# ASSESSING SAVINGS FROM GROUP MEASURES PROPOSED BY HOUSTON AMMENDMENTS FOR THE 2009 IECC (RESIDENTIAL PROVISIONS)

**A Report for the City of Houston**

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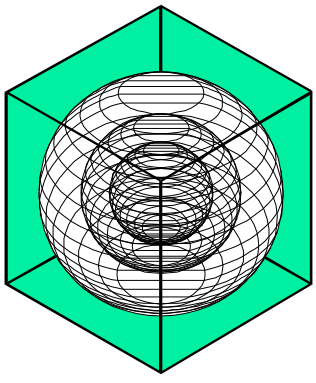

**ENERGY SYSTEMS LABORATORY**

**Texas Engineering Experiment Station**
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## Disclaimer

**Executive Summary**

This report assesses several group measures that have been proposed by the City of Houston officials as part of the amendments to the 2009 IECC code – the Houston Amendments. The proposed group measures are for both single-family and multi-family units. There are eleven group measures for single-family units with electric cooling and natural gas heating (Electric/Natural Gas), seven group measures for multi-family units with electric cooling and natural gas heating (Electric/Natural Gas) and five group measures for multi-family units with electric cooling and heating (All-Electric). As prescribed in the Houston Amendments, the adoption of any one group should achieve a minimum of five percent improvement above the minimum requirements of the 2009 IECC code when complying with the prescriptive path outlined in the code. The assessment was performed using 2009 IECC compliant base-case simulation models for the single-family and multi-family units. Group measures to be assessed consisted of measures for the envelope, lighting, mechanical systems and domestic hot water heating systems as well as options for on-site renewable energy generation. Site energy consumption was considered for the assessment. For the single-family unit (Electric/Natural Gas) - site energy savings were in the range of 5% to 32%. For the multi-family unit (Electric/Natural Gas) – site energy savings were in the range of 3% to 22%. For the multi-family unit (All Electric) – site energy savings were in the range of 7% to 26%. The results are provided in Table ES-1, Table ES-2 and Table ES-3.

**Table ES - 1: Annual Energy Savings Obtained from Implementing Grouped Efficiency Strategies for Single-Family Units (Electric/Natural Gas)**

| EFFICIENCY MEASURES FOR SINGLE-FAMILY UNITS (Electric / Natural Gas) | | 2009 Site Energy |
|---|---|---|
| **Groups** | **Measures** | |
| Group 1 | Solar Domestic Hot Water System (32 sq.ft. collector area/unit) | 9% |
| Group 2 | Photovoltaic Array for 6kW | 32% |
| Group 3 | Photovoltaic Array for Partial Demand at 4kW | 21% |
| Group 4 | Photovoltaic Array for Partial Demand at 2kW | 11% |
| Group 5 | Mechanical Systems within Conditioned Spaces | 8% |
| Group 6 | Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Radiant Barrier<br>Decreased Duct Leakage to Outside: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area<br>Improved SEER: 14 SEER | 8% |
| Group 7 | Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Decreased Duct Leakage to Outside: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area<br>Improved SEER: 15 SEER | 7% |
| Group 8 | Improved AFUE: 0.93 AFUE<br>Decreased Infiltration: 5 $ACH_{50}$<br>Decreased Duct Leakage to Outside: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area<br>Improved SEER: 15 SEER | 11% |
| Group 9 | Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Improved DHW System Efficiency: Tankless Water Heater, Energy Factor: 0.748 | 6% |
| Group 10 | Reduced Internal Heat Gain: 100% Energy Star CFL Indoor Lamps | 5% |
| Group 11 | Improved Windows: Decreased U-Factor (U-0.35) | 7% |

**Table ES - 2: Annual Energy Savings Obtained from Implementing Grouped Efficiency Strategies for Multi-Family Units (Electric/Natural Gas)**

| EFFICIENCY MEASURES FOR MULTI-FAMILY UNITS (Electric / Natural Gas) | | Site Energy |
|---|---|---|
| **Groups** | **Measures** | |
| Group 1 | Solar Domestic Hot Water System (21 sq.ft. collector area/unit) | 13% |
| Group 2 | Photovoltaic Array for 2kW/Unit | 22% |
| Group 3 | Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Improved DHW System Efficiency: Tankless water heater, Energy Factor: 0.748<br>Decreased Infiltration: 5 $ACH_{50}$ | 11% |
| Group 4 | Improved DHW System Efficiency: Tankless Water Heater, Energy Factor: 0.748<br>Decreased Duct Leakage to Outside: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area (Upper Floor Only)<br>Improved SEER: 14 SEER | 10% |
| Group 5 | Mechanical Systems within Conditioned Spaces (Upper Floor Only) | 3% |
| Group 6 | Decreased Infiltration: 5 $ACH_{50}$<br>Improved SEER: 14 SEER<br>Improved AFUE: 0.93 AFUE<br>Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps | 9% |
| Group 7 | Improved DHW System Efficiency: Tankless water heater, Energy Factor: 0.748<br>Decreased Duct Leakage to Outside: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area (Upper Floor Only)<br>Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Improved Windows: Decreased U-Factor (U-0.35) | 14% |

Note: Shaded cells indicate the group fails to achieve higher than 5% of energy savings above the 2009 IECC code.

**Table ES - 3: Annual Energy Savings Obtained from Implementing Grouped Efficiency Strategies for Multi-Family Units (All-Electric)**

| EFFICIENCY MEASURES FOR MULTI-FAMILY UNITS (All Electric) | | Site Energy |
|---|---|---|
| **Groups** | **Measures** | |
| Group 1 | Solar Domestic Hot Water System (21 sq.ft. collector area/unit) | 7% |
| Group 2 | Photovoltaic Array for 2kW/Unit | 26% |
| Group 3 | Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Mechanical in Conditioned Space (Upper Floor Only)<br>Improved SEER: 14 SEER<br>Improved Windows: Decreased U-Factor (U-0.35)**<br>Decreased Infiltration: 5 $ACH_{50}$ * | 13% |
| Group 4 | Improved DHW System Efficiency: Tankless Water Heater, Energy Factor 0.98****<br>Decreased Duct Leakage: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area (Upper Floor Only)***<br>Improved SEER:14 SEER<br>Decreased Infiltration: 5 $ACH_{50}$*<br>Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Improved Windows: Decreased U-Factor (U-0.35)** | 12% |
| Group 5 | Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Decreased Duct Leakage: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area (Upper Floor Only)***<br>Improved SEER: 14 SEER<br>Improved Windows: Decreased U-Factor (U-0.35)**<br>Decreased Infiltration: 5 $ACH_{50}$* | 11% |

## Table of Contents

## List of Tables

## List of Figures

## 1. Organization of the Report

This report is organized in the following order:

- Section 1 briefs the reader about the organization of the report.
- Section 2 presents the introduction and purpose of the report.
- Section 3 describes the base-case building which is based on the specifications in the 2009 IECC and certain other assumptions.
- Section 4 describes the proposed groups of energy efficiency measures.
- Section 5 presents the results of the simulation runs and the conclusions.

## 2. Introduction

The Energy Systems Laboratory was requested to perform an assessment of groups of energy efficiency measures proposed by the City of Houston officials as part of the proposed amendments to the IECC 2009 code – the Houston Amendments. As per the amendments *"New residences and apartments and new additions that exceed 500 ft$^2$ to existing residences and apartments must use 5% less energy as shown by one of the methods indicated in Sections 110.2.1, 110.2.2 and 110.2.3."* This report addresses Section 110.2.3 which presents options packages which are to be used to comply with the amendments. The objective is to estimate the energy savings that would be obtained from implementing these groups of measures over the 2009 IECC code following the prescriptive path for compliance and determine whether or not the savings were above the 5% minimum limit set by the Houston Amendments.

## 3. Base Case Building Description

In order to assess the proposed savings over the 2009 IECC code a set of simulations was conducted using the RES3ST.inp (version 4.01.08) DOE-2.1e input file. TMY2 weather file for Harris County, Texas was used to simulate the weather conditions for Houston, Texas which is in Climate Zone 2 as per the IECC climate zone classification. Two base-case building simulation models were designed using the specifications described in the 2009 IECC code for the single-family and multi-family construction, and certain other assumptions. The single-family structure is a south facing single-story building with an area of 2,325 ft$^2$ (NAHB 2003). The multi-family model consists of 2 storied building with four units on each floor. The units are configured in a way that three walls of each unit are exposed to the exterior. The area of each multi-family unit is 1,006 ft$^2$ (NAHB 2003).

The base-case house is described in terms of the envelope, space conditions and systems. The envelope is described further, in terms of the following building components: above grade walls, ceilings, roofs, attics, doors and glazing. The above grade walls are of the wood frame type, with a cavity insulation of R-13. The ceilings are also of wood frame construction with the insulation of R-30 which is located on the ceiling. A vented unconditioned attic is modeled above the ceiling. Both the single-family and multi-family buildings have slab-on-grade floor construction for conditioned spaces adjacent to the ground.

The glazing for the single-family standard reference house is set at 15% of conditioned floor area (IECC 2009), and is equally distributed on four orientations (N, E, S & W). The glazing for the multi-family standard reference house is set at 8% of conditioned floor area (NAHB, 2003), and is equally distributed on two of the three exterior walls. The fenestration has a U-factor of 0.65 and SHGC of 0.3. There is no external shading.

The space conditions are described in terms of space temperature setpoint, air exchange rate, mechanical ventilation, and internal gains. Space temperature setpoints are set at 72°F for heating and 75°F for cooling. No set back is simulated. The attics are vented, with 1 $ft^2$ of leakage area per 300 $ft^2$ of ceiling area. The leakage of the conditioned area of the house is defined in terms of specific leakage area (SLA), which is set at 0.00036, assuming no energy recovery. The internal heat gains are calculated using information from Table 405.5.2(1) and Section 404.1 of the 2009 IECC. The following equation is obtained from Table 405.5.2(1):

$$I_{gain} = 17{,}900 + 23.8 \times CFA + 4104 \times N_{br.} \text{ (Btu/day per dwelling unit)}$$

Where CFA = Conditioned floor area and $N_{br}$ = Number of bedrooms

The resultant internal heat gain is divided between lighting and equipment using the procedure described in a report by Hendron et. al. (2008) which describes the Building America research benchmark building. The resultant lighting gain is further modified to match the specification in Section 404.1 of the 2009 IECC which requires the use of 50% of the lamps in permanently installed lighting fixtures to be high-efficacy lamps.

The mechanical systems are described in terms of provisions for mechanical ventilation, duct position, duct leakage, duct insulation, heating system, cooling system and service water heating systems. Annual vent fan energy usage due to mechanical ventilation is required in the base-case only when mechanical ventilation is required in the proposed design. For the single-family unit the ducts are positioned in the attic. For the multi-family units the ducts of the second floor units are positioned in the attic, while ducts of the first floor units are in conditioned space. The duct leakage for ducts positioned in the attic is set at 10% (5% for supply ducts and 5% for return ducts). The duct leakage for ducts in conditioned space is assumed to be 0. The value of both supply duct insulation for ducts positioned in the attic is set at R-8 and return duct insulation is set at R-6. Duct insulation for ducts in conditioned space is assumed to be adiabatic.

The cooling system fuel type is electric with minimum efficiency set at SEER13. The heating system uses natural gas as the fuel type with a minimum efficiency of 0.78 AFUE. The service water heating uses natural gas as fuel type. The tank temperature is set at 120°F. The efficiency of this water heater is dictated by the equation provided in Table 504.2 of the IECC 2009.

$$\text{Energy Factor for Electric Water Heaters} = 0.67 - 0.0019V$$

Where V = Storage capacity of the DHW tank

This results in a minimum efficiency of 0.594 for the single-family base-case and a minimum efficiency of 0.613 for multi-family base-case building. Domestic hot water usage is calculated using the equation provided in the Table 404.5.2(1) of the IECC 2009 code:

$$\text{Usage} = 30 + 10 \times N_{br} \text{ (gal/day)}$$

Specifications and assumptions for the single-family and multi-family units are presented in Table 1 and Table 2 below.

## Table 1: Specification for a Single-Family Standard Reference House

| Characteristics | Assumptions and Specifications | Information Source | Comments |
|---|---|---|---|
| **Building** | | | |
| **Building Type** | Single family, detached house | | |
| **Gross Area** | 2,325 sq. ft. (48.21 ft. x 48.21 ft.) | NAHB (2003) | |
| **Number of Floors** | 1 | NAHB (2003) | |
| **Floor to Floor Height (ft.)** | 8 | NAHB (2003) | |
| **Orientation** | South facing | | |
| **Construction** | | | |
| **Construction** | Light-weight wood frame with 2x4 studs spaced at 16" on center | NAHB (2003) | |
| **Floor** | Slab-on-grade floor | NAHB (2003) | |
| **Roof Configuration** | Unconditioned, vented attic | NAHB (2003) | |
| **Roof Absorptance** | 0.75 | 2009 IECC, Table 405.5.2(1) | |
| **Ceiling Insulation (hr-sq.ft.-°F/Btu)** | R-30 | 2009 IECC, Table 402.1.1 | Assuming insulation on ceiling. |
| **Wall Absorptance** | 0.75 | 2009 IECC, Table 405.5.2(1) | |
| **Wall Insulation (hr-sq.ft.-°F/Btu)** | R-13 | 2009 IECC, Table 402.1.1 | |
| **Slab Perimeter Insulation** | R-0 | 2009 IECC, Table 402.1.1 | |
| **U-Factor of Glazing (Btu/hr-sq.ft.-°F)** | 0.65 | 2009 IECC, Table 402.1.1 | |
| **Solar Heat Gain Coefficient (SHGC)** | 0.3 | 2009 IECC, Table 402.1.1 | |
| **Window Area** | 15% Window to Floor Area Ratio (WFAR) distributed equally on all orientations | 2009 IECC, Table 405.5.2(1) | This amounts to 348.88 sq. ft. of total window area with 22.61% window to wall area ratio for two exterior walls. |
| **Exterior Shading** | None | 2009 IECC, Table 405.5.2(1) | |
| **Roof Radiant Barrier** | No | | |
| **Space Conditions** | | | |
| **Space Temperature Set point** | 72°F Heating,<br>75°F Cooling,<br>No set-back | 2009 IECC, Table 405.5.2 (1) | |
| **Internal Heat Gains** | Lighting: 0.29 kW<br>Equipment: 0.63 kW | 2009 IECC, Section 404.1 | This assumes heat gains from lighting, equipment and occupants.<br>50% of installed permanent fixtures are high efficacy lamps as per code.<br>The % breakdown of the lighting and equipment component is adopted from Hendron et al. 2008. |
| **Number of Bedrooms** | 4 | | Calculated from area assigned to each unit. |
| **Mechanical Systems** | | | |
| **Mechanical Ventilation** | None, except when mechanical ventilation is specified.<br>Annual vent fan energy use:<br>kWhr/yr =<br>$0.03942 \times CFA + 29.565 \times (N_{br} + 1)$ | 2009 IECC, Table 405.5.2 (1) | |
| **HVAC System Type** | Electric cooling (air conditioner)<br>Natural gas heating (gas fired furnace) | | |
| **HVAC System Efficiency** | AC: SEER 13<br>Furnace: 0.78 AFUE | 2009 IECC, Table 503.2.3 (2), 503.2.3 (4) | |
| **Cooling Capacity (Btu/hr)** | 62,000 | | 450 sq. ft./ton. |
| **Heating Capacity (Btu/hr)** | 62,000 | | 1.0 x cooling capacity. |
| **DHW System Type** | 40-gallon tank type gas water heater | ASHRAE Applications Handbook (2003) | |
| **DHW Heater Energy Factor** | Gas<br>EF:0.594 | 2009 IECC, Table 504.2 | Gas: 0.67-0.0019 V EF,<br>Where V=storage volume (gal). |
| **Duct Location** | Attic | NAHB (2003) | |
| **Duct Leakage (% )** | 5.00% (supply & return) | 2009 IECC, Sec. 403.2.2 | Tested: 8 CFM/100 sq.ft. of CFA to outdoors.<br>Untested: DSE = 0.88 |
| **Duct Insulation (hr-sq.ft.-°F/Btu)** | R-8 (supply)<br>R-6 (return) | 2009 IECC, Sec. 403.2.1 | |
| **Supply Air Flow (CFM/ton)** | 360 | | |
| **Attic Infiltration** | 0.0033 | 2009 IECC, Table 405.5.2 (1) | 1 sq.ft. per 300 sq.ft. of ceiling area. |
| **Infiltration Rate (SG)** | SLA = 0.00036 | 2009 IECC, Table 405.5.2 (1), ASHRAE 119 Section 5.1 | |

## Table 2: Specification for a Multi-Family Standard Reference House

| Characteristics | Assumptions and Specifications | Information Source | Comments |
|---|---|---|---|
| **Building** | | | |
| **Building Type** | Multifamily unit<br>8 units per building | | |
| **Gross Area** | 1,006 sq. ft. (31.6 ft. x 31.6 ft.) | NAHB (2003) | |
| **Number of Floors (Entire building)** | 2 floors<br>4 units per floor | NAHB (2003) | |
| **Floor to Floor Height (ft.)** | 8 | NAHB (2003) | |
| **Number of Exposed Walls (Per unit)** | 3 exposed walls | | |
| **Construction** | | | |
| **Construction** | Light-weight wood frame with<br>2x4 studs spaced at 16" on center | NAHB (2003) | |
| **Floor** | Slab-on-grade floor for lower units | NAHB (2003) | |
| **Roof Configuration** | Unconditioned, vented attic | NAHB (2003) | |
| **Roof Absorptance** | 0.75 | 2009 IECC, Table 405.5.2(1) | |
| **Ceiling Insulation (hr-sq.ft.-°F/Btu)** | R-30 | 2009 IECC, Table 402.1.1 | Assuming insulation on ceiling. |
| **Wall Absorptance** | 0.75 | 2009 IECC, Table 405.5.2(1) | |
| **Wall Insulation (hr-sq.ft.-°F/Btu)** | R-13 | 2009 IECC, Table 402.1.1 | |
| **Slab Perimeter Insulation** | R-0 | 2009 IECC, Table 402.1.1 | |
| **U-Factor of Glazing (Btu/hr-sq.ft.-°F)** | 0.65 | 2009 IECC, Table 402.1.1 | |
| **Solar Heat Gain Coefficient (SHGC)** | 0.3 | 2009 IECC, Table 402.1.1 | |
| **Window Area** | 8% window to floor area ratio (WFAR)<br>distributed equally on 2 orientations | NAHB (2003) | This amounts to 79.38 sq. ft. of total window area with 15.7% window to wall area ratio for two exterior walls. |
| **Exterior Shading** | None | 2009 IECC, Table 405.5.2(1) | |
| **Roof Radiant Barrier** | No | | |
| **Space Conditions** | | | |
| **Space Temperature Set point** | 72°F Heating,<br>75°F Cooling,<br>No set-back | 2009 IECC, Table 405.5.2 (1) | |
| **Internal Heat Gains** | Lighting: 0.16 kW<br>Equipment: 0.36 kW | 2009 IECC, Section 404.1 | This assumes heat gains from lighting, equipment and occupants.<br>50% of installed permanent fixtures are high efficacy lamps as per code.<br>The % breakdown of the lighting and equipment component is adopted from Hendron et al. 2008. |
| **Number of Bedrooms** | 2 | | Calculated from the area assigned to each unit. |
| **Mechanical Systems** | | | |
| **Mechanical Ventilation** | None, except when mechanical ventilation is specified.<br>Annual vent fan energy use:<br>kWhr/yr =<br>$0.03942 \times CFA + 29.565 \times (N_{br} + 1)$ | 2009 IECC, Table 405.5.2 (1) | |
| **HVAC System Type** | Electric cooling (air conditioner) and<br>Natural gas heating (gas fired furnace) | | |
| **HVAC System Efficiency** | AC: SEER 13<br>Furnace: 0.78 AFUE | 2009 IECC,<br>Table 503.2.3 (2), 503.2.3 (4) | |
| **Cooling Capacity (Btu/hr)** | 26,826 | | 450 sq. ft./ton. |
| **Heating Capacity (Btu/hr)** | 26,826 | | 1.0 x cooling capacity. |
| **DHW System Type** | 30-gallon tank type gas water heater | ASHRAE Applications Handbook (2003) | |
| **DHW Heater Energy Factor** | Gas<br>EF: 0.613 | 2009 IECC, Table 504.2 | Gas: 0.67-0.0019 V EF<br>Electric: 0.97-0.00132 V EF<br>Where V=storage volume (gal.). |
| **Duct Location** | Top Floor: Unconditioned, vented attic | NAHB (2003) | |
| | Lower Floor: In conditioned space | NAHB (2003) | |
| **Duct Leakage (%)** | Top Floor: 5.0% (supply & return) | 2009 IECC, Sec. 403.2.2 | Tested: 8 CFM/100 sq.ft. of CFA to outdoors. |
| | Lower Floor: 0% | | |
| **Duct Insulation (hr-sq.ft.-°F/Btu)** | Top Floor: R-8 (supply)<br>R-6 (return) | 2009 IECC, Sec. 403.2.1 | |
| | Lower Floor: Adiabatic | | |
| **Supply Air Flow (CFM/ton)** | 360 | | |
| **Attic Infiltration** | 0.0033 (Top floor only) | 2009 IECC, Table 405.5.2 (1) | 1 sq.ft. per 300 sq.ft. of ceiling area. |
| **Infiltration Rate (SG)** | SLA = 0.00036 | 2009 IECC, Table 405.5.2 (1), ASHRAE 119 Section 5.1 | |

## 4. Proposed Energy Efficiency Measures

Efficiency measures to be assessed consisted of measures for the envelope, lighting, space conditions, mechanical systems and domestic hot water heating systems as well as options for on-site renewable energy generation. The efficiency measures included measures for the building envelope such as installation of radiant barrier under roofs, improved U-value specifications for glazing; efficiency measures for improving space conditions such as the use of compact florescent lamps (CFLs) and decreased infiltration; measures to improve the performance and efficiency of mechanical systems such as decreased duct leakage, mechanical systems in conditioned spaces, improved air-conditioner and furnace efficiency; measures to improve the efficiency of domestic hot water heating which includes the installation of tankless water heaters and solar domestic water heating; and measures that call for the generation of on-site electricity using photovoltaic (PV) arrays.

These measures were grouped together by the City of Houston Authorities in order to provide option packages for single-family units as well as for multi-family units. As per the amendments, adoption of any single group should achieve a minimum five percent improvement above the minimum provisions of the 2009 IECC code. There are eleven groups of efficiency measures for the single-family units (Electric/Natural Gas), seven groups of efficiency measures for the multi-family units (Electric/Natural Gas) and five groups of efficiency measures for the multifamily units (All-Electric). The groups are presented in Table 5, Table 6 and Table 7 below.

The first and second sub-sections describe the equipment used in the installation of the solar domestic hot water system and the equipment used in the installation of the photovoltaic array for on-site renewable energy production. The third subsection describes the impact of mechanical ventilation on infiltration calculations.

### *4.1 Solar Domestic Hot Water System*

The amendments require the installation of a solar domestic water system with 64 $ft^2$ of collector area and a 80 gallon storage hot water tank. The specifications for the flat plate collectors and the storage tank selected for this analysis are provided below:

**Solar Collector:**
Collector Size:
- 47.2 in. x 97.2 in. - For Single-Family Unit
- 47.2 in. x 97.2 in. - For Multi-Family Unit

Number of collectors: 1
Gross Collector Area per Collector:
- 31.91 $ft^2$ - For Single-Family Unit
- 20.78 $ft^2$ - For Multi-Family Unit

Aperture Area per Collector:
- 29.93 $ft^2$. - For Single-Family Unit
- 19.20 $ft^2$. - For Multi-Family Unit

**Storage tank/ Heat exchanger:**
Capacity:
- 40 gallons - For Single-Family Unit
- 30 gallons- For Multi-Family Unit

Dimensions: 58-3/4 inch height, 24-1/2 inch diameter
Insulation: R-17.3

*4.2 Photovoltaic (PV) Array Installation*

The amendments require the installation of PV arrays for 6kW, 4kW and 2kW to fully or partially meet the electricity requirements of the base-case units by means of on-site renewable energy generation. This requirement is equivalent to the installation of 10, 20 or 30 panels at 205 watts at a minimum of 16% efficiency. Specifications of the PV arrays selected for this analysis are provided below:

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

*4.3 Accounting for Mechanical Ventilation*

As per Table 405.5.2(1) of the 2009 IECC for residences with mechanical ventilation rate that are tested – measured air exchange rate combined with the mechanical ventilation rate which shall not be less than:

$$Q = 0.01 \times CFA + 7.5 \times (Nbr + 1)$$

Where:

Q = mechanical ventilation rate (cfm)

CFA = Conditioned floor area

Nbr = Number of bedrooms

The mechanical ventilation for a 2,325 $ft^2$ house with 4 bedrooms is equal to:

$$0.01 \times 2325 + 7.5 \times (4 + 1) = 60.75 \text{ cfm}$$

This translates to 0.20 $ACH_n$[1].

The mechanical ventilation for a 1006 $ft^2$ house with 2 bedrooms is equal to:

$$0.01 \times 1006 + 7.5 \times (2 + 1) = 32.56 \text{ cfm}$$

This translates to 0.24 $ACH_n$[1].

As per section 4.4 of ASHRAE Standard-136 1993 (RA 2006), the air change rate provided by ventilation fans operating during a particular time period i shall be combined with that provided by infiltration $A_I$ to find the combined effective air change rate $A_{Ei}$ that applies during that time period. The combined effective air change rate shall be calculated using:

$$A_{Ei} = A_{Si} + ((A_{Li} - A_{Si})^2 + A_I{}^2)^{0.5}$$

Where

$A_I$ = Infiltration rate (ACHn),

$A_{Li}$ = Larger of the total supply fan flow and the total exhaust fan flow during the time period i and

$A_{Si}$ = The smaller of the total supply fan flow and the total exhaust fan flow during the time period i.

As per the HA recommendations the reduced infiltration rate is set at 5ACH50 which translates to 0.25 ACHn.

Assuming no exhaust fans, for 2325 $ft^2$ building:

$$A_{Ei} = 0 + ((0.20 - 0)^2 + 0.25^2)^{0.5}$$

[1] ACHn = cfm x 60/Conditioned Volume

$$A_{Ei} = 0.32\ ACH_n$$

Assuming no exhaust fans, for 1006 ft$^2$ building:

$$A_{Ei} = 0 + ((0.24 - 0)^2 + 0.25^2)^{0.5}$$

$$A_{Ei} = 0.35\ ACH_n$$

Also, depending on the operation of the supply fan the combined effective air change rate shall be calculated for each combination of operation of fans using the above equation. The annual value of the combined effective air change rate shall be calculated using:

$$A_E = \frac{8760}{\sum_{i=1}^{n}(\frac{\tau_i}{A_{Ei}})}$$

where

$\tau_i$ =The time per year for which the particular combination of operating fans used to calculate $A_{Ei}$ was in effect

n = the number of time periods in the year with different values of $A_{Ei}$.

Table 3 presents the calculation summary of incorporating the mechanical ventilation system in the calculations for infiltration for the whole house. This calculation is performed assuming that the mechanical ventilation system operates for 10 minutes every 60 minutes, for 2325 ft$^2$ building (Approximately 20% runtime):

**Table 3: Calculation Summary for Mechanical Ventilation System for a 2325 ft$^2$ Building**

| n | $A_{Si} + ((A_{Li} - A_{Si})^2 + A_I{}^2)^{0.5}$ | $A_{Ei}$ | $\tau_i$ | $\frac{\tau}{A_{Ei}}$ |
|---|---|---|---|---|
| 1 | $0 + ((0.20 - 0)^2 + 0.25^2)^{0.5}$ | 0.32 | 1,460 | 4,563 |
| 2 | $0 + ((0 - 0)^2 + 0.25^2)^{0.5}$ | 0.25 | 7,008 | 28,032 |
| | | TOTAL | **8,760** | **33,763** |

Hence the combined effective air change can be calculated as:

$$A_E = \frac{8760}{\sum_{i=1}^{n}(\frac{\tau}{A_{Ei}})}$$

$$= 8760 / 33{,}763$$

$$= 0.26\ \text{ACHn}$$

Assuming the mechanical ventilation system operates for 10 minutes every 60 minutes, for 1006 ft$^2$ building (Approximately 20% runtime):

**Table 4: Calculation Summary for Mechanical Ventilation System for a 1006 ft$^2$ Building**

| n | $A_{Si} + ((A_{Li} - A_{Si})^2 + A_I{}^2)^{0.5}$ | $A_{Ei}$ | $\tau_i$ | $\frac{\tau}{A_{Ei}}$ |
|---|---|---|---|---|
| 1 | $0 + ((0.24 - 0)^2 + 0.25^2)^{0.5}$ | 0.35 | 1,460 | 4,171 |
| 2 | $0 + ((0 - 0)^2 + 0.25^2)^{0.5}$ | 0.25 | 7,008 | 28,032 |
| | | TOTAL | **8,760** | **33,371** |

Hence the combined effective air change can be calculated as:

$$A_E = \frac{8760}{\sum_{i=1}^{n}(\frac{\tau}{A_{Ei}})}$$

$$= 8760 / 33{,}371$$

= 0.26 ACHn

**Table 5: Combined Energy-Savings for Single-Family Units (Electricity/Natural Gas)**

| Groups | Measures | Notes |
|---|---|---|
| Group 1 | • Solar Domestic Hot Water System (32 $ft^2$ collector area/unit) | 1 |
| Group 2 | • Photovoltaic Array for 6kW | 2 |
| Group 3 | • Photovoltaic Array for Partial Demand at 4kW | 3 |
| Group 4 | • Photovoltaic Array for Partial Demand at 2kW | 4 |
| Group 5 | • Mechanical Systems within Conditioned Spaces | 5 |
| Group 6 | • 75% Energy Star CFL Indoor Lamps<br>• Radiant Barrier<br>• Decreased Duct Leakage to outside (maximum 4.8 cfm/100 $ft^2$ of conditioned floor area)<br>• 14 SEER AC | 6<br>8<br>9<br>12 |
| Group 7 | • 75% Energy Star CFL Indoor Lamps<br>• Decreased Duct Leakage to outside (maximum 4.8 cfm/100 $ft^2$ of conditioned floor area)<br>• Improved SEER (minimum 15) | 6<br>9<br>13 |
| Group 8 | • Improved Furnace Efficiency (minimum .93 AFUE)<br>• Decreased Infiltration 5 ACH50<br>• Decreased Duct Leakage to outside (maximum 4.8 cfm/100 $ft^2$ of conditioned floor area)<br>• Improved SEER (minimum 15) | 15<br>11<br>9<br>13 |
| Group 9 | • 75% Energy Star CFL Indoor Lamps<br>• Tankless water heater (minimum .748 Energy Factor) | 6<br>10 |
| Group 10 | • 100% Energy Star CFL Indoor Lamps | 7 |
| Group 11 | • Decreased U-Factor (maximum .50) | 14 |

**Table 6: Combined Energy-Savings for Multi-Family Units (Electricity/Natural Gas)**

| Groups | Measures | Notes |
|---|---|---|
| Group 1 | • Solar Domestic Hot Water System (21 $ft^2$ collector area/unit) | 1 |
| Group 2 | • Photovoltaic Array for 2kW/unit | 4 |
| Group 3 | • 75% Energy Star CFL Indoor Lamps<br>• Tankless water heater (minimum .748 Energy Factor)<br>• Decreased Infiltration 5 ACH50 | 6<br>10<br>11 |
| Group 4 | • Tankless water heater (minimum .748 Energy Factor)<br>• Decreased Duct Leakage to outside (4.8 cfm/100 $ft^2$ of conditioned floor area)<br>Upper Floor Only<br>• Improved SEER (minimum 14) | 10<br>9<br>12 |
| Group 5 | • Mechanical Systems within Conditioned Spaces Upper Floor Only | 5 |
| Group 6 | • Decreased Infiltration 5 ACH50<br>• Improved SEER (minimum 14)<br>• Improved Furnace Efficiency (minimum .93 AFUE)<br>• 75% Energy Star CFL Indoor Lamps | 11<br>12<br>15<br>6 |
| Group 7 | • Tankless water heater (minimum .748 Energy Factor)<br>• Decreased Duct Leakage to outside (maximum 4.8 cfm/100 $ft^2$ of conditioned floor area)<br>Upper Floor Only<br>• 75% Energy Star CFL Indoor Lamps<br>• Decreased U-Factor (maximum .35) | 10<br>9<br>6<br>14 |

**Table 7: Combined Energy-Savings for Multi-Family Units (All-Electric)**

| Groups | Measures | Notes |
|---|---|---|
| Group 1 | • Photovoltaic Array for 2kW/unit | 4 |
| Group 2 | • Solar Domestic Hot Water System (21 $ft^2$ collector area/unit) | 1 |
| Group 3 | • 75% Energy Star CFL Indoor Lamps<br>• Mechanical Systems within Conditioned Spaces Upper Floor Only<br>• Improved SEER (minimum 14)<br>• Decreased U-Factor (maximum .35)<br>• Decreased Infiltration 5 ACH50 | 6<br>5<br>12<br>14<br>11 |
| Group 4 | • Tankless water heater (minimum .97 Energy Factor)<br>• Decreased Duct Leakage to outside (4.8 cfm/100 $ft^2$ of conditioned floor area) Upper Floor Only<br>• Improved SEER (minimum 14)<br>• Decreased Infiltration 5 ACH50<br>• 75% Energy Star CFL Indoor Lamps<br>• Decreased U-Factor (maximum .35) | 10<br>9<br>12<br>11<br>6<br>14 |
| Group 5 | • 75% Energy Star CFL Indoor Lamps<br>• Decreased Duct Leakage to outside (4.8 cfm/100 $ft^2$ of conditioned floor area) Upper Floor Only<br>• Improved SEER (minimum 14)<br>• Decreased U-Factor (maximum .35)<br>• Decreased Infiltration 5 ACH50 | 6<br>9<br>12<br>14<br>11 |

**Notes:**

1. Solar Domestic Hot Water System: *For single-family, storage tank type 40 gallon DHW heater with 32 square feet collector area. For multi-family, storage tank type 30 gallon DHW heater with 21 square feet collector area*
2. Photovoltaic Array for 6kW: *Equivalent to 30 panels at 205 watts each at minimum 16% efficiency*
3. Photovoltaic Array for Partial Demand at 4kW: *Equivalent to 20 panels at 205 watts each at minimum 16% efficiency*
4. Photovoltaic Array for Partial Demand at 2kW: *Equivalent to 10 panels at 205 watts each at minimum 16% efficiency*
5. Mechanical Systems within Conditioned Spaces: *Ducts in ventilated attic moved to location within the thermal envelope of conditioned space including unventilated attic space*
6. 75% Energy Star CFL/LED Indoor Lamps: *Permanent compact florescent lamps excluding closets*
7. 100% Energy Star CFL/LED Indoor Lamps: *Permanent compact florescent lamps excluding closets*
8. Radiant Barrier is ASTM C1371
9. Decreased Duct Leakage (from maximum 8cfm/100 $ft^2$ to 4.8 cfm/100 $ft^2$): *Ducts tested with less than or equal to 4.8 cfm/ 100 $ft^2$ of conditioned floor area leakage to the outside*
10. Tankless water heater (from .93 to .98 Energy Factor for All-Electric residential unit) *Manufacturer's rating*
11. Decreased Infiltration (from 7 ACH to 5 ACH): tested with a blower door at a pressure of 33.5 psf (50 Pa). Provisions for mechanical ventilation, the rate of which shall not be less than 0.01 x CFA + 7.5 x (Nbr +1).
12. Improved SEER (from 13 to 14): *Manufacturer's rating*
13. Improved SEER (from 13 to 15): *Manufacturer's rating*
14. Decreased U-factor (from .65 to .35): *NFRC 100 and 200*

## 5. Results and Conclusions

Table 8 presents the results of the simulation runs for the single-family unit (Electric/Natural Gas), Table 9 presents the results of the simulation runs for the multi-family unit (Electric/Natural Gas) and Table 10 presents the results of the simulation runs for the multi-family unit (All-Electric). Site energy consumption is presented in these tables. The total end-use energy consumption is provided in Appendix A of this report.

For the single-family unit (Electric/Natural Gas), savings are in the range of 5% and 32%. Maximum savings are obtained from installing a photovoltaic array to generate 6 kW of electricity resulting in site energy savings of 32%. Group 10 specifying 100% EnergyStar CFL Indoor Lamps is the least effective measure with site energy savings of 5%.

For the multi-family units (Electric/Natural Gas), when considering the site energy consumption, savings are in the range of 3% and 22%. Maximum savings of 22% are obtained from installing a photovoltaic array generating 2 kW of electricity per unit. Group 5 specifying mechanical systems in conditioned space for upper floors of the multi-family unit is the least effective measure with the energy saving of 3%. This measure does not qualify for the 5% above code criteria which is to be met to comply with the Houston Amendments.

Finally, for the multi-family units (All-Electric), when considering the site energy consumption, savings are in the range of 7% and 26%. Maximum savings of 26% are obtained from implementing Group 2 which specifies the installation of a photovoltaic array generating 2 kW of electricity per unit. Group 1 specifying solar domestic hot water heaters is the least effective measure which on implementation results in site energy savings of 7%.

It was noted that the only group that failed to meet the 5% above code requirements for Houston Amendments is Group 5 of the provisions for multi-family units (Electric/Natural Gas). It is recommended that this group measure be removed from the amendments.

**Table 8: Annual Energy Savings Obtained from Implementing Grouped Efficiency Strategies for Single-Family Units (Electric/Natural Gas)**

| EFFICIENCY MEASURES FOR SINGLE-FAMILY UNITS (Electric / Natural Gas) | | 2009 Site Energy |
|---|---|---|
| **Groups** | **Measures** | |
| Group 1 | Solar Domestic Hot Water System (32 sq.ft. collector area/unit) | 9% |
| Group 2 | Photovoltaic Array for 6kW | 32% |
| Group 3 | Photovoltaic Array for Partial Demand at 4kW | 21% |
| Group 4 | Photovoltaic Array for Partial Demand at 2kW | 11% |
| Group 5 | Mechanical Systems within Conditioned Spaces | 8% |
| Group 6 | Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Radiant Barrier<br>Decreased Duct Leakage to Outside: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area<br>Improved SEER: 14 SEER | 8% |
| Group 7 | Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Decreased Duct Leakage to Outside: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area<br>Improved SEER: 15 SEER | 7% |
| Group 8 | Improved AFUE: 0.93 AFUE<br>Decreased Infiltration: 5 $ACH_{50}$<br>Decreased Duct Leakage to Outside: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area<br>Improved SEER: 15 SEER | 11% |
| Group 9 | Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Improved DHW System Efficiency: Tankless Water Heater, Energy Factor: 0.748 | 6% |
| Group 10 | Reduced Internal Heat Gain: 100% Energy Star CFL Indoor Lamps | 5% |
| Group 11 | Improved Windows: Decreased U-Factor (U-0.35) | 7% |

**Table 9: Annual Energy Savings Obtained from Implementing Grouped Efficiency Strategies for Multi-Family Units (Electric/Natural Gas)**

| EFFICIENCY MEASURES FOR MULTI-FAMILY UNITS (Electric / Natural Gas) | | Site Energy |
|---|---|---|
| **Groups** | **Measures** | |
| Group 1 | Solar Domestic Hot Water System (21 sq.ft. collector area/unit) | 13% |
| Group 2 | Photovoltaic Array for 2kW/Unit | 22% |
| Group 3 | Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Improved DHW System Efficiency: Tankless water heater, Energy Factor: 0.748<br>Decreased Infiltration: 5 $ACH_{50}$ | 11% |
| Group 4 | Improved DHW System Efficiency: Tankless Water Heater, Energy Factor: 0.748<br>Decreased Duct Leakage to Outside: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area (Upper Floor Only)<br>Improved SEER: 14 SEER | 10% |
| Group 5 | Mechanical Systems within Conditioned Spaces (Upper Floor Only) | 3% |
| Group 6 | Decreased Infiltration: 5 $ACH_{50}$<br>Improved SEER: 14 SEER<br>Improved AFUE: 0.93 AFUE<br>Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps | 9% |
| Group 7 | Improved DHW System Efficiency: Tankless water heater, Energy Factor: 0.748<br>Decreased Duct Leakage to Outside: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area (Upper Floor Only)<br>Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Improved Windows: Decreased U-Factor (U-0.35) | 14% |

Note: Shaded cells indicate the group fails to achieve higher than 5% of energy savings above the 2009 IECC code.

**Table 10: Annual Energy Savings Obtained from Implementing Grouped Efficiency Strategies for Multi-Family Units (All-Electric)**

| EFFICIENCY MEASURES FOR MULTI-FAMILY UNITS (All Electric) | | Site Energy |
|---|---|---|
| **Groups** | **Measures** | |
| Group 1 | Solar Domestic Hot Water System (21 sq.ft. collector area/unit) | 7% |
| Group 2 | Photovoltaic Array for 2kW/Unit | 26% |
| Group 3 | Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Mechanical in Conditioned Space (Upper Floor Only)<br>Improved SEER: 14 SEER<br>Improved Windows: Decreased U-Factor (U-0.35)**<br>Decreased Infiltration: 5 $ACH_{50}$ * | 13% |
| Group 4 | Improved DHW System Efficiency: Tankless Water Heater, Energy Factor 0.98****<br>Decreased Duct Leakage: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area (Upper Floor Only)***<br>Improved SEER:14 SEER<br>Decreased Infiltration: 5 $ACH_{50}$*<br>Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Improved Windows: Decreased U-Factor (U-0.35)** | 12% |
| Group 5 | Reduced Internal Heat Gain: 75% Energy Star CFL Indoor Lamps<br>Decreased Duct Leakage: 4.8 cfm per 100 sq.ft. of Conditioned Floor Area (Upper Floor Only)***<br>Improved SEER: 14 SEER<br>Improved Windows: Decreased U-Factor (U-0.35)**<br>Decreased Infiltration: 5 $ACH_{50}$* | 11% |

## 6. References

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## Appendix 1: End-Use Energy Consumption

### Table A- 1: End-Use Energy Consumption for Single-Family Units (Electric/Natural Gas) on Implementing Group Strategies

| | IECC 2009 Test Cases | From F & PVF Chart | | | | | | ENERGY CONSUMPTION (MMBtu) | | | | | | | 2009 Site Energy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | On-Site Renewable Energy | Total | Total 2009 Source | Electricity | Electricity C+P+V | Gas | Lights | Equip | Heat | Cool | Pumps & Misc | Vent Fans | DHW | % Diff. |
| GROUP MEASURES FOR SINGLE FAMILY UNITS (Electric / Natural Gas) | Base-case | | 88.1 | 100.6 | 44.2 | 16.7 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | 8.5% |
| | Group 1 | | 80.6 | 95.3 | 45.6 | 18.1 | 35.0 | 8.7 | 18.8 | 27.2 | 12.0 | 1.6 | 4.5 | 7.8 | |
| | Base-case | | 88.1 | 100.6 | 44.2 | 16.7 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | 32.2% |
| | Group 2 | 28.38 | 59.7 | 48.2 | 15.8 | 0.0 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | |
| | Base-case | | 88.1 | 100.6 | 44.2 | 16.7 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | 21.5% |
| | Group 3 | 18.92 | 69.2 | 48.2 | 25.3 | 0.0 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | |
| | Base-case | | 88.1 | 100.6 | 44.2 | 16.7 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | 10.7% |
| | Group 4 | 9.46 | 78.6 | 70.9 | 34.7 | 7.2 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | |
| | Base-case | | 88.1 | 100.6 | 44.2 | 16.7 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | 7.8% |
| | Group 5 | | 81.2 | 88.2 | 41.8 | 14.3 | 39.4 | 8.7 | 18.8 | 22.8 | 10.3 | 0.2 | 3.8 | 16.6 | |
| | Base-case | | 88.1 | 100.6 | 44.2 | 16.7 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | 7.8% |
| | Group 6 | | 81.2 | 88.2 | 37.6 | 12.8 | 43.6 | 6.0 | 18.8 | 27.0 | 9.6 | 0.2 | 3.0 | 16.6 | |
| | Base-case | | 88.1 | 100.6 | 44.2 | 16.7 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | 7.5% |
| | Group 7 | | 81.5 | 88.1 | 37.4 | 12.6 | 44.1 | 6.0 | 18.8 | 27.5 | 9.2 | 0.2 | 3.2 | 16.6 | |
| | Base-case | | 88.1 | 100.6 | 44.2 | 16.7 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | 7.8% |
| | Group 8A | | 81.2 | 88.2 | 41.8 | 14.3 | 39.4 | 8.7 | 18.8 | 22.8 | 10.3 | 0.2 | 3.8 | 16.6 | |
| | Base-case | | 88.9 | 103.2 | 45.0 | 17.5 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 5.3 | 16.6 | 11.2% |
| | Group 8 | | 78.9 | 84.3 | 41.1 | 13.6 | 37.8 | 8.7 | 18.8 | 21.2 | 9.4 | 0.2 | 4.0 | 16.6 | |
| | Base-case | | 88.1 | 100.6 | 44.2 | 16.7 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | 6.5% |
| | Group 9 | | 82.4 | 96.4 | 41.0 | 16.2 | 41.4 | 6.0 | 18.8 | 28.3 | 11.6 | 0.2 | 4.4 | 13.1 | |
| | Base-case | | 88.1 | 100.6 | 44.2 | 16.7 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | 4.5% |
| | Group 10 | | 84.1 | 99.8 | 38.1 | 15.7 | 45.9 | 3.6 | 18.8 | 29.3 | 11.2 | 0.2 | 4.3 | 16.6 | |
| | Base-case | | 88.1 | 100.6 | 44.2 | 16.7 | 43.8 | 8.7 | 18.8 | 27.2 | 12.0 | 0.2 | 4.5 | 16.6 | 7.2% |
| | Group 11 | | 81.8 | 93.8 | 44.2 | 16.7 | 37.6 | 8.7 | 18.8 | 21.0 | 12.2 | 0.2 | 4.3 | 16.6 | |

**Notes:**
For the option of solar water heaters the energy use of a pump (1/3 hp) has been added to the simulation results with an assumption that the pump runs for 12 hours a day every day of the year.
When considering the option of mechanical ventilation, a fan energy for a 2325 $ft^2$ house w/ 4 bedrooms was added.

**Table A- 2: End-Use Energy Consumption for Multi-Family Units (Electric/Natural Gas) on Implementing Group Strategies**

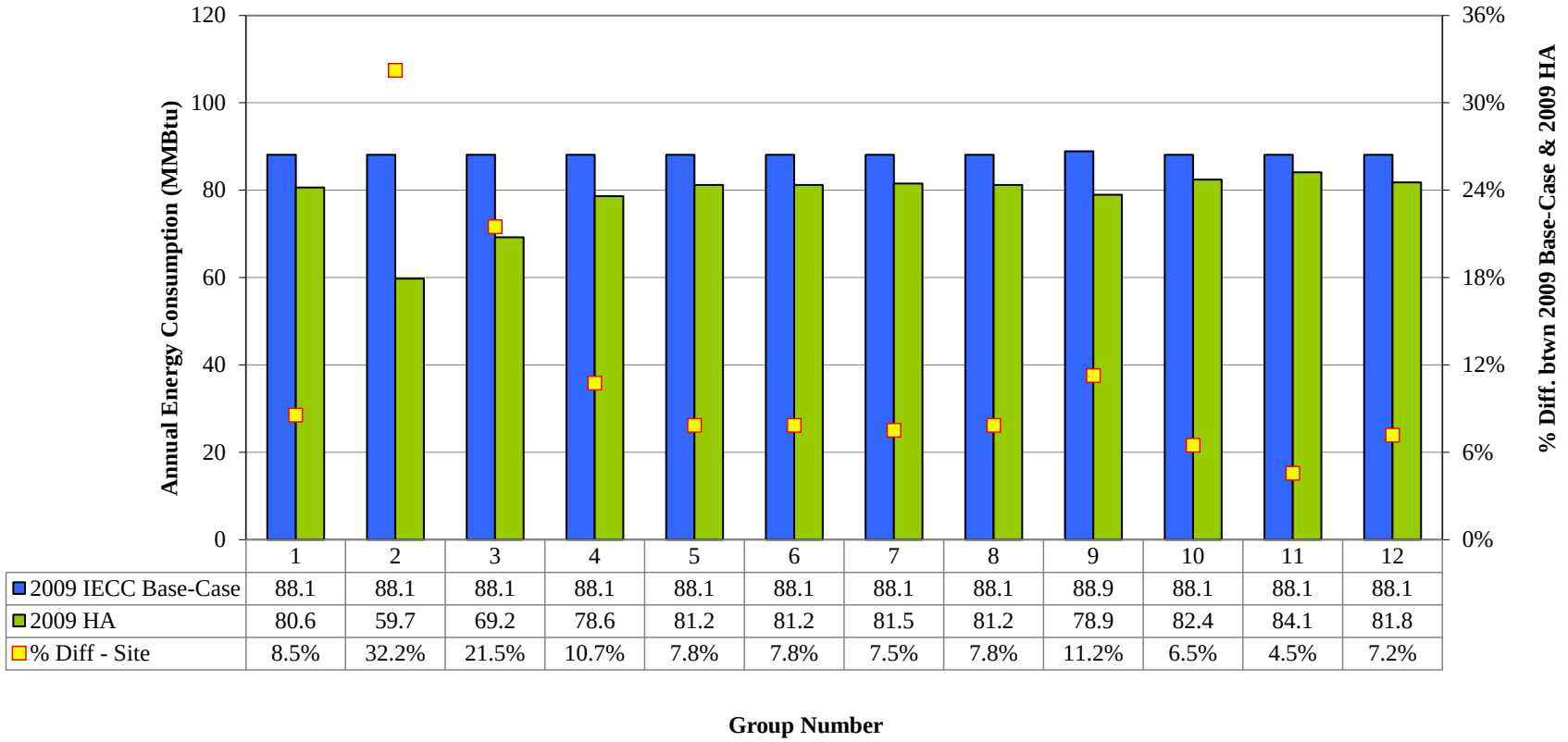
| | IECC 2009 Test Cases | From F & PVF Chart | | | | | | ENERGY CONSUMPTION (MMBtu) | | | | | | | 2009 Site Energy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | On-Site Renewable Energy | Total | Total 2009 Source | Electricity | Electricity C+P+V | Gas | Lights | Equip | Heat | Cool | Pumps & Misc | Vent Fans | DHW | % Diff. |
| GROUP MEASURES FOR MULTI-FAMILY UNITS (Electric / Natural Gas) | Base-case | | 344.0 | 362.7 | 184.4 | 59.6 | 159.6 | 38.4 | 86.4 | 59.6 | 43.4 | 1.6 | 14.6 | 100.0 | 12.7% |
| | Group 1 | | 300.3 | 337.4 | 195.5 | 70.7 | 104.8 | 38.4 | 86.4 | 59.6 | 43.4 | 12.7 | 14.6 | 45.2 | |
| | Base-case | | 344.0 | 362.7 | 184.4 | 59.6 | 159.6 | 38.4 | 86.4 | 59.6 | 43.4 | 1.6 | 14.6 | 100.0 | 22.0% |
| | Group 2 | 75.69 | 268.3 | 175.6 | 108.7 | 0.0 | 159.6 | 38.4 | 86.4 | 59.6 | 43.4 | 1.6 | 14.6 | 100.0 | |
| | Base-case | | 347.5 | 373.7 | 187.9 | 63.1 | 159.6 | 38.4 | 86.4 | 59.6 | 43.4 | 1.6 | 18.1 | 100.0 | 11.4% |
| | Group 3 | | 307.9 | 336.9 | 172.4 | 59.6 | 136.1 | 26.4 | 86.4 | 60.1 | 40.5 | 1.6 | 17.5 | 76.0 | |
| | Base-case | | 344.0 | 362.7 | 184.4 | 59.6 | 159.6 | 38.4 | 86.4 | 59.6 | 43.4 | 1.6 | 14.6 | 100.0 | 9.8% |
| | Group 4 | | 310.2 | 306.4 | 175.1 | 50.3 | 135.0 | 38.4 | 86.4 | 59.0 | 38.0 | 1.6 | 10.7 | 76.0 | |
| | Base-case | | 344.0 | 362.7 | 184.4 | 59.6 | 159.6 | 38.4 | 86.4 | 59.6 | 43.4 | 1.6 | 14.6 | 100.0 | 3.0% |
| | Group 5 | | 333.7 | 341.3 | 179.5 | 54.7 | 154.1 | 38.4 | 86.4 | 54.1 | 39.8 | 1.6 | 13.3 | 100.0 | |
| | Base-case | | 347.5 | 373.7 | 187.9 | 63.1 | 159.6 | 38.4 | 86.4 | 59.6 | 43.4 | 1.6 | 18.1 | 100.0 | 9.1% |
| | Group 6 | | 315.8 | 329.6 | 164.9 | 52.1 | 150.9 | 26.4 | 86.4 | 50.9 | 36.6 | 1.6 | 13.9 | 100.0 | |
| | Base-case | | 344.0 | 362.7 | 184.4 | 59.6 | 159.6 | 38.4 | 86.4 | 59.6 | 43.4 | 1.6 | 14.6 | 100.0 | 14.0% |
| | Group 7 | | 296.0 | 315.3 | 168.4 | 55.6 | 127.9 | 26.4 | 86.4 | 51.9 | 40.6 | 1.6 | 13.4 | 76.0 | |

**Notes:**
For the option of solar water heaters the energy use of a pump (1/3 hp) has been added to the simulation results with an assumption that the pump runs for 12 hours a day every day of the year.
When considering the option of mechanical ventilation, a fan energy for a 2325 $ft^2$ house w/ 4 bedrooms was added.

**Table A- 3: End-Use Energy Consumption for Single-Family Units (All-Electric) on Implementing Group Strategies**

| | IECC 2009 Test Cases | From F & PVF Chart | | | | | | ENERGY CONSUMPTION (MMBtu) | | | | | | | 2009 Site Energy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | On-Site Renewable Energy | Total | Total 2009 Source | Electricity | Electricity C+P+V | Gas | Lights | Equip | Heat | Cool | Pumps & Misc | Vent Fans | DHW | % Diff. |
| GROUP MEASURES FOR MULTIFAMILY FAMILY UNITS (All Electric) | Base-case | | 288.6 | 515.3 | 288.9 | 164.1 | | 38.4 | 86.4 | 42.1 | 43.4 | 1.6 | 14.6 | 62.4 | 7.3% |
| | Group 1 | | 267.4 | 447.9 | 267.4 | 142.6 | | 38.4 | 86.4 | 42.1 | 43.4 | 12.7 | 14.6 | 29.8 | |
| | Base-case | | 285.9 | 506.8 | 286.2 | 161.4 | | 38.4 | 86.4 | 39.4 | 43.4 | 1.6 | 14.6 | 62.4 | 25.5% |
| | Group 2 | 75.69 | 212.9 | 277.6 | 213.2 | 88.4 | | 38.4 | 86.4 | 42.1 | 43.4 | 1.6 | 14.6 | 62.4 | |
| | Base-case | | 292.1 | 526.3 | 292.4 | 167.6 | | 38.4 | 86.4 | 42.1 | 43.4 | 1.6 | 18.1 | 62.4 | 12.9% |
| | Group 3 | | 254.3 | 434.3 | 251.1 | 138.3 | | 26.4 | 86.4 | 31.2 | 33.9 | 1.6 | 9.2 | 62.4 | |
| | Base-case | | 292.1 | 526.3 | 292.4 | 167.6 | | 38.4 | 86.4 | 42.1 | 43.4 | 1.6 | 18.1 | 62.4 | 12.5% |
| | Group 4 | | 255.6 | 448.1 | 255.5 | 142.7 | | 26.4 | 86.4 | 33.7 | 35.7 | 1.6 | 13.3 | 58.4 | |
| | Base-case | | 292.1 | 526.3 | 292.4 | 167.6 | | 38.4 | 86.4 | 42.1 | 43.4 | 1.6 | 18.1 | 62.4 | 11.2% |
| | Group 5 | | 259.3 | 460.7 | 259.5 | 146.7 | | 26.4 | 86.4 | 33.7 | 35.7 | 1.6 | 13.3 | 62.4 | |

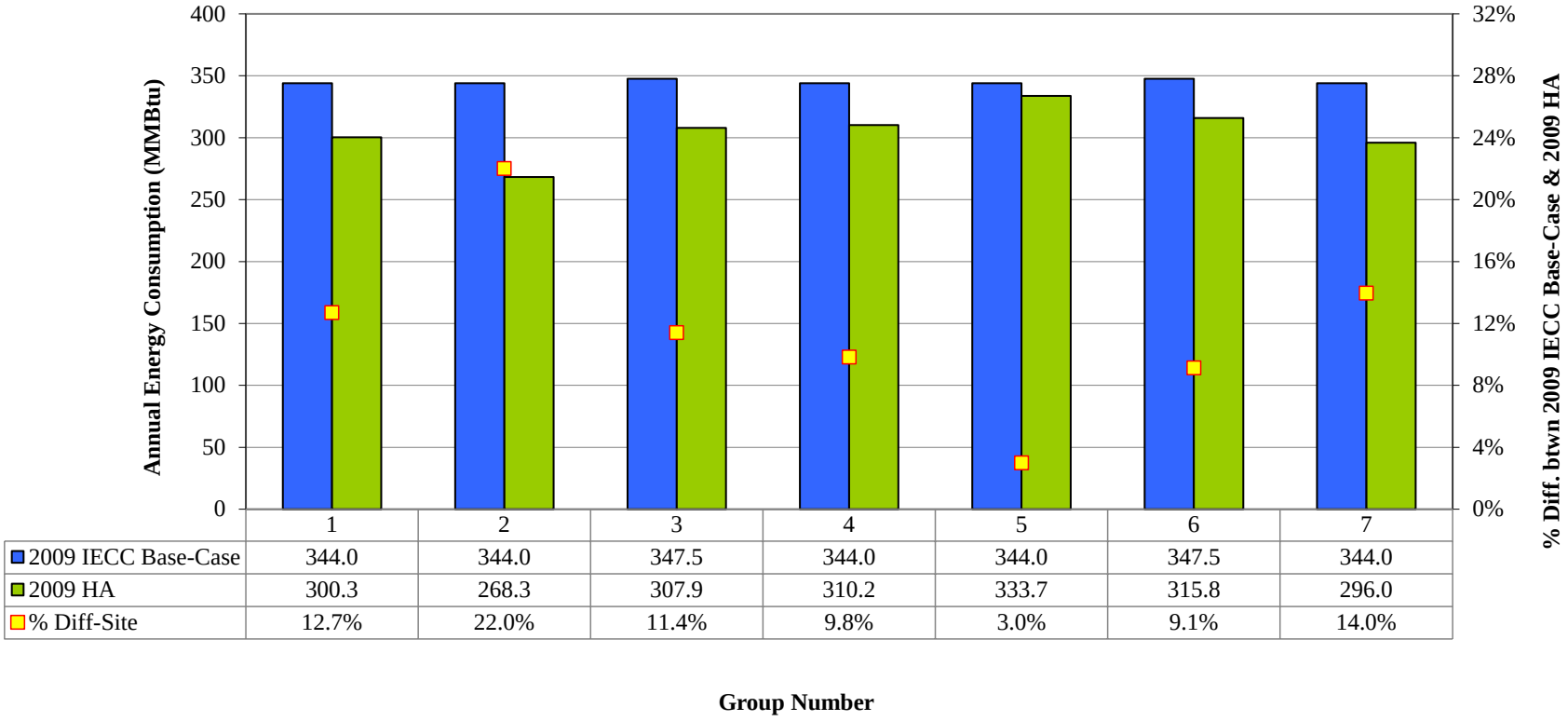
**Notes:**
For the option of solar water heaters the energy use of a pump (1/3 hp) has been added to the simulation results with an assumption that the pump runs for 12 hours a day every day of the year.
When considering the option of mechanical ventilation, a fan energy for a 2325 $ft^2$ house w/ 4 bedrooms was added.




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 IECC Base-Case | 88.1 | 88.1 | 88.1 | 88.1 | 88.1 | 88.1 | 88.1 | 88.1 | 88.9 | 88.1 | 88.1 | 88.1 |
| 2009 HA | 80.6 | 59.7 | 69.2 | 78.6 | 81.2 | 81.2 | 81.5 | 81.2 | 78.9 | 82.4 | 84.1 | 81.8 |
| % Diff - Site | 8.5% | 32.2% | 21.5% | 10.7% | 7.8% | 7.8% | 7.5% | 7.8% | 11.2% | 6.5% | 4.5% | 7.2% |

**Group Number**

**Figure A-1: Assessment of Group Measures for the 2009 IECC Compliant Single-Family Unit (Electric / Natural Gas) – Site Energy Consumption**




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 2009 IECC Base-Case | 344.0 | 344.0 | 347.5 | 344.0 | 344.0 | 347.5 | 344.0 |
| 2009 HA | 300.3 | 268.3 | 307.9 | 310.2 | 333.7 | 315.8 | 296.0 |
| % Diff-Site | 12.7% | 22.0% | 11.4% | 9.8% | 3.0% | 9.1% | 14.0% |

**Figure A-2: Assessment of Group Measures for the 2009 IECC Compliant Multi-Family Unit (Electric / Natural Gas) – Site Energy Consumption**


| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 2009 IECC Base-Case | 288.6 | 285.9 | 292.1 | 292.1 | 292.1 |
| 2009 HA | 267.4 | 212.9 | 254.3 | 255.6 | 259.3 |
| % Diff-Site | 7.3% | 25.5% | 12.9% | 12.5% | 11.2% |

**Figure A-3: Assessment of Group Measures for the 2009 IECC Compliant Multi-Family Unit (All - Electric) – Site Energy Consumption**