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RECOMMENDATIONS FOR 15% ABOVE-CODE ENERGY EFFICIENCY MEASURES ON IMPLEMENTING HOUSTON AMENDMENTS TO SINGLE-FAMILY BUILDINGS IN HOUSTON TEXAS

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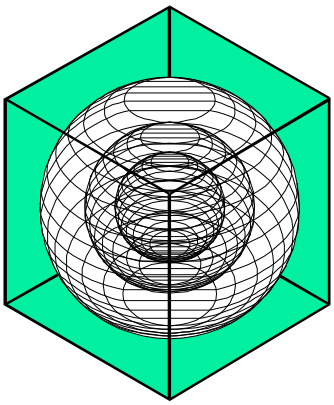

ENERGY SYSTEMS LABORATORY

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Executive Summary:

This report presents detailed information about the analysis that was performed to calculate the energy saving potential for residential buildings in Houston. In this analysis the energy efficient measures were proposed by the building officials of the City of Houston. Along with the options proposed by the officials, additional measures were selected from the previously-conducted 15% above code energy analysis conducted by the Energy Systems Laboratory for residential houses across the State of Texas. A total of thirty measures were selected based on the energy savings above the base case. These measures were categorized into five groups: Renewable Power Options, Heating Ventilation and Air Conditioning (HVAC), Fenestration, Envelope and Lighting and Domestic Hot Water (DHW) options. The analysis was performed using a simulation model[1] of an International Energy Conservation Code (IECC)-compliant, single family residence in Houston, Texas. Four sets of simulations were considered based on the choice of heating fuel type and thermostat setback: a) natural gas (i.e., gas-fired furnace for space heating, and gas water heater for domestic water heating) with thermostat setback, b) electricity (i.e., heat pump for space heating, and electric water heater for domestic water heating) with thermostat setback, c) natural gas (i.e., gas-fired furnace for space heating, and gas water heater for domestic water heating) without thermostat setback, and d) electricity (i.e., heat pump for space heating, and electric water heater for domestic water heating) without thermostat setback. Individual measures were then categorized into four groups: 2 to 5%, 5 to 10%, and 10 to 15% and above 15% energy savings above base case. Ten grouped measures were then simulated from combining individual measures from the four categories whose combined savings are more than 15% above the base case. The cost of implementation of the individual as well as grouped measures was also calculated along with a simple payback period. The photovoltaic options presented the maximum savings in the approximate range of 15-40% for all base-case houses. The solar thermal option for domestic water heating presented energy savings above 15-20% for all of the base-case houses.

[1] The analysis was conducted using the Laboratory's IC3 calculator, sngfam2st.inp version 2.50.08.

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1: Introduction

The work reported in this document was developed at the request of the City of Houston building officials. The City of Houston asked the Laboratory to analyze the energy reduction of the measures that were proposed by them for the residential buildings in the City of Houston. This report contains the results of the measures that the city officials proposed along with additional measures which were selected from the 15% above code energy analysis conducted by the Energy Systems Laboratory for residential houses across the State of Texas. Four sets of simulations based on the choice of heating fuel type and thermostat setback were considered: a) natural gas (i.e., gas-fired furnace for space heating, and gas water heater for domestic water heating) with thermostat setback, b) electricity (i.e., heat pump for space heating, and electric water heater for domestic water heating) with thermostat setback, c) natural gas (i.e., gas-fired furnace for space heating, and gas water heater for domestic water heating) without thermostat setback, and d) electricity (i.e., heat pump for space heating, and electric water heater for domestic water heating) without thermostat setback. The simulations were conducted using version 2.50.08 of the DOE-2 input file and the TMY2 weather file for the city of Houston, Texas.

2: Organization of the Report

The report is organized in the following order: Section 1 presents the introduction and purpose of the report. Section 2 describes the base-case model, the selection of measures, simulation input, results and simple payback periods. Section 3 describes the base-case building model used for the simulation. Section 4 provides the assumption for costs that are used for the calculation of total savings and payback periods. Sections 5 and 6 discuss the selection of 31 individual energy efficient measures, simulation inputs for these measures, and annual energy savings from these measures along with the simple payback calculations. Sections 7 and 8 describe the group measures, their selection process and the simulation results and simple paybacks from group measures. Section 9 gives detailed descriptions of each of the individual measures, cost of implementation of the measures and the simple payback period for each individual measure. Section 10 provides a comparison between Houston amendments and 15% above residential code analysis.

3: Base-Case Building Description

The measures in this analysis are based on measures proposed by Houston building officials along with additional measures taken from the 15% above code energy analysis conducted by the Energy Systems Laboratory for residential houses across the State of Texas (Malhotra et. al. 2007).

The base-case house assumptions are based on the “Standard Design” as defined in Chapter 4 of the 2001 IECC and certain other assumptions which are described throughout this document. Four sets of simulations based on the choice of heating fuel type and thermostat setback were considered: a) Natural Gas Heating (i.e., gas-fired furnace for space heating, and gas water heater for domestic water heating) with thermostat setback, b) electric heating (i.e., heat pump for space heating, and electric water heater for domestic water heating) with thermostat setback, c) Natural Gas Heating (i.e., gas-fired furnace for space heating, and gas water heater for domestic water heating) without thermostat setback, and d) Electric Heating (i.e., heat pump for space heating, and electric water heater for domestic water heating) without thermostat setback.

The base-case building is a 2,325 sq. ft., square-shaped, one story, single-family, detached house facing South, with a floor-to-ceiling height of 8 feet. The house has a vented attic with a roof pitched at 23 degrees, which contains the HVAC systems and ductwork. The wall construction is light-weight

wood frame with 2X4 studs at 16” on center with slab-on-grade-floor which reflects the survey information of actual construction obtained from the National Association of Home Builders (NAHB 2003). The ceiling insulation is R-30 and wall insulation is R-13 as recommended by the 2001 IECC. The building has a wall and roof absorptance of 0.75, window area is 18% of the total conditioned floor space as required by the 2001 IECC. As described in Chapter 4 of the IECC 2001, the windows have no exterior shading, the window glazing has a U-value of 0.47 Btu/hr-sq.ft.°F and solar heat gain coefficient is 0.4. The space temperature set points are 68°F Heating, 78°F Cooling, with a 5°F set-back/ set-up for winter and summer, respectively, for 6 hours per day. The total internal heat gain is assumed to be 0.88 kW (modeled as 0.44 kW for lighting and 0.44 kW for equipment). As required by the 2001 ECC code no occupants are assumed in the simulated house. All the space conditions are taken as per 2001 IECC. Table 1 summarizes the base-case building characteristics used in the DOE-2 simulation model. The simulation results are based on the TMY2 hourly weather data for Houston.

4: Assumptions for Cost

The cost analysis for different measures was carried out using three different utility cost rates. The cost of energy for each case is 30% more over the previous case. The intention of using the three cases is to calculate the pay backs in the event of an increase in fuel prices over a period of time. The cost of electricity and natural gas for the first period were taken as 0.15 $/kWh for electricity and $1.00/CCF for natural gas. The cost of electricity and natural gas for the second period were taken as 0.20 $/kWh for electricity and $1.5/CCF for natural gas and for the third period the costs were 0.25 $/kWh for electricity and $2.00/CCF for natural gas respectively.

Table 1: Characteristics of the Base Case Simulation Model

CHARACTERISTIC	SOURCES	HOUSTON BASECASE		
		ASSUMPTIONS		COMMENTS
Building				
Building type		Single family, detached house		
Gross area	NAHB (2003)	2,325 sq. ft. (48.22 ft. x 48.22 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		0.75		Solar Reflectance SR=0.35
Ceiling insulation (hr-sq.ft.-°F/Btu)	2001 IECC, Table 502.2.4(6), (p.83)	R-30		Based on HDD65 and 27% window-to-wall area ratio
Wall absorptance		0.75		Assuming brick facia exterior
Wall insulation (hr-sq.ft.-°F/Btu)	2001 IECC, Table 402.1.1(1), (p.63)	R-13		Based on HDD65
Slab Perimeter Insulation	2001 IECC, Table 502.2.4(6), (p.83)	None		Based on HDD65 and 27% window-to-wall area ratio
Ground reflectance	DOE2.1e User Manual (LBL 1993)	0.24		Assuming grass
U-Factor of glazing (Btu/hr-sq.ft.°F)	2001 IECC, Table 402.1.1(2), (p.63)	0.47		Based on HDD65
Solar Heat Gain Coefficient (SHGC)	2001 IECC, Section 402.1.3.1.4, (p.64)	0.4		0.4 for HDD < 3500, and 0.68 for HDD ≥ 3500
Window area	2001 IECC, Section 402.1.1, (p.63)	18% of conditioned floor area		This amounts to 418.5 sq. ft. window area and 27% window-to-wall area ratio for the assumed base case building configuration
Exterior shading	2001 IECC, Section 402.1.3.1.3, (p.64)	None		
Roof radiant barrier		No		
Roof Radiant barrier emissivity		0.05		
Slope of roof		5:12		Steep slope (5:12 Slope of roof = 23 degree)
Space Conditions				
Space temperature setpoint	2001 IECC, Table 402.1.3.5, (p.64)	68°F Heating, 78°F Cooling, 5°F set-back/ set-up for winter and summer, respectively, for 6 hours per day		
Internal heat gains	2001 IECC, Section 402.1.3.6, (p.65)	0.88 kW (modeled as 0.44 kW for lighting and 0.44 kW for equipment)		
Number of occupants	2001 IECC, Section 402.1.3.6, (p.65)	None		Assuming internal gains include heat gain from occupants
Mechanical Systems		Electric/Gas	All-electric	
HVAC system type		Electric cooling (air conditioner) and natural gas heating (gas fired furmace)	Electric cooling and heating (air conditioner with heat pump)	
HVAC system efficiency	NAECA (2006)	SEER 13 AC, 0.78 AFUE furnace	SEER 13 AC, 7.7 HSPF heat pump	DOE is trying to raise the min AFUE to 80% for "non-weatherized" gas furnaces installed indoors.
Cooling capacity (Btu/hr)		62000		500 sq. ft./ton
Heating capacity (Btu/hr)		62000		1.0 x cooling capacity
DHW system type	Tank size from ASHRAE HVAC Systems and Equipment Handbook	40-gallon tanktype gas water heater	50-gallon tanktype electric water heater (without a pilot light)	
DHW heater energy factor	2001 IECC, Table 504.2, (p.91)	0.54	0.86	(a) 0.62-0.0019V, (b) 0.93-0.00132V, Where V=storage volume (gal.)
Duct location	NAHB (2003)	Unconditioned, vented attic		20-30%
Duct leakage (%)	Parker et al. (1993)	20% (supply) and 10% (return)		
Duct insulation (hr-sq.ft.-°F/Btu)	2001 IECC (As per 2001 source tableNo:503.3.3.3)	R-8 (supply) and R-4 (return)		
HVAC duct static pressure	2001IECC	1		
Supply air flow (CFM/ton)	2001 IECC	360		
Infiltration rate (ACH)	2001 IECC	0.462		ACH=normalized leakage (0.57) X weather factor, and weather factor for Houston=0.81

5: Individual Energy Efficient Measures (EEMs)

For the analysis, 31 individual measures were considered, some of which were proposed by Houston City officials and others taken from the Laboratory's previous 15% above code analysis report. These include measures for the renewable power options, options related to HVAC system and air distribution system, fenestration, building envelope, and domestic hot water (DHW) system. These measures were simulated by modifying the selected parameters used for the DOE-2 simulation model. Table 2 shows the EEMs which are simulated for the base case house with natural gas heating and heat pump heating. The measures for the simulation without thermostat setback are the same as that of the case with thermostat setback.

Table 2: Individual Energy Efficient Measures for a House with Natural Gas Heating and Heat Pump Heating

	1	Base Case Natural Gas	Base Case Heat Pump	Source
Renewable Power Options	2	PV Array for 6kW	PV Array for 6kW	City of Houston Officials
	3	PV Array for Partial Demand at 4kW	PV Array for Partial Demand at 4kW	City of Houston Officials
	4	PV Array for Partial Demand at 2kW	PV Array for Partial Demand at 2kW	City of Houston Officials
HVAC Options	5	Manual J: Increased Sqft/ton	Manual J: Increased Sqft/ton	City of Houston Officials
	6	Decreased Supply Airflow	Decreased Supply Airflow	City of Houston Officials
	7	Increased Supply Airflow	Increased Supply Airflow	City of Houston Officials
	8	Decreased Duct Static Pressure	Decreased Duct Static Pressure	City of Houston Officials
	9	Decreased Duct Leakage	Decreased Duct Leakage	City of Houston Officials
	10	Mechanical Systems within Conditioned Spaces	Mechanical Systems within Conditioned Spaces	15% above code analysis
	11	Improved SEER	Improved SEER	15% above code analysis
	12	Improved Furnace Efficiency	Improved Heat Pump	15% above code analysis
Fenestration	13	Decreased SHGC	Decreased SHGC	15% above code analysis
	14	Decreased SHGC & U Value	Decreased SHGC & U Value	15% above code analysis
	15	Window Shading	Window Shading	15% above code analysis
	16	Window Shading and Redistribution	Window Shading and Redistribution	15% above code analysis
Envelope	17	Radiant Barrier	Radiant Barrier	City of Houston Officials
	18	Clay Tiles with a Reflectance of >.40	Clay Tiles with a Reflectance of >.40	City of Houston Officials
	19	Other Roofs with a Reflectance of >.50	Other Roofs with a Reflectance of >.50	City of Houston Officials
	20	Decreased Infiltration	Decreased Infiltration	City of Houston Officials
	21	Increased Infiltration	Increased Infiltration	City of Houston Officials
	22	Low Slope Roof with Increased Reflectance	Low Slope Roof with Increased Reflectance	City of Houston Officials
	23	Low Slope Roof	Low Slope Roof	City of Houston Officials
Lighting Options	24	25% Energy Star CFL Indoor Lamps	25% Energy Star CFL Indoor Lamps	City of Houston Officials
	25	50% Energy Star CFL Indoor Lamps	50% Energy Star CFL Indoor Lamps	City of Houston Officials
	26	Incandescent w occ	Incandescent w/occ	City of Houston Officials
	27	CFL w/o occ	CFLw/o occ	City of Houston Officials
	28	CFL w/ occ	CFL w/occ	City of Houston Officials
DHW Measures	29	Tankless Gas Water Heater	Tankless Gas Water Heater	15% above code analysis
	30	Removal of Pilot Light	NA	15% above code analysis
	31	Solar DHW System	Solar DHW System	15% above code analysis

5.1 Simulation Inputs for Individual Measures

Table 3 and Table 4 list the parameters used for the Energy Efficient Measures (EEMs) for an electric/gas house, for four different options: (a) Base Case with natural gas heating with setback (b) Base Case with heat pump heating with setback, respectively, located in Houston (Harris County), Texas. The parameters used for the without setback option are the same as those with the setback options. The first row of values in all the tables presents information used in the base case runs. The remaining rows present information used in the simulation of the individual energy efficiency measures. The shaded cell in each row indicates the change in the value used to simulate the measure. A detailed description of these measures is included in Section 9.

Table 3: Simulation Input for Base Case House with Natural Gas Heating

	EEM #	Energy Efficiency Measure	Cooling System Sizing (ft2/ton)	Supply Air Flow (CFM/ton)	Supply Fan Static Pressure	Supply Duct Leakage (%)	Return Duct Leakage (%)	Duct in Conditioned Space	Improved SEER	Improved AFUE	Improved HSPF	SHGC	U-Value	Shading	Shading	Shading	Shading	WWR% for Front Side Wall	WWR% area for Back Side Wall	WWR% for Right Side Wall	WWR% for Left Side Wall	Radiant Barrier	Roof Abs	Infiltration Rate (ACH/hr)	Pitch of Roof (degree)	Lighting (kW)	Energy Factor
	1	Base case Natural Gas w/ setback	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
Renewable Power Options	2	PV Array for 6kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	3	PV Array for Partial Demand at 4kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	4	PV Array for Partial Demand at 2kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
HVAC Options	5	Manual J: Increased Sqft/ton	**650**	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	6	Decreased Supply Airflow	500	**250**	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	7	Increased Supply Airflow	500	**450**	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	8	Decreased Duct Static Pressure	500	360	**0.5**	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	9	Decreased Duct Leakage	500	360	1.0	**6.70%**	**3.30%**	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	10	Mechanical Systems within Conditioned	500	360	1.0	**0%**	**0%**	**ROOM**	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	11	Improved SEER	500	360	1.0	20%	10%	ATTIC	**15**	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	12	Improved Furnace Efficiency	500	360	1.0	20%	10%	ATTIC	13	**0.93**	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
Fenestration	13	Decreased SHGC	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	**0.3**	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	14	Decreased SHGC & U Value	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	**0.3**	**0.35**	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	15	Window Shading	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	**2**	**2**	**2**	**2**	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	16	Window Shading and Redistribution	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	**2**	**2**	**2**	**2**	**48.82**	**27.12**	**16.27**	**16.27**	N	0.75	0.462	23	0.44	0.54
Envelope	17	Radiant Barrier	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	**Y**	0.75	0.462	23	0.44	0.54
	18	Clay Tiles with a Reflectance of >.40	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	**0.55**	0.462	23	0.44	0.54
	19	Other Roofs with a Reflectance of >.50	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	**0.4**	0.462	23	0.44	0.54
	20	Decreased Infiltration	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.35**	23	0.44	0.54
	21	Increased Infiltration	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.65**	23	0.44	0.54
	22	Low Slope Roof with Increased Reflectance	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	**0.3**	0.462	**9.5**	0.44	0.54
	23	Low Slope Roof	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	**9.5**	0.44	0.54
Lighting Options	24	25% Energy Star CFL Indoor Lamps	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	**0.36**	0.54
	25	50% Energy Star CFL Indoor Lamps	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	**0.28**	0.54
	26	Incandescent w occ	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	27	CFL w/o occ	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
	28	CFL w occ	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
DHW Measures	29	Tankless Gas Water Heater	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	**0.748**
	30	Removal of Pilot Light	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	**0.57**
	31	Solar DHW System	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54

Table 4: Simulation Input for Base Case House with Heat Pump Heating

	1	Base case Heat Pump w/ setback	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
Renewable Power Options	2	PV Array for 6kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	3	PV Array for Partial Demand at 4kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	4	PV Array for Partial Demand at 2kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
HVAC Options	5	Manual J: Increased Sqft/ton	**650**	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	6	Decreased Supply Airflow	500	**250**	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	7	Increased Supply Airflow	500	**450**	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	8	Decreased Duct Static Pressure	500	360	**0.5**	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	9	Decreased Duct Leakage	500	360	1.0	**6.70%**	**3.30%**	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	10	Mechanical Systems within Conditioned	500	360	1.0	**0%**	**0%**	**ROOM**	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	11	Improved SEER	500	360	1.0	20%	10%	ATTIC	**15**	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	12	Improved Heat Pump Efficiency	500	360	1.0	20%	10%	ATTIC	13	0.78	**8.50**	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
Fenestration	13	Decreased SHGC	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	**0.3**	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	14	Decreased SHGC & U Value	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	**0.3**	**0.35**	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	15	Window Shading	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	**2**	**2**	**2**	**2**	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	16	Window Shading and Redistribution	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	**2**	**2**	**2**	**2**	**48.82**	**27.12**	**16.27**	**16.27**	N	0.75	0.462	23	0.44	0.86
Envelope	17	Radiant Barrier	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	**Y**	0.75	0.462	23	0.44	0.86
	18	Clay Tiles with a Reflectance of >.40	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	**0.55**	0.462	23	0.44	0.86
	19	Other Roofs with a Reflectance of >.50	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	**0.4**	0.462	23	0.44	0.86
	20	Decreased Infiltration	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.35**	23	0.44	0.86
	21	Increased Infiltration	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.65**	23	0.44	0.86
	22	Low Slope Roof with Increased Reflectance	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	**0.3**	0.462	**9.5**	0.44	0.86
	23	Low Slope Roof	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	**9.5**	0.44	0.86
Lighting Options	24	25% Energy Star CFL Indoor Lamps	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	**0.36**	0.86
	25	50% Energy Star CFL Indoor Lamps	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	**0.28**	0.86
	26	Incandescent w occ	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	27	CFLw/o occ	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	28	CFL w occ	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
DHW Measures	29	Tankless Water Heater	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	**0.95**
	30	Removal of Pilot Light	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
	31	Solar DHW System	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86

6: Simulation Results for Individual Measures

Table 5 through Table 8 show the impact of individual EEMs on energy consumption for different end-uses for each of the four options respectively. Figure 1 through Figure 4 provide graphical results of the analysis of the EEMs. The annual energy use presented in these tables was obtained from the BEPS report of the DOE-2 output file for all four cases: (a) base case natural gas w/ setback (b) base case heat pump w/ setback (c) base case natural gas w/o setback (d) base case heat pump w/o setback, respectively. The tables also include the calculated energy savings of the EEMs when compared to the base-case energy consumption which is presented in the last column.

6.1 Base Case

Table 5 shows that the total annual energy consumption for the base-case house with natural gas heating (with setbacks) which is 81.097 MMBtu of which 15.8% is for cooling, 12.6% is for heating, 20.5% is for domestic water heating, 26.4% is for other end-uses (that includes for lighting and equipment, for heating and cooling fans, and pump and miscellaneous). Similarly Table 6 shows total annual energy consumption for the base-case house with heat pump heating (with setbacks) which is 65.50 MMBtu of which 15.8% for cooling, 4.4% for heating, 12.9% for domestic water heating and 26.4% for other end-uses (that includes for lighting and equipment, for heating and cooling fans, and pump and miscellaneous). Table 7 shows total annual energy consumption for the base-case house with natural gas heating (without) setbacks which is 87.10 MMBtu of which: 21.0% for cooling, 17% for heating, 23.5% for domestic water heating and 30.3% for other end-uses (that includes for lighting and equipment, for heating and cooling fans, and pump and miscellaneous) and 1% for outdoor lighting.

Table 8 shows total annual energy consumption for the base-case house with heat pump heating (without) setbacks which is 69.50 MMBtu of which: 26.3% for cooling, 7.5% for heating, 18.6% for domestic water heating and 38% for other end-uses (that includes for lighting and equipment, for heating and cooling fans, and pump and miscellaneous) and 1.3% for outdoor lighting.

Table 5: Simulation Results for the Base Case with Natural Gas Heating (w/ setback), Houston, TX

	EEM #	Energy Efficiency Measure	Total Energy Consumed (MMBtu)	Outdoor Lighting Load	Cooling Load (MMBtu)	Heating Load (MMBtu)	Others (MMBtu)	Fans &Pumps (MMBtu)	DHW (MMBtu)	Diff. %
	1	Base case Natural Gas w/ setback	81.10	0.90	15.80	12.60	26.40	4.90	20.50	0.00%
Renewable Power Options	2	PV Array for 6kW	52.89	0.90	15.80	12.60	26.40	4.90	20.50	34.79%
	3	PV Array for Partial Demand at 4kW	62.29	0.90	15.80	12.60	26.40	4.90	20.50	23.19%
	4	PV Array for Partial Demand at 2kW	71.69	0.90	15.80	12.60	26.40	4.90	20.50	11.60%
HVAC Options	5	Manual J: Increased Sqft/ton	80.60	0.90	15.50	12.40	26.40	4.90	20.50	0.62%
	6	Decreased Supply Airflow	78.70	0.90	14.40	12.20	26.40	4.30	20.50	2.96%
	7	Increased Supply Airflow	84.20	0.90	16.90	13.00	26.40	6.50	20.50	-3.82%
	8	Decreased Duct Static Pressure	78.50	0.90	15.00	13.20	26.40	2.50	20.50	3.21%
	9	Decreased Duct Leakage	75.00	0.90	12.40	9.90	26.40	4.90	20.50	7.52%
	10	Mechanical Systems within Conditioned Spaces	72.00	0.90	10.90	8.40	26.40	4.90	20.50	11.22%
	11	Improved SEER	77.70	0.90	13.30	12.90	26.40	3.70	20.50	4.19%
	12	Improved Furnace Efficiency	79.00	0.90	15.80	10.50	26.40	4.90	20.50	2.59%
Fenestration	13	Decreased SHGC	80.40	0.90	13.70	14.50	26.40	4.40	20.50	0.86%
	14	Decreased SHGC & U Value	77.90	0.90	14.00	11.70	26.40	4.40	20.50	3.95%
	15	Window Shading	79.80	0.90	13.90	13.70	26.40	4.40	20.50	1.60%
	16	Window Shading and Redistribution	78.20	0.90	13.40	12.70	26.40	4.30	20.50	3.58%
Envelope	17	Radiant Barrier	80.20	0.90	15.10	12.50	26.40	4.80	20.50	1.11%
	18	Clay Tiles with a Reflectance of >.40	80.90	0.90	15.50	12.70	26.40	4.90	20.50	0.25%
	19	Other Roofs with a Reflectance of >.50	80.60	0.90	15.30	12.70	26.40	4.80	20.50	0.62%
	20	Decreased Infiltration	78.00	0.90	15.20	10.40	26.40	4.60	20.50	3.82%
	21	Increased Infiltration	86.40	0.90	16.60	16.60	26.40	5.40	20.50	-6.54%
	22	Low Slope Roof with Increased Reflectance	80.60	0.90	15.20	12.80	26.40	4.80	20.50	0.62%
	23	Low Slope Roof	81.70	0.90	16.40	12.50	26.40	5.00	20.50	-0.74%
Lighting Options	24	25% Energy Star CFL Indoor Lamps	78.60	0.90	15.10	13.30	24.00	4.80	20.50	3.08%
	25	50% Energy Star CFL Indoor Lamps	76.20	0.90	14.50	14.00	21.60	4.70	20.50	6.04%
	26	Incandescent w occ	80.24	0.04	15.80	12.60	26.40	4.90	20.50	1.06%
	27	CFL w/o occ	80.44	0.24	15.80	12.60	26.40	4.90	20.50	0.81%
	28	CFL w occ	80.01	0.01	15.80	12.80	26.40	4.50	20.50	1.34%
DHW Measures	29	Tankless Gas Water Heater	75.40	0.90	15.80	12.60	26.40	4.90	14.80	7.03%
	30	Removal of Pilot Light	80.00	0.90	15.80	12.60	26.40	4.90	19.40	1.36%
	31	Solar DHW System	65.01	0.90	15.80	12.60	26.40	6.37	2.94	19.84%

Table 6: Simulation Results for the Base Case with Heat Pump Heating (w/ setback), Houston, TX

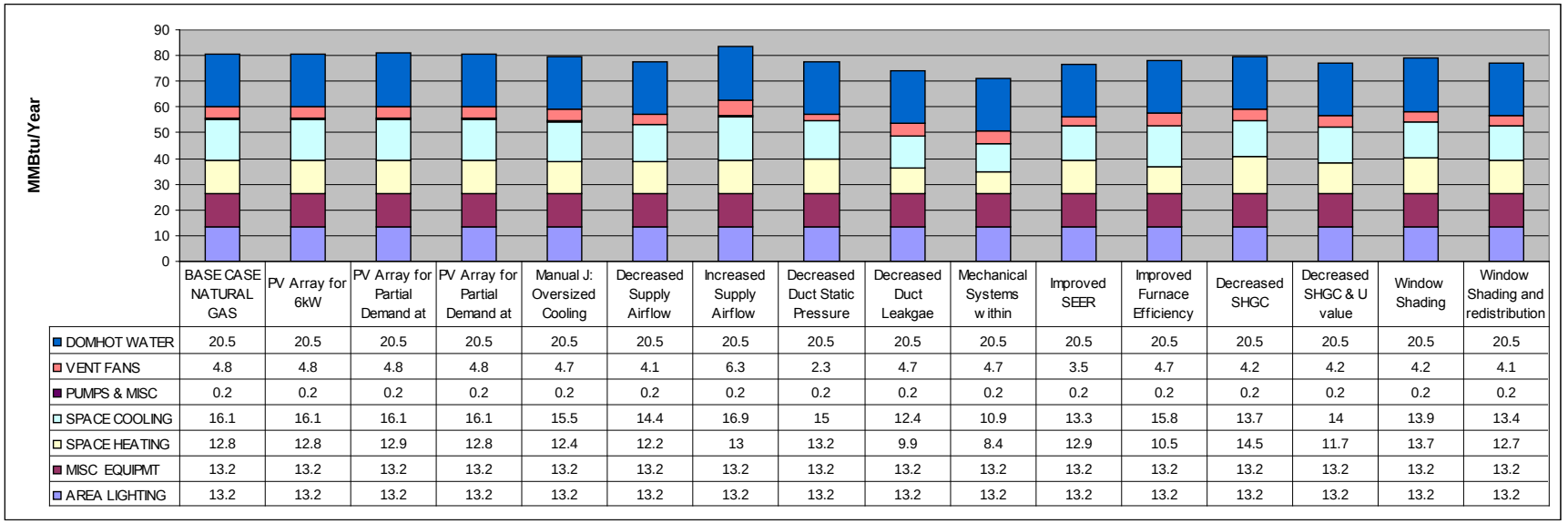
	EEM #	Energy Efficiency Measure	Total Energy Consumed (MMBtu)	Outdoor Lighting Load	Cooling Load (MMBtu)	Heating Load (MMBtu)	Others (MMBtu)	Fans &Pumps (MMBtu)	DHW (MMBtu)	Diff. %
	1	Base case Heat Pump w/ setback	65.50	0.90	15.80	4.40	26.40	5.10	12.90	0.00%
Renewable Power Options	2	PV Array for 6kW	37.29	0.90	15.80	4.40	26.40	5.10	12.90	43.07%
	3	PV Array for Partial Demand at 4kW	46.69	0.90	15.80	4.40	26.40	5.10	12.90	28.71%
	4	PV Array for Partial Demand at 2kW	56.09	0.90	15.80	4.40	26.40	5.10	12.90	14.36%
HVAC Options	5	Manual J: Increased Sqft/ton	64.90	0.90	15.50	4.10	26.40	5.10	12.90	0.92%
	6	Decreased Supply Airflow	63.20	0.90	14.40	4.20	26.40	4.40	12.90	3.51%
	7	Increased Supply Airflow	68.20	0.90	16.90	4.50	26.40	6.60	12.90	-4.12%
	8	Decreased Duct Static Pressure	62.30	0.90	15.00	4.50	26.40	2.60	12.90	4.89%
	9	Decreased Duct Leakage	61.30	0.90	12.40	3.60	26.40	5.10	12.90	6.41%
	10	Mechanical Systems within Conditioned Spaces	59.40	0.90	10.90	3.20	26.40	5.10	12.90	9.31%
	11	Improved SEER	61.80	0.90	13.30	4.40	26.40	3.90	12.90	5.65%
	12	Improved Heat Pump Efficiency	65.10	0.90	15.80	4.00	26.40	5.10	12.90	0.61%
Fenestration	13	Decreased SHGC	63.40	0.90	13.70	4.90	26.40	4.60	12.90	3.21%
	14	Decreased SHGC & U Value	62.80	0.90	14.00	4.10	26.40	4.50	12.90	4.12%
	15	Window Shading	63.30	0.90	13.90	4.60	26.40	4.60	12.90	3.36%
	16	Window Shading and Redistribution	62.40	0.90	13.40	4.40	26.40	4.40	12.90	4.73%
Envelope	17	Radiant Barrier	64.60	0.90	15.10	4.30	26.40	5.00	12.90	1.37%
	18	Clay Tiles with a Reflectance of >.40	65.10	0.90	15.50	4.40	26.40	5.00	12.90	0.61%
	19	Other Roofs with a Reflectance of >.50	64.90	0.90	15.30	4.40	26.40	5.00	12.90	0.92%
	20	Decreased Infiltration	63.90	0.90	15.20	3.70	26.40	4.80	12.90	2.44%
	21	Increased Infiltration	67.80	0.90	16.60	5.40	26.40	5.60	12.90	-3.51%
	22	Low Slope Roof with Increased Reflectance	64.80	0.90	15.20	4.40	26.40	5.00	12.90	1.07%
	23	Low Slope Roof	66.00	0.90	16.40	4.30	26.40	5.10	12.90	-0.76%
Lighting Options	24	25% Energy Star CFL Indoor Lamps	62.30	0.90	15.10	4.50	24.00	4.90	12.90	4.89%
	25	50% Energy Star CFL Indoor Lamps	59.40	0.90	14.50	4.70	21.60	4.80	12.90	9.31%
	26	Incandescent w occ	64.64	0.04	15.80	4.40	26.40	5.10	12.90	1.31%
	27	CFLw/o occ	64.84	0.24	15.80	4.40	26.40	5.10	12.90	1.00%
	28	CFL w occ	64.61	0.01	15.80	4.40	26.40	5.10	12.90	1.35%
DHW Measures	29	Tankless Water Heater	64.30	0.90	15.80	4.40	26.40	5.10	11.70	1.83%
	30	Removal of Pilot Light	65.50	0.90	15.80	4.40	26.40	5.10	12.90	0.00%
	31	Solar DHW System	55.92	0.90	15.80	4.40	26.40	6.57	1.85	14.63%

Table 7: Simulation Results for the Base Case with Natural Gas Heating (w/o setback), Houston, TX

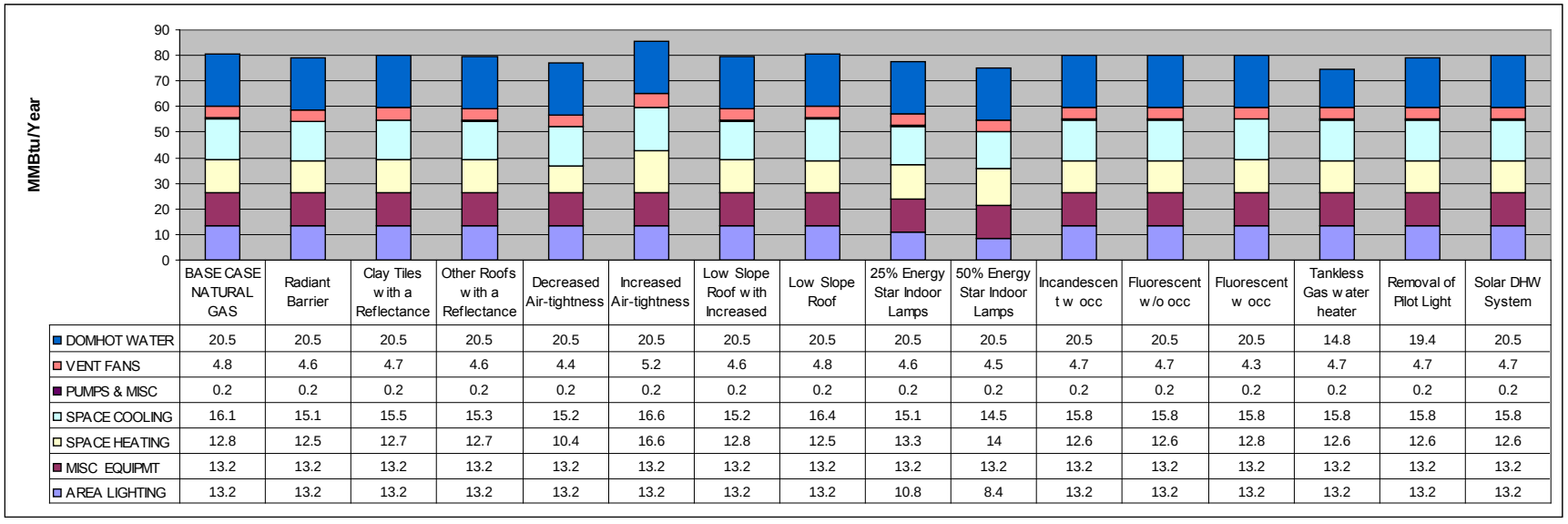
	EEM #	Energy Efficiency Measure	Total Energy Consumed (MMBtu)	Outdoor Lighting Load	Cooling Load (MMBtu)	Heating Load (MMBtu)	Others (MMBtu)	Fans &Pumps (MMBtu)	DHW (MMBtu)	Diff. %
	1	Base case Natural Gas w/o setback	87.10	0.90	18.30	15.40	26.40	5.60	20.50	0.00%
Renewable Power Options	2	PV Array for 6kW	58.89	0.90	18.30	15.40	26.40	5.60	20.50	32.39%
	3	PV Array for Partial Demand at 4kW	68.29	0.90	18.30	15.40	26.40	5.60	20.50	21.59%
	4	PV Array for Partial Demand at 2kW	77.69	0.90	18.30	15.40	26.40	5.60	20.50	10.80%
HVAC Options	5	Manual J: Increased Sqft/ton	86.50	0.90	18.00	15.10	26.40	5.60	20.50	0.69%
	6	Decreased Supply Airflow	84.60	0.90	16.80	14.90	26.40	5.10	20.50	2.87%
	7	Increased Supply Airflow	90.70	0.90	19.60	15.90	26.40	7.40	20.50	-4.13%
	8	Decreased Duct Static Pressure	84.30	0.90	17.40	16.20	26.40	2.90	20.50	3.21%
	9	Decreased Duct Leakage	79.70	0.90	14.30	12.00	26.40	5.60	20.50	8.50%
	10	Mechanical Systems within Conditioned Spaces	76.20	0.90	12.60	10.20	26.40	5.60	20.50	12.51%
	11	Improved SEER	83.30	0.90	15.50	15.80	26.40	4.20	20.50	4.36%
	12	Improved Furnace Efficiency	84.60	0.90	18.30	12.90	26.40	5.60	20.50	2.87%
Fenestration	13	Decreased SHGC	86.40	0.90	16.00	17.50	26.40	5.10	20.50	0.80%
	14	Decreased SHGC & U Value	83.30	0.90	16.30	14.20	26.40	5.00	20.50	4.36%
	15	Window Shading	85.70	0.90	16.30	16.50	26.40	5.10	20.50	1.61%
	16	Window Shading and Redistribution	84.10	0.90	15.80	15.60	26.40	4.90	20.50	3.44%
Envelope	17	Radiant Barrier	86.20	0.90	17.60	15.30	26.40	5.50	20.50	1.03%
	18	Clay Tiles with a Reflectance of >.40	86.80	0.90	18.00	15.50	26.40	5.50	20.50	0.34%
	19	Other Roofs with a Reflectance of >.50	86.50	0.90	17.70	15.50	26.40	5.50	20.50	0.69%
	20	Decreased Infiltration	83.40	0.90	17.50	12.80	26.40	5.30	20.50	4.25%
	21	Increased Infiltration	93.40	0.90	19.40	20.00	26.40	6.20	20.50	-7.23%
	22	Low Slope Roof with Increased Reflectance	86.70	0.90	17.70	15.70	26.40	5.50	20.50	0.46%
	23	Low Slope Roof	87.80	0.90	19.00	15.30	26.40	5.70	20.50	-0.80%
Lighting Options	24	25% Energy Star CFL Indoor Lamps	84.60	0.90	17.60	16.20	24.00	5.40	20.50	2.87%
	25	50% Energy Star CFL Indoor Lamps	82.30	0.90	17.00	17.00	21.60	5.30	20.50	5.51%
	26	Incandescent w occ	86.24	0.04	18.30	15.40	26.40	5.60	20.50	0.99%
	27	CFL w/o occ	86.44	0.24	18.30	15.40	26.40	5.60	20.50	0.75%
	28	CFL w occ	86.21	0.01	18.30	15.40	26.40	5.60	20.50	1.02%
DHW Measures	29	Tankless Gas Water Heater	81.40	0.90	18.30	15.40	26.40	5.60	14.80	6.54%
	30	Removal of Pilot Light	86.00	0.90	18.30	15.40	26.40	5.60	19.40	1.26%
	31	Solar DHW System	71.01	0.90	18.30	15.40	26.40	7.07	2.94	18.48%

Table 8: Simulation Results for the Base Case with Heat Pump Heating (w/o setback), Houston, TX

	EEM #	Energy Efficiency Measure	Total Energy Consumed (MMBtu)	Outdoor Lighting Load	Cooling Load (MMBtu)	Heating Load (MMBtu)	Others (MMBtu)	Fans &Pumps (MMBtu)	DHW (MMBtu)	Diff. %
	1	Base case Heat Pump/ w/o setback	69.50	0.90	18.30	5.20	26.40	5.80	12.90	0.00%
Renewable Power Options	2	PV Array for 6kW	41.29	0.90	18.30	5.20	26.40	5.80	12.90	40.59%
	3	PV Array for Partial Demand at 4kW	50.69	0.90	18.30	5.20	26.40	5.80	12.90	27.06%
	4	PV Array for Partial Demand at 2kW	60.09	0.90	18.30	5.20	26.40	5.80	12.90	13.53%
HVAC Options	5	Manual J: Increased Sqft/ton	68.90	0.90	18.00	4.90	26.40	5.80	12.90	0.86%
	6	Decreased Supply Airflow	67.10	0.90	16.80	4.90	26.40	5.20	12.90	3.45%
	7	Increased Supply Airflow	72.80	0.90	19.60	5.40	26.40	7.60	12.90	-4.75%
	8	Decreased Duct Static Pressure	66.00	0.90	17.40	5.40	26.40	3.00	12.90	5.04%
	9	Decreased Duct Leakage	64.60	0.90	14.30	4.30	26.40	5.80	12.90	7.05%
	10	Mechanical Systems within Conditioned Spaces	62.40	0.90	12.60	3.80	26.40	5.80	12.90	10.22%
	11	Improved SEER	65.40	0.90	15.50	5.30	26.40	4.40	12.90	5.90%
	12	Improved Heat Pump Efficiency	69.10	0.90	18.30	4.80	26.40	5.80	12.90	0.58%
Fenestration	13	Decreased SHGC	67.20	0.90	16.00	5.70	26.40	5.30	12.90	3.31%
	14	Decreased SHGC & U Value	66.50	0.90	16.30	4.90	26.40	5.10	12.90	4.32%
	15	Window Shading	67.30	0.90	16.30	5.50	26.40	5.30	12.90	3.17%
	16	Window Shading and Redistribution	66.30	0.90	15.80	5.20	26.40	5.10	12.90	4.60%
Envelope	17	Radiant Barrier	68.70	0.90	17.60	5.20	26.40	5.70	12.90	1.15%
	18	Clay Tiles with a Reflectance of >.40	69.10	0.90	18.00	5.20	26.40	5.70	12.90	0.58%
	19	Other Roofs with a Reflectance of >.50	68.80	0.90	17.70	5.20	26.40	5.70	12.90	1.01%
	20	Decreased Infiltration	67.60	0.90	17.50	4.50	26.40	5.40	12.90	2.73%
	21	Increased Infiltration	72.40	0.90	19.40	6.40	26.40	6.40	12.90	-4.17%
	22	Low Slope Roof with Increased Reflectance	68.90	0.90	17.70	5.30	26.40	5.70	12.90	0.86%
	23	Low Slope Roof	70.30	0.90	19.00	5.20	26.40	5.90	12.90	-1.15%
Lighting Options	24	25% Energy Star CFL Indoor Lamps	66.40	0.90	17.60	5.40	24.00	5.60	12.90	4.46%
	25	50% Energy Star CFL Indoor Lamps	63.50	0.90	17.00	5.60	21.60	5.50	12.90	8.63%
	26	Incandescent w occ	68.64	0.04	18.30	5.20	26.40	5.80	12.90	1.24%
	27	CFL w/o occ	68.84	0.24	18.30	5.20	26.40	5.80	12.90	0.95%
	28	CFL w occ	68.61	0.01	18.30	5.20	26.40	5.80	12.90	1.28%
DHW Measures	29	Tankless Water Heater	68.30	0.90	18.30	5.20	26.40	5.80	11.70	1.73%
	30	Removal of Pilot Light	69.50	0.90	18.30	5.20	26.40	5.80	12.90	0.00%
	31	Solar DHW System	59.92	0.90	18.30	5.20	26.40	7.27	1.85	13.79%

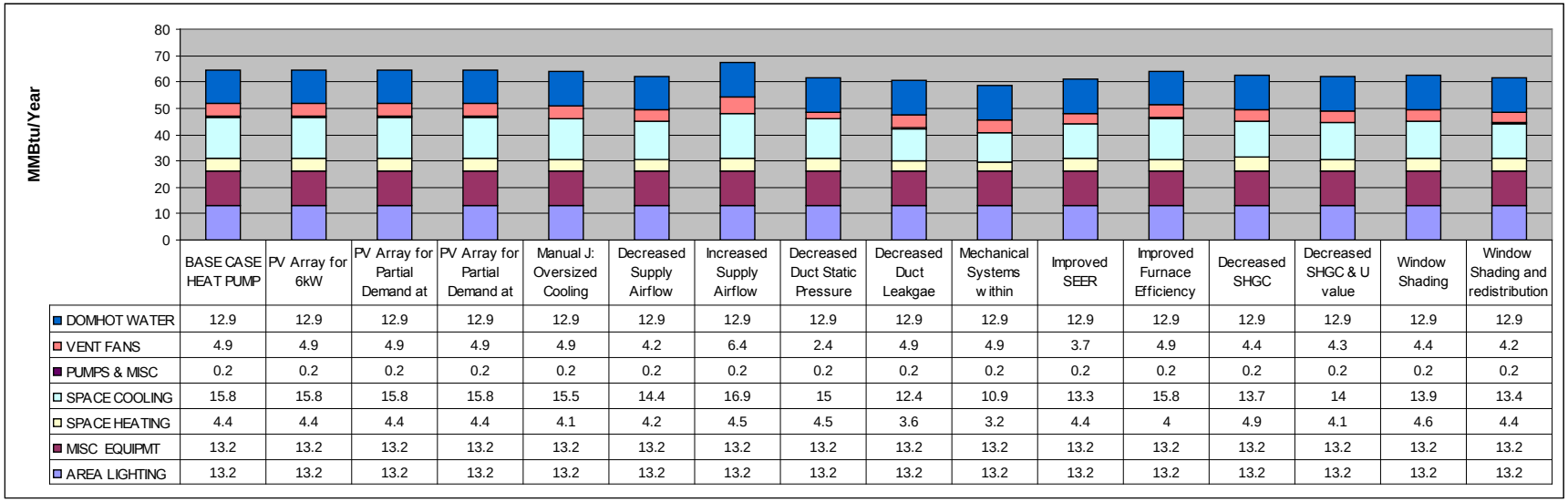


	BASE CASE NATURAL GAS	PV Array for 6kW	PV Array for Partial Demand at	PV Array for Partial Demand at	Manual J: Oversized Cooling	Decreased Supply Airflow	Increased Supply Airflow	Decreased Duct Static Pressure	Decreased Duct Leakgae	Mechanical Systems within	Improved SEER	Improved Furnace Efficiency	Decreased SHGC	Decreased SHGC & U value	Window Shading	Window Shading and redistribution
DOMHOT WATER	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5
VENT FANS	4.8	4.8	4.8	4.8	4.7	4.1	6.3	2.3	4.7	4.7	3.5	4.7	4.2	4.2	4.2	4.1
PUMPS & MISC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SPACE COOLING	16.1	16.1	16.1	16.1	15.5	14.4	16.9	15	12.4	10.9	13.3	15.8	13.7	14	13.9	13.4
SPACE HEATING	12.8	12.8	12.9	12.8	12.4	12.2	13	13.2	9.9	8.4	12.9	10.5	14.5	11.7	13.7	12.7
MISC EQUIPMT	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
AREA LIGHTING	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2

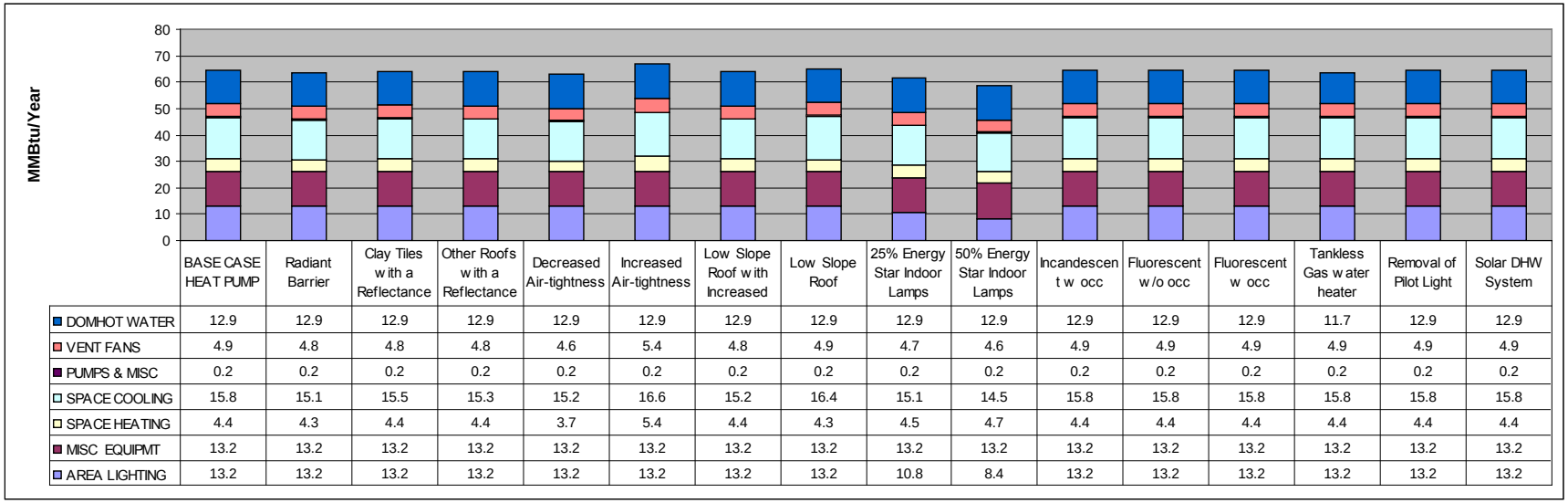


	BASE CASE NATURAL GAS	Radiant Barrier	Clay Tiles with a Reflectance	Other Roofs with a Reflectance	Decreased Air-tightness	Increased Air-tightness	Low Slope Roof with Increased	Low Slope Roof	25% Energy Star Indoor Lamps	50% Energy Star Indoor Lamps	Incandescent w occ	Fluorescent w/o occ	Fluorescent w occ	Tankless Gas water heater	Removal of Pilot Light	Solar DHW System
DOMHOT WATER	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	14.8	19.4	20.5
VENT FANS	4.8	4.6	4.7	4.6	4.4	5.2	4.6	4.8	4.6	4.5	4.7	4.7	4.3	4.7	4.7	4.7
PUMPS & MISC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SPACE COOLING	16.1	15.1	15.5	15.3	15.2	16.6	15.2	16.4	15.1	14.5	15.8	15.8	15.8	15.8	15.8	15.8
SPACE HEATING	12.8	12.5	12.7	12.7	10.4	16.6	12.8	12.5	13.3	14	12.6	12.6	12.8	12.6	12.6	12.6
MISC EQUIPMT	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
AREA LIGHTING	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	10.8	8.4	13.2	13.2	13.2	13.2	13.2	13.2

Figure 1: Energy Use of various EEMs for Base Case House with Natural Gas Heating (w/ setback), Houston, TX

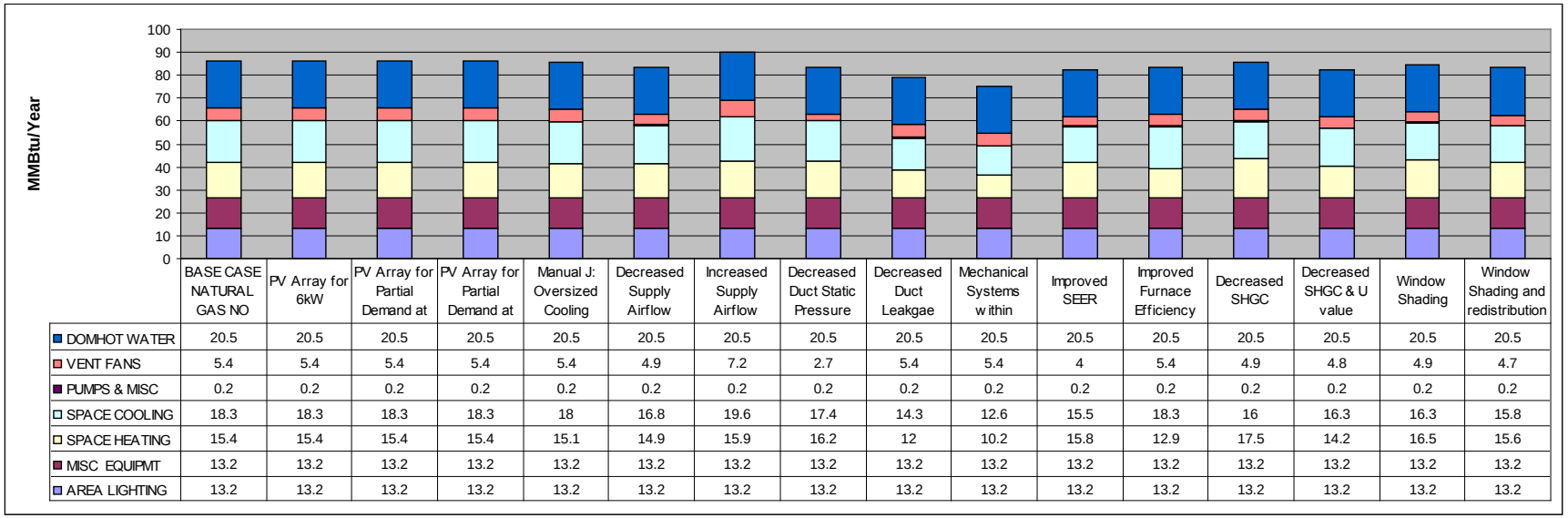


	BASE CASE HEAT PUMP	PV Array for 6kW	PV Array for Partial Demand at	PV Array for Partial Demand at	Manual J: Oversized Cooling	Decreased Supply Airflow	Increased Supply Airflow	Decreased Duct Static Pressure	Decreased Duct Leakgae	Mechanical Systems within	Improved SEER	Improved Furnace Efficiency	Decreased SHGC	Decreased SHGC & U value	Window Shading	Window Shading and redistribution
DOMHOT WATER	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9
VENT FANS	4.9	4.9	4.9	4.9	4.9	4.2	6.4	2.4	4.9	4.9	3.7	4.9	4.4	4.3	4.4	4.2
PUMPS & MISC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SPACE COOLING	15.8	15.8	15.8	15.8	15.5	14.4	16.9	15	12.4	10.9	13.3	15.8	13.7	14	13.9	13.4
SPACE HEATING	4.4	4.4	4.4	4.4	4.1	4.2	4.5	4.5	3.6	3.2	4.4	4	4.9	4.1	4.6	4.4
MISC EQUIPMT	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
AREA LIGHTING	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2

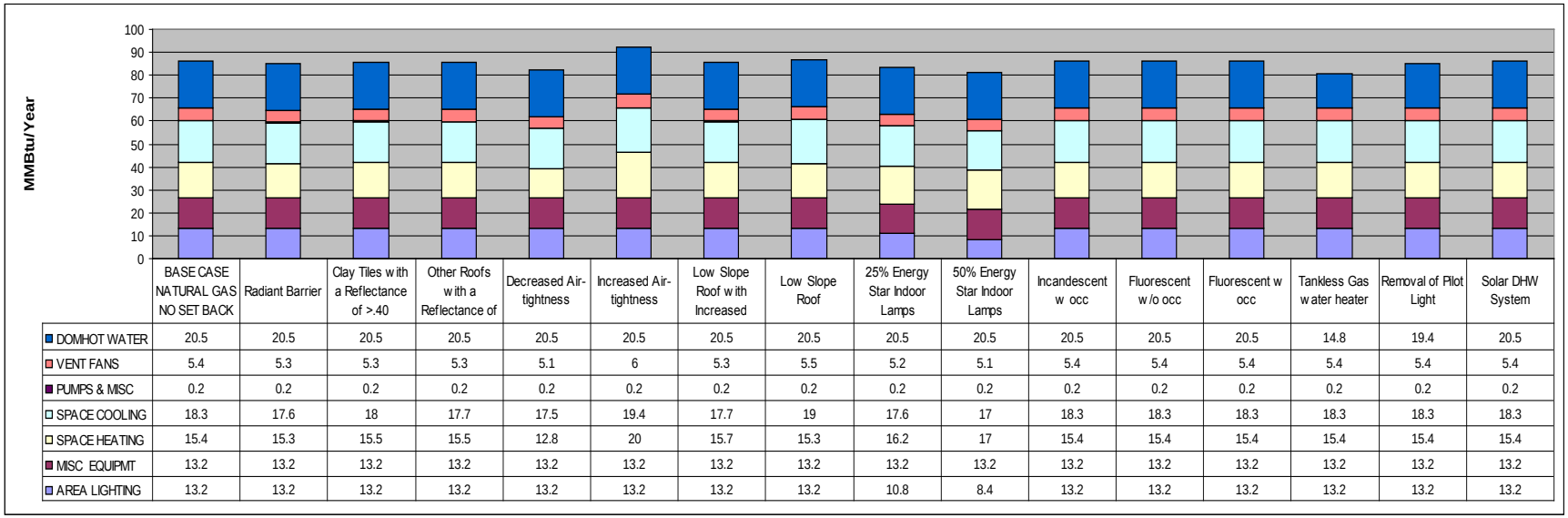


	BASE CASE HEAT PUMP	Radiant Barrier	Clay Tiles with a Reflectance	Other Roofs with a Reflectance	Decreased Air-tightness	Increased Air-tightness	Low Slope Roof with Increased	Low Slope Roof	25% Energy Star Indoor Lamps	50% Energy Star Indoor Lamps	Incandescent w occ	Fluorescent w/o occ	Fluorescent w occ	Tankless Gas water heater	Removal of Pilot Light	Solar DHW System
DOMHOT WATER	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	11.7	12.9	12.9
VENT FANS	4.9	4.8	4.8	4.8	4.6	5.4	4.8	4.9	4.7	4.6	4.9	4.9	4.9	4.9	4.9	4.9
PUMPS & MISC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SPACE COOLING	15.8	15.1	15.5	15.3	15.2	16.6	15.2	16.4	15.1	14.5	15.8	15.8	15.8	15.8	15.8	15.8
SPACE HEATING	4.4	4.3	4.4	4.4	3.7	5.4	4.4	4.3	4.5	4.7	4.4	4.4	4.4	4.4	4.4	4.4
MISC EQUIPMT	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
AREA LIGHTING	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	10.8	8.4	13.2	13.2	13.2	13.2	13.2	13.2

Figure 2: Energy Use of various EEMs for Base Case House with Heat Pump Heating (w/ setback), Houston, TX

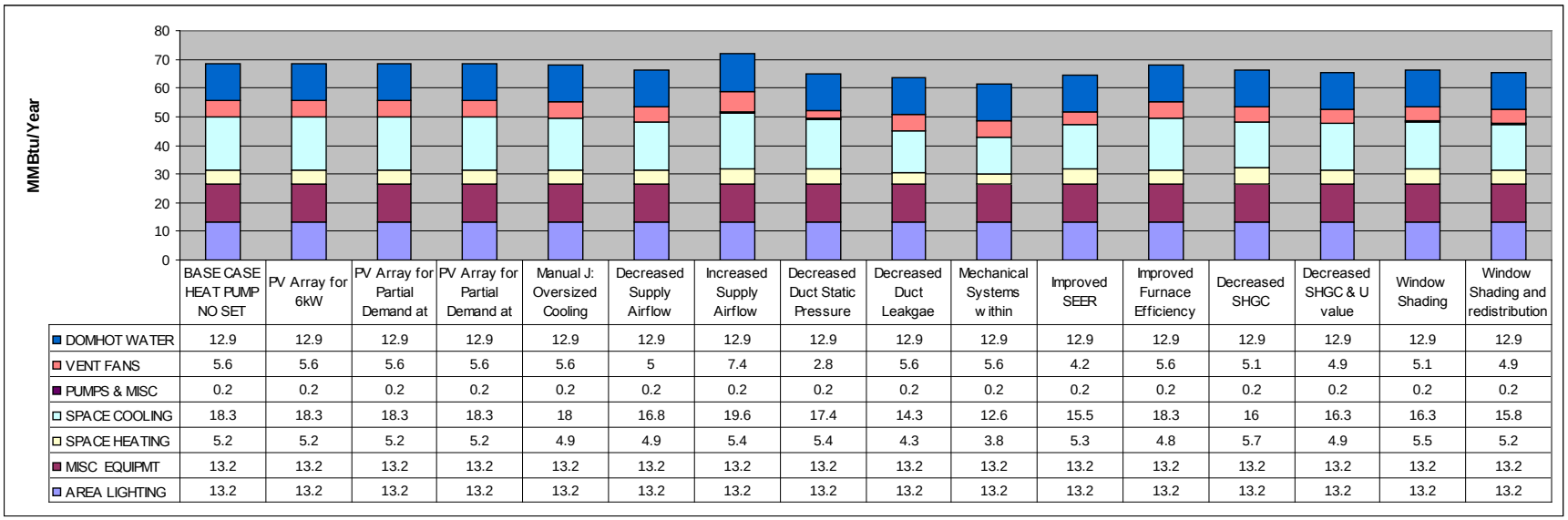


	BASE CASE NATURAL GAS NO	PV Array for 6kW	PV Array for Partial Demand at	PV Array for Partial Demand at	Manual J: Oversized Cooling	Decreased Supply Airflow	Increased Supply Airflow	Decreased Duct Static Pressure	Decreased Duct Leakgae	Mechanical Systems within	Improved SEER	Improved Furnace Efficiency	Decreased SHGC	Decreased SHGC & U value	Window Shading	Window Shading and redistribution
DOMHOT WATER	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5
VENT FANS	5.4	5.4	5.4	5.4	5.4	4.9	7.2	2.7	5.4	5.4	4	5.4	4.9	4.8	4.9	4.7
PUMPS & MISC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SPACE COOLING	18.3	18.3	18.3	18.3	18	16.8	19.6	17.4	14.3	12.6	15.5	18.3	16	16.3	16.3	15.8
SPACE HEATING	15.4	15.4	15.4	15.4	15.1	14.9	15.9	16.2	12	10.2	15.8	12.9	17.5	14.2	16.5	15.6
MISC EQUIPMT	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
AREA LIGHTING	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2

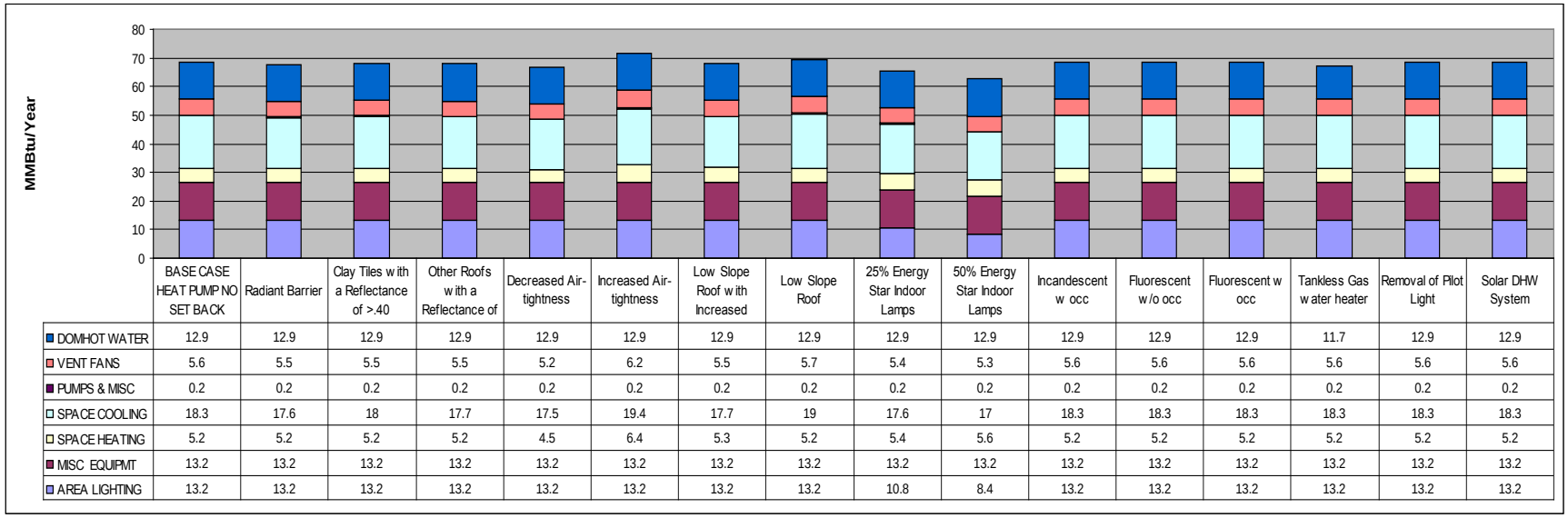


	BASE CASE NATURAL GAS NO SET BACK	Radiant Barrier	Clay Tiles with a Reflectance of >.40	Other Roofs with a Reflectance of	Decreased Air-tightness	Increased Air-tightness	Low Slope Roof with Increased	Low Slope Roof	25% Energy Star Indoor Lamps	50% Energy Star Indoor Lamps	Incandescent w occ	Fluorescent w/o occ	Fluorescent w occ	Tankless Gas water heater	Removal of Pilot Light	Solar DHW System
DOMHOT WATER	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	14.8	19.4	20.5
VENT FANS	5.4	5.3	5.3	5.3	5.1	6	5.3	5.5	5.2	5.1	5.4	5.4	5.4	5.4	5.4	5.4
PUMPS & MISC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SPACE COOLING	18.3	17.6	18	17.7	17.5	19.4	17.7	19	17.6	17	18.3	18.3	18.3	18.3	18.3	18.3
SPACE HEATING	15.4	15.3	15.5	15.5	12.8	20	15.7	15.3	16.2	17	15.4	15.4	15.4	15.4	15.4	15.4
MISC EQUIPMT	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
AREA LIGHTING	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	10.8	8.4	13.2	13.2	13.2	13.2	13.2	13.2

Figure 3: Energy Use of various EEMs for Base Case House with Natural Gas Heating (w/o setback), Houston, TX



	BASE CASE HEAT PUMP NO SET	PV Array for 6kW	PV Array for Partial Demand at	PV Array for Partial Demand at	Manual J: Oversized Cooling	Decreased Supply Airflow	Increased Supply Airflow	Decreased Duct Static Pressure	Decreased Duct Leakgae	Mechanical Systems within	Improved SEER	Improved Furnace Efficiency	Decreased SHGC	Decreased SHGC & U value	Window Shading	Window Shading and redistribution
DOMHOT WATER	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9
VENT FANS	5.6	5.6	5.6	5.6	5.6	5	7.4	2.8	5.6	5.6	4.2	5.6	5.1	4.9	5.1	4.9
PUMPS & MISC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SPACE COOLING	18.3	18.3	18.3	18.3	18	16.8	19.6	17.4	14.3	12.6	15.5	18.3	16	16.3	16.3	15.8
SPACE HEATING	5.2	5.2	5.2	5.2	4.9	4.9	5.4	5.4	4.3	3.8	5.3	4.8	5.7	4.9	5.5	5.2
MISC EQUIPMT	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
AREA LIGHTING	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2



	BASE CASE HEAT PUMP NO SET BACK	Radiant Barrier	Clay Tiles with a Reflectance of >.40	Other Roofs with a Reflectance of	Decreased Air-tightness	Increased Air-tightness	Low Slope Roof with Increased	Low Slope Roof	25% Energy Star Indoor Lamps	50% Energy Star Indoor Lamps	Incandescent w occ	Fluorescent w/o occ	Fluorescent w occ	Tankless Gas water heater	Removal of Pilot Light	Solar DHW System
DOMHOT WATER	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	11.7	12.9	12.9
VENT FANS	5.6	5.5	5.5	5.5	5.2	6.2	5.5	5.7	5.4	5.3	5.6	5.6	5.6	5.6	5.6	5.6
PUMPS & MISC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
SPACE COOLING	18.3	17.6	18	17.7	17.5	19.4	17.7	19	17.6	17	18.3	18.3	18.3	18.3	18.3	18.3
SPACE HEATING	5.2	5.2	5.2	5.2	4.5	6.4	5.3	5.2	5.4	5.6	5.2	5.2	5.2	5.2	5.2	5.2
MISC EQUIPMT	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
AREA LIGHTING	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	10.8	8.4	13.2	13.2	13.2	13.2	13.2	13.2

Figure 4: Energy Use of various EEMs for Base Case House with Heat Pump Heating (w/o setback), Houston, TX

7: Simulation Inputs for the Group Measures

Group measures are the combination of individual measures. Individual measures are grouped into four different categories: 2-5%, 5-10%, 10-15%, above 15%, as well as based on their savings above base case. Individual EEMs with marginal savings above the base case (i.e. below 2% savings above base case) are not used in the group measures combination. After categorizing, ten group measures have been formed to combine the individual measures so that the combined savings of each measure in the group is more than 15% above the base case. Table 9 through Table 12 show the categorization of the individual EEMs for each of the four options. Table 13 presents a list of the grouped measures for the base case with natural gas heating and the base case with an all electric system. Table 14 and Table 15 present the parameters used in the simulation of the group measures for the four different options. The first row of values in all the tables contains information used in the base case runs. The remaining rows present information used in the simulation of the group energy efficiency measures. The shaded cells in each row indicate the change in the values of parameters of individual measures selected to simulate the group measure.

Table 9: Grouping of Results for the Base Case with Natural Gas Heating (w/ setback), Houston, TX

Range	EEM #	Individual Measures	Percentage Energy Savings above Basecase (%)	Estimated Cost ($)	Type of Cost
Above 15%	3	PV Array for Partial Demand at 4kW	23.2%	$29,000	New System
	2	PV Array for 6kW	34.8%	$41,000	New System
	31	Solar DHW System	19.8%	$2,900 - $5,200	New System
10-15%	10	Mechanical Systems within Conditioned Spaces	11.2%	$1,000 - $7,000	Marginal
	4	PV Array for Partial Demand at 2kW	11.6%	$17,000	New System
5-10%	25	50% Energy Star CFL Indoor Lamps	6.0%	$45 - $100	Marginal
	29	Tankless Gas Water Heater	7.0%	$1,000 - $3,500	Marginal
	9	Decreased Duct Leakage	7.5%	$200 - $450	New System
2-5%	12	Improved Furnace Efficiency	2.6%	$600 - $1,500	Marginal
	16	Window Shading and Redistribution	3.6%	$3,100 - $3,500	New System
	24	25% Energy Star CFL Indoor Lamps	3.1%	$25 - $50	Marginal
	8	Decreased Duct Static Pressure	3.2%	$0 - $250	Marginal
	20	Decreased Infiltration	3.8%	$350 - $1,500	Marginal
	14	Decreased SHGC & U Value	3.9%	$800 - $1,100	Marginal
	11	Improved SEER from 13 to 15	4.2%	$900 - $2,500	Marginal

Table 10: Grouping of Results for the Base Case with Heat Pump Heating (w/ setback), Houston, TX

Range	EEM #	Individual Measures	Percentage Energy Savings above Basecase (%)	Estimated Cost ($)	Type of Cost
Above 15%	3	PV Array for Partial Demand at 4kW	28.7%	$29,000	New System
	2	PV Array for 6kW	43.1%	$41,000	New System
10-15%	4	PV Array for Partial Demand at 2kW	14.4%	$17,000	New System
	31	Solar DHW System	14.6%	$2,900 - $5,200	New System
5-10%	15	Window Shading	3.4%	$3,100 - $3,500	New System
	11	Improved SEER from 13 to 15	5.7%	$1,500 - $2,400	Marginal
	9	Decreased Duct Leakage	6.4%	$200 - $450	New System
	16	Window Shading and Redistribution	4.7%	$3,100 - $3,500	New System
	10	Mechanical Systems within Conditioned Spaces	9.3%	$1,000 - $7,000	Marginal
	25	50% Energy Star CFL Indoor Lamps	9.3%	$45 - $100	Marginal
2-5%	20	Decreased Infiltration	2.4%	$350 - $1,500	Marginal
	14	Decreased SHGC & U Value	4.1%	$800 - $1,100	Marginal
	24	25% Energy Star CFL Indoor Lamps	4.9%	$25 - $50	Marginal
	8	Decreased Duct Static Pressure	4.9%	$0 - $250	Marginal

Table 11: Grouping of Results for the Base Case with Natural Gas Heating (w/o setback), Houston, TX

Range	EEM #	Individual Measures	Percentage Energy Savings above Basecase (%)	Estimated Cost ($)	Type of Cost
Above 15%	3	PV Array for Partial Demand at 4kW	21.6%	$29,000	New System
	2	PV Array for 6kW	32.4%	$41,000	New System
	31	Solar DHW System	18.5%	$2,900 - $5,200	New System
10-15%	10	Mechanical Systems within Conditioned Spaces	12.5%	$1,000 - $7,000	Marginal
	4	PV Array for Partial Demand at 2kW	10.8%	$17,000	New System
5-10%	25	50% Energy Star CFL Indoor Lamps	5.5%	$45 - $100	Marginal
	29	Tankless Gas Water Heater	6.5%	$1,000 - $3,500	Marginal
	9	Decreased Duct Leakage	8.5%	$200 - $450	New System
2-5%	12	Improved Furnace Efficiency	2.9%	$600 - $1,500	Marginal
	16	Window Shading and Redistribution	3.4%	$3,100 - $3,500	New System
	24	25% Energy Star CFL Indoor Lamps	2.9%	$25 - $50	Marginal
	8	Decreased Duct Static Pressure	3.2%	$0 - $250	Marginal
	20	Decreased Infiltration	4.3%	$350 - $1,500	Marginal
	14	Decreased SHGC & U Value	4.4%	$800 - $1,100	Marginal
	11	Improved SEER from 13 to 15	4.4%	$900 - $2,500	Marginal

Table 12: Grouping of Results for the Base Case with Heat Pump Heating (w/o setback), Houston, TX

Range	EEM #	Individual Measures	Percentage Energy Savings above Basecase (%)	Estimated Cost ($)	Type of Cost
Above 15%	3	PV Array for Partial Demand at 4kW	27.1%	$29,000	New System
	2	PV Array for 6kW	40.6%	$41,000	New System
10-15%	4	PV Array for Partial Demand at 2kW	13.5%	$17,000	New System
	31	Solar DHW System	13.8%	$2,900 - $5,200	New System
5-10%	15	Window Shading	3.2%	$3,100 - $3,500	New System
	11	Improved SEER from 13 to 15	5.9%	$1,500 - $2,400	Marginal
	9	Decreased Duct Leakage	7.1%	$200 - $450	New System
	16	Window Shading and Redistribution	4.6%	$3,100 - $3,500	New System
	10	Mechanical Systems within Conditioned Spaces	10.2%	$1,000 - $7,000	Marginal
	25	50% Energy Star CFL Indoor Lamps	8.6%	$45 - $100	Marginal
2-5%	20	Decreased Infiltration	2.7%	$350 - $1,500	Marginal
	14	Decreased SHGC & U Value	4.3%	$800 - $1,100	Marginal
	24	25% Energy Star CFL Indoor Lamps	4.5%	$25 - $50	Marginal
	8	Decreased Duct Static Pressure	5.0%	$0 - $250	Marginal

Table 13: Grouped Measures for Base Case House with Natural Gas Heating and Heat Pump Heating

Groups	Base Case with Natural Gas Heating		Base Case with Heat Pump Heating	
	EEM #	Measures	EEM #	Measures
Group 1	31	Solar DHW System	3	PV Array for Partial Demand at 4kW
Group 2	2	PV Array for 6kW	2	PV Array for 6kW
Group 3	3	PV Array for Partial Demand at 4kW	4	PV Array for Partial Demand at 2kW
			20	Decreased Infiltration
Group 4	10	Mechanical Systems within Conditioned Spaces	31	Solar DHW System
	25	50% Energy Star Indoor Lamps	20	Decreased Infiltration
Group 5	4	PV Array for Partial Demand at 2kW	25	50% Energy Star CFL Indoor Lamps
	9	Decreased Duct Leakage	9	Decreased Duct Leakage
Group 6	29	Tankless Gas Water Heater	10	Mechanical Systems within Conditioned Spaces
	25	50% Energy Star CFL Indoor Lamps	11	Improved SEER from 13 to 15
	20	Decreased Infiltration	20	Decreased Infiltration
Group 7	9	Decreased Duct Leakage	25	50% Energy Star CFL Indoor Lamps
	25	50% Energy Star CFL Indoor Lamps	11	Improved SEER from 13 to 15
	11	Improved SEER from 13 to 15	14	Decreased SHGC & U Value
Group 8	9	Decreased Duct Leakage	9	Decreased Duct Leakage
	11	Improved SEER from 13 to 15	24	25% Energy Star CFL Indoor Lamps
	14	Decreased SHGC & U Value	11	Improved SEER from 13 to 15
	20	Decreased Infiltration	15	Window Shading
Group 9	9	Decreased Duct Leakage	9	Decreased Duct Leakage
	14	Decreased SHGC & U Value	14	Decreased SHGC & U Value
	8	Decreased Duct Static Pressure	11	Improved SEER from 13 to 15
	16	Window Shading and Redistribution	20	Decreased Infiltration
Group 10	9	Decreased Duct Leakage	24	25% Energy Star CFL Indoor Lamps
	11	Improved SEER from 13 to 15	8	Decreased Duct Static Pressure
	20	Decreased Infiltration	16	Window Shading and Redistribution
	12	Improved Furnace Efficiency	14	Decreased SHGC & U Value

Table 14: Simulation Inputs for the Grouped Measures for the Base Case House with Natural Gas Heating

Group #	Energy Efficiency Measure	Cooling System Sizing (ft2/ton)	Supply Air Flow (CFM/ton)	Supply Fan Static Pressure	Supply Duct Leakage (%)	Return Duct Leakage (%)	Duct in Conditioned Space	Improved SEER	Improved AFUE	Improved HSPF	SHGC	U-Value	Shading	Shading	Shading	Shading	WWR% for front side wall	WWR% area for backside wall	WWR% for right side wall	WWR% for left side wall	Radiant Barrier	Roof Abs	Infiltration Rate (ACH/hr)	Pitch of Roof (degree)	Lighting (kW)	Energy Factor
	Base case Natural Gas w/ setback	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
1	Group 1 - Solar DHW System	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
2	Group 2 -PV Array for 6kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
3	Group 3 -PV Array for 4kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
4	Group 4 -Mechanical Systems within Conditioned Space -50% Energy Star Lighting	500	360	1.0	**0%**	**0%**	**ROOM**	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	**0.28**	0.54
5	Group 5 -PV Array for Partial Demand at 2kW -Decreased Duct Leakage	500	360	1.0	**6.70%**	**3.30%**	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.54
6	Group 6 -50% Energy Star CFL Indoor Lamps - Tankless Water Heater - Decreased Infiltration	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.35**	23	**0.28**	**0.748**
7	Group 7 -50% Energy Star Indoor Lamps -Decreased Duct Leakage -Improved SEER from 13 to 15	500	360	1.0	**6.70%**	**3.30%**	ATTIC	**15**	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	**0.28**	0.54
8	Group 8 - Decreased Duct Leakage - Improved SEER from 13 to 15 - Decreased SHGC and U - Decreased Infiltration	500	360	1.0	**6.70%**	**3.30%**	ATTIC	**15**	0.78	7.70	**0.3**	**0.35**	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.35**	23	0.44	0.54
9	Group 9 -Decreased Duct Leakage -Decreased Static Pressure -Decreased SHGC & U-Value -Window Shading and Redistribution	500	360	**0.5**	**6.70%**	**3.30%**	ATTIC	13	0.78	7.70	**0.3**	**0.35**	**2**	**2**	**2**	**2**	**48.82**	**27.12**	**16.27**	**16.27**	N	0.75	0.462	23	0.44	0.54
10	Group 10 -Improved Furnace Efficiency -Decreased Infiltration -Decreased Duct Leakage -Improved SEER from 13 to 15	500	360	1.0	**6.70%**	**3.30%**	ATTIC	**15**	**0.93**	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.35**	23	0.44	0.54

Table 15: Simulation Inputs for Grouped Measures for the Base Case House with Heat Pump Heating

Group #	Energy Efficiency Measure	Cooling System Sizing (ft2/ton)	Supply Air Flow (CFM/ton)	Supply Fan Static Pressure	Supply Duct Leakage (%)	Return Duct Leakage (%)	Duct in Conditioned Space	Improved SEER	Improved AFUE	Improved HSPF	SHGC	U-Value	Shading	Shading	Shading	Shading	WWR% for front side wall	WWR% area for backside wall	WWR% for right side wall	WWR% for left side wall	Radiant Barrier	Roof Abs	Infiltration Rate (ACH/hr)	Pitch of Roof (degree)	Lighting (kW)	Energy Factor
	Base case Heat Pump w/ setback	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
1	Group 1 - PV Array for Partial Demand at 4kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
2	Group 2 -PV Array for 6kW	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	0.44	0.86
3	Group 3 -PV Array for Partial Demand at 2kW -Decreased Infiltration	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.35**	23	0.44	0.86
4	Group 4 -Solar DHW System -Decreased Infiltration	500	360	1.0	20%	10%	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.35**	23	0.44	0.86
5	Group 5 -50% Energy star CFL Indoor Lamps - Decreased Duct Leakage	500	360	1.0	**6.70%**	**3.30%**	ATTIC	13	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	**0.28**	0.86
6	Group 6 -Mechanical Systems within Conditioned Spaces -Improved SEER from 13 to 15 - Decreased Infiltration	500	360	1.0	**0%**	**0%**	**ROOM**	15	0.78	7.70	0.4	0.47	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.35**	23	0.44	0.86
7	Group 7 -50% Energy Star Indoor Lamps -Improved SEER from 13 to 15 -Decreased SHGC & U Value.	500	360	1.0	20%	10%	ATTIC	**15**	0.78	7.70	**0.3**	**0.35**	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	0.462	23	**0.28**	0.86
8	Group 8 -Window Shading -Decreased Duct Leakage -Improved SEER from 13 to 15 - 25% Energy Star CFL Indoor Lamps	500	360	1.0	**6.70%**	**3.30%**	ATTIC	**15**	0.78	7.70	0.4	0.47	**2**	**2**	**2**	**2**	27.30	27.30	27.30	27.30	N	0.75	0.462	23	**0.36**	0.86
9	Group 9 -Decreased Duct Leakage -Decreased Infiltration -Improved SEER from 13 to 15 -Decreased SHGC & U Value	500	360	1.0	**6.70%**	**3.30%**	ATTIC	**15**	0.78	7.70	**0.3**	**0.35**	0	0	0	0	27.30	27.30	27.30	27.30	N	0.75	**0.35**	23	0.44	0.86
10	Group 10 - Window Shading and Redistribution - 25% Energy Star CFL Indoor Lamps - Decreased Duct Static Pressure - Decreased SHGC & U Value	500	360	**0.5**	20%	10%	ATTIC	13	0.78	7.70	**0.3**	**0.35**	**2**	**2**	**2**	**2**	**48.82**	**27.12**	**16.27**	**16.27**	N	0.75	0.462	23	**0.36**	0.86

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8: Simulation Results for Grouped Measures

8.1 Energy Savings from Grouped Measures

Table 16 shows the energy savings from a different group measure for the base-case house with natural gas heating with setbacks. The first 3 groups consist of renewable power options—all achieved a savings of more than 19%.

Group 8, which is a combination of decreased duct leakage, improved SEER, decreased SHGC &U-value and decreased infiltration, provided the maximum energy savings of 16.9% above the base case.

Group 5, which is a combination of PV Array for Partial Demand at 2kW and decreased duct leakage, provided the energy savings of 19.1% above base case. Table 18 shows the energy savings from different group measures for the base-case house with heat pump heating with setbacks. The first 2 groups consist of renewable power options and all achieved a savings of more than 28%.

Group 7, which is a combination of 50% Energy Star CFL indoor lamps, improved SEER from 13 to 15 and decreased SHGC & U-value, provided the maximum energy savings of 17.6 % above base case. Group 8, which is a combination of decreased duct leakage, 25% Energy Star CFL indoor lamps, improved SEER from 13 to 15 and window shading, provided the maximum savings of 17.4 % above base case. Table 20 shows the energy savings from different a group measure for the base-case house with natural gas heating without setbacks. The first 2 groups consist of renewable power options; both the groups achieved a savings more than 18%.

In Group 8 the combination of decreased duct leakage, improved SEER from 13 to 15, decreased SHGC & U-value and decreased infiltration, provided the maximum savings of 18.6% above base case. Table 22 shows the energy savings from a different group measure for the base-case house with heat pump heating without setbacks. The first 2 groups consist of renewable power options—all achieved a savings more than 27%.

Group 8, the combination of window shading, decreased duct leakage, improved SEER from 13 to 15, 25% Energy Star CFL indoor lamps, provided the maximum savings of 18.4% above base case.

Group 7, the combination of 50% Energy Star CFL indoor lamps, improved SEER from 13 to 15, decreased SHGC & U-value, provided the maximum savings of 17.7% above the base case. Table 17, Table 19, Table 21 and Table 23 provide the corresponding energy cost savings and payback for the sets of measures for the four base case options.

Table 16: Combined Energy Savings of Grouped Measures for Base Case House with Natural Gas Heating (w/ setback), Houston, TX

Groups	EEM #	Measures	Combined Energy Savings (%)	Electricity Savings (kWh/yr)	Combined Gas Savings (CCF/yr)
Group 1	**31**	Solar DHW System	20.4%	-313	172
Group 2	**2**	PV Array for 6kW	35.3%	8,385	2
Group 3	**3**	PV Array for Partial Demand at 4kW	23.8%	5,629	2
Group 4	**10**	Mechanical Systems within Conditioned Spaces	17.9%	3,283	33
	25	50% Energy Star Indoor Lamps			
Group 5	**4**	PV Array for Partial Demand at 2kW	19.7%	3,870	28
	9	Decreased Duct Leakage			
Group 6	**29**	Tankless Gas Water Heater	17.6%	2,227	66
	25	50% Energy Star CFL Indoor Lamps			
	20	Decreased Infiltration			
Group 7	**9**	Decreased Duct Leakage	17.4%	3,722	15
	25	50% Energy Star CFL Indoor Lamps			
	11	Improved SEER from 13 to 15			
Group 8	**9**	Decreased Duct Leakage	17.5%	2,667	50
	11	Improved SEER from 13 to 15			
	14	Decreased SHGC & U Value			
	20	Decreased Infiltration			
Group 9	**9**	Decreased Duct Leakage	16.0%	2,960	29
	14	Decreased SHGC & U Value			
	8	Decreased Duct Static Pressure			
	16	Window Shading and Redistribution			
Group 10	**9**	Decreased Duct Leakage	16.3%	2,198	56
	11	Improved SEER from 13 to 15			
	20	Decreased Infiltration			
	12	Improved Furnace Efficiency			

Table 17: Energy Cost[2] Savings and Payback from Grouped Measures for Base Case House with Natural Gas Heating (w/setback), Houston, TX

Groups	EEM #	Measures	Combined Energy Cost Savings ($) Cost-1	Combined Energy Cost Savings ($) Cost-2	Combined Energy Cost Savings ($) Cost-3	Combined Total Cost ($)	Simple Estimated Payback (yrs) For Cost-1	Simple Estimated Payback (yrs) For Cost-2	Simple Estimated Payback (yrs) For Cost-3
Group 1	**31**	Solar DHW System	$157	$196	$235	$2,900 - $5,200	18.5 - 33.2	14.8 - 26.5	12.3 - 22.1
Group 2	**2**	PV Array for 6kW	$1,344	$1,680	$2,016	$41,000	30.5	24.4	20.3
Group 3	**3**	PV Array for Partial Demand at 4kW	$903	$1,129	$1,355	$29,000	32.1	25.7	21.4
Group 4	**10**	Mechanical Systems within Conditioned Spaces	$565	$706	$847	$1,045 - $7,100	1.9 - 12.6	1.5 - 10.1	1.2 - 8.4
	25	50% Energy Star Indoor Lamps							
Group 5	**4**	PV Array for Partial Demand at 2kW	$653	$816	$979	$17,200 - $17,450	26.3 - 26.7	21.1 - 21.4	17.6 17.8
	9	Decreased Duct Leakage							
Group 6	**29**	Tankless Gas Water Heater	$436	$545	$653	$1,395 - $5,100	3.2 - 11.7	2.6 - 9.4	2.1 - 7.8
	25	50% Energy Star CFL Indoor Lamps							
	20	Decreased Infiltration							
Group 7	**9**	Decreased Duct Leakage	$613	$766	$920	$1,145 - $3,050	1.9 - 5.0	1.5 - 4.0	1.2 - 3.3
	25	50% Energy Star CFL Indoor Lamps							
	11	Improved SEER from 13 to 15							
Group 8	**9**	Decreased Duct Leakage	$487	$609	$731	$2,250 - $5,550	4.6 - 11.4	3.7 - 9.1	3.1 - 7.6
	11	Improved SEER from 13 to 15							
	14	Decreased SHGC & U Value							
	20	Decreased Infiltration							
Group 9	**9**	Decreased Duct Leakage	$509	$636	$763	$4,100 - $5,300	8.1 - 10.4	6.4 - 8.3	5.4 - 6.9
	14	Decreased SHGC & U Value							
	8	Decreased Duct Static Pressure							
	16	Window Shading and Redistribution							
Group 10	**9**	Decreased Duct Leakage	$419	$524	$629	$2,050 - $5,950	4.9 - 14.2	3.9 - 11.4	3.3 - 9.5
	11	Improved SEER from 13 to 15							
	20	Decreased Infiltration							
	12	Improved Furnace Efficiency							

[2] Energy costs used for analysis:
Cost 1: Electricity ($/kWh) 0.16 and Gas ($/CCF) 1.2
Cost 2: Electricity ($/kWh) 0.2 and Gas ($/CCF) 1.5
Cost 3: Electricity ($/kWh) 0.24 and Gas ($/CCF) 1.8

Table 18: Combined Energy Savings for Grouped Measures for Base Case House with Heat Pump Heating (w/ setback), Houston, TX

Groups	EEM #	Measures	Combined Energy Savings (%)	Electricity Savings (kWh/yr)
Groups 1	**3**	PV Array for Partial Demand at 4kW	28.7%	5,512
Groups 2	**2**	PV Array for 6kW	43.1%	8,268
Group 3	**4**	PV Array for Partial Demand at 2kW	16.8%	3,225
	20	Decreased Infiltration		
Group 4	**31**	Solar DHW System	17.1%	3,277
	20	Decreased Infiltration		
Group 5	**25**	50% Energy Star CFL Indoor Lamps	15.3%	2,931
	9	Decreased Duct Leakage		
Group 6	**10**	Mechanical Systems within Conditioned Spaces	15.3%	2,931
	11	Improved SEER from 13 to 15		
	20	Decreased Infiltration		
Group 7	**25**	50% Energy Star CFL Indoor Lamps	17.6%	3,370
	11	Improved SEER from 13 to 15		
	14	Decreased SHGC & U Value		
Group 8	**9**	Decreased Duct Leakage	17.4%	3,341
	24	25% Energy Star CFL Indoor Lamps		
	11	Improved SEER from 13 to 15		
	15	Window Shading		
Group 9	**9**	Decreased Duct Leakage	15.7%	3,019
	14	Decreased SHGC & U Value		
	11	Improved SEER from 13 to 15		
	20	Decreased Infiltration		
Group 10	**24**	25% Energy Star CFL Indoor Lamps	15.7%	3,019
	8	Decreased Duct Static Pressure		
	16	Window Shading and Redistribution		
	14	Decreased SHGC & U Value		

Table 19: Energy Cost Savings and Payback from Grouped Measures for Base Case House with Heat Pump Heating (w/ setback), Houston, TX

Groups	EEM #	Measures	Combined Energy Cost Savings ($) Cost-1	Combined Energy Cost Savings ($) Cost-2	Combined Energy Cost Savings ($) Cost-3	Combined Total Cost ($)	Simple Estimated Payback (yrs) For Cost-1	Simple Estimated Payback (yrs) For Cost-2	Simple Estimated Payback (yrs) For Cost-3
Groups 1	**3**	PV Array for Partial Demand at 4kW	$882	$1,102	$1,323	$29,000	32.9	26.3	21.9
Groups 2	**2**	PV Array for 6kW	$1,323	$1,654	$1,984	$41,000	31.0	24.8	20.7
Group 3	**4**	PV Array for Partial Demand at 2kW	$516	$645	$774	$17,350 - $18,500	33.6 - 35.9	26.9 - 28.7	22.4 - 23.9
	20	Decreased Infiltration							
Group 4	**31**	Solar DHW System	$524	$655	$787	$3,250 - $6,700	6.2 - 12.8	5.0 - 10.2	4.1 - 8.5
	20	Decreased Infiltration							
Group 5	**25**	50% Energy Star CFL Indoor Lamps	$469	$586	$703	$245 - $550	0.5 - 1.2	0.4 - 0.9	0.3 - 0.8
	9	Decreased Duct Leakage							
Group 6	**10**	Mechanical Systems within Conditioned Spaces	$469	$586	$703	$2,850 - $10,900	6.1 - 23.2	4.9 - 18.6	4.1 - 15.5
	11	Improved SEER from 13 to 15							
	20	Decreased Infiltration							
Group 7	**25**	50% Energy Star CFL Indoor Lamps	$539	$674	$809	$2,345 - $3,600	4.3 - 6.7	3.5 - 5.3	2.9 - 4.5
	11	Improved SEER from 13 to 15							
	14	Decreased SHGC & U Value							
Group 8	**9**	Decreased Duct Leakage	$535	$668	$802	$4,825 - $6,400	9.0 - 12.0	7.2 - 9.6	6.0 - 8.0
	24	25% Energy Star CFL Indoor Lamps							
	11	Improved SEER from 13 to 15							
	15	Window Shading							
Group 9	**9**	Decreased Duct Leakage	$483	$604	$725	$2,850 - $5,450	5.9 - 11.3	4.7 - 9.0	3.9 - 7.5
	14	Decreased SHGC & U Value							
	11	Improved SEER from 13 to 15							
	20	Decreased Infiltration							
Group 10	**24**	25% Energy Star CFL Indoor Lamps	$483	$604	$725	$3,925 - $4,900	8.1 - 10.1	6.5 - 8.1	5.4 - 6.8
	8	Decreased Duct Static Pressure							
	16	Window Shading and Redistribution							
	14	Decreased SHGC & U Value							

Table 20: Combined Energy Savings for Grouped Measures for Base Case House with Natural Gas Heating (w/o setback), Houston, TX

Groups	EEM #	Measures	Combined Energy Savings (%)	Electricity Savings (kWh/yr)	Combined Gas Savings (CCF/yr)
Group 1	**31**	Solar DHW System	18.5%	-430	170
Group 2	**2**	PV Array for 6kW	32.4%	8,268	0
Group 3	**3**	PV Array for Partial Demand at 4kW	21.6%	5,512	0
Group 4	**10**	Mechanical Systems within Conditioned Spaces	18.3%	3,458	40
	25	50% Energy Star CFL Indoor Lamps			
Group 5	**4**	PV Array for Partial Demand at 2kW	19.3%	3,928	33
	9	Decreased Duct Leakage			
Group 6	**25**	50% Energy Star CFL Indoor Lamps	16.4%	2,198	66
	29	Tankless Gas Water Heater			
	20	Decreased Infiltration			
Group 7	**25**	50% Energy Star CFL Indoor Lamps	17.5%	3,957	17
	9	Decreased Duct Leakage			
	11	Improved SEER from 13 to 15			
Group 8	**9**	Decreased Duct Leakage	18.6%	2,960	59
	11	Improved SEER from 13 to 15			
	14	Decreased SHGC & U Value			
	20	Decreased Infiltration			
Group 9	**9**	Decreased Duct Leakage	16.8%	3,253	34
	8	Decreased Duct Static Pressure			
	14	Decreased SHGC & U Value			
	16	Window Shading and Redistribution			
Group 10	**12**	Improved Furnace Efficiency	17.3%	2,433	66
	20	Decreased Infiltration			
	9	Decreased Duct Leakage			
	11	Improved SEER from 13 to 15			

Table 21: Energy Cost Savings and Payback from Grouped Measures for Base Case House with Natural Gas Heating (w/o setback), Houston, TX

Groups	EEM #	Measures	Combined Energy Cost Savings ($) Cost-1	Combined Energy Cost Savings ($) Cost-2	Combined Energy Cost Savings ($) Cost-3	Combined Total Cost ($)	Simple Estimated Payback (yrs) For Cost-1	Simple Estimated Payback (yrs) For Cost-2	Simple Estimated Payback (yrs) For Cost-3
Group 1	**31**	Solar DHW System	$136	$170	$204	$2,900 - $5,200	21.4 - 38.3	17.1 - 30.6	14.2 - 25.5
Group 2	**2**	PV Array for 6kW	$1,323	$1,654	$1,984	$41,000	31.0	24.8	20.7
Group 3	**3**	PV Array for Partial Demand at 4kW	$882	$1,102	$1,323	$29,000	32.9	26.3	21.9
Group 4	**10**	Mechanical Systems within Conditioned Spaces	$601	$751	$902	$1,045 - $7,100	1.7 - 11.8	1.4 - 9.4	1.2 - 7.9
	25	50% Energy Star CFL Indoor Lamps							
Group 5	**4**	PV Array for Partial Demand at 2kW	$668	$835	$1,002	$17,200 - $17,450	25.7 - 26.1	20.6 - 20.9	17.2 17.4
	9	Decreased Duct Leakage							
Group 6	**25**	50% Energy Star CFL Indoor Lamps	$431	$539	$646	$1,395 - $5,100	3.2 - 11.8	2.6 - 9.5	2.2 - 7.9
	29	Tankless Gas Water Heater							
	20	Decreased Infiltration							
Group 7	**25**	50% Energy Star CFL Indoor Lamps	$653	$816	$979	$1,145 - $3,050	1.8 - 4.7	1.4 - 3.7	1.2 - 3.1
	9	Decreased Duct Leakage							
	11	Improved SEER from 13 to 15							
Group 8	**9**	Decreased Duct Leakage	$545	$681	$817	$2,250 - $5,550	4.1 - 10.2	3.3 - 8.2	2.8 - 6.8
	11	Improved SEER from 13 to 15							
	14	Decreased SHGC & U Value							
	20	Decreased Infiltration							
Group 9	**9**	Decreased Duct Leakage	$561	$702	$842	$4,100 - $5,300	7.3 - 9.4	5.8 - 7.6	4.9 - 6.3
	8	Decreased Duct Static Pressure							
	14	Decreased SHGC & U Value							
	16	Window Shading and Redistribution							
Group 10	**12**	Improved Furnace Efficiency	$468	$586	$703	$2,050 - $5,950	4.4 - 12.7	3.5 - 10.2	2.9 - 8.5
	20	Decreased Infiltration							
	9	Decreased Duct Leakage							
	11	Improved SEER from 13 to 15							

Table 22: Combined Energy Savings for Grouped Measures for Base Case House with Heat Pump Heating (w/o setback), Houston, TX

Groups	EEM #	Measures	Combined Energy Savings (%)	Electricity Savings (kWh/yr)
Groups 1	**3**	PV Array for Partial Demand at 4kW	27.1%	5,512
Groups 2	**2**	PV Array for 6kW	40.6%	8,268
Group 3	**4**	PV Array for Partial Demand at 2kW	16.3%	3,313
	20	Decreased Infiltration		
Group 4	**31**	Solar DHW System	16.5%	3,365
	20	Decreased Infiltration		
Group 5	**25**	50% Energy Star CFL Indoor Lamps	15.5%	3,165
	9	Decreased Duct Leakage		
Group 6	**10**	Mechanical Systems within Conditioned Spaces	16.5%	3,370
	20	Decreased Infiltration		
	11	Improved SEER from 13 to 15		
Group 7	**11**	Improved SEER from 13 to 15	17.7%	3,605
	14	Decreased SHGC & U Value		
	25	50% Energy Star CFL Indoor Lamps		
Group 8	**15**	Window Shading	18.4%	3,751
	9	Decreased Duct Leakage		
	11	Improved SEER from 13 to 15		
	24	25% Energy Star CFL Indoor Lamps		
Group 9	**9**	Decreased Duct Leakage	16.8%	3,429
	20	Decreased Infiltration		
	11	Improved SEER from 13 to 15		
	14	Decreased SHGC & U Value		
Group 10	**16**	Window Shading and Redistribution	20.1%	4,103
	24	25% Energy Star CFL Indoor Lamps		
	8	Decreased Duct Static Pressure		
	14	Decreased SHGC & U Value		

Table 23: Energy Cost Savings and Payback for Grouped Measures for Base Case House with Heat Pump Heating (w/o setback), Houston, TX

Groups	EEM #	Measures	Combined Energy Cost Savings ($) Cost-1	Combined Energy Cost Savings ($) Cost-2	Combined Energy Cost Savings ($) Cost-3	Combined Total Cost ($)	Simple Estimated Payback (yrs) For Cost-1	Simple Estimated Payback (yrs) For Cost-2	Simple Estimated Payback (yrs) For Cost-3
Groups 1	**3**	PV Array for Partial Demand at 4kW	$882	$1,102	$1,323	$29,000	32.9	26.3	21.9
Groups 2	**2**	PV Array for 6kW	$1,323	$1,654	$1,984	$41,000	31.0	24.8	20.7
Group 3	**4**	PV Array for Partial Demand at 2kW	$530	$663	$795	$17,350 - $18,500	32.7 - 34.9	26.2 - 27.9	21.8 - 23.3
	20	Decreased Infiltration							
Group 4	**31**	Solar DHW System	$538	$673	$808	$3,250 - $6,700	6.0 - 12.4	4.8 - 10.0	4.0 - 8.3
	20	Decreased Infiltration							
Group 5	**25**	50% Energy Star CFL Indoor Lamps	$506	$633	$760	$245 - $550	0.5 - 1.1	0.4 - 0.9	0.3 - 0.7
	9	Decreased Duct Leakage							
Group 6	**10**	Mechanical Systems within Conditioned Spaces	$539	$674	$809	$2,850 - $10,900	5.3 - 20.2	4.2 - 16.2	3.5 - 13.5
	20	Decreased Infiltration							
	11	Improved SEER from 13 to 15							
Group 7	**11**	Improved SEER from 13 to 15	$577	$721	$865	$2,345 - $3,600	4.1 - 6.2	3.3 - 5.0	2.7 - 4.2
	14	Decreased SHGC & U Value							
	25	50% Energy Star CFL Indoor Lamps							
Group 8	**15**	Window Shading	$600	$750	$900	$4,825 - $6,400	8.0 - 10.7	6.4 - 8.5	5.4 - 7.1
	9	Decreased Duct Leakage							
	11	Improved SEER from 13 to 15							
	24	25% Energy Star CFL Indoor Lamps							
Group 9	**9**	Decreased Duct Leakage	$549	$686	$823	$2,850 - $5,450	5.2 - 9.9	4.2 - 7.9	3.5 - 6.6
	20	Decreased Infiltration							
	11	Improved SEER from 13 to 15							
	14	Decreased SHGC & U Value							
Group 10	**16**	Window Shading and Redistribution	$657	$821	$985	$3,925 - $4,900	6.0 - 7.5	4.8 - 6.0	4.0 - 5.0
	24	25% Energy Star CFL Indoor Lamps							
	8	Decreased Duct Static Pressure							
	14	Decreased SHGC & U Value							

9: Description of Energy Efficient Measures (EEMs)

This section includes a description of EEMs, their impact on the energy use, increased cost of implementation[3], and simple payback calculations. Annual end-use energy use (MMBtu) was obtained from the BEPS report. The detailed payback calculations are performed for only those measures whose energy savings are above 2% more than the base case. The payback calculations are done for all four options: base case house with natural gas heating with and without setbacks and base case house with heat pump heating with and without setback.

9.1 Renewable Power Options

Base Case: There are no PV panels installed for the base case.

Test case: The test case house is assumed to be grid-connected with a 6W, 4 kW or 2 kW PV array of Kyocera multi-crystalline solar cells (16% efficiency). The analysis of long-term performance was performed using a PV F-CHART analysis for the typical weather conditions of Houston and using TMY2 weather data and for the given mounting conditions, i.e. array tilt depending on the roof tilt (for the summer peak cooling loads, an array tilted at about 15 degrees, i.e. latitude minus 15 degrees, is expected to provide maximum output).

The details of the PV array for the required capacities are as follows:

PV modules	: Kyocera KD210GX-LP (210Watt) or Kyocera KD205GX-LP (205Watts) (Multi-crystalline solar cells)
Efficiency	: 16%
Panel Size	: 1500 mm x 990 mm (59.1 in x 39 in.)

For 6 kW system 28 to 30 panels were used with a total PV array area making up to 480 sq.ft, for 4 kW system 19 to 20 panels were used with a total PV array area making up to 320 sq.ft and for 2 kW system 10 panels were used with a total PV array area making up to 160 sq.ft respectively.

For analysis of the PV system using PV F-CHART following parameters were used.

Cell Temperature at NOCT conditions	: 120.2 deg.F (49 deg.C)
Array reference efficiency	: 0.16
Array reference temperature	: 77 deg.F (25 deg.C)
Maximum power efficiency temperature coefficient	: 5.02 x 10^-3 A/deg.C
Efficiency of maximum power point tracking electronics	: 0.9
Efficiency of power conditioning electronics	: 0.88
Array area	: (based on installed wattage)
Array slope	: 30 degrees
Array azimuth	: 0 (south)

[3] The ranges of total implementation cost for some measures were modified according to the recommendations of stakeholders.

Table 24: Output of the PV Array System

	2 kW system		4 kW system		6 kW system	
	Solar (kWh)	PV (kWh)	Solar (kWh)	PV (kWh)	Solar (kWh)	PV (kWh)
Jan	1619	189	3239	378	4858	567
Feb	1644	192	3289	383	4933	575
Mar	2131	239	4263	477	6394	716
Apr	2170	237	4341	474	6511	710
May	2382	254	4765	509	7147	763
Jun	2435	256	4871	511	7306	767
Jul	2459	256	4918	512	7377	769
Aug	2449	256	4897	512	7346	768
Sep	2304	244	4607	488	6911	732
Oct	2328	253	4656	507	6984	760
Nov	1842	208	3684	415	5526	623
Dec	1471	173	2941	345	4412	518
Year	25235	2756	50471	5512	75706	8268

For each of the four options there is a 34.79%, 23.19% and 11.60% reduction in the energy consumption with the installation of 6 kW, 4 kW and 2 kW PV panels, respectively.

Implementation Cost: The cost of installation varies with type of system, for a 6 kW system the cost is around $41000 and for 4 kW and 2 kW systems the costs are $29,000 and $17,000 respectively. Details of the costs[4] for installing different PV arrays are given in Table 25.

Table 25: Cost of Instillation of PV Array

			6 kW System		4 kW System		2 kW System	
Item No.	Description	Unit Price	Quantity	Amount	Quantity	Amount	Quantity	Amount
1	Kyocera 210W Solar Modules	$966.00	30	$28,980.00	20	$19,320.00	10	$9,660.00
2	Xantrex Inverter (XW6048, XW4024, GT2.8)	Different	1	$4,500.00	1	$3,250.00	1	$2,375.00
3	Array Frames	$30.00	30	$900.00	20	$600.00	10	$300.00
4	DC/AC Disconnect	$115.00	2	$230.00	2	$230.00	2	$230.00
5	20 amp Two pole Breaker	$27.50	1	$27.50	1	$27.50	1	$27.50
6	Combiner Box	$65.00	1	$65.00	1	$65.00	1	$65.00
7	Wire, Conduit and Connecters	$500.00	1	$500.00	1	$500.00	1	$500.00
	Subtotal			**$35,202.50**		**$23,992.50**		**$13,157.50**
	Tax			$2,904.21		$1,979.38		$1,085.49
	Labor			$3,000.00		$2,800.00		$2,500.00
	Total			**41,107**		**28,772**		**16,743**

4 http://www.txspc.com/PDF/Non%20Austin%20Residential%20Grid%20Tie%20Brochure.pdf

Payback Calculation:

PV Array for 6 kW

Base Case with Natural Gas Heating With Setback

Electricity cost savings = 8,268 kWh/year x 0.16/kWh = 1323/year
Total energy cost savings = $1,323
Implementation cost = $41,000
Simple Payback = 31 years

Base Case with Heat Pump Heating With Setback

Electricity cost savings = 8,268 kWh/year x 0.16/kWh = 1323/year
Total energy cost savings = $1323
Implementation cost = $41000
Simple Payback = 31 years

Base Case with Natural Gas Heating Without Setback

Electricity cost savings = 8,268 kWh/year x 0.16/kWh = 1323/year
Total energy cost savings = $1,323
Implementation cost = $41,000
Simple Payback = 31 years

Base Case with Heat Pump Heating Without Setback

Electricity cost savings = 8,268 kWh/year x 0.16/kWh = 1323/year
Total energy cost savings = $1,323
Implementation cost = $41,000
Simple Payback = 31 years

PV Array for 4 kW

Base Case with Natural Gas Heating With Setback

Electricity cost savings = 5,512 kWh/year x 0.16/kWh = 882/year
Total energy cost savings = $882
Implementation cost = $29,000
Simple Payback = 32.87 years

Base Case with Heat Pump Heating With Setback

Electricity cost savings = 5,512 kWh/year x 0.16/kWh = 882/year
Total energy cost savings = $882
Implementation cost = $29,000
Simple Payback = 32.87 years

Base Case with Natural Gas Heating Without Setback

Electricity cost savings = 5,512 kWh/year x 0.16/kWh = 882/year
Total energy cost savings = $882
Implementation cost = $29,000
Simple Payback = 32.87 years

Base Case with Heat Pump Heating Without Setback

Electricity cost savings = 5,512 kWh/year x 0.16/kWh = 882/year
Total energy cost savings = $882

Implementation cost = $29,000
Simple Payback = 32.87 years

PV Array for 2 kW

Base Case with Natural Gas Heating With Setback
Electricity cost savings = 2,756 kWh/year x 0.16/kWh = 441/year
Total energy cost savings = $441
Implementation cost = $17,000
Simple Payback = 38.54 years

Base Case with Heat Pump Heating With Setback
Electricity cost savings = 2,756 kWh/year x 0.16/kWh = 441/year
Total energy cost savings = $441
Implementation cost = $17,000
Simple Payback = 38.54 years

Base Case with Natural Gas Heating Without Setback
Electricity cost savings = 2,756 kWh/year x 0.16/kWh = 441/year
Total energy cost savings = $441
Implementation cost = $17,000
Simple Payback = 38.54 years

Base Case with Heat Pump Heating Without Setback
Electricity cost savings = 2,756 kWh/year x 0.16/kWh = 441/year
Total energy cost savings = $441
Implementation cost = $17,000
Simple Payback = 38.54 years

9.2: HVAC Options

9.2.1 System Sizing

Base case: System sizing for the base-case model is assumed to be 500 sq. ft/ton as per standard/field practice.

Test case: Manual-J calculations are used for efficient system sizing as reported by building officials and are around 650sqft/ton.

Implementation Cost: Since this measure was not considered in any of the group measures, the costs associated with implementing this measure are not included.

Figure 5: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (System sizing)

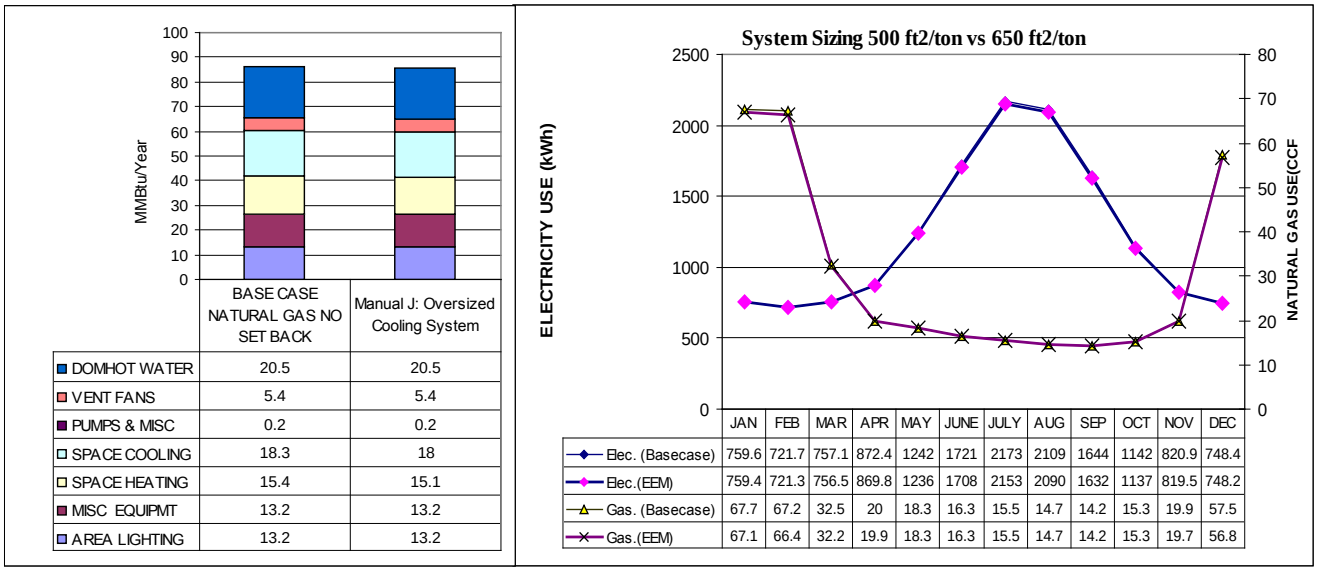
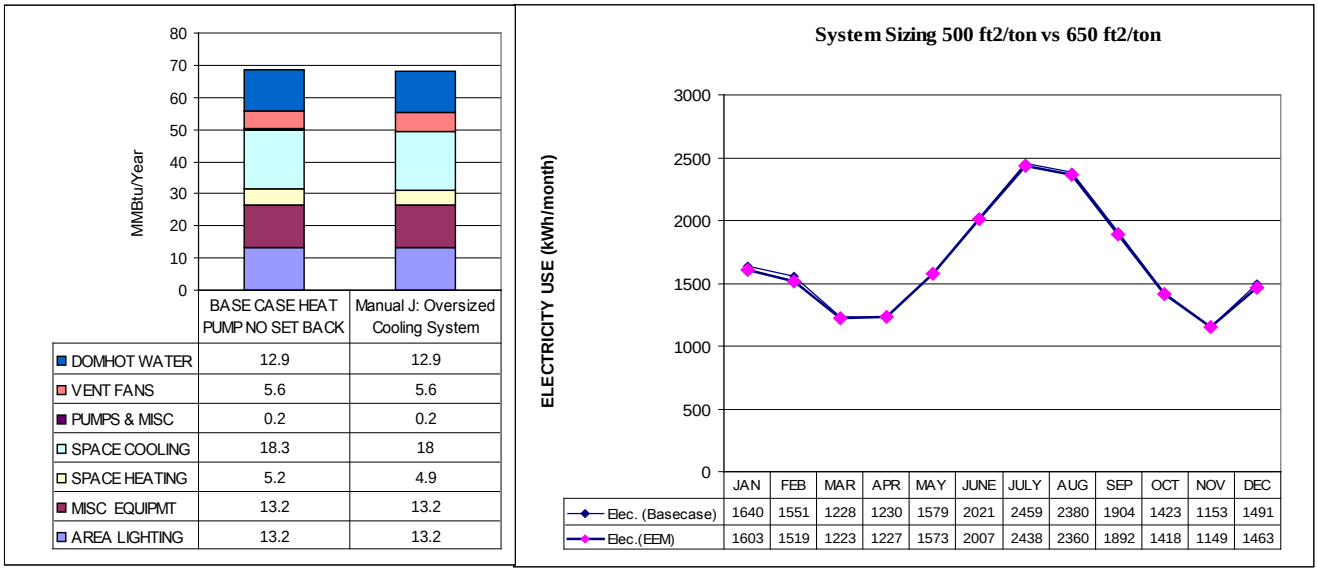


Figure 6: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (System sizing)



9.2.2 Airflow Through the Air Handler

Base case: Airflow for the base case was set at 360cfm/ton as per requirements proposed by the City of Houston officials.

Test case: Two cases were simulated: one with decreased air flow and one with increased air flow. In test case 1) a reduced value of 250cfm/ton is considered and in 2) increased value of 450 cfm/ton is considered to check the sensitivity of the model.

Implementation Cost: Since this measure was not considered in any of the group measures, the costs associated with implementing this measure are not included.

Note: A check on the percentage of hours of unmet loads will need to be made to justify the benefits of using this measure.

Figure 7: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Decreased Supply Airflow)

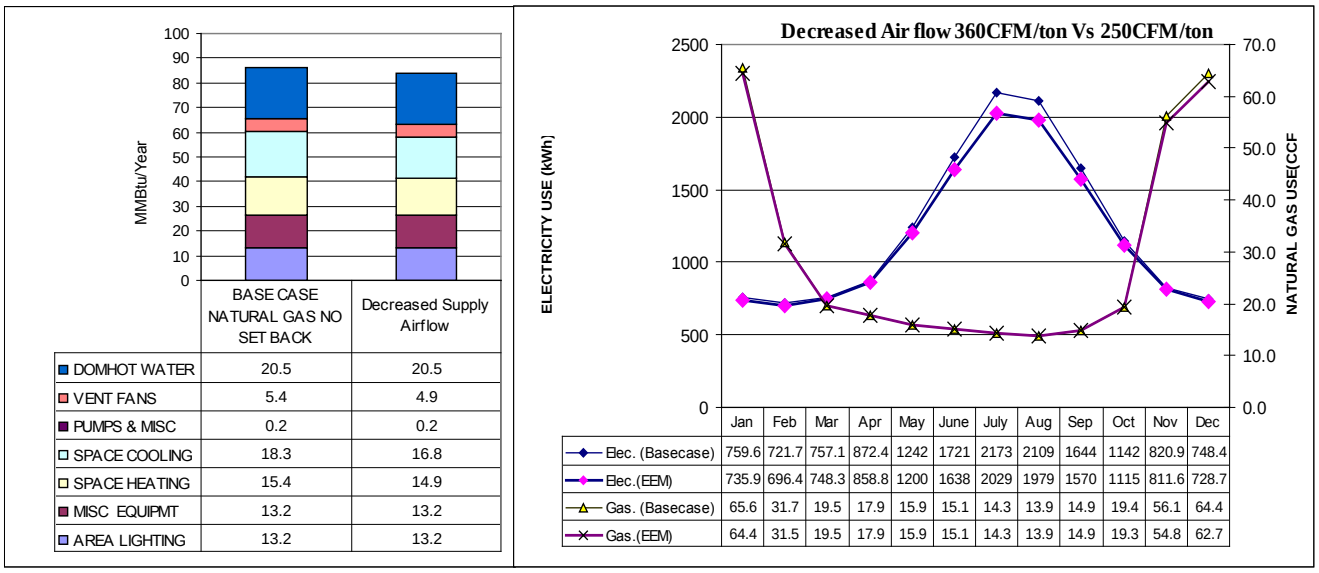


Figure 8: Monthly Energy consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Decreased Supply Airflow)

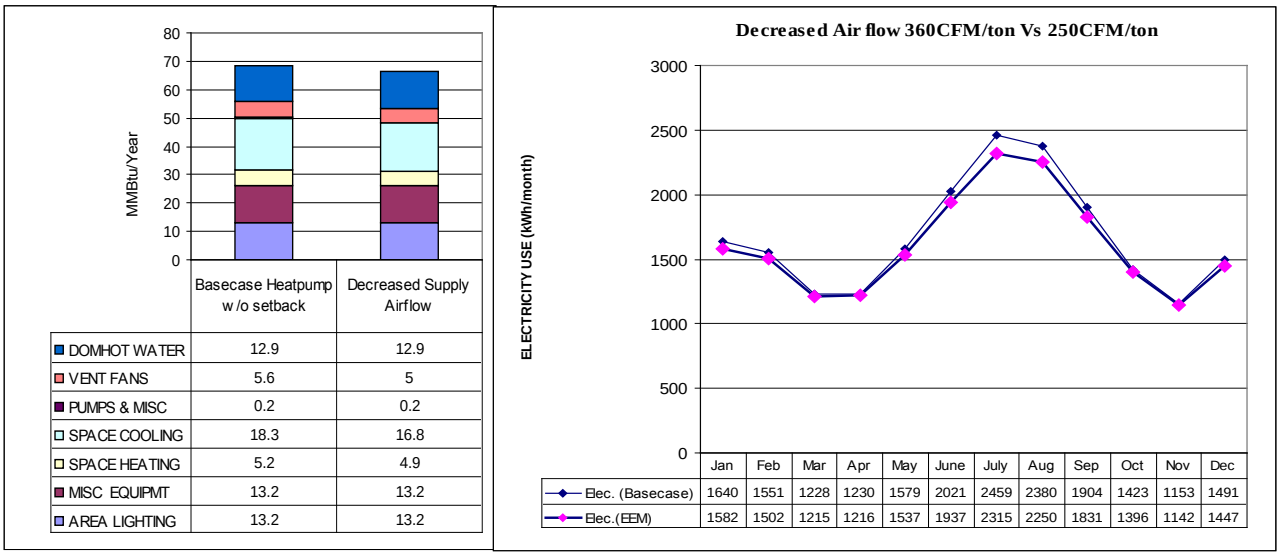
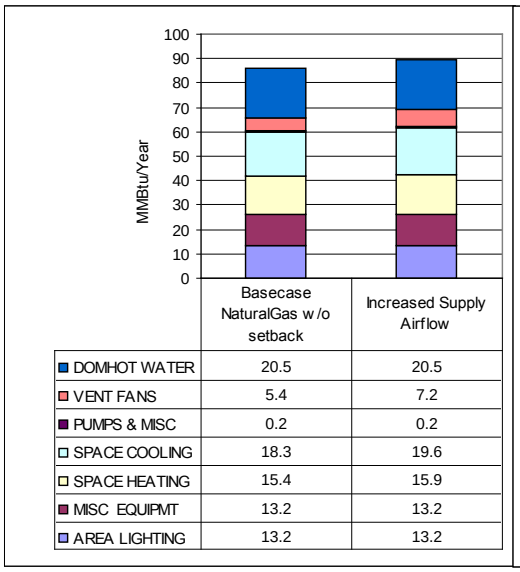
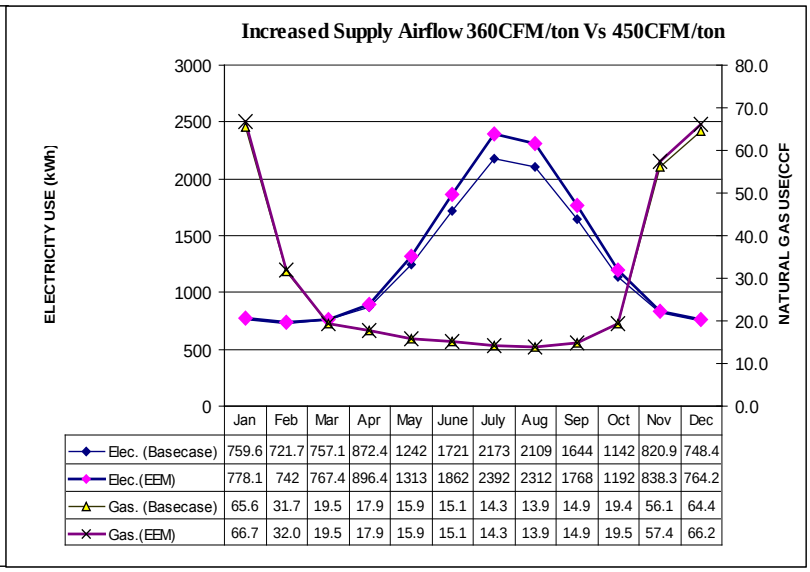


Figure 9: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Increased Supply Airflow)

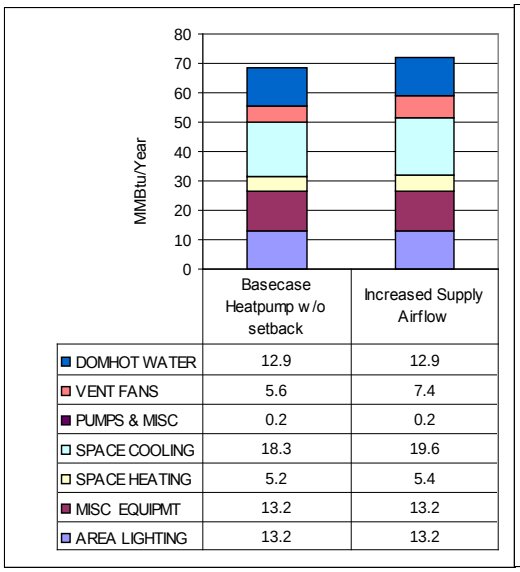


	Basecase NaturalGas w/o setback	Increased Supply Airflow
DOMHOT WATER	20.5	20.5
VENT FANS	5.4	7.2
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	19.6
SPACE HEATING	15.4	15.9
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2

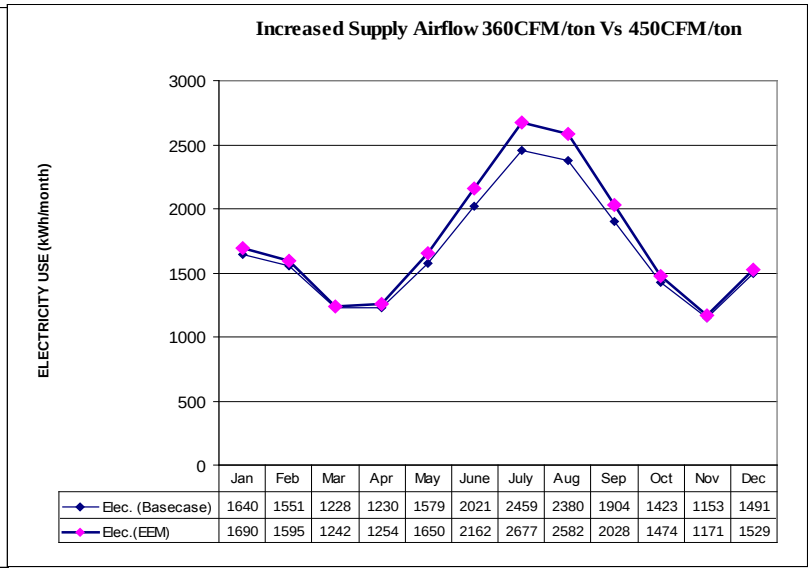


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Elec.(EEM)	778.1	742	767.4	896.4	1313	1862	2392	2312	1768	1192	838.3	764.2
Gas. (Basecase)	65.6	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.4	56.1	64.4
Gas.(EEM)	66.7	32.0	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.5	57.4	66.2

Figure 10: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Increased Supply Airflow)



	Basecase Heatpump w/o setback	Increased Supply Airflow
DOMHOT WATER	12.9	12.9
VENT FANS	5.6	7.4
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	19.6
SPACE HEATING	5.2	5.4
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491
Elec.(EEM)	1690	1595	1242	1254	1650	2162	2677	2582	2028	1474	1171	1529

9.2.3 Static Pressure

Base case: As requested by the City of Houston officials, the static duct pressure is set at 1"WC.

Test case: For the test case the static pressure for HVAC duct system is set at 0.5"WC measured as per the NCI (National Comfort Institute) standard and certified by a third party.

Implementation Cost: The cost for implementing the change in static pressure is $250. The cost information is obtained from estimated costs proposed by the City of Houston officials. These costs are listed in Appendix A-1.

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

Electricity cost savings	= 938 kWh/year x 0.16/kWh = $150/year
Gas cost savings	= -6 CCF/year x $1.2/CCF = -$7/year
Total energy cost savings	= $143
Implementation cost	= $250
Simple Payback	= 1.74 years

Base Case House with Heat Pump Heating With Setback

Electricity cost savings	= 938 kWh/year x 0.16/kWh = $150/year
Total energy cost savings	= $150
Implementation cost	= $250
Simple Payback	= 1.66 years

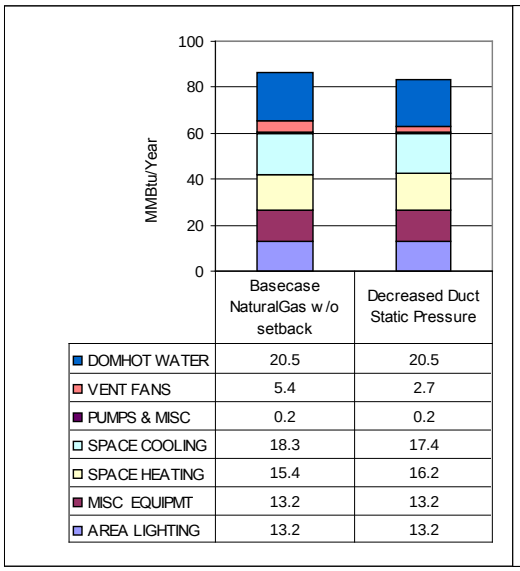
Base Case House with Natural Gas Heating Without Setback

Electricity cost savings	= 1,055 kWh/year x 0.16/kWh = $169/year
Gas cost savings	= -8 CCF/year x $1.2/CCF = -$9/year
Total energy cost savings	= $159
Implementation cost	= $250
Simple Payback	= 1.57 years

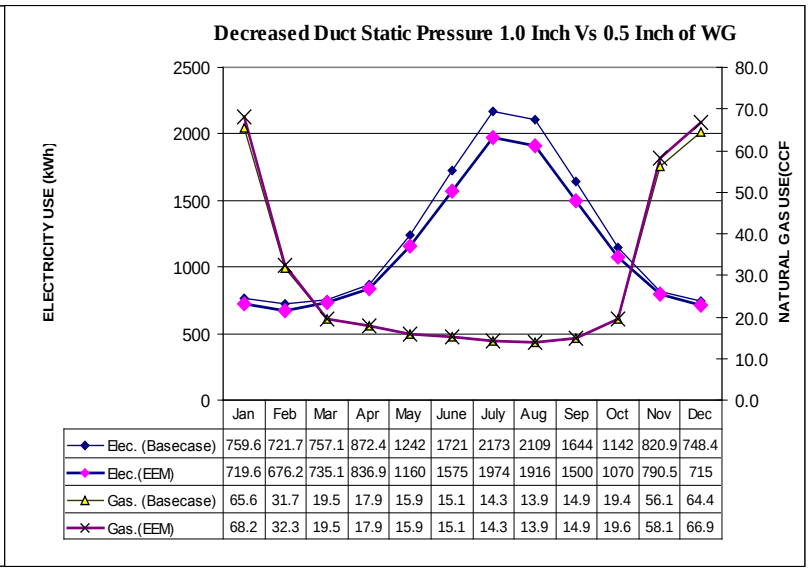
Base Case House with Heat Pump Heating Without Setback

Electricity cost savings	= 1,026 kWh/year x 0.16/kWh = $267/year
Total energy cost savings	= $164
Implementation cost	= $250
Simple Payback	= 1.52 years

Figure 11: Monthly Energy consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Decreased Duct Static Pressure)

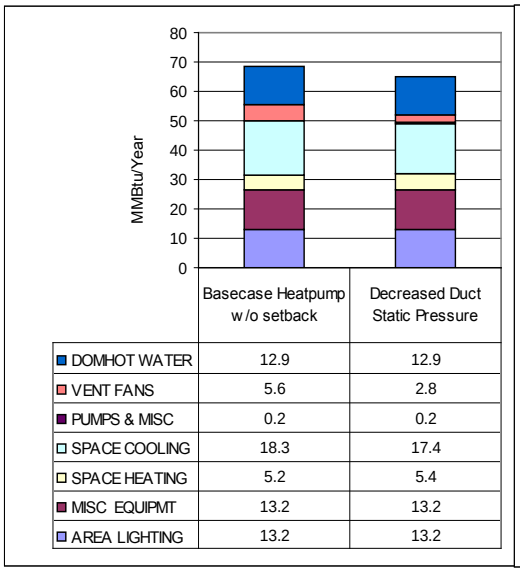


	Basecase NaturalGas w/o setback	Decreased Duct Static Pressure
DOMHOT WATER	20.5	20.5
VENT FANS	5.4	2.7
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	17.4
SPACE HEATING	15.4	16.2
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2

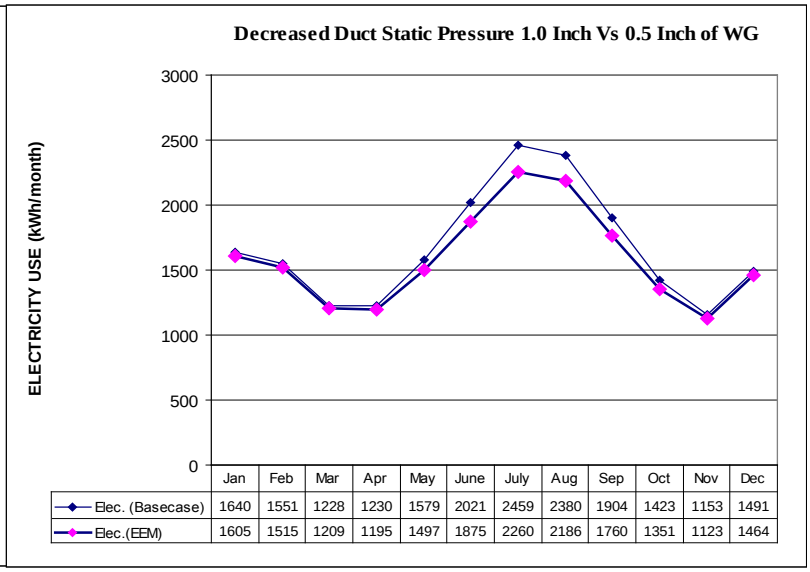


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Elec.(EEM)	719.6	676.2	735.1	836.9	1160	1575	1974	1916	1500	1070	790.5	715
Gas. (Basecase)	65.6	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.4	56.1	64.4
Gas.(EEM)	68.2	32.3	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.6	58.1	66.9

Figure 12: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Decreased Duct Static Pressure)



	Basecase Heatpump w/o setback	Decreased Duct Static Pressure
DOMHOT WATER	12.9	12.9
VENT FANS	5.6	2.8
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	17.4
SPACE HEATING	5.2	5.4
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491
Elec.(EEM)	1605	1515	1209	1195	1497	1875	2260	2186	1760	1351	1123	1464

9.2.4 Duct Leakage

Base case: As noted from field measurements, the duct leakage for the efficiency measure was set at 20% for supply and 10% for return ducts.

Test case: As requested by the City of Houston, the energy efficiency measure would be re-set at 6.7% for supply and 3.3% for return ducts.

Implementation Cost: The cost of implantation for decreasing the duct leakages is between $200-$450. Table 26 provides details of the cost incurred for improving duct system in order to decrease leakage.

Table 26: Cost of Improving the Duct System

Air Distribution System Measures			Cost ($)	Total Increased Cost ($)	Reference Table (Appendix A-2)
Base Case	9% duct leakage	628 sq. ft. supply and 117 sq. ft. return duct area	$110 (material) + $330 (installation)	$450-$650*	Table Duct-2 - No. 1, 2
Test Case	0% duct leakage				

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

Electricity cost savings	= 996 kWh/year x 0.16/kWh = $159/year
Gas cost savings	= 26 CCF/year x $1.2/CCF = $31/year
Total energy cost savings	= $191
Implementation cost	= $200-450
Simple Payback	= 1.04 years-2.35 years

Base Case House with Heat Pump Heating With Setback

Electricity cost savings	= 1,231 kWh/year x 0.16/kWh = $197/year
Total energy cost savings	= $197
Implementation cost	= $200-450
Simple Payback	= 1.01 years-2.28 years

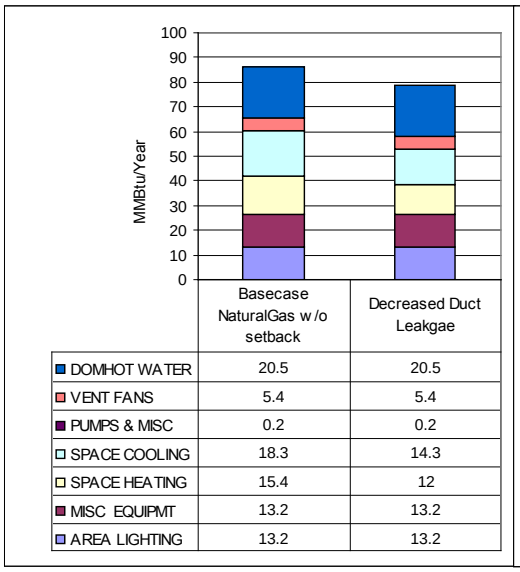
Base Case House with Natural Gas Heating Without Setback

Electricity cost savings	= 1,172 kWh/year x 0.16/kWh = $188/year
Gas cost savings	= 33 CCF/year x $1.2/CCF = $40/year
Total energy cost savings	= $227
Implementation cost	= $200-450
Simple Payback	= 0.88 years-1.98 years

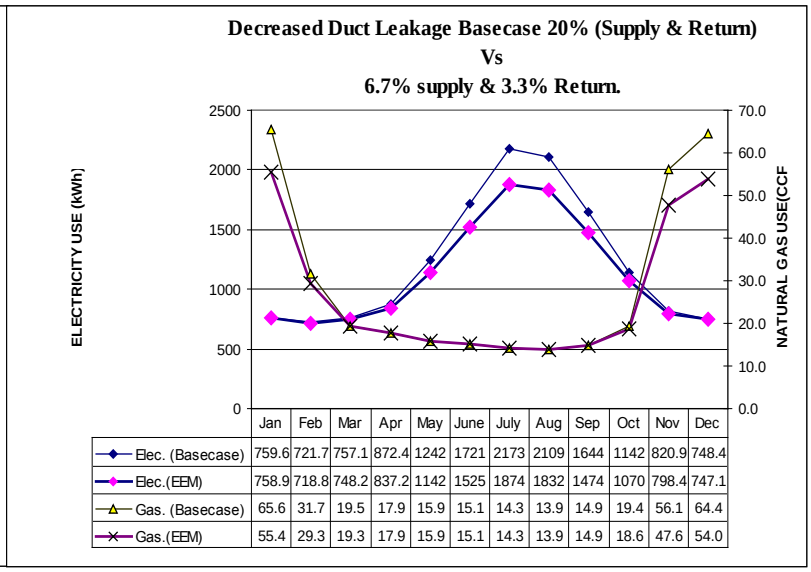
Base Case House with Heat Pump Heating Without Setback

Electricity cost savings	= 1,431 kWh/year x 0.16/kWh = $230/year
Total energy cost savings	= $230
Implementation cost	= $200-450
Simple Payback	= 0.86 years-1.95 years

Figure 13: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Decreased Duct Leakage)

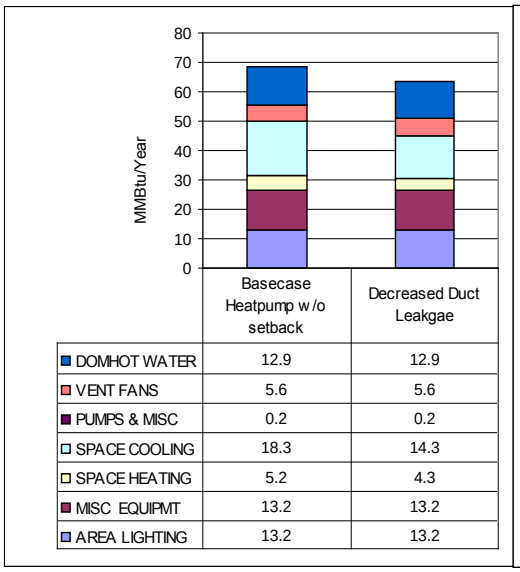


	Basecase NaturalGas w/o setback	Decreased Duct Leakgae
DOMHOT WATER	20.5	20.5
VENT FANS	5.4	5.4
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	14.3
SPACE HEATING	15.4	12
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2

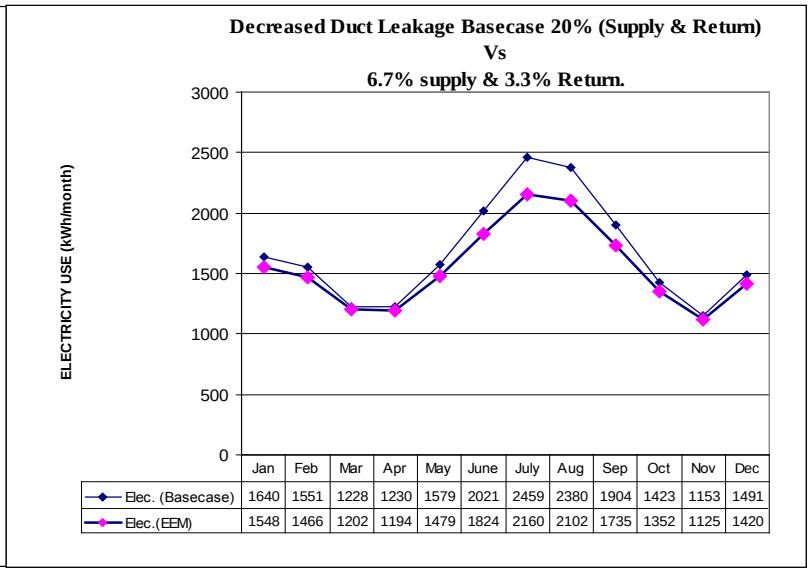


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Elec.(EEM)	758.9	718.8	748.2	837.2	1142	1525	1874	1832	1474	1070	798.4	747.1
Gas. (Basecase)	65.6	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.4	56.1	64.4
Gas.(EEM)	55.4	29.3	19.3	17.9	15.9	15.1	14.3	13.9	14.9	18.6	47.6	54.0

Figure 14: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Decreased Duct Leakage)



	Basecase Heatpump w/o setback	Decreased Duct Leakgae
DOMHOT WATER	12.9	12.9
VENT FANS	5.6	5.6
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	14.3
SPACE HEATING	5.2	4.3
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491
Elec.(EEM)	1548	1466	1202	1194	1479	1824	2160	2102	1735	1352	1125	1420

9.2.5 Mechanical Systems Within the Conditioned Space

Base case: The base case air distribution system, which includes the HVAC unit and the ducts, is located in the unconditioned, vented attic. The attic was assumed to have an air infiltration rate of 15 ACH[5]. The insulation for supply and return ducts are R-8 and R-4, respectively[6]. A 10% duct leakage was assumed for the base case house[7].

Test case: 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.

Implementation Cost: The cost information for this measure is obtained using the sources listed in Appendix A-3 and summarized in Table 27. It shows that locating the duct in the conditioned space would increase the cost by $1,000 to $7,000.

Table 27: Cost Information for Relocation of Ductwork from Attic to Conditioned Space

Air Distribution System Measures			Cost ($)	Total Increased Cost ($)	Reference Table (Appendix A-3)
Base Case	Duct in unconditioned space	2,325 sq. ft. conditioned floor area	$0.20/ft.	$1,000-$7,000	Table Duct-3 - No. 1,2,3.
Test Case	Duct in conditioned space				

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

Electricity cost savings = 1,436 kWh/year x 0.16/kWh = $230/year
Gas cost savings = 41 CCF/year x $1.2/CCF = $49/year
Total energy cost savings = $279
Implementation cost = $1,000-$7,000
Simple Payback = 3.58 to 25.06 years

Base Case House with Heat Pump Heating With Setback

Electricity cost savings = 1.788 kWh/year x 0.16/kWh = $286/year
Total energy cost savings = $286
Implementation cost = $1,000-$7,000
Simple Payback = 3.49 to 24.47 years

Base Case House with Natural Gas Heating Without Setback

Electricity cost savings = 1,672 kWh/year x 0.16/kWh = $267/year
Gas cost savings = 50 CCF/year x $1.2/CCF = $61/year
Total energy cost savings = $328
Implementation cost = $1,000-$7,000
Simple Payback = 3.04 to 21.34 years

Base Case House with Heat Pump Heating Without Setback

Electricity cost savings = 2.081 kWh/year x 0.16/kWh = $333/year
Total energy cost savings = $333

[5] This infiltration rate was chosen to match measured data by Kim (2006).
[6] This requirement can be found in Table 503.3.3.3 (ICC 2001).
[7] This is based on the information found in Parker et al. (1993).

Implementation cost = $1,000-$7,000
Simple Payback = 3 to 21 years

Figure 15: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Mechanical System in Conditioned Space)

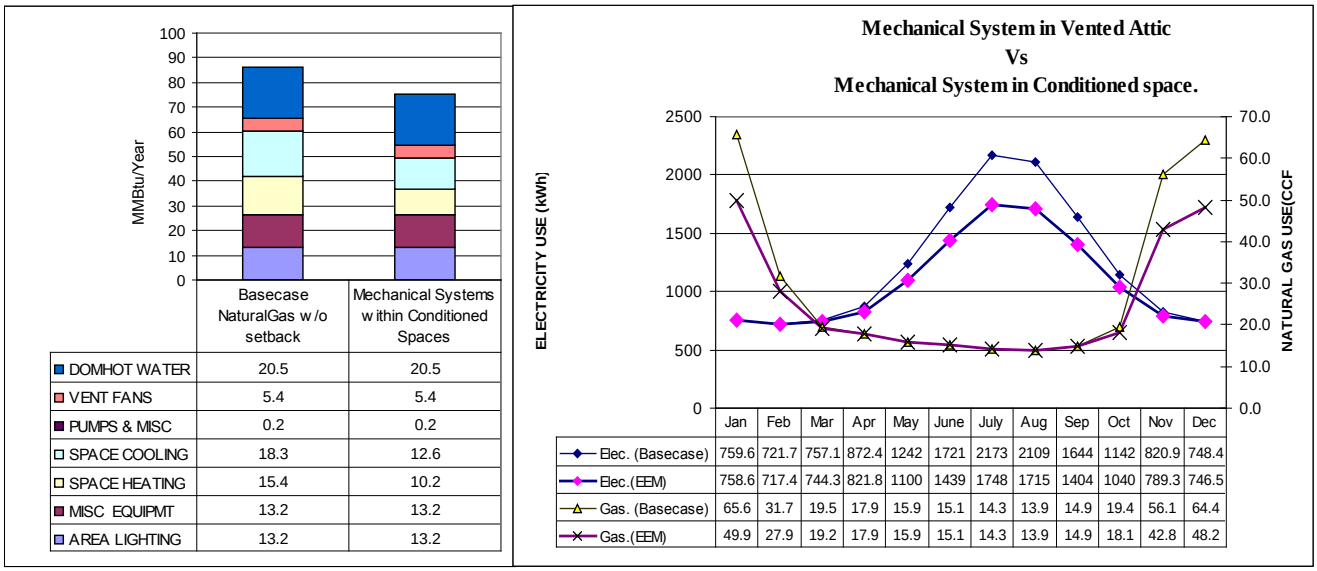
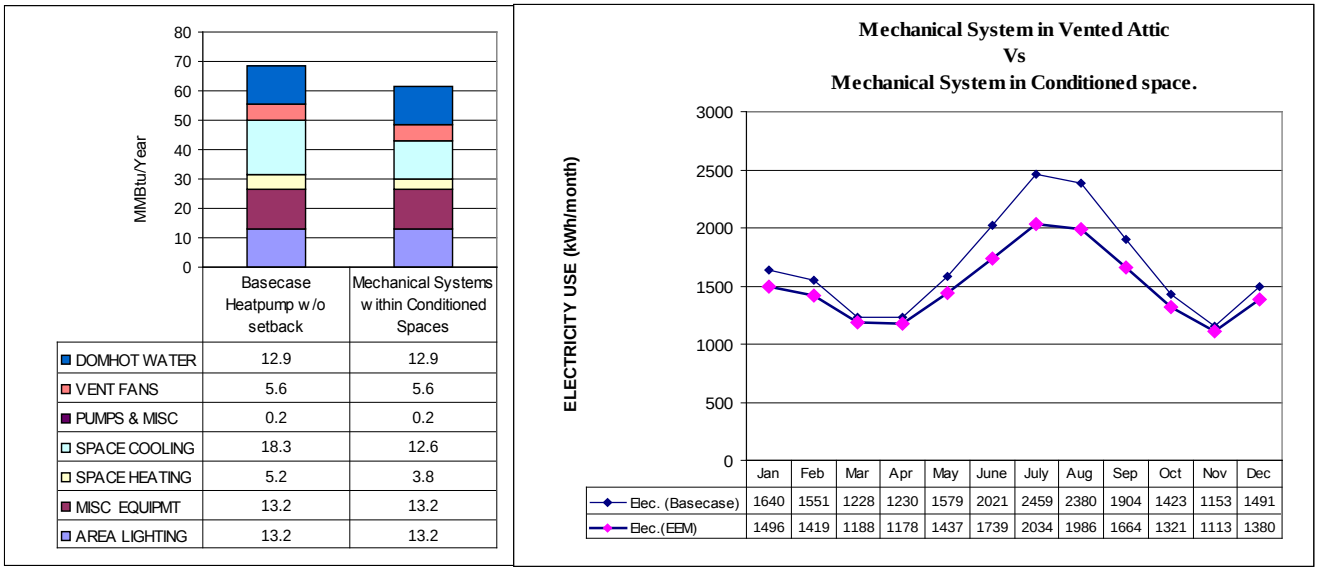


Figure 16: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Mechanical System in Conditioned Space)



9.2.6 Improved SEER

Base Case: The base case HVAC system is comprised of a SEER 13 air-conditioner and a gas-fired, forced-air furnace of 0.78 Annual Fuel Utilization Efficiency (AFUE)[8]. The capacity of the cooling system is 55,800 Btu/hr, which assumes 500 sq. ft. per ton. The capacity of the heating system is 72,540 Btu/hr, which assumes 1.3 times the cooling capacity. The heating and cooling set-points were 68°F for winter and 78°F for summer, with a 5°F setback/setup (for winter and summer, respectively) for six hours early in the morning[9].

Test case: For test case, the SEER 13 air conditioner in base-case house was replaced with a similarly sized SEER 15 air conditioner.

Implementation Cost: The cost information for this measure is obtained using the sources listed in Appendix A-4, and is summarized in Table 28. It shows that replacing a SEER 13 air conditioner with a SEER 15 air conditioner would increase the cost by $900 to $2,500.

Table 28: Cost Information for Upgrading the Air Conditioner

HVAC System Measures		Capacity	Equipment Cost ($)	Labor Cost ($)	Total Increased Cost ($)	Reference Table (Appendix A-4)
NATURAL GAS HEATING/NATURAL GAS DHW SYSTEM						
Base Case	SEER 13 Air Conditioning System	5 ton	$3,300-$4,550 (Avg. $3,925)	n/a	$900-$2,500	Table Air Conditioning with Gas Heat - No. 1, 2, 5, 7, 11
Test Case	SEER 15 Air Conditioning System		$4,800-$6,560			Table Air Conditioning with Gas Heat - No. 3, 4, 6, 8, 12

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

Electricity cost savings = 1,084 kWh/year x 0.16/kWh = $174/year
Gas cost savings = 41 CCF/year x $1.2/CCF = $49/year
Total energy cost savings = $279
Implementation cost = $900-$2,500
Simple Payback = 3.23 to 8.96 years

Base Case House with Heat Pump Heating With Setback

Electricity cost savings = 1,788 kWh/year x 0.16/kWh = $286/year
Total energy cost savings = $286
Implementation cost = $900-$2,500
Simple Payback = 3.15 to 8.74 years

Base Case House with Natural Gas Heating Without Setback

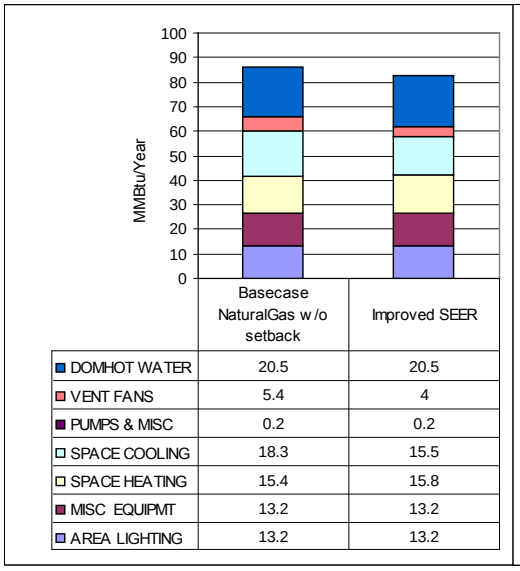
Electricity cost savings = 1,672 kWh/year x 0.16/kWh = $267/year
Gas cost savings = 50 CCF/year x $1.2/CCF = $61/year
Total energy cost savings = $328
Implementation cost = $900-$2,500
Simple Payback = 2.74 to 7.62 years

[8] The efficiency of HVAC system is determined by NAECA 2006.
[9] As defined by Table 402.1.3.5, p.64, of the 2001 IECC.

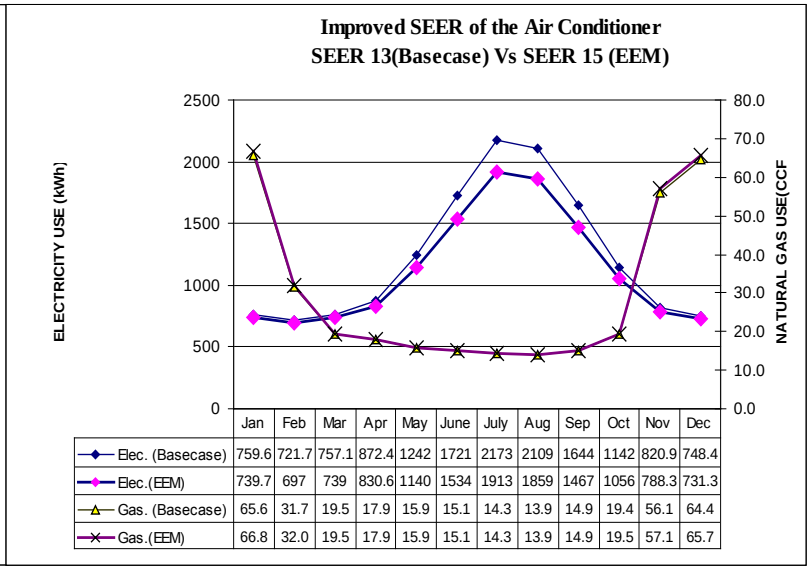
Base Case House with Heat Pump Heating Without Setback

Electricity cost savings = 2,081 kWh/year x 0.16/kWh = $333/year
Total energy cost savings = $333
Implementation cost = $900-$2,500
Simple Payback = 2.7 to 7.51 years

Figure 17: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Improved SEER)

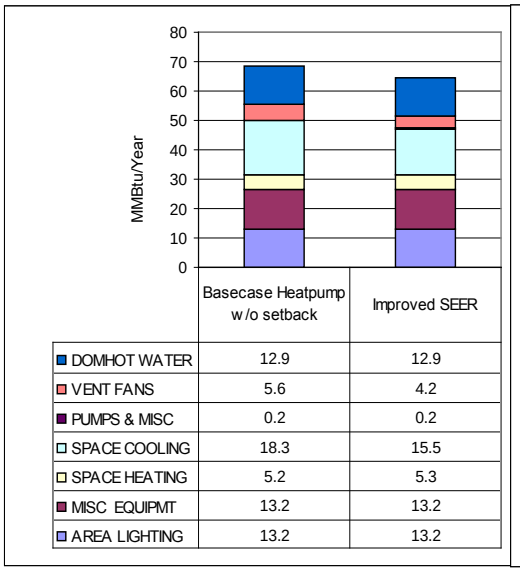


	Basecase NaturalGas w/o setback	Improved SEER
DOMHOT WATER	20.5	20.5
VENT FANS	5.4	4
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	15.5
SPACE HEATING	15.4	15.8
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2

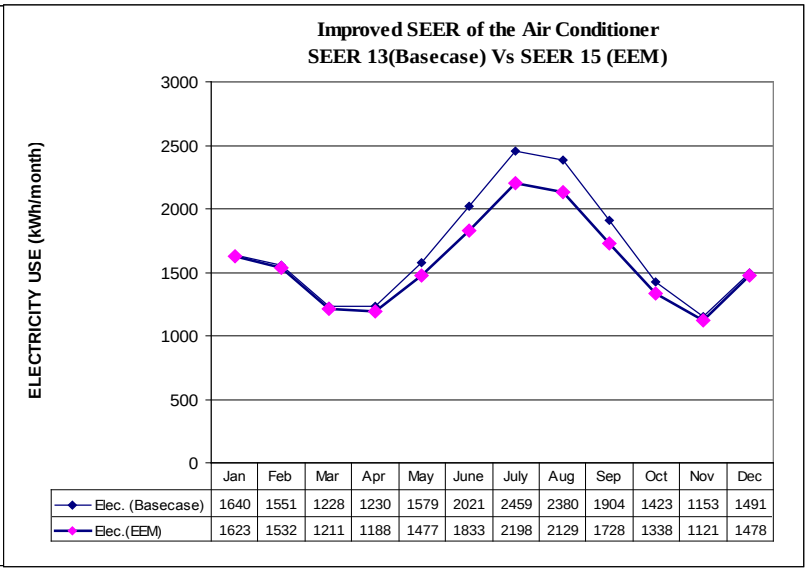


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Elec.(EEM)	739.7	697	739	830.6	1140	1534	1913	1859	1467	1056	788.3	731.3
Gas. (Basecase)	65.6	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.4	56.1	64.4
Gas.(EEM)	66.8	32.0	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.5	57.1	65.7

Figure 18: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Improved SEER)



	Basecase Heatpump w/o setback	Improved SEER
DOMHOT WATER	12.9	12.9
VENT FANS	5.6	4.2
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	15.5
SPACE HEATING	5.2	5.3
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491
Elec.(EEM)	1623	1532	1211	1188	1477	1833	2198	2129	1728	1338	1121	1478

9.2.7 Improved Furnace Efficiency

Base case: For the base case with natural gas heating, the HVAC system includes a central air-conditioning system and a gas-fired furnace for space heating. The base case HVAC system comprises a SEER 13 air-conditioner and a gas-fired, forced-air furnace with Annual Fuel Utilization Efficiency (AFUE) of 0.78. The capacity of the cooling system is 55,800 Btu/hr, which assumes 500 sq. ft. per ton. The capacity of the heating system is 72,540 Btu/hr, as prescribed by the City of Houston officials. The heating and cooling set-points were 68°F for winter and 78°F for summer, with a 5°F setback/setup (for winter and summer, respectively) for six hours early in the morning.

Test case: For this analysis, the gas-fired furnace in the base case house (0.78 AFUE) was replaced with a similarly sized condensing furnace with an AFUE of 0.93.

Implementation Cost: The cost information for this measure is obtained using the sources listed in Appendix A-5, and is summarized in Table 29. It shows that in an electric/gas house, replacing a 0.78 AFUE furnace with a 0.93 AFUE furnace would increase the cost by $600 to $1,500.

Table 29: Cost Information for Upgrading the Furnace.

HVAC System Measures		Capacity	Equipment Cost ($)	Labor Cost ($)	Total Increased Cost ($)	Reference Table (Appendix A-5)
NATURAL GAS HEATING/NATURAL GAS DHW SYSTEM						
Base Case	0.78 AFUE Furnace (w/o pilot light)	70,000 Btuh	$770-$1,310 (Avg. $1,040)	n/a	$600-$1,500	Table Furnace - No. 3, 4, 6, 8
Test Case	0.93 AFUE Furnace (w/o pilot light)		$1,660-$2,500			Table Furnace- No. 2, 5, 7, 9

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

Gas cost savings = 20 CCF/year x $1.2/CCF = $24/year
Total energy cost savings = $24
Implementation cost = $600-$1,500
Simple Payback = 25 to 62.5 years

Base Case House with Natural Gas Heating Without Setback

Gas cost savings = 24 CCF/year x $1.2/CCF = $29/year
Total energy cost savings = $29
Implementation cost = $600-$1,500
Simple Payback = 20.6 to 51.72 years

Figure 19: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Improved SEER)

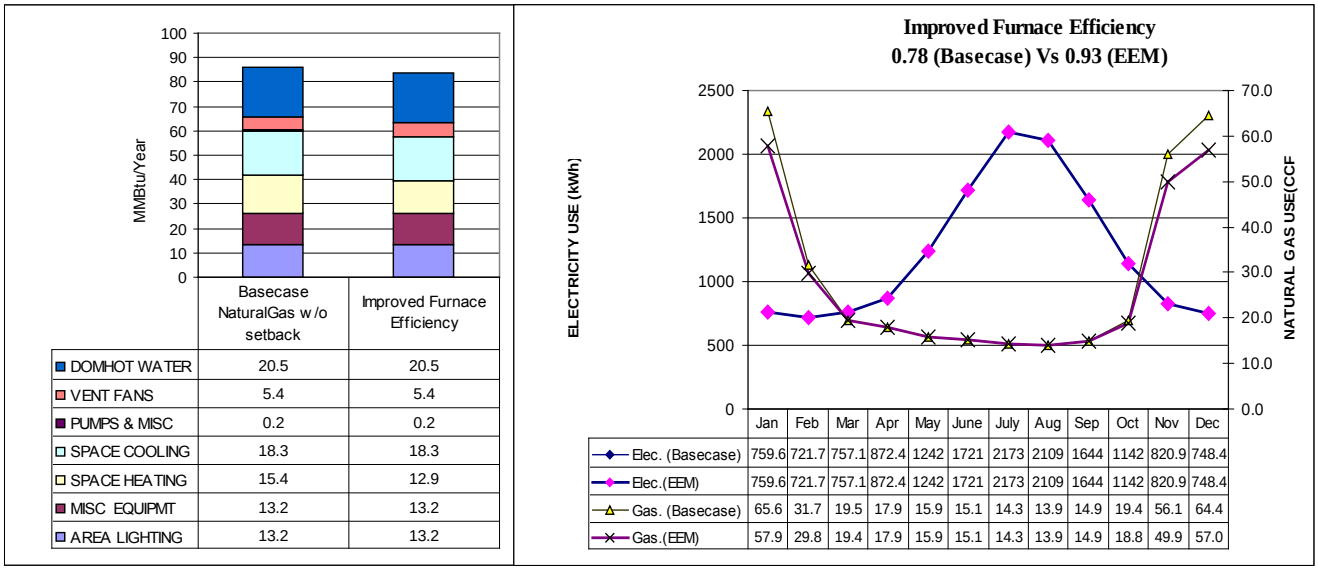
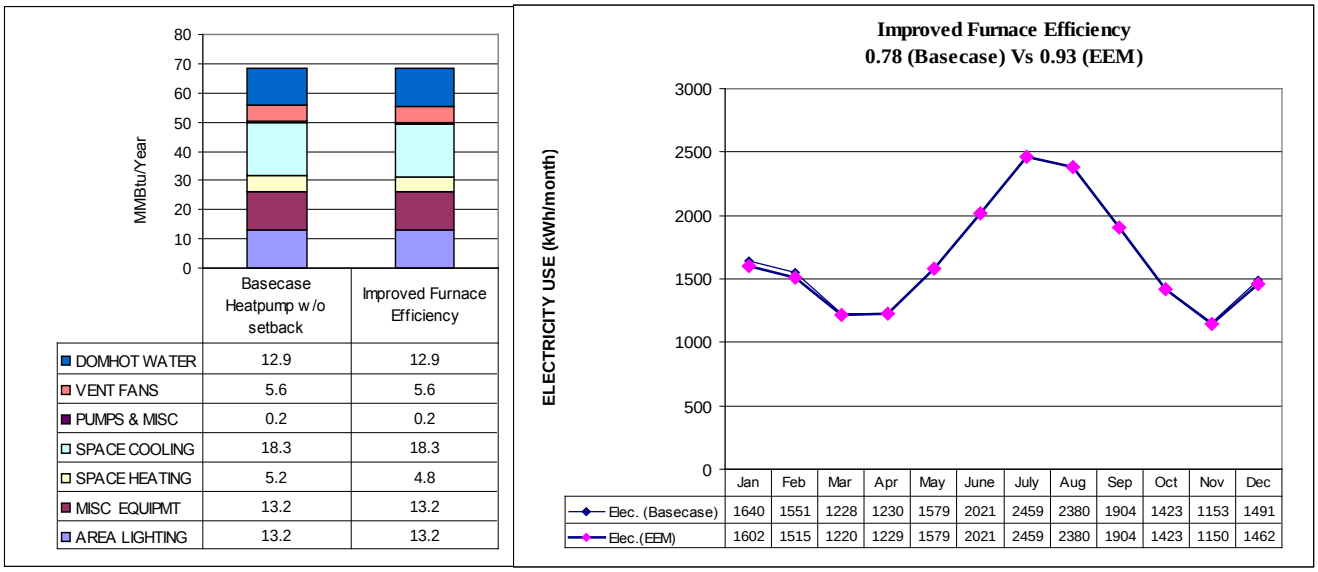


Figure 20: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Improved SEER)



9.3: Fenestration Options

Base case: The base case house has a window area equal to 18% of the floor area distributed equally on all four sides with no exterior shading as per the 2001 IECC, section 402.1.3.5. Based on the climate-specific characteristics for the standard design, the base case house was modeled with U-value 0.47 Btu/h-sq. ft.-°F[10] and solar heat gain coefficient (SHGC) of 0.4011.

9.3.1 Decreased SHGC

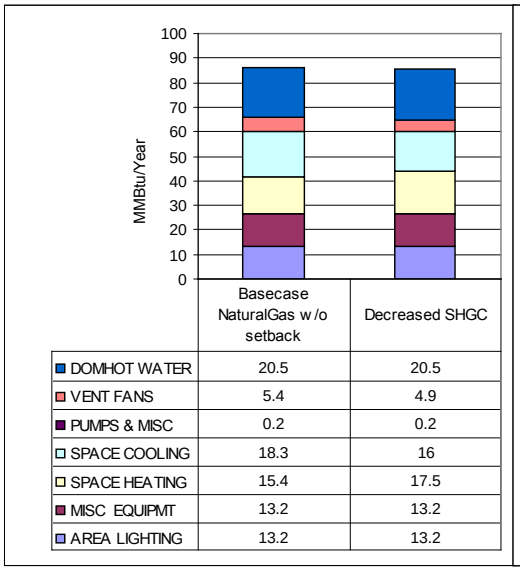
Base case: The base case SHGC value is 0.40.

Test case: The Houston building officials recommended a SHGC value of 0.35 for the test case but as per the 15% above code report an SHGC of 0.3 is taken for test case as it is more stringent than the one recommended by Houston building officials.

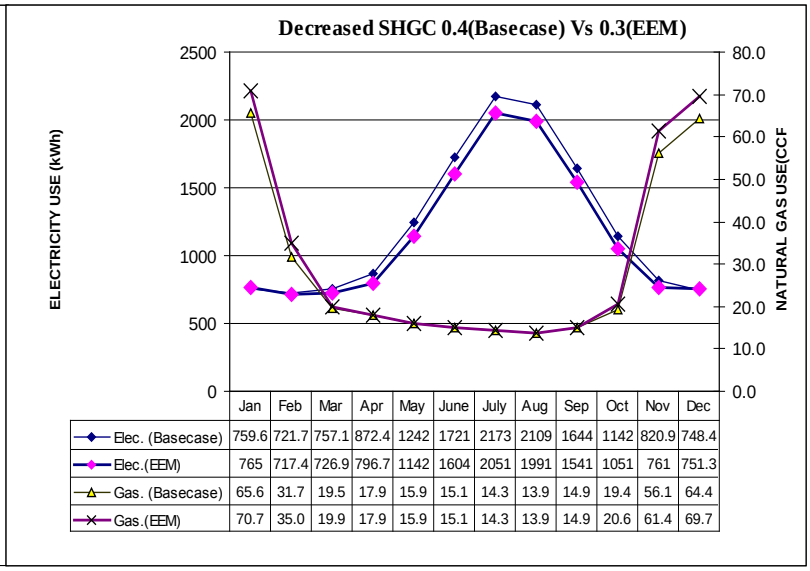
Implementation Cost: Since this measure was not considered in any of the group measures, the costs associated with implementing this measure are not included.

[10] As defined in the table 402.1.1(2), p.63, of 2001 IECC
[11] As defined in section 402.1.3.1.4, p.64 of 2001 IECC

Figure 21: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Decreased SHGC)

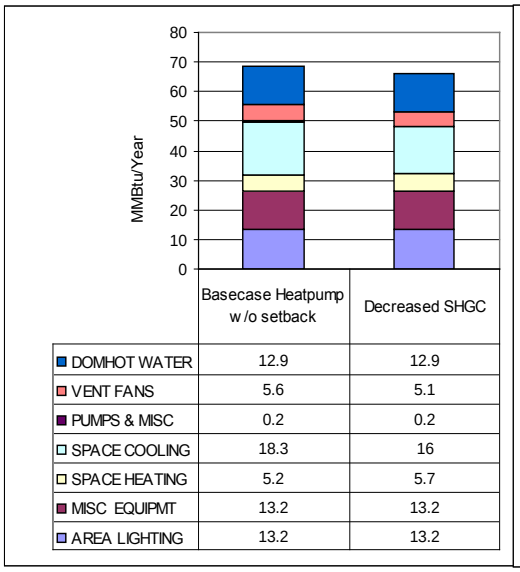


	Basecase NaturalGas w/o setback	Decreased SHGC
DOMHOT WATER	20.5	20.5
VENT FANS	5.4	4.9
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	16
SPACE HEATING	15.4	17.5
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2

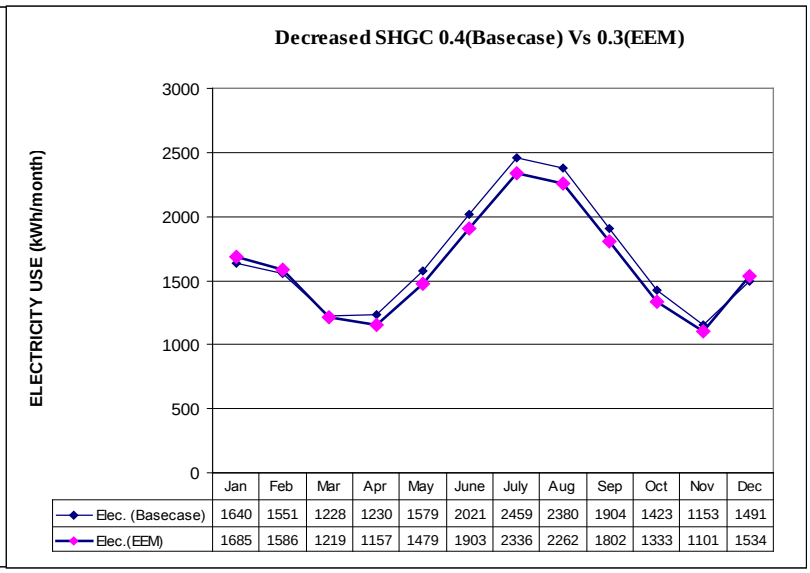


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Elec.(EEM)	765	717.4	726.9	796.7	1142	1604	2051	1991	1541	1051	761	751.3
Gas. (Basecase)	65.6	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.4	56.1	64.4
Gas.(EEM)	70.7	35.0	19.9	17.9	15.9	15.1	14.3	13.9	14.9	20.6	61.4	69.7

Figure 22: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Decreased SHGC)



	Basecase Heatpump w/o setback	Decreased SHGC
DOMHOT WATER	12.9	12.9
VENT FANS	5.6	5.1
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	16
SPACE HEATING	5.2	5.7
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491
Elec.(EEM)	1685	1586	1219	1157	1479	1903	2336	2262	1802	1333	1101	1534

9.3.2 Decreased SHGC and U-Value

Base case: The base case U-Factor is taken as 0.47 Btu/h-sq. ft.-°F and SHGC as 0.35.

Test case: For the test case the U-Factor is taken as 0.35 Btu/h-sq. ft.-°F and an SHGC of 0.30.

Implementation Cost: Cost of improving the SHGC and U-value of the fenestration system will cost between $900-$1,100.

Table 30: Cost Information for Upgrading the SHGC and U-Value of Fenestration

Envelope and Fenestration Measures		Dimensions/Quantity	Cost ($)	Total Increased Cost ($)	Reference Table (Appendix A-3)
Base Case	Air Filled, Double Pane, Aluminum Frame	No. of (36"x60") windows: 27	$96-$112 per window	$800-$1,100*	Table Windows-Summary- No. 2, 4.
Test Case	Argon Filled Glazing and Vinyl Frame		$170-$210 per window		Table Windows-Summary- No. 1, 3.

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

Electricity cost savings = 674 kWh/year x 0.16/kWh = $108/year
Gas cost savings = 9 CCF/year x $1.2/CCF = $10/year
Total energy cost savings = $118
Implementation cost = $900-$1,100
Simple Payback = 7.6 to 9.32 years

Base Case House with Heat Pump Heating With Setback

Electricity cost savings = 791 kWh/year x 0.16/kWh = $127/year
Total energy cost savings = $127
Implementation cost = $900-$1,100
Simple Payback = 7.08 to 8.66 years

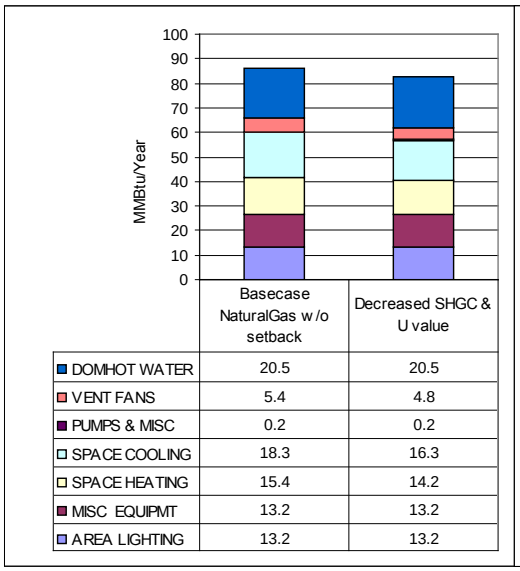
Base Case House with Natural Gas Heating Without Setback

Electricity cost savings = 762 kWh/year x 0.16/kWh = $122/year
Gas cost savings = 12 CCF/year x $1.2/CCF = $14/year
Total energy cost savings = $136
Implementation cost = $900-$1,100
Simple Payback = 6.61 to 8.08 years

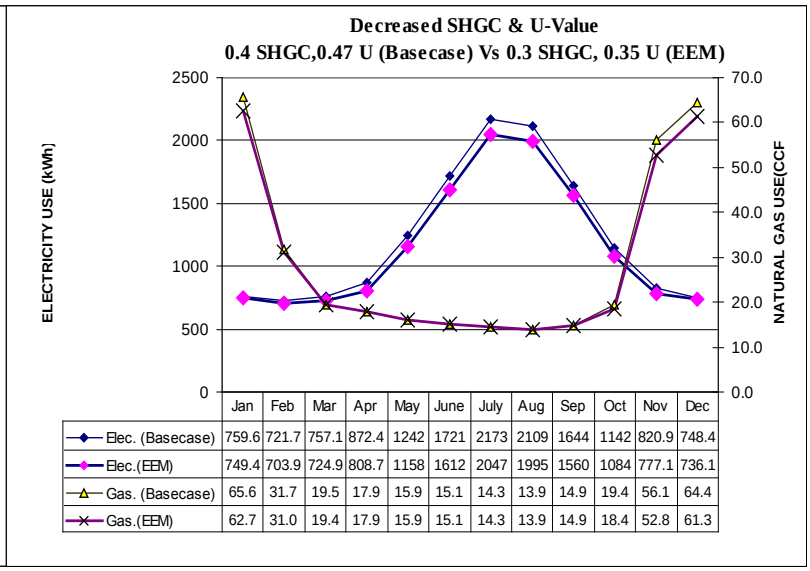
Base Case House with Heat Pump Heating Without Setback

Electricity cost savings = 879 kWh/year x 0.16/kWh = $141/year
Total energy cost savings = $141
Implementation cost = $900-$1,100
Simple Payback = 6.38 to 7.8 years

Figure 23: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Decreases SHGC & U-Value)

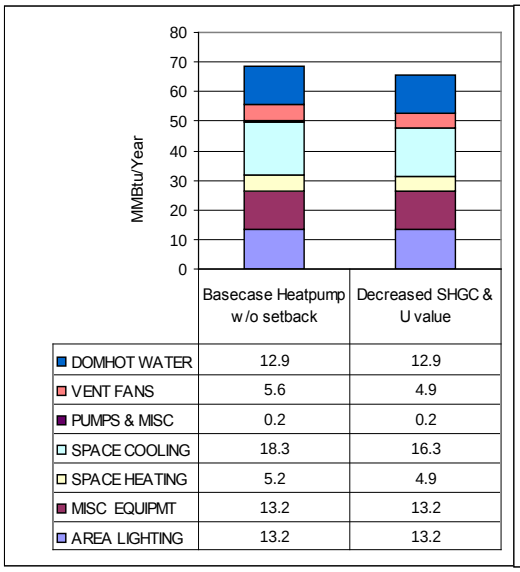


	Basecase NaturalGas w/o setback	Decreased SHGC & U value
DOMHOT WATER	20.5	20.5
VENT FANS	5.4	4.8
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	16.3
SPACE HEATING	15.4	14.2
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2

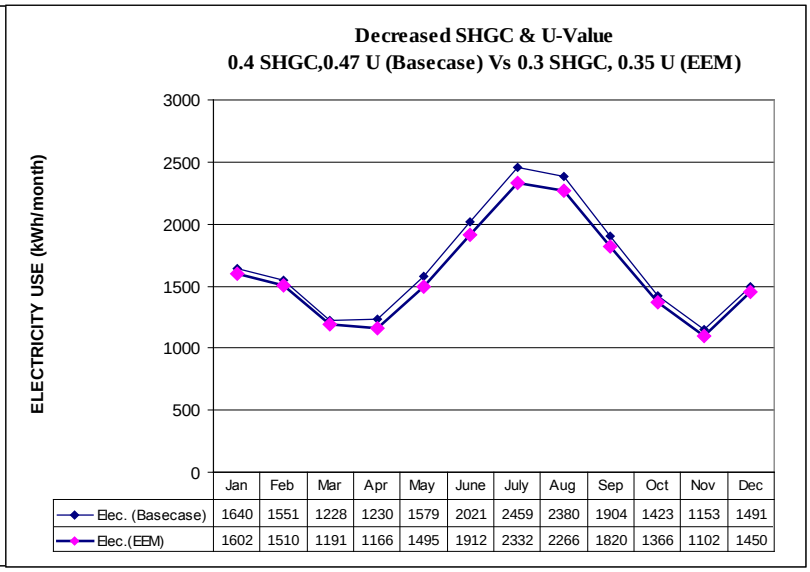


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Elec.(EEM)	749.4	703.9	724.9	808.7	1158	1612	2047	1995	1560	1084	777.1	736.1
Gas. (Basecase)	65.6	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.4	56.1	64.4
Gas.(EEM)	62.7	31.0	19.4	17.9	15.9	15.1	14.3	13.9	14.9	18.4	52.8	61.3

Figure 24: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Decreases SHGC & U-Value)



	Basecase Heatpump w/o setback	Decreased SHGC & U value
DOMHOT WATER	12.9	12.9
VENT FANS	5.6	4.9
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	16.3
SPACE HEATING	5.2	4.9
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491
Elec.(EEM)	1602	1510	1191	1166	1495	1912	2332	2266	1820	1366	1102	1450

9.3.3 Window Shading

Base case: Base case is simulated without any widow shading for the windows.

Test case: This measure was simulated by modeling 4 ft. roof overhangs on all four sides. The gross window area, orientation, and other characteristics were kept the same as the base case house, which did not have overhangs. The depth of overhangs was determined from the recommendations by Malhotra and Haberl (2006). However, the overhang depth on all sides is not optimized for construction cost.

Implementation Cost: The cost information for this measure is obtained using the sources listed in Appendix A-3, and is summarized in the following table. It shows that adding 4 ft. roof overhangs would increase the cost by $3,100 to $3,500.

Table 31: Cost Information for Providing Roof Eaves

Envelope and Fenestration Measures		Dimensions/Quantity	Cost ($)	Total Increased Cost ($)	Reference Table (Appendix A-3)
Base Case	No Window Shading	193 ft. perimeter	$16-$23/linear foot	$3,100-$3,500	Table Shading-1 - No. 1, 2, 3, 4, Table Shading-2 -No. 1
Test Case	4' Eaves		$34-$39/linear foot		Table Shading-1 - No. 4, Table Shading-2 - No. 2

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

Electricity cost savings = 703 kWh/year x 0.16/kWh = $113/year
Gas cost savings = -11 CCF/year x $1.2/CCF = -$13/year
Total energy cost savings = $100
Implementation cost = $3,100-$3,500
Simple Payback = 31 to 35 years

Base Case House with Heat Pump Heating With Setback

Electricity cost savings = 645 kWh/year x 0.16/kWh = $103/year
Total energy cost savings = $103
Implementation cost = $3,100-$3,500
Simple Payback = 30.09 to 33.98 years

Base Case House with Natural Gas Heating Without Setback

Electricity cost savings = 733 kWh/year x 0.16/kWh = $117/year
Gas cost savings = -11 CCF/year x $1.2/CCF = -$13/year
Total energy cost savings = $104
Implementation cost = $3,100-$3,500
Simple Payback = 29.8 to 33.65 years

Base Case House with Heat Pump Heating Without Setback

Electricity cost savings = 645 kWh/year x 0.16/kWh = $103/year
Total energy cost savings = $103
Implementation cost = $3,100-$3,500
Simple Payback = 30.09 to 33.98 years

Figure 25: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Window Shading)

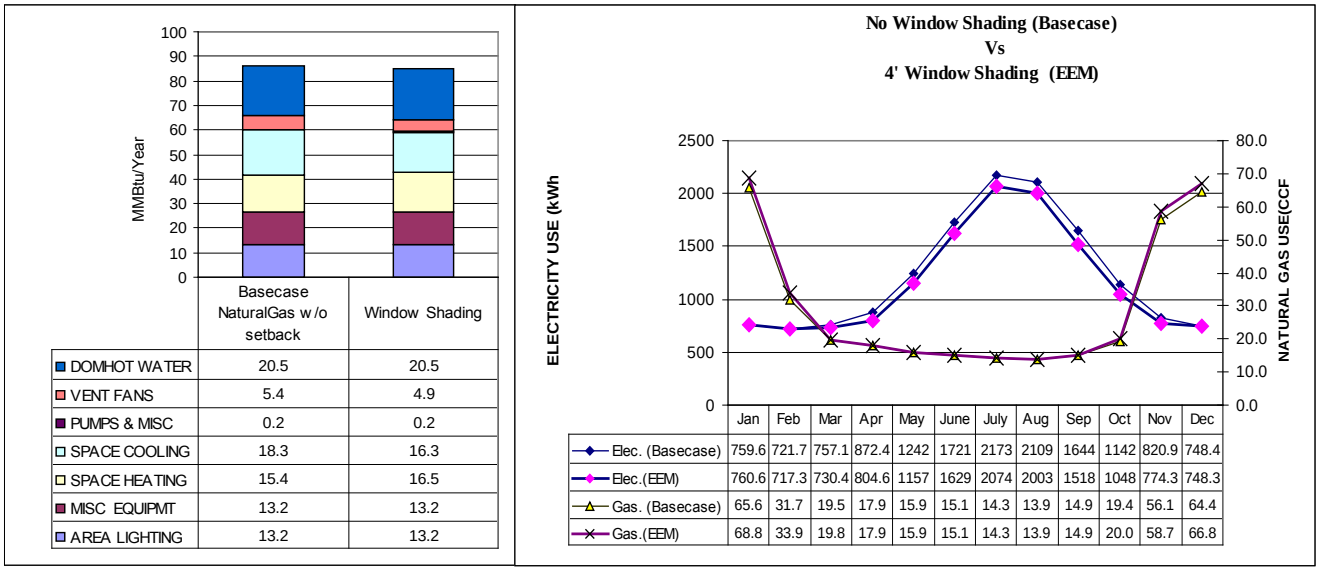
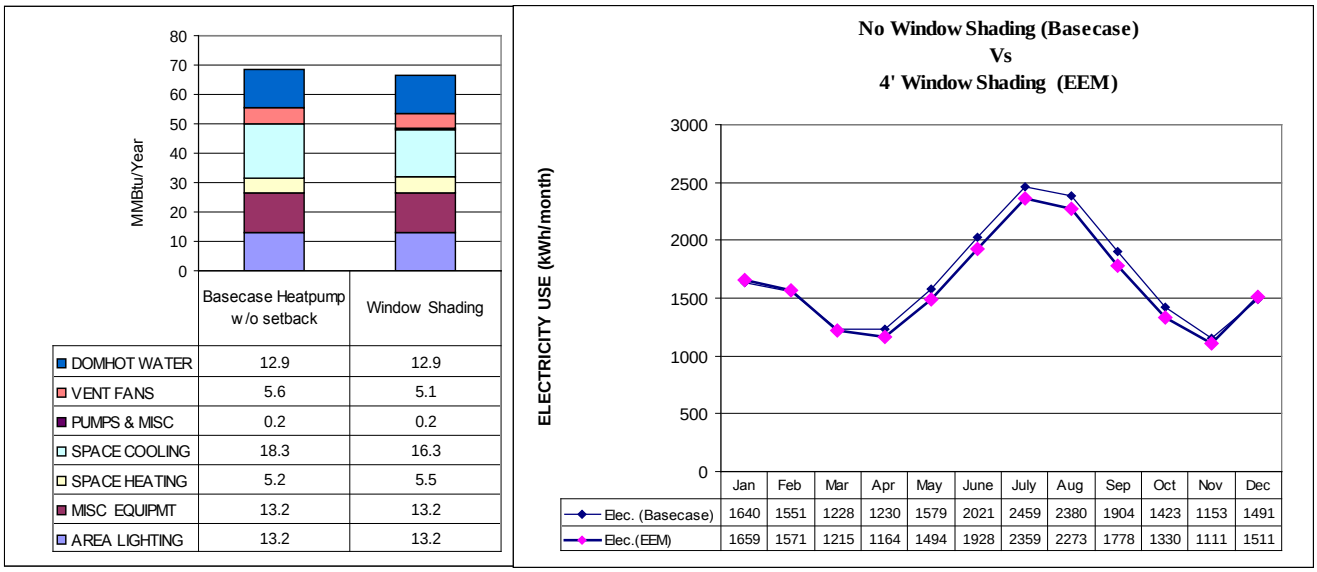


Figure 26: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Decreases SHGC & U-Value)



9.3.4 Window Shading and Redistribution

Base case: The window-to-floor area ratio for the base-case house is 18%, equally distributed on all four sides. This translates to 27.3% window-to-wall area ratio equally distributed on all four sides. The base-case house is simulated without any window shading.

Test case: For this measure, the house was simulated with the windows distributed 48.82% on the south, 27.12% on the north, and 16.27 % each on east and west orientations. A 2-foot roof overhang was also included on all four sides.

Implementation Cost: The cost information for this measure is obtained using the sources listed in Appendix A-3, and is summarized in the following table. It shows that adding 4 ft. roof overhangs would increase the cost by $3,100 to $3,500. However, considering window redistribution in a new construction project would have no increased cost.

Table 32: Cost Information for Providing Roof Eaves

Envelope and Fenestration Measures		Dimensions/Quantity	Cost ($)	Total Increased Cost ($)	Reference Table (Appendix A-3)
Base Case	No Window Shading	193 ft. perimeter	$16-$23/linear foot	$3,100-$3,500	Table Shading-1 - No. 1, 2, 3, 4, Table Shading-2 -No. 1
Test Case	4' Eaves		$34-$39/linear foot		Table Shading-1 - No. 4, Table Shading-2 - No. 2

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

Electricity cost savings = 879 kWh/year x 0.16/kWh = $141/year
Gas cost savings = -1 CCF/year x $1.2/CCF = -$1/year
Total energy cost savings = $140
Implementation cost = $3,100-$3,500
Simple Payback = 22.14 to 25 years

Base Case House with Heat Pump Heating With Setback

Electricity cost savings = 909 kWh/year x 0.16/kWh = $103/year
Total energy cost savings = $145
Implementation cost = $3,100-$3,500
Simple Payback = 21.37 to 24.13 years

Base Case House with Natural Gas Heating Without Setback

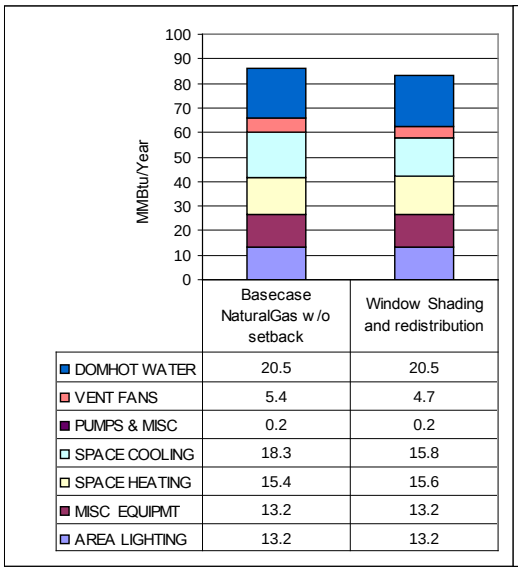
Electricity cost savings = 938 kWh/year x 0.16/kWh = $150/year
Gas cost savings = -2 CCF/year x $1.2/CCF = -$2/year
Total energy cost savings = $148
Implementation cost = $3,100-$3,500
Simple Payback = 20.94 to 23.64 years

Base Case House with Heat Pump Heating Without Setback

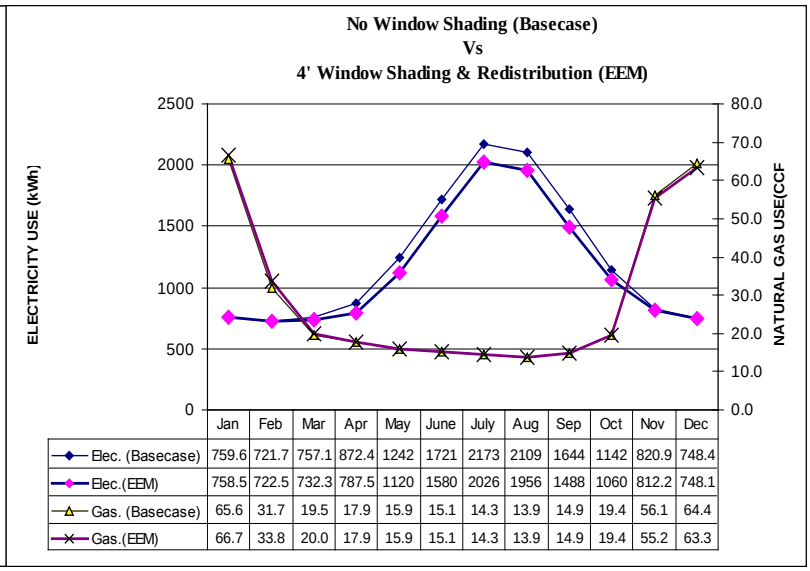
Electricity cost savings = 938 kWh/year x 0.16/kWh = $150/year
Total energy cost savings = $150

Implementation cost = $3,100-$3,500
Simple Payback = 20.66 to 23.33 years

Figure 27: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Window Shading and Redistribution)

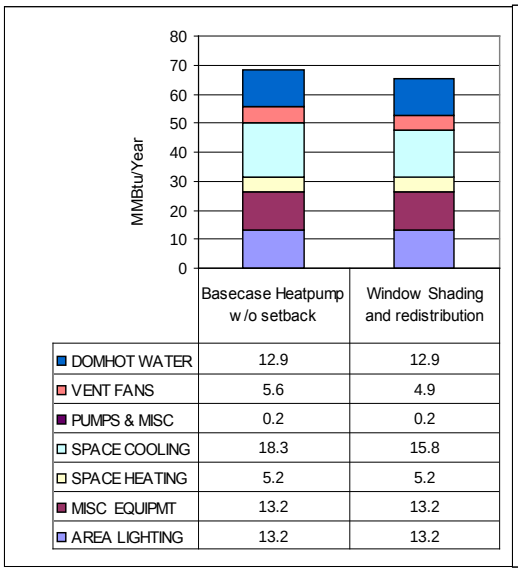


	Basecase NaturalGas w/o setback	Window Shading and redistribution
DOMHOT WATER	20.5	20.5
VENT FANS	5.4	4.7
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	15.8
SPACE HEATING	15.4	15.6
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2

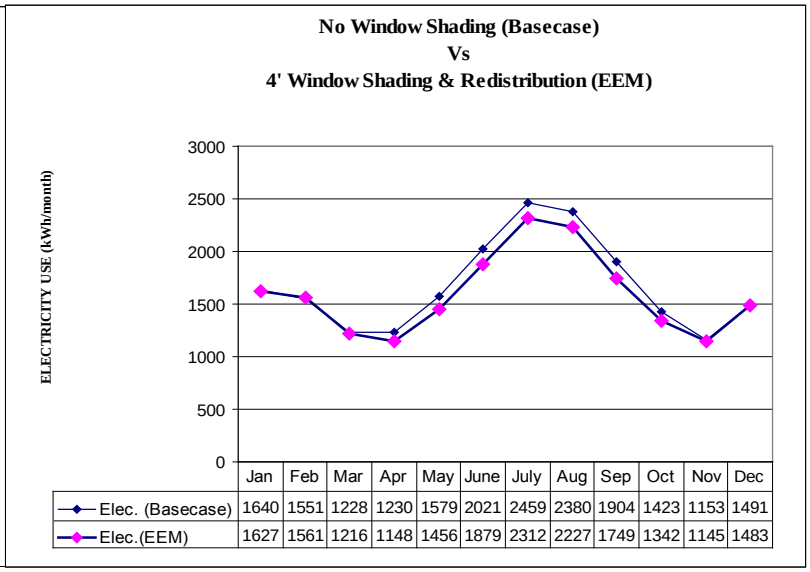


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Elec.(EEM)	758.5	722.5	732.3	787.5	1120	1580	2026	1956	1488	1060	812.2	748.1
Gas. (Basecase)	65.6	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.4	56.1	64.4
Gas.(EEM)	66.7	33.8	20.0	17.9	15.9	15.1	14.3	13.9	14.9	19.4	55.2	63.3

Figure 28: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Window Shading and Redistribution)



	Basecase Heatpump w/o setback	Window Shading and redistribution
DOMHOT WATER	12.9	12.9
VENT FANS	5.6	4.9
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	15.8
SPACE HEATING	5.2	5.2
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491
Elec.(EEM)	1627	1561	1216	1148	1456	1879	2312	2227	1749	1342	1145	1483

9.4: Envelope Options

9.4.1 Radiant Barrier

Base case: The base case is simulated with radiant barrier option set to "No."

Test case: In test case the radiant barrier option set to "Yes."

Implementation Cost: Since this measure was not considered in any of the group measures, the costs associated with implementing this measure are not included.

Figure 29: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Radiant Barrier)

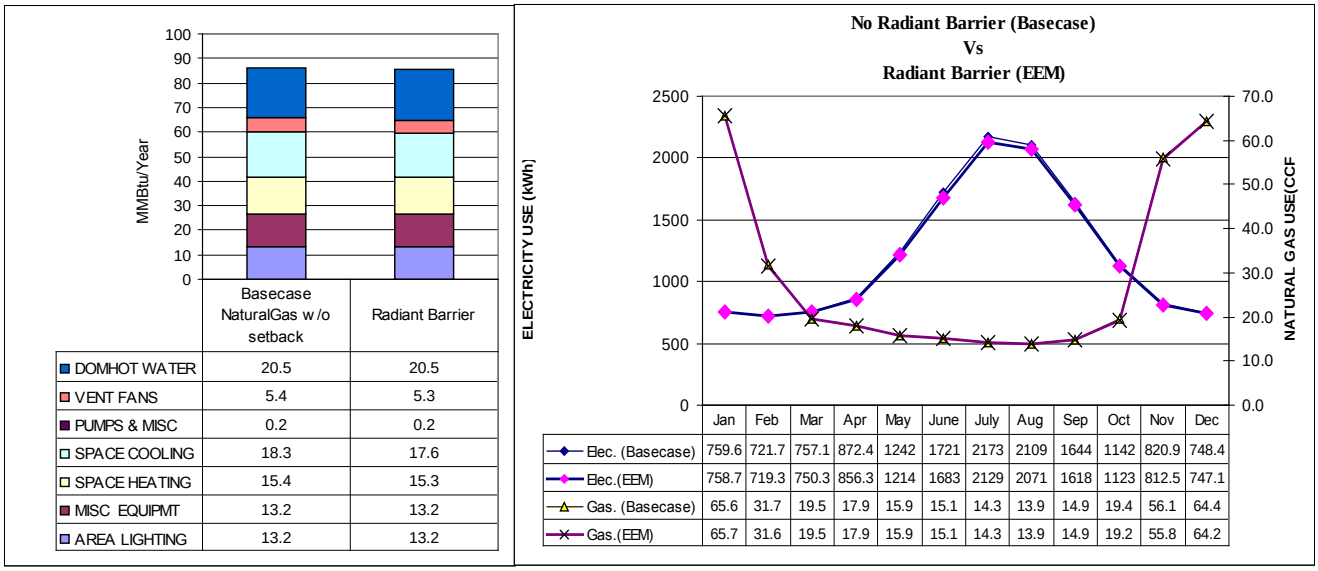
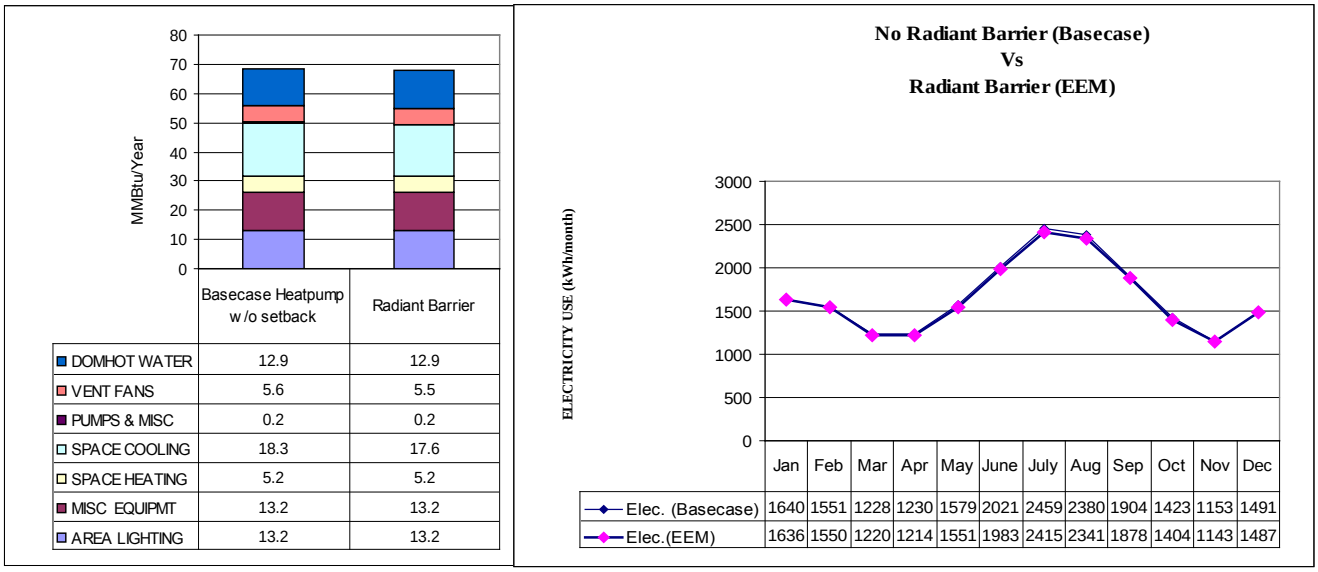


Figure 30: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Radiant Barrier)



9.4.2 Decreased Infiltration

Base case: The infiltration in terms of air change rate for the base case house is set to be 0.467 ACH for Houston[12] is calculated from the following formula:

ACH = Normalized Leakage X Weather Factor[13]

In this case, normalized leakage is equal to 0.57 and weather factor for Houston is 0.81 based on the weather factor specified in ASHRAE Standard 136 (ASHRAE 1993)[14].

Test cases: Two test cases were simulated: one with the decreased air change of 0.35 ACH and one with the increases air change 0.65 ACH as requested by the City of Houston officials.

Implementation Cost: Cost of decreasing infiltration is between $350- $1,500.

Table 33: Cost Information for Improving Air Tightness in Buildings

Envelope and Fenestration Measures		Dimensions/Quantity	Cost ($)	Total Increased Cost ($)	Reference Table (Appendix A-3)
Base Case	Infiltration Rate: 0.462 ACH	2325 sq. ft. conditioned floor area	$150-$500 (material) + $200-$500 (blower door test)	$350-$1,500*	-
Test Case	Increased Air Tightness- infiltration Rate: 0.35 ACH				Table Increased Air-tightness - No. 1, 2.

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

Electricity cost savings = 264 kWh/year x 0.16/kWh = $42/year
Gas cost savings = 21 CCF/year x $1.2/CCF = $26/year
Total energy cost savings = $68
Implementation cost = $350-$1,500
Simple Payback = 5.15 to 22.06 years

Base Case House with Heat Pump Heating With Setback

Electricity cost savings = 469 kWh/year x 0.16/kWh = $75/year
Total energy cost savings = $75
Implementation cost = $350-$1,500
Simple Payback = 4.66 to 20 years

Base Case House with Natural Gas Heating Without Setback

Electricity cost savings = 322 kWh/year x 0.16/kWh = $52/year
Gas cost savings = 25 CCF/year x $1.2/CCF = $30/year
Total energy cost savings = $85
Implementation cost = $350-$1,500
Simple Payback = 4.12 to 17.65 years

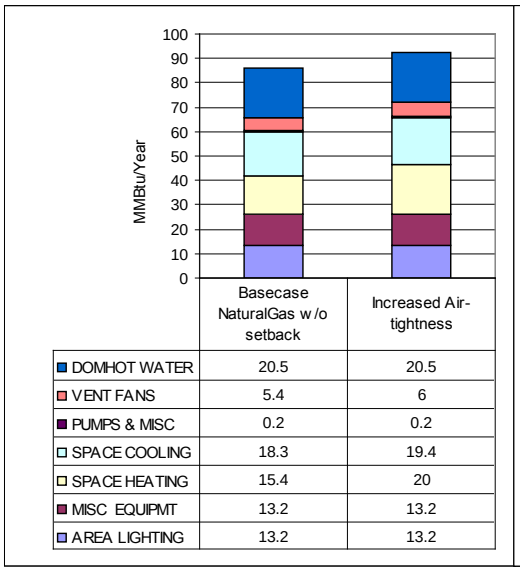
Base Case House with Heat Pump Heating Without Setback

Electricity cost savings = 557 kWh/year x 0.16/kWh = $89/year

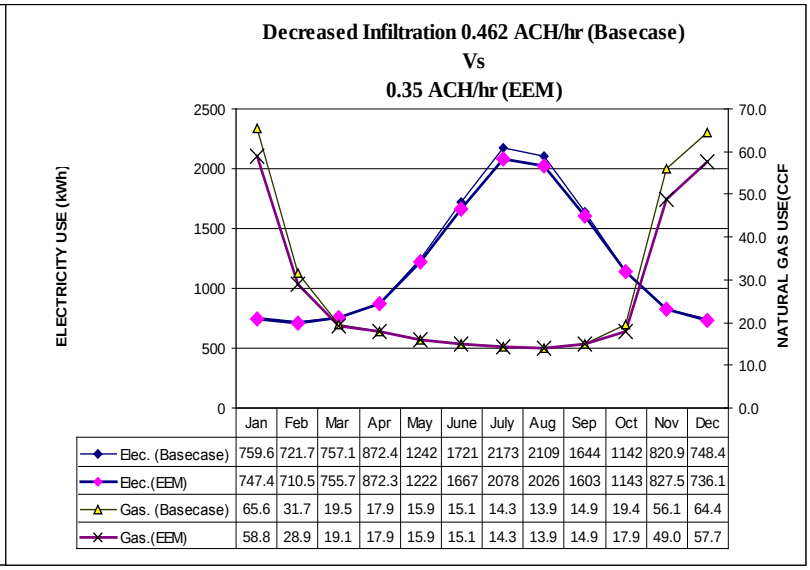
[12] The air infiltration rate for different location ranged from 0.43 ACH to 0.94 ACH.
[13] As per the formula defined in section 402.1.3.10, p.65, 2001 IECC.
[14] This requirement can be found in Section 402.1.3.10, p.65.

Total energy cost savings = $89
Implementation cost = $350-$1,500
Simple Payback = 3.93 to 16.85 years

Figure 31: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Decreased Infiltration)

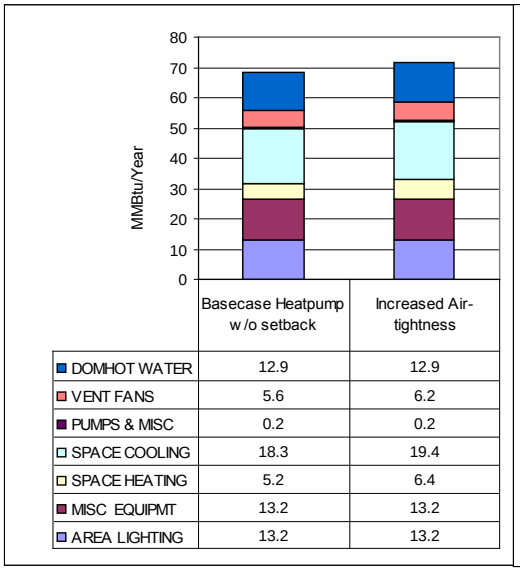


	Basecase NaturalGas w/o setback	Increased Air-tightness
DOMHOT WATER	20.5	20.5
VENT FANS	5.4	6
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	19.4
SPACE HEATING	15.4	20
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2

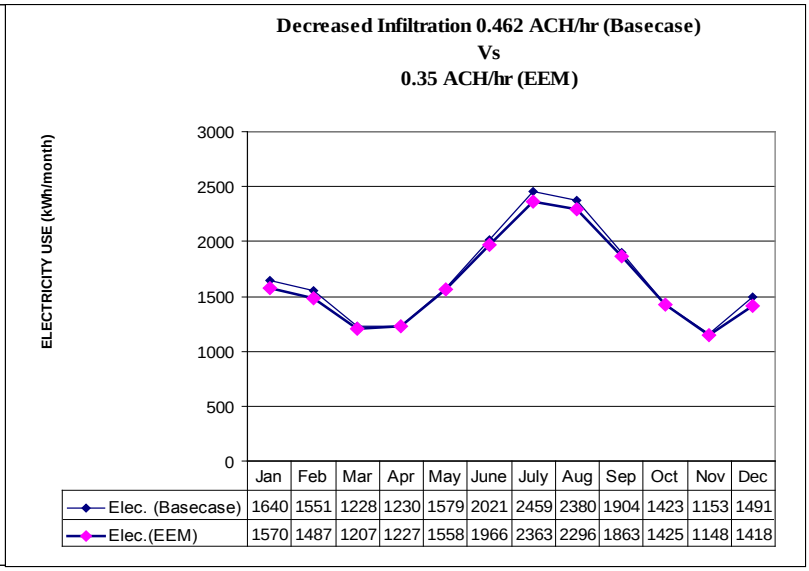


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Elec.(EEM)	747.4	710.5	755.7	872.3	1222	1667	2078	2026	1603	1143	827.5	736.1
Gas. (Basecase)	65.6	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.4	56.1	64.4
Gas.(EEM)	58.8	28.9	19.1	17.9	15.9	15.1	14.3	13.9	14.9	17.9	49.0	57.7

Figure 32: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Decreased Infiltration)



	Basecase Heatpump w/o setback	Increased Air-tightness
DOMHOT WATER	12.9	12.9
VENT FANS	5.6	6.2
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	19.4
SPACE HEATING	5.2	6.4
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491
Elec.(EEM)	1570	1487	1207	1227	1558	1966	2363	2296	1863	1425	1148	1418

9.4.3 Low Slope Roof with Increased Reflectance

Base case: The base case roof has a slope of (23°) with an absorptance of 0.75.

Test case: The test case building has been simulated with the roof having slope of (9°) with the decreased roof absorptance of 0.3.

Implementation Cost: Since this measure was not considered in any of the group measures, the costs associated with implementing this measure are not included.

Figure 33: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Decreased Roof Pitch and Increased Reflectance)

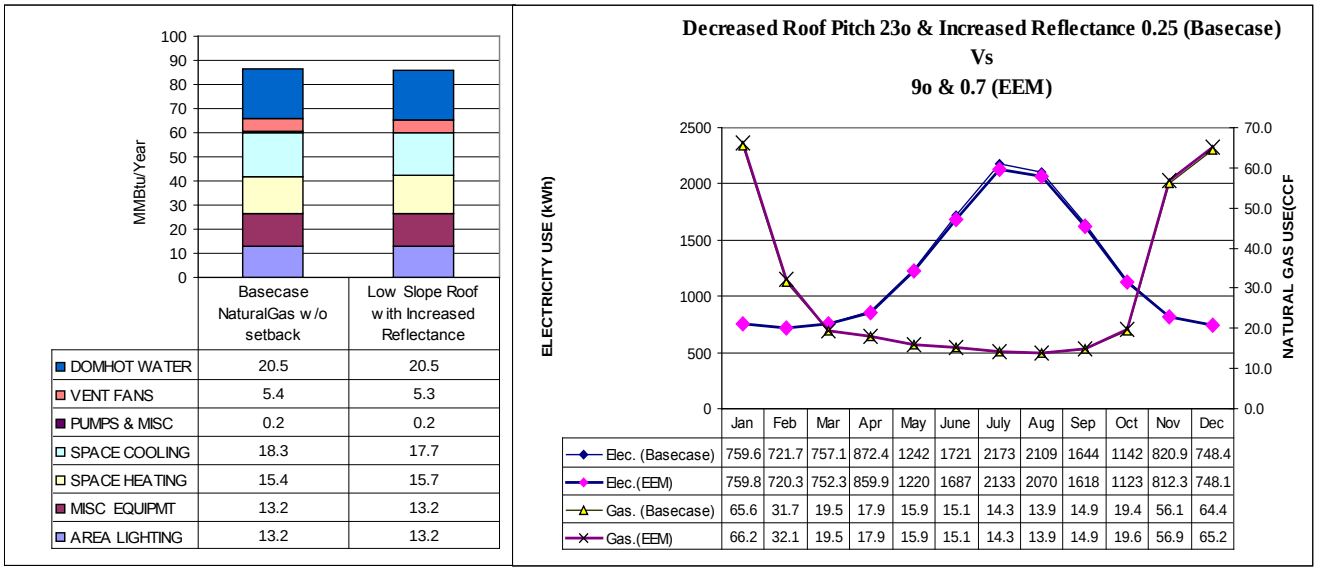
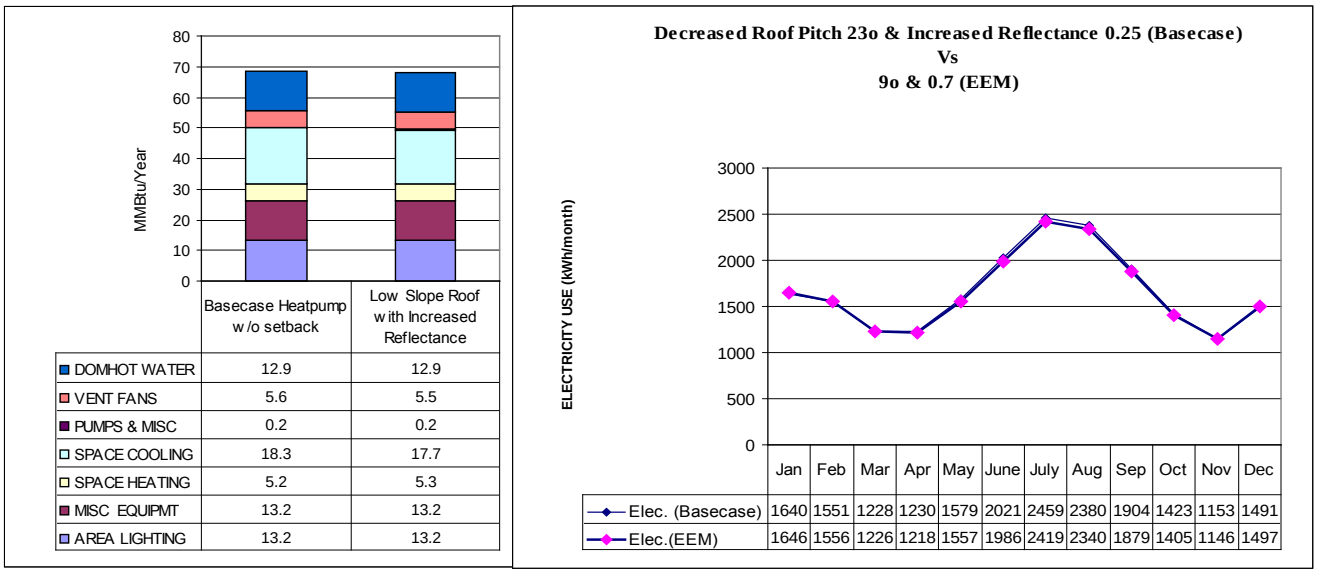


Figure 34: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Decreased Roof Pitch and Increased Reflectance)



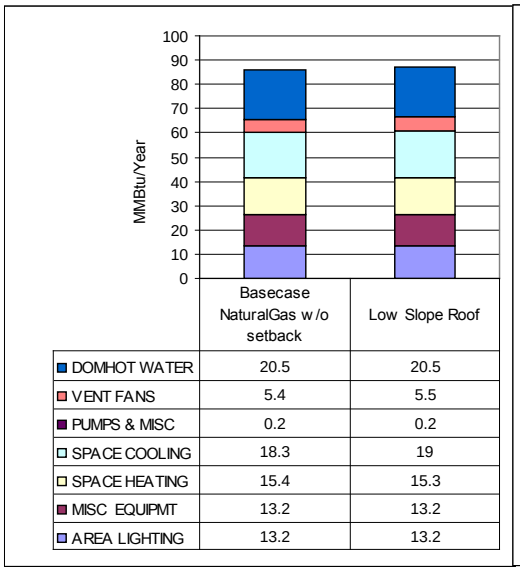
9.4.4 Low Slope Roof

Base case: The base case roof has a slope of 23°.

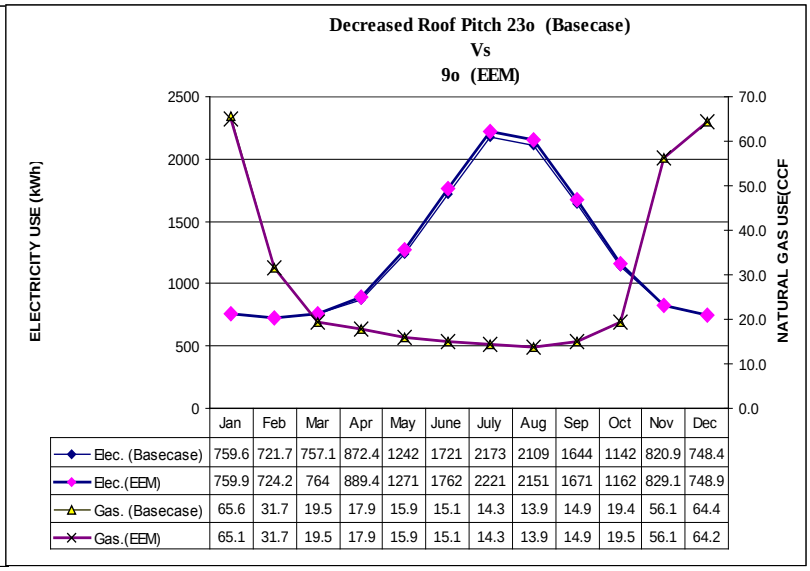
Test case: The slope of the roof for the test case is 9º.

Implementation Cost: Since this measure was not considered in any of the group measures, the costs associated with implementing this measure are not included.

Figure 35: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Decreased Roof Pitch)

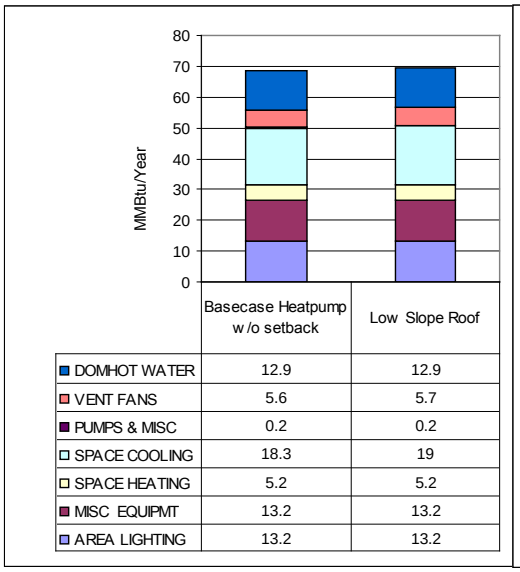


	Basecase NaturalGas w/o setback	Low Slope Roof
DOMHOT WATER	20.5	20.5
VENT FANS	5.4	5.5
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	19
SPACE HEATING	15.4	15.3
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2

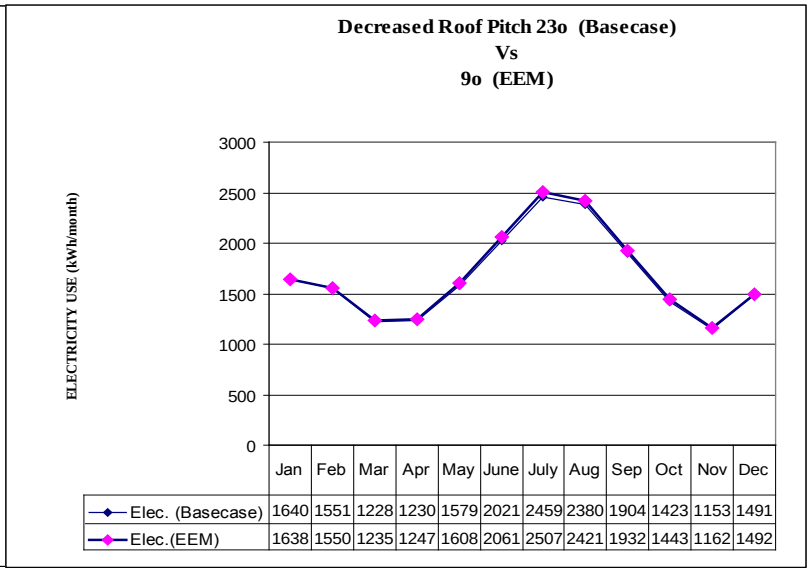


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Elec.(EEM)	759.9	724.2	764	889.4	1271	1762	2221	2151	1671	1162	829.1	748.9
Gas. (Basecase)	65.6	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.4	56.1	64.4
Gas.(EEM)	65.1	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.5	56.1	64.2

Figure 36: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Decreased Roof Pitch)



	Basecase Heatpump w/o setback	Low Slope Roof
DOMHOT WATER	12.9	12.9
VENT FANS	5.6	5.7
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	19
SPACE HEATING	5.2	5.2
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491
Elec.(EEM)	1638	1550	1235	1247	1608	2061	2507	2421	1932	1443	1162	1492

9.5: Lighting Options

9.5.1 25% Energy Star Indoor Lamps

Base case: 100% incandescent fixtures are assumed for the base-case house. Section 402.1.3.6 of the IECC describes the internal heat gain to be 0.88 kW. It is assumed that 0.44 kW are allocated to heat gains from lighting and 0.44kW are allocated from miscellaneous equipment.

Test case 1: For test case 25% Energy Star fluorescent lamps were used assuming that a fluorescent lamp uses 75% less energy than an incandescent lamp —the resulting internal heat gain from lights of which 25% are fluorescent lamps is 0.36 kW.

Implementation Cost: The cost of implementing the 25% Energy Star indoor lighting is $100. The cost information for this measure is obtained from estimated costs proposed by the City of Houston officials. These costs are listed in Appendix A-1.

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

Electricity cost savings	= 935 kWh/year x 0.16/kWh = $150/year
Gas cost savings	= -7 CCF/year x $1.2/CCF = -$8/year
Total energy cost savings	= $142
Implementation cost	= $100
Simple Payback	= 0.70 years

Base Case House with Heat Pump Heating With Setback

Electricity cost savings	= 938 kWh/year x 0.16/kWh = $150/year
Total energy cost savings	= $150
Implementation cost	= $100
Simple Payback	= 0.67 years

Base Case House with Natural Gas Heating Without Setback

Electricity cost savings	= 967 kWh/year x 0.16/kWh = $155/year
Gas cost savings	= -8 CCF/year x $1.2/CCF = -$9/year
Total energy cost savings	= $145
Implementation cost	= $100
Simple Payback	= 0.69 years

Base Case House with Heat Pump Heating Without Setback

Electricity cost savings	= 909 kWh/year x 0.16/kWh = $145/year
Total energy cost savings	= $145
Implementation cost	= $100
Simple Payback	= 0.69 years

Figure 37: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (25% Energy Star CFL Lamps)

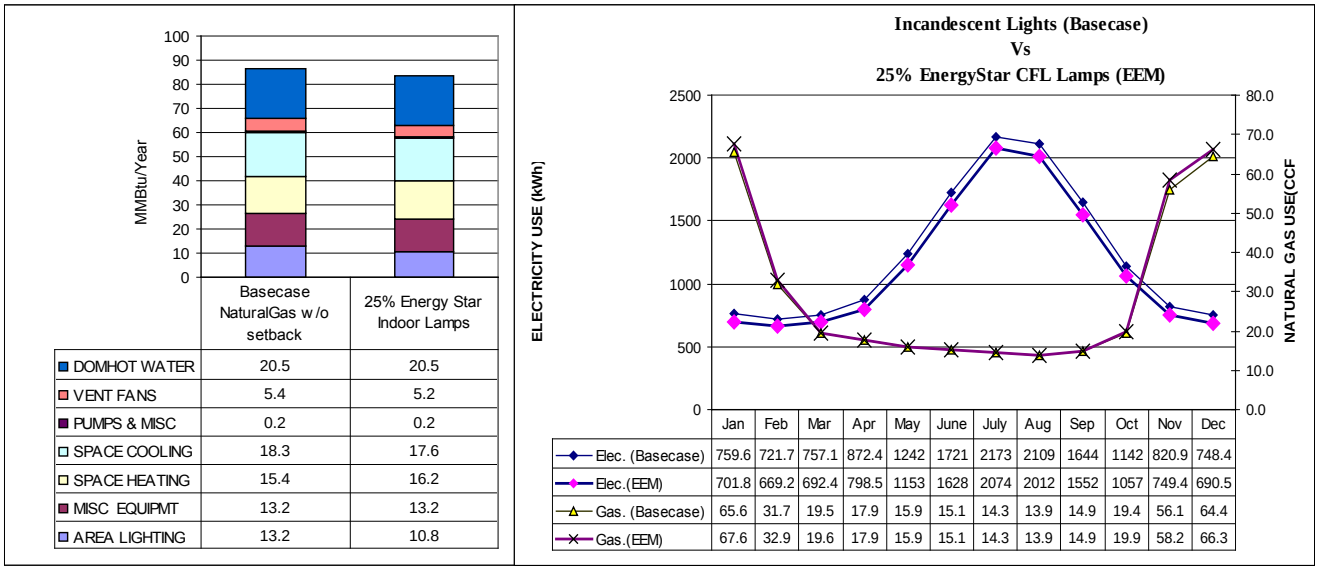
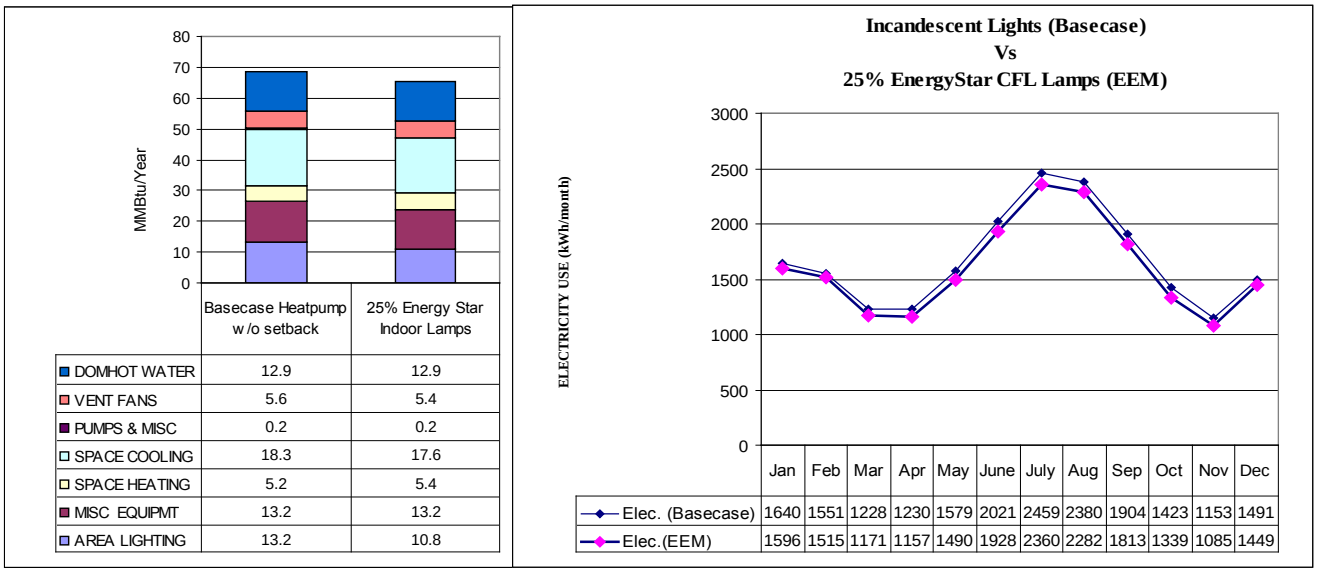


Figure 38: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (25% Energy Star CFL Lamps)



9.5.2 50% Energy Star Indoor Lamps

Base case: 100% incandescent fixtures are assumed for the base case house. Section 402.1.3.6 of the IECC describes the internal heat gain to be 0.88 kW. It is assumed that 0.44 kW are allocated to heat gains from lighting and 0.44 kW are allocated from miscellaneous equipment.

Test case: For the test case, 50% Energy Star fluorescent lamps were used. Assuming that a fluorescent lamp uses 75% less energy than an incandescent lamp –the resulting internal heat gain from lights is 50% less which is 0.275 kW.

Implementation Cost: Cost of implementing the 25% Energy Star indoor lighting is $500-$800.

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

Electricity cost savings	= 1,846 kWh/year x 0.16/kWh = $295/year
Gas cost savings	= -14 CCF/year x $1.2/CCF = -$16/year
Total energy cost savings	= $142
Implementation cost	= $500-$800
Simple Payback	= 3.52 to 5.63 years

Base Case House with Heat Pump Heating With Setback

Electricity cost savings	= 1,788 kWh/year x 0.16/kWh = $286/year
Total energy cost savings	= $286
Implementation cost	= $500-$800
Simple Payback	= 1.75 to 2.80 years

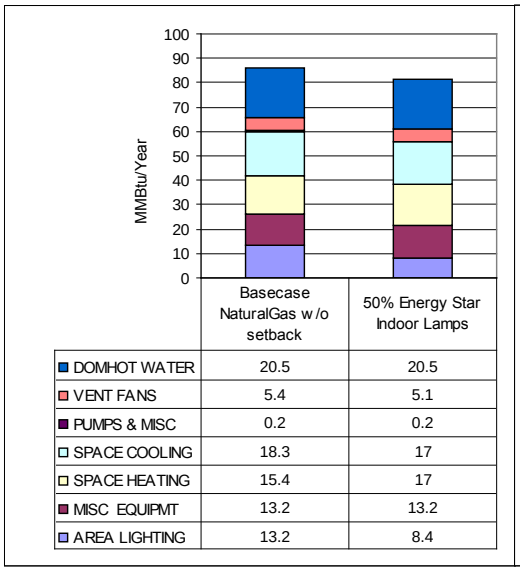
Base Case House with Natural Gas Heating Without Setback

Electricity cost savings	= 1,876 kWh/year x 0.16/kWh = $300/year
Gas cost savings	= -16 CCF/year x $1.2/CCF = -$19/year
Total energy cost savings	= $281
Implementation cost	= $500-$800
Simple Payback	= 1.78 to 2.85 years

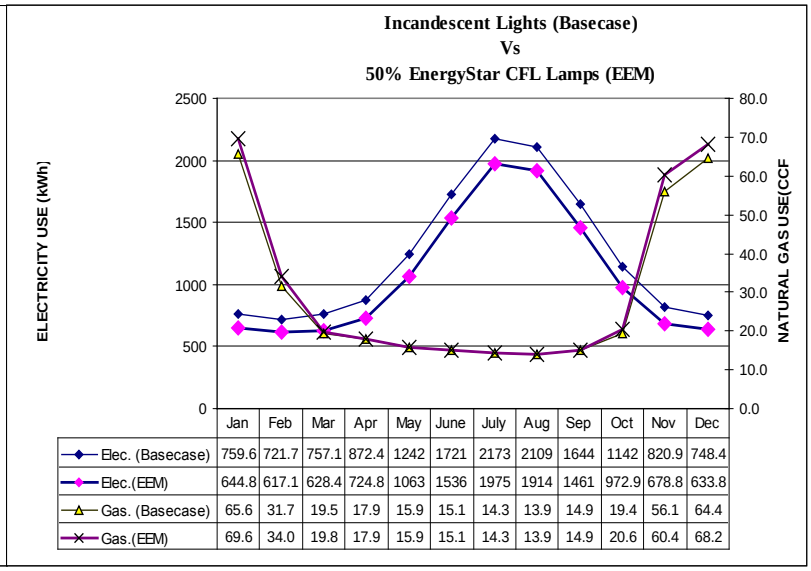
Base Case House with Heat Pump Heating Without Setback

Electricity cost savings	= 1,758 kWh/year x 0.16/kWh = $281/year
Total energy cost savings	= $281
Implementation cost	= $500-$800
Simple Payback	= 1.78 to 2.85 years

Figure 39: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (50% Energy Star CFL Lamps)

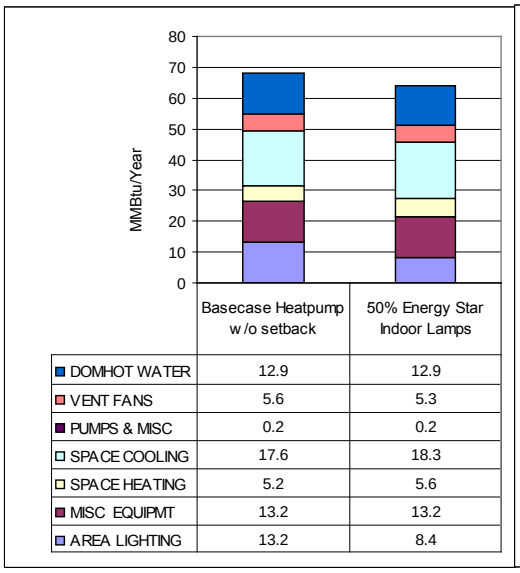


	Basecase NaturalGas w/o setback	50% Energy Star Indoor Lamps
DOMHOT WATER	20.5	20.5
VENT FANS	5.4	5.1
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	17
SPACE HEATING	15.4	17
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	8.4

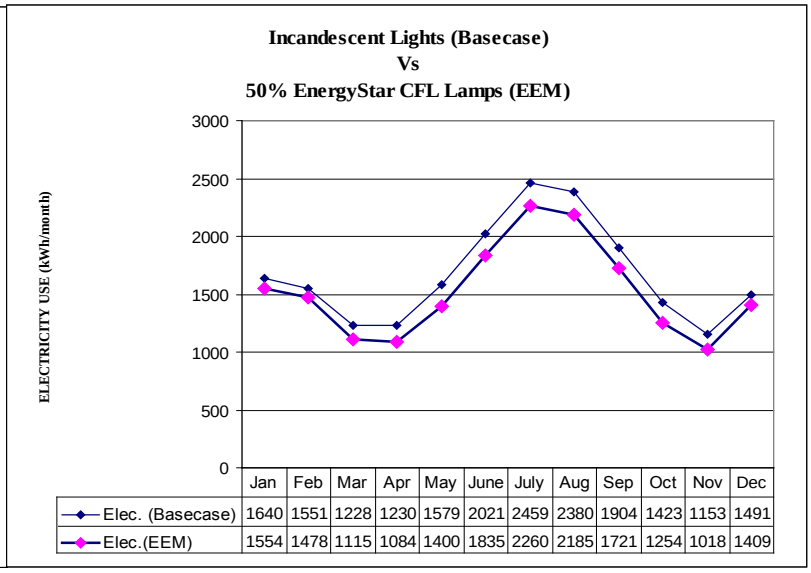


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Elec.(EEM)	644.8	617.1	628.4	724.8	1063	1536	1975	1914	1461	972.9	678.8	633.8
Gas. (Basecase)	65.6	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.4	56.1	64.4
Gas.(EEM)	69.6	34.0	19.8	17.9	15.9	15.1	14.3	13.9	14.9	20.6	60.4	68.2

Figure 40: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (50% Energy Star CFL Lamps)



	Basecase Heatpump w/o setback	50% Energy Star Indoor Lamps
DOMHOT WATER	12.9	12.9
VENT FANS	5.6	5.3
PUMPS & MISC	0.2	0.2
SPACE COOLING	17.6	18.3
SPACE HEATING	5.2	5.6
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	8.4



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491
Elec.(EEM)	1554	1478	1115	1084	1400	1835	2260	2185	1721	1254	1018	1409

9.5.3 Exterior Lighting: Incandescent with Occupancy Sensors

Base case: 100% incandescent fixtures are assumed for the base case house without occupancy sensors.

Test case: 100% incandescent fixtures are assumed for the base case house with occupancy sensors.

Implementation Cost: Since this measure was not considered in any of the group measures, the costs associated with implementing this measure are not included.

Figure 41: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Incandescent with Occupancy Sensors)

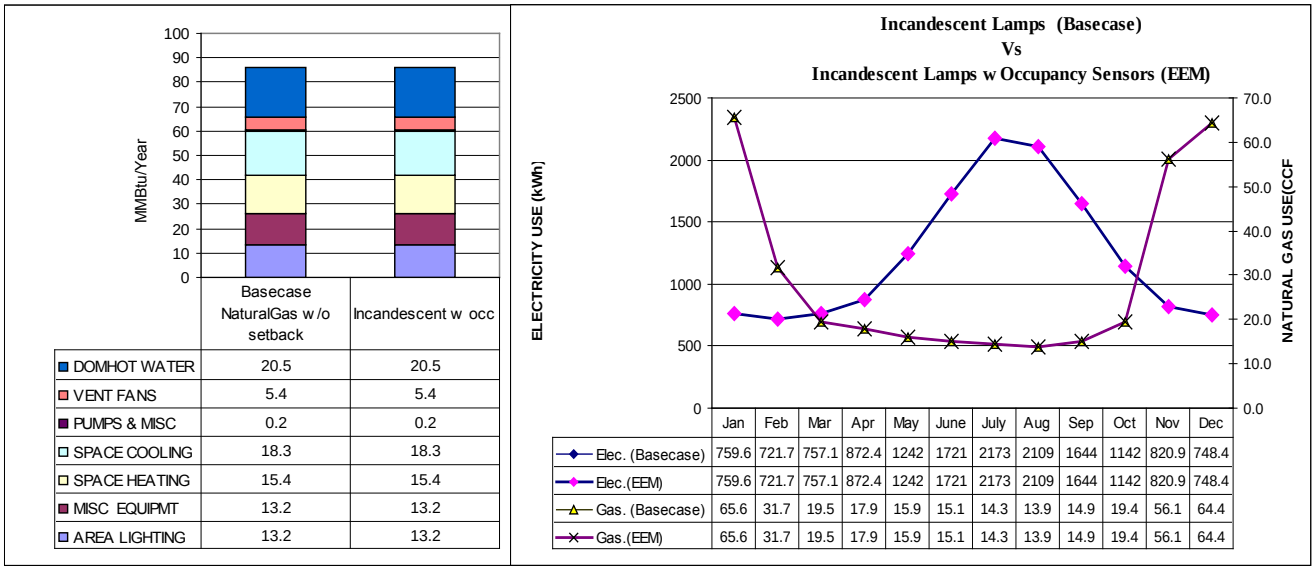
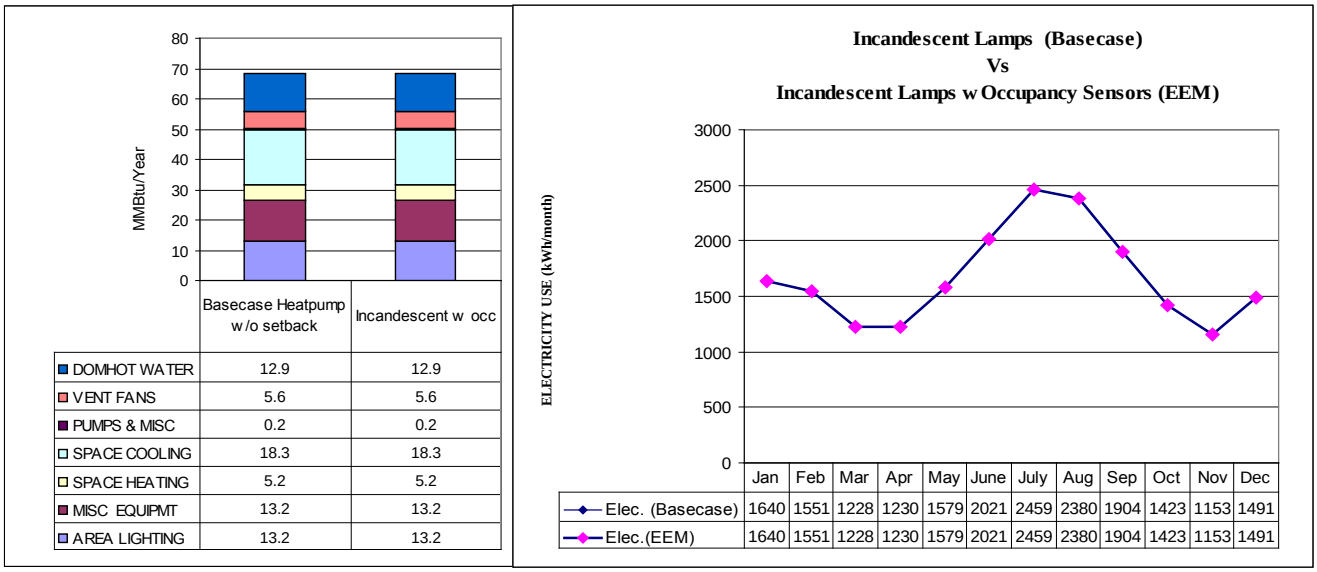


Figure 42: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Incandescent with Occupancy Sensors)



9.5.4 Exterior Lighting: Fluorescent Lamps without Occupancy Sensors

Base case: 100% incandescent fixtures are assumed for the base case house without occupancy sensors.

Test case: For the test case fluorescent lamps were used without occupancy sensors.

Implementation Cost: Since this measure was not considered in any of the group measures, the costs associated with implementing this measure are not included.

Figure 43: Monthly Energy consumption for the Base-case House With Natural Gas Heating (w/o setback) and EEM (CFL Lamps w/o Occupancy Sensors)

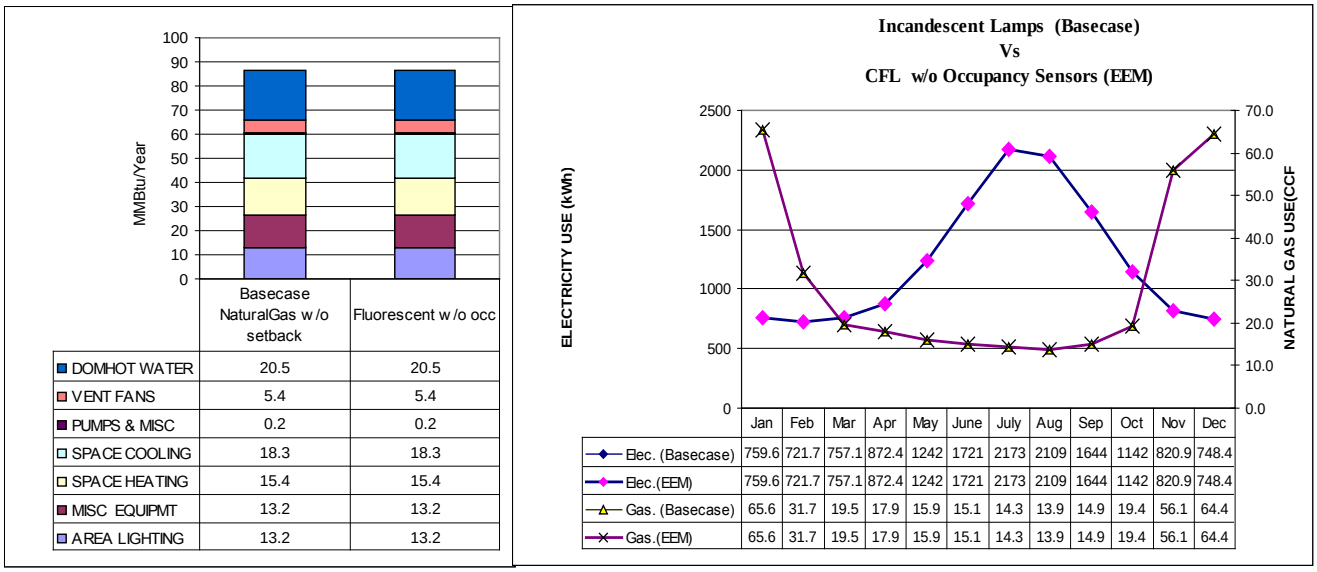
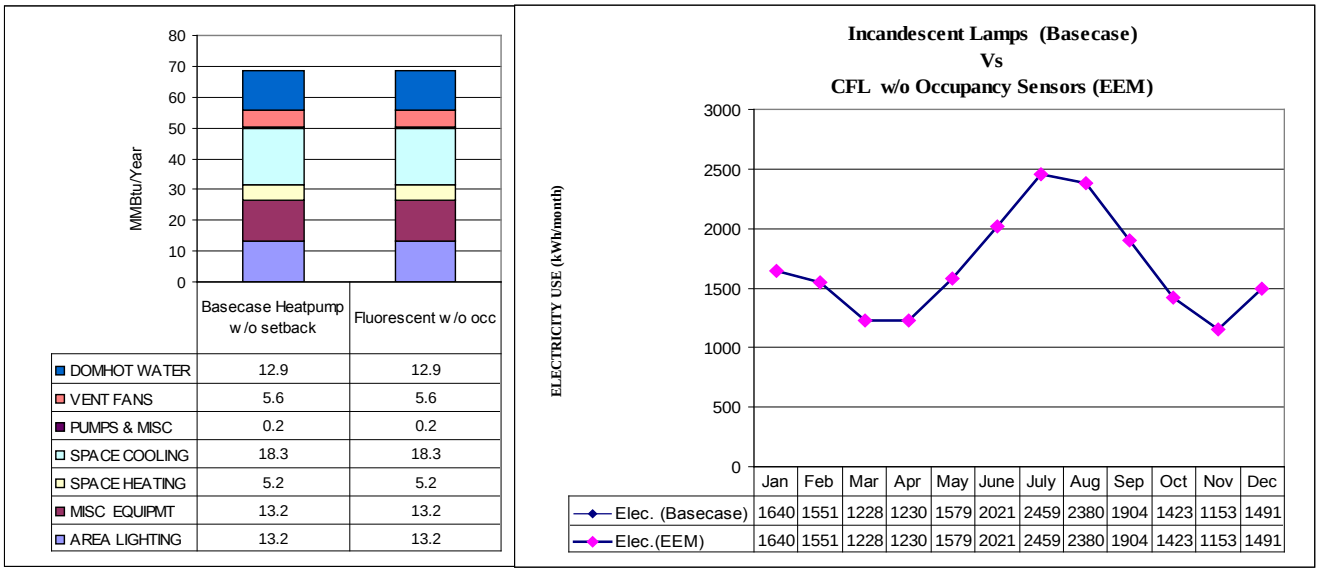


Figure 44: Monthly Energy consumption for the Base-case House With Heat Pump Heating (w/o setback) and EEM (CFL Lamps w/o Occupancy Sensors)



9.5.5 Exterior Lighting: Fluorescent Lamps with Occupancy Sensors

Base case: 100% incandescent fixtures are assumed for the base case house without occupancy sensors.

Test case: For test case fluorescent lamps were used with occupancy sensors.

Implementation Cost: Since this measure was not considered in any of the group measures, the costs associated with implementing this measure are not included.

Figure 45: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (CFL Lamps w/ Occupancy Sensors)

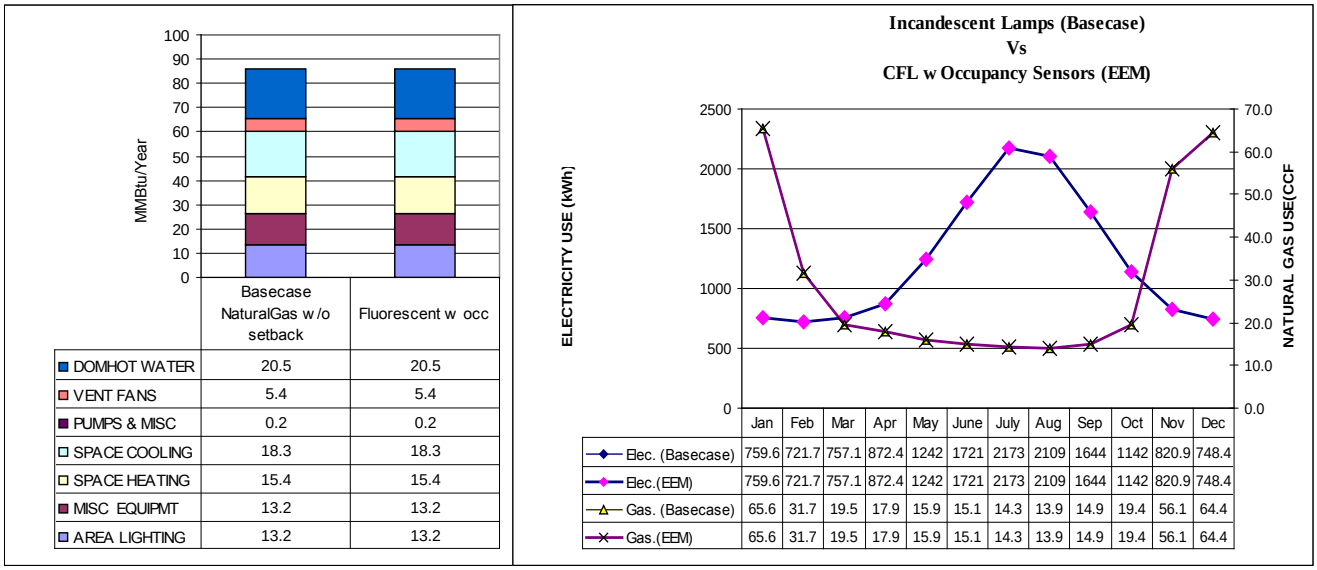
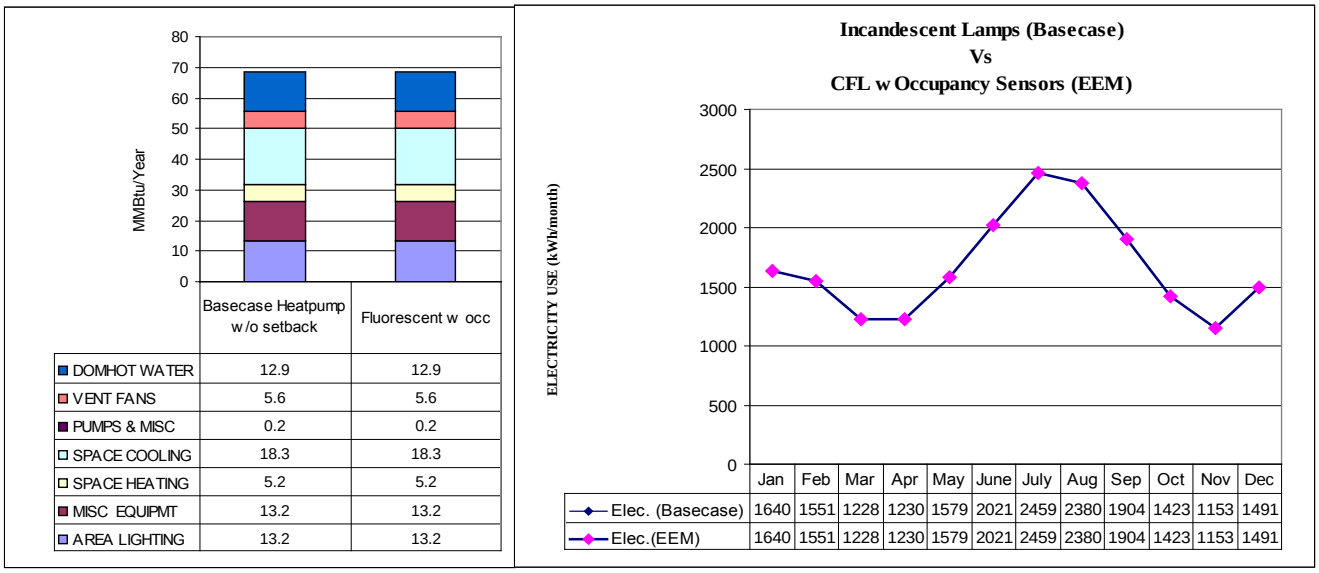


Figure 46: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (CFL Lamps w/o Occupancy Sensors)



9.6: DHW Measures

9.6.1 Tankless Gas Water Heater

Base case: A storage tank type DHW heater is simulated for the base case house. For the house with the natural gas heating the DHW energy factor is set at 0.54 and electric/heat pump house the DHW energy factor is set at 0.86. Energy factor ratings incorporate the energy usage of the pilot light in the gas DHW heater.

Test case: For a house with natural gas heating, the resultant change in the DHW Energy Factor (EF) from 0.54 to 0.748[15]. For a house with heat pump heating, this measure was simulated by increasing the DHW energy factor from 0.86 to 0.95.

Implementation Cost: The cost information for this measure is obtained using the sources listed in Appendix A-1 and is summarized in the following table. It shows that in an electric/gas house, installing a tankless gas water heater would increase the cost by $1,000-$3,500. Installing a tankless electric water heater in an all-electric house would increase the cost only by $700 to $1,400.

Table 34: Cost Information for Tankless Water Heating Systems

DHW System Measures		Capacity	Equipment Cost ($)	Installation Cost ($)	Total Increased Cost ($)	Reference Table (Appendix A-1)
NATURAL GAS HEATING/NATURAL GAS DHW SYSTEM						
Base Case	Tank type: Gas Water Heater w/ pilot light	40/50 Gallon	$310-$410 (Avg: $360)	$240		Table Water Heater-1 - No. 7,8,9,10. Water Heater-2 - No. 3,5.
Test Case	Tankless Gas Water Heater w/o pilot light	7.4 GPM	$930-$1,460	$720-$1,200	$1,000-$3,500*	Table Water Heater-1 - No. 1,2,3,4,5,6.
HEAT PUMP/ELECTRIC DHW SYSTEM						
Base Case	Tank type: Elec. Water Heater	40/50 Gallon	$270-$385 (Avg: $330)	$240		Table Water Heater-1 - No. 17,18. Water Heater-2 - No. 2.
Test Case	Tankless Elec. Water Heater	3.5-4.5 GPM	$585-$750	$720-$1,200	$700-$1,400	Table Water Heater-1 - No. 19, 20, 21, 22.

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

Gas cost savings = 55 CCF/year x $1.2/CCF = $66/year
Total energy cost savings = $66
Implementation cost = $1,000-$3,500
Simple Payback = 15.15 to 53 years

Base Case House with Heat Pump Heating With Setback

Electricity cost savings = 352 kWh/year x 0.16/kWh = $56/year
Total energy cost savings = $56
Implementation cost = $700-$1,400

[15] The EF for the tankless water heater is based on a survey of manufacturers and recommendations of the 2008 California Building Energy Efficiency Standards.

Simple Payback = 12.5 to 25 years

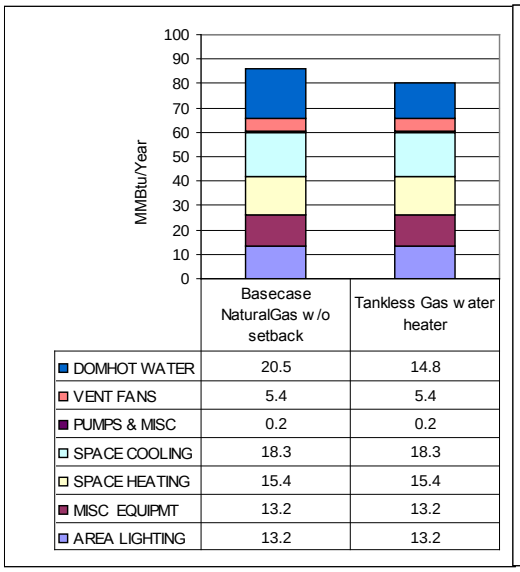
Base Case House with Natural Gas Heating Without Setback

Gas cost savings = 55 CCF/year x $1.2/CCF = $66/year
Total energy cost savings = $66
Implementation cost = $1,000-$3,500
Simple Payback = 15.15 to 53 years

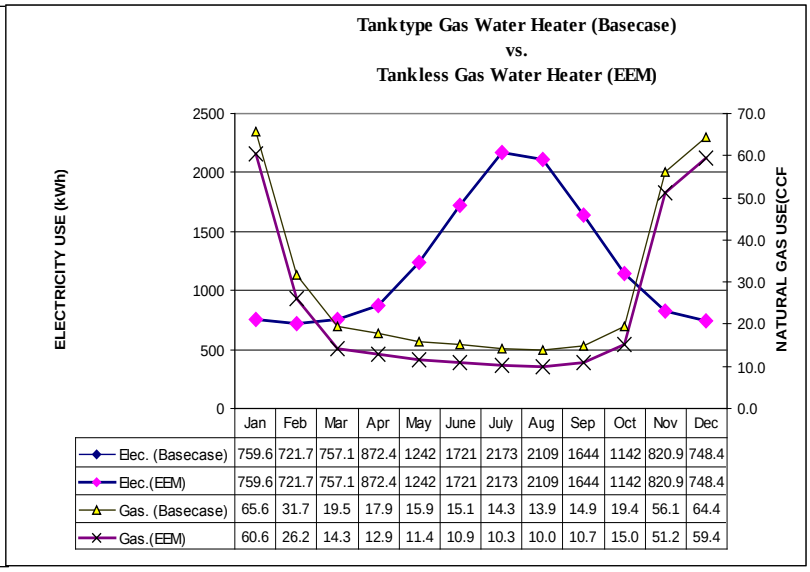
Base Case House with Heat Pump Heating Without Setback

Electricity cost savings = 352 kWh/year x 0.16/kWh = $56/year
Total energy cost savings = $56
Implementation cost = $700-$1,400
Simple Payback = 12.5 to 25 years

Figure 47: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Tankless Gas Water Heater)

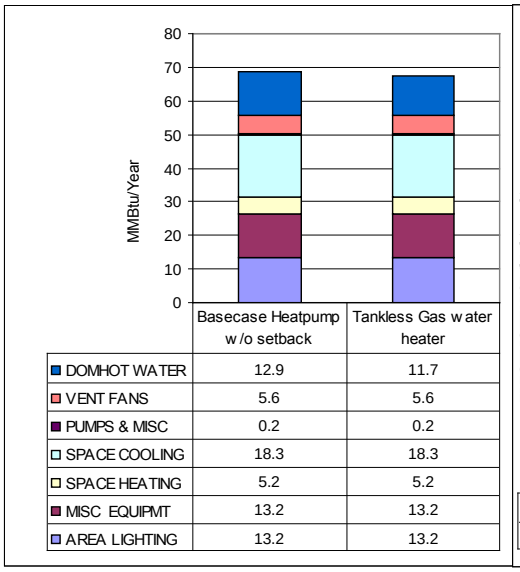


	Basecase NaturalGas w/o setback	Tankless Gas water heater
DOMHOT WATER	20.5	14.8
VENT FANS	5.4	5.4
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	18.3
SPACE HEATING	15.4	15.4
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2

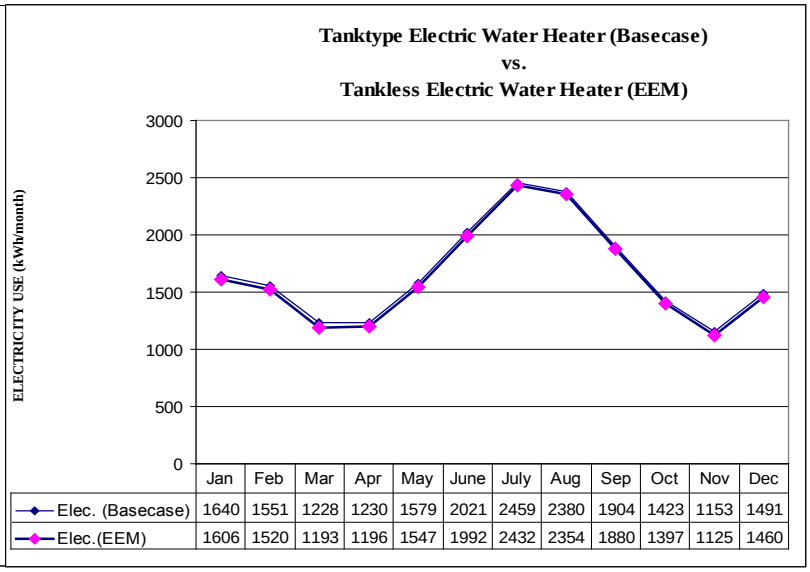


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Elec.(EEM)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Gas. (Basecase)	65.6	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.4	56.1	64.4
Gas.(EEM)	60.6	26.2	14.3	12.9	11.4	10.9	10.3	10.0	10.7	15.0	51.2	59.4

Figure 48: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Tankless Electric Water Heater)



	Basecase Heatpump w/o setback	Tankless Gas water heater
DOMHOT WATER	12.9	11.7
VENT FANS	5.6	5.6
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	18.3
SPACE HEATING	5.2	5.2
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491
Elec.(EEM)	1606	1520	1193	1196	1547	1992	2432	2354	1880	1397	1125	1460

9.6.2 Removal of Pilot Light

Base Case: For house with natural gas heating, the base case domestic hot water (DHW) system is a 40-gallon, storage type with a standing pilot light that consumes 500 Btu/hr and a calculated energy factor (EF) of 0.54.

Test case: This measure is applicable only for house with natural gas heating that has a gas DHW heater. In order to simulate the impact of removing the pilot light, a higher EF of 0.5716 is chosen.

Implementation Cost: The cost information for this measure is obtained using the sources listed in Appendix A-1, and is summarized in the following table. It shows that replacing a gas water heater with a standing pilot light with a gas water heater without a standing pilot light would increase the cost by $200 to $600.

Table 35: Cost Information for Water Heaters Without a Pilot Light

DHW System Measures		Capacity	Equipment Cost ($)	Installation Cost ($)	Total Increased Cost ($)	Reference Table (Appendix A-1)
NATURAL GAS HEATING/NATURAL GAS DHW SYSTEM						
Base Case	Tank type: Gas Water Heater w/ pilot light	40/50 Gallon	$310-$410 (Avg: $360)	$240		Table Water Heater-1 - No. 7, 8, 9, 10 Water Heater-2 - No. 3, 5
Test Case	Tank type: Gas Water Heater w/o pilot light	40 Gallon	$565-$985	$240	$200-$600	Table Water Heater-1 - No. 11, 12, 15, 16

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

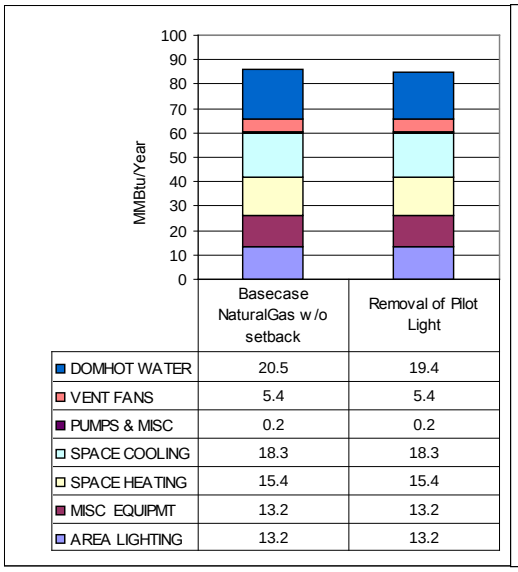
Gas cost savings = 11 CCF/year x $1.2/CCF = $13/year
Total energy cost savings = $13
Implementation cost = $200-$600
Simple Payback = 15.38 to 46.15 years

Base Case House with Natural Gas Heating Without Setback

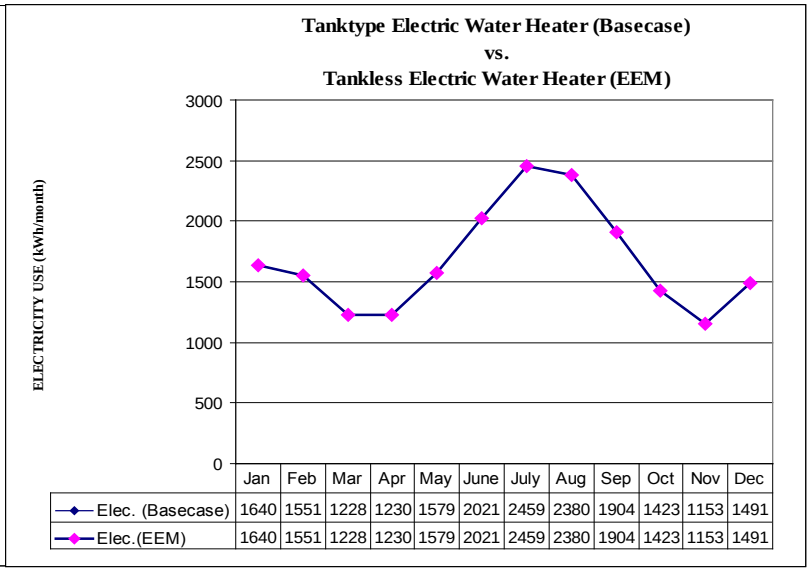
Gas cost savings = 11 CCF/year x $1.2/CCF = $13/year
Total energy cost savings = $13
Implementation cost = $200-$600
Simple Payback = 15.38 to 46.15 years

[16] The EF for the water heater without pilot light is based on a survey of manufacturers.

Figure 49: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Removal of Pilot Light)

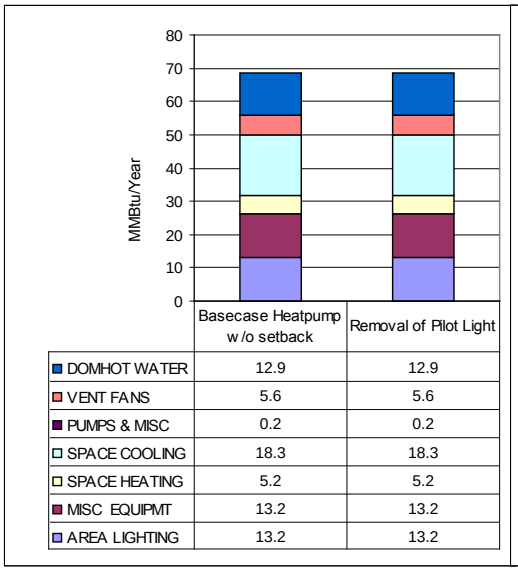


	Basecase NaturalGas w/o setback	Removal of Pilot Light
DOMHOT WATER	20.5	19.4
VENT FANS	5.4	5.4
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	18.3
SPACE HEATING	15.4	15.4
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2

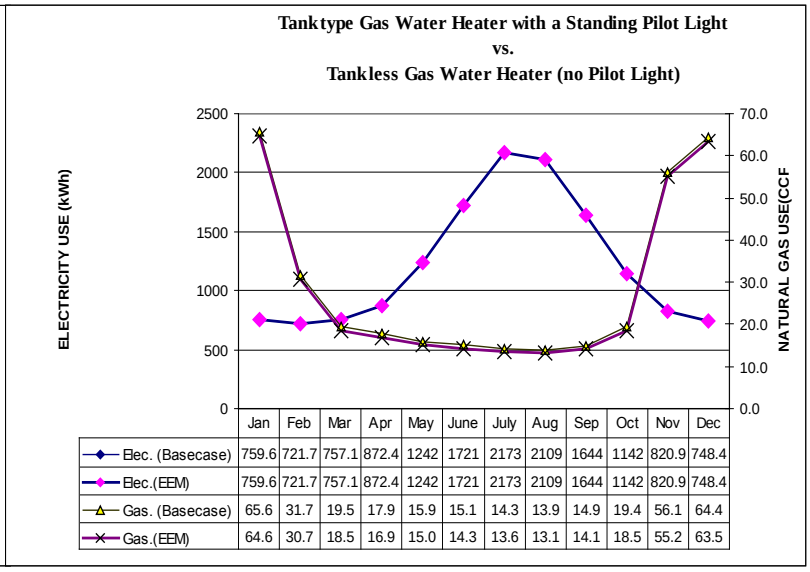


	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491
Elec.(EEM)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491

Figure 50: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (No Pilot Light)



	Basecase Heatpump w/o setback	Removal of Pilot Light
DOMHOT WATER	12.9	12.9
VENT FANS	5.6	5.6
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	18.3
SPACE HEATING	5.2	5.2
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Elec. (Basecase)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Elec.(EEM)	759.6	721.7	757.1	872.4	1242	1721	2173	2109	1644	1142	820.9	748.4
Gas. (Basecase)	65.6	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.4	56.1	64.4
Gas.(EEM)	64.6	30.7	18.5	16.9	15.0	14.3	13.6	13.1	14.1	18.5	55.2	63.5

9.6.3 Solar Domestic Water Heating System

Base Case: For a house with natural gas heating, the base case domestic hot water (DHW) system is a 40-gallon, storage type with a standing pilot light that consumes 500 Btu/hr and has a calculated energy factor (EF) of 0.54. For a house with heat pump heating, the base case DHW system is a 50-gallon, storage type electric water heater. The energy factor (EF) of the system is 0.86. The daily hot water use was calculated as 70 gallons/day, which assumes that the house has four bedrooms. The hot water supply temperature is 120°F.

The method to simulate DHW in DOE-2.1e while using the energy factor is based on Building America House Performance Analysis Procedures (NREL 2001) which assumes a constant hourly DHW use and eliminates the efficiency dependence on part-loads.

Test case: For this measure, a solar thermal DHW system, comprised of two 32 sq. ft. of flat plate solar collectors was simulated 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, considering a hot water use of 70 gallons/day, year-round. Table 36 lists the characteristics of the solar thermal system for Houston. In this analysis, 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 pump.

Table 36: Solar DHW System Characteristics

Number of collector panels	2
Collector panel area	32 sq. ft.
Collector slope	30 deg.
Collector azimuth (South=0)	0 deg.
Number of glazings	1
Collector flow rate/area	11 lb/hr-sq. ft.
Water set temperature	120 deg. F
Daily hot water usage	70 gal.

Implementation Cost: The cost information for this measure is obtained using the sources listed in Appendix A-1, and is summarized in the following table. It shows that installing a solar DHW system would increase the cost by $2,900 to $5,200.

Table 37: Cost Information for Solar Domestic Hot Water Systems

DHW System Measures		Capacity	Equipment Cost ($)	Installation Cost ($)	Total Increased Cost ($)	Reference Table (Appendix A-1)
NATURAL GAS HEATING/NATURAL GAS DHW SYSTEM						
Base Case	Tank type: Gas Water Heater w/ pilot light	40/50 Gallon	$310-$410 (Avg: $360)	$240		Table Water Heater-1 - No. 7, 8, 9, 10 Water Heater-2 - No. 3, 5.
Test Case	Solar Water Heater	80 Gallon	$3,300	$2,500	$2,900-$5,200*	Table Solar Water Heater - No. 1, 2, 3
HEAT PUMP/ELECTRIC DHW SYSTEM						
Base Case	Tank type: Elec. Water Heater	40/50 Gallon	$270-$385 (Avg: $330)	$240		Table Water Heater-1 - No. 17, 18 Water Heater-2 - No. 2.
Test Case	Solar Water Heater	80 Gallon	$3,300	$2,500	$2,900-$5,200*	Table Solar Water Heater - No. 1, 2, 3

Payback Calculation:

Base Case House with Natural Gas Heating With Setback

Electricity cost savings	= -430 kWh/year x 0.16/kWh = -$69/year
Gas cost savings	= 170 CCF/year x $1.2/CCF = $205/year
Total energy cost savings	= $136
Implementation cost	= $2,900-$5,200
Simple Payback	= 21.32 to 38.23 years

Base Case House with Heat Pump Heating With Setback

Electricity cost savings	= 2,808 kWh/year x 0.16/kWh = $449/year
Total energy cost savings	= $449
Implementation cost	= $2,900-$5,200
Simple Payback	= 6.46 to 11.58 years

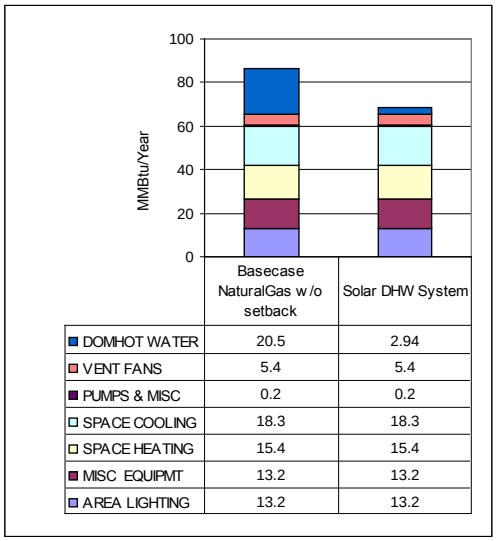
Base Case House with Natural Gas Heating Without Setback

Electricity cost savings	= -430 kWh/year x 0.16/kWh = -$69/year
Gas cost savings	= 170 CCF/year x $1.2/CCF = $205/year
Total energy cost savings	= $136
Implementation cost	= $2,900-$5,200
Simple Payback	= 21.32 to 38.23 years

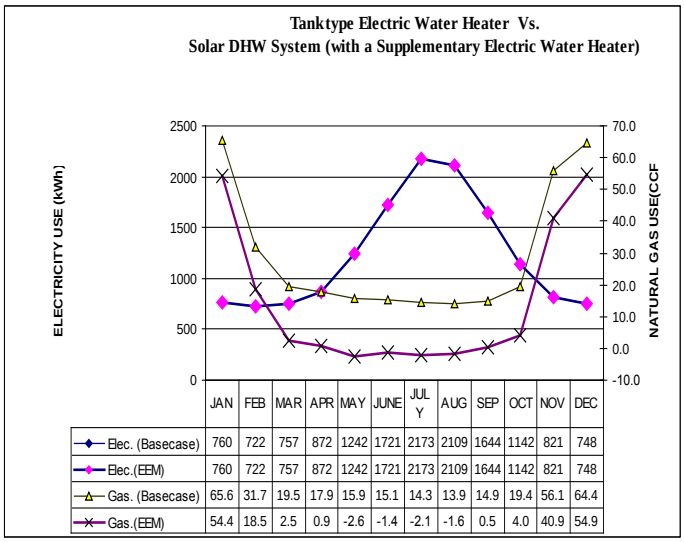
Base Case House with Heat Pump Heating Without Setback

Electricity cost savings	= 2,808 kWh/year x 0.16/kWh = $449/year
Total energy cost savings	= $449
Implementation cost	= $2,900-$5,200
Simple Payback	= 6.46 to 11.58 years

Figure 51: Monthly Energy Consumption for the Base Case House With Natural Gas Heating (w/o setback) and EEM (Solar DHW System)

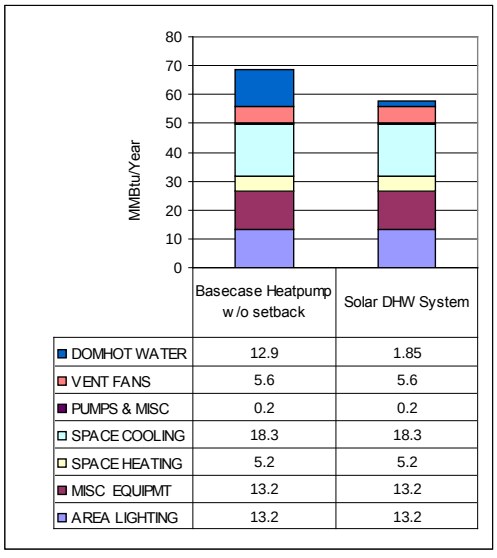


	Basecase NaturalGas w/o setback	Solar DHW System
DOMHOT WATER	20.5	2.94
VENT FANS	5.4	5.4
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	18.3
SPACE HEATING	15.4	15.4
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2

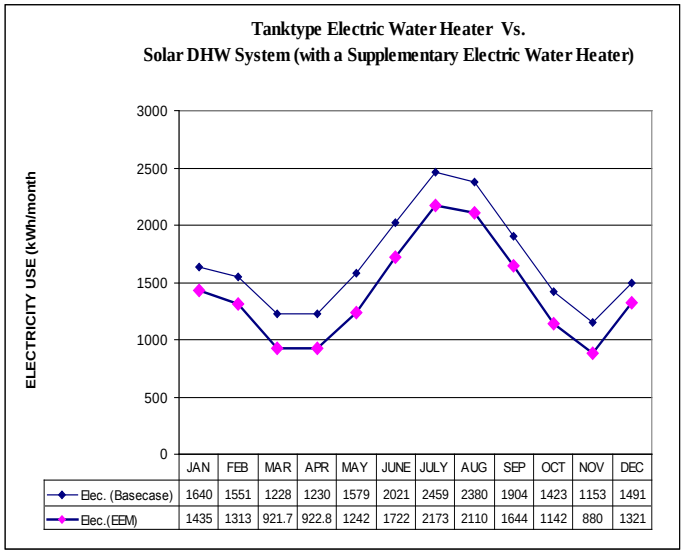


	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Elec. (Basecase)	760	722	757	872	1242	1721	2173	2109	1644	1142	821	748
Elec.(EEM)	760	722	757	872	1242	1721	2173	2109	1644	1142	821	748
Gas. (Basecase)	65.6	31.7	19.5	17.9	15.9	15.1	14.3	13.9	14.9	19.4	56.1	64.4
Gas.(EEM)	54.4	18.5	2.5	0.9	-2.6	-1.4	-2.1	-1.6	0.5	4.0	40.9	54.9

Figure 52: Monthly Energy Consumption for the Base Case House With Heat Pump Heating (w/o setback) and EEM (Solar DHW System)



	Basecase Heatpump w/o setback	Solar DHW System
DOMHOT WATER	12.9	1.85
VENT FANS	5.6	5.6
PUMPS & MISC	0.2	0.2
SPACE COOLING	18.3	18.3
SPACE HEATING	5.2	5.2
MISC EQUIPMT	13.2	13.2
AREA LIGHTING	13.2	13.2



	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Elec. (Basecase)	1640	1551	1228	1230	1579	2021	2459	2380	1904	1423	1153	1491
Elec.(EEM)	1435	1313	921.7	922.8	1242	1722	2173	2110	1644	1142	880	1321

10. Comparison of Houston Amendment Analysis Results with 15% Above Code Analysis for Residential Buildings

There is a difference when comparing savings obtained from the 15% above code energy analysis, conducted by the Energy Systems Laboratory for residential houses across the State of Texas, (Malhotra 2007) and the savings presented in this study. This difference is caused by several factors:

- Input file versions: The version of the input file used to execute simulations for the Houston amendment analysis has been updated to include improved part-load curves for furnace and cooling equipment. Other improvements include re-organizing the window area input and improving the method for calculating air infiltration.
- Base case settings: Several measures, such as the reduction in the power consumed by the pilot light and increased duct leakage, have been incorporated in the base case settings.
- Energy efficiency measures: Several energy efficiency measures, such as decreasing the SHGC and U-values, have resulted in finding different savings from the two reports.

The percentage difference in savings obtained from the two studies and a detailed explanation of the difference for each measure is explained in Table 38 below.

EEM #	MEASURES	SAVINGS 15% ABOVE CODE	SAVINGS FROM IMPLEMENTATION OF HOUSTON AMENDMENTS	% INCREASE / DECREASE	COMMENTS
1	Tankless Gas Water Heater (without a Standard Pilot Light)	9.3	9.25	0.54	In the Houston Amendment analysis, the pilot light is removed from the base-case calculations for domestic hot water heaters.
2	Solar Domestic Hot Water System	15.2	19.84	-30.53	Different methods of calculation were used determine the savings from implementing the solar domestic water systems for the two analysis.
3	Removal of Pilot Light from Domestic Hot Water System	5.5	1.36	75.27	In the 15% above code analysis the energy consumption of the pilot light is taken to be 500 Btu/hr. In the Houston Amendment analysis the energy consumption of the pilot light is taken to be 100 Btu/hr.
4	Mechanical Systems within Conditioned Spaces	8.5	11.22	-32.00	For 15% above code analysis the duct leakage is taken as 20% - 10% supply & 10% return. In the Houston Amendment analysis the duct leakage is taken as is taken as 30% - 20% supply & 10% leakage.
5	Improved Duct Sealing	4.3	7.52	-74.88	For 15% above code analyis the duct leakage is reduced from 30% to 10%. For Houston Amendment analysis the duct leakage is reduced from 20% to 10%.
6	Reduced air infiltration	2.1	3.82	-81.90	In the Houston Amendment analysis, the method for calculating air infiltration was updated. This method is more sensitive than the method used for calculating infiltration in the 15% above code analysis.
7	Window shading	2.1	1.73	17.62	For the 15% above code analysis the sill height is set at 1ft above the ground. For the Houston Amendment Analysis the sill height (2ft or lower)changes with the window area input. The lintel height remains constant at 7ft.
8	Window shading and redistribution	3.6	3.08	14.44	
9	Decreased SHGC & U-value	2.6	3.95	-51.92	For 15% above code analysis the U & SHGC values are modified from U 0.47 to 0.42 & SHGC 0.4 to 0.33. For Houston Amendment analysis the U & SHGC values are modified from U 0.47 to 0.35 & SHGC 0.4 to 0.3.
10	Improved SEER from 13 to 15	2.7	4.19	-55.19	In Houston Amendment analysis higher efficiency specifications are considered for fans when modeling SEER AC units ≥ 15. Moreover, the default cooling partload curves in DOE-2 for the cooling equipment were changed to new partload curves curves as proposed by LBNL (Henderson et. al, 1999).
11	Improved Furnace Efficiency	1.9	2.59	-36.32	The default partload curves in DOE-2 for the furnace equipment were changed to new furnace partload curves as presented in an LBNL report (Henderson et.al, 1999).

Table 38: Comparison of Houston Amendment Analysis Results with 15% Above Code Analysis for Residential Buildings

11: References

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Malhotra, M. and J. Haberl. 2006. An Analysis of Maximum Residential Energy Efficiency in Hot and Humid Climates. Fifteenth Symposium on Improving Building Systems in Hot and Humid Climates. Orlando, FL.

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Parker, D., P. Fairey, and L. Gu. 1993. Simulation of the Effects of Duct Leakage and Heat Transfer on Residential Space Cooling Energy Use. *Energy and Buildings,* 20(2):97-113.

Appendix A

Cost Information

Appendix A-1: Estimated Costs for Individual Measures from the City of Houston Authorities

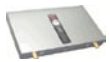
Individual Measures	Estimated Cost from the City of Houston
PV Array for 6kW	$7,500 per kW
PV Array for Partial Demand at 4kW	Recently: $28,000 for 3 ½ kW no battery
PV Array for Partial Demand at 2kW	same
Decreased Duct Static Pressure from 1.0 to .5 inch	Would go along with decreased duct leakage $200 (Maci)
Decreased Duct Leakage from 15% to 5% (6% Energy Star)	$350 for learning curve + test $150 - $300
Mechanical Systems within Conditioned Spaces	2 costs – redesign house plans (concerns about combustion in cond. Space – not priced) $750 - $1,250 (Brian) Includes - Duct changes, Attic wrap, Foam costs more Closets need to be insulated due to sound $2,000 - $10,000 (Maci, Mike) - higher with blown insulation
Improved SEER from 13 to 15	$500 – typical 5 ton unit ($400-$500 per half ton)
Improved Furnace Efficiency from .78 to .93	$900 for .92 (Mike said Lennox then jumps to .95)
Decreased SHGC .4 to .3 & U-value from .47 to .35	??? how many windows (Maci) $350 - $500 for vinyl
Window Shading and redistribution W/E = 16.27%, S=48.82%, N=27.12	Design costs only and unlikely except for custom homes on outskirts
Decreased Infiltration .462 to .35 ACH	$200 (training) Polyseal, taping
25% Energy Star CFL Indoor Lamps	$100 - Usually bedroom fixtures
50% Energy Star CFL Indoor Lamps	$500-$800 - Affects designer fixtures or can lights
Tankless Gas water heater .54 to .748 Energy Factor	$800 (Brian)
Solar DHW System 80 gal.	
TEST COSTS:	
Duct Blaster	$150 - $300 test
Static Pressure	$100
Blower Door	$150 - $300
Combo duct blaster and blower door	$150 high volume - $300

Appendix A-2: Cost of DHW Systems

Water Heater -1

Item	No.	Price	Brand	Type of Fuel	Model	Energy Factor	Capacity	Description	Pictures	Source	Contact Person
Tankless Gas Water Heater	1	$999.00	Paloma	Natural Gas	Model PTG-74PVN	0.82	7.4 GPM	Whole Home 7.4 GPM Natural Gas Tankless Water Heater With Remote Control; Electronic iginition; Supplies hot water for 2 to 3 applications; 199,900 BTU burner.		http://www.homedepot.com/ (Date: 05/09/2006)	Internet Price
	2	$949.00	Bosch AquaStar	Natural Gas	Model 250SX-NG	0.85	6.4 GPM	Whole House Gas Tankless Water Heater; Electronic iginition; Supplies hot water for 2 applications.		http://www.homedepot.com/ (Date: 05/09/2006)	Internet Price
	3	$929.00	Rheem	Natural Gas	RTG-74PVN	0.82	7.4 GPM	Rheem Tankless 7.4 GPM- Indoor Tankless Water Heater- 7.4 Gallon; 19000-199,900 btuh.		http://www.hmwallace.com/index.asp?PageAction=VIEWPROD&ProdID=2016 (Date: 05/15/2006)	Internet Price
	4	$1,397.00	Takagi	Natural Gas	T-KD20	0.84 (85% thermal efficiency)	6.9 GPM	First hour rating: 240 GPH. Min 20,000 Btu Max 185,000 Btu. Outlet Temp: 95-180°F. No pilot light. (Qualify for $300 TAX credit)		http://www.tanklesswaterheaters.com/takagitk1.html; http://www.designerplumbing.com	Retail Price
	5	$1457/$1401	Takagi	Natural Gas	T-K1S/T-K2	85% thermal efficiency	6.9 GPM	First hour rating: 240 GPH. Min 20,000 Btu Max 190,000 Btu. Outlet Temp: 95-180°F. Electronic ignition. No pilot light. (Qualify for $300 TAX credit)		http://www.tanklesswaterheaters.com/takagitk1.html; http://www.designerplumbing.com	Retail Price
	6	$2,297.00	Takagi	Natural Gas	T-M1	0.81 (82.4% thermal efficiency)	9.6 GPM	First hour rating: 300 GPH. Min 25,000 Btu Max 235,000 Btu. Outlet Temp: 95-180°F. Electronic ignition. No pilot light. (Qualify for $300 TAX credit)		http://www.tanklesswaterheaters.com/takagitk1.html; http://www.designerplumbing.com	Retail Price
Tank-type Gas Water Heater with Pilot light	7	$377.99($409.99)	Kenmore	Natural Gas	#33926(#33916)		40(50) Gallon	Kenmore Power Miser 9, 40(50) gal. Gas Water Heater; Hourly input -40,000 BTU.		http://www.sears.com/ (Date: 05/09/2006)	
	8	$215.95($232.50)	State	Natural Gas	GS6 40YBRT	0.60 (0.58)	40 (50) Gallon	Select® Standard Vent Gas Water Heaters; Feature C3 Technology™ that protects against accidental ignition of flammable vapors like those from gasoline; Green Choice™ gas burner produces 33% lower NOx emissions than standard burners		http://www.statewaterheaters.com/lit/media/spec/res-gas/SSG43-4.pdf (Date: 05/11/2006)	CITY SUPPLY COMPANY, INC. HOUSTON, TX 77003 B: 713-224-1643
	9	$325.00	Rheem	Natural Gas	22V40F	0.6	40 Gallon	Guardian Fury® Gas Water Heaters.		http://www.rheem.com/consumer/catalogRes_detail.asp?id=76 (Date: 05/15/2006)	HUGHES 541 GRAHAM ROAD COLLEGE STATION, TX 77845 Phone: (979) 690-7636 Fax: (979) 690-7821 Communication with Barney on 05/15/2006.
	10	$310.00	A.O. Smith	Natural Gas	GCV50	0.58	50 Gallon	ProMax gas water heaters. Hourly input: 40000Btu/h.		http://www.hotwater.com/lit/spec/media/res_gas/ARG-SS002-0405N.pdf (Date: 5/17/2006)	Valley Supply, College Station, TX (979) 779-7042 (979) 823-5522 (FAX) Communication with John on 5/17/2006

Appendix A-2: Cost of DHW Systems (cont.)

Tank-type Gas Water Heater with Electronic Ignition	11	$757.50	State	Natural Gas	PR6 40 XCVIT	0.61	40 Gallon	Select ®Power-Vent residenital gas water heater; hourly input-40000Btu; Equipped with nearly-indestructible silicon nitride hot surface igniter.		http://www.stateind.com/lit/media/spec/res-gas/SPVG6-1-4.pdf (Date: 05/10/2006)	STATE Water Heaters 1-800-365-0024 ACT PIPE & SUPPLY, INC. 6900 WEST SAM HOUSTON PARKWAY NORTH HOUSTON, TX 77041 B: 713-937-0600 713-933-0426 (Eckhard)
	12	$817.50	State	Natural Gas	PR6 40 XBPDT	0.59(0.58)	40 Gallon	Select ®Power Direct-Vent residenital gas water heater; hourly input-40000Btu; Equipped with nearly-indestructible silicon nitride hot surface igniter.		http://www.stateind.com/lit/media/spec/res-gas/SPDVG5-1-4.pdf (Date: 5/10/2006)	
	13	$585.00	Rheem	Natural Gas	42VRP40	0.64	40 Gallon	PowerVent High Efficiency, Induced Draft Gas Water Heater; Electronic ignition system		http://www.rheem.com/consumer/catalogRes_detail.asp?id=68 (Date: 5/15/2006)	HUGHES 541 GRAHAM ROAD COLLEGE STATION, TX 77845 Phone: (979) 690-7636 Fax: (979) 690-7821 Communication with Barney on 05/15/2006.
	14	$565.00	Ruud	Natural Gas	PVP40F	0.62	40 Gallon	PowerVent Induced Draft Gas Water Heater with the Guardian System™; Electronic ignition system		http://www.rheem.com/consumer/catalogRes_detail.asp?id=68&brand=Ruud (Date: 5/15/2006)	
	15	$985.00	A.O. Smith	Natural Gas	GPDH-50/GPDT-50	0.58	50 Gallon	Power House® Sealed Shot Power Direct-Vent Gas Water Heaters; horizontal and vertical venting options up to 45 feet; Advanced Intelli-Vent gas control valve with rugged silicon nitride hot surface igniter; Closed-combustion, two-pipe system draws clean combustion air from outside, vents outside the home; Environmentally friendly Green Choice™ gas burner reduces NOx emissions by 33% compared to standard burners; Hourly input: 40000/65000Btu/h.		http://www.hotwater.com/lit/spec/media/res_gas/A7521.pdf (Date: 5/17/2006)	Valley Supply, College Station, TX (979) 779-7042 (979) 823-5522 (FAX) Communication with John on 5/17/2006
	16	$1,200.00	A.O. Smith	Natural Gas	GPHE-50	90% Thermal Efficiency	50 Gallon	Vertex™ Power-Vent Gas Water Heaters; Money-saving 90% thermal efficiency; Endless hot water means homeowners will always get "one more hot shower"; Hot water output similar to larger, less efficient 75-gallon unit; Equipped with nearly indestructible silicon nitride hot surface ignitor – no standing pilot; Hourly input: 76000 Btu/h.		http://www.hotwater.com/lit/spec/media/res_gas/ARGSS01306.pdf (Date: 5/17/2006)	David Cunningham Hugh M. Cunningham 137555 Benchmark Dallas , TX 75234 B/ 972-888-3808 F/ 972-888-3838 Communication on 5/17/2006
Tank-type Electric Water Heater	17	$269.99($299.99)	Kenmore	Electric	#32946(#32154)		40(50) Gallon	Kenmore Power Miser 9(12), 40(50) gallon Electric Water Heater; Kilowatt Hrs. per Year- 4721(4622).		http://www.sears.com/ (Date: 05/09/2006)	
	18	$188.00		Electric			55 Gallon			http://www.toolbase.org/ToolbaseResources/level4TechInv.aspx?ContentDetailID=599&BucketID=6&CategoryID=9	TOOLBASE Techspecs, by the NAHB Research Center for the Partnership for Advancing Technology in Housing (PATH).
Tankless Electric Water Heater	19	$585.00		Electric			Whole House			http://www.toolbase.org/ToolbaseResources/level4TechInv.aspx?ContentDetailID=599&BucketID=6&CategoryID=9	TOOLBASE Techspecs, by the NAHB Research Center for the Partnership for Advancing Technology in Housing (PATH).
	20	$750/$775	Stiebel Eltron	Electric	Tempra 29/36		4.5 GPM	Single phase 150 amp residential electric water heater.		http://www.tanklesswaterheaters.com/stiebeleltron.html	Retail Price
	21	$749.00	EEMAX	Electric	Series Three	99% Efficiency	4.0 GPM	EEMAX Series Three Residential Heater Single phase 150 amp residential electric water heater.		http://www.tanklesswaterheaters.com/eemaxheaters.html	Retail Price
	22	$596.00	PowerStar	Electric	AE125	0.95	3.5 GPM	PowerStar AE125 Electric Whole House Tankless; Provides up to 3.5 gallons per minute(50 degree temp rise) for water usage at 105° F: 2 sinks or 1 shower.		http://www.tanklesswater.com/ (Date: 05/09/2006)	

Appendix A-2: Cost of DHW Systems (cont.)

Water Heater -2

Item	No.	Price	Fuel Type	Desciption	Installation Cost	Energy Savings	Life	Source	Contact Person
Tankless Water Heater	1	$200-$1500	Gas/Electric	From $200 for small electric undersink unit to over $1500 for high capacity gas fired unit	2-4 Times higher than the tank type.	Electric tankless water heaters cost 10-20% less to operate than comparable tank-type heaters. Gas savings may be about 20-40%.	Tankless: 20 years Tanktype: 10-15 years	http://www.toolbase.org/TechInventory/TechDetails.aspx?ContentDetailID=979&BucketID=6&CategoryID=13	
Tankless Water Heater	2				3 times the tank-type.	Installation cost for tank type is about $240 (3 hours). The installation cost for tankless water heater is about $640-1200 (8 to 15 hours).			All State Plumbing (979-268-4300)
Tank-Type Water Heater	3	$383.00	Gas	Average Price		Energy Consumption: 234 Therms/year	9 years	10 CFR Part 430, Energy Conservation Program for Consumer Products: Energy Conservation Standards for Water Heaters; Final Rule. Federal Register: Part III, Department of Energy, Office of Energy Efficiency and Renewable Energy.	
Tank-Type Water Heater	4	$380.00	Electric	Average Price		Energy Consumption: 3,459 kWh/year	14 years		
Tank-Type Water Heater	5	$501.00	Gas	Average Price for New Water Heater after the 2004 water heater standards take effect		Compare to item 2, estimated price increase (efficiency only) is $58. Annual utillity bill savings is $12.74. Simple payback is 3.6 year. Average net savings over appliance life is $30. Energy savings per year is 22 therms.	9 years		
Tank-Type Water Heater	6	$486.00	Electric	Average Price for New Water Heater after the 2004 water heater standards take effect		Compare to item 3, estimated price increase (efficiency only) is $101. Annual utillity bill savings is $13.05. Simple payback is 7.4 year. Average net savings over appliance life is $23. Energy savings per year is 188 kWh.	14 years		

Water Heater -3

Item	No.	Price	Brand	Type of Fuel	Model	Energy Factor	Capacity	Description	Pictures	Source	Contact Person
Heat Pump Water Heater	1	$600-$2000 for the HPWH, $300-700 for installation		Electric						Federal Technology Alert, US Department of Energy, 1995	
	2	$1,425.00	DEC-Therma-Stor	Electric	HP-80	2.5	First hour rating: 62 gallons.	Ambient Air HPWH. Tank size: 80 Gallon. Water heating capacity: 10600 Btu/hr. Cooling Capacity: 7500 Btu/hr. Electrical Power Input: 0.8 kW.		Federal Technology Alert, US Department of Energy, 1995	
	3	$1,748.00	DEC-Therma-Stor	Electric	HP-120-18-30	2.5	First hour rating: 99 gallons.	Ambient Air HPWH. Tank size: 120 Gallon. Water heating capacity: 10600 Btu/hr. Cooling Capacity: 7700 Btu/hr. Electrical Power Input: 6.8 kW.		Federal Technology Alert, US Department of Energy, 1995	
	4	$2,082.00	DEC-Therma-Vent	Electric	HP-VAC-80	2.1	First hour rating: 70 gallons.	Exhaust Air HPWH. Tank size: 80 Gallon. Water heating capacity: 8300 Btu/hr. Cooling Capacity: 7000 Btu/hr. Electrical Power Input: 1.2 kW.		Federal Technology Alert, US Department of Energy, 1995	
	5	$2,229.00	DEC-Therma-Vent	Electric	HP-VAC-120	2.2	First hour rating: 103 gallons.	Exhaust Air HPWH. Tank size: 120 Gallon. Water heating capacity: 8300 Btu/hr. Cooling Capacity: 7000 Btu/hr. Electrical Power Input: 1.1 kW.		Federal Technology Alert, US Department of Energy, 1995	
	6	$1521 ($175 for installation)	DEC-Therma-Vent	Electric	VHP-80	2.5	First hour rating: 64 gallons.	Exhaust Air HPWH. Tank size: 80 Gallon. Water heating capacity: 7100 Btu/hr. Cooling Capacity: 6000 Btu/hr. Electrical Power Input: 3.3 kW.		Federal Technology Alert, US Department of Energy, 1995	

Appendix A-3: Cost of Air Distribution System Measures

Duct-2

Improved Duct Sealing:

No.	Description	Material Cost ($/ft2)	Labor Cost ($/ft)	Conditioned Floor Area (ft2)	Supply Duct Area (ft2)	Return Duct Area (ft2)	Total Material Cost ($)	Total Labor Cost ($)	Total Cost ($)	Sources
1	Using metal foil backed buty1 tape and mastic to seal duct leaks.	$0.15	$0.45	2325	628	116	$111.60	$334.80	**$446.40**	http://epb.lbl.gov/Publications/lbl-38537.pdf
2	Repairing the duct system								**$200.00**	Cummings, J.B., J.J. Tooley Jr., M. Moyer, and R. Dunsmore. 1990. "Impacts of Duct Leakage on Infiltration Rates, Space Conditioning Energy Use, and Peak Electrical Demand in Florida Homes". Proc. ACEEE Summer Study 1994. 9:65-76.

Duct-3

Duct in Conditioned Space

No.	Description	Conditioned Floor Area (ft2)	HVAC Material *	HVAC Labor	Incremental Framing Cost ($)	Incremental Drywall Cost ($)	Total Increased Construction Cost ($)	Sources
1	Side-by-side comparison of two identical single-story homes where ductwork was installed after drywall was complete using a bulkhead dropped down from the ceiling,which ran along the long axis of the house; Supply branches, perpendicular to the supply line, were fitted with high-throw diffusers placed at room interior walls						**$230.00**	http://www.toolbase.org/pdf/techinv/ductsinconditionedspace_techspec.pdf
2	Duct in Unconditioned Space		$252.00	$103.00				http://www.toolbase.org/pdf/techinv/ductsinconditionedspace_techspec.pdf
	Duct in Conditioned Space		$201.00	$100.00	$50.00	$282.00	**$278.00**	
3	In the affordable home with simple floor plan, ducts were created with trunk line spanning length of home in constructed bulkhead along first-floor ceiling; Registers off the trunk line serve both floors. A central return was provided at the landing of an open stairway	2325	Increased cost: $0.2 per ft2				**$465.00**	http://www.toolbase.org/pdf/techinv/ductsinconditionedspace_techspec.pdf

*Material cost savings include shorter duct runs and smaller diameter duct line.

Appendix A-4: Cost of Envelope and Fenestration Measures

Increased Air-tightness

No.	Method for increasing air-tightness	Unit cost ($/windows or Door)	# of Windows	# of Doors	Total Cost - weather strip ($)	Blower Door Test	Total Cost ($/house)	Source
1	Weather Strip - Window	0.5 ~ 12 (Windows)	27	-	$14-$324	-	$350-$1000	http://www.mme.state.va.us/de/hbchap4.html
	Weather Strip - Window	$4.6 ~ $8 (Material Only)	27	-	$124.2 - $216	-		Lowes 3225 FREEDOM BLVD. BRYAN, TX 77802 (979) 774-4141
	Weather Strip - Window	$20 (Material $15 + Labor $5)	27	-	$540	-		Enercon Manufacturing (Mr. Oscar Beard) 1312 W Villa Maria Rd. Bryan, TX. 77801
	Weather Strip - Door	8~15 (Door)	-	3	$24-$45	-		http://www.mme.state.va.us/de/hbchap4.html
	Blower door test	-	-	-	-	$200-$500		http://www.powerhousetv.com/stellent2/groups/public/documents/pub/phtv_se_we_gs_000530.hcsp
2	Air sealing package (Blower door test included)	-	-	-	-	-	$500 - $1000	http://www.nbnnews.com/NBN/issues/2006-03-06/Research/index.html

Windows-Summary

	No.	Description	Total Conditioned Floor Area (ft2)	Total Windows Area (ft2)	Number of Windows (36"X60")	Unit Cost ($)	Total Cost ($)	Increased Cost ($)	Source
Builders' Cost	1	Thermflect/Argon, Low-Conductance Spacer, Double Pane	2325	418	27	$170.00	$4,590.00	$2,000	Builder's Cost: CertainTeed http://www.certainteed.com, Table Windows-2, No.1
	2	Air Filled, Double Pane, Aluminum Frame	2325	418	27	$96.00	$2,592.00		Builder' Cost: Atrium Companies, Inc, HR Windows® (Average of No.2 and No. 3 in Table Windows-1).
Lowe's	3	Argon Filled Glazing and Vinyl Frame	2325	418	27	$210.00	$5,670.00	$2,700	Lowe's: Pella - ThermaStar, Table Windows-2, No.5
	4	Air Filled, Double Pane, Aluminum Frame	2325	418	27	$112.00	$3,024.00		Lowe's: MI Windows and Doors- BetterBilt, Table Windows-2, No.2.

Appendix A-4: Cost of Envelope and Fenestration Measures (cont.)

Windows-1

No.	Glazing Type	Frame	Window Style	Window Size	Total Unit U Value	Center of Glass U-Value	Solar Heat Gain Coefficient (SHGC)	Daylight Trans-mittance	Price ($)	Manufacturer /Distributor	Contact Person
1	Thermflect/Argon, Low-Conductance Spacer, Double Pane	Vinyl	Single-Hung w/o Grid	36" X 60"	0.31	0.25	0.29	0.71	Builder's Cost: $170	CertainTeed http://www.certainteed.com	Enercon Windows & Hardware 1312 W Villa Maria, Bryan, Texas 77801 (979) 823-3639 Communication with Oscar Beard on 05/17/2006.
2	Air-filled, Low-e, Double Pane	Aluminum	Single-Hung w/o Grid	36" X 60"	0.37		0.29	0.67	Builder's Cost: $110	Atrium Companies, Inc, HR Windows®	
3	Air-filled, Double Pane	Aluminum	Single-Hung w/o Grid	36" X 60"	0.52		0.6	0.81	Builder's Cost: $82	Atrium Companies, Inc, HR Windows®	

1. Tested in accordance with NFRC 100-97. Data applicable for double-pane insulating units using either double-strength double pane glass with a 1/2" air space or single-strength glass with 9/16" air space.

Appendix A-4: Cost of Envelope and Fenestration Measures (cont.)

Shading-1

No.	Eave Construction	Unit cost ($/linear foot)	Perimeter (ft)	Total Cost ($/house)	Increased Cost	Source
1	Wood Eave with open Soffitt including blocking, screened 2" holes for ventilation with paint.	$15.28	193	$2,949.04		http://osfm.fire.ca.gov/pdf/regulations/UWIC-BRpt091004.pdf
2	Wood Eave with enclosed Soffitt including blocking, screened 2" holes for ventilation with paint.	$19.37	193	$3,738.41		http://osfm.fire.ca.gov/pdf/regulations/UWIC-BRpt091004.pdf
3	Wood-framed eave with enclosed, stucco-covered Soffitt incl. blocking, screened 2" holes for ventilation with paint.	$33.26	193	$6,419.18		http://osfm.fire.ca.gov/pdf/regulations/UWIC-BRpt091004.pdf
4	Average width of eave: 16 inch	$23.00	193	$4,439.00		http://osfm.fire.ca.gov/pdf/regulations/UWIC-BRpt091004.pdf
	4 ft eave	$39.00	193	$7,527.00	$3,088.00	Paige, Jefferson Christian Custom Homes, August 2006.

Shading-2

		Procedure	UNIT	Quantity	Unit Cost (Material)	Total Cost (Material)	Unit Cost (Labor)	Total Cost (Labor)	Total Cost ($/LF)	Source
1	Eave with enclosed soffitt $ per LF (Assuming eave length as 1ft)	Install 2"x4" side supports at wall and fascia	LF	2	0.38	0.76	1.73	3.46	4.22	
		Install 3/8" plywood soffitt	SF	1	1.36	1.36	1.48	1.48	2.84	
		Install vent screen, 3"	LF	1	0.44	0.44	1.99	1.99	2.43	
		Drill 2" 0 hole	EA	2			2.8	5.6	5.6	
		Paint, primer with 2 finish coats	SF	2	0.34	0.68	0.38	0.76	1.44	
		Total Cost				3.24		13.29	**16.53**	
2	Increasing Eave Length to 4ft	Install 2"x4" side supports at wall and fascia	LF	5	0.38	1.9	1.73	8.65	10.55	http://osfm.fire.ca.gov/pdf/regulations/UWIC-BRpt091004.pdf#search=%22Cost-Benefit%20Evaluation%20of%20Proposed%20California%22
		Install 3/8" plywood soffitt	SF	4	1.36	5.44	1.48	5.92	11.36	
		Install vent screen, 3"	LF	1	0.44	0.44	1.99	1.99	2.43	
		Drill 2" 0 hole	EA	2			2.8	5.6	5.6	
		Paint, primer with 2 finish coats	SF	2	0.34	0.68	0.38	0.76	1.44	
		Increased Roof Area	SF	3	1	3			**3**	
		Total Cost				11.46		22.92	34.38	
3	Increased cost per house:		Total perimeter	193					**3445.05**	

Appendix A-5: Cost of HVAC System Measures

Air Conditioning with Gas Heat System

Item	No.	Price	Brand	Type of Fuel	Model	Efficiency	Capacity	Description	Pictures	Source
Air Conditioning with Gas Heat (Carrier)	1	$4,550.00	Carrier	Electric for cooling, gas for heating	Condenser: 24ABR360 Coil: CNRHP6024 Furnace: 58STA110 1-22	13 SEER/ 80%AFUE	5 ton	R-22 phase out refrigerant; Pilot-free PowerHeat™ ignition		http://www.residential.carrier.com (Date: 05/12/2006)
	2	$5,424.00	Carrier	Electric for cooling, gas for heating	Condenser: 24ABa360 Coil: CNRHP6024 Furnace: 58STA110 1-22	13 SEER/ 80%AFUE	5 ton	R-410A EPA compliant refrigerant; Pilot-free PowerHeat™ ignition		http://www.residential.carrier.com (Date: 05/12/2006)
	3	$6,276.00	Carrier	Electric for cooling, gas for heating	Out of stock, no longer available	15 SEER/ 80% AFUE	5 ton	R-22 phase out refrigerant; Pilot-free PowerHeat™ ignition		http://www.residential.carrier.com (Date: 05/12/2006)
	4	$6,561.00	Carrier	Electric for cooling, gas for heating	Condenser: 24ACA560 Coil: CNRHP6024 Furnace: 58STA110 1-22	15 SEER/ 80%AFUE	5 ton	R-410A EPA compliant refrigerant; Pilot-free PowerHeat™ ignition		http://www.residential.carrier.com (Date: 05/12/2006)
Air Conditioning with Gas Heat (Carrier)	5	$3,933.00	Lennox	Electric for cooling, gas for heating		13 SEER/ 80%AFUE	5 ton	Ref. Type: R-22, Gas Furnace: 135000 Btu/hr		http://www.smarterwayinc.com/res_systems/gas_furnace/Lennox.asp
	6	$5,786.00	Lennox	Electric for cooling, gas for heating		15 SEER/ 80%AFUE	5 ton	Ref. Type: R-410A, Gas Furnace: 135000 Btu/hr		http://www.smarterwayinc.com/res_systems/gas_furnace/Lennox.asp

Appendix A-5: Cost of HVAC System Measures (cont.)

Air Conditioning with Gas Heat (All Makers)	7	$4,500.00	All Makers	Electric for cooling, gas for heating	n/a	13 SEER/ 80%AFUE	5 ton	$1,300 / Ton including duct work $6,500 for 5-ton unit with duct work $4,500 for 5-5on unit without duct work		Aggieland A/C & Heating
	8	$6,200.00	All Makers	Electric for cooling, gas for heating	n/a	15 SEER/ 80%AFUE	5 ton	$1,615 / Ton including duct work $8,075 for 5-ton unit with work $6,200 for 5-ton unit without duct work		Aggieland A/C & Heating
	9		All Makers	Electric for cooling, gas for heating	n/a	13 SEER/ 80%AFUE	5 ton	$12,000 includes duct work.		ACC-Aggieland Climate Control
	10		All Makers	Electric for cooling, gas for heating	n/a	15 SEER/ 80%AFUE	5 ton	$13,000 includes duct work.		ACC-Aggieland Climate Control
	11	$3,300.00	All Makers	Electric for cooling, gas for heating	n/a	13 SEER/ 80%AFUE	5 ton	$1,500 / Ton including duct work. $7,500 for 5-ton unit with duct work $3,300 for 5-ton unit (No Duct Work & No Labor)		IntelAir Heating & Cooling LLC
	12	$4,800.00	All Makers	Electric for cooling, gas for heating	n/a	15 SEER/ 80%AFUE	5 ton	$1,800 / Ton including duct work $9,000 for 5-ton unit with duct work $4,800 for 5-ton unit (No Duct Work & No Labor)		IntelAir Heating & Cooling LLC

Appendix A-5: Cost of HVAC System Measures (cont.)

Heat Pump

Item	No.	Price	Brand	Type of Fuel	Model	Efficiency	Capacity	Description	Pictures	Source
Heat Pump (Carrier - Up to 19 SEER and 9.5 HSPF)	1		Carrier	Electric	25HPA3	13 SEER/8.5 HSPF	Heating Capacity: 18,000 - 60,000 Btu/h Cooling Capacity: 1.5 - 5 tons	Carrier Performance Series Heat Pump; Versatile heating and cooling heat pump for maximum home comfort; Up to 15 SEER and 9.0 HSPF; Models include 25HPA5, 25HPA4, 25HPA3, 25HPR3, 38YXA, 38YZA, 38YSP.		http://www.residential.carrier.com/products/acheatpumps/heatpumps/index.shtml (Date: 5/12/2006)
	2		Carrier	Electric	25HCA3	13 SEER/8 HSPF	Heating Capacity: 18,000 - 60,000 Btu/h Cooling Capacity: 1.5 - 5 tons	Carrier Comfort Series Heat Pump Economical heating and cooling heat pump for optimal home comfort; Up to 14 SEER and 8.5 HSPF; Models include 25HCA4, 25HCA3, 25HCR3, 38YRA, 38YSA.		http://www.residential.carrier.com/products/acheatpumps/heatpumps/index.shtml (Date: 5/12/2006)
Heat Pump (Goodman)	3	$3,189.00	Goodman	Electric	GSH130601A ARUF061	13 SEER/8.5 HSPF	Heating Capacity: 55000 Btu/h Cooling Capacity: 5 ton	Goodman 5 Ton 13 Seer Air Conditioning System with Heat Pump; One Goodman fully charged outdoor heat pump air conditioning condensing unit; One matched indoor air handling unit; One supplemental heating element.		Price: http://acdirect.com/ (Date: 05/11/2006) Product: http://www.goodmanmfg.com/
	4	$3,492.00	Goodman	Electric	GSH140601A AEPF4260	14.5 SEER/8.5 HSPF	Heating Capacity: 55000 Btu/h Cooling Capacity: 5 ton	Goodman 5.0 Ton 14.5 Seer Air Conditioning System with Heat Pump: One Goodman fully charged outdoor heat pump air conditioning condensing unit ; One matched indoor air handling unit, multi-position including evaporator cooling coil ; One supplemental heating element up to 15 Kw (10Kw up to 3 Ton).		http://acdirect.com/heat_pump_goodman_heat_pump_rudd_heat_pump_.php (Date: 07/31/06)

Appendix A-5: Cost of HVAC System Measures (cont.)

Heat Pump (Ruud)	5	$3,591.00	Ruud	Electric	UPNE-060JAZ UHLA-HM6024JA	13 SEER/8.5 HSPF	Heating Capacity: 57000 Btu/h Cooling Capacity: 5 ton	Achiever by Ruud 5 Ton 13 Seer Variable Speed Air Conditioning System with Heat Pump; One Ruud UPNE series 13 SEER heat pump condenser; One matched indoor air handling unit; One Ruud supplemental electric heating kit.		Price: http://acdirect.com/ (Date: 05/11/2006) Product: http://www.ruudac.com
	6	$4,366.00	Ruud	Electric		14 SEER/8.5 HSPF		One Ruud UPNE series 14 SEER heat pump condenser One Ruud factory-matched indoor air handler One Ruud supplemental electric heating kit (with electric heat and heat pumps)		http://acdirect.com/xcart/product.php?productid=290 (Date: 07/31/06)
Heat Pump (Rheem)	7	$4,400.00	Rheem	Electric		13 SEER	5 ton	Price includes labor but not duct work		
	8	$5,100.00	Rheem	Electric		14 SEER	5 ton	Price includes labor but not duct work		
	9	$6,100.00	Rheem	Electric		16 SEER	5 ton	Price includes labor but not duct work		
Heat Pump (All Makers)	10	$5,000.00	All Makers	Electric.	n/a	13 SEER/8.5 HSPF	5 ton	$1400 / Ton including duct work $7000 for 5-ton unit with duct work $5000 for 5-ton unit without duct work		Aggieland A/C & Heating
	11	$7,000.00	All Makers	Electric.	n/a	15 SEER/8.5 HSPF	5 ton	$1800 / Ton including duct work $9000 for 5-5on unit with duct work $7000 for 5-ton unit without duct work		Aggieland A/C & Heating
	12	$3,600.00	All Makers	Electric.	n/a	13 SEER/ 8.5 HSPF	5 ton	$1,800 / Ton including duct work $9000 for 5-ton unit with duct work $3600 for 5-ton unit (No Duct Work & No Labor)		IntelAir Heating & Cooling LLC
	13	$5,800.00	All Makers	Electric.	n/a	15 SEER/ 8.5 HSPF	5 ton	$2,000 / Ton including duct work $10000 for 5-ton unit with duct work $5800 for 5-ton unit (No Duct Work & No Labor)		IntelAir Heating & Cooling LLC
Heat Pump (Trane)	14	$4,050.00	Trane	Electric	2TWR306081	13 SEER/ 8.5 HSPF	5 ton	$2700 for installation		JC Innovative Services
	15	$4,950.00	Trane	Electric.	2TWZ9060B1	15 SEER/ 8.75HSPF	5 ton	$3300 for installation		JC Innovative Services
Heat Pump (Lennox)	16	$3,584.00	Lennox	Electric		13 SEER/ 8.5 HSPF	5 ton	R-22		http://www.smarterwayinc.com/res_systems/heat_pump/heatpump1.asp#Lennox
	17	$5,872.00	Lennox	Electric.		16 SEER/ 8.75HSPF	5 ton	R-410		http://www.smarterwayinc.com/res_systems/heat_pump/heatpump1.asp#Lennox

Appendix A-5: Cost of HVAC System Measures (cont.)

Furnace

Item	No.	Price	Brand	Type of Fuel	Model	Efficiency	Capacity	Description	Pictures	Source
Gas Furnace (Carrier- up to 96.6% AFUE)	1		Carrier	Natural Gas	58MVB	96.6% AFUE	40,000 - 120,000 BTUH	Infinity 96 Gas Furnace; Muitipoise, condensing, direct vent/non direct vent gas furnace; Variable speed blower; Pilot-free PowerHeat™ ignition.		http://www.residential.carrier.com/products/furnaces/gas/index.shtml (Date: 5/11/2006)
	2	About $1000 increase in cost	Carrier	Natural Gas	58MTB	93% AFUE	38,000 - 128,000 BTUH	Performance 93 Gas Furnace; Muitipoise, condensing, direct vent/non direct vent; 4-5 speed blower; Pilot-free PowerHeat™ ignition.		http://www.residential.carrier.com/products/furnaces/gas/index.shtml (Date: 5/11/2006)
	3		Carrier	Natural Gas	58CTA, 58CTX	80% AFUE	40,000 - 154,000 BTUH	Performance 80 Gas Furnace; Induced-combustion; Enhanced comfort control with dual stages of heating; 4-5 speed blower; Pilot-free PowerHeat™ ignition.		http://www.residential.carrier.com/products/furnaces/gas/index.shtml (Date: 5/11/2006)
Gas Furnace (Goodman- 80% to 93% AFUE)	4	$1063/$768	Goodman	Natural Gas	GMV81155CXA/GMS81155CNA	80% AFUE	115,000 BTUH	GMV8 Series 80% AFUE Two-Stage, Variable-Speed/GMS8/GDS8 Series 80% AFUE Single-Stage, Multi-Speed; Upflow/Horiz.		http://www.smarterwayinc.com/res_components/gas_furnace/lennox.asp
	5	$1,658.00	Goodman	Natural Gas	GMV91155DXA	93% AFUE	115,000 BTUH	GMV9/GCV9 Series 93% AFUE Two-Stage, Variable-Speed, Upflow/Horiz.		http://www.smarterwayinc.com/res_components/gas_furnace/lennox.asp
Gas Furnace (Rheem- 80% to 93% AFUE)	6	$1,200.00	Rheem	Natural Gas	RGPN15EARJR	80% AFUE	125,000BTUH	Rheem® Natural / Propane Gas Furnaces		
	7	$2100/$2300	Rheem	Natural Gas	RGRA12ERAJS/RGFD12ERCMS	93% AFUE	120,000 BTUH	Rheem® 1-Stage Multi-Speed / Rheem® Modulating Variable Speed		
Gas Furnace (Lennox- 80% to 93% AFUE)	8	$1,314.00	Lennox	Natural Gas	G40UH60D135	80% AFUE	132,000 BTUH	Up/Horiz		Barkers Heating and Cooling, http://www.smarterwayinc.com/res_components/gas_furnace/lennox.asp
	9	$2492/$2043	Lennox	Natural Gas	G61MPV60D135/G61MP60D135	94% AFUE	132,000 BTUH	Lennox Signature® Collection G61V 94+% AFUE Two-Stage, Variable-Speed Furnaces/Lennox Signature® Collection G61 94.1% AFUE Two-Stage, Multi-Speed Furnaces. Up/Horiz./Down		