

Cost-Effective Energy Efficiency Measures for 15% Above 2009 IECC Code-Compliant House for Residential Buildings in Texas

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ABSTRACT

This paper presents cost-effective recommendations for achieving 15% above code-compliant house energy performance, which are based on the 2009 International Energy Conservation Code (IECC), for single-family residences across the State of Texas. The recommendations were developed for three 2009 IECC climate zones in Texas along with simple payback calculations. A total of seventeen measures based on the energy savings above the base-case house were selected. These measures include building envelope and fenestration, HVAC system, Domestic Hot Water (DHW) system, lighting, and renewable options. The implementation costs of each individual measure were also calculated along with simple payback calculations. These measures were then combined to achieve the total source energy savings of the group which were 15% above the base-case, 2009 IECC code-compliant house. For each climate zone, three combinations were developed for each house type: (a) electric/gas house and (b) all-electric house. Combinations were assembled to minimize payback. Finally, the corresponding NO_x, SO_x and CO₂ emissions savings for each combination were calculated based on the US EPA's eGrid database for Texas.

INTRODUCTION

In the 79th Legislature (2005) the Energy Systems Laboratory was required to develop three alternative methods for achieving 15% above-code energy savings in new residential, commercial and industrial construction. Since 2005, the Laboratory has continued to work closely with code officials, energy raters, manufacturers, state officials and other stakeholders to develop cost effective energy efficiency measures. This paper presents detailed information about the recommendations for achieving 15% above 2009 International Energy Conservation Code (IECC) code-compliant house energy performance for single-family residences across the State of Texas. To calculate the percent above the 2009 IECC code-compliant house from energy

efficiency measures, total source energy savings from heating, cooling, lighting, equipment, and DHW were considered for emissions reductions determination¹. This information is useful to homebuilders, code officials, utility demand side energy managers, homeowners and others who wish to construct residential buildings that exceed the minimum national energy code requirements².

METHODOLOGY

The analysis was performed using the Laboratory's simulation model, which is based on the DOE-2.1e simulation of a 2009 IECC code-compliant, single family residence³ and the appropriate TMY2 weather files. Seventeen counties in Texas for which TMY2 data is available (Figure 1) were selected and categorized into three climate zones (Climate Zone 2, 3, and 4) according to 2009 IECC Climate Zone classification. Of the seventeen counties, nine counties were classified as Climate Zone 2, and seven were classified as Climate Zone 3. For Climate Zone 4, only Potter County was simulated with the Amarillo TMY2 data.

To begin, the 2009 IECC code-compliant base-case models were constructed for each climate zone. The two options for the choice of heating fuel type were: (a) natural gas (gas-fired furnace for space heating and a gas water heater for domestic water heating), and (b) all electric (heat pump for space

¹ The end-uses covered by the 2009 IECC include heating, cooling, and DHW energy only per Section 405.1 of the 2009 IECC. The source energy multipliers of 3.16 for electricity and 1.1 for natural gas were applied to site energy use per Section 405.3 of the 2009 IECC.

² The energy efficiency provisions of the 2009 International Residential Code (IRC) are adopted as the energy code in Texas for single-family residential construction and become effective on January 1, 2012. Meeting the requirements of the 2009 IECC is one of the compliance options of the 2009 IRC per Section N1101.2 of the 2009 IRC.

³ The IC3, developed by the Energy Systems Laboratory (ESL) of the Texas A&M University System, is a Residential Energy Services Network (RESNET)-accredited web-based, code-compliance software to demonstrate the performance of proposed single family residences according to the Texas Building Energy Performance Standards (TBEPS).

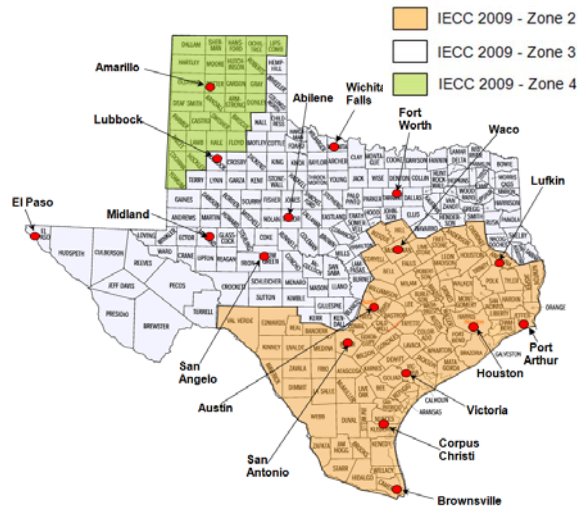


Figure 1. 2009 IECC Climate Zone Classification and Available TMY2 Weather Files in Texas

heating and electric water heater for domestic water heating)⁴. A total of seventeen energy efficiency measures were then applied to the base-case models to determine the savings of each measure. These measures were simulated by modifying the selected parameters used for the DOE-2 simulation model. The solar measures including solar PV and solar DHW were calculated using the PV-F Chart (Klein and Beckman 1994) and F-Chart (Klein and Beckman 1983) programs, respectively. The implementation costs for each measure were also calculated along with simple payback calculations. Cost information was obtained from various resources, including: Texas manufacturers, local contractors, and online suppliers.

To develop the recommendations by climate zone, the simulation results for seventeen counties were grouped according to the corresponding climate zone. The measures were then combined to achieve the total source energy savings of the group that is 15% more efficient than the base-case 2009 IECC code-compliant house. The results from individual measures and cost analysis were used to guide the selection of measures for the combined group analysis. For each combination, an additional, combined simulation was performed. The results include three combinations for each house type ((a) electric/gas house and (b) all-electric house) in each climate zone. Finally, the corresponding NO_x, SO_x and CO₂ emissions savings of each combination were

⁴ For the remainder of this report, these houses will be referred to as: (a) electric/gas house and (b) all-electric house, respectively.

calculated based on the US EPA's 2007 eGrid database for Texas⁵.

Base-Case Building Description

The base-case building simulation model in this analysis is based on the standard design as defined in Chapter 4 of the 2009 IECC and certain assumptions, which are described throughout this document. The base-case building is a 2,325 sq. ft., square-shape, one story, single-family, detached house oriented N, S, E, W, with a floor-to-ceiling height of 8 feet. Half of the lamps in the house are assumed to be Energy Star permanent CFL or fluorescent lamps. The house has an attic with a 23 degree pitched roof, with the HVAC systems and ductwork in the attic. The base-case building envelope and system characteristics were determined from the general characteristics and the climate-specific characteristics as specified in the 2009 IECC. Table 1 summarizes the base-case building characteristics used in the simulation model for each climate zone.

Assumptions for the Cost Analysis

The cost analysis for different measures was carried out based on utility costs of \$0.11/kWh for electricity and \$0.84/therm (Climate Zone 2) and \$0.64/therm (Climate Zone 3 and 4) for natural gas. The electric rate was determined based on the information compiled by the Public Utility Commission of Texas⁶. For the natural gas unit cost, annual average rates calculated for San Antonio⁷, Dallas⁸, and Amarillo⁹ were used in the analysis for Climate Zone 2, 3 and 4 respectively.

ENERGY EFFICIENCY MEASURES (EEMs) AND IMPLEMENTATION COSTS

Table 2 lists seventeen energy efficiency measures considered in this analysis. These measures

⁵ The emissions savings were calculated using the 2007 eGRID which were specially prepared for Texas by Mr. Art Diem at the US EPA.

⁶ PUCT. 2010. *Average Annual Rate Comparison for Residential Electric Service: July 2010*. Austin, TX: Public Utility Commission of Texas. Retrieved September 30, 2010, from <http://www.puc.state.tx.us/electric/rates/RESrate.cfm>

⁷ CPS Energy. 2010. *Fuel and Regulatory Charges*. San Antonio, TX: CPS Energy. Retrieved November 9, 2010, from http://www.cpsenergy.com/Residential/Billing_Payments/Fuel_and_Regulatory_Charges/index.asp

⁸ Atmos Energy. 2010a. *Atmos Energy Tariffs for Mid-Tex: September 2010 Mid-Tex GCR Rates*. Dallas, TX: Atmos Energy. Retrieved September 30, 2010, from <http://www.atmosenergy.com/about/tariffs.html?st=mtx&pass=1>

⁹ Atmos Energy. 2010b. *Atmos Energy Tariffs for West Texas: September 2010 Texas (West) GCA Rates*. Dallas, TX: Atmos Energy. Retrieved September 30, 2010, from <http://www.atmosenergy.com/about/tariffs.html?st=TX&pass=1>

Table 1. Base Case Building Description

Characteristics	Information Source	Assumptions			Comments
		2009 IECC Climate Zone: 2	2009 IECC Climate Zone: 3	2009 IECC Climate Zone: 4	
Building					
Building Type		Single family, detached house			
Gross Area	NAHB (2003)	2,325 sq. ft. (48.21 ft. x 48.21 ft.)			
Number of Floors	NAHB (2003)	1			
Floor to Floor Height (ft.)	NAHB (2003)	8			
Orientation		South facing			
Construction					
Construction	NAHB (2003)	Light-weight wood frame with 2x4 studs spaced at 16" on center			
Floor	NAHB (2003)	Slab-on-grade floor			
Roof Configuration	NAHB (2003)	Unconditioned, vented attic			
Roof Absorptance	2009 IECC, Table 405.5.2(1)	0.75			Solar reflectance SR= 0.25
Ceiling Insulation (hr-sq.ft.-°F/Btu)	2009 IECC, Table 402.1.3 (402.1.1)	R-27.84	R-32.51		
Wall Absorptance	2009 IECC, Table 405.5.2(1)	0.75			Assuming brick facia exterior
Wall Insulation (hr-sq.ft.-°F/Btu)	2009 IECC, Table 402.1.3 (402.1.1)	R-11.8			
Slab Perimeter Insulation	2009 IECC, Table 402.1.3 (402.1.1)	None	R-10		
Ground Reflectance	DOE2.1e User Manual (LBL 1993)	0.24			Assuming grass
U-Factor of Glazing (Btu/hr-sq.ft.-°F)	2009 IECC, Table 402.1.3	0.65	0.5	0.35	
Solar Heat Gain Coefficient (SHGC)	2009 IECC, Table 402.1.1	0.3		0.4	
Window Area	2009 IECC, Table 405.5.2 (1)	15% of conditioned floor area			This amounts to 348.75 sq. ft. window area and 22.61% window-to-wall area ratio for the assumed base case building configuration.
Exterior Shading		None			
Roof Radiant Barrier		No			Roof Radiant Barrier Emissivity=0.05
Slope of Roof		5:12			Steep slope (5:12 Slope of roof =23 degrees)
Space Conditions					
Space Temperature Set point	2009 IECC, Table 405.5.2 (1)	72°F Heating, 75°F Cooling, no set-back			
Internal Heat Gains	2009 IECC, Table 405.5.2 (1)	1.095 kW (modeled as 0.547 kW for lighting and 0.547 kW for equipment)			This assumes heat gains from lighting, equipment and occupants.
Number of Occupants	2009 IECC, Table 405.5.2 (1)	None			Assuming internal gains include heat gain from occupants
Mechanical Systems					
HVAC System Type		Gas & Electric Type: Electric cooling (air conditioner) and natural gas heating (gas fired furnace)			
		All Electric Type: Electric cooling and heating (air conditioner with heat pump)			
HVAC System Efficiency	2009 IECC, Table 503.2.3 (2), 503.2.3 (4)	Gas & Electric Type: SEER 13 AC, 0.78 AFUE furnace			
		All Electric Type: SEER 13 AC, 7.7 HSPF heat pump			
Cooling Capacity (Btu/hr)		55,800			500 sq. ft./ton
Heating Capacity (Btu/hr)		55,800			1.0 x cooling capacity
DHW System Type	Tank size from ASHRAE HVAC Systems and Equipment Handbook	Gas & Electric Type: 40-gallon tank type gas water heater with a standing pilot light			
		All Electric Type: 50-gallon tank type electric water heater (without a pilot light)			
DHW Heater Energy Factor	2009 IECC, Table 504.2	Gas & Electric Type: 0.594			Gas: 0.67-0.0019 V EF Electric: <=12 KW: 0.97-0.00132 V EF >12kW: 1.73V+155SL Btu/h Where V=storage volume (gal.)
		All Electric Type: 0.904			
Duct Location	NAHB (2003)	Unconditioned, vented attic			20-30%
Duct Leakage (%)	2009 IECC, Sec. 403.2.2	5.56% (supply) and 5.56% (return)			Total: 8 CFM/100 ft² to outdoor
Duct Insulation (hr-sq.ft.-°F/Btu)	2009 IECC, Sec. 403.2.1	R-8 (supply) and R-6 (return)			
HVAC Duct Static Pressure		1			
Supply Air Flow (CFM/ton)		360			
Infiltration Rate (SG)	2009 IECC, Table 405.5.2 (1), ASHRAE 119 Section 5.1	SLA= 0.00036			

include building envelope and fenestration, HVAC system, domestic hot water (DHW) system, lighting, and renewable options. In addition, two different house types were considered: (a) an electric/gas house and (b) an all-electric house.

1) Radiant Barrier in the Attic

This measure was simulated by inserting a radiant barrier in the attic model in a position directly beneath the sloped roof. It was estimated that installing a radiant barrier in an attic would increase the cost by \$300 - \$880.

Table 2. Energy Efficiency Measures

	EEM No	Electric/Gas House	All-Electric House
Envelope and Fenestration Measures	1	Radiant Barrier in Attics (with Ducts in Attics)	
	2	Sealed (Unvented) Attic	
	3	Window Shading (None to 2 ft. Eaves on All Sides)	
	4	Window Shading and Redistribution (22.6% Equal Windows on All Sides with No Shading to S=40.7%, N=22.6%, E/W = 13.6% with 2ft. Eaves on All Sides)	
	5 ¹⁾	Decreased Window SHGC (Climate Zone 2 & 3: from .3 to .2)	
	6	Decreased Window U Value (Climate Zone 2: from 0.65 to 0.3; Climate Zone 3: from 0.5 to 0.3; Climate Zone 4: from 0.35 to 0.3)	
	7 ¹⁾	Decreased Window SHGC & U Value (Climate Zone 2: from .3 to .2 SHGC & from 0.65 to 0.3 U-Value; Climate Zone 3: from .3 to .2 SHGC & from 0.5 to 0.3 U-Value)	
HVAC System Measures	8	Relocate Mechanical Systems within Conditioned Space	
	9	Improved Air Conditioner SEER (from 13 to 15 SEER)	Improved Heat Pump Efficiency (from 13 to 15 SEER and from 7.70 to 8.50 HSPF)
	10	Improved Furnace Efficiency (from 0.78 to 0.93 AFUE)	-
Domestic Hot Water Measures	11	Tankless Gas Water Heater (without a Standing Pilot Light)	-
	12	Removal of Pilot Light from Domestic Hot Water System	-
	13	Solar Domestic Hot Water System (32 sq. ft. collector, 65 gal tank)	
	14	Solar Domestic Hot Water System (64 sq. ft. collector, 80 gal tank)	
Lighting Measures	15	75% Energy Star Permanent CFL or Fluorescent Indoor Lamps	
	16	100% Energy Star Permanent CFL or Fluorescent Indoor Lamps	
Renewable Power	17	4 kW Photovoltaic Array	

1) EEM 5 and 7 were not applied to Climate Zone 4.

2) Sealed Attic

This measure analyzed the energy savings that would occur if the house had a sealed (unvented) attic with insulation installed on the sloped roof. The attic was assumed to have no leakage area. The house was assumed to be 25% tighter than the base-case house. The duct leakage was decreased by half: from a total of 11.2% to 5.6% duct leakage. It was estimated that sealing the attics would increase the cost by \$2,000 - \$3,500.

3) Window Shading

This measure was simulated by modeling two foot roof overhang on all four sides. The gross window area, orientation, and other characteristics were kept the same as the base-case house. It was estimated that this measure would increase the cost by \$800 - \$1,000.

4) Window Shading and Redistribution

For this measure, the house was simulated with the windows distributed 41% on the south, 23 % on the north, 14 % each on east and west orientations. A two foot roof overhang was also included on all four sides. Adding a two foot of roof overhang is estimated to increase the cost by \$800 - \$1,000.

However, window redistribution in a new construction would have no increased cost.

5) Decreased Window SHGC

In this option, the base-case Solar Heat Gain Coefficient (SHGC) value was 0.3 for Climate Zone 2 and 3. For the test-case house, a SHGC of 0.2 was used. For Potter County, this measure was not considered, due to negative savings because of the increased heating energy penalty. This measure was assumed to increase the cost by \$200 - \$400.

6) Decreased Window U-Value

In this option, the base-case U-Factor was taken as 0.65 Btu/h-sq.ft.-F for Climate Zone 2, 0.50 Btu/h-sq.ft.-F for Climate Zone 3, and 0.35 Btu/h-sq.ft.-F for Climate Zone 4. For the test-case house, a U-Factor of 0.30 Btu/h-sq.ft.-F was used. In this analysis, it was estimated that improving the U-value of the fenestration system would increase the cost by \$600 - \$900 for Climate Zone 2 and 3; and by \$350 - \$900 for Climate Zone 4.

7) Decreased Window SHGC and U-Value

In this option, a U-Factor of 0.30 Btu/h-sq.ft.-F and a SHGC of 0.2 were used for the test case with a similar base case as option six. For Potter County, this measure was not considered because of the increased heating energy penalty. This measure was estimated to increase the cost by \$900 - \$1,100.

8) Mechanical Systems within Conditioned Space

This measure analyzed the energy savings that would occur if the HVAC system, including the supply and return ductwork, was moved from the attic location, assumed in the base-case house, to a location within the thermal envelope of the conditioned space. Relocating mechanical systems within conditioned space was estimated to increase the cost by \$1,000 - \$7,000.

9) Improved Air Conditioner SEER

In this option, the Seasonal Energy Efficiency Ratio (SEER) 13 air conditioner in an electric/gas base-case house was replaced with a similarly sized SEER 15 air conditioner. For an all-electric house, the SEER 13/HSPF 7.7 heat pump was replaced with a similarly sized SEER 15/Heating Seasonal Performance Factor (HSPF) 8.5 heat pump. Replacing a SEER 13 air conditioner with a SEER 15 air conditioner was estimated to increase the cost by \$900 - \$2,500 in an electric/gas house. Replacing a SEER 13/HSPF 7.7 heat pump with a SEER 15/HSPF 8.5 heat pump would increase the cost by \$1,200 - \$2,500 in the all-electric house.

10) Improved Furnace Efficiency

For this simulation, the gas-fired furnace in an electric/gas base-case house (0.78 Annual Fuel Utilization Efficiency (AFUE)) was replaced with a similarly sized condensing furnace with an AFUE of 0.93. This measure did not include all-electric residences. Costs for this option were expected to be \$800 - \$1,300.

11) Tankless Gas Water Heater

This measure was simulated by increasing the DHW energy factor from 0.59 to 0.75¹⁰. This measure was applicable only for an electric/gas house that had a gas DHW heater and is expected to increase the cost by \$900 - \$1,400.

12) Removal of Pilot Light from Tank-Type Domestic Hot Water system

In order to simulate the impact of removing the standing pilot light, a higher energy factor of 0.66 was chosen. This measure is applicable only for an electric/gas house that has a gas DHW heater and would increase the cost by \$100 - \$500.

13 & 14) Solar Domestic Hot Water System

This measure analyzed the energy savings that would occur if the house had a solar DHW system, which is consisted of one or two 32 sq.ft. of flat plate solar collectors using the F-Chart program (Klein and Beckman 1983). In this analysis, the collector tilt was assumed to be the same as the latitude of the location. Any supplementary hot water heating was provided by the base-case water heating system. Also, additional electricity use was taken into account for operating the solar pump. This measure would increase the cost by \$2,200 - \$3,000 for 32 sq.ft. of collector and by \$3,200 - \$4,000 for 64 sq.ft. of collector.

15 & 16) EnergyStar Permanent CFL or Fluorescent Indoor Lamps

To calculate the energy savings from efficient lighting measures, an EnergyStar permanent CFL or fluorescent indoor fixtures were assumed using 75% less energy than an incandescent lamp providing the same lumen output. The calculated savings from replacing the existing incandescent lighting fixtures with CFL or fluorescent lamps were 0.445 kW for 75% replacements and 0.342 kW for 100% replacement for a 2,325 ft² house. The increased cost would be \$25 - \$110 for 75% replacements and \$50 - \$215 for 100% replacements.

17) 4kW Photovoltaic Array

The final test-case house was assumed to be grid-connected, 4 kW PV array of multi-crystalline solar cells (16% efficiency)¹¹. The analysis of the PV performance was conducted using the PV F-Chart program (Klein and Beckman 1994) and the appropriate TMY2 weather files. In this analysis, the array tilt was assumed to be the same as the latitude of the corresponding location. Installing a 4 kW photovoltaic array was estimated to increase the cost by \$20,000 - \$30,000.

RESULTS FOR INDIVIDUAL MEASURES

Table 3 to 5 summarize the detailed results of the simulations and cost analysis for three representative

¹⁰ The EF for the tankless water heater is based on a survey of manufacturers and recommendations of the Davis Energy Group (DEG 2006) which was relied upon in developing the 2008 California Building Energy Efficiency Standards.

¹¹ Kyocera KD210GX-LP (210Watt) and KD205GX-LP (205Watts) were referenced for the parameters required in the PV F-Chart program.

counties in each climate zone, including: Harris County for Climate Zone 2, Tarrant County for Climate Zone 3 and Potter County for Climate Zone 4. The same analysis was performed for an additional fourteen counties to develop the recommendations by climate zone.

Base-Case Energy Use

The base-case total annual source energy consumption of an electric/gas house was 232.7 MMBtu/yr for Harris County, 238.9 MMBtu/yr for Tarrant County, and 255.0 MMBtu/yr for Potter County. This includes: 1) Harris County: 23.2% for cooling, 10.7% for heating, 44.5% for lighting and equipment, 13.7% for fans and pumps, and 7.8% for domestic water heating; 2) Tarrant County: 20.4% for cooling, 14.7% for heating, 43.4% for lighting and equipment, 13.5% for fans and pumps, and 8.0% for domestic water heating; and 3) Potter County: 11.4% for cooling, 26.7% for heating, 40.6% for lighting and equipment, 12.6% for fans and pumps, and 8.6% for domestic water heating.

The base-case total annual source energy consumption of an all-electric house was 244.9 MMBtu/yr (71,776 kWh/yr) for Harris County, 250.0 MMBtu/yr (73,270 kWh/yr) for Tarrant County, and 282.5 MMBtu/yr (82,796 kWh/yr) for Potter County. This includes: 1) Harris County: 22.1% for cooling, 8.8% for heating, 42.3% for lighting and equipment, 12.9% for fans and pumps, and 13.9% for domestic water heating; 2) Tarrant County: 19.5% for cooling, 11.9% for heating, 41.5% for lighting and equipment, 12.6% for fans and pumps, and 14.5% for domestic water heating; and 3) Potter County: 10.3% for cooling, 26.2% for heating, 36.7% for lighting and equipment, 11.7% for fans and pumps, and 15.1% for domestic water heating.

This suggests that the measures that reduce lighting energy use will have a large impact on reducing the total energy use. For Potter County in Climate Zone 4, the measures that reduce the heating energy use will have a large impact on reducing the total energy use compared to Climate Zone 2 and 3 where it will have a lesser impact. It is also noted that since 2009 IECC code compliance is determined based on source energy consumption, measures that reduce electricity consumption will have more influence on savings (%) than measures that decrease natural gas consumption for an electric/gas house.

Energy Savings from Various EEMs

Of the seventeen measures, renewable energy option such as solar PV presented the largest savings in the range of 24.4% to 29.0% for both types of houses across all three counties. The replacements of existing incandescent lighting fixtures with Energy

Star permanent CFL or fluorescent lamps also resulted in considerable energy savings ranging from: 6.9% to 9.7% with 100% replacements; and 3.6% to 5.0% with 75% replacements.

Locating the HVAC unit and the ducts in the conditioned space resulted in a significant savings of 8.0% to 9.4% in an electric/gas house and 6.3% to 6.7% in an all-electric house across the three counties. The energy use reduction from improved AC efficiency with a SEER 15 air-conditioner was more pronounced for Harris and Tarrant County: 6.7% and 6.0% in an electric/gas house and 7.1% and 6.7% in an all-electric house, respectively. For Potter County in Climate Zone 4, the resultant savings were somewhat less at 4.1% in an electric/gas house and 5.6% in an all-electric house. The savings from improved furnace efficiency with a 0.93 AFUE furnace for an electric/gas house varied by climate zone: 1.7% for Harris County, 2.3% for Tarrant County, and 4.3% for Potter County.

Among the DHW measures, the solar DHW measures had a larger impact in an all-electric house than in an electric/gas house: (a) electric/gas house: 2.9% to 3.6% with a 32 sq.ft. collector and 4.6% to 5.7% with a 64 sq.ft. collector; and (b) all-electric house: 5.9% to 7.1% with a 32 sq.ft. collector and 8.8% to 10.3 with a 64 sq.ft. collector. Both the tankless water heater and the removal of the pilot light from the DHW for an electric/gas house resulted in small savings, less than 2%.

Among the envelope and fenestration measures, sealed (unvented) attics resulted in a significant savings of 5.6% to 7.7% in an electric/gas house and 4.4% to 5.6% in an all-electric house. Not surprisingly, higher savings (7.7% in an electric/gas house and 5.6% in an all-electric house) were observed for Potter County in Climate Zone 4. Improved windows by decreasing SHGC and U-value yielded a combined energy savings of: (a) electric/gas house: 7.9% for Harris County and 5.6% for Tarrant County and (b) all-electric house: 7.1% for Harris County and 5.6% for Tarrant County. For Potter County, decreasing SHGC measures (EEM 5 and 7) were not considered due to the negative savings because of the increased heating energy penalty.

The addition of overhangs was more effective when combined with a redistribution of the windows with a greater percentage of windows on the south and a lesser percentage of windows on the east and west. With combined window redistribution and overhang, the total energy savings were 2.8% to 3.0% in an electric/gas house, and 2.6% to 2.9% in an all-electric house. Finally, the savings from installing radiant barrier in attics were less than 2% for all cases. This lower value is consistent with other

studies that included well-insulated ducts and attic insulation.

Cost Effectiveness of Various EEMs

It should be noted that, due to the difference in the unit cost of electricity and gas, the total energy cost savings for a measure are not always of the same order as the total energy savings. These savings depend on the fuel type associated with the end use affected by that measure. Because of this, measures that reduced electricity use for space cooling or lighting and equipment in both types of houses and heating in the all-electric house resulted in significant energy cost savings compared to the measures that reduced only gas use. For example, the solar DHW measure with a 64 sq. ft. collector yielded a similar or higher savings (%) than the lighting measure that replaces 75% of existing incandescent lamps with Energy Star permanent CFL or fluorescent lamps in an electric/gas house, but the cost savings were much smaller because the cost savings from the significant reduction in gas use was offset by the increased cost of electricity use for operating the solar pump.

For both types of houses, solar PV and lighting measures that showed a significant reduction in electricity use were very effective in reducing the total energy cost. The measures that reduced electricity use for cooling and fans and pumps also resulted in high energy cost savings. These measures include sealed attic, improved windows, locating mechanical systems in the conditioned spaces, and improved AC efficiency. Solar DHW measures were more cost-effective for the all-electric housed.

To estimate the cost-effectiveness of measures, a simple payback was calculated using the implementation costs obtained from various resources. The cost-effectiveness of a measure depends upon the energy cost savings versus the cost of implementation. Most of the common measures had nearly equal payback periods for both type of houses, except for the solar DHW system. For the all-electric houses, the solar DHW system had a payback period of 11.6 to 20.2 years for Harris County; 11.4 to 16.2 years for Tarrant County; and 10.1 to 13.8 years for Potter County.

For both type of houses, the most cost-effective measures were lighting measures (EEM 15 to 16) with the shortest payback periods of 0.2 to 1.1 years across the counties. Improved window performance measures (EEM 5 to 7) yielded the second shortest payback periods (3.3 to 9.6 years) for Harris and Tarrant County. Installing radiant barrier in attics and improving the AC efficiency also yielded relatively short payback periods.

15% ENERGY SAVINGS ABOVE 2009 IECC CODE-COMPLIANT HOUSE

The savings results of seventeen counties were then grouped according to the corresponding 2009 IECC climate zone to develop the recommendations by climate zone. Grouped measures are the combination of individual measures. The results from individual measures and cost analysis were used to guide the selection of measures for this group analysis. The measures were then combined and resimulated to achieve the total source energy savings of the group is 15% above the base-case 2009 IECC code-compliant house. Because the measures are interdependent in many cases, the resultant savings of the grouped measures were not always the same as the sum of the savings of the individual measures. In a similar fashion as the analysis of the individual measures, the grouped measures were simulated by modifying all the parameters of combined individual measures. In each climate zone, three combinations were proposed for each base case: (a) electric/gas house with natural gas heating; and (b) all-electric house with heat pump heating. Figure 2 to 7 present the results of the analysis.

In each figure, the first table summarizes the results obtained from individual measures in terms of annual source energy savings, energy cost savings, estimated costs for each measure implemented individually, and payback period. The second table summarizes the results obtained by implementing three combinations of measures to achieve 15% or more total energy savings, and includes: energy savings, energy cost savings, estimated costs, and payback period for each combination. Information regarding the ozone emissions for each of the combinations is also presented in terms of combined annual NO_x, SO₂, and CO₂ emission savings.

The example groups represent one way of grouping to achieve 15% savings above the base case. In this analysis, each combination was intended to have a different payback period. The most cost-effective combination has a payback period of: (a) electric/gas house: 2.1 to 3.2 years for Climate Zone 2, 2.9 to 5.6 years for Climate Zone 3, and 4.8 to 7.3 years for Climate Zone 4; and (b) all-electric house: 2.1 to 3.2 years for Climate Zone 2, 2.9 to 5.5 years for Climate Zone 3, and 5.0 to 9.0 years for Climate Zone 4. On the other hand, a payback period of the least cost-effective combination is: (a) electric/gas house: 6.7 to 31.1 years for Climate Zone 2, 7.5 to 29.9 years for Climate Zone 3, and 8.3 to 36.8 years for Climate Zone 4; and (b) all-electric house: 10.1 to 28.6 years for Climate Zone 2, 9.1 to 27.0 years for Climate Zone 3, and 8.6 to 22.4 years for Climate Zone 4.

SUMMARY

This paper presents detailed information about recommendations for achieving 15% above code-compliant house energy performance, which are based on the 2009 International Energy Conservation Code (IECC), for single-family residences across the State of Texas. A total of seventeen measures were selected. The most cost-effective measures were lighting measures with the shortest payback periods of 0.2 to 1.1 years across the climate zones. Improved window performance measures (EEM 5 to 7) yielded the second shortest payback periods (2.5 to 13.8 years) for Climate Zone 2 and 3. Installing a radiant barrier in attics and improving the AC efficiency also yielded relatively short payback periods.

These measures were then combined to achieve a total source energy savings for the group of 15% above the base-case 2009 IECC code-compliant house. In each climate zone, three combinations were developed for each base case: (a) electric/gas house and (b) all-electric house. Each combination was formed to have a low payback period. The corresponding emissions savings of each combination were calculated based on the US EPA's eGrid database for Texas. The most cost-effective combination has a payback period of: (a) electric/gas house: 2.1 to 3.2 years for Climate Zone 2, 2.9 to 5.6 years for Climate Zone 3, and 4.8 to 7.3 years for Climate Zone 4; and (b) all-electric house: 2.1 to 3.2 years for Climate Zone 2, 2.9 to 5.5 years for Climate Zone 3, and 5.0 to 9.0 years for Climate Zone 4.

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Table 3. Simulation Results for Individual EEMs (Harris County, Climate Zone 2)

EEM #	Energy Efficiency Measure (EEM)	Source Energy Use by End-Uses (MMBtu/yr)					Source Energy Use by Fuel Types (MMBtu/yr)		Savings Above Base Case (Source %)			\$ Savings (\$/yr)	Increased Marginal Cost (\$)	Increased New System Cost (\$)	Payback (yrs)	
		Cooling	Heating	Lgt & Equip	Fans & Pumps	DHW	Total	Elec.	Gas	Elec.	Gas					Total
(a) Electric/Gas House Base Case (Harris County)		54.0	24.9	103.6	31.9	18.3	232.7	189.6	43.1							
Envelope and Fenetration Measures	1 Radiant Barrier in Attics (with Ducts in Attics)	51.5	24.2	103.6	30.3	18.3	228.0	185.5	42.5	2.2%	1.5%	2.0%	\$47		\$300 - \$880	6.4 - 18.7
	2 Sealed (Unvented) Attic	49.3	19.8	103.6	28.8	18.3	219.8	181.7	38.1	4.2%	11.7%	5.6%	\$119	\$2,000 - \$3,500		16.8 - 29.4
	3 Window Shading (2ft overhang on all sides)	49.9	25.7	103.6	30.0	18.3	227.6	183.6	44.0	3.2%	-2.0%	2.2%	\$55		\$800 - \$1,000	14.7 - 18.3
	4 Window Shading and Redistribution (2ft overhang on all sides, S=40.70%, N=22.61%, E/W = 13.57%)	49.6	25.2	103.6	29.4	18.3	226.1	182.6	43.5	3.7%	-0.8%	2.8%	\$68		\$800 - \$1,000	11.7 - 14.6
	5 Decreased SHGC (CZ 2: from .3 to .2)	49.0	26.8	103.6	29.7	18.3	227.4	182.3	45.1	3.8%	-4.6%	2.3%	\$59	\$200 - \$400		3.4 - 6.8
	6 Decreased U Value (CZ 2: from 0.65 to 0.3)	49.6	19.6	103.6	28.4	18.3	219.5	181.7	37.8	4.2%	12.2%	5.7%	\$121	\$600 - \$900		5.0 - 7.4
	7 Decreased SHGC (CZ 2: from .3 to .2) & U Value (CZ 2: from 0.65 to 0.3)	44.6	21.6	103.6	26.2	18.3	214.3	174.4	39.8	8.0%	7.7%	7.9%	\$180	\$900 - \$1,100		5.0 - 6.1
HVAC System Measures	8 Mechanical Systems Within Conditioned Spaces	45.5	20.4	103.6	26.2	18.3	214.0	175.4	38.6	7.5%	10.5%	8.0%	\$180	\$1,000 - \$7,000		5.6 - 39.0
	9 Improved SEER (from 13 to 15)	45.5	25.4	103.6	24.3	18.3	217.2	173.5	43.7	8.5%	-1.3%	6.7%	\$160	\$900 - \$2,500		5.6 - 15.6
	10 Improved Furnace Efficiency (from .78 to .93 AFUE)	54.0	20.9	103.6	31.9	18.3	228.8	189.6	39.2	0.0%	9.2%	1.7%	\$30	\$800 - \$1,300		26.5 - 43.0
Domestic Hot Water Measures	11 Tankless Gas Water Heater (from .594 to .748 Energy Factor)	54.0	24.9	103.6	31.9	14.4	228.9	189.6	39.3	0.0%	8.9%	1.7%	\$29	\$900 - \$1,400		30.6 - 47.6
	12 Removal of Pilot Light from DHW	54.0	24.9	103.6	31.9	16.4	230.9	189.6	41.3	0.0%	4.3%	0.8%	\$14	\$100 - \$500		7.0 - 35.0
	13 Solar DHW System (32 sq. ft. collector, 65 gal tank)	54.0	24.9	103.6	36.3	7.1	226.0	194.0	32.0	-2.3%	25.8%	2.9%	\$40		\$2,200 - \$3,000	55.0 - 75.0
	14 Solar DHW System (64 sq. ft. collector, 65 gal tank)	54.0	24.9	103.6	36.3	3.1	222.0	194.0	27.9	-2.3%	35.2%	4.6%	\$71		\$3,200 - \$4,000	45.1 - 56.4
Lighting Measures	15 75% Energy Star Permanent CFL or Fluorescent Indoor Lamps	51.8	26.2	93.9	31.0	18.3	221.1	176.6	44.4	6.8%	-3.1%	5.0%	\$122	\$25 - \$110		0.2 - 0.9
	16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps	49.9	27.5	84.1	30.3	18.3	210.1	164.3	45.8	13.3%	-6.1%	9.7%	\$238	\$50 - \$215		0.2 - 0.9
Renewable Power Options	17 4 kW PV Array	37.0	24.9	71.0	21.9	18.3	172.9	129.8	43.1	31.5%	0.0%	25.7%	\$610		\$20,000 - \$30,000	32.8 - 49.2
(b) All-Electric House¹⁾ Base Case (Harris County)		54.0	21.5	103.6	31.6	34.1	244.9	244.9	-							
Envelope and Fenetration Measures	1 Radiant Barrier in Attics (with Ducts in Attics)	51.5	21.2	103.6	30.0	34.1	240.5	240.5	-	1.8%	-	1.8%	\$45		\$300 - \$880	6.6 - 19.5
	2 Sealed (Unvented) Attic	49.3	18.0	103.6	29.1	34.1	234.2	234.2	-	4.4%	-	4.4%	\$110	\$2,000 - \$3,500		18.2 - 31.9
	3 Window Shading (2ft overhang on all sides)	49.9	22.1	103.6	29.7	34.1	239.5	239.5	-	2.2%	-	2.2%	\$55		\$800 - \$1,000	14.6 - 18.2
	4 Window Shading and Redistribution (2ft overhang on all sides, S=40.70%, N=22.61%, E/W = 13.57%)	49.6	21.8	103.6	29.4	34.1	238.6	238.6	-	2.6%	-	2.6%	\$65		\$800 - \$1,000	12.4 - 15.5
	5 Decreased SHGC (CZ 2: from .3 to .2)	49.0	22.8	103.6	29.4	34.1	238.9	238.9	-	2.5%	-	2.5%	\$61	\$200 - \$400		3.3 - 6.5
	6 Decreased U Value (CZ 2: from 0.65 to 0.3)	49.6	18.0	103.6	28.4	34.1	233.8	233.8	-	4.5%	-	4.5%	\$113	\$600 - \$900		5.3 - 8.0
	7 Decreased SHGC (CZ 2: from .3 to .2) & U Value (CZ 2: from 0.65 to 0.3)	44.6	19.3	103.6	25.9	34.1	227.5	227.5	-	7.1%	-	7.1%	\$177	\$900 - \$1,100		5.1 - 6.2
HVAC System Measures	8 Mechanical Systems Within Conditioned Spaces	45.5	18.3	103.6	27.2	34.1	228.8	228.8	-	6.6%	-	6.6%	\$164	\$1,000 - \$7,000		6.1 - 42.6
	9 Improved SEER (from 13 to 15) and Heat Pump Efficiency (from 7.70 to 8.50 HSPF)	45.5	20.2	103.6	24.0	34.1	227.5	227.5	-	7.1%	-	7.1%	\$177	\$1,200 - \$2,500		6.8 - 14.1
Domestic Hot Water Measures	13 Solar DHW System (32 sq. ft. collector, 65 gal tank)	54.0	21.5	103.6	36.0	15.2	230.4	230.4	-	5.9%	-	5.9%	\$148		\$2,200 - \$3,000	14.8 - 20.2
	14 Solar DHW System (64 sq. ft. collector, 65 gal tank)	54.0	21.5	103.6	36.0	8.2	223.4	223.4	-	8.8%	-	8.8%	\$220		\$3,200 - \$4,000	14.6 - 18.2
Lighting Measures	15 75% Energy Star Permanent CFL or Fluorescent Indoor Lamps	51.8	22.4	93.9	30.7	34.1	232.9	232.9	-	4.9%	-	4.9%	\$123	\$25 - \$110		0.2 - 0.9
	16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps	49.9	23.4	84.1	30.0	34.1	221.5	221.5	-	9.5%	-	9.5%	\$239	\$50 - \$215		0.2 - 0.9
Renewable Power Options	17 4 kW PV Array	40.8	16.2	78.3	23.9	25.8	185.1	185.1	-	24.4%	-	24.4%	\$610		\$20,000 - \$30,000	32.8 - 49.2

1) EEM 10,11 and 12 were not applied to All-Electric House.

Table 4. Simulation Results for Individual EEMs (Tarrant County, Climate Zone 3)

EEM #	Energy Efficiency Measure (EEM)	Source Energy Use by End-Uses (MMBtu/yr)					Source Energy Use by Fuel Type (MMBtu/yr)		Savings Above Base Case (Source %)			\$ Savings (\$/yr)	Increased Marginal Cost (\$)	Increased New System Cost (\$)	Payback (yrs)	
		Cooling	Heating	Lgt & Equip	Fans & Pumps	DHW	Total	Elec.	Gas	Elec.	Gas					Total
	(a) Electric/Gas House Base Case (Tarrant County)	48.7	35.2	103.6	32.2	19.1	238.9	184.5	54.3							
Envelope and Fenetration Measures	1 Radiant Barrier in Attics (with Ducts in Attics)	46.1	34.5	103.6	30.7	19.1	234.1	180.4	53.7	2.2%	1.2%	2.0%	\$46		\$300 - \$880	6.6 - 19.2
	2 Sealed (Unvented) Attic	44.9	28.6	103.6	29.1	19.1	225.3	177.6	47.7	3.8%	12.1%	5.7%	\$109	\$2,000 - \$3,500		18.3 - 32.0
	3 Window Shading (2ft overhang on all sides)	44.6	36.6	103.6	30.0	19.1	234.0	178.2	55.8	3.4%	-2.6%	2.0%	\$56		\$800 - \$1,000	14.2 - 17.8
	4 Window Shading and Redistribution (2ft overhang on all sides, S=40.70%, N=22.61%, E/W = 13.57%)	43.9	35.4	103.6	29.7	19.1	231.8	177.3	54.6	3.9%	-0.4%	3.0%	\$73		\$800 - \$1,000	11.0 - 13.7
	5 Decreased SHGC (CZ 3: from .3 to .2)	43.9	38.3	103.6	30.3	19.1	235.3	177.9	57.4	3.6%	-5.7%	1.5%	\$50	\$200 - \$400		4.0 - 8.0
	6 Decreased U Value (CZ3: from 0.5 to 0.3)	43.9	33.0	103.6	29.1	19.1	228.8	176.6	52.1	4.3%	4.0%	4.2%	\$93	\$600 - \$900		6.4 - 9.6
	7 Decreased SHGC (CZ 3: from .3 to .2) & U Value (CZ3: from 0.5 to 0.3)	39.2	36.3	103.6	27.2	19.1	225.4	170.0	55.4	7.9%	-2.0%	5.6%	\$142	\$900 - \$1,100		6.3 - 7.8
HVAC System Measures	8 Mechanical Systems Within Conditioned Spaces	41.1	28.9	103.6	26.5	19.1	219.3	171.3	48.1	7.2%	11.5%	8.2%	\$172	\$1,000 - \$7,000		5.8 - 40.7
	9 Improved SEER (from 13 to 15)	41.1	36.0	103.6	24.6	19.1	224.5	169.4	55.1	8.2%	-1.4%	6.0%	\$150	\$900 - \$2,500		6.0 - 16.6
Domestic Hot Water Measures	10 Improved Furnace Efficiency (from .78 to .93 AFUE)	48.7	29.6	103.6	32.2	19.1	233.3	184.5	48.7	0.0%	10.3%	2.3%	\$33	\$800 - \$1,300		24.5 - 39.8
	11 Tankless Gas Water Heater (from .594 to .748 Energy Factor)	48.7	35.2	103.6	32.2	15.2	234.9	184.5	50.4	0.0%	7.3%	1.7%	\$23	\$900 - \$1,400		39.1 - 60.8
	12 Removal of Pilot Light from DHW	48.7	35.2	103.6	32.2	17.3	237.0	184.5	52.5	0.0%	3.4%	0.8%	\$11	\$100 - \$500		9.2 - 46.0
	13 Solar DHW System (32 sq. ft. collector, 65 gal tank)	48.7	35.2	103.6	36.6	6.4	230.6	188.9	41.6	-2.4%	23.4%	3.5%	\$32		\$2,200 - \$3,000	67.7 - 92.4
Lighting Measures	14 Solar DHW System (64 sq. ft. collector, 65 gal tank)	48.7	35.2	103.6	36.6	2.7	226.9	188.9	37.9	-2.4%	30.2%	5.0%	\$51		\$3,200 - \$4,000	63.2 - 79.0
	15 75% Energy Star Permanent CFL or Fluorescent Indoor Lamps	47.1	37.0	93.9	31.6	19.1	228.6	172.5	56.1	6.5%	-3.2%	4.3%	\$112	\$25 - \$110		0.2 - 1.0
Renewable Power Options	16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps	45.2	38.7	84.1	31.0	19.1	218.1	160.2	57.9	13.2%	-6.5%	8.7%	\$228	\$50 - \$215		0.2 - 0.9
	17 4 kW PV Array	30.8	35.2	65.5	20.4	19.1	171.0	116.7	54.3	36.8%	0.0%	28.4%	\$692		\$20,000 - \$30,000	28.9 - 43.3
	(b) All-Electric House¹⁾ Base Case (Tarrant County)	48.7	29.7	103.6	31.6	36.3	250.0	250.0	-							
Envelope and Fenetration Measures	1 Radiant Barrier in Attics (with Ducts in Attics)	46.1	29.4	103.6	30.0	36.3	245.5	245.5	-	1.8%	-	1.8%	\$45		\$300 - \$880	6.6 - 19.5
	2 Sealed (Unvented) Attic	44.9	25.3	103.6	29.7	36.3	239.8	239.8	-	4.0%	-	4.0%	\$103	\$2,000 - \$3,500		19.4 - 33.9
	3 Window Shading (2ft overhang on all sides)	44.6	30.7	103.6	29.4	36.3	244.6	244.6	-	2.1%	-	2.1%	\$55		\$800 - \$1,000	14.6 - 18.2
	4 Window Shading and Redistribution (2ft overhang on all sides, S=40.70%, N=22.61%, E/W = 13.57%)	43.9	29.7	103.6	29.1	36.3	242.7	242.7	-	2.9%	-	2.9%	\$74		\$800 - \$1,000	10.8 - 13.5
	5 Decreased SHGC (CZ 3: from .3 to .2)	43.9	31.6	103.6	29.4	36.3	244.9	244.9	-	2.0%	-	2.0%	\$52	\$200 - \$400		3.9 - 7.8
	6 Decreased U Value (CZ3: from 0.5 to 0.3)	43.9	28.1	103.6	28.4	36.3	240.5	240.5	-	3.8%	-	3.8%	\$97	\$600 - \$900		6.2 - 9.3
	7 Decreased SHGC (CZ 3: from .3 to .2) & U Value (CZ3: from 0.5 to 0.3)	39.2	30.3	103.6	26.5	36.3	236.1	236.1	-	5.6%	-	5.6%	\$142	\$900 - \$1,100		6.3 - 7.8
HVAC System Measures	8 Mechanical Systems Within Conditioned Spaces	41.1	25.3	103.6	27.8	36.3	234.2	234.2	-	6.3%	-	6.3%	\$161	\$1,000 - \$7,000		6.2 - 43.4
	9 Improved SEER (from 13 to 15) and Heat Pump Efficiency (from 7.70 to 8.50 HSPF)	41.1	28.1	103.6	24.0	36.3	233.2	233.2	-	6.7%	-	6.7%	\$171	\$1,200 - \$2,500		7.0 - 14.6
Domestic Hot Water Measures	13 Solar DHW System (32 sq. ft. collector, 65 gal tank)	48.7	29.7	103.6	36.0	14.1	232.1	232.1	-	7.1%	-	7.1%	\$193		\$2,200 - \$3,000	11.4 - 15.6
	14 Solar DHW System (64 sq. ft. collector, 65 gal tank)	48.7	29.7	103.6	36.0	7.8	225.8	225.8	-	9.7%	-	9.7%	\$246		\$3,200 - \$4,000	13.0 - 16.2
Lighting Measures	15 75% Energy Star Permanent CFL or Fluorescent Indoor Lamps	47.1	31.0	93.9	31.0	36.3	239.2	239.2	-	4.3%	-	4.3%	\$110	\$25 - \$110		0.2 - 1.0
	16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps	45.2	31.9	84.1	30.3	36.3	227.8	227.8	-	8.8%	-	8.8%	\$226	\$50 - \$215		0.2 - 1.0
Renewable Power Options	17 4 kW PV Array	35.5	21.6	75.5	23.0	26.5	182.1	182.1	-	27.1%	-	27.1%	\$692		\$20,000 - \$30,000	28.9 - 43.3

1) EEM 10,11 and 12 were not applied to All-Electric House.

Table 5. Simulation Results for Individual EEMs (Potter County, Climate Zone 4)

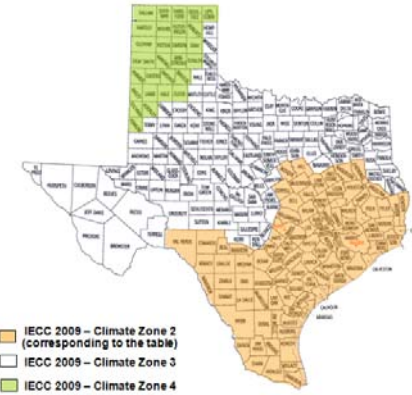
	EEM #	Energy Efficiency Measure (EEM)	Source Energy Use by End-Uses (MMBtu/yr)					Source Energy Use by Fuel Type (MMBtu/yr)		Savings Above Base Case (Source %)			\$ Savings (\$/yr)	Increased Marginal Cost (\$)	Increased New System Cost (\$)	Payback (yrs)	
			Cooling	Heating	Lgt & Equip	Fans & Pumps	DHW	Total	Elec.	Gas	Elec.	Gas					Total
		(a) Electric/Gas House Base Case (Potter County¹)	29.1	68.1	103.6	32.2	22.0	255.0	165.0	90.1							
Envelope and Fenetration Measures	1	Radiant Barrier in Attics (with Ducts in Attics)	27.2	67.2	103.6	31.0	22.0	251.0	161.8	89.2	1.9%	1.0%	1.6%	\$37		\$300 - \$880	8.0 - 23.6
	2	Sealed (Unvented) Attic	26.5	55.1	103.6	28.1	22.0	235.4	158.3	77.1	4.0%	14.4%	7.7%	\$143	\$2,000 - \$3,500		14.0 - 24.4
	3	Window Shading (2ft overhang on all sides)	24.6	70.8	103.6	30.3	22.0	251.5	158.6	92.8	3.8%	-3.1%	1.4%	\$48		\$800 - \$1,000	16.5 - 20.6
	4	Window Shading and Redistribution (2ft overhang on all sides, S=40.70%, N=22.61%, E/W = 13.57%)	24.0	68.8	103.6	29.4	22.0	247.8	157.1	90.8	4.8%	-0.7%	2.8%	\$77		\$800 - \$1,000	10.4 - 13.0
	6	Decreased U Value (C24 from 0.35 to 0.3)	29.4	64.8	103.6	31.6	22.0	251.4	164.6	86.8	0.2%	3.7%	1.4%	\$22	\$350 - \$900		15.6 - 40.1
HVAC System Measures	8	Mechanical Systems Within Conditioned Spaces	25.0	53.8	103.6	26.5	22.0	230.9	155.2	75.8	5.9%	15.9%	9.4%	\$183	\$1,000 - \$7,000		5.5 - 38.2
	9	Improved SEER (from 13 to 15)	24.3	69.6	103.6	25.0	22.0	244.6	152.9	91.6	7.3%	-1.7%	4.1%	\$114	\$900 - \$2,500		7.9 - 22.0
	10	Improved Furnace Efficiency (from .78 to .93 AFUE)	29.1	57.2	103.6	32.2	22.0	244.2	165.0	79.2	0.0%	12.1%	4.3%	\$63	\$800 - \$1,300		12.6 - 20.5
Domestic Hot Water Measures	11	Tankless Gas Water Heater (from .594 to .748 Energy Factor)	29.1	68.1	103.6	32.2	18.2	251.2	165.0	86.2	0.0%	4.3%	1.5%	\$22	\$900 - \$1,400		40.2 - 62.5
	12	Removal of Pilot Light from DHW	29.1	68.1	103.6	32.2	20.1	253.2	165.0	88.2	0.0%	2.1%	0.7%	\$11	\$100 - \$500		9.2 - 46.0
	13	Solar DHW System (32 sq. ft. collector, 65 gal tank)	29.1	68.1	103.6	36.6	8.5	245.9	169.4	76.6	-2.7%	15.0%	3.6%	\$38		\$2,200 - \$3,000	58.2 - 79.4
Lighting Measures	14	Solar DHW System (64 sq. ft. collector, 65 gal tank)	29.1	68.1	103.6	36.6	3.1	240.5	169.4	71.1	-2.7%	21.0%	5.7%	\$65		\$3,200 - \$4,000	49.0 - 61.2
	15	75% Energy Star Permanent CFL or Fluorescent Indoor Lamps	27.5	70.5	93.9	31.9	22.0	245.8	153.3	92.5	7.1%	-2.7%	3.6%	\$105	\$25 - \$110		0.2 - 1.0
Renewable Power Options	16	100% Energy Star Permanent CFL or Fluorescent Indoor Lamps	26.2	72.9	84.1	31.6	22.0	236.8	141.9	94.9	14.0%	-5.4%	7.1%	\$207	\$50 - \$215		0.2 - 1.0
	17	4 kW PV Array	16.0	68.1	57.1	17.8	22.0	181.0	90.9	90.1	44.9%	0.0%	29.0%	\$756		\$20,000 - \$30,000	26.5 - 39.7
		(b) All-Electric House² Base Case (Potter County¹)	29.1	73.9	103.6	33.2	42.7	282.5	282.5	-							
Envelope and Fenetration Measures	1	Radiant Barrier in Attics (with Ducts in Attics)	27.2	73.0	103.6	31.9	42.7	278.4	278.4	-	1.5%	-	1.5%	\$42		\$300 - \$880	7.2 - 21.0
	2	Sealed (Unvented) Attic	26.5	62.9	103.6	31.0	42.7	266.7	266.7	-	5.6%	-	5.6%	\$161	\$2,000 - \$3,500		12.4 - 21.7
	3	Window Shading (2ft overhang on all sides)	24.6	75.8	103.6	31.3	42.7	278.1	278.1	-	1.6%	-	1.6%	\$45		\$800 - \$1,000	17.7 - 22.2
	4	Window Shading and Redistribution (2ft overhang on all sides, S=40.70%, N=22.61%, E/W = 13.57%)	24.0	73.9	103.6	30.3	42.7	274.6	274.6	-	2.8%	-	2.8%	\$81		\$800 - \$1,000	9.9 - 12.4
	6	Decreased U Value (C24 from 0.35 to 0.3)	29.4	71.1	103.6	32.5	42.7	279.3	279.3	-	1.1%	-	1.1%	\$32	\$350 - \$900		10.9 - 28.0
HVAC System Measures	8	Mechanical Systems Within Conditioned Spaces	25.0	61.3	103.6	31.0	42.7	263.5	263.5	-	6.7%	-	6.7%	\$193	\$1,000 - \$7,000		5.2 - 36.2
	9	Improved SEER (from 13 to 15) and Heat Pump Efficiency (from 7.70 to 8.50 HSPF)	24.3	70.5	103.6	25.6	42.7	266.7	266.7	-	5.6%	-	5.6%	\$161	\$1,200 - \$2,500		7.4 - 15.5
Domestic Hot Water Measures	13	Solar DHW System (32 sq. ft. collector, 65 gal tank)	29.1	73.9	103.6	37.6	18.1	262.3	262.3	-	7.1%	-	7.1%	\$217		\$2,200 - \$3,000	10.1 - 13.8
	14	Solar DHW System (64 sq. ft. collector, 65 gal tank)	29.1	73.9	103.6	37.6	9.1	253.4	253.4	-	10.3%	-	10.3%	\$297		\$3,200 - \$4,000	10.8 - 13.5
Lighting Measures	15	75% Energy Star Permanent CFL or Fluorescent Indoor Lamps	27.5	75.5	93.9	32.9	42.7	272.4	272.4	-	3.6%	-	3.6%	\$103	\$25 - \$110		0.2 - 1.1
	16	100% Energy Star Permanent CFL or Fluorescent Indoor Lamps	26.2	77.4	84.1	32.5	42.7	262.9	262.9	-	6.9%	-	6.9%	\$200	\$50 - \$215		0.3 - 1.1
Renewable Power Options	17	4 kW PV Array	21.4	54.6	76.5	24.5	31.5	208.4	208.4	-	26.2%	-	26.2%	\$756		\$20,000 - \$30,000	26.5 - 39.7

1) EEM 5 and 7 were not applied to Climate Zone 4.
 2) EEM 10,11 and 12 were not applied to All-Electric House.

Natural Gas Heating (Climate Zone 2)

Description of Individual Measures

Individual Measures	Annual Source Energy Savings (%) ¹	Annual Energy Savings (\$/year) ²	Estimated Cost (\$)		Simple Estimated Payback (yrs)
			Marginal Cost ³	New System Cost ⁴	
A Envelope and Fenestration Measures					
1 Radiant Barrier in Attics (with Ducts in Attics) (L;a;b;H;h) ⁷	1.6% - 2.5%	\$38 - \$57		\$300 - \$880	5.2 - 23.2
2 Sealed (Unvented) Attic (L;a;c;g;H;i)	5.4% - 6.6%	\$116 - \$145	\$2,000 - \$3,500		13.8 - 30.2
3 Window Shading (None to 2 ft. Eaves on All Sides) (L;i;H;a)	2.0% - 2.6%	\$52 - \$65		\$800 - \$1,000	12.3 - 19.2
4 Window Shading and Redistribution (22.6% Equal Windows on All Sides with No Shading to S=40.7%, N=22.6%, E/W = 13.6% with 2ft. Eaves on All Sides) (L;i;H;g)	2.7% - 3.0%	\$66 - \$73		\$800 - \$1,000	10.9 - 15.1
5 Decreased Window SHGC (Climate Zone 2: from 0.3 to 0.2) (L;i;H;a)	1.7% - 3.2%	\$51 - \$81	\$200 - \$400		2.5 - 7.8
6 Decreased Window U Value (Climate Zone 2: from 0.65 to 0.3) (L;a;H;i)	4.8% - 6.7%	\$111 - \$148	\$600 - \$900		4.0 - 8.1
7 Decreased Window SHGC & U Value (Climate Zone 2: from 0.3 to 0.2 SHGC & from 0.65 to 0.3 U-Value) (L;e;H;d)	7.9% - 8.6%	\$179 - \$201	\$900 - \$1,100		4.5 - 6.1
B HVAC System Measures					
8 Relocate Mechanical Systems within Conditioned Space (L;a;H;i)	7.5% - 8.5%	\$173 - \$195	\$1,000 - \$7,000		5.1 - 40.5
9 Improved Air Conditioner SEER (from 13 to 15 SEER) (L;h;H;a)	6.1% - 8.5%	\$146 - \$211	\$900 - \$2,500		4.3 - 17.1
10 Improved Furnace Efficiency (from 0.78 to 0.93 AFUE) (L;a;H;i)	0.6% - 2.5%	\$12 - \$47	\$800 - \$1,300		17.0 - 110.5
C Domestic Hot Water Measures					
11 Tankless Gas Water Heater (without a Standing Pilot Light) (L;a;d,g,i;H;b,c,e,f,h)	1.6% - 1.7%	\$29 - \$30	\$900 - \$1,400		29.8 - 47.6
12 Removal of Pilot Light from Tank-Type Hot Water System (L=H;a,b,c,d,e,f,g,h,i)	0.8% - 0.8%	\$14 - \$15	\$100 - \$500		6.6 - 35.0
13 Solar Domestic Hot Water System (32 sq. ft. collector, 65 gal tank) (L;e;H;d)	2.9% - 3.6%	\$40 - \$55		\$2,200 - \$3,000	40.3 - 75.0
14 Solar Domestic Hot Water System (64 sq. ft. collector, 80 gal tank) (L;a;H;h)	4.3% - 5.0%	\$68 - \$79		\$3,200 - \$4,000	40.3 - 58.4
D Lighting Measures					
15 75% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L;i;H;a,c)	4.3% - 5.1%	\$111 - \$130	\$25 - \$110		0.2 - 1.0
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L;i;H;a)	8.5% - 10.3%	\$222 - \$259	\$50 - \$215		0.2 - 1.0
E Renewable Power Measures					
17 4 kW Photovoltaic Array (L;b;H;d)	25.3% - 28.0%	\$610 - \$686		\$20,000 - \$30,000	29.2 - 49.2



Description of Combined Measures to Achieve 15% Savings Above 2009 IECC Code-Compliant House

Combination of Measures ⁵	Combined Source Energy Savings	Combined Energy Savings (\$/year) ²	Combined Estimated Cost (\$)		Simple Estimated Payback (yrs)	NO _x Emissions Annual (lbs/yr)	SO ₂ Emissions Annual (lbs/yr)	CO ₂ Emissions Annual (tons/yr) ⁶
			Marginal Cost ³	New System Cost ⁴				
Combination 1 (L;i;H;a)⁷								
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L;i;H;a)	16.9% - 18.6%	\$406 - \$461	\$50 - \$215		2.1 - 3.2	5.8 - 6.6	3.6 - 4.1	2.5 - 2.8
7 Decreased Window SHGC & U Value (Climate Zone 2: from 0.3 to 0.2 SHGC & from 0.65 to 0.3 U-Value) (L;e;H;d)			\$900 - \$1,100					
Combination 2 (L;f;H;a)								
7 Decreased Window SHGC & U Value (Climate Zone 2: from 0.3 to 0.2 SHGC & from 0.65 to 0.3 U-Value) (L;e;H;d)	15.0% - 16.6%	\$333 - \$406	\$900 - \$1,100		5.2 - 13.5	4.7 - 5.8	2.8 - 3.5	2.0 - 2.5
9 Improved Air Conditioner SEER (from 13 to 15 SEER) (L;h;H;a)			\$900 - \$2,500					
1 Radiant Barrier in Attics (with Ducts in Attics) (L;a;b;H;h)			\$300 - \$880					
Combination 3 (L;f;H;a)								
8 Relocate Mechanical Systems within Conditioned Space (L;a;H;i)	15.0% - 16.4%	\$338 - \$405	\$1,000 - \$7,000		6.7 - 31.1	4.8 - 5.8	2.8 - 3.6	2.1 - 2.5
9 Improved Air Conditioner SEER (from 13 to 15 SEER) (L;h;H;a)			\$900 - \$2,500					
3 Window Shading (None to 2 ft. Eaves on All Sides) (L;i;H;a)			\$800 - \$1,000					

Note:

- Total source energy savings from heating, cooling, lighting, equipment and DHW for emissions reductions determination.
- Savings depend on fuel mix used.
 - Energy Cost: Electricity = \$0.11/kWh
 - Natural gas = \$0.84/therm
- Marginal cost = new system cost - original system cost
- New system cost = new system cost only
- See individual measures above for specific savings
- Conversion factor: 1 ton = 2,000 lbs
- L = County with the low est annual source energy savings; H = County with the highest annual source energy savings
 County code: a = Cameron; b = Nueces; c = Victoria; d = Bexar; e = Harris; f = Jefferson; g = Travis; h = Angelina; i = McLennan

[2009 IECC Code-Compliant House Description]

- * Building type: Residential
- * Gross area: 2,325 sq-ft
- * Building dimension: 48.2ft x 48.2ft x 8ft (WxLxH)
- * Number of floors: 1
- * Floor-to-floor height: 8ft
- * Window -to-floor ratio: 15% (Window -to-wall ratio: 22.6%)
- * Lighting: 50% Energy Star permanent CFL or fluorescent lamps
- * HVAC system: SEER 13 AC and 0.78 AFUE furnace
- * DHW: 0.59 EF NG heater
- * Duct Location: Unconditioned, vented attic
- * Duct Leakage to Outdoor: 8 cfm/100 sq-ft CFA

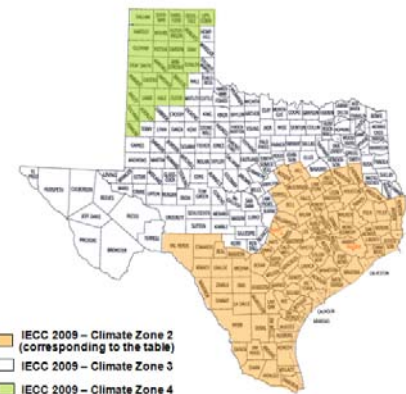


Figure 2. 15% Total Source Energy Savings Above 2009 IECC Code-Compliant House for an Electric/Gas House in Climate Zone 2, TX

Heat Pump Heating (Climate Zone 2)

Description of Individual Measures

Individual Measures	Annual Source Energy Savings (%) ¹	Annual Energy Savings (\$/year) ²	Estimated Cost (\$)		Simple Estimated Payback (yrs)
			Marginal Cost ³	New System Cost ⁴	
A Envelope and Fenestration Measures					
1 Radiant Barrier in Attics (with Ducts in Attics) (L;a;b;H:h) ⁷	1.5% - 2.2%	\$39 - \$55		\$300 - \$880	5.5 - 22.7
2 Sealed (Unvented) Attic (L;g;H:b)	4.0% - 5.2%	\$103 - \$132	\$2,000 - \$3,500		15.1 - 33.9
3 Window Shading (None to 2 ft. Eaves on All Sides) (L;e;g;i;H;a)	2.2% - 2.5%	\$55 - \$64		\$800 - \$1,000	12.4 - 18.2
4 Window Shading and Redistribution (22.6% Equal Windows on All Sides with No Shading to S=40.7%, N=22.6%, E/W = 13.6% with 2ft. Eaves on All Sides) (L;e;H:f)	2.6% - 3.0%	\$64 - \$74		\$800 - \$1,000	10.8 - 15.5
5 Decreased Window SHGC (Climate Zone 2: from 0.3 to 0.2) (L;f;H;a)	2.1% - 3.1%	\$55 - \$81	\$200 - \$400		2.5 - 7.3
6 Decreased Window U Value (Climate Zone 2: from 0.65 to 0.3) (L;a;H;f)	4.1% - 5.3%	\$106 - \$139	\$600 - \$900		4.3 - 8.5
7 Decreased Window SHGC & U Value (Climate Zone 2: from 0.3 to 0.2 SHGC & from 0.65 to 0.3 U-Value) (L;e;H;d)	7.1% - 7.6%	\$177 - \$197	\$900 - \$1,100		4.6 - 6.2
B HVAC System Measures					
8 Relocate Mechanical Systems within Conditioned Space (L;e;f;H;d)	6.6% - 6.9%	\$161 - \$177	\$1,000 - \$7,000		5.6 - 43.4
9 Improved Heat Pump Efficiency (from 13 to 15 SEER and from 7.70 to 8.50 HSPF) (L;h;H;a)	6.7% - 8.3%	\$168 - \$216	\$1,200 - \$2,500		5.6 - 14.9
C Domestic Hot Water Measures					
13 Solar Domestic Hot Water System (32 sq. ft. collector, 65 gal tank) (L;e;H;d)	5.9% - 7.3%	\$148 - \$187		\$2,200 - \$3,000	11.8 - 20.2
14 Solar Domestic Hot Water System (64 sq. ft. collector, 80 gal tank) (L;a;H;h)	8.1% - 9.6%	\$211 - \$240		\$3,200 - \$4,000	13.3 - 19.0
D Lighting Measures					
15 75% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L;i;H;c)	4.4% - 5.1%	\$113 - \$129	\$25 - \$110		0.2 - 1.0
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L;i;H;a)	8.6% - 10.1%	\$226 - \$261	\$50 - \$215		0.2 - 1.0
E Renewable Power Measures					
17 4 kW Photovoltaic Array (L;b;H;d)	24.3% - 26.6%	\$610 - \$686		\$20,000 - \$30,000	29.2 - 49.2



■ IECC 2009 - Climate Zone 2 (corresponding to the table)
■ IECC 2009 - Climate Zone 3
■ IECC 2009 - Climate Zone 4

Description of Combined Measures to Achieve 15% Savings Above 2009 IECC Code-Compliant House

Combination of Measures ⁵	Combined Source Energy Savings	Combined Energy Savings (\$/year) ²	Combined Estimated Cost (\$)		Simple Estimated Payback (yrs)	NO _x Emissions Annual (lbs/yr)	SO ₂ Emissions Annual (lbs/yr)	CO ₂ Emissions Annual (tons/yr) ⁶
			Marginal Cost ³	New System Cost ⁴				
Combination 1 (L;i;H;a)⁷								
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L;i;H;a)	16.2% - 17.7%	\$409 - \$458	\$50 - \$215		2.1 - 3.2	5.9 - 6.6	3.7 - 4.1	2.5 - 2.8
7 Decreased Window SHGC & U Value (Climate Zone 2: from 0.3 to 0.2 SHGC & from 0.65 to 0.3 U-Value) (L;e;H;d)			\$900 - \$1,100					
Combination 2 (L;h;H;a)								
15 75% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L;i;H;c)	17.3% - 19.4%	\$429 - \$503	\$25 - \$110		4.2 - 8.7	6.2 - 7.2	3.9 - 4.5	2.6 - 3.1
7 Decreased Window SHGC & U Value (Climate Zone 2: from 0.3 to 0.2 SHGC & from 0.65 to 0.3 U-Value) (L;e;H;d)			\$900 - \$1,100					
9 Improved Heat Pump Efficiency (from 13 to 15 SEER and from 7.70 to 8.50 HSPF) (L;h;H;a)			\$1,200 - \$2,500					
Combination 3 (L;a;H;h)								
8 Relocate Mechanical Systems within Conditioned Space (L;e;f;H;d)	15.0% - 16.3%	\$384 - \$415	\$1,000 - \$7,000		10.1 - 28.6	5.5 - 6.0	3.5 - 3.7	2.3 - 2.5
14 Solar Domestic Hot Water System (64 sq. ft. collector, 80 gal tank) (L;a;H;h)			\$3,200 - \$4,000					

Note:

- Total source energy savings from heating, cooling, lighting, equipment and DHW for emissions reductions determination.
- Energy Cost: Electricity = \$0.11/kWh
- Marginal cost = new system cost - original system cost
- New system cost = new system cost only
- See individual measures above for specific savings
- Conversion factor: 1 ton = 2,000 lbs
- L = County with the low est annual source energy savings; H = County with the highest annual source energy savings
County code: a = Cameron; b = Nueces; c = Victoria; d = Bexar; e = Harris; f = Jefferson; g = Travis; h = Angeline; i = McLennan

[2009 IECC Code-Compliant House Description]

- * Building type: Residential
- * Gross area: 2,325 sq-ft
- * Building dimension: 48.2ft x 48.2ft x 8ft (WxLxH)
- * Number of floors: 1
- * Floor-to-floor height: 8ft
- * Window -to-floor ratio: 15% (Window -to-w all ratio: 22.6%)
- * Lighting: 50% Energy Star permanent CFL or fluorescent lamps
- * HVAC system: SEER 13 AC and 7.7 HSPF heat pump
- * DHW: 0.90 EF Electric heater
- * Duct Location: Unconditioned, vented attic
- * Duct Leakage to Outdoor: 8 cfm/100 sq-ft CFA

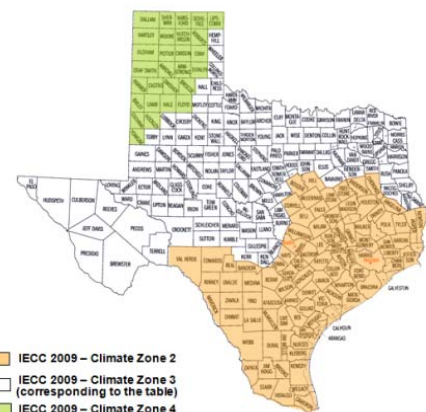


Figure 3. 15% Total Source Energy Savings Above 2009 IECC Code-Compliant House for an All-Electric House in Climate Zone 2, TX

Natural Gas Heating (Climate Zone 3)

Description of Individual Measures

Individual Measures	Annual Source Energy Savings (%) ¹	Annual Energy Savings (\$/year) ²	Estimated Cost (\$)		Simple Estimated Payback (yrs)
			Marginal Cost ³	New System Cost ⁴	
A Envelope and Fenestration Measures					
1 Radiant Barrier in Attics (with Ducts in Attics) (L;p ;H;I) ⁷	1.6% - 3.1%	\$40 - \$66		\$300 - \$880	4.5 - 22.0
2 Sealed (Unvented) Attic (L;n ;H;o)	5.7% - 7.2%	\$109 - \$148	\$2,000 - \$3,500		13.5 - 32.0
3 Window Shading (None to 2 ft. Eaves on All Sides) (L;o ;H;I)	1.5% - 2.8%	\$48 - \$73		\$800 - \$1,000	11.0 - 20.9
4 Window Shading and Redistribution (22.6% Equal Windows on All Sides with No Shading to S=40.7%, N=22.6%, E/W = 13.6% with 2ft. Eaves on All Sides) (L;o;p ;H;I)	2.7% - 3.5%	\$71 - \$85		\$800 - \$1,000	9.4 - 14.1
5 Decreased Window SHGC (Climate Zone 3: from 0.3 to 0.2) (L;o ;H;I)	0.4% - 2.3%	\$32 - \$68	\$200 - \$400		2.9 - 12.6
6 Decreased Window U Value (Climate Zone 3: from 0.5 to 0.3) (L;a,n,p ;H;I)	4.2% - 4.7%	\$92 - \$102	\$600 - \$900		5.9 - 9.8
7 Decreased Window SHGC & U Value (Climate Zone 3: from 0.3 to 0.2 SHGC & from 0.5 to 0.3 U-Value) (L;o ;H;I)	4.4% - 6.6%	\$119 - \$163	\$900 - \$1,100		5.5 - 9.2
B HVAC System Measures					
8 Relocate Mechanical Systems within Conditioned Space (L;I ;H;p)	7.6% - 9.3%	\$153 - \$201	\$1,000 - \$7,000		5.0 - 45.7
9 Improved Air Conditioner SEER (from 13 to 15 SEER) (L;o ;H;I)	4.3% - 6.1%	\$114 - \$154	\$900 - \$2,500		5.8 - 21.9
10 Improved Furnace Efficiency (from 0.78 to 0.93 AFUE) (L;I ;H;o)	2.2% - 4.0%	\$29 - \$58	\$800 - \$1,300		13.9 - 44.2
C Domestic Hot Water Measures					
11 Tankless Gas Water Heater (without a Standing Pilot Light) (L;p ;H;k,I,n)	1.5% - 1.7%	\$22 - \$23	\$900 - \$1,400		39.1 - 62.5
12 Removal of Pilot Light from Tank-Type Hot Water System (L;p ;H;j,k,I,m,n,o)	0.7% - 0.8%	\$11 - \$11	\$100 - \$500		9.2 - 46.0
13 Solar Domestic Hot Water System (32 sq. ft. collector, 65 gal tank) (L;p ;H;I)	3.3% - 4.8%	\$32 - \$45		\$2,200 - \$3,000	48.8 - 94.1
14 Solar Domestic Hot Water System (64 sq. ft. collector, 80 gal tank) (L;p ;H;I)	4.7% - 6.0%	\$51 - \$62		\$3,200 - \$4,000	51.6 - 79.0
D Lighting Measures					
15 75% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L;p ;H;I)	3.7% - 4.5%	\$106 - \$113	\$25 - \$110		0.2 - 1.0
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L;p ;H;I)	7.4% - 9.0%	\$208 - \$228	\$50 - \$215		0.2 - 1.0
E Renewable Power Measures					
17 4 kW Photovoltaic Array (L;p ;H;I)	26.3% - 34.9%	\$692 - \$824		\$20,000 - \$30,000	24.3 - 43.3



Description of Combined Measures to Achieve 15% Savings Above 2009 IECC Code-Compliant House

Combination of Measures ⁵	Combined Source Energy Savings	Combined Energy Savings (\$/year) ²	Combined Estimated Cost (\$)		Simple Estimated Payback (yrs)	NO _x Emissions Annual (lbs/yr)	SO ₂ Emissions Annual (lbs/yr)	CO ₂ Emissions Annual (tons/yr) ⁶
			Marginal Cost ³	New System Cost ⁴				
Combination 1 (L;j,k ;H;I)^{7,8}								
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L;p ;H;I)	15.3% - 17.5%	\$391 - \$434	\$50 - \$215		2.9 - 5.6	5.6 - 6.2	3.8 - 4.2	2.3 - 2.6
7 Decreased Window SHGC & U Value (Climate Zone 3: from 0.3 to 0.2 SHGC & from 0.5 to 0.3 U-Value) (L;o ;H;I)			\$900 - \$1,100					
1 Radiant Barrier in Attics (with Ducts in Attics) (L;p ;H;I)				\$300 - \$880				
Combination 2 (L;o ;H;I)								
15 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L;p ;H;I)	16.0% - 17.1%	\$383 - \$422	\$50 - \$215		4.1 - 10.5	5.5 - 6.1	3.2 - 3.6	2.4 - 2.6
9 Improved Air Conditioner SEER (from 13 to 15 SEER) (L;o ;H;I)			\$900 - \$2,500					
10 Improved Furnace Efficiency (from 0.78 to 0.93 AFUE) (L;I ;H;o)			\$800 - \$1,300					
Combination 3 (L;n ;H;p)								
8 Relocate Mechanical Systems within Conditioned Space (L;I ;H;p)	15.0% - 16.2%	\$315 - \$358	\$1,000 - \$7,000		7.5 - 29.9	4.5 - 5.1	1.9 - 2.4	2.1 - 2.5
10 Improved Furnace Efficiency (from 0.78 to 0.93 AFUE) (L;I ;H;o)			\$800 - \$1,300					
7 Decreased Window SHGC & U Value (Climate Zone 3: from 0.3 to 0.2 SHGC & from 0.5 to 0.3 U-Value) (L;o ;H;I)			\$900 - \$1,100					

Note:

- Total source energy savings from heating, cooling, lighting, equipment and DHW for emissions reductions determination.
- Savings depend on fuel mix used.
* Energy Cost: Electricity = \$0.11/kWh
Natural gas = \$0.64/therm
- Marginal cost = new system cost - original system cost
- New system cost = new system cost only
- See individual measures above for specific savings
- Conversion factor: 1 ton = 2,000 lbs
- L = County with the lowest annual source energy savings; H = County with the highest annual source energy savings
County code: j = Tom Green; k = Midland; I = El Paso; m = Taylor; n = Tarrant; o = Lubbock; p = Wichita
- Lubbock and Wichita counties were excluded in the savings analysis for Combination 1.

[2009 IECC Code-Compliant House Description]

- * Building type: Residential
- * Gross area: 2,325 sq-ft
- * Building dimension: 48.2ft x 48.2ft x 8ft (WxLxH)
- * Number of floors: 1
- * Floor-to-floor height: 8ft
- * Window-to-floor ratio: 15% (Window-to-w all ratio: 22.6%)
- * Lighting: 50% Energy Star permanent CFL or fluorescent lamps
- * HVAC system: SEER 13 AC and 0.78 AFUE furnace
- * DHW: 0.59 EF NG heater
- * Duct Location: Unconditioned, vented attic
- * Duct Leakage to Outdoor: 8 cfm/100 sq-ft CFA

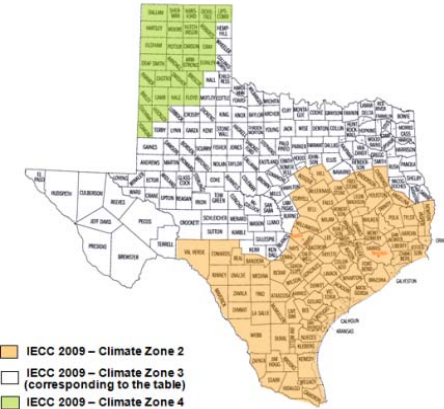


Figure 4. 15% Total Source Energy Savings Above 2009 IECC Code-Compliant House for an Electric/Gas House in Climate Zone 3, TX

Heat Pump Heating (Climate Zone 3)

Description of Individual Measures

Individual Measures	Annual Source Energy Savings (%) ¹	Annual Energy Savings (\$/year) ²	Estimated Cost (\$)		Simple Estimated Payback (yrs)
			Marginal Cost ³	New System Cost ⁴	
A Envelope and Fenestration Measures					
1 Radiant Barrier in Attics (with Ducts in Attics) (L:p;H:I) ⁷	1.6% - 2.7%	\$45 - \$68		\$300 - \$880	4.4 - 19.5
2 Sealed (Unvented) Attic (L:n;H:p)	4.0% - 5.6%	\$103 - \$158	\$2,000 - \$3,500		12.7 - 33.9
3 Window Shading (None to 2 ft. Eaves on All Sides) (L:o;H:I)	1.8% - 3.1%	\$48 - \$77		\$800 - \$1,000	10.3 - 20.7
4 Window Shading and Redistribution (22.6% Equal Windows on All Sides with No Shading to S=40.7%, N=22.6%, E/W = 13.6% with 2ft. Eaves on All Sides) (L:m,o,p;H:I)	2.7% - 3.6%	\$71 - \$90		\$800 - \$1,000	8.9 - 14.1
5 Decreased Window SHGC (Climate Zone 3: from 0.3 to 0.2) (L:o;H:I)	1.1% - 2.8%	\$29 - \$71	\$200 - \$400		2.8 - 13.8
6 Decreased Window U Value (Climate Zone 3: from 0.5 to 0.3) (L:j;m;H:I)	3.7% - 4.1%	\$97 - \$110	\$600 - \$900		5.5 - 9.3
7 Decreased Window SHGC & U Value (Climate Zone 3: from 0.3 to 0.2 SHGC & from 0.5 to 0.3 U-Value) (L:o;H:I)	4.7% - 6.5%	\$126 - \$164	\$900 - \$1,100		5.5 - 8.7
B HVAC System Measures					
8 Relocate Mechanical Systems within Conditioned Space (L:l;H:p)	5.9% - 7.3%	\$148 - \$206	\$1,000 - \$7,000		4.8 - 47.2
9 Improved Heat Pump Efficiency (from 13 to 15 SEER and from 7.70 to 8.50 HSPF) (L:o;H:p)	5.7% - 6.8%	\$155 - \$193	\$1,200 - \$2,500		6.2 - 16.2
C Domestic Hot Water Measures					
13 Solar Domestic Hot Water System (32 sq. ft. collector, 65 gal tank) (L:p;H:I)	7.0% - 9.3%	\$193 - \$233		\$2,200 - \$3,000	9.4 - 15.6
14 Solar Domestic Hot Water System (64 sq. ft. collector, 80 gal tank) (L:p;H:I)	9.0% - 10.9%	\$246 - \$284		\$3,200 - \$4,000	11.3 - 16.3
D Lighting Measures					
15 75% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L:o,p;H:I)	3.8% - 4.5%	\$103 - \$113	\$25 - \$110		0.2 - 1.1
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L:o,p;H:I)	7.5% - 9.0%	\$203 - \$226	\$50 - \$215		0.2 - 1.1
E Renewable Power Measures					
17 4 kW Photovoltaic Array (L:p;H:I)	24.8% - 32.8%	\$692 - \$824		\$20,000 - \$30,000	24.3 - 43.3



Description of Combined Measures to Achieve 15% Savings Above 2009 IECC Code-Compliant House

Combination of Measures ⁵	Combined Source Energy Savings	Combined Energy Savings (\$/year) ²	Combined Estimated Cost (\$)		Simple Estimated Payback (yrs)	NO _x Emissions Annual (lbs/yr)	SO ₂ Emissions Annual (lbs/yr)	CO ₂ Emissions Annual (tons/yr) ⁶
			Marginal Cost ³	New System Cost ⁴				
Combination 1 (L;j;H:I)^{7,8}								
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L:o,p;H:I)	15.2% - 17.5%	\$397 - \$438	\$50 - \$215		2.9 - 5.5	5.7 - 6.3	3.6 - 4.0	2.4 - 2.7
7 Decreased Window SHGC & U Value (Climate Zone 3: from 0.3 to 0.2 SHGC & from 0.5 to 0.3 U-Value) (L:o;H:I)			\$900 - \$1,100					
1 Radiant Barrier in Attics (with Ducts in Attics) (L:p;H:I)				\$300 - \$880				
Combination 2 (L:o;H:I)								
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps (L:o,p;H:I)	16.7% - 20.3%	\$451 - \$516	\$50 - \$215		4.2 - 8.5	6.5 - 7.4	4.1 - 4.7	2.7 - 3.1
7 Decreased Window SHGC & U Value (Climate Zone 3: from 0.3 to 0.2 SHGC & from 0.5 to 0.3 U-Value) (L:o;H:I)			\$900 - \$1,100					
9 Improved Heat Pump Efficiency (from 13 to 15 SEER and from 7.70 to 8.50 HSPF) (L:o;H:p)			\$1,200 - \$2,500					
Combination 3 (L:n;H:I)								
8 Relocate Mechanical Systems within Conditioned Space (L:l;H:p)	16.0% - 16.9%	\$407 - \$461	\$1,000 - \$7,000		9.1 - 27.0	5.9 - 6.6	3.7 - 4.2	2.5 - 2.8
14 Solar Domestic Hot Water System (64 sq. ft. collector, 80 gal tank) (L:p;H:I)				\$3,200 - \$4,000				

Note:

- Total source energy savings from heating, cooling, lighting, equipment and DHW for emissions reductions determination.
- Energy Cost: Electricity = \$0.11/kWh
- Marginal cost = new system cost - original system cost
- New system cost = new system cost only
- See individual measures above for specific savings
- Conversion factor: 1 ton = 2,000 lbs
- L = County with the low est annual source energy savings; H = County with the highest annual source energy savings
County code: j = Tom Green; k = Midland; l = El Paso; m = Taylor; n = Tarrant; o = Lubbock; p = Wichita
- Lubbock and Wichita counties were excluded in the savings analysis for Combination 1.

[2009 IECC Code-Compliant House Description]

- Building type: Residential
- Gross area: 2,325 sq-ft
- Building dimension: 48.2ft x 48.2ft x 8ft (WxLxH)
- Number of floors: 1
- Floor-to-floor height: 8ft
- Window -to-floor ratio: 15% (Window -to-w all ratio: 22.6%)
- Lighting: 50% Energy Star permanent CFL or fluorescent lamps
- HVAC system: SEER 13 AC and 7.7 HSPF heat pump
- DHW: 0.90 EF Electric heater
- Duct Location: Unconditioned, vented attic
- Duct Leakage to Outdoor: 8 cfm/100 sq-ft CFA

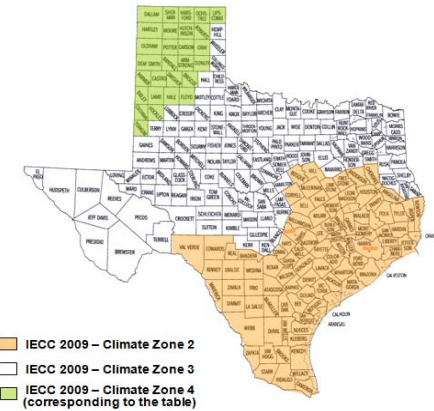


Figure 5. 15% Total Source Energy Savings Above 2009 IECC Code-Compliant House for an All-Electric House in Climate Zone 3, TX

Natural Gas Heating (Climate Zone 4)

Description of Individual Measures

Individual Measures	Annual Source Energy Savings (%) ¹	Annual Energy Savings (\$/year) ²	Estimated Cost (\$)		Simple Estimated Payback (yrs)
			Marginal Cost ³	New System Cost ⁴	
A Envelope and Fenestration Measures					
1 Radiant Barrier in Attics (w ith Ducts in Attics)	1.6%	\$37		\$300 - \$880	8.0 - 23.6
2 Sealed (Unvented) Attic	7.7%	\$143	\$2,000 - \$3,500		14.0 - 24.4
3 Window Shading (None to 2 ft. Eaves on All Sides)	1.4%	\$48		\$800 - \$1,000	16.5 - 20.6
4 Window Shading and Redistribution (22.6% Equal Windows on All Sides w ith No Shading to S=40.7%, N=22.6%, E/W = 13.6% w ith 2ft. Eaves on All Sides)	2.8%	\$77		\$800 - \$1,000	10.4 - 13.0
6 Decreased Window U Value (Climate Zone 4: from 0.35 to 0.3)	1.4%	\$22	\$350 - \$900		15.6 - 40.1
B HVAC System Measures					
8 Relocate Mechanical Systems w ithin Conditioned Space	9.4%	\$183	\$1,000 - \$7,000		5.5 - 38.2
9 Improved Air Conditioner SEER (from 13 to 15 SEER)	4.1%	\$114	\$900 - \$2,500		7.9 - 22.0
10 Improved Furnace Efficiency (from 0.78 to 0.93 AFUE)	4.3%	\$63	\$800 - \$1,300		12.6 - 20.5
C Domestic Hot Water Measures					
11 Tankless Gas Water Heater (w ithout a Standing Pilot Light)	1.5%	\$22	\$900 - \$1,400		40.2 - 62.5
12 Removal of Pilot Light from Tank-Type Hot Water System	0.7%	\$11	\$100 - \$500		9.2 - 46.0
13 Solar Domestic Hot Water System (32 sq. ft. collector, 65 gal tank)	3.8%	\$38		\$2,200 - \$3,000	58.2 - 79.4
14 Solar Domestic Hot Water System (64 sq. ft. collector, 80 gal tank)	5.7%	\$65		\$3,200 - \$4,000	49.0 - 61.2
D Lighting Measures					
15 75% Energy Star Permanent CFL or Fluorescent Indoor Lamps	3.6%	\$105	\$25 - \$110		0.2 - 1.0
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps	7.1%	\$207	\$50 - \$215		0.2 - 1.0
E Renewable Power Measures					
17 4 kW Photovoltaic Array	29.0%	\$756		\$20,000 - \$30,000	26.5 - 39.7



■ IECC 2009 – Climate Zone 2
■ IECC 2009 – Climate Zone 3
■ IECC 2009 – Climate Zone 4 (corresponding to the table)

Description of Combined Measures to Achieve 15% Savings Above 2009 IECC Code-Compliant House

Combination of Measures ⁵	Combined Source Energy Savings	Combined Energy Savings (\$/year) ²	Combined Estimated Cost (\$)		Simple Estimated Payback (yrs)	NO _x Emissions Annual (lbs/yr)	SO ₂ Emissions Annual (lbs/yr)	CO ₂ Emissions Annual (tons/yr) ⁶
			Marginal Cost ³	New System Cost ⁴				
Combination 1								
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps	15.0%	\$346	\$50 - \$215		4.8 - 7.3	5.0	2.8	2.2
10 Improved Furnace Efficiency (from 0.78 to 0.93 AFUE)			\$800 - \$1,300					
4 Window Shading and Redistribution (22.6% Equal Windows on All Sides w ith No Shading to S=40.7%, N=22.6%, E/W = 13.6% w ith 2ft. Eaves on All Sides)				\$800 - \$1,000				
Combination 2								
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps	15.6%	\$381	\$50 - \$215		4.6 - 10.5	5.5	3.1	2.4
10 Improved Furnace Efficiency (from 0.78 to 0.93 AFUE)			\$800 - \$1,300					
9 Improved Air Conditioner SEER (from 13 to 15 SEER)			\$900 - \$2,500					
Combination 3								
8 Relocate Mechanical Systems w ithin Conditioned Space	15.0%	\$307	\$1,000 - \$7,000		8.3 - 36.8	4.4	1.9	2.2
9 Improved Air Conditioner SEER (from 13 to 15 SEER)			\$900 - \$2,500					
1 Radiant Barrier in Attics (w ith Ducts in Attics)				\$300 - \$880				
6 Decreased Window U Value (Climate Zone 4: from 0.35 to 0.3)				\$350 - \$900				

Note:

- Total source energy savings from heating, cooling, lighting, equipment and DHW for emissions reductions determination.
- Savings depend on fuel mix used.
* Energy Cost: Electricity = \$0.11/kWh
Natural gas = \$0.64/therm
- Marginal cost = new system cost - original system cost
- New system cost = new system cost only
- See individual measures above for specific savings
- Conversion factor: 1 ton = 2,000 lbs
- In climate zone 4, the savings were calculated only for Potter.

[2009 IECC Code-Compliant House Description]

- * Building type: Residential
- * Gross area: 2,325 sq-ft
- * Building dimension: 48.2ft x 48.2ft x 8ft (WxLxH)
- * Number of floors: 1
- * Floor-to-floor height: 8ft
- * Window -to-floor ratio: 15% (Window -to-w all ratio: 22.6%)
- * Lighting: 50% Energy Star permanent CFL or fluorescent lamps
- * HVAC system: SEER 13 AC and 0.78 AFUE furnace
- * DHW: 0.59 EF NG heater
- * Duct Location: Unconditioned, vented attic
- * Duct Leakage to Outdoor: 8 cfm/100 sq-ft CFA

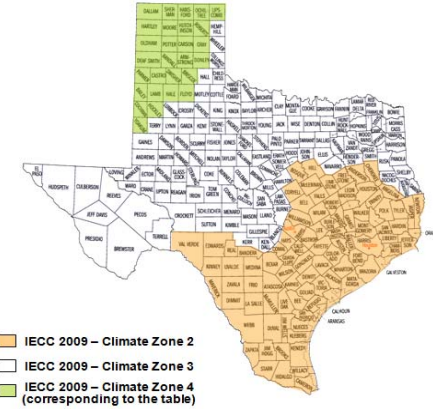


Figure 6. 15% Total Source Energy Savings Above 2009 IECC Code-Compliant House for an Electric/Gas House in Climate Zone 4, TX

Heat Pump Heating (Climate Zone 4)

Description of Individual Measures

Individual Measures	Annual Source Energy Savings (%) ¹	Annual Energy Savings (\$/year) ²	Estimated Cost (\$)		Simple Estimated Payback (yrs)
			Marginal Cost ³	New System Cost ⁴	
A Envelope and Fenestration Measures					
1 Radiant Barrier in Attics (with Ducts in Attics)	1.5%	\$42		\$300 - \$880	7.2 - 21.0
2 Sealed (Unvented) Attic	5.6%	\$161	\$2,000 - \$3,500		12.4 - 21.7
3 Window Shading (None to 2 ft. Eaves on All Sides)	1.6%	\$45		\$800 - \$1,000	17.7 - 22.2
4 Window Shading and Redistribution (22.6% Equal Windows on All Sides with No Shading to S=40.7%, N=22.6%, E/W = 13.6% with 2ft. Eaves on All Sides)	2.8%	\$81		\$800 - \$1,000	9.9 - 12.4
6 Decreased Window U Value (Climate Zone 4; from 0.35 to 0.3)	1.1%	\$32	\$350 - \$900		10.9 - 27.9
B HVAC System Measures					
8 Relocate Mechanical Systems within Conditioned Space	6.7%	\$193	\$1,000 - \$7,000		5.2 - 36.2
9 Improved Heat Pump Efficiency (from 13 to 15 SEER and from 7.70 to 8.50 HSPF)	5.6%	\$161	\$1,200 - \$2,500		7.4 - 15.5
C Domestic Hot Water Measures					
13 Solar Domestic Hot Water System (32 sq. ft. collector, 65 gal tank)	7.5%	\$217		\$2,200 - \$3,000	10.1 - 13.8
14 Solar Domestic Hot Water System (64 sq. ft. collector, 80 gal tank)	10.3%	\$297		\$3,200 - \$4,000	10.8 - 13.5
D Lighting Measures					
15 75% Energy Star Permanent CFL or Fluorescent Indoor Lamps	3.6%	\$103	\$25 - \$110		0.2 - 1.1
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps	6.9%	\$200	\$50 - \$215		0.3 - 1.1
E Renewable Power Measures					
17 4 kW Photovoltaic Array	26.2%	\$756		\$20,000 - \$30,000	26.5 - 39.7



Description of Combined Measures to Achieve 15% Savings Above 2009 IECC Code-Compliant House

Combination of Measures ⁵	Combined Source Energy Savings	Combined Energy Savings (\$/year) ²	Combined Estimated Cost (\$)		Simple Estimated Payback (yrs)	NO _x Emissions Annual (lbs/yr)	SO ₂ Emissions Annual (lbs/yr)	CO ₂ Emissions Annual (tons/yr) ⁶
			Marginal Cost ³	New System Cost ⁴				
Combination 1								
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps	15.0%	\$413	\$50 - \$215		5.0 - 9.0	5.9	3.7	2.5
9 Improved Heat Pump Efficiency (from 13 to 15 SEER and from 7.70 to 8.50 HSPF)			\$1,200 - \$2,500					
4 Window Shading and Redistribution (22.6% Equal Windows on All Sides with No Shading to S=40.7%, N=22.6%, E/W = 13.6% with 2ft. Eaves on All Sides)				\$800 - \$1,000				
Combination 2								
16 100% Energy Star Permanent CFL or Fluorescent Indoor Lamps	15.7%	\$453	\$50 - \$215		5.6 - 9.0	6.5	4.1	2.7
13 Solar Domestic Hot Water System (32 sq. ft. collector, 65 gal tank)				\$2,200 - \$3,000				
1 Radiant Barrier in Attics (with Ducts in Attics)				\$300 - \$880				
Combination 3								
8 Relocate Mechanical Systems within Conditioned Space	17.0%	\$491	\$1,000 - \$7,000		8.6 - 22.4	7.1	4.4	3.0
14 Solar Domestic Hot Water System (64 sq. ft. collector, 80 gal tank)				\$3,200 - \$4,000				

Note:

- Total source energy savings from heating, cooling, lighting, equipment and DHW for emissions reductions determination.
- Energy Cost: Electricity = \$0.11/kWh
- Marginal cost = new system cost - original system cost
- New system cost = new system cost only
- See individual measures above for specific savings
- Conversion factor: 1 ton = 2,000 lbs
- In climate zone 4, the savings were calculated only for Potter.

[2009 IECC Code-Compliant House Description]

- * Building type: Residential
- * Gross area: 2,325 sq-ft
- * Building dimension: 48.2ft x 48.2ft x 8ft (WxLxH)
- * Number of floors: 1
- * Floor-to-floor height: 8ft
- * Window -to-floor ratio: 15% (Window -to-wall ratio: 22.6%)
- * Lighting: 50% Energy Star permanent CFL or fluorescent lamps
- * HVAC system: SEER 13 AC and 7.7 HSPF heat pump
- * DHW: 0.90 EF Electric heater
- * Duct Location: Unconditioned, vented attic
- * Duct Leakage to Outdoor: 8 cfm/100 sq-ft CFA



Figure 7. 15% Total Source Energy Savings Above 2009 IECC Code-Compliant House for an All-Electric House in Climate Zone 4, TX