HUMAN SUBJECT COMPLIANCE

VPR Office of the Vice President for Research

Date August 15, 2003

MEMORANDUM

TO:	Piljae Im Architecture MS 3137
FROM:	Dr. E. Murl Bailey, CIP, Advisor Institutional Review Board MS 1112
SUBJECT:	IRB Protocol Review

Title: A Methodology to Evaluate Energy Savings and NOx Emissions Reductions from the Adoption of the 2000 IECC to New Residences in Nonattainment and Affected Counties in Texas

Protocol Number: 2003-0376
Review Category: Exempt from Full Review
Approval Date: August 15, 2003 **to** August 14, 2004

The approval determination was based on the following Code of Federal Regulations http://ohrp.osophs.dhhs.gov/humansubjects/guidance/45cfr46.htm

____ **46.101(b)(1)**	____ **46.101(b)(4)**
✓ **46.101(b)(2)**	____ **46.101(b)(5)**
____ **46.101(b)(3)**	____ **46.101(b)(6)**

Remarks:

The Institutional Review Board – Human Subjects in Research, Texas A&M University has reviewed and approved the above referenced protocol. Your study has been approved for one year. As the principal investigator of this study, you assume the following responsibilities:

Renewal: Your protocol must be re-approved each year in order to continue the research. You must also complete the proper renewal forms in order to continue the study after the initial approval period.

Adverse events: Any adverse events or reactions must be reported to the IRB immediately.

Amendments: Any changes to the protocol, such as procedures, consent/assent forms, addition of subjects, or study design must be reported to and approved by the IRB.

Informed Consent/Assent: All subjects should be given a copy of the consent document approved by the IRB for use in your study.

Completion: When the study is complete, you must notify the IRB office and complete the required forms.

PART 46.101 PROTECTION OF HUMAN SUBJECTS

46.101

(a) Except as provided in paragraph (b) of this section, this policy applies to all research involving human subjects conducted, supported or otherwise subject to regulation by any Federal Department or Agency which takes appropriate administrative action to make the policy applicable to such research. This includes research conducted by Federal civilian employees or military personnel, except that each Department or Agency head may adopt such procedural modifications as may be appropriate from an administrative standpoint. It also includes research conducted, supported, or otherwise subject to regulation by the Federal Government outside the United States.

(1) Research that is conducted or supported by a Federal Department or Agency, whether or not it is regulated as defined in 46.102(e), must comply with all sections of this policy.

(2) Research that is neither conducted nor supported by a Federal Department or Agency but is subject to regulation as defined in 46.102(e) must be reviewed and approved, in compliance with 46.101, 46.102, and 46.107 through 46.117 of this policy, by an Institutional Review Board (IRB) thatoperates in accordance with the pertinent requirements of this policy.

(b) Unless otherwise required by Department or Agency heads, research activities in which the only involvement of human subjects will be in one or more of the following categories are exempt from this policy:[1]

(1) Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless:
(i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

(3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if:
(i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) Federal statute(s) require(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.

(4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

(5) Research and demonstration projects which are conducted by or subject to the approval of Department or Agency heads, and which are designed to study, evaluate, or otherwise examine:
(i) Public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.

(6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed or (ii) if a food isconsumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration or approved by the Environmental Protection Agency or the Food Safety and Inspection Service of the U.S. Department of Agriculture.

VITA

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Research Interests:

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Building Energy Simulation