Whole-House Analysis of Energy Efficiency Upgrades for Existing Homes

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About the Authors

This research project was conducted by Newport Partners LLC of Davidsonville, MD. Newport Partners performs technical, regulatory, and market research and analysis related to the built environment, with a specific focus on the energy performance of buildings and building systems.

Executive Summary

Residential buildings consume roughly 20% of energy used in the United States. With the proliferation of modern energy codes and equipment standards, new residential buildings typically perform at a much higher energy performance level than older, existing buildings. Opportunities for increasing the energy performance of existing homes have attracted the attention of the Department of Energy, the Environmental Protection Agency, utility companies, and state energy offices, which have all responded by developing incentives and programs to spur residential energy retrofits across the country. While incentives of this type may facilitate market interest, the key to the success of energy retrofit programs and incentives is homeowner involvement.

Throughout the life of a home, homeowners are faced with many opportunities to make an investment that will impact their home's energy consumption, carbon footprint, and their monthly cash flow. Years ago, equipment or appliance replacements were not considered opportunities for energy savings, largely because of the stable price of energy and limited replacement options. However, the current landscape is more complex due to significant technology innovations, variability in energy prices, and a greater awareness of the environmental impact of competing technologies.

Decisions on where and when to invest in residential efficiency upgrades can be difficult for a homeowner, especially when it comes to paying a premium for higher efficiency equipment. Questions such as, "How much energy is this supposed to save?" and "How long will it take me to recoup my investment?" are valid, but credible answers are not often available. When a home is undergoing an energy retrofit, homeowners are faced with the challenge of prioritizing among multiple improvements, so the question becomes, "What are the most cost-effective changes that I can make to improve the energy efficiency of my home?" This crucial question also arises when incentives or tax credits are available for improving the overall efficiency of a home, and could become a much more common question for homeowners as more programs of this type are offered by the state or federal government.

This study is intended to serve as a guide for answering questions related to prioritizing energy upgrades for existing homes. Taking a homeowner's perspective, the study evaluated dozens of energy-efficiency upgrades (referred to as "energy efficiency measures" or EEMs). Through the application of building energy simulation tools and additional analysis, a full range of EEMs were evaluated for their energy, economic, and environmental performance at 10 locations across the continental United States covering different climates. The objective of the study was to provide a credible performance analysis of competing EEMs, with added focus on the performance of propane systems.

Because the study was executed from a homeowner's perspective, energy savings of various EEMs were considered relevant in so far as they were found to be cost-effective. The metric for cost-effectiveness was simple payback, which is an expression for the years required to recoup a first-cost investment (labor and materials) in an EEM based on expected annual energy cost savings. If an EEM was found to have a payback of 10 years or fewer, the emissions savings associated with the payback were also reported. Emissions data could thus serve as a second evaluation point to assist homeowners in choosing between EEMs with comparable paybacks.

EEMs that consistently performed well across multiple regions included high-efficacy lighting (paybacks at one year or less) and air sealing of the building envelope (paybacks at one to three years). Among the appliance EEMs evaluated, selection of an Energy Star refrigerator instead of a standard refrigerator provided a payback of five to seven years but low annual emissions savings, at 0.03 to 0.07 metric tons of carbon dioxide (CO2). A more balanced appliance choice with an attractive payback and emissions savings was the selection of a propane clothes dryer over an electric clothes dryer. This choice showed a payback of three to six years with annual emissions savings of 0.1 to 0.34 metric tons of CO2, three to four times the emissions savings of the Energy Star refrigerator.

The economic and emissions performance of space heating and cooling EEMs were highly dependent on region/climate. A consistent performer across the majority of climate zones was found by specifying a high-efficiency propane furnace in lieu of a standard-efficiency propane furnace. This EEM provided a payback of one year in mixed-humid, cold-very cold, and Northeast regions, with associated annual emissions savings of 2.52 to 3.76 metric tons of CO2. The dual-fuel system, which was composed of a high-efficiency air source heat pump (ASHP) working in tandem with a high-efficiency propane furnace, was another excellent performer. In all climates but the hot-humid and hot-dry/mixed-dry, the dual fuel system had simple paybacks of four to six years, with the highest associated annual emissions savings of any EEM in the study, at 7.28 metric tons of CO2 when chosen over a standard ASHP in a mixed-humid climate. These savings were sufficient to offset the CO2 emissions associated with 1.3 passenger cars every year.

Other EEMs, such as water heating, were strong regional performers. For example, while economics and emissions savings for water heating EEMs were minor in warmer climates, they were especially attractive in the Northeast, where several water heating EEMs were strong performers. In the Northeast, five water heating EEMs, including heating oil, electric, and propane units, had economic paybacks of fewer than five years, with the propane tankless condensing unit offering the highest annual emissions savings at 0.62 metric tons of CO2. Propane tankless water heating technology also offers ancillary benefits such as a high hot water delivery rate (roughly triple the First Hour Rating of a 50 gallon electric storage water heater) and a life expectancy over 50% longer than storage tank units.

Not all EEMs were found to have attractive paybacks. For example, selection of an Energy Star clothes washer or dishwasher was found to have a payback of greater than 10 years across all regions, largely due to higher first costs, which in some cases could be associated with premium features generally provided with these appliances. Though not commonly specified in retrofit scenarios due to high first costs and integration challenges, ground source heat pumps

(GSHPs) were also included in this study and found to have paybacks of 10 years or greater in all regions. Solar photovoltaic systems also were found to have paybacks of 10 years or greater. In some areas and applications, high first costs may be partially offset by federal, state, and local incentives, which would make solar PV systems, GSHPs, propane tankless water heaters, and some high-efficiency space-heating systems more cost competitive. This study did not undertake to quantify these incentives due to their transitory nature and the fact that they could not be uniformly applied across the locations and scenarios covered within the study's scope.

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Introduction

A central heating system fails on a winter day, a water heater begins leaking, a light bulb burns out, old windows are becoming drafty, the local hardware store is running a sale on ceiling insulation—each time these incidents occur, homeowners have the opportunity to make an investment that will impact future cash flow, energy consumption, and their home's carbon footprint. Years ago, these events generally had simple solutions, largely because of stable energy prices and limited equipment replacement options. However, the current landscape is more complicated, due to continued technology innovations, instability/increases in energy prices, and a greater awareness of the environmental impact of competing technologies.

Decisions on where and when to invest in residential energy-efficient equipment can be difficult for a consumer, especially when it comes to paying a premium for higher efficiency equipment. Questions such as, "How much energy is this supposed to save?" and "How long will it take me to recoup my investment?" are valid, but credible answers are not often available. In other circumstances, such as when a home is undergoing an energy retrofit, homeowners are faced with the challenge of prioritizing among multiple improvements. Then the question becomes, "What are the most cost-effective changes I can make to improve the energy efficiency of my home?" This crucial question also arises when incentives or tax credits are available for improving the overall efficiency of a home, and could become a much more common question for homeowners as more programs of this type are offered by the state or federal government.

This study is intended to serve as a guide for answering such questions about prioritizing energy-efficiency investments for existing homes. Taking a homeowner's perspective, the study evaluated dozens of energy-efficiency upgrades (referred to as "energy efficiency measures" or EEMs) that are categorized as elective EEMs and non-elective EEMs. Elective EEMs are those that are at the discretion of the homeowner, measures which do not require immediate action or replacement (e.g., adding attic insulation). Non-elective EEMs are those that are prone to failure and are generally replaced with haste due to a loss of some critical function in the home's operation (e.g., a new refrigerator). A glossary is provided in Appendix A that defines this and other terms used throughout the report.

Through the application of building energy simulation tools and additional analysis, a full range of elective and non-elective EEMs were evaluated on the basis of their economic, energy, and environmental performance at 10 locations across the country that covered five climate regions. The objective of the study was to provide a credible performance analysis of competing EEMs, with added focus on the performance of propane systems.

Methodology

Household energy use varies widely based on such parameters as climate, number of occupants, occupant behavior, and building and mechanical systems. This study focused on typical energy use for average single-family detached households. In doing so, many assumptions were made in developing the models that produced the study results. The most relevant of these assumptions are provided within this section.

Locating and Characterizing the Reference Homes

To make the study relevant for homeowners across the continental United States, 10 geographically and climatically diverse locations were selected to characterize five regions:

- Hot-Humid: Orlando, FL and Dallas, TX
- Mixed-Humid: Columbia, MO and Baltimore, MD
- Cold-Very Cold (not including the Northeast): Grand Rapids, MI and Duluth, MN
- Northeast: Buffalo, NY and Manchester, NH
- Hot-Dry/Mixed-Dry: Sacramento, CA and Las Vegas, NV

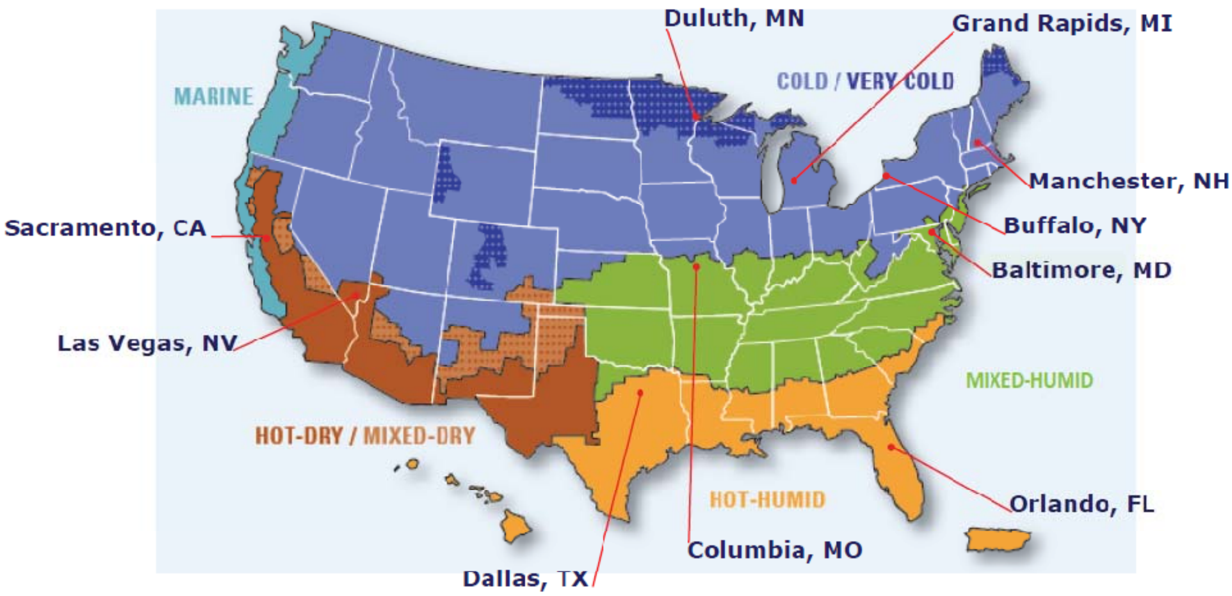

Figure 1: Elective EEM paybacks and emissions savings for Mixed-Humid Climate.

Building energy simulation models require dozens of inputs to be able to characterize the interrelationships of building systems. Insulation levels, air tightness, glazing percentage, orientation, and mechanical and equipment efficiencies are just a few of the inputs that affect the energy use of the home. Several resources were leveraged to identify typical building characteristics of the existing reference home, including DOE sources, legacy building codes, engineering references, studies from Lawrence Berkley National Laboratory, and professional judgment.

In general, the reference home was a 1970s-era home with three bedrooms and two baths, with 1,660 square feet on the first floor. Foundation type, either basement or slab on grade, varied by location. The reference home's existing heating equipment was assumed to be an old propane furnace, except in the Northeast where a heating oil boiler was used. Existing water heating equipment for the reference home was assumed to be an electric tank, except in the Northeast where a heating oil water heater was used. Central air cooling was assumed for all homes. The modeled efficiency of existing heating, cooling, and water heating equipment was calculated based on DOE algorithms that adjust listed efficiency as a function of equipment age (e.g., two-thirds useful life) and assumed maintenance schedule (e.g., rarely maintained); see the "systems evaluated" for methodology. A detailed list of resources and assumptions can be found in Appendix B.

Building Energy Simulations

Building energy simulations were conducted with the assistance of REM/Rate software, Wrightsoft's Right-Loop software, Energy Gauge USA software, and DOE spreadsheets. Energy Gauge USA was used for evaluating water heating only, based on its robust water heating tool, which enabled detailed modeling of solar water heating as well as other alternatives. DOE's Building America Analysis Spreadsheet[1] was used to calculate the performance of appliances such as clothes dryers, clothes washers, and dishwashers. This tool was selected based on its highly detailed interface and well-documented methodology, which has been shaped and vetted through extensive field testing. Right-Loop provided sizing calculations for GSHP loop fields. REM/Rate, one of the most widely recognized residential energy modeling software programs, was selected to model all other EEMs.

Systems Evaluated

Homeowners have many opportunities to improve their homes' energy efficiency. Some of these opportunities are "elective", such as increasing attic insulation or replacing old, drafty windows, while other opportunities typically arise when equipment fails ("non-elective"). Dozens of energy-efficiency measures were identified in this study, and categorized based on being elective or non-elective. While any EEM could theoretically be elective, for practical purposes, this study identified non-elective EEMs as any measure prone to sudden failure or malfunction that would generally require immediate repair or replacement. This distinction resulted in the groupings listed in Figure 2.

[1] U.S. DOE. 2007. Building America Analysis Spreadsheet. Accessed Sep. 22, 2010 from http://www1.eere.energy.gov/buildings/building_america/perf_analysis.html.

Elective EEMs	Non-Elective EEMs
Building envelope improvements: windows, air sealing, ceiling insulation	Mechanical systems: furnaces, heat pumps, central air conditioners, boilers, water heaters (including solar)
Renewable energy systems: solar photovoltaic	Lighting
Duct sealing	Appliances: clothes washers and dryers, dishwashers, refrigerators

Figure 2: Elective and non-elective EEMs evaluated, grouped by system type.

Each EEM evaluated had certain energy performance characteristics associated with it, whether a thermal rating (e.g., R-value, U-factor, SHGC, etc.), an efficiency rating (SEER, AFUE, COP, MEF, EER, HSPF, EF, etc.), or an expected performance outcome (e.g., reduced duct leakage through application of an aerosolized sealant). Efficiency values for new high-performance and new standard-efficiency equipment were determined based on industry norms applicable as of 2010 (e.g., federal regulations, tax incentive criteria, or Energy Star criteria) as well as product availability (e.g., AHRI product database).

When quantifying the energy and emissions savings associated with elective EEMs, it was necessary to assume and account for the efficiency of existing equipment. For example, the energy saved by window replacement was directly affected by the efficiency of the space heating and cooling equipment. Equipment efficiency was assumed to have complied with federal standards at the time of its purchase, but to have decreased over time based on a lack of regular maintenance. The age of the reference home's existing mechanical equipment was assumed to be two-thirds of its useful life, based on an industry study.[2] The equation used to adjust the effective efficiency of mechanical equipment as a function of time was sourced from DOE,[3] and applied to space heating and cooling equipment as well as water heaters:

$$EFF = (Base\ EFF) * (1 - M)^{age}$$

Where:

EFF = adjusted efficiency of the unit (e.g. a SEER rating)

Base EFF = initial efficiency rating (e.g. federal minimum SEER)

M = maintenance factor

Age = age of the unit in years.

[2] Seiders, D., G. Ahluwalia, et al. 2007. Study of Life Expectancy of Home Components. National Association of Home Builders, Bank of America Home Equity.

[3] Hendron, R. 2006. Building America Performance Analysis Procedures for Existing Homes. U.S. DOE. NREL/TP-550-38238.

For example, a central AC unit was assumed to have a useful life of 15 years. At two-thirds its useful life, this unit would be 10 years old (manufactured in 2000). Based on federal regulations, the base efficiency of an AC unit manufactured in 2000 was 10 SEER. A maintenance factor of 0.03 was suggested by DOE for a central AC unit that is "seldom or never maintained." Plugging these values into the efficiency adjustment equation yielded a value of 7.4 SEER for the existing AC unit. A complete list of equipment efficiencies and energy performance characteristics assumptions for EEMs can be found in Appendix C.

	Tank-Based Water Heater	Air Source Heat Pump/ Air Conditioner	Furnace	Boiler
Useful Life (years)	10	10-16	15-20	13-21
2/3 Useful Life (years)	7	10	12	11

Figure 3: Useful life of equipment based on industry study.

For space conditioning equipment and water heating equipment, equipment sizing can have a significant impact on operational energy use. To ensure consistency in selecting equipment to match targeted loads, industry sizing standards and protocol were employed wherever possible. For example, space heating and cooling loads were calculated using Manual J 8th Edition, with the application of over sizing limits established by guidance from groups such as the Air-Conditioning Contractors of America (ACCA) and the Energy Star Homes program.

Storage tank water heating equipment was sized based on the first hour rating (FHR) required to satisfy the reference home's three-bedroom and two-bath layout. The targeted FHR was then overlaid with the Air-Conditioning, Heating, and Refrigeration Institute's (AHRI) Directory of Certified Product Performance to identify units adequately sized to meet the targeted FHR (e.g., 40-gallon propane storage tank). It should be noted that the minimum flow rate specification for the propane tankless water heaters in the study (4 GPM with a 75F temperature rise) far outpaced the first hour rating of the storage tank water heaters, with the tankless units providing roughly triple the hourly hot water output. The electric tankless unit's minimum flow rate specification also outpaced the first hour rating of the storage tank water heaters, but at a flow rate that was roughly half that of the propane tankless (about 2.3 GPM with a 75F temperature rise). This is a limit of the technology in the electric tankless units currently found in the market.

For appliances such as clothes washers, dishwashers, refrigerators, and clothes dryers, capacities were based on a scan of the most typical sizes available from retail suppliers.

See Appendix C for the specifications of the EEMs covered within this study.

In total, the EEM scenarios evaluated in this study included the following groups and subsets.

- **Building envelope**
  a. Replace existing windows with modern windows that meet performance requirements of current federal tax credits (SHGC=0.30, U-0.30)[4]
  b. Air sealing of building envelope to reduce infiltration (30% improvement)
  c. Increase attic insulation to levels that meet requirements of the 2009 International Energy Conservation Code (IECC)
- **Lighting and appliances**
  a. Lighting: Replace all incandescent bulbs with new incandescent bulbs or high-efficacy fluorescent lighting
  b. Clothes dryer: Replace old electric clothes dryer with a new electric or propane clothes dryer
  c. Refrigerator: Replace with standard or Energy Star refrigerator
  d. Dishwasher: Replace with standard or Energy Star dishwasher
  e. Clothes washer: Replace with standard or Energy Star clothes washer
- **Mechanical space heating and cooling systems**
  a. Aerosolized duct sealing to reduce duct leaks and loss of conditioned air
  b. Replace old propane furnace with: standard- or high-efficiency propane furnace; propane dual-fuel high-efficiency system[5]; standard- or high-efficiency ASHP; GSHP[6]
  c. Replace old heating oil boiler with (Northeast only): standard- or high-efficiency propane boiler, standard- or high-efficiency heating oil boiler
  d. Replace old ASHP with (hot/humid, mixed/humid, and hot/dry, mixed/dry climates only): standard- or high-efficiency ASHP; propane dual-fuel high-efficiency system; GSHP
  e. Replace old central AC with: standard- or high-efficiency AC
- **Mechanical water heating systems**
  a. Replace heating oil (Northeast only) or electric storage water heater (all other regions) with:
     i. Propane standard-efficiency tank
     ii. Propane high-efficiency storage, non-condensing

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[4] Potential air sealing benefits of window retrofits were not quantified within this study, due to high variability of the condition of current windows as well as varying installation techniques with respect to air sealing.

[5] A dual-fuel system uses both an air source heat pump and a forced air propane-fired furnace. In heating mode, this system uses the ASHP until the outdoor temperature falls below a pre-determined threshold (generally between 32-38 deg F), at which point, the ASHP switches off and the propane-fired furnace takes over heating. By switching to the propane furnace in cold conditions, the system avoids having to use the ASHP when its efficiency is lowest. This also reduces the system's overall CO2 emissions significantly compared to an ASHP-only system.

[6] GSHP systems were assumed to employ vertical boreholes, based on limited availability for trenching in retrofit installations. Loop fields were sized using WrightSoft's Right-Loop design module.

iii. Propane high-efficiency storage, condensing
iv. Propane tankless, non-condensing
v. Propane tankless, condensing
vi. Electric standard-efficiency tank
vii. Electric high-efficiency tank
viii. Electric tankless
ix. Electric heat pump water heater (HPWH)[7]
x. Heating oil standard-efficiency tank
xi. Solar hot water with a storage tank and propane tankless, non-condensing backup

- **Renewables: Add a solar photovoltaic system to the home**

Economic Considerations

When purchasing an EEM, first costs are typically the first consideration of homeowners. A secondary, though no less important, consideration is the potential energy cost savings of the unit over time. A metric that is typically used to evaluate this interrelationship is “simple payback,” which is a measure of the amount of time required to recoup the net first costs of a system, based on annual energy cost savings.

Net first costs can vary based on the replacement situation. For cases where a change in energy sources was required—such as switching from an existing electric clothes dryer to a new propane clothes dryer—costs of installing a new gas line to the appliance were captured within the net first costs.[8]

For the case of elective EEMs, the net first cost was equal to the entire first cost of the EEM, including materials and installation costs. For elective EEMs, the entire first cost of the EEM was used because it was reflective of the homeowner’s investment in energy efficiency. With non-elective EEMs, the net first cost was taken as the difference between the materials and installation cost of the premium EEM and a standard, low-cost alternative (e.g., the difference in cost between a high performance 95 AFUE furnace and a federal minimum standard 78 AFUE furnace). In the case of elective EEMs, the difference in first costs was used because it was reflective of the of the homeowner’s investment in energy efficiency.

[7] Electric heat pump water heaters heat water similar to the way that ASHPs heat homes, by “pumping” heat from the surrounding air into the water, and achieving efficiencies over twice that of standard efficiency electric tanks. HPWHs are stand-alone, tank-based units that are becoming more common within the market place, with several manufacturers now offering models, and with Energy Star now recognizing this product category.

[8] Where required, costs associated with fuel switching from heating oil or electricity to propane included costs of installing interior gas lines to the appliance. Expenses associated with removal of heating oil tanks, installation of propane tanks, and installation of exterior propane lines were not accounted for due to large regional and site variability.

Similarly, the method for calculating annual energy cost savings varied based on whether an elective or non-elective EEM was being implemented. Annual cost savings of elective EEMs were found by subtracting the energy costs of the home after installation of the EEM from the energy costs of the home prior to the EEM being installed. For non-elective EEMs, annual cost savings were found by subtracting the energy costs of the home after installation of the EEM from the energy costs of the same home operating with a new, lowest-cost EEM alternative. For instance, in the case where a new 95 AFUE furnace is installed in an existing home, the energy costs savings for this non-elective EEM would be found by subtracting the total energy costs of the home under operation of the new 95 AFUE furnace from the total energy costs of the home under operation of a new 78 AFUE furnace.

Within this study, first costs were developed through multiple sources: RS Means construction data, retail pricing surveys, and DOE rulemaking documents. Where retail pricing was employed, average prices were taken across available models. For example, retail pricing was pursued for clothes washers. Prices for standard clothes washers were found to range from $329 to $779, with an average of $456 across 16 models. Prices for Energy Star clothes washers were found to range from $404 to $1,499, with an average of $899 across 121 models. The higher priced Energy Star models often contained many premium features that the standard models did not, but separating the cost of the energy-efficiency upgrade associated with the Energy Star models from the cost of the extra features was not tenable. While consumers could legitimately find pricing for these and other items that would alter the study's economic findings, the study attempted to develop reasonable, representative, and indiscriminate pricing across all EEMs.

Location factors were applied to develop regional differences in the pricing of labor and materials. Though some of the labor could have conceivably been performed by a homeowner (e.g., replacing light bulbs, air sealing, etc.), all work was assumed to be completed by a contractor. While some of the EEMs studied were eligible for tax credits or other financial incentives at the time the analysis was conducted, incentives were excluded from the economic analysis. This decision was made because tax credits and incentives are transitory and could not be uniformly applied under all situations (e.g., exclusions for equipment bought for rental property, income limit exclusions, etc.). The average first costs of EEMs across all sites are provided in Appendix C.

Annual energy costs associated with EEMs were developed by from applying state-level energy rates to the energy use associated with EEMs, as projected by building energy simulations. Energy rates were either sourced directly, or developed from, DOE Energy Information Administration data (year 2009) at the state level. The residential retail rates used in this report can be found in Figure 4.

Analysis Location		Propane Cost ($/gallon)	Heating oil ($/gallon)	Electricity ($/kWh)
Sacramento	CA	2.00	n/a	0.15
Orlando	FL	2.35	n/a	0.12
Baltimore	MD	2.38	n/a	0.15
Grand Rapids	MI	1.86	n/a	0.12
Duluth	MN	1.60	n/a	0.10
Columbia	MO	1.59	n/a	0.08
Manchester	NH	2.45	2.30	0.16
Las Vegas	NV	2.00	n/a	0.13
Buffalo	NY	2.34	2.48	0.18
Dallas	TX	2.03	n/a	0.13
AVERAGE		**2.06**	**2.39**	**0.13**

Figure 4: Elective and non-elective EEMs evaluated, grouped by system type.

Environmental Impact, Emissions

While annual energy costs are useful in identifying the energy and economic impacts of various EEMs, they fall short of gauging the environmental impact of different EEMs. Perhaps the most widely recognized environmental metric for this purpose is CO2 emissions. Because not all energy is generated equally, CO2 emissions vary depending upon the energy source. Particularly, utility grid-sourced electricity generally has a much higher CO2 output per unit of energy supplied to a home than do fuels consumed at the house, such as propane and heating oil. The higher CO2 emission rate typically associated with electricity can generally be attributed to almost half of U.S. electricity being sourced from the combustion of coal at power plants.

Emissions were compiled by applying emissions factors to the energy use associated with EEMs. Electricity emissions factors were sourced from the EPA's Emissions & Generation Resource Integrated Database (eGRID)[9]. Emissions factors for propane and heating oil were sourced from the EPA's "Carbon Dioxide Emission Factors for Stationary Combustion."[10] Based on these sources, emission factors per British thermal unit (Btu) of energy consumed on site are provided in Figure 5, with propane having 14% lower emissions than heating oil and 62% lower

[9] U.S. EPA. December 2008. eGRID2007 Version 1.1 Year 2005 Summary Tables. http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2007V1_1_year05_SummaryTables.pdf. Last accessed September 27, 2010.

[10] U.S. DOE EIA. Voluntary Reporting of Greenhouse Gases Program, Fuel and Energy Sources Codes and Emissions Coefficients, http://www.eia.doe.gov/oiaf/1605/coefficients.html. Last accessed September 27, 2010.

emissions than electricity. While Figure 4 provides a national outlook on electricity emissions factors, those factors used in the study were based on state averages, as per EPA accounting. A list of emissions factors used for each location is provided in Appendix D.

Analysis Location	CO_2 Emissions (metric tons per billion Btu)		
	Propane	Heating Oil	Electricity
Average of CA, FL, MD, MI, MN, MO, NH, NV, NY, and TX	63	73	165

Figure 5: Residential CO_2 emissions factors associated with consumption of various fuels.

Results – Economic and Environmental Analysis

Results are grouped by climate and region. Across all EEMs, simple paybacks were calculated and ranked. EEMs with paybacks of 10 years or less were considered attractive, and their associated emissions savings were reported. EEMs with paybacks of greater than 10 years were considered irrelevant options for typical cost-conscious consumers; exact paybacks were not provided for these EEMs, and their associated emissions savings were not reported. Results were grouped according to whether the EEM was non-elective (any measure prone to sudden failure or malfunction that would generally require immediate repair or replacement) or elective. The main purpose of organizing EEMs in this way was to clearly identify the reference system used in developing performance comparisons. Paybacks developed for the non-elective EEMs could also be used by homeowners to make informed decisions regarding proactive replacements, when equipment is nearing its useful life. Proactive replacement can provide multiple advantages to a homeowner, such as the opportunity to shop around for competitive pricing, greater product selection, the ability to vet contractors, and the opportunity to take advantage of credits/rebates for high efficiency equipment.

Hot-Humid Climate

The hot-humid climate, represented by Dallas and Orlando, is characterized by heavy space cooling loads, and low water heating and space heating loads. Of the five elective EEMs surveyed, three had paybacks less than or equal to 10 years – aerosolized duct sealing, air sealing of the building envelope, and increasing ceiling insulation from an assumed level of roughly R-7 to R-30 (which meets current energy codes). Aerosolized duct sealing was especially attractive because of the assumption that the ducts were located within the attic (Figure 6). Elective EEMs with paybacks greater than ten years included replacement windows and solar photovoltaics.

Elective EEM Results, Hot-Humid Climate		
Elective EEM	**Payback (years)**	**Annual Emissions Savings (metric tons CO2)**
Aerosolized Duct Sealing	3	0.79
Air Sealing	3	0.41
Ceiling Insulation	6	1.03
Windows, Solar Photovoltaics	>10	n/a

Figure 6: Elective EEM paybacks and emissions savings for Hot-Humid Climate.

Annual carbon emissions savings associated with the elective EEMs surveyed can be found in Figure 6 and Figure 7. The addition of ceiling insulation provided the greatest emissions savings, at 1.03 metric tons of CO2 per year, more than twice that provided by the air sealing. The payback for ceiling insulation was also roughly twice that of air sealing, but still attractive at six years.

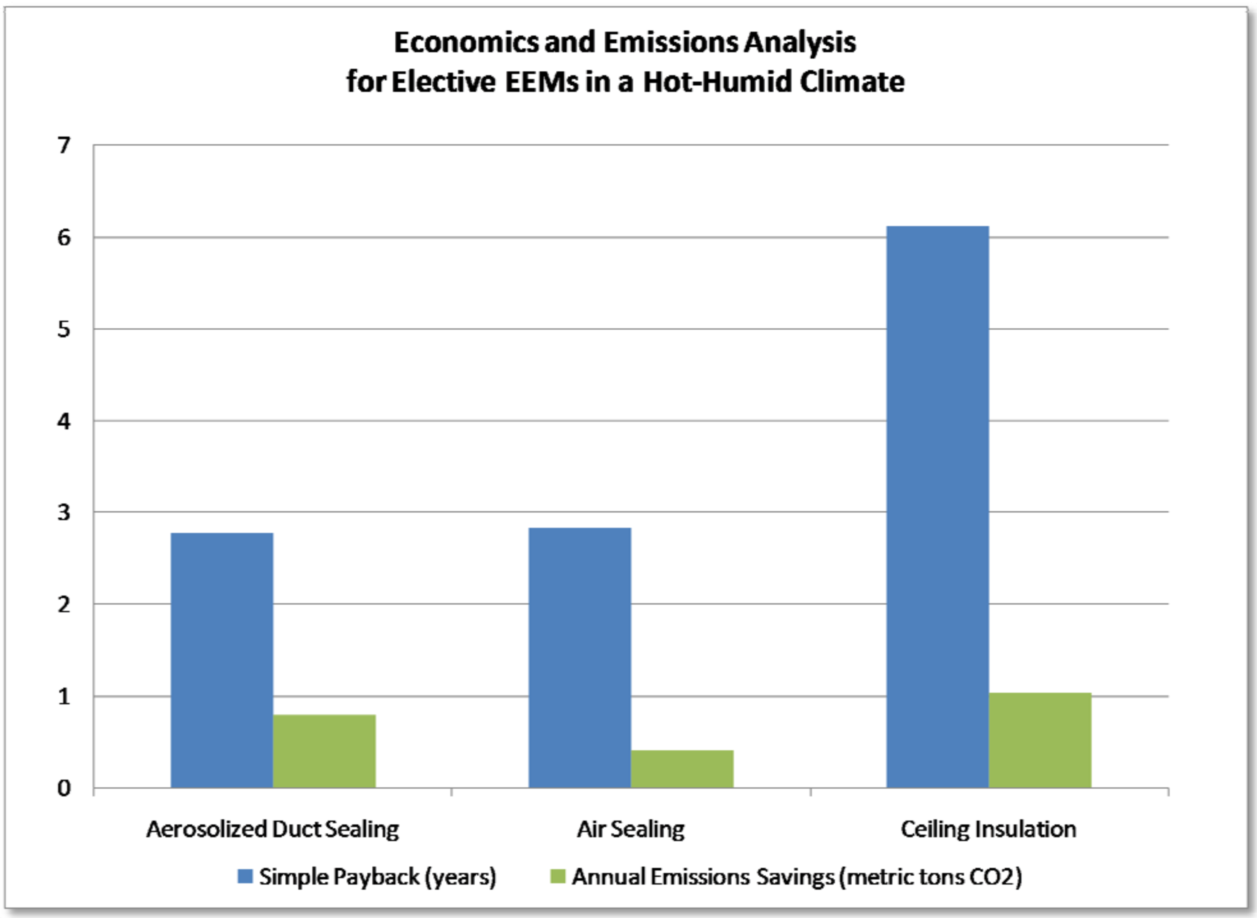

Figure 7: Elective EEM paybacks and emissions savings for Mixed-Humid Climate.

Of the non-elective replacements, there were several improved EEMs that had paybacks less than or equal to 10 years. The most attractive EEMs in terms of paybacks included replacement of incandescent lighting with high-efficacy fluorescent lights, with a payback of less than one year. In the case that a typical home in a hot-humid climate had a propane furnace that required replacement, there were several options with paybacks of less than seven years, including a high efficiency propane furnace and a dual-fuel system (high efficiency ASHP with high efficiency propane furnace back-up). Though the payback of the dual-fuel system was a little longer than other alternatives within this climate zone, it would provide insurance against volatile energy prices by permitting the home owner to switch to the lowest cost energy source. A full list of paybacks across all non-elective EEMs can be found in Figure 8, which compares higher cost, improved EEMs to lower cost, standard EEMs. Figure 8 also identifies the simple payback and emissions savings associated with selecting the improved EEM over the lowest first cost, standard model.

Annual emissions savings associated with EEMs with paybacks of 10 years or less were found to range from 0.06 metric tons of CO2 to 3.70 metric tons of CO2. The highest projected savings were found in the dual-fuel system, with the lowest projected savings occurring for the Energy Star refrigerator.

Non-Elective EEM Results, Hot-Humid Climate					
Category	Sub-Category	Standard EEM (lowest first cost option)	Improved EEM	Improved versus Standard EEM Analysis: Payback (years)	Improved versus Standard EEM Analysis: Annual Emissions Savings (metric tons CO2)
Space Heating and Cooling	Replace AC	Standard AC	High Efficiency AC	6	0.55
	Replace ASHP	Standard ASHP	High Efficiency ASHP	7	0.57
			High Efficiency Propane Furnace; Dual-Fuel System; Ground Source Heat Pump	>10	n/a
	Replace Propane Furnace	Standard Propane Furnace	Standard Efficiency ASHP	5	2.26
			High Efficiency Propane Furnace	5	0.52
			High Efficiency ASHP	5	2.83
			Dual-Fuel System	6	3.70
			Ground Source Heat Pump	>10	n/a
Lighting and Appliances	Replace Lighting	90% Incandescent	100% High Efficacy Fluorescent	1	0.72
	Replace Appliance	Standard Refrigerator	ENERGY STAR Refrigerator	6	0.06
		Electric Clothes Dryer	Propane Clothes Dryer	6	0.30
		Standard Clothes Washer	ENERGY STAR Clothes Washer	>10	n/a
		Standard Dish Washer	ENERGY STAR Dish Washer	>10	n/a
Water Heating	Replace Electric Tank Water Heater	Standard Electric Tank	Electric High Efficiency Tank	6	0.07
			Heat Pump Water Heater	9	0.85
			Electric Tankless; Propane Tankless, Condensing and	>10	n/a

Non-Elective EEM Results, Hot-Humid Climate					
Category	Sub-Category	Standard EEM (lowest first cost option)	Improved EEM	Improved versus Standard EEM Analysis	
				Payback (years)	Annual Emissions Savings (metric tons CO2)
			Non-condensing; Propane High Efficiency Tank, Condensing and Non-condensing; Solar & Propane Tankless		

Figure 8: Non-elective EEM paybacks and emissions savings for Hot-Humid Climate.

Mixed-Humid Climate

Baltimore, MD and Columbia, MO were the locations used to model the mixed-humid climate, which is known to have well-balanced space heating and cooling loads. Homes in the mixed-humid climate were assumed to have conditioned basement foundations, with ducts in conditioned space (e.g., not in the attic or crawlspace). The existing windows were assumed to be either single- or double-pane aluminum, and ceiling insulation was assumed to be poor (consistent with installed levels from the mid-1970s).

Among the five elective EEMs evaluated, all but the solar PV system were projected to have a payback of under 10 years, with air sealing, duct sealing, and ceiling insulation paybacks under five years. Emissions savings associated with these elective EEMs vary between 1.09 and 2.30 metric tons of CO2 on an annual basis.

Elective EEM Results, Mixed-Humid Climate		
Elective EEM	Payback (years)	Annual Emissions Savings (metric tons CO2)
Air Sealing	1	1.26
Aerosolized Duct Sealing	4	1.74
Ceiling Insulation	4	1.09
Windows	8	2.30
Solar Photovoltaics	>10	n/a

Figure 9: Elective EEM paybacks and emissions savings for Mixed-Humid Climate.

Regarding the non-elective EEMs for the mixed-humid climate (Figure 11), high-efficacy lighting again showed the fastest payback, at one year. A high-efficiency propane furnace as a replacement for an existing furnace also had a one-year payback, while saving almost twice the amount of CO2 emissions per year as the high-efficacy lighting (2.52 versus 1.28 metric tons CO2).

As in the hot-humid climates, the dual-fuel system offered good paybacks versus either a standard ASHP or propane furnace (≤ 6 years), while offering the greatest emissions savings of all EEMs, at 7.28 metric tons of CO2. These annual savings are the equivalent of removing 1.3

passenger cars from the road for a year, and the dual-fuel system provided best opportunity to a homeowner to make a significant, positive environmental impact through the selection of EEMs.

In this balanced climate, a high-efficiency ASHP provided a favorable payback when replacing an existing propane furnace (four years) or ASHP (six years), but actually resulted in higher CO_2 emissions than a new standard-efficiency propane furnace. Due to high first costs, the GSHP's payback was roughly 10 years.

Figure 10 illustrates these paybacks and emissions of alternative EEMs, showing that the high-efficiency propane furnace and dual-fuel systems provided both attractive economics and emissions savings.

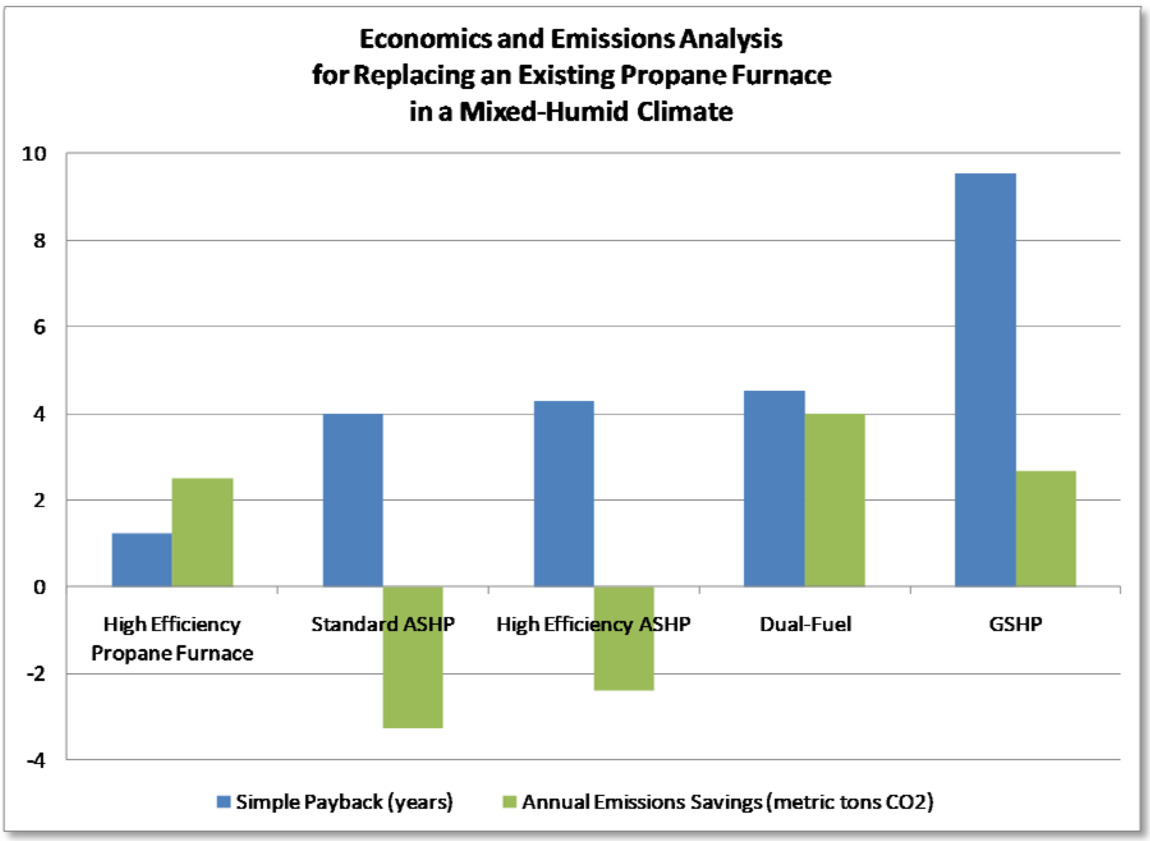

Figure 10: Economics and emissions associated with replacement of an existing propane furnace in a mixed-humid climate. The standard, low-cost replacement EEM that serves as the basis of these paybacks is a standard-efficiency (78 AFUE) propane furnace.

Within the appliances category, selecting a propane clothes dryer versus an electric clothes dryer provided a six-year payback, equal to that of an Energy Star refrigerator versus a standard refrigerator. While the paybacks were equal for these two appliances, the propane clothes dryer provided emissions savings at more than four times the rate as the Energy Star refrigerator. Paybacks for Energy Star clothes washers and dishwashers exceeded 10 years, largely due to the high first costs associated with Energy Star products, which also may have incorporated premium features (see the Methodology section for more information).

<table>
<tr><th colspan="6">Non-Elective EEM Results, Mixed-Humid Climate</th></tr>
<tr><th rowspan="2">Category</th><th rowspan="2">Sub-Category</th><th rowspan="2">Standard EEM (lowest first cost option)</th><th rowspan="2">Improved EEM</th><th colspan="2">Improved versus Standard EEM Analysis</th></tr>
<tr><th>Payback (years)</th><th>Annual Emissions Savings (metric tons CO2)</th></tr>
<tr><td rowspan="10">Space Heating and Cooling</td><td>Replace AC</td><td>Standard AC</td><td>High Efficiency AC</td><td>>10</td><td>n/a</td></tr>
<tr><td rowspan="3">Replace ASHP</td><td rowspan="3">Standard ASHP</td><td>Dual-Fuel System</td><td>6</td><td>7.28</td></tr>
<tr><td>High Efficiency ASHP</td><td>6</td><td>0.88</td></tr>
<tr><td>High Efficiency Propane Furnace; Ground Source Heat Pump</td><td>>10</td><td>n/a</td></tr>
<tr><td rowspan="5">Replace Propane Furnace</td><td rowspan="5">Standard Propane Furnace</td><td>High Efficiency Propane Furnace</td><td>1</td><td>2.52</td></tr>
<tr><td>Standard Efficiency ASHP</td><td>4</td><td>(3.27)</td></tr>
<tr><td>High Efficiency ASHP</td><td>4</td><td>(2.40)</td></tr>
<tr><td>Dual-Fuel System</td><td>5</td><td>4.01</td></tr>
<tr><td>Ground Source Heat Pump</td><td>10</td><td>2.67</td></tr>
<tr><td rowspan="5">Lighting and Appliances</td><td>Replace Lighting</td><td>90% Incandescent</td><td>100% High Efficacy Fluorescent</td><td>1</td><td>1.28</td></tr>
<tr><td rowspan="4">Replace Appliance</td><td>Standard Refrigerator</td><td>ENERGY STAR Refrigerator</td><td>6</td><td>0.07</td></tr>
<tr><td>Electric Clothes Dryer</td><td>Propane Clothes Dryer</td><td>6</td><td>0.39</td></tr>
<tr><td>Standard Clothes Washer</td><td>ENERGY STAR Clothes Washer</td><td>>10</td><td>n/a</td></tr>
<tr><td>Standard Dish Washer</td><td>ENERGY STAR Dish Washer</td><td>>10</td><td>n/a</td></tr>
<tr><td rowspan="2">Water Heating</td><td rowspan="2">Replace Electric Tank Water Heater</td><td rowspan="2">Standard Electric Tank</td><td>Electric High Efficiency Tank</td><td>7</td><td>0.09</td></tr>
<tr><td>Heat Pump Water Heater; Electric Tankless; Propane Tankless, Condensing and Non-condensing; Propane High Efficiency Storage, Condensing and Non-condensing; Solar & Propane Tankless</td><td>>10</td><td>n/a</td></tr>
</table>

Figure 11: Non-elective EEM paybacks and emissions savings for Mixed-Humid Climate.

Hot-Dry/Mixed-Dry

This region is characteristic of much of the southwest United States, and is represented within this study by Sacramento, CA and Las Vegas, NV. High solar gain and high cooling loads are energy challenges of this region, which also has larger space heating and water heating loads than the hot-humid climate, and higher cooling loads than the mixed-humid climate.

Elective EEM Results, Hot-Dry/Mixed-Dry Climate		
Elective EEM	**Payback (years)**	**Annual Emissions Savings (metric tons CO2)**
Air Sealing	3	0.86
Aerosolized Duct Sealing	3	0.38
Ceiling Insulation	5	1.28
Windows, Solar Photovoltaics	>10	n/a

Figure 12: Elective EEM paybacks and emissions savings for Hot-Dry/Mixed-Dry Climate.

Regarding the elective EEMs evaluated, air and duct sealing remained attractive, with paybacks of three years. Increasing the R-value of the ceiling from R-7 to R-30 resulted in a payback of five years, lower than in heating-dominated climates. Both window replacement and solar PV installation had a payback of more than 10 years, but the economics of these systems could potentially be improved by tax credits and incentives, which were not captured in this study (see Methodology section).

Considering the non-elective EEMs (Figure 14), the most attractive paybacks were in lighting and the replacement of a standard propane furnace with higher-efficiency equipment. This is consistent with findings from the hot-humid and mixed-humid region. When replacing an existing ASHP or propane furnace, the dual-fuel system again had the greatest emissions savings for systems with paybacks of 10 years or less. Across all EEMs evaluated, the magnitude of emissions savings was generally lower for EEMs in the hot-dry/mixed-dry climate compared to other climates based on low electricity emissions factors for the representative states of California and Nevada. In other words, electricity generation in these states produces fewer emissions than other states based on a lower proportion of coal-fired power generation.

Among the appliances evaluated, selecting a propane clothes dryer instead of an electric clothes dryer provided the best payback, at five years, and four times the emissions savings of installing an Energy Star refrigerator (Figure 13). Five high-efficiency water heating units provided paybacks of less than or equal to 10 years in the hot-dry/mixed-dry climate. Of these, two emerging technologies—the propane tankless condensing unit and the HPWH—were ranked first and second in water heater emissions savings. The improvement in the economic performance of high-efficiency water heaters within this climate can be partially attributed to higher than average electricity rates in the representative states of California Nevada (~$0.14/kWh across the two states).

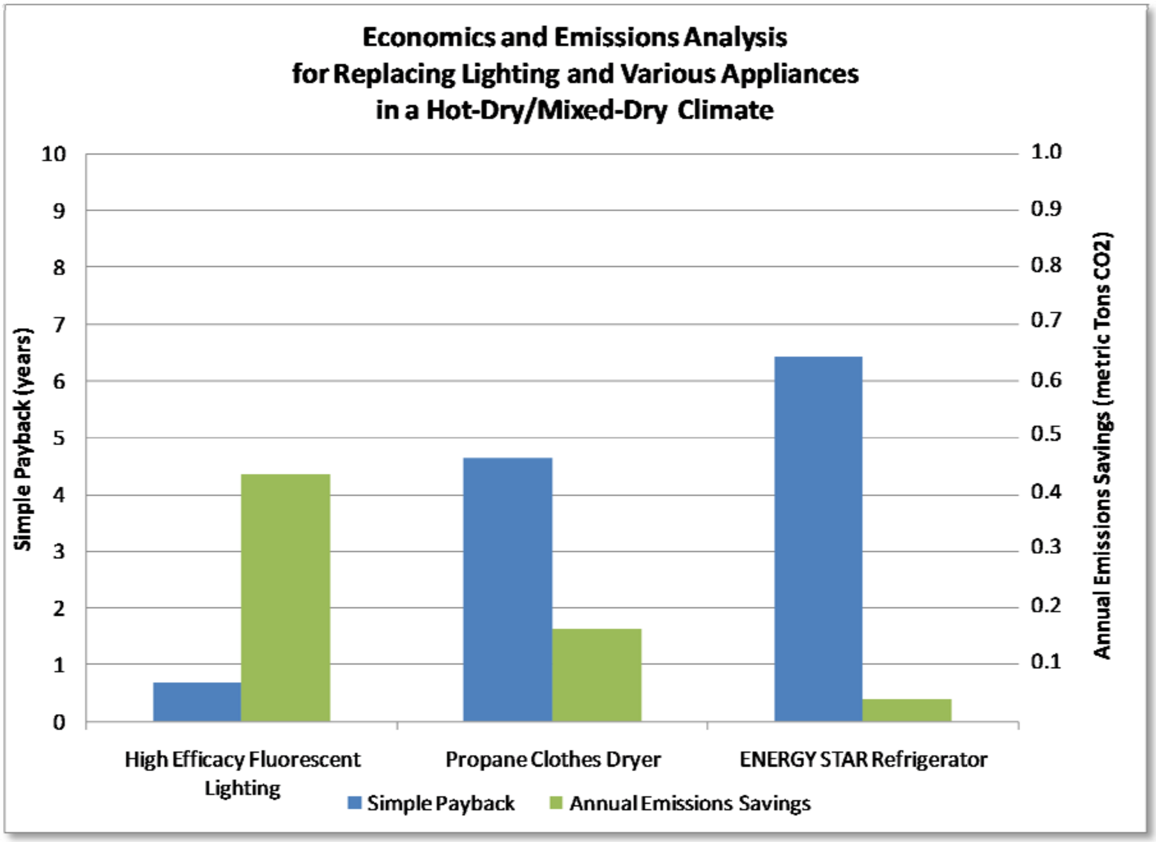

Figure 13: Elective EEM paybacks and emissions savings for Hot-Dry/Mixed-Dry Climate.

Non-Elective EEM Results, Hot-Dry/Mixed-Dry Climate					
Category	Sub-Category	Standard EEM (lowest first cost option)	Improved EEM	Improved versus Standard EEM Analysis	
				Payback (years)	Annual Emissions Savings (metric tons CO2)
Space Heating and Cooling	Replace AC	Standard AC	High Efficiency AC	8	0.37
	Replace ASHP	Standard ASHP	High Efficiency ASHP	7	0.49
			Dual-Fuel System	9	1.26
			High Efficiency Propane Furnace; Ground Source Heat Pump	>10	n/a
	Replace Propane Furnace	Standard Propane Furnace	High Efficiency Propane Furnace	4	0.88
			Standard Efficiency ASHP	5	2.99
			High Efficiency ASHP	5	3.48
			Dual-Fuel System	6	4.25
			Ground Source Heat Pump	>10	n/a
Lighting and Appliances	Replace Lighting	90% Incandescent	100% High Efficacy Fluorescent	1	0.43
	Replace Appliance	Electric Clothes Dryer	Propane Clothes Dryer	5	0.16
		Standard Refrigerator	ENERGY STAR Refrigerator	6	0.04
		Standard Clothes Washer	ENERGY STAR Clothes Washer	>10	n/a
		Standard Dish Washer	ENERGY STAR Dish Washer	>10	n/a
Water Heating	Replace Electric Tank Water Heater	Standard Electric Tank	Electric High Efficiency Tank	6	0.06
			Propane Tankless, Non-condensing	8	0.62
			Propane High Efficiency Tank, Non-Condensing	9	0.44
			Propane Tankless, Condensing	10	0.71
			Heat Pump Water Heater	10	0.66
			Electric Tankless; Propane High Efficiency Tank, Condensing; Solar & Propane Tankless	>10	n/a

Figure 14: Non-elective EEM paybacks and emissions savings for Hot-Dry/Mixed-Dry Climate.

Cold-Very Cold (not including the Northeast)

The cold-very cold climate is represented by cities in two Midwestern states, Michigan and Minnesota. Within this study, this region is characterized by relatively lower electricity rates, high cooling loads, extremely cold temperatures, high electricity emissions factors (from coal-fired electric generation), high water heating loads, and low cooling loads. Not surprisingly, most of the elective EEMs had attractive paybacks due to the large heating loads, with all but solar PV having a payback of less than or equal to 10 years. Of these, replacing existing windows with high-performance windows (U-0.30, SHGC=0.30) had the longest payback at nine years, but also the highest annual emissions savings.

Elective EEM Results, Cold-Very Cold Climate		
Elective EEM	**Payback (years)**	**Annual Emissions Savings (metric tons CO2)**
Air Sealing	1	2.07
Aerosolized Duct Sealing	3	1.49
Ceiling Insulation	4	2.26
Windows	9	2.31
Solar Photovoltaics	>10	n/a

Figure 15: Elective EEM paybacks and emissions savings for Cold-Very Cold Climate.

Analyses of warmer climates included replacement scenarios for existing ASHPs, but in cold climates, ASHPs are generally not installed due to diminished heating capacity and efficiency at lower outdoor temperatures. For this reason, the existing ASHP scenario was replaced with an existing propane boiler scenario, which is a much more common heating system in cold climates. For this non-elective replacement scenario, a high-efficiency propane boiler has a payback of five years when serving as the replacement in lieu of a standard propane boiler.

Based on paybacks, the most attractive non-elective EEMs were selecting a high-efficiency propane furnace when replacing an existing propane furnace (one year) and replacing incandescent lighting with high-efficacy fluorescent lights (one year). The high-efficiency propane furnace also displaced the dual-fuel system as the EEM with the highest emissions savings, due to a combination of low ASHP efficiency at cold temperatures, more extreme cold weather than other regions, and high electricity emissions factors for the representative Midwestern states. When used to replace a propane furnace, ASHPs and the GSHP had paybacks of more than 10 years.

Acceptable paybacks (less than or equal to 10 years) were also provided by Energy Star refrigerators, propane clothes dryers, high-efficiency electric tank water heaters, and three propane water heaters (propane tankless, non-condensing; propane tankless, condensing; and propane high-efficiency tank, non-condensing). Within the cold-very cold climate, a ranking of emissions savings is provided in Figure 16 for all EEMs (elective and non-elective) with paybacks less than or equal to 10 years. The high-efficiency propane furnace, the dual-fuel system, and replacement windows account for the top three emissions saving EEMs for this climate.

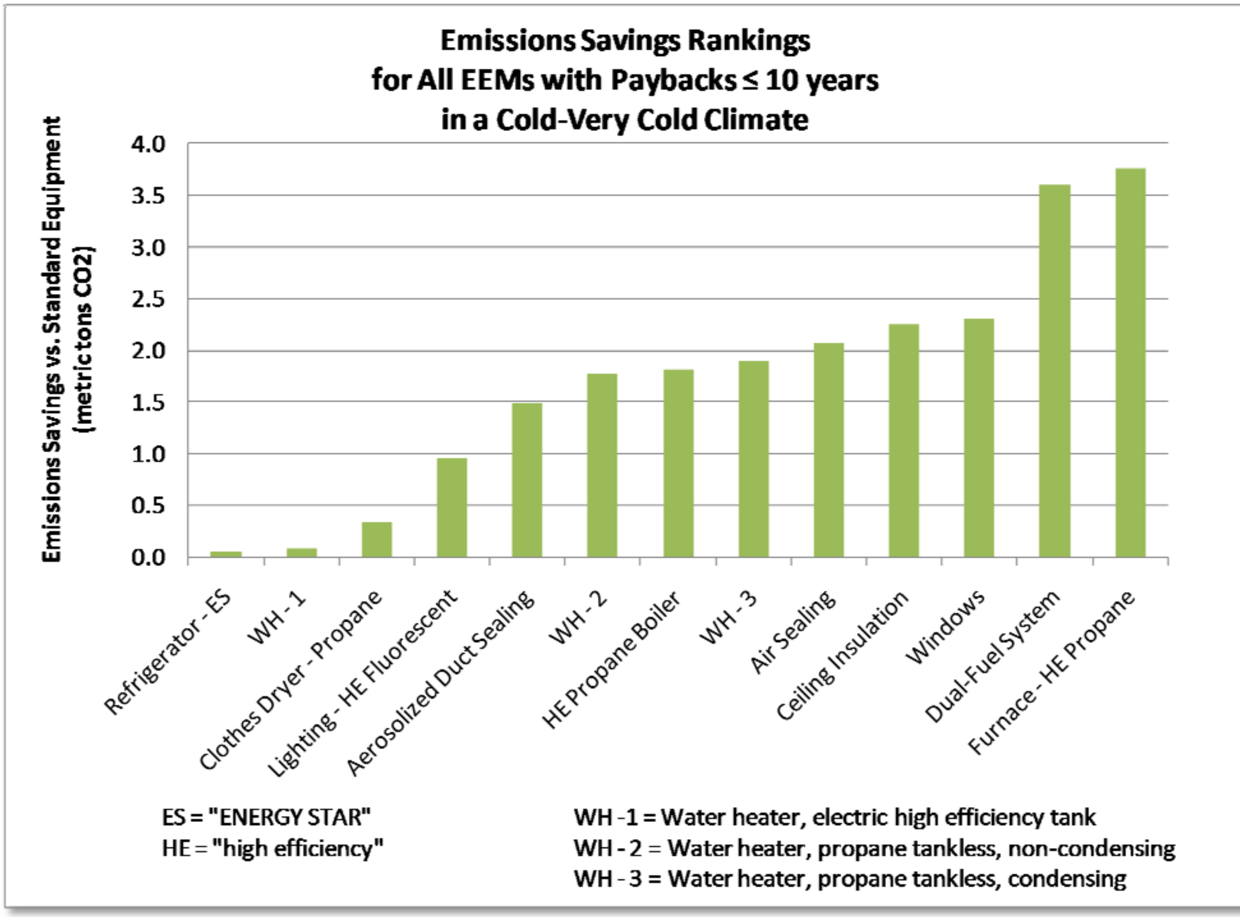

Figure 16: Emissions savings across elective and non-elective EEMs with paybacks less than or equal to 10 years in a Cold-Very Cold climate.

Non-Elective EEM Results, Cold-Very Cold Climate					
Category	Sub-Category	Standard EEM (lowest first cost option)	Improved EEM	Improved versus Standard EEM Analysis	
				Payback (years)	Annual Emissions Savings (metric tons CO2)
Space Heating and Cooling	Replace AC	Standard AC	High Efficiency AC	>10	n/a
	Replace Propane Boiler	Standard Propane Boiler	High Efficiency Propane Boiler	5	1.81
	Replace Propane Furnace	Standard Propane Furnace	High Efficiency Propane Furnace	1	3.76
			Dual-Fuel System	5	3.60
			Standard Efficiency ASHP; High Efficiency ASHP; Ground Source Heat Pump	>10	n/a
Lighting and Appliances	Replace Lighting	90% Incandescent	100% High Efficacy Fluorescent	1	0.95
	Replace Appliance	Electric Clothes Dryer	Propane Clothes Dryer	6	0.34
		Standard Refrigerator	ENERGY STAR Refrigerator	7	0.06
		Standard Clothes Washer	ENERGY STAR Clothes Washer	>10	n/a
		Standard Dish Washer	ENERGY STAR Dish Washer	>10	n/a
Water Heating	Replace Electric Tank Water Heater	Standard Electric Tank	Electric High Efficiency Tank	7	0.08
			Propane Tankless, Non-condensing	9	1.77
			Propane Tankless, Condensing	9	1.89
			Propane High Efficiency Tank, Non-Condensing	10	1.59
			Heat Pump Water Heater; Electric Tankless; Propane High Efficiency Tank, Condensing; Solar & Propane Tankless	>10	n/a

Figure 17: Non-elective EEM paybacks and emissions savings for Cold-Very Cold Climate.

Northeast

The Northeast region shares a similar climate with the cold-very cold region, but was analyzed separately based on notable differences in energy sources (e.g., heating oil employed in much of the Northeast), energy prices, and electricity emissions rates. This region has some of the most attractive non-elective EEM paybacks in the country, driven by heavy space and water heating loads and high energy prices. However, some of the elective EEM paybacks lagged behind those seen in other parts of the country based on assumptions of better existing building infrastructure, especially as related to windows and ceiling insulation.

For example, the representative Northeast home in Manchester, NH was assumed to have existing double-pane wood windows of U-0.55 (37% better thermal performance than the next best existing window) and existing ceiling insulation of R-22 (over three times that assumed in other climates). These higher performing existing building envelope systems resulted in longer paybacks for their relevant EEMs. Also, based on DOE's Residential Energy Consumption Survey[11], the existing heating system for the Northeast was assumed to be a heating-oil fired boiler with hydronic distribution (i.e., radiators). Under this assumption, aerosolized duct sealing only saved energy when the central AC was operating, and therefore had a much longer payback as compared to other regions. Results can be found in Figure 18.

Elective EEM Results, Northeast Region		
Elective EEM	**Payback (years)**	**Annual Emissions Savings (metric tons CO2)**
Air Sealing	1	1.98
Ceiling Insulation	8	1.45
Aerosolized Duct Sealing, Windows, Solar Photovoltaics	>10	n/a

Figure 18: Elective EEM paybacks and emissions savings for Northeast region.

Among the non-elective EEMs, the Northeast shared some common themes with other regions, including the solid economic and environmental performance of the high-efficiency propane furnace and high-efficacy fluorescent lighting, both of which enjoyed rapid paybacks of one year. However, the analysis of heating oil systems in the Northeast yielded several key insights not available in other regions:

- Replacement of a heating oil boiler with a standard- or high-efficiency heating oil boiler provided rapid paybacks (one year or less), and also resulted in 23% to 38% greater emissions than a high-efficiency propane boiler (which had a five-year payback).
- The lowest first-cost system for replacing an existing heating oil furnace was found to be a propane-fired furnace. However, there were four systems that achieved paybacks in less than five years versus the standard propane furnace (standard- and high-efficiency heating oil furnace, high-efficiency propane furnace, and the dual-fuel

[11] U.S. DOE, Energy Information Administration. Residential Energy Consumption Survey. http://www.eia.doe.gov/emeu/recs/.

system). Of these, the dual-fuel system provided the greatest emissions savings, at more than 4.6 times that of the high-efficiency heating oil furnace.

Due to a combination of high electricity rates and high water heating loads, the Northeast region also had the most favorable paybacks for water heating systems within this study. There were several systems that had paybacks of fewer than 10 years when compared with a standard electric tank water heater. The top three water heating systems, in order of increasing paybacks, were the heating oil standard-efficiency tank; the propane high-efficiency tank, non-condensing; and the propane tankless, non-condensing unit. Of these, the unit with the lowest emissions was the propane tankless, non-condensing unit. These findings are illustrated in Figure 19.

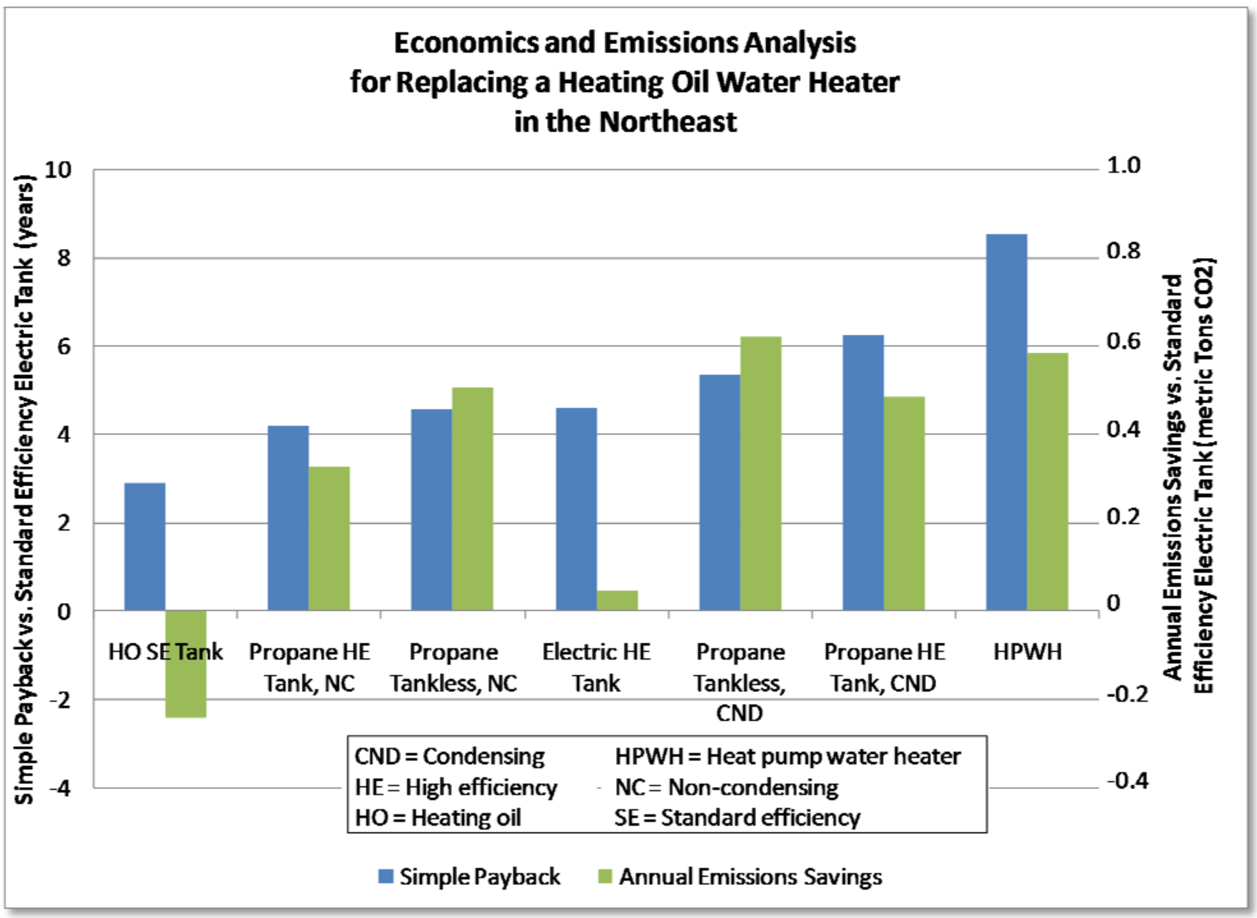

Figure 19: Performance analysis for replacing a heating oil water heater in the Northeast. The standard, low-cost replacement EEM that serves as the basis of these paybacks is a standard efficiency electric tank water heater.

Non-Elective EEM Results, Northeast Region					
Category	Sub-Category	Standard EEM (lowest first cost option)	Improved EEM	Improved versus Standard EEM Analysis	
				Payback (years)	Annual Emissions Savings (metric tons CO2)
Space Heating and Cooling	Replace AC	Standard AC	High Efficiency AC	>10	n/a
	Replace Propane Boiler	Standard Propane Boiler	High Efficiency Propane Boiler	9	1.37
	Replace Propane Furnace	Standard Propane Furnace	High Efficiency Propane Furnace	1	2.94
			Dual-Fuel System	4	4.52
			Standard Efficiency ASHP; High Efficiency ASHP; Ground Source Heat Pump	>10	n/a
	Replace Heating Oil Boiler	Standard Propane Boiler	Standard Heating Oil Boiler	<1	(1.49)
			High Efficiency Heating Oil Boiler	1	(0.36)
			High Efficiency Propane Boiler	5	1.37
	Replace Heating Oil Furnace	Standard Propane Furnace	Standard Heating Oil Furnace	1	(1.15)
			High Efficiency Propane Furnace	1	2.94
			High Efficiency Heating Oil Furnace	2	0.98
			Dual-Fuel System	4	4.52
			Standard Efficiency ASHP; High Efficiency ASHP; Ground Source Heat Pump	>10	n/a
Lighting and Appliances	Replace Lighting	90% Incandescent	100% High Efficacy Fluorescent	1	0.40
	Replace Appliance	Electric Clothes Dryer	Propane Clothes Dryer	3	0.10
		Standard Refrigerator	ENERGY STAR Refrigerator	5	0.03
		Standard Clothes Washer	ENERGY STAR Clothes Washer	>10	n/a
		Standard Dish Washer	ENERGY STAR Dish Washer	>10	n/a
Water Heating	Replace Heating Oil Tank Water Heater	Standard Electric Tank	Heating Oil Tank, Standard Efficiency	3	(0.24)
			Propane High Efficiency Tank, Non-Condensing	4	0.33
			Propane Tankless, Non-condensing	5	0.51
			Electric High Efficiency Tank	5	0.05
			Propane Tankless, Condensing	5	0.62
			Propane High Efficiency Tank, Non-Condensing	6	0.48
			Heat Pump Water Heater	9	0.58
			Electric Tankless; Solar & Propane Tankless	>10	n/a

Figure 20: Non-elective EEM paybacks and emissions savings for Northeast region.

Conclusions

The results of the study identify the most cost-effective measures for improving the energy efficiency of existing homes, considering first costs (labor and materials) and annual energy use and costs. Taking a homeowner's perspective, the study evaluated dozens of energy-efficiency upgrades (referred to as "energy efficiency measures" or EEMs), based on their associated economics (e.g., simple payback) and CO2 emissions. Other important performance considerations may also be part of a homeowner's decision, even though they are not directly captured in the payback metric (e.g. high hot water output rate from propane tankless water heaters).

EEMs were grouped into non-elective and elective measures to distinguish between items that typically require immediate replacement when they fail (e.g., refrigerator, water heater, central heating, etc.) versus measures that are non-essential for a home to function but have other intrinsic value (e.g., replacement of older windows, increasing ceiling insulation, air sealing the home, etc.).

While the study assumed that non-elective EEMs were replaced at failure, the payback and emissions analysis of non-elective EEMs can also be used by homeowners in making informed decisions about proactive replacements of equipment. For all EEMs, pre- and post-EEM energy performance characteristics are captured in Appendix C.

Elective EEMs

Five elective EEMs were studied: air sealing, aerosolized duct sealing, replacement windows, solar photovoltaics, and ceiling insulation. Of the elective EEMs, air sealing consistently had the best payback across all regions, at one to three years, assuming that a 30% reduction in air infiltration could be realized through moderate efforts. Aerosolized duct sealing typically had the second best payback, ranging from three to four years across all regions except the Northeast, where its effectiveness was limited based on the assumption of a boiler with hydronic distribution being the primary source of heating. Ceiling insulation paybacks ranged from four to eight years, assuming that the existing ceiling insulation was poor (see Appendix B for detailed assumptions of existing insulation at individual sites). Based on the improved U-factor and the Solar Heat Gain Coefficient (SHGC) of replacement windows, this EEM was found to offer paybacks of less than 10 years in the cold-very cold climate and mixed-humid climate.

Not all EEMs were found to have attractive paybacks. However, EEMs with unattractive paybacks may still appeal to homeowners due to other intrinsic benefits, such as better aesthetics, improved function, enhanced comfort, or technological appeal. Other EEMs, such as a solar photovoltaic system, which had a payback of over 10 years across all regions, can become more attractive once federal, state, and local incentives are factored into the system's first costs. Further, in some categories like water heating, only a few high efficiency products in the category will quality for incentives and rebates (e.g., propane tankless and heat pump water heaters), which will differentiate them from competitors. However, this study did not undertake to quantify these incentives due to their transitory nature and the fact that they could not be uniformly applied across the locations and scenarios covered within the study's scope.

Non-Elective EEMs

More than 30 non-elective EEMs replacement scenarios were evaluated within the study. Non-elective EEMs were categorized as those prone to sudden failure or malfunction, that would generally require immediate repair or replacement, including lighting; appliances; and space cooling, space heating, and water heating equipment. However, the economic analysis for the non-elective EEMs could also be used by homeowners to make informed decisions regarding proactive replacements, when equipment is nearing its useful life. Proactive replacement can provide multiple advantages to a homeowner, such as opportunity to shop around for competitive pricing, greater selection, and the ability to vet contractors.

Efficiency of Aging Equipment

According to the Department of Energy (DOE),[11] the efficiency of mechanical equipment decreases as the equipment ages, based on the equipment's maintenance schedule. Assuming that existing equipment in a home was standard efficiency when installed, and assuming seldom maintenance, the following are DOE-projected efficiencies at various ages. "Useful life" is a metric that was determined through a study by the National Association of Home Builders and Bank of America.[12] The reduction in efficiency captured in the following table makes a compelling argument for proactive equipment replacement prior to failure. See the Methodology section for more information.

Equipment, Efficiency Rating When New	2/3 Useful Life		Useful Life	
	Age (years)	Expected Efficiency	Age (years)	Expected Efficiency
Furnace: 78 AFUE	12	65 AFUE	17.5	60 AFUE
ASHP: 6.8 HSPF; 10 SEER	11	4.9 HSPF; 7.2 SEER	16	4.2 HSPF; 6.9 SEER

References:

11. Hendron, R. 2006. Building America Performance Analysis Procedures for Existing Homes. U.S. DOE. NREL/TP-550-38238.

12. Seiders, D., G. Ahluwalia, et al. 2007. Study of Life Expectancy of Home Components. National Association of Home Builders, Bank of America Home Equity.

Results from the non-elective EEM replacement scenarios are grouped according to system category.

Lighting and Appliances

Replacing incandescent lighting with high-efficacy fluorescents was a consistent and strong economic performer, with paybacks of one year or less and annual emissions savings of 0.4 to 1.28 metric tons of CO2. Selection of an Energy Star refrigerator versus a standard refrigerator provided a payback of five to seven years but low annual emissions savings, at 0.03 to 0.07 metric tons of CO2. A more balanced appliance choice with an attractive payback and emissions savings was the selection of a propane clothes dryer over an electric clothes dryer. This choice was expected to have a payback of three to six years with annual emissions savings of 0.1 to 0.34 metric tons of CO_2, three to four times the emissions savings of the Energy Star refrigerator. Selection of an Energy Star clothes washer or dishwasher was found to have a payback of greater than 10 years across all regions, largely due to high first costs associated with the premium features generally provided with these appliances.

Space Cooling and Heating

Where space cooling was provided by a central AC unit, selecting a high-efficiency AC unit instead of a standard-efficiency unit provided a payback of six to eight years in hot climates (hot-humid and hot-dry/mixed-dry) with associated emissions savings of 0.37 to 0.55 metric tons of CO_2. In other regions, this EEM was unattractive due to low cooling loads.

The economic and emissions performance of space heating EEMs were also highly dependent on climate. A consistent performer across most climate zones was a high-efficiency propane furnace in lieu of a standard-efficiency propane furnace. This EEM provided a payback of one year in mixed-humid, cold-very cold, and Northeast regions, and associated annual emissions savings of 2.52 to 3.76 metric tons of CO_2. The dual-fuel system, which was composed of a high-efficiency ASHP working in tandem with a high-efficiency propane furnace, was another excellent performer. In all climates but the hot-humid and hot-dry/mixed-dry, the dual-fuel system had simple paybacks of four to six years, with the highest associated annual emissions savings of any EEM in the study, at 7.28 metric tons of CO_2 when chosen over a standard ASHP in a mixed-humid climate.

ASHPs had attractive paybacks in hot climates, but GSHPs had paybacks of greater than 10 years in all but the mixed-humid climate. High paybacks for GSHPs, which had low annual energy costs, were attributed to extremely high first costs, driven in large part by expensive vertical loop fields. In some areas and applications, these high first costs may be offset by federal, state, and local incentives, which would make GSHPs more cost-competitive. However, the same is true of nearly all high-efficiency EEMs covered within this study, and this analysis was beyond the study’s scope.

In the Northeast region, there were a few attractive options for replacing an existing heating oil furnace. Of the options, selection of a standard-efficiency propane furnace was found to be the lowest first-cost system when replacing a fuel oil furnace. Selecting a high-efficiency propane furnace versus the standard-efficiency propane furnace resulted in a payback of one year, and provided three times the annual emissions savings as specifying a high-efficiency heating oil furnace.

Further, in-depth analysis on heating system performance may be found in PERC’s “Comparative Analysis of Residential Heating Systems” report.

Water Heating

Overall, there were not many water heating EEMs that were consistently attractive from an economics basis. The high-efficiency electric tank water heater provided a payback of 10 years or less across all regions studied; however, its associated CO_2 emissions were also consistently much higher than alternatives. In the Northeast, however, there were several water heating EEMs that provided good opportunities for strong paybacks and emissions savings. Five EEMs, including heating oil, electric, and propane units, had economic paybacks less than or equal to 5 years, with the propane tankless, condensing unit offering the highest annual emissions savings at 0.62 metric tons of CO_2. Propane tankless water heating technology also offers ancillary benefits such as a high hot water delivery rate (roughly triple the First Hour Rating of a 50 gallon electric storage water heater) and a life expectancy over 50% longer than storage tank units. A more in-depth analysis which specifically focuses on water heating system performance is found in PERC's "Energy, Economic, and Environmental Analysis of Residential Water Heating Systems" report. This 2010 study is a highly detailed analysis of 11 residential water heating systems which examines the 7-year total cost of systems, which reflects both first costs and annual energy costs.

Appendix A: Glossary of Terms

Aerosolized duct-sealing – this technology involves injecting aerosolized sealant particles into a pressurized duct system where the particles adhere to crack edges to effectively seal leaks.

AFUE – also known as Annual Fuel Utilization Efficiency, this is expressed as the relationship between the amount of fuel entering a furnace or boiler and the amount of space heat that fuel is converted into. It is commonly expressed as a percentage.

AHRI – this acronym stands for the Air-Conditioning, Heating, and Refrigeration Institute, which provides certification and performance information on heating, ventilation, air conditioning, and refrigeration equipment and components.

ASHP – also known as an air source heat pump, these systems are typically used in moderate climates to heat and cool a home by using a vapor compression cycle to "pump" heat from a low temperature source to a higher temperature sink.

Btu – also known as a British thermal unit, it is the amount of heat required to raise one pound of water one degree Fahrenheit.

Condensing – for purposes of this report, this is a characteristic of some water heaters that use the heat from exhaust gases to assist in heating the water. Condensing units typically operate at a higher efficiency than non-condensing units.

COP – this acronym stands for Coefficient of Performance, and is a heating efficiency metric for a GSHP that is computed by dividing the heat output of a heat pump by the energy input.

EEM – this acronym stands for Energy Efficiency Measures. The report delineates between elective and non-elective EEMs. For the purposes of this report, elective measures are upgrades to a home that do not require immediate action by the homeowner. On the other hand, non-elective measures are typically made in haste, based upon the loss of a critical function in the home's operation.

EER – also known as Energy Efficiency Ratio, it is the measure of how efficiently a cooling system will operate when the outside air is assumed to be a specific temperature. Higher values signify a more efficient system.

EF – also known as Energy Factor, this relates to the efficiency level of a water heater. Within groupings of water heater equipment operating with the same energy source, higher values indicate more efficient systems. On its own, EF is an inadequate measure for comparing energy costs across water heating equipment of differing fuel types.

FHR – also known as First Hour Rating, this is the amount of hot water a water heater can provide on a per hour basis, when starting with a full tank of water.

GSHP – also known as a ground source heat pump, these units use the relatively constant temperature of the earth to regulate a home's indoor air temperature.

HSPF – also known as Heating Seasonal Performance Factor, this is a measure of the heating efficiency of a heat pump. Higher values indicate systems that are more efficient.

IECC – this acronym stands for the International Energy Conservation Code, which is the primary national model energy code.

Manual J 8th Edition – from the Air Conditioning Contractors of America (ACCA), this manual serves as the industry standard for estimating residential heating and cooling loads.

MEF – also known as Modified Energy Factor, is a metric for clothes washer energy performance. The higher the value, the more efficient the clothes washer is.

Metric ton – a unit of measure equal to 2,204.6 pounds.

Non-condensing – for purposes of this report, this characteristic refers to water heaters that do not extract heat from combustion gases to the point of condensation. In general, non-condensing units are less efficient than condensing units.

R-value – this provides a measure of a material's resistance to heat flow. The greater the value, the more resistant a material is to heat flow. It applies primarily to insulation.

SEER – also known as Seasonal Energy Efficiency Ratio, it is the measure of the cooling efficiency of an air conditioner or heat pump. Higher values signify cooling systems that are more efficient.

SHGC – also known as the Solar Heat Gain Coefficient, is a measure of the fraction of the sun's heat that passes through a window. Expressed as a value between zero and one, a lower value signifies less transmission of solar heat.

U-factor – similar to an R-value, this measures the rate of heat flow through a material. The lower the value, the better the material will be able to insulate. It is most often applied to windows.

Appendix B: Reference Home Assumptions

Existing Homes Characteristics - Circa 1973

City	Sacramento	Orlando	Baltimore	Grand Rapids	Duluth	Columbia	Manchester	Las Vegas	Buffalo	Dallas
State	CA	FL	MD	MI	MN	MO	NH	NV	NY	TX
Census Division	Pacific	South Atlantic	South Atlantic	East North Central	West North Central	West North Central	New England	Mountain	Middle Atlantic	West South Central
County	Sacramento	Orange	Baltimore City	Kent	St. Louis	Boone	Hillsborough	Clark	Erie	Dallas
Climate Zone, IECC	3	2	4	5	7	4	5	3	5	3
Climate Zone, Building America	Hot-Dry	Hot-Humid	Mixed-Humid	Cold	Very Cold	Mixed-Humid	Cold	Mixed-Dry	Cold	Hot-Humid
Design Heating Temperature	34	42	17	5	-15	5	-1	32	6	25
Heating Degree Days, base 65	2775	660	4714	6927	9906	5214	7483	2535	6799	2420
Cooling Degree Hours, base 74	10464	33985	9504	4555	849	14475	1993	43153	3044	36294
Cooling Employed (Yes=1, No=0)	1	1	1	1	1	1	1	1	1	1
House orientation for front of home	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE
Above grade sqft	1660	1660	1660	1660	1660	1660	1660	1660	1660	1660
Aspect ratio	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Length (ft)	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5
Width (ft)	35.7	35.7	35.7	35.7	35.7	35.7	35.7	35.7	35.7	35.7
First Floor Ceiling Height (ft)	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Second Floor Ceiling Height (ft)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Conditioned area (sqft)	1660	1660	3320	3320	3320	3320	3320	1660	3320	1660
Conditioned volume (cuft)	13280	13280	24900	24900	24900	24900	24900	13280	24900	13280
Housing Type (SFD = single family detached)	SFD	SFD	SFD	SFD	SFD	SFD	SFD	SFD	SFD	SFD
# Stories (floors on or above grade)	1	1	1	1	1	1	1	1	1	1
Number of bedrooms	3	3	3	3	3	3	3	3	3	3
Conditioned floors (including basement where applicable)	1	1	2	2	2	2	2	1	2	1
Foundation										
Slab on grade (Yes=1, No=0)	1	1	0	0	0	0	0	1	0	1
Crawl (Yes=1, No=0)	0	0	0	0	0	0	0	0	0	0
Basement (Yes=1, No=0)	0	0	1	1	1	1	1	0	1	0
Conditioned basement (Yes=1, No=0)	0	0	1	1	1	1	1	0	1	0
Basement slab area (sqft)	N/A	N/A	1660	1660	1660	1660	1660	N/A	1660	N/A
Slab on grade area (sqft)	1660	1660	N/A	N/A	N/A	N/A	N/A	1660	N/A	1660
Slab on grade vertical insulation R-value (Assumed grade I)	0	0	N/A	N/A	N/A	N/A	N/A	0	N/A	0
Slab on grade vertical insulation depth (ft)	0	0	N/A	N/A	N/A	N/A	N/A	0	N/A	0
Foundation Full Perimeter (ft)	164.4	164.4	164.4	164.4	164.4	164.4	164.4	164.4	164.4	164.4
Basement slab or slab on grade Total Exposed Perimeter (ft)	164.4	164.4	164.4	164.4	164.4	164.4	164.4	164.4	164.4	164.4
Basement blanket insulation R-value (Assumed grade I)	N/A	N/A	9	9	9	9	9	N/A	9	N/A
Basement blanket insulation height (ft)	N/A	N/A	7	7	7	7	7	N/A	7	N/A
Basement wall average height above grade (ft)	N/A	N/A	2	2	2	2	2	N/A	2	N/A
Basement wall floor to ceiling height (ft)	N/A	N/A	7	7	7	7	7	N/A	7	N/A
Basement wall type (UB=Block, uninsulated cores)	N/A	N/A	UB	UB	UB	UB	UB	N/A	UB	N/A
Basement slab depth below grade (ft)	N/A	N/A	5	5	5	5	5	N/A	5	N/A
Band Joist										
Band joist area (sqft)	N/A	N/A	164.4	164.4	164.4	164.4	164.4	N/A	164.4	N/A
Cavity insulation R-value (Assumed grade I)	N/A	N/A	9	9	9	9	9	N/A	9	N/A
Cavity insulation thickness (in)	N/A	N/A	3.5	3.5	3.5	3.5	3.5	N/A	3.5	N/A

Existing Homes Characteristics - Circa 1973, Continued										
City	Sacramento	Orlando	Baltimore	Grand Rapids	Duluth	Columbia	Manchester	Las Vegas	Buffalo	Dallas
State	CA	FL	MD	MI	MN	MO	NH	NV	NY	TX
Above Grade Wall										
Stud depth and insulation depth (in)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Stud spacing (in o.c.)	16" o.c.	16" o.c.	16" o.c.	16" o.c.	16" o.c.	16" o.c.	16" o.c.	16" o.c.	16" o.c.	16" o.c.
Cavity insulation R-value (Assumed grade I)	9	9	9	9	9	9	9	9	9	9
Gross area (sqft)	1315	1315	1315	1315	1315	1315	1315	1315	1315	1315
Window Type (Al = Aluminum, Wd = Wood)	Al	Al	Al	Wd	Wd	Al	Wd	Al	Wd	Al
Number of Window Panes	1	1	1	1	1	2	2	1	1	1
Window U-value	1.27	1.27	1.27	0.89	0.89	0.87	0.55	1.27	0.89	1.27
Window SHGC	0.75	0.75	0.75	0.64	0.64	0.67	0.56	0.75	0.64	0.75
Window area (sqft)	149.4	149.4	186.8	186.8	186.8	186.8	186.8	149.4	186.8	149.4
NW	49.8	49.8	62.3	62.3	62.3	62.3	62.3	49.8	62.3	49.8
SE	49.8	49.8	62.3	62.3	62.3	62.3	62.3	49.8	62.3	49.8
NE	24.9	24.9	31.1	31.1	31.1	31.1	31.1	24.9	31.1	24.9
SW	24.9	24.9	31.1	31.1	31.1	31.1	31.1	24.9	31.1	24.9
# of 12 ft2 windows	12	12	15	15	15	15	15	12	15	12
# of 6 ft2 windows	1	1	1	1	1	1	1	1	1	1
Interior shading, winter	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Interior shading, summer	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Overhang depth (ft)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Overhang to top of window (ft)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Overhang to bottom of window (ft)	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Doors - Assumed 2 1/4" wood, solid core, R-2.8, 20 sqft; 2 locations: front, rear										
Attic/Ceiling										
Gross area (sqft)	1660	1660	1660	1660	1660	1660	1660	1660	1660	1660
Total insulation R-value (Assumed grade I)	7	7	7	11	7	7	22	7	7	7
Cavity insulation R-value (Assumed grade I)	7	7	7	11	7	7	19	7	7	7
Cavity insulation thickness (in)	2.3	2.3	2.3	3.7	2.3	2.3	5.5	2.3	2.3	2.3
Continuous insulation R-value (Assumed grade I)	0	0	0	0	0	0	3	0	0	0
Bottom chord/rafter spacing (in oc)	16	16	16	16	16	16	16	16	16	16
Bottom chord/rafter size, wxh (in)	1.5x5.5	1.5x5.5	1.5x5.5	1.5x5.5	1.5x5.5	1.5x5.5	1.5x5.5	1.5x5.5	1.5x5.5	1.5x5.5
Solar absorptance	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Mechanical Equipment										
Location of space heating and cooling equipment (A=attic, B=basement)	A	A	B	B	B	B	B	A	B	A
Location of water heater (F=first floor, G=garage, B=basement)	G	G	B	B	B	B	B	G	B	G
Heating set point (deg F)	70	70	70	70	70	70	70	70	70	70
Cooling set point (deg F)	75	75	75	75	75	75	75	75	75	75
Programmable T-stat (Yes=1, No=0)	0	0	0	0	0	0	0	0	0	0
Default heating/cooling system with derated efficiencies (PF = propane furnace 65 AFUE; AC = Central AC with effective 7.4 SEER; FOB = fuel oil boiler 56 AFUE), efficiencies derated based on DOE algorithm and age assumed at 2/3 useful life	PF, AC	PF, AC	PF, AC	PF, AC	PF, AC	PF, AC	FOB, AC	PF, AC	FOB, AC	PF, AC
Duct System										
Location (A=attic, B=basement)	A	A	B	B	B	B	B	A	B	A
Thermal efficiency of ducts	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Duct insulation R-value (unconditioned space only)	4	4	4	4	4	4	4	4	4	4
Infiltration, SLA	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066
Infiltration, ELA	158	158	316	316	316	316	316	158	316	158
Cooling season ventilation	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural

Sources for Existing Home Characteristics:

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- Huang, J.; and Gu, L. 2002. Prototype Residential Buildings to Represent the U.S. Housing Stock. Draft LBNL Report. Berkeley, CA: Lawrence Berkeley National Laboratory.
- Model Energy Code. 1989. Council of American Building Officials.
- U.S. Department of Energy, Energy Information Administration. Residential Energy Consumption Survey. http://www.eia.doe.gov/emeu/recs/.

Appendix C: Energy Efficiency Measures Analyzed

EEM Parameters							
Division	EEM	Fuel type	Description	Capacity	Base Efficiency or Rating	Adjusted Equipment Efficiency	Average First Cost
Building Envelope	Windows	N/A	Existing wood window, single pane	N/A	U=0.89; SHGC=0.64	N/A	N/A
		N/A	Existing wood window, double pane	N/A	U=0.55; SHGC=0.56	N/A	N/A
		N/A	Existing aluminum window, single pane	N/A	U=1.27; SHGC=0.75	N/A	N/A
		N/A	Existing aluminum window, double pane	N/A	U=0.87; SHGC=0.67	N/A	N/A
		N/A	New energy efficient windows	N/A	U=0.30; SHGC=0.30	N/A	$8,093
	Air Sealing	N/A	Existing	N/A	SLA: 0.00066	N/A	N/A
		N/A	New	N/A	SLA: 0.00046	N/A	$482
	Ceiling Insulation	N/A	Existing	N/A	R-7: CA,FL,MD,MN,MO,NV, NY,TX; R-11: MI; R-22: NH	N/A	N/A
		N/A	New	N/A	R-30: CA,FL,NV,TX; R-38:MD,MO,NH,NY,MI; R-49: MN	N/A	$2,902
Lighting and Appliances	Lighting	Electric	New, 90% incandescent, 10% fluorescent	N/A	Assume 10% of all lighting is fluorescent, 90% is incandescent	N/A	$142
		Electric	New, 100% fluorescent	N/A	Assume 100% lighting is fluorescent	N/A	$264
	Clothes Washer	Electric	New, standard	3.5 ft3	MEF=1.4; WF=8.8	N/A	$438
		Electric	New, ENERGY STAR	4.0 ft3	MEF=2.3; WF=4.3	N/A	$863
	Clothes Dryer	Electric	New	7 ft3	3.01 lbs/kWh	N/A	$734
		Propane	New	7 ft3	2.67 lbs/kWh	N/A	$798
	Refrigerator	Electric	New, standard	18 ft3	452 kWh/yr	N/A	$601
		Electric	New, ENERGY STAR	18 ft3	362 kWh/yr	N/A	$672
	Dishwasher	Electric	New, standard	Standard	Energy Guide Label: 404 kWh/yr	N/A	$210
		Electric	New, ENERGY STAR	Standard	Energy Guide Label: 317 kWh/yr	N/A	$663
Space Heating and Cooling Systems	Duct Sealing	N/A	Existing	N/A	Qualitative RESNET distribution efficiency defaults: 0.80 in unconditioned space, 0.88 in conditioned space	N/A	N/A
		N/A	New/Improved: Aerosolized	N/A	RESNET "Reduced leakage" defaults: 0.88 distribution efficiency for ducts in unconditioned space, 0.96 for ducts in conditioned space	N/A	$1,017

EEM Parameters, Continued							
Division	**EEM**	**Fuel type**	**Description**	**Capacity**	**Base Efficiency or Rating**	**Adjusted Equipment Efficiency**	**Average First Cost**
Space Heating and Cooling Systems, Continued	Furnace	Propane	Existing	Varies	78 AFUE	65 AFUE	N/A
		Propane	New, standard	Varies	78 AFUE	78 AFUE	$973
		Propane	New, "high efficiency"	Varies	95 AFUE	95 AFUE	$1,506
		Oil	Existing	Varies	78 AFUE	64 AFUE	N/A
		Oil	New, standard	Varies	78 AFUE	78 AFUE	$2,307
		Oil	New, "high efficiency"	Varies	95 AFUE	95 AFUE	$4,990
	Boiler	Propane	Existing	Varies	80 AFUE	65 AFUE	N/A
		Propane	New, standard	Varies	80 AFUE	80 AFUE	$3,243
		Propane	New, "high efficiency"	Varies	95 AFUE	95 AFUE	$5,502
		Oil	Existing	Varies	80 AFUE	56 AFUE	N/A
		Oil	New, standard	Varies	80 AFUE	80 AFUE	$3,318
		Oil	New, "high efficiency"	Varies	90 AFUE	90 AFUE	$4,771
	Heat Pump	Electric, heating	Existing ASHP	Varies	6.8 HSPF	4.9 HSPF	N/A
		Electric, cooling		Varies	10 SEER	7.2 SEER	
		Electric, heating	New ASHP, standard	Varies	7.7 HSPF	7.7 HSPF	$4,483
		Electric, cooling		Varies	13 SEER	13 SEER	
		Electric, heating	New ASHP, "high efficiency"	Varies	8.5 HSPF	8.5 HSPF	$5,390
		Electric, cooling		Varies	15 SEER	15 SEER	
		Electric, heating	New, ground source	Varies	3.3 COP	3.3 COP	$33,470
		Electric, cooling		Varies	14.1 EER	14.1 EER	
	Dual Fuel	Propane; Electric, heating	New, "high efficiency" propane furnace & ASHP	Varies	95 AFUE; 8.5 HSPF	95 AFUE; 8.5 HSPF	$6,896
		Electric, cooling	New ASHP, "high efficiency"	Varies	15 SEER	15 SEER	
	AC unit	Electric	Existing	Varies	10 SEER	7.4 SEER	N/A
		Electric	New, standard	Varies	13 SEER	13 SEER	$3,054
		Electric	New, "high efficiency"	Varies	16 SEER	16 SEER	$3,729
Water Heating Systems	Water heater	Electric, tank	Existing	50	0.86 EF	0.84 EF	N/A
		Electric, tank	New, standard	50	0.90 EF	0.90 EF	$700
		Electric, tank	New, "high efficiency"	50	0.93 EF	0.93 EF	$795
		Electric, tank	New, Heat Pump Water Heater	50	2.0 EF	2.0 EF	$2,679
		Propane, tank	Existing	40	0.54 EF	0.49 EF	N/A
		Propane, tank	New, standard	40	0.59 EF	0.59 EF	$889
		Propane, tank	New, "high efficiency", non-condensing	40	0.67 EF	0.67 EF	$1,636
		Propane, tank	New, "high efficiency", condensing	50	0.80 EF	0.80 EF	$2,435
		Oil, tank	Existing	32	0.53 EF	0.50 EF	N/A
		Oil, tank	New, standard	32	0.53 EF	0.50 EF	$1,584
		Propane, tankless	New, non-condensing	4 gpm w/75 deg F rise	0.82 EF	0.82 EF	$2,041
		Propane, tankless	New, condensing	4 gpm w/75 deg F rise	0.94 EF	0.94 EF	$2,493
		Electric, tankless	New	2.3 gpm	0.99 EF	0.99 EF	$1,409
		Solar & Propane, tankless	New, non-condensing	4 gpm w/75 deg F rise	0.82 EF + 2 flat plate collectors	0.82 EF + 2 flat plate collectors	$11,707
Renewables	Solar PV	Electric	New	3.5 kW	92% inverter efficiency, array south facing, tilted at roof pitch of 5/12 (22.6 deg), 350 sqft of collector area	N/A	N/A

Appendix D: Emissions Factors

State	Heating Oil (metric tons CO_2/gal)	Propane (metric tons CO_2/gal)	Electricity (metric tons CO_2/kWh)
CA	0.01015	0.00575	0.00024
FL	0.01015	0.00575	0.00061
MD	0.01015	0.00575	0.00061
MI	0.01015	0.00575	0.00061
MN	0.01015	0.00575	0.00072
MO	0.01015	0.00575	0.00084
NH	0.01015	0.00575	0.00036
NV	0.01015	0.00575	0.00065
NY	0.01015	0.00575	0.00038
TX	0.01015	0.00575	0.00061

Sources:

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