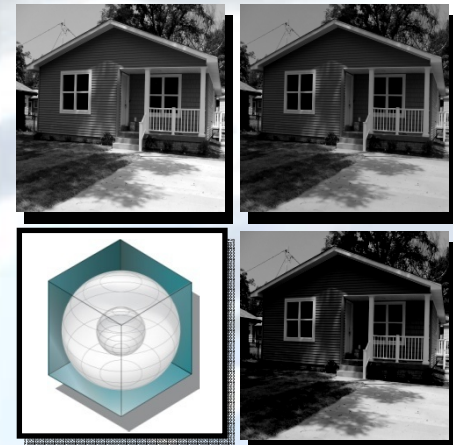


# RECOMMENDATIONS FOR 15% ABOVE-CODE ENERGY EFFICIENCY MEASURES FOR SINGLE FAMILY RESIDENCES

Mini Malhotra  
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**Energy Systems Laboratory  
Texas Engineering Experiment Station  
Texas A&M University System**



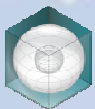
# ACKNOWLEDGEMENTS

**Faculty/Staff:** Tom Fitzpatrick, Don Gilman, Mushtaq Ahmed, Juan-Carlos Baltazar, Sherrie Hughes, Angie Shafer, Larry Degelman, David Claridge, Dan Turner, Stephen O'Neal.

**Students:** Piljae Im, Seongchan Kim, Soolyeon Cho, Ben Burkert, Indira Mohandross, Kyle Marshall, Matt Moss, Megan Bednarz, Robert Stackhouse.

**TCEQ:** Steve Anderson, Akin Olubiyi.

**USEPA:** Art Diem, Julie Rosenberg.



# OUTLINE

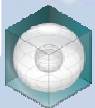
Introduction

Base-Case Building

Energy Efficiency Measures

Results

Conclusion



# INTRODUCTION

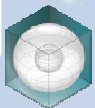
## THE 79<sup>TH</sup> LEGISLATURE TO ENHANCE EFFECTIVENESS OF SENATE BILL 5

### Requires the Laboratory

To develop 3 methods for achieving at least 15% potential energy savings in residential, commercial and industrial construction.

### The Process

- Worked on residential and commercial measures
- Held stakeholders meetings
- Refined measures



# BASE-CASE HOUSE

## 2001 IECC for Residential Buildings

### Two system types:

**Electric cooling Natural gas heating (Electric / Gas)**

**Electric cooling Electric heating (All - Electric)**

### Building Envelope

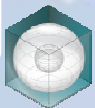
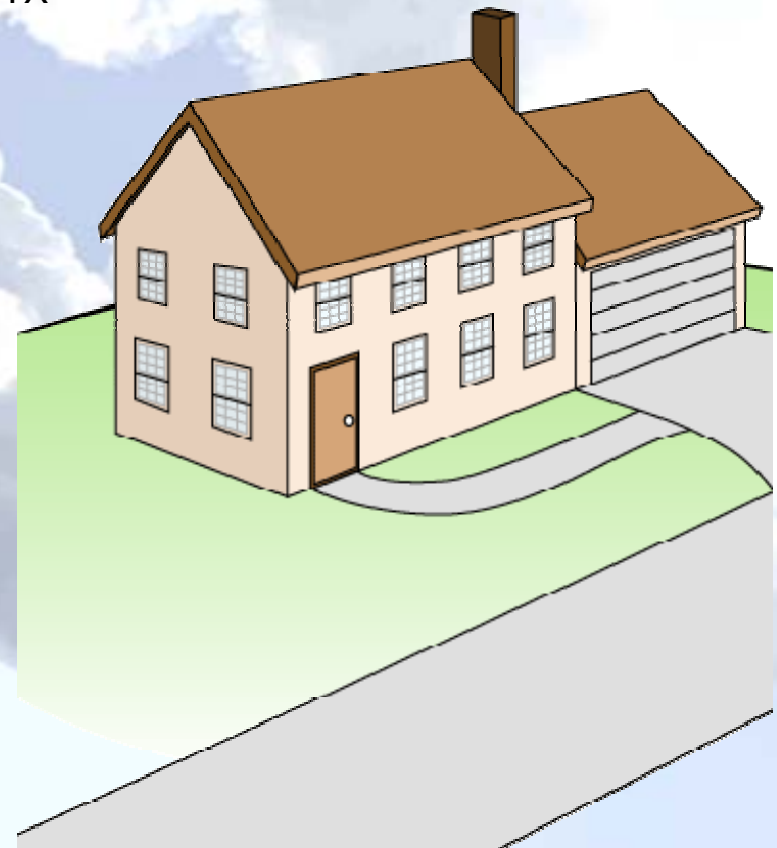
- Detached single story (2,325 ft<sup>2</sup>) in Houston, TX
- Vented, unconditioned attic
- Light-weight, wood frame construction
- Ceiling R-value: R-30
- Wall R-value: R-13
- Un-insulated, slab-on-grade

### Fenestration

- 18% window-to-floor area ratio
- U-value: 0.47 Btu/hr °F ft<sup>2</sup>
- SHGC: 0.40

### Air Infiltration

- Conditioned space 0.47 ACH
- Attic 15 ACH



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# BASE-CASE

## 2001 IECC for Residential Buildings

### Two system types:

**Electric cooling Natural gas heating (Electric / Gas)**

**Electric cooling Electric heating (All - Electric)**

### HVAC System Characteristics

#### For cooling

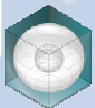
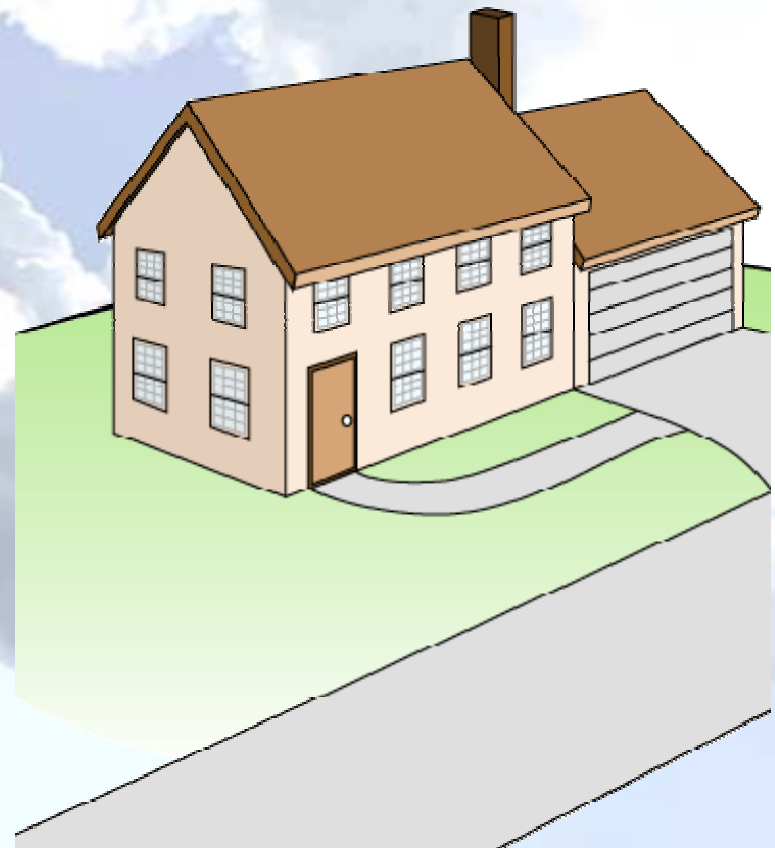
- Air-conditioner with SEER 13

#### For heating

- Electric / gas building –  
Gas fired forced air furnace AFUE - 0.78
- All-Electric building –  
Heat Pump HSPF – 7.7

### Air Distribution System Characteristics

- Ducts in the attic
- 10% duct leakage
- Supply duct R-value – R-8
- Return duct R-value – R-4



# BASE-CASE

## 2001 IECC for Residential Buildings

### Two system types:

**Electric cooling Natural gas heating (Electric / Gas)**

**Electric cooling Electric heating (All - Electric)**

### DHW System Characteristics

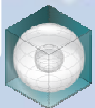
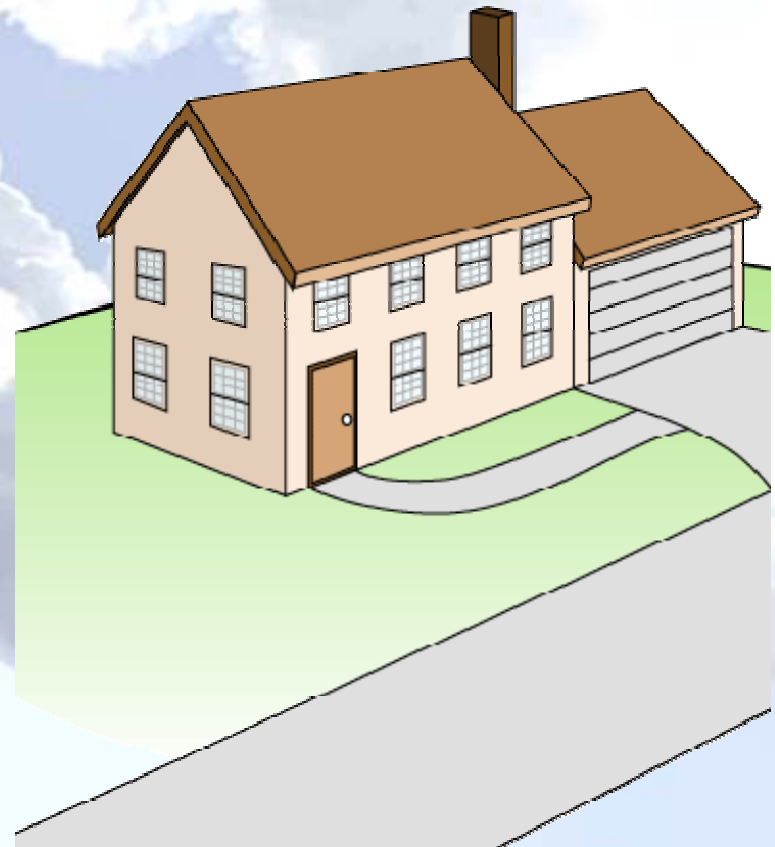
- Daily hot water use 70 gallons/day

#### For Electric / Gas

- 40 gallon storage
- Energy Factor – 0.54
- Pilot light

#### For All-Electric

- 50 gallon storage
- Energy Factor – 0.86



# ENERGY EFFICIENCY MEASURES

## 12 INDIVIDUAL MEASURES

### DHW System Measures

#### 1. Tankless Domestic Water Heater (Electric/Gas & All-Electric)

##### For Electric / Gas

- No Pilot light
- Energy Factor raised from 0.54 to 0.85

##### For All-Electric

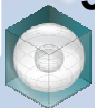
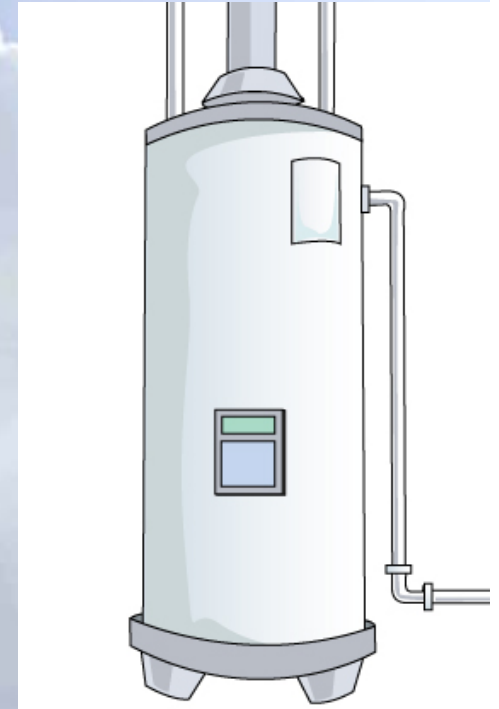
- Energy Factor raised from 0.86 to 0.95

#### 2. Solar Domestic Water Heater (Electric/Gas & All-Electric)

##### Solar DHW Characteristics

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

#### 3. Removal of Standing Pilot Light from Gas DHW (Electric/Gas)



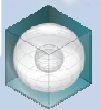
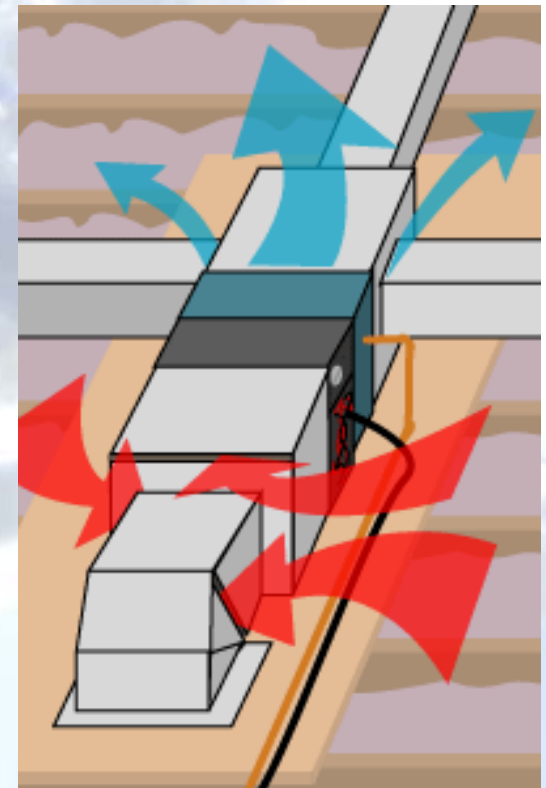


# ENERGY EFFICIENCY MEASURES

## 12 INDIVIDUAL MEASURES

### Air Distribution System Measures

4. **Ducts in Conditioned Space** (Electric/Gas & All-Electric)
  - Moving ductwork and HVAC system within the thermal envelope
  
5. **Improved Duct Sealing** (Electric/Gas & All-Electric)
  - Changing from 10% to 5%



# ENERGY EFFICIENCY MEASURES

## 12 INDIVIDUAL MEASURES

### Envelope & Fenestration Measures

#### 6. Increased Air-Tightness

- Changing from 0.47 to 0.35

#### 7. Addition of Window Shading

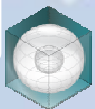
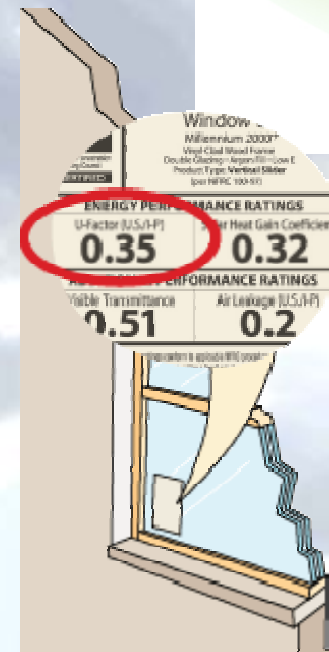
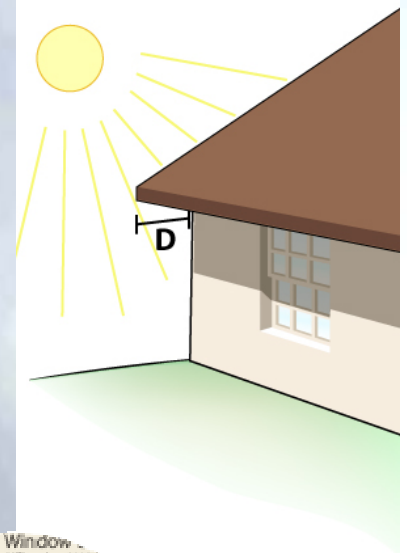
- Roof overhangs of 4 ft

#### 8. Window Shading and Re-distribution

- From 18% WFAR distributed 25%WWAR on each orientation to windows distributed 45% on the south, 25% on the north, 15% each on east and west orientations
- 4 ft. roof overhang was also included on all four sides

#### 9. Improved Window Performance

- Uvalue 0.47 to 0.42 Btu/h-sq. ft.-°F
- SHGC 0.40 to 0.33



# ENERGY EFFICIENCY MEASURES

## 12 INDIVIDUAL MEASURES

### HVAC System Measures

#### 10. Improved Air Conditioning Efficiency

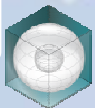
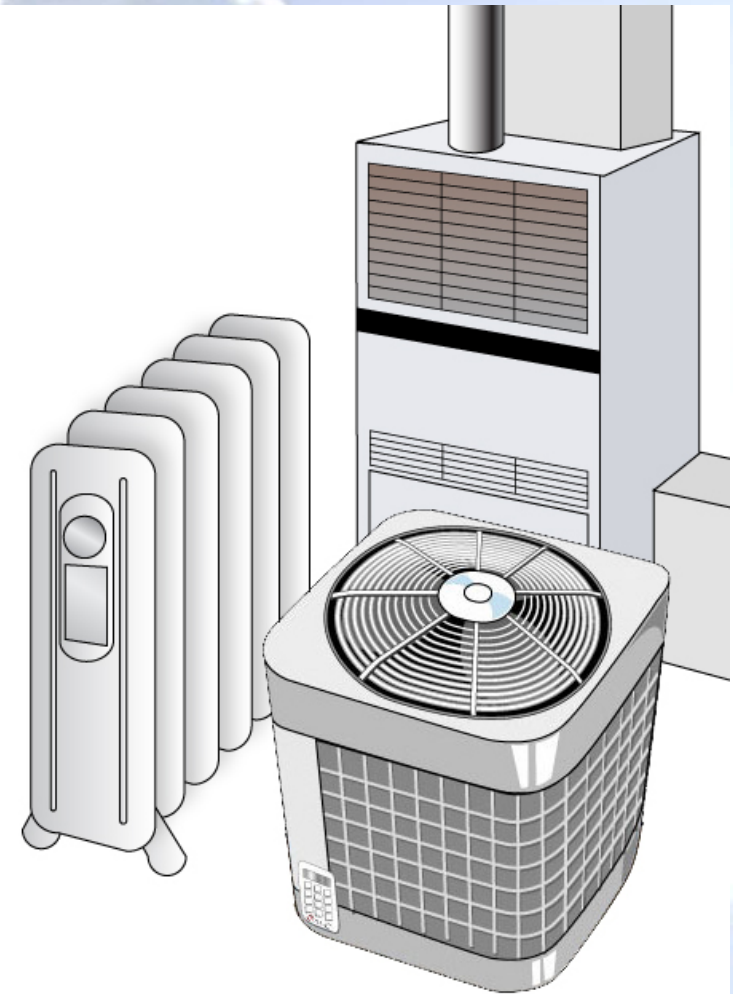
- From SEER 13 to SEER 15

#### 11. Improved Furnace Efficiency

- From 0.78 AFUE to 0.93 AFUE

#### 12. Improved Efficiency of the Heat Pump

- From 7.7 HSPF to 8.5 HSPF



# ENERGY EFFICIENCY MEASURES

## COMBINED SET OF MEASURES

### Combination 1

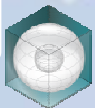
- Tankless Water Heater (Without Standing Pilot Light)
- Relocate HVAC Unit Including Supply and Return Ducts in Conditioned Space

### Combination 2

- Solar Domestic Hot Water System
- Improved Duct Sealing (5% Duct Leakage)
- Improved Air Conditioner (SEER 15)

### Combination 3

- Removal of Pilot Light from DHW System
- Relocate HVAC Unit including Supply and Return Air-Ducts in Conditioned Space
- Window Shading and Redistribution



# RESULTS

## PROCESS ADOPTED FOR ANALYSIS

### **CALCULATING ENERGY SAVED**

- Annual energy use for individual and combined measures

### **CALCULATING COSTS**

- Energy Cost
- First Costs

**PAYBACK**  
Number of Years

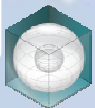
INTRODUCTION

BASECASE

EEM'S

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# RESULTS

## DHW System Measures for Electric / Gas Building

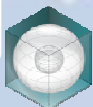
EEM	ENERGY USE (MBtu/yr)					ENERGY SAVINGS			FIRST COST (\$)	PAY BACK (\$)
	COOLING	HEATING	DHW	OTHER	TOTAL	MBtu/yr	%	\$/yr		
BASECASE	15.9	9.4	24.8	29	78.9					
TANKLESS	15.9	9.4	17.4	29	71.6	7.3	9.3	73	1000 3500	13.7 47.5
SOLAR	15.9	9.4	12.6	29	66.9	12	15.2	74	2900 5200	39.3 70.5
REMOVAL OF PILOT LIGHT	15.9	9.4	20.4	29	74.5	4.3	5.5	43	200 600	4.7 14

### Energy Savings

- Tankless: 9.3%
- Solar Water Heater: 15.2%
- Removal of Pilot Light: 5.5%

### Payback Period

- Tankless Water Heater: 13.7 to 47.5 years
- Solar Water Heater: 39 to 70 years
- Removal of Pilot Light: 4.7 to 14 years



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# RESULTS

## Air Distribution System Measures for Electric / Gas Building

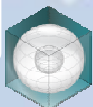
EEM	ENERGY USE (MBtu/yr)					ENERGY SAVINGS			FIRST COST (\$)	PAY BACK (\$)
	COOLING	HEATING	DHW	OTHER	TOTAL	MBtu/yr	%	\$/yr		
BASECASE	15.9	9.4	24.8	29	78.9					
UNIT, DUCTS IN COND SPACE	11.3	7.2	24.8	29	72.2	6.7	8.5	221	1000 7000	4.5 31.7
DUCT SEALING	13.5	8.4	24.8	29	75.5	3.4	4.3	117	450 650	3.9 5.6

### Energy Savings

- HVAC Unit & Duct in Conditioned Space: 8.5%
- Improved Duct Sealing: 4.3%

### Pay Back Period

- HVAC Unit & Duct in Conditioned Space: 4.5 to 31.7 years
- Improved Duct Sealing: 3.9 to 5.6 years



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# RESULTS

## Envelope & Fenestration Measures for Electric / Gas Building

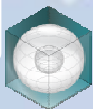
EEM	ENERGY USE (MBtu/yr)					ENERGY SAVINGS			FIRST COST (\$)	PAY BACK (\$)
	COOLING	HEATING	DHW	OTHER	TOTAL	MBtu/yr	%	\$/yr		
BASECASE	15.9	9.4	24.8	29	78.9					
AIR TIGHTNESS	15.4	8.3	24.8	28.9	77.2	1.7	2.1	35	350 1500	10 43
SHADING	13	11	24.8	28.6	77.2	1.7	2.1	128	3100 3500	24 27
SHADING + REDISTRIBUTN	12.7	10.2	24.8	28.5	76	2.8	3.6	152	3100 3500	20 23
PERFORMANCE	13.9	9.5	24.8	28.7	76.8	2.1	2.6	97	800 1100	8 11

### Energy Savings

- Air Tightness: 2.1%
- Shading: 2.1%
- Shading + Window Redistribution: 3.6%
- Window Performance: 2.6%

### Pay Back Period

- Air Tightness: 10 to 43 years
- Shading: 24 to 27 years
- Shading + Window Redistribution: 20 to 23 years
- Window Performance: 8 to 11 years



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# RESULTS

## HVAC System Measures for Electric / Gas Building

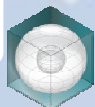
EEM	ENERGY USE (MBtu/yr)					ENERGY SAVINGS			FIRST COST (\$)	PAY BACK (\$)
	COOLING	HEATING	DHW	OTHER	TOTAL	MBtu/yr	%	\$/yr		
BASECASE	15.9	9.4	24.8	29	78.9					
SEER 15	13.8	9.4	24.8	29	76.8	2.1	2.7	93	900 2500	9.7 26.9
AFUE 0.93	15.9	7.8	24.8	29	77.4	1.5	1.9	15	600 1500	40 100

### Energy Savings

- SEER 15: 2.7%
- AFUE 0.93: 1.9%

### Pay Back Period

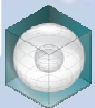
- SEER 15: 9.7 to 26.9 years
- AFUE 0.93: 40 to 100 years



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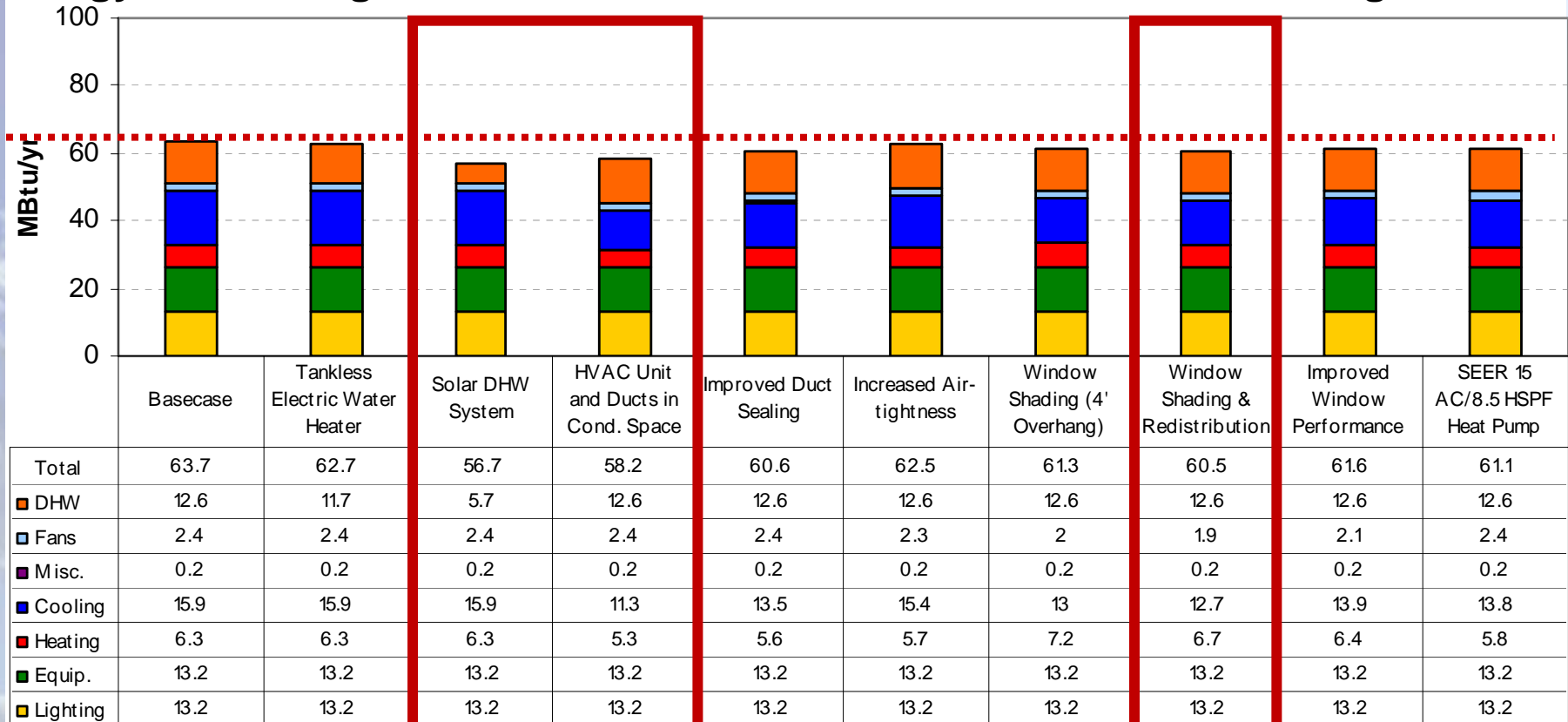
# RESULTS

## Energy Use Savings from Individual Measures for Electric / Gas Building

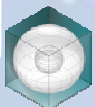


# RESULTS

## Energy Use Savings from Individual Measures for All-Electric Building



	Base Case	Tankless	Solar DHW	Unit & Ducts in Cond.	Improved Duct Sealing	Increase Air Tightness	Shading Overhang	Shading & Redstrn.	Window Perform.	SEER 15
<b>TOTAL</b>	63.7	62.7	56.7	58.2	60.6	62.5	61.3	60.5	61.6	61.1
<b>SAVINGS%</b>		1.5	10.9	8.7	4.8	1.8	3.7	5.0	3.3	4.1



## Natural Gas Heating (Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller Counties)

Description of Individual Measures

Individual Measures	Annual Energy Savings (%)	Annual Energy Savings (\$/year) <sup>4</sup>	Estimated Cost (\$)	
			Marginal Cost <sup>1</sup>	New System Cost <sup>2</sup>
<b>A Domestic Hot Water Measures</b>				
1 Tankless Gas Water Heater (without a Standing Pilot Light)	9.3%	\$73	\$1,000 - \$3,500	
2 Solar Domestic Hot Water System	15.2%	\$74		\$2,900 - \$5,200
3 Removal of Pilot Light from Domestic Hot Water System	5.5%	\$43	\$200 - \$600	
<b>B Air Distribution System Measures</b>				
4 Relocate HVAC Unit including Supply and Return Ducts in Conditioned Space	8.5%	\$221	\$1,000 - \$7,000	
5 Improved Duct Sealing (10% to 5% Duct Leakage)	4.3%	\$117		\$450 - \$650
<b>C Envelope and Fenestration Measures</b>				
6 Reduced Air Infiltration (0.46 to 0.35 Air-changes/hr)	2.1%	\$35		\$350 - \$1,500
7 Window Shading (None to 4 ft. Eaves on All Sides)	2.1%	\$128		\$3,100 - \$3,500
8 Window Shading and Redistribution (Equal Windows on All Four Sides with No Shading to 45% Windows on the South with 4ft. Eaves on All Four Sides)	3.6%	\$152		\$3,100 - \$3,500
9 Improved Windows (U-factor: 0.47 to 0.42 Btu/h-ft-F, SHGC: 0.4 to 0.33)	2.6%	\$97	\$800 - \$1,100	
<b>D HVAC System Measures</b>				
10 Air Conditioner (SEER 13 to SEER 15)	2.7%	\$93	\$900 - \$2,500	
11 Furnace (0.78 AFUE to 0.93 AFUE)	1.0%	\$15	\$600 - \$1,500	



Description of Combined Measures to Achieve 15% Above Code Savings

Combination of Measures <sup>3</sup>	Combined Energy Savings (%)	Combined Energy Savings (\$/year)	Combined Estimated Cost (\$)		Combined Annual NO <sub>x</sub> Emissions Savings (lbs/year)	Combined Ozone Season Period NO <sub>x</sub> Emissions Savings (lbs/day)	Simple Estimated Payback (yrs)
			Marginal Cost <sup>1</sup>	New System Cost <sup>2</sup>			
<b>Combination 1</b>							
1 Tankless Gas Water Heater (without a Standing Pilot Light)	17.8%	\$295	\$1,000 - \$3,500		2.39	0.018	6.8 - 35.7
4 Relocate HVAC Unit including Supply and Return Ducts in Conditioned Space			\$1,000 - \$7,000				
<b>Combination 2</b>							
2 Solar Domestic Hot Water System	21.8%	\$269		\$2,900 - \$5,200	1.50	0.011	15.8 - 31.0
5 Improved Duct Sealing (10% to 5% Duct Leakage)				\$450 - \$650			
10 Air Conditioner (SEER 13 to SEER 15)			\$900 - \$2,500				
<b>Combination 3</b>							
3 Removal of Pilot Light from Domestic Hot Water System	16.8%	\$383	\$200 - \$600		2.99	0.025	11.2 - 29.0
4 Relocate HVAC Unit including Supply and Return Ducts in Conditioned Space			\$1,000 - \$7,000				
8 Window Shading and Redistribution (Equal Windows on All Four Sides with No Shading to 45% Windows on the South with 4ft. Eaves on All Four Sides)				\$3,100 - \$3,500			

Note:

- Marginal cost = new system cost - original system cost
- New system cost = new system cost only
- See individual measures above for specific savings  
\* Energy Cost: Electricity cost = \$0.15/kWh  
Natural gas cost = \$1.00/therm
- Savings depend on fuel mix used. See detailed writeup

**Table 5a: 15% Above Code Savings (Residential Heating) for Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller Counties**



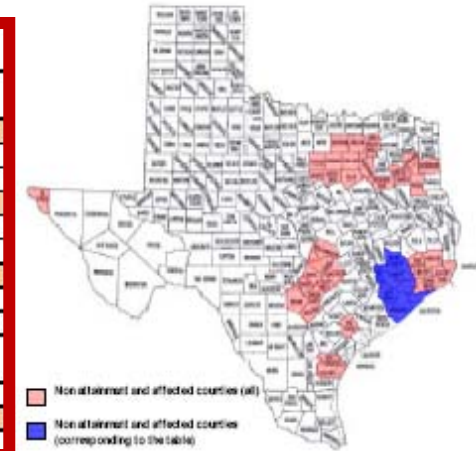
Energy Systems Laboratory - August 2007

COMBINATION	COMBINED ENERGY SAVINGS	PAYBACK YEARS
COMBINATION 1	17.8%	6.8 – 35.7
COMBINATION 2	21.8%	15.8 – 31
COMBINATION 3	16.8%	11.2 - 29

## Electric Heating (Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller Counties)

Description of Individual Measures

Individual Measures	Annual Energy Savings (%)	Annual Energy Savings (\$/year)	Estimated Cost (\$)	
			Marginal Cost <sup>1</sup>	New System Cost <sup>2</sup>
<b>A Domestic Hot Water Measures</b>				
1 Tankless Electric Water Heater	1.5%	\$42	\$700 - \$1,400	
2 Solar Domestic Hot Water System	10.9%	\$304		\$2,900 - \$5,200
<b>B Air Distribution System Measures</b>				
4 Relocate HVAC Unit including Supply and Return Ducts in Conditioned Space	8.7%	\$242	\$1,000 - \$7,000	
5 Improved Duct Sealing (10% to 5% Duct Leakage)	4.8%	\$134		\$450 - \$650
<b>C Envelope and Fenestration Measures</b>				
6 Reduced Air Infiltration (0.46 to 0.35 Air-changes/hr)	1.8%	\$50		\$350 - \$1,500
7 Window Shading (None to 4 ft. Eaves on All Sides)	3.7%	\$103		\$3,100 - \$3,500
8 Window Shading and Redistribution (Equal Windows on All Four Sides with No Shading to 45% Windows on the South with 4ft. Eaves on All Four Sides)	5.0%	\$141		\$3,100 - \$3,500
9 Improved Windows (U-factor: 0.47 to 0.42 Btu/h-s-F, SHGC: 0.4 to 0.33)	3.3%	\$92	\$800 - \$1,100	
<b>D HVAC System Measures</b>				
12 Air Conditioner with Heat Pump (SEER 13/7.7 HSPF to SEER 15/8.5 HSPF)	4.1%	\$114	\$1,500 - \$2,400	



Description of Combined Measures to Achieve 15% Above Code Savings

Combination of Measures <sup>3</sup>	Combined Energy Savings (%)	Combined Energy Savings (\$/year)	Combined Estimated Cost (\$)		Combined Annual NO <sub>x</sub> Emissions Savings (lbs/year)	Combined Ozone Season Period NO <sub>x</sub> Emissions Savings (lbs/day)	Simple Estimated Payback (yrs)
			Marginal Cost <sup>1</sup>	New System Cost <sup>2</sup>			
<b>Combination 1</b>							
2 Solar Domestic Hot Water System	15.7%	\$438		\$2,900 - \$5,200	1.01	0.020	7.6 - 13.4
5 Improved Duct Sealing (10% to 5% Duct Leakage)				\$450 - \$650			
<b>Combination 2</b>							
1 Tankless Electric Water Heater	15.4%	\$431	\$700 - \$1,400		3.26	0.029	9.3 - 27.6
4 Relocate HVAC Unit including Supply and Return Ducts in Conditioned Space			\$1,000 - \$7,000				
9 Improved Windows (U-factor: 0.47 to 0.42 Btu/h-s-F, SHGC: 0.4 to 0.33)			\$800 - \$1,100				
12 Air Conditioner with Heat Pump (SEER 13/7.7 HSPF to SEER 15/8.5 HSPF)			\$1,500 - \$2,400				
<b>Combination 3</b>							
1 Tankless Electric Water Heater	15.1%	\$422	\$700 - \$1,400		3.19	0.026	14.5 - 22.4
5 Improved Duct Sealing (10% to 5% Duct Leakage)				\$450 - \$650			
6 Reduced Air Infiltration (0.46 to 0.35 Air-changes/hr)				\$350 - \$1,500			
8 Window Shading and Redistribution (Equal Windows on All Four Sides with No Shading to 45% Windows on the South with 4ft. Eaves on All Four Sides)				\$3,100 - \$3,500			
12 Air Conditioner with Heat Pump (SEER 13/7.7 HSPF to SEER 15/8.5 HSPF)				\$1,500 - \$2,400			

Note:

- Marginal cost = new system cost - original system cost
- New system cost = new system cost only
- See individual measures above for specific savings  
 \* Energy Cost: Electricity cost = \$0.15/kWh  
 Natural gas cost = \$1.00/therm
- Savings depend on fuel mix used. See detailed writeup

(Building)

**Table 5b: 15% Above Code Savings (Residential Heating) for Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller Counties**



Energy Systems Laboratory - August 2007

COMBINATION	COMBINED ENERGY SAVINGS	PAYBACK YEARS
COMBINATION 1	15.7%	7.6 – 13.4
COMBINATION 2	15.4%	9.3 – 27.6
COMBINATION 3	15.1%	14.5 – 22.4

# CONCLUSIONS

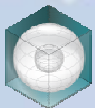
## FOR ELECTRIC / GAS BUILDING IN HOUSTON:

### Most Effective Individual Measures

	<b>ENERGY SAVINGS</b>	<b>PAYBACK</b>
•Removal of Pilot Light	<b>17.8%</b>	<b>9 Years</b>
•Improving Duct Sealing	<b>21.8%</b>	<b>5 Years</b>
•Improved Window Performance	<b>16.8%</b>	<b>10 Years</b>

### Most Effective Combination of Measures

Combination 1	<b>ENERGY SAVINGS</b>	<b>PAYBACK</b>
•Tankless DHW Heater	<b>17.8%</b>	<b>6.8 – 35.7 Years</b>
•Relocate HVAC unit including supply and return ducts in conditioned space		



# CONCLUSIONS

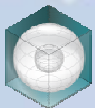
## FOR ALL - ELECTRIC BUILDING IN HOUSTON:

### Most Effective Individual Measures

	<b>ENERGY SAVINGS</b>	<b>PAYBACK</b>
•Improved Duct Sealing	<b>17.8%</b>	<b>4 Years</b>
•Improved Window Performance	<b>3.3%</b>	<b>10 Years</b>
•Solar Hot Water System	<b>10.9%</b>	<b>13 Years</b>

### Most Effective Combination of Measures

Combination 1	<b>ENERGY SAVINGS</b>	<b>PAYBACK</b>
•Solar Hot Water System	<b>15.7%</b>	<b>7.6 – 13.5 Years</b>
•Improved Duct Sealing		



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