Review and Analysis of Equipment Trade-offs in Residential Energy Codes

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Energy Efficient Codes Coalition

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Executive Summary

This report examines the homeowner energy cost impacts of reinstating equipment trade-offs, as proposed by the National Association of Homebuilders (NAHB) in RE166-13 for the residential energy chapter of the 2015 IECC. Such trade-offs would allow the installation of less-efficient windows, reduced insulation levels, or increased infiltration in exchange for installing more efficient heating, cooling, or water heating systems. The ICC's Governmental Member Voting Representatives removed these trade-offs from the 2009 IECC, and reaffirmed their removal in 2012. Since that time, most states have adopted the 2009 or 2012 editions of the IECC and rejected efforts to reinstate equipment trade-offs. The elimination of these trade-offs was based on the recognition that they weaken the energy efficiency of new buildings, both initially and over the life of the home.

Including Equipment Trade-Offs Would Significantly Weaken the IECC

This analysis shows that the equipment trade-offs proposed in RE166-13 would increase homeowner energy bills significantly. They would reduce the energy savings the IECC is intended to produce in two ways (both of which were identified by the U.S. Department of Energy (DOE) in its statutorily-mandated determination[1] on the 2009 IECC):

1. **Free ridership effect:** Because high-efficiency equipment is already widely used in the residential construction market,[2] there is substantial free ridership[3] potential from permitting equipment trade-offs. Adding equipment trade-offs in the 2015 IECC would allow the weakening of building envelopes based on unwarranted trade-off credit for equipment *that is being installed anyway*.

2. **Balance of lifecycle energy waste:** The IECC's stated intent is to save energy "over the useful life of the building" (see 2012 IECC Section R101.3). A lifecycle analysis of equipment trade-offs therefore requires that the differential lifetimes of equipment vs. envelope technologies be taken into account. But the performance compliance trade-off method in the IECC only considers energy use for the first year of operation. Heating, cooling or water heating equipment typically lasts between 10 and 20 years while envelope measures typically last 30-50 years or more. When the original equipment is replaced, homeowners would be expected to install new equipment at the efficiency levels prevailing at that time, but the "trade-off" home would have a weaker envelope than the 2012 IECC-compliant home. So while a home using equipment trade-offs might show equivalent first-year energy costs, its weaker envelope will increase energy bills over the life of the building.

The IECC Without Equipment Trade-offs is Critical to Long-Term Energy Savings

The effects of energy wasted by free ridership and lifecycle impacts would be substantial over the long lives of today's homes, and would significantly erode the energy efficiency gains that the IECC process has achieved since 2006. This analysis shows that trading off the commonly installed 90+ AFUE furnace for weaker envelope efficiency, in the high proportion of homes where such furnaces are installed anyway, would by itself increase national-average homeowner energy costs by 6% to 9, depending on the furnace efficiency selected.[4] On a national level, the table below shows that the 30-year present value of higher homeowner

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[1] See Appendix K for language from DOE determination of the 2009 IECC.
[2] 90+ AFUE gas furnaces account for half of all units sold in recent years, and a higher percentage in colder states.
[3] Free ridership is defined as giving policy or program credit for actions that would have occurred without the policy or program.
[4] See Appendix J for impacts for each equipment type and efficiency level.

energy bills from trading-off a 90 AFUE furnace for a weaker envelope would be about $400 million.

Energy Cost Impacts of Permitting AFUE 90 Furnace Trade-offs

	Years 1-20 Free Ridership	Years 21-30 Balance-of-Lifecycle	30 Year Total
Energy Cost Impact ($)	$335,285,848	$167,642,924	$502,928,772
Energy Cost Impact - Present Value ($)	$292,431,744	$102,818,134	**$395,249,878**
Carbon Impact (MTCO2e)	1,642,497	821,248	2,463,745
Natural Gas Impact (Therms)	308,691,672	154,345,836	463,037,508

While $400 million in higher energy bills sounds like a lot of money, it represents the impacts for only a single average year of housing starts. If such trade-offs continued for just one 3-year code cycle, homeowners could be saddled with more than $1.1 billion in needlessly-high energy bills.

Beyond the commonly installed 90 AFUE gas furnace, if builders used a wider range of trade-offs for higher efficiency heating equipment, air conditioners, and water heaters, this could increase individual homeowner energy costs by a national average 11% to 22% and the increase in homeowner energy bills would roughly double accordingly. Simply upgrading water heaters, for example, would increase energy use by an average of 9% for a tankless gas water heater or 10% for an electric heat pump water heater, as builders would be able to permanently reduce building envelope efficiency for short-life equipment. Home builders are free to upgrade equipment already, and many do, for any number of reasons. But to give code compliance credit for such actions would weaken the IECC's intended energy efficiency goals, now and over the long term.

The IECC Without Equipment Trade-offs is Current National Policy

The 2009 American Recovery and Reinvestment Act (ARRA) made state adoption of and compliance with the 2009 IECC a condition for receiving State Energy Program ARRA grants. Accordingly, all fifty states submitted letters committing to adopt residential codes that meet or exceed the 2009 IECC, and many states used grant funds to implement and improve compliance with it. The DOE has issued its statutory-required determinations on the 2009 and 2012 IECC, finding they would improve energy efficiency over previous versions, thereby requiring states to review these codes for potential adoption. Two-thirds of the states and numerous localities have enacted the 2009 or 2012 IECC residential energy code without equipment trade-off provisions.

In summary, the IECC has not allowed equipment trade-offs since 2006, and their removal has been a key element of the IECC's 30% improvement in energy efficiency. The proponents of RE166-13 claim that this code change is 'energy neutral', and one hearing witness stated that 'a BTU is a BTU.' This analysis shows those statements to be factually incorrect. Reintroducing equipment trade-offs in the 2015 IECC would increase new homes' energy use substantially, imposing needless homeowner energy bill increases for the life of the home.

Beyond the effects quantified in this analysis, trade-offs have other effects not measured in the IECC performance calculation procedure. They would: (1) increase initial construction and later replacement costs for the larger equipment sizes that weaker envelopes create, (2) raise future electricity bills from increased peak demand, and (3) increase energy costs as homeowners adjust thermostats to compensate for reduced comfort levels.

1. Background and Methodology

This report examines the impacts of reintroducing equipment trade-offs in residential building energy codes, as proposed by the National Association of Homebuilders in RE166-13 for the 2015 IECC, and in related proposed code changes. Proposal RE166-13 seeks to require the baseline efficiency of space heating, space cooling, and service water heating building components of the standard reference design to be fixed at federal minimum standards – even in cases where higher-efficiency equipment is the market norm. This would allow trade-offs that weaken other, more permanent building components, even in cases where the HVAC or water heating equipment is already being installed in response to consumer demand or utility incentives. In the 2012 IECC, baseline space heating, space cooling, and service water heating efficiencies are set at the same levels as those proposed to be installed, and no trade-offs are permitted between equipment and the thermal envelope or other non-equipment components.

The analysis in this report examines the following five scenarios (detailed in Appendix D to H):

1. Scenario 1 – Gas Home with 90 AFUE Gas Furnace
2. Scenario 2 – Gas Home with Common High Efficiency Equipment
3. Scenario 3 – Gas Home with Advanced Efficiency Equipment
4. Scenario 4 – Electric Home with Common High Efficiency Equipment
5. Scenario 5 – Electric Home with Advanced Efficiency Equipment

Each scenario is used to determine the potential impact of using equipment trade-off for non-mechanical (i.e. envelope) measures in the home. Scenario 1, the 90 AFUE gas furnace case, is used throughout the main body of the report as a conservative approach to examine the technical and market potential impacts of using this single measure as a means to trade-off with non-equipment measures. The remaining four scenarios are detailed in the Appendices and can be used to assess potential impacts in addition to the 90 AFUE gas furnace impacts.

Federal Equipment Standards

Unlike other efficiency measures in the building where the code can set reasonable, efficient code baselines reflecting market penetration considerations, Federal law preempts building energy codes from requiring equipment efficiencies or establishing baselines above the federal mandatory minimum standards. However, U.S. Department of Energy data shown in Exhibit 1-1 indicates that a substantial number of gas furnaces sold across the country exceed the federal minimum efficiency standards. Roughly half of all new gas heated homes being built include high-efficiency heating equipment that exceeds standards required by the federal government.

Exhibit 1-1. U.S. Department of Energy Estimated Equipment Market Penetration[5]

Gas Furnace Efficiency Levels	Estimated Market Penetrations	
	North Climate Zones	South Climate Zones
80-89.9	30%	73%
90-91.9	15%	4%
92-94.9	32%	15%
95-97.9	22%	8%
≥98	1%	0%

[5] 2011-06-06 Technical Support Document: Energy Efficiency Program for Consumer Products: Residential Central Air Conditioners, Heat Pumps, and Furnaces

The equipment trade-off proposal would be applicable when a builder elects to use the IECC's performance path, rather than the prescriptive path. While the prescriptive path requires specific energy efficiency levels for measures, the performance path allows the builder flexibility in achieving compliance, by allowing certain building components to be less efficient than would be required by the prescriptive path, in exchange for increased efficiency in other building components.

The evaluation of this "balancing act" is achieved through an energy modeling process that compares a standard reference design for the home to the builder's proposed design, where the standard reference design represents the baseline for code-compliance. The current standard reference design disallows the equipment trade-off by requiring that the efficiency values for heating, cooling and water heating equipment equal the values to be used by the builder in the proposed design, focusing the flexibility among measures such as envelope, ducts and other non-equipment measures.

"Free Ridership"

The RE166-13 code change proposal to reinstate equipment trade-offs by setting equipment efficiencies in the standard reference design at the federal mandatory minimum standards would allow for efficiency levels for relatively short-lived equipment to reduce the stringency of the envelope and other long-lived provisions. Because high-efficiency (meaning, more efficient than the current federal standard requires) equipment is already widely used in the residential construction market, in practice this proposal could result in substantial reductions in envelope efficiency and therefore lost energy savings. This is known as a "free ridership effect" and is analyzed further in Section 3 of this report.

Balance of Lifecycle Energy Waste

While the free ridership effect of an equipment trade-off causes an increase in energy use throughout the life of the original equipment, there is an additional source of energy waste during the time after the original equipment is replaced and throughout the remaining life of the home. Heating, cooling or water heating equipment typically lasts between 10 and 20 years while envelope measures typically last 30-50 years or more. When the original equipment is replaced, homeowners would be expected to install new equipment at the efficiency levels prevailing at that time, but the "trade-off" home would have a weaker envelope than the IECC-2012 compliant home. So while a home using equipment trade-offs might show equivalent first-year energy costs under the modified IECC, that home with its weaker envelope will use more energy over the life of the building. We call this the "balance of lifecycle energy waste," and analyze it further in Section 4 of this report.

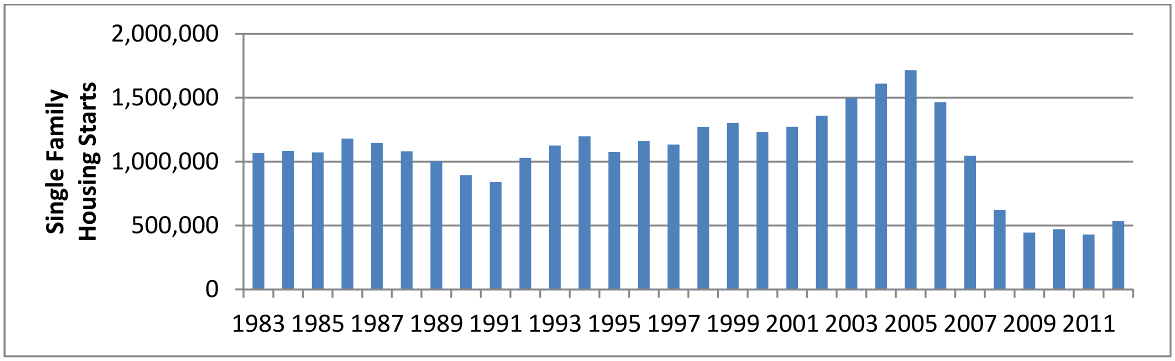
Methodology

Homes modeled for this analysis were configured to the single family home prototype of the U.S. Department of Energy's *Methodology for Evaluating Cost-Effectiveness of Residential Code Changes*, as shown in Appendix A. Using ICF's Beacon Residential DOE-2 based building energy simulation tool, energy analysis was performed to determine (1) the possible reductions in envelope efficiency that could result from equipment trade-offs, and (2) the long term energy implications from equipment trade-offs, at both the single-home and national levels. To assess national-level effects the U.S. Census housing start average data were used, as shown in Exhibit 1-2, based on the historic housing start data shown in Exhibit 1-3.

Exhibit 1-2. U.S. Census Single Family Housing Start Statistics & HVAC System Type Data

	Highest	Lowest	Average
Year	2005	2011	-
Housing Starts	1,715,800	430,500	1,079,067
Gas Furnace Homes	1,022,591	256,572	643,108
Heat Pump Homes	693,209	173,928	435,959

Exhibit 1-3. U.S. Census Single Family Housing Starts 1983-2012[6]



As noted above, available data on number of housing starts and market penetration of high-efficiency equipment formed the basis of these analyses, but in order to paint a comprehensive picture of the potential impacts, a number of assumptions were identified and incorporated into the calculations in order to present a conservative analysis:

- **Assessment of free ridership:** The national potential free ridership impacts could be based on expected future market penetrations of efficient equipment, absent the incentive created by a code trade-off. To be conservative, however, the analysis uses the current U.S. DOE data on equipment penetration by equipment efficiency; this approach conservatively assumes that market penetration will not increase prior to during the period when the ability to use the equipment trade-off would be reinstated, if RE-166 were to become part of the 2015 IECC.
- **Assessment of balance of lifecycle:** The national potential balance of lifecycle impacts could be based on the number of homes built through the performance path and using the equipment trade-off. The number of homes using the performance path depends on a number of factors, but as the easiest code compliance path for many homes, especially those free-riders where HVAC or water heating equipment is already more efficient than the minimum DOE national standard, the number of homes using the performance path could increase significantly. While that is possible, we conservatively assume for this analysis that only the homes that are currently free riders (i.e., those being built today with high-efficiency equipment) will use the performance path trade-offs in the future, and thus be subject to balance of lifecycle impacts.

[6] http://www.census.gov/construction/nrc/

- **90 AFUE Potential Impacts:** The free rider market potential analysis uses another very conservative assumption that all homes currently installing 90 AFUE or greater efficiency gas furnaces would only use the trade-off credits from a 90 AFUE furnace. The market potential impact would be higher if we also took into account the homes that currently install higher than 90 AFUE gas furnaces in estimating the impacts for both the free ridership and balance of lifecycle effects. US DOE estimated market penetration data in Exhibit 1-1 indicates that approximately 55% of all homes built in the North and approximately 23% of all homes built in the South install ≥92 AFUE furnaces.

2. Example Scenarios – How Much Envelope Efficiency Can be Traded Off?

Contrary to the RE166-13 reason statement and hearing testimony, equipment trade-offs are not “energy neutral” and the statement that a “BTU is a BTU” is not correct when efficient equipment is already widely installed without using trade-offs to weaken envelopes. Nor is the equipment trade-off energy-neutral over the full lifetime of a new home when less-permanent (shorter service life) features replace more permanent (longer service life) features. A true analysis of the impact to the homeowner must consider the impact of various measures, initially and over the life of the home. Several examples have been developed in this section to quantify the energy usage that could be traded between the thermal envelope and efficient equipment is such trade-offs were permitted.

House A vs. House B - Basis for Comparing Trade-off Scenarios

This example of the national average long-term energy usage and cost impact of equipment trade-offs, as shown in Exhibit 2-1, is based on two identically-sized homes, with identical location, operation, occupancy and ownership. The only differences are: (1) House A is built to the 2012 IECC prescriptive envelope criteria, with federal minimum-standard equipment, and (2) House B is built using efficient-equipment trade-offs to reduce thermal envelope component efficiencies below IECC prescriptive criteria. Under the RE166-13 proposal, both would be code compliant. The advanced-efficiency HVAC equipment in House B is described in further in Appendix F and includes a 96 AFUE furnace and 19 SEER split-system AC, and a 0.80 EF gas water heater.

Exhibit 2-1. House A (2012 IECC) vs. House B (Advanced equipment with weaker envelope)

Year 1 Energy Cost	$767	$767
A/C Size	3.5 tons	5 tons
Year 21 Energy Cost	$668	$767
Year 21 Electricity kWh	5,330 kWh	6,058 kWh
Year 21 Electricity kW	1.4 kW	1.8 kW
Year 21 Gas Therms	532 Therms	583 Therms
Year 21 CO2e	16,686 lbs CO2e	18,734 lbs CO2e

In the first year, House A and House B in theory use the same amount of energy, however, as heating, cooling, and water heating equipment is replaced every 10 to 20 years, House A will outperform House B because it will benefit from both the stronger thermal envelope and the improvements in equipment efficiency that history shows are likely to occur within its first replacement cycle. In the last 20 years, NAECA standards for residential heating, cooling, and hot water equipment have increased, making it likely that by the time equipment used for trade-offs is replaced, federal standards will have increased further. In any event, a homeowner can be expected to install the same efficiency of replacement equipment regardless of whether the home used the equipment trade-off or a better envelope. For the purposes of calculating energy savings impacts over the life of the building, this means that the savings claimed from equipment trade-offs should only be counted for the first equipment lifecycle, while the losses from longer-term envelope features should be accounted for over the longer term.

In addition, owners of House B will need to pay the added costs for larger equipment both at construction and upon replacement. This equipment oversizing also adds to risk of peak shortages on electricity grids and to the likelihood of higher electric rates to pay for increased system peak capacity. In addition, homeowners with weaker envelopes will be saddled with homes that will not remain as comfortable, and that can increase energy bills further by causing occupants to adjust thermostat settings to compensate for this loss of comfort.

House A vs. House B - Year One

Based on the House A vs. House B framework described above, this section presents example trade-offs that produce equivalent first-year energy costs under the proposed RE166-13 equipment trade-off methodology by shifting calculated energy costs from envelope components to the proposed advanced equipment. Exhibit 2-2 shows a simple trade-off using the commonly-installed 90 AFUE gas furnace to trade-down the envelope efficiency criteria. This results in a 6-9% shift of energy costs in mixed and cold climates from the envelope components to the equipment. In this case, the impact is a national average $43 of energy costs shifted from upgrading a furnace to 90 AFUE and degrading wall insulation by a national average of R-4.

As shown in Appendix B, these wall insulation reductions range from R-20 to R-15, R-20+5 to R-19 and R-20+5 to R-15+3 in various climate zones. These are significant reductions in wall insulation, which can affect energy use, wood used in wall assemblies, framing practices, and air leakage through wall. While this illustrates only one type of trade-off, the builder may choose to trade-off a series of measures. Note that the insulation values in Exhibits 2-2 include a weighted national average R-value and are not nominal insulation values. Appendix B shows nominal insulation values by Climate Zone. Appendices E through H include the example trade-offs for the other four scenarios examined in this analysis.

Exhibit 2-2. Scenario 1: House A vs. House B – 90 AFUE Gas Furnace

	House A (2012 IECC)	House B (Equipment Trade-off)
Natural Gas Furnace	80 AFUE	90 AFUE
Air Conditioner	13 SEER North / 14 SEER South	13 SEER North / 14 SEER South
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
Wall R-Value*	18	14
Ceiling R-Value*	43	43
Floor R-Value*	19	19
Window U-Factor*	0.35	0.35
Window SHGC*	0.33	0.34
Infiltration ACH50*	3.5	3.5
Energy Code Compliance with Trade-off: Deemed “energy neutral”		
Equipment Trade-off: Shifts $43 of annual costs from equipment to envelope		

*Equivalent national average energy efficiency feature. Each energy feature varies by climate zone; see Appendix B for climate zone-specific energy efficiency features.

House A vs. House B - Examples of Weakened Envelope Efficiencies

To flesh out the phrase “weakened envelope” into more concrete terms, this section examines a typical home in Climate Zone 3, to illustrate the kinds of envelope measures that can be traded off for high efficiency heating, cooling, and water heating equipment. In this example, a 90 AFUE gas furnace, 19 SEER air conditioner, and a 0.80 EF water heater were installed in the home in Climate Zone 3.

Exhibit 2-3. Climate Zone 3 Example of House A vs. House B – Advanced Equipment

	House A (2012 IECC)	House B (Equipment Trade-off)
Natural Gas Furnace	80 AFUE	96 AFUE
Air Conditioner	14 SEER	19 SEER
Water Heater	0.62 EF Gas DHW	0.80 EF Gas DHW
Wall R-Value	20	11
Ceiling R-Value	38	38
Floor R-Value	19	19
Window U-Factor	0.35	0.75
Window SHGC	0.25	0.50
Infiltration ACH50	3	7
Duct Leakage to Outdoors (CFM/100 sq.ft.)	4	10
Energy Code Compliance with Trade-off: Deemed “energy neutral”		
Equipment Trade-off: Shifts $66 of annual costs from equipment to envelope		

If RE166-13 were to be approved and assuming no mandatory measures are in place to prevent these trade-offs, using this set of equipment in a trade-off would permit significant weakening a number of building components, including each of the following measures in a single home:

- **Wall insulation – from R-20 to R-11**. This could mean weakening a 6-inch wall with cavity and sheathing insulation to a 4-inch wall with low-density insulation and no insulated sheathing.
- **Window U-factor – from 0.35 to 0.75**. This would more than double the energy losses through windows, increase condensation and moisture problems, and reduce occupant comfort, potentially inducing increased energy use through thermostat adjustments.
- **Window SHGC – from 0.25 to 0.50.** By doubling solar heat gain, this weakening would increase peak cooling loads, and reduce occupant comfort, potentially inducing increased energy use through thermostat adjustments.
- **Infiltration – from 3 ACH50 to 7 ACH50**. This would more than double air filtration, making the home significantly draftier and less comfortable, potentially inducing increased energy use through thermostat adjustments.
- **Duct leakage to outdoors – from 4 CFM/100 SF to 10 CFM/100 SF**. Increased duct leakage can lead to oversized equipment, reduction of delivered air to designated spaces, and reduced comfort, potentially inducing increased energy use through thermostat adjustments.

The effects of weakened envelopes can have significant impacts on actual energy consumption in ways not measured by the IECC performance path calculation methods. While the proposed trade-offs claimed in this example could claim to be energy cost neutral under the modified IECC in the first year, the trade-offs would result in larger equipment capacities (63% larger furnace and 80% larger air conditioner), higher peak electricity demand (22% increase), and significant comfort reduction due to having a leakier home, with leakier ducts and with more extreme temperature near the exterior walls and windows of the home.

The larger equipment sizes will increase the cost of future equipment. Higher peak demand will increase the risk of power shortages during peak times and can increase future electric rates. The occupant comfort losses will likely lead to higher energy bills than estimated in the IECC calculation procedure, as occupants adjust thermostats higher in winter and lower in summer to adjust for poorer comfort performance from windows and walls.

None of these negative effects are accounted for in the IECC performance path trade-off calculation provisions.

3. Free Ridership Energy Savings Impacts

This section examines, for both a typical home and in national-aggregate terms, the energy cost impacts associated with free ridership related to equipment trade-offs. As discussed earlier, free ridership in this context means giving code compliance credit for installation of equipment that would be installed anyway, without weakening the envelope, as a results of other market forces. The energy cost impacts are calculated to account for the effects of trading down the efficiency of non-equipment features (i.e. envelope and ducts) of the home for high-efficiency heating, cooling and/or water heating equipment that have efficiency levels that exceed federal minimum standards. These free-rider impacts occur immediately for all homes where high efficiency equipment would have been installed anyway. While the effects can be calculated for a typical home, they become more meaningful on an aggregate basis, because it is not possible to pinpoint whether an individual home would have received the upgraded equipment in the absence of a trade-off incentive.

The free-rider effects on energy costs on a typical individual home can be minimal ($1 per year from a gas furnace upgrade in a hot climate) or very large (more than $200 per year impact using high efficiency equipment). Averaged across climate zones, these free-rider effects range from $20 to $99 per year per home.

While it is not possible to predict how many homes would be affected by the free-rider effect, it is reasonable to expect a substantial shift toward use of such trade-offs through the IECC performance path. Builders would quickly realize that they can get compliance credit either for free (if already planning to use high-efficiency equipment) or at modest cost to upgrade HVAC or hot water equipment. Additionally, if the trade-off were built into the computerized rating software that is already used for a high fraction of new homes, or into widely disseminated “builder option packages,” the use of trade-offs via the performance path would increase still further. For the purposes of this analysis, we examined both technical potential impacts (assuming 100% of new homes are affected) and the estimated “likely market potential” impacts (assuming a percentage of the market is affected based on DOE equipment market penetration data[7]).

At the national level, the results of this analysis include:

- A technical potential for increased energy costs of $481,079,678 (present value) over a 20-year useful life of a 90 AFUE gas furnace for a single year of housing construction.
- An estimated market potential for increased energy costs of $292,431,744 (present value) over the 20-year useful life of a 90 AFUE gas furnace for a single year of housing construction and the expected market penetration data for furnaces based on DOE data.

As noted above, these impacts come from a single year of housing construction based on the U.S Census estimates shown in Exhibit 1-1. For each additional year that such trade-offs remain in effect, a like amount of lost energy savings would be added to the household cost burdens of U.S. homeowners. These results show that there is significant free-rider impact potential, based on the widely-used 90 AFUE furnace alone. Appendices D-H document a series of scenarios to illustrate free rider effects for 90 AFUE furnaces and other combinations of high-efficiency mechanical equipment.

[7] Table 8.4.36 of 2011-06-06 Technical Support Document: Energy Efficiency Program for Consumer Products: Residential Central Air Conditioners, Heat Pumps, and Furnaces.

Individual-Home Impact of Equipment Trade-off Free Ridership

The IECC performance path calculation procedure, if revised to permit equipment trade-offs, would serve to shift energy costs from equipment to envelope features, on a nominally "energy neutral," first-year basis. The calculation procedure uses the unstated assumption that free ridership does not occur, and therefore that first-year energy costs are not affected by free ridership. The calculation procedure also ignores the life of the various measures, which is addressed in the next section. The reality in the marketplace, which is a concern for code officials and other policymakers, is that free ridership is very common for some kinds of equipment. This analysis, therefore, moves from the nominal "cost-shifting" framework applied earlier to an assessment of the more likely costs that homeowners would actually incur from free ridership.

For an individual home, the free ridership impact of a single commonly-installed piece of upgraded equipment (such as a 90 AFUE condensing gas furnace) will result in increased energy costs averaging $748 nationally (on a 30-year present-value basis). These energy cost increases range by climate zone from $17 in the warmest climate to $2,483 in the coldest climates. In other words, if builder uses a furnace "upgrade" that would have happened anyway without the IECC trade-off, and uses the trade-off to install poorer-performing windows, walls, air ducts, etc., the owners of that home over 30 years would pay an average of $748 in higher energy bills, and in the coldest states would pay up to $2500 more.

Exhibit 3-1 shows the results of the free ridership analysis for an individual home using the 90 AFUE gas furnace scenario described in Section 2. Each of the other scenarios (with combinations of higher efficiency equipment) is documented in Appendices E-H.

Exhibit 3-1. Individual Home Free Ridership Impact - Gas Furnace - 90 AFUE

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	90 AFUE
Air Conditioner	13 SEER North / 14 SEER South	13 SEER North / 14 SEER South
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
20 year Impacts for One Home		
Energy Cost Impact - National Average		$858
Energy Cost Impact – Range of Climate Zone Averages		$20-2,840
Energy Cost Impact Present Value - National Average		$748
Energy Cost Impact Present Value - Range of Climate Zone Averages		$17-2,483
Carbon Impact - National Average		8,086 lbs CO2e
Carbon Impact - Range of Climate Zone Averages		212-34,900 lbs CO2e
Electricity Impact - National Average		0 kWh
Electricity Impact – Range of Climate Zone Averages		0 kWh
Natural Gas Impact - National Average		760 Therms
Natural Gas Impact – Range of Climate Zone Averages		20-3,280 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Appendix A details the configuration of the individual home used in this analysis, which aligns with the single family detached home contained in the U.S. Department of Energy's *Methodology for Evaluating Cost-Effectiveness of Residential Code Changes*.

National Impact of Free Ridership from Equipment Trade-offs

Exhibit 3-2 takes the results shown in Exhibits 3-1 one step further, by applying the housing start data in Exhibit 1-2 to assess the range of national technical potential impacts and then applies the estimated equipment market penetration to assess the market potential impacts. Exhibit 1-2 displays the distribution of housing starts by equipment type; these distributions are used in the calculations results stated by system type in Exhibit 3-2 and Appendices E-H. For example, the quantity of housing starts used in Exhibit 3-2 uses the number of gas furnace homes shown in Exhibit 1-2 and excludes all other housing starts.

Exhibit 3-2. National Free Ridership Impact - Gas Furnace - 90 AFUE

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	90 AFUE
Air Conditioner	13 SEER North / 14 SEER South	13 SEER North / 14 SEER South
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
20-year Technical Potential for One Year of Gas Furnace Home Housing Starts		
Energy Cost Impact		$551,578,985
Energy Cost Impact Present Value		$481,079,678
Carbon Impact		2,600,084 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		488,761,813 Therms
Estimated Equipment Market Penetration[8]		
90+ AFUE Gas Furnace (South)		27%
90+ AFUE Gas Furnace (North)		70%
20-year Market Potential for One Year of Gas Furnace Home Housing Starts		
Energy Cost Impact		$335,285,848
Energy Cost Impact Present Value		$292,431,744
Carbon Impact		1,642,497 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		308,691,672 Therms

For the purposes of this analysis, housing starts in 2012 IECC Climate Zones 1-3 were included in the South and starts in 2012 IECC Climate Zones 4-8 were included in the North. The estimated share of housing starts by 2012 IECC Climate Zone was sourced from the U.S. Department of Energy's *Methodology for Evaluating Cost-Effectiveness of Residential Code Changes*.

[8] Table 8.4.36 of 2011-06-06 Technical Support Document: Energy Efficiency Program for Consumer Products: Residential Central Air Conditioners, Heat Pumps, and Furnaces.

4. Balance-of-Lifecycle Energy Impacts

This section examines individual-home and national-aggregate impacts from using equipment trade-offs over the balance of the building lifecycle (after replacing the original equipment). However, unlike Section 3, the analysis bypasses the free ridership effects, and considers the impacts following the initial equipment lifecycle only. This approach is based on the logic that after the original equipment is replaced, one can no longer assume that the savings associated with equipment efficiencies will persist. We make the assumption that both House A and House B would receive the same efficiency equipment upon replacement. It is likely that market conditions combined with updated DOE efficiency standards would raise the efficiency levels of future equipment after 20 years. But even if equipment efficiencies do not change over two decades, one can assume that the same equipment would be installed in both houses. However, House A will have better envelope efficiency than House B, and therefore House B will use more energy over the balance of the building life.

The savings-erosion effects calculated in this section accordingly focus on the ten-year period following the initial 20-year equipment lifecycle. Building lifecycle impacts were calculated using conservative assumptions for the service lives of measures. For the purpose of this analysis, the assumed equipment life was conservatively set at 20 years, even though some types of affected equipment are expected to last only 10-15 years. Non-equipment measure lives were set at 30 years, even though permanent envelope measures typically remain in place much longer. The conservative nature of these assumptions means that actual building lifecycle impacts of permitting equipment trade-offs in the IECC would likely be higher.

Individual Home Balance of Lifecycle Impact of Equipment Trade-offs

For an individual home, the impacts of using a slightly upgraded efficient gas furnace (90 AFUE condensing furnace) to downgrade the non-equipment features of the home will result in life-cycle energy losses of $1 to $142 per year from years 21 through 30. This translates into increased homeowner energy bills present value in the range of $6 to $873 on a present value basis, and averaging $263 per home nationally. Exhibit 4-1 shows the lifecycle impacts on energy, costs and carbon for an individual home for years 21 through 30.

Exhibit 4-1. Individual Home Balance of Lifecycle Impact - Gas Furnace - 90 AFUE

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	90 AFUE
Air Conditioner	13 SEER North / 14 SEER South	13 SEER North / 14 SEER South
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
Year 21-30 Impacts for One Home		
Energy Cost Impact - National Average		$429
Energy Cost Impact - Climate Zone Averages		$10-1,420
Energy Cost Impact Present Value - National Average		$263
Energy Cost Impact Present Value - Climate Zone Averages		$6-873
Carbon Impact - National Average		4,043 lbs CO2e
Carbon Impact - Climate Zone Averages		106-17,450 lbs CO2e
Electricity Impact - National Average		0 kWh
Electricity Impact - Climate Zone Averages		0 kWh
Natural Gas Impact - National Average		380 Therms
Natural Gas Impact - Climate Zone Averages		10-1,640 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts

National Balance of Lifecycle Impact of Equipment Trade-offs

Similar to the national impact analysis for free ridership outlined in Section 3, Exhibits 4-2 takes the results of the scenario in Exhibits 4-1 one step further, by applying the average housing start data in Exhibit 1-2 to assess the range of national impacts from years 21 through 30, for each annual cohort of new homes built. The balance of lifecycle impact is above and beyond the free ridership impacts estimated in Section 3 of this report. The balance of lifecycle impacts occur in all homes that use an equipment trade-off to downgrade any non-equipment measures, including insulation, windows and ducts.

The market penetration data, also used for the free rider market potential calculations, is used as a conservative basis to estimate the number of homes that would use the performance path to degrade any non-equipment measures with an equipment trade-off. The technical potential is then used with the equipment market penetration data to estimate the market potential impacts for the balance of lifecycle impact for the 90 AFUE gas furnace in Exhibit 4-2 below.

Exhibit 4-2. National Balance of Lifecycle Impact - Gas Furnace - 90 AFUE

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	90 AFUE
Air Conditioner	13 SEER North / 14 SEER South	13 SEER North / 14 SEER South
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
Year 21-30 Technical Potential Impacts for One Year of Average Gas Furnace Home Housing Starts		
Energy Cost Impact		$275,789,493
Energy Cost Impact Present Value		$169,146,165
Carbon Impact		1,300,042 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		24,4380,907 Therms
Estimated Equipment Market Penetration[9]		
90+ AFUE Gas Furnace (South)		27%
90+ AFUE Gas Furnace (North)		70%
Year 21-30 Market Potential Impacts for One Year of Average Gas Furnace Home Housing Starts		
Energy Cost Impact		$167,642,924
Energy Cost Impact Present Value		$102,818,134
Carbon Impact		821,248 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		154,345,836 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

[9] Table 8.4.36 of 2011-06-06 Technical Support Document: Energy Efficiency Program for Consumer Products: Residential Central Air Conditioners, Heat Pumps, and Furnaces.

5. Summary

This paper set out to calculate the impacts of two effects that quantitatively invalidate the assertion of RE166-13 proponents that trade-offs of high-efficiency equipment for weaker envelopes is "energy neutral," i.e. that such trade-offs leave homeowners with the same energy bills as without the trade-offs. These two effects are:

- **Free ridership** - the effect of market forces that already cause efficient equipment to be installed for other reasons (including tax credits, utility incentives, supplier marketing, and effects of reduced costs due to technology improvements and economies of scale). Market data shows that substantial portions of U.S. heating, cooling, and hot water equipment are already being installed at efficiency levels that would receive trade-off credit under RE166-13. Because these systems would be installed anyway, a substantial portion of the claimed savings from these trade-offs would not occur.
- **Balance of lifecycle impact** - the effect of differential service lives between equipment and envelope components. Equipment has shorter service lives (10-20 years) than envelope components (30-50 years or more). Because one must assume that the same efficiencies would apply to equipment installed after its initial lifecycle, only the savings from the first lifecycle of equipment efficiency can be affirmatively claimed in trading off efficient equipment for weaker envelopes. But envelope measures persist much longer, and the energy waste from degrading them through trade-offs persists well beyond those next 20 years.

This analysis worked through these effects systematically, using a "House A vs. House B" framework, in which House A has IECC-compliant envelope components with minimum standard equipment, and House B has higher-efficiency equipment with envelope efficiencies below the IECC prescriptive values. Through this framework, we considered free ridership and lifecycle effects, for gas- and electric-heated homes, and for a range of commonly-installed and advanced efficiency equipment. Beginning with per-home calculations using ICF's Beacon Residential modeling platform, national housing starts data were used to expand the results to the national level. The analysis also differentiated between technical potential impacts (assuming 100% of new homes could be affected) and market potential impacts (using available market data to apportion impacts conservatively to most likely market patterns).

Exhibit 5-1 combines the free ridership and life cycle impacts calculated in Sections 3 and 4 above, to sum up the full 30-year technical potential for increased homeowner energy bills from using equipment trade-offs based on a 90 AFUE furnace. For the combined 30-year results, the results include the present value calculation to bring back the impacts to a current-year perspective.

Exhibit 5-1. National Impact - Gas Furnace - 90 AFUE

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	90 AFUE
Air Conditioner	13 SEER North / 14 SEER South	13 SEER North / 14 SEER South
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
Free Rider Technical Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$551,578,985
Energy Cost Impact 30-yr Present Value		$404,875,207
Carbon Impact		2,600,084 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		488,761,813 Therms
Balance of Lifecycle Technical Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$275,789,493
Energy Cost Impact 30-yr Present Value		$169,146,165
Carbon Impact		1,300,042 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		244,380,907 Therms
30-year Technical Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$827,368,478
Energy Cost Impact 30-yr Present Value		$574,021,372
Carbon Impact		3,900,126 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		733,142,720 Therms
Estimated Equipment Market Penetration		
90+ AFUE Gas Furnace (South)		27%
90+ AFUE Gas Furnace (North)		70%
30-year Market Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$502,928,772
Energy Cost Impact 30-yr Present Value		$395,249,878
Carbon Impact		2,463,745MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		463,037,508 Therms

It is important to note that these impacts are only from ***one year*** of housing starts. For each subsequent year that such trade-offs remain permissible in the IECC, impacts would increase by a like amount. In other words, ten years' worth of housing starts would produce roughly ten times the impacts. But as this analysis shows, there are significant implications for permitting such trade-offs, even for a single year.

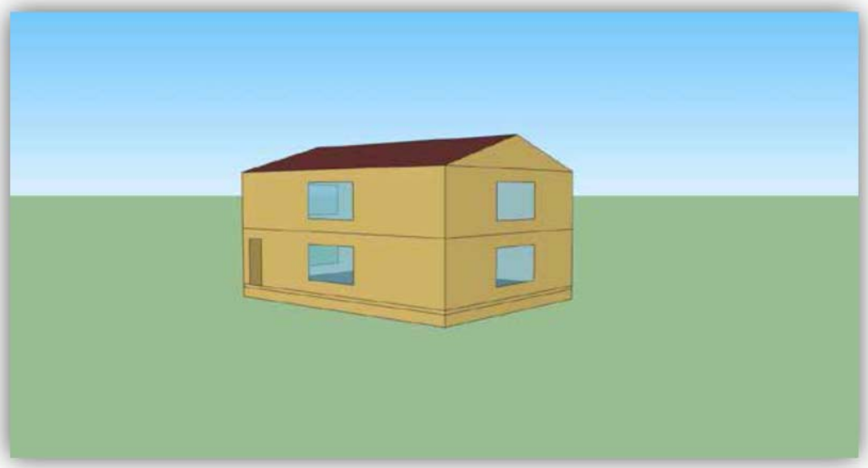
Appendix A: Modeling Characteristics

Homes studied in this analysis were configured to the single family home prototype of the U.S. Department of Energy's *Methodology for Evaluating Cost-Effectiveness of Residential Code Changes*, as displayed in Exhibit A-1. Additionally, the present value calculation methodology described in the U.S. DOE's methodology was referenced in calculation of 30 year present value data for this analysis. The energy cost is based on DOE data for both electricity[10] and natural gas[11]. The carbon emissions are based on EPA data for electricity[12] and natural gas[13].

Exhibit A-1. Detailed Home Configuration Characteristics

Component	Assumption
Housing Type	Single Family Detached
Conditioned Floor Area	2,400 ft^2
Perimeter length	140 ft
Gross exterior wall area	2,380 ft^2
Door area	42 ft^2
Ceiling Height	8.5 ft
Area below roof/ceilings	1,200 ft^2, 70% with attic, 30% cathedral
Aspect Ratio	1.33
Number of Stories	Two
Window to Floor Area	15%, equally distributed
Foundation Types	Slab-on-grade, basement, and crawlspace
Weather Locations	105 TMY3 weather locations, with representative locations encompassing all climate zones types for all 50 states

Exhibit A-2. U.S. Department of Energy's Single Family Home Prototype



[10] http://www.eia.gov/electricity/data/eia826/

[11] http://www.eia.gov/dnav/ng/ng_pri_sum_a_epg0_prs_dmcf_a.htm

[12] http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

[13] http://www.energystar.gov/ia/business/evaluate_performance/Emissions_Supporting_Doc.pdf

Appendix B: Trade-off Scenario Characteristics

Energy analysis was performed to determine the annual natural gas and electricity consumption in each home type studied. This appendix contains the full building component characteristic and building energy consumption values by 2012 IECC Climate Zone for each of the scenarios studied. This includes:

- Homes with a 2012 IECC envelope paired with federal minimum efficiency, industry average, standard practice, and advanced practice space conditioning and domestic hot water equipment.
- Homes with the 2012 IECC envelope paired with 90 AFUE space heating equipment and the associated possible envelope reductions.
- Homes with envelope reductions trade-offs possible with common high efficiency equipment, and advanced space conditioning and water heating equipment.

Exhibit B-1. 2012 IECC + Federal Minimum Equipment

HVAC System Type	Gas Furnace with Central AC									Air Source Heat Pump								
Building Component	**CZ 1**	**CZ 2**	**CZ 3**	**CZ 4**	**CZ 4C**	**CZ 5**	**CZ 6**	**CZ 7**	**CZ 8**	**CZ 1**	**CZ 2**	**CZ 3**	**CZ 4**	**CZ 4C**	**CZ 5**	**CZ 6**	**CZ 7**	**CZ 8**
Thermal Envelope																		
Wood Frame Wall R-value	13	13	20	20	20	20	20+5	20+5	20+5	13	13	20	20	20	20	20+5	20+5	20+5
Ceiling R-value	30	38	38	49	49	49	49	49	49	30	38	38	49	49	49	49	49	49
Floor R-value	13	13	19	19	30	30	30	38	38	13	13	19	19	30	30	30	38	38
Window U-factor	0.4	0.4	0.35	0.35	0.32	0.32	0.32	0.32	0.32	0.4	0.4	0.35	0.35	0.32	0.32	0.32	0.32	0.32
Window SHGC	0.25	0.25	0.25	0.40	0.40	0.40	0.40	0.40	0.40	0.25	0.25	0.25	0.40	0.40	0.40	0.40	0.40	0.40
Infiltration (ACH50)	5	5	3	3	3	3	3	3	3	5	5	3	3	3	3	3	3	3
Space Conditioning Equipment																		
AFUE/HSPF	80	80	80	80	80	80	80	80	80	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2
AC SEER	14	14	14	14/13	14/13	14/13	13	13	13	14	14	14	14	14	14	14	14	14
Domestic Hot Water Equipment																		
40 Gallon Gas EF	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Ductwork																		
Duct R-value	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Duct Leakage CFM25/100ft^2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Energy																		
Annual $	1456	665	560	832	812	937	994	1039	1501	1497	743	720	1123	762	1550	1938	2236	5716
Annual kWh	7883	7065	5266	5453	4723	5133	4778	4922	4783	7194	11733	10001	14981	13888	18060	20493	24332	38469
Annual Therms	216	331	418	650	704	852	956	1246	1766	0	0	0	0	0	0	0	0	0

Exhibit B-2. 90 AFUE with 2012 IECC and 90 AFUE as Equipment Trade-off

	Gas Furnace with Central AC - 2012 IECC Federal Minimum Equipment (90 AFUE)									Gas Furnace with Central AC –Equipment Trade-off								
Building Component	**CZ 1**	**CZ 2**	**CZ 3**	**CZ 4**	**CZ4C**	**CZ 5**	**CZ 6**	**CZ 7**	**CZ 8**	**CZ 1**	**CZ 2**	**CZ 3**	**CZ 4**	**CZ4C**	**CZ 5**	**CZ 6**	**CZ 7**	**CZ 8**
Thermal Envelope																		
Wood Frame Wall R-value	13	13	20	20	20	20	20+5	20+5	20+5	13	11	15	15	15	15	19	15+3	15+3
Ceiling R-value	30	38	38	49	49	49	49	49	49	30	38	38	49	49	49	49	49	49
Floor R-value	13	13	19	19	30	30	30	38	38	13	13	19	19	30	30	30	38	38
Window U-factor	0.4	0.4	0.35	0.35	0.32	0.32	0.32	0.32	0.32	0.4	0.4	0.35	0.35	0.32	0.32	0.32	0.32	0.32
Window SHGC	0.25	0.25	0.25	0.40	0.40	0.40	0.40	0.40	0.40	0.25	0.3	0.25	0.4	0.40	0.4	0.4	0.4	0.4
Infiltration (ACH50)	5	5	3	3	3	3	3	3	3	5	5	3	3	3	3	3	3	3
Space Conditioning Equipment																		
AFUE/HSPF	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
AC SEER	14	14	14	14/13	14/13	14/13	13	13	13	14	14	14	14/13	14/13	14/13	13	13	13
Domestic Hot Water Equipment																		
40 Gallon Gas EF	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Ductwork																		
Duct R-value	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Duct Leakage CFM25/100ft^2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Energy																		
Annual $	1455	652	536	780	756	866	911	947	1359	1455	646	568	832	807	926	915	988	1420
Annual kWh	7883	7065	5266	5453	4723	5133	4778	4922	4783	7883	7014	5395	5581	4764	5228	4781	4961	4817
Annual Therms	215	320	397	606	657	787	876	1139	1602	215	318	416	641	699	836	880	1186	1668

*Underlined values denote change from 2012 IECC building component or Federal Minimum Equipment efficiencies.

Exhibit B-4. 2012 IECC + Common High-Efficiency Equipment

	Gas Furnace with Central AC									Air Source Heat Pump								
Building Component	CZ 1	CZ 2	CZ 3	CZ 4	CZ4C	CZ 5	CZ 6	CZ 7	CZ 8	CZ 1	CZ 2	CZ 3	CZ 4	CZ 4C	CZ 5	CZ 6	CZ 7	CZ 8
Thermal Envelope																		
Wood Frame Wall R-value	13	13	20	20	20	20	20+5	20+5	20+5	13	13	20	20	20	20	20+5	20+5	20+5
Ceiling R-value	30	38	38	49	49	49	49	49	49	30	38	38	49	49	49	49	49	49
Floor R-value	13	13	19	19	30	30	30	38	38	13	13	19	19	30	30	30	38	38
Window U-factor	0.4	0.4	0.35	0.35	0.32	0.32	0.32	0.32	0.32	0.4	0.4	0.35	0.35	0.32	0.32	0.32	0.32	0.32
Window SHGC	0.25	0.25	0.25	0.40	0.40	0.40	0.40	0.40	0.40	0.25	0.25	0.25	0.4	0.40	0.4	0.4	0.4	0.4
Infiltration (ACH50)	5	5	3	3	3	3	3	3	3	5	5	3	3	3	3	3	3	3
Space Conditioning Equipment																		
AFUE/HSPF	92	92	92	92	95	95	95	95	95	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
AC SEER	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Domestic Hot Water Equipment																		
40 Gallon Electric EF	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Ductwork																		
Duct R-value	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Duct Leakage CFM25/100ft^2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Energy Cost																		
Annual $	1426	640	528	767	732	834	874	908	1299	1442	721	706	1103	752	1524	1909	2203	5658
Annual kWh	7761	6977	5230	5420	4721	5117	4748	4915	4781	7077	11542	9886	14802	13777	17848	20262	24068	38152
Annual Therms	215	318	393	598	638	759	843	1094	1533	0	0	0	0	0	0	0	0	0

Exhibit B-5. 2012 IECC + Advanced Equipment

	Gas Furnace with Central AC									Air Source Heat Pump								
Building Component	CZ 1	CZ 2	CZ 3	CZ 4	CZ4C	CZ 5	CZ 6	CZ 7	CZ 8	CZ 1	CZ 2	CZ 3	CZ 4	CZ 4C	CZ 5	CZ 6	CZ 7	CZ 8
Thermal Envelope																		
Wood Frame Wall R-value	13	13	20	20	20	20	20+5	20+5	20+5	13	13	20	20	20	20	20+5	20+5	20+5
Ceiling R-value	30	38	38	49	49	49	49	49	49	30	38	38	49	49	49	49	49	49
Floor R-value	13	13	19	19	30	30	30	38	38	13	13	19	19	30	30	30	38	38
Window U-factor	0.4	0.4	0.35	0.35	0.32	0.32	0.32	0.32	0.32	0.4	0.4	0.35	0.35	0.32	0.32	0.32	0.32	0.32
Window SHGC	0.25	0.25	0.25	0.40	0.40	0.40	0.40	0.40	0.40	0.25	0.25	0.25	0.4	0.40	0.40	0.4	0.4	0.4
Infiltration (ACH50)	5	5	3	3	3	3	3	3	3	5	5	3	3	3	3	3	3	3
Space Conditioning Equipment																		
AC SEER	96	96	96	96	96	96	96	96	96	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Heat Pump HSPF	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
Domestic Hot Water Equipment																		
40 Gallon Electric EF	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
Ductwork																		
Duct R-value	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Duct Leakage CFM25/100ft^2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Energy Cost																		
Annual $	1242	570	494	727	727	817	859	899	1289	1288	661	674	1055	732	1467	1846	2135	5716
Annual kWh	6954	6393	4992	5205	4708	5017	4688	4899	4777	6733	11003	9590	14377	13544	17385	19768	23518	38469
Annual Therms	215	314	387	584	634	754	837	1085	1521	0	0	0	0	0	0	0	0	0

*Underlined values denote change from 2012 IECC building component or Federal Minimum Equipment efficiencies.

Exhibit B-7. Equipment Trade-off + Common High-Efficiency Equipment

	Gas Furnace with Central AC									Air Source Heat Pump								
Building Component	CZ 1	CZ 2	CZ 3	CZ 4	CZ C	CZ 5	CZ 6	CZ 7	CZ 8	CZ 1	CZ 2	CZ 3	CZ 4	CZ 4C	CZ 5	CZ 6	CZ 7	CZ 8
Thermal Envelope																		
Wood Frame Wall R-value	13	11	11	15	15	15	15+5	15+5	15+5	11	11	19	19	19	19	19+5	19+5	19+5
Ceiling R-value	30	38	38	49	49	49	49	49	49	30	38	38	49	49	49	49	49	49
Floor R-value	13	13	19	19	30	30	30	38	38	13	13	19	19	30	30	30	38	38
Window U-factor	0.4	0.4	0.35	0.35	0.35	0.35	0.32	0.32	0.32	0.4	0.45	0.38	0.37	0.33	0.33	0.33	0.34	0.33
Window SHGC	0.27	0.25	0.25	0.40	0.40	0.40	0.40	0.40	0.40	0.28	0.25	0.25	0.4	0.40	0.4	0.4	0.4	0.4
Infiltration (ACH50)	5	5	3	3	3	3	3	3	3	5	5	3	3	3	3	3	3	3
Space Conditioning Equipment																		
AFUE/HSPF	92	92	92	92	95	95	95	95	95	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
AC SEER	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Domestic Hot Water Equipment																		
40 Gallon Electric EF	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Ductwork																		
Duct R-value	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Duct Leakage CFM25/100ft^2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Energy Cost																		
Annual $	1453	653	561	818	806	923	999	1042	1494	1498	738	715	1115	758	1537	1925	2239	5712
Annual kWh	7874	7060	5359	5546	4768	5227	4914	5025	4880	7195	11692	9962	14918	13846	17968	20399	24404	38492
Annual Therms	215	321	413	632	697	835	958	1250	1753	0	0	0	0	0	0	0	0	0

Exhibit B-8. Equipment Trade-off + Advanced Equipment

	Gas Furnace with Central AC									Air Source Heat Pump								
Building Component	CZ 1	CZ 2	CZ 3	CZ 4	CZ 4C	CZ 5	CZ 6	CZ 7	CZ 8	CZ 1	CZ 2	CZ 3	CZ 4	CZ 4C	CZ 5	CZ 6	CZ 7	CZ 8
Thermal Envelope																		
Wood Frame Wall R-value	5	5	5	5	5	5	13	11	11	5	5	11	11	11	11	15	11+3	11+5
Ceiling R-value	15	19	38	49	49	49	49	49	49	15	30	30	38	49	49	49	49	49
Floor R-value	13	13	19	19	30	30	30	38	38	13	13	19	19	30	30	30	38	38
Window U-factor	0.75	0.7	0.6	0.37	0.35	0.32	0.35	0.35	0.35	0.75	0.75	0.75	0.6	0.7	0.7	0.32	0.32	0.32
Window SHGC	0.5	0.5	0.5	0.4	0.40	0.40	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.50	0.50	0.4	0.4	0.4
Infiltration (ACH50)	5	5	3	3	3	3	3	3	3	5	5	3	3	3	3	3	3	3
Space Conditioning Equipment																		
AFUE/HSPF	96	96	96	96	96	96	96	96	96	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.2
AC SEER	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
Domestic Hot Water Equipment																		
40 Gallon Electric EF	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
Ductwork																		
Duct R-value	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Duct Leakage CFM25/100ft^2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Energy Cost																		
Annual $	1454	679	577	848	843	975	970	1051	1522	1187	739	699	1170	762	1629	2063	2261	5716
Annual kWh	9063	7979	5824	5578	4838	5301	4874	5053	4919	6088	11941	11229	15652	14008	18976	21823	24690	38469
Annual Therms	154	285	400	663	727	884	938	1262	1786	0	0	0	0	0	0	0	0	0

*Underlined values denote change from 2012 IECC building component or Federal Minimum Equipment efficiencies.

Appendix C: Energy Trade-off Analysis

Since packages of upgrades contain equipment with varying useful lives, conservative values were selected for equipment and thermal enclosure components, respectively, based on both NAHB's *Study of Life Expectancy of Home Components* and reasonable consumer expectations for how long equipment should last prior to replacement.

- A 20 year useful life was assumed for mechanical equipment as this useful life was the longest noted in the NAHB study for any equipment upgrade. Additionally, the homeowner can reasonably expect to replace any or all mechanical equipment within this timeframe. This value is conservatively high, as the useful life of many equipment components such as water heaters may be significantly less than this.
- A 30 year useful life was assumed for thermal envelope components as many components will remain intact for the lifetime of the home and at the 30 year timeframe, the homeowner can reasonably expect the need to begin replacing certain thermal envelope components within the home.

First, the first year value of the energy trade-off was calculated by determining the shift in energy cost from the thermal envelope to the equipment. Second a present value calculation was performed using the useful lives assumed above to obtain a 30 year present value of the energy traded off. This is an indication of the energy savings potential over the first 30 years of operation for both the homes with and without the equipment trade-off. Lastly, to determine the difference in cost benefits after 30 years, Exhibit C-3 contains the cost savings associated with providing a thermal envelope that meets the 2012 IECC.

Exhibit C-1. First Year Value of Energy Trade-off

Thermal Envelope	HVAC Efficiency	HVAC System Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 4c	CZ 5	CZ 6	CZ 7	CZ 8
2012 IECC	Common High-Efficiency	Gas Furnace + Central AC	$30	$25	$33	$65	$80	$103	$120	$131	$202
2012 IECC	Common High-Efficiency	Air Source Heat Pump	$54	$21	$13	$20	$9	$25	$29	$33	$58
2012 IECC	Advanced Equipment	Gas Furnace + Central AC	$213	$95	$66	$106	$85	$120	$134	$140	$213
2012 IECC	Advanced Equipment	Air Source Heat Pump	$209	$82	$46	$68	$30	$82	$92	$101	$135
2012 IECC	90 AFUE	Gas Furnace + Central AC	$1	$13	$25	$53	$56	$71	$82	$91	$142
Equipment Trade-off	Common High-Efficiency	Gas Furnace + Central AC	$30	$25	$33	$65	$80	$103	$120	$131	$202
Equipment Trade-off	Common High-Efficiency	Air Source Heat Pump	$54	$21	$13	$20	$9	$25	$29	$33	$58
Equipment Trade-off	Advanced Equipment	Gas Furnace + Central AC	$213	$95	$66	$106	$85	$120	$134	$140	$213
Equipment Trade-off	Advanced Equipment	Air Source Heat Pump	$209	$82	$46	$68	$30	$82	$92	$101	$135
Equipment Trade-off	90 AFUE	Gas Furnace + Central AC	$1	$13	$25	$53	$56	$71	$82	$91	$142

Exhibit C-2. Present Value of Life Cycle Energy Trade-off (Years 1-20)

HVAC Efficiency	HVAC System Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 4c	CZ 5	CZ 6	CZ 7	CZ 8
Common High-Efficiency	Gas Furnace + Central AC	$515	$432	$572	$1,134	$1,396	$1,794	$2,091	$2,277	$3,524
Common High-Efficiency	Air Source Heat Pump	$949	$374	$231	$346	$163	$444	$508	$572	$1,007
Advanced Equipment	Gas Furnace + Central AC	$3,723	$1,660	$1,160	$1,842	$1,486	$2,087	$2,341	$2,439	$3,708
Advanced Equipment	Air Source Heat Pump	$3,642	$1,422	$796	$1,182	$522	$1,437	$1,605	$1,754	$2,355
90 AFUE	Gas Furnace + Central AC	$17	$232	$428	$916	$985	$1,242	$1,438	$1,596	$2,483

Exhibit C-3. Present Value of Life Cycle Energy Trade-off (Years 21-30)

Thermal Envelope	HVAC Efficiency	HVAC System Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 4c	CZ 5	CZ 6	CZ 7	CZ 8
2012 IECC	Common High-Efficiency	Gas Furnace + Central AC	$696	$584	$773	$1,533	$1,887	$2,424	$2,826	$3,078	$4,763
2012 IECC	Common High-Efficiency	Air Source Heat Pump	$1,283	$505	$312	$468	$220	$600	$686	$773	$1,361
2012 IECC	Advanced Equipment	Gas Furnace + Central AC	$5,032	$2,244	$1,568	$2,490	$2,009	$2,820	$3,164	$3,296	$5,012
2012 IECC	Advanced Equipment	Air Source Heat Pump	$4,922	$1,922	$1,076	$1,598	$706	$1,942	$2,170	$2,370	$3,183
2012 IECC	90 AFUE	Gas Furnace + Central AC	$23	$313	$578	$1,238	$1,331	$1,679	$1,943	$2,157	$3,357
Equipment Trade-off	Common High-Efficiency	Gas Furnace + Central AC	$515	$432	$572	$1,134	$1,396	$1,794	$2,091	$2,277	$3,524
Equipment Trade-off	Common High-Efficiency	Air Source Heat Pump	$949	$374	$231	$346	$163	$444	$508	$572	$1,007
Equipment Trade-off	Advanced Equipment	Gas Furnace + Central AC	$3,723	$1,660	$1,160	$1,842	$1,486	$2,087	$2,341	$2,439	$3,708
Equipment Trade-off	Advanced Equipment	Air Source Heat Pump	$3,642	$1,422	$796	$1,182	$522	$1,437	$1,605	$1,754	$2,355
Equipment Trade-off	90 AFUE	Gas Furnace + Central AC	$17	$232	$428	$916	$985	$1,242	$1,438	$1,596	$2,483

Exhibit C-4. Present Value of Life Cycle Energy Trade-off Impacts (Years 21-30)

HVAC Efficiency	HVAC System Type	CZ 1	CZ 2	CZ 3	CZ 4	CZ 4c	CZ 5	CZ 6	CZ 7	CZ 8
Common High-Efficiency	Gas Furnace + Central AC	$181	$152	$201	$399	$491	$631	$735	$801	$1,239
Common High-Efficiency	Air Source Heat Pump	$334	$131	$81	$122	$57	$156	$178	$201	$354
Advanced Equipment	Gas Furnace + Central AC	$1,309	$584	$408	$648	$523	$734	$823	$857	$1,304
Advanced Equipment	Air Source Heat Pump	$1,280	$500	$280	$416	$184	$505	$564	$617	$828
90 AFUE	Gas Furnace + Central AC	$6	$81	$150	$322	$346	$437	$505	$561	$873

Appendix D: Scenario 1 – 90 AFUE Gas Furnace

Appendix D includes the set of exhibits for the 90 AFUE scenario. The exhibits are consistent for each of the five scenarios from Appendix D through Appendix H and include the following:

1. House A vs. House B Example Trade-off Scenario
2. Individual Home Free Ridership Trade-off Impact
3. National Free Ridership Trade-off Impact
4. Individual Home Balance of Lifecycle Trade-off Impact
5. National Balance of Lifecycle Trade-off Impact
6. National Trade-off Impact Summary

Exhibit D-1 is one example of a equipment trade-off for this scenario showing national average energy efficiency values. Numerous examples could be developed, however this example is intending to be a typical possible trade-off based on the 90 AFUE gas furnace scenario. The values in this Appendix represent national average impacts from equipment trade-offs along with ranges of climate zone average impacts. Climate zone-specific data is available in Appendix B and Appendix C for each scenario. For more details and explanation of the House A vs. House B comparison, see Section 2.

Exhibit D-1. House A vs. House B – 90 AFUE Gas Furnace

	House A (2012 IECC)	House B (Equipment Trade-off)
Natural Gas Furnace	80 AFUE	90 AFUE
Air Conditioner	13 SEER North / 14 SEER South	13 SEER North / 14 SEER South
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
Wall R-Value*	18	14
Ceiling R-Value*	43	43
Floor R-Value*	19	19
Window U-Factor*	0.35	0.35
Window SHGC*	0.33	0.34
Infiltration ACH50*	3.5	3.5
Energy Code Compliance with Trade-off: Deemed “energy neutral”		
Equipment Trade-off: Shifts $43 of annual costs from equipment to envelope		

Exhibit D-2 and D-3 includes the potential impacts of free ridership for the 90 AFUE gas furnace scenario for a single home and on a national basis. Exhibit D-4 and D-5 includes the potential balance of lifecycle impacts for the 90 AFUE gas furnace scenario for a single home and on a national basis. Each exhibit shows the equipment characteristics, energy cost, present value of the energy cost, carbon impact, electricity impact and the natural gas impact. In addition to showing the national average value, the exhibits also include the range of climate zone averages to provide more context on the potential free ridership impacts across the country.

For more details and explanation of the individual home and national free ridership impact, see Section 3, and for the individual home and national balance of lifecycle impact, see Section 4.

Exhibit D-2. Individual Home Free Ridership Impact - Gas Furnace - 90 AFUE

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	90 AFUE
Air Conditioner	13 SEER North / 14 SEER South	13 SEER North / 14 SEER South
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
20 year Impacts for One Home		
Energy Cost Impact - National Average		$858
Energy Cost Impact – Range of Climate Zone Averages		$20-2,840
Energy Cost Impact Present Value - National Average		$748
Energy Cost Impact Present Value - Range of Climate Zone Averages		$17-2,483
Carbon Impact - National Average		8,086 lbs CO2e
Carbon Impact - Range of Climate Zone Averages		212-34,900 lbs CO2e
Electricity Impact - National Average		0 kWh
Electricity Impact – Range of Climate Zone Averages		0 kWh
Natural Gas Impact - National Average		760 Therms
Natural Gas Impact – Range of Climate Zone Averages		20-3,280 Therms

Exhibit D-3. National Free Ridership Impact - Gas Furnace - 90 AFUE

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	90 AFUE
Air Conditioner	13 SEER North / 14 SEER South	13 SEER North / 14 SEER South
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
20-year Technical Potential for One Year of Gas Furnace Home Housing Starts		
Energy Cost Impact		$551,578,985
Energy Cost Impact Present Value		$481,079,678
Carbon Impact		2,600,084 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		488,761,813 Therms
Estimated Equipment Market Penetration[14]		
90+ AFUE Gas Furnace (South)		27%
90+ AFUE Gas Furnace (North)		70%
20-year Market Potential for One Year of Gas Furnace Home Housing Starts		
Energy Cost Impact		$335,285,848
Energy Cost Impact Present Value		$292,431,744
Carbon Impact		1,642,497 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		308,691,672 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

[14] Table 8.4.36 of 2011-06-06 Technical Support Document: Energy Efficiency Program for Consumer Products: Residential Central Air Conditioners, Heat Pumps, and Furnaces.

Exhibit D-4. Individual Home Balance of Lifecycle Impact - Gas Furnace - 90 AFUE

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	90 AFUE
Air Conditioner	13 SEER North / 14 SEER South	13 SEER North / 14 SEER South
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
Year 21-30 Impacts for One Home		
Energy Cost Impact - National Average		$429
Energy Cost Impact - Climate Zone Averages		$10-1,420
Energy Cost Impact Present Value - National Average		$263
Energy Cost Impact Present Value - Climate Zone Averages		$6-873
Carbon Impact - National Average		4,043 lbs CO2e
Carbon Impact - Climate Zone Averages		106-17,450 lbs CO2e
Electricity Impact - National Average		0 kWh
Electricity Impact - Climate Zone Averages		0 kWh
Natural Gas Impact - National Average		380 Therms
Natural Gas Impact - Climate Zone Averages		10-1,640 Therms

Exhibit D-5. National Balance of Lifecycle Impact - Gas Furnace - 90 AFUE

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	90 AFUE
Air Conditioner	13 SEER North / 14 SEER South	13 SEER North / 14 SEER South
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
Year 21-30 Technical Potential Impacts for One Year of Average Gas Furnace Home Housing Starts		
Energy Cost Impact		$275,789,493
Energy Cost Impact Present Value		$169,146,165
Carbon Impact		1,300,042 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		24,4380,907 Therms
Estimated Equipment Market Penetration[15]		
90+ AFUE Gas Furnace (South)		27%
90+ AFUE Gas Furnace (North)		70%
Year 21-30 Market Potential Impacts for One Year of Average Gas Furnace Home Housing Starts		
Energy Cost Impact		$167,642,924
Energy Cost Impact Present Value		$102,818,134
Carbon Impact		821,248 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		154,345,836 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

[15] Table 8.4.36 of 2011-06-06 Technical Support Document: Energy Efficiency Program for Consumer Products: Residential Central Air Conditioners, Heat Pumps, and Furnaces.

Exhibit D-6 combines the free ridership and life cycle impacts, calculated in Sections 3 and 4 above, to sum up the full 30-year technical potential for increased homeowner energy bills from using equipment trade-offs. For the combined, 30-year results, we use a present value calculation to bring back this impacts to a current-year perspective.

Exhibit D-6. National Impact - Gas Furnace - 90 AFUE

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	90 AFUE
Air Conditioner	13 SEER North / 14 SEER South	13 SEER North / 14 SEER South
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
Free Rider Technical Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$551,578,985
Energy Cost Impact 30-yr Present Value		$404,875,207
Carbon Impact		2,600,084 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		488,761,813 Therms
Balance of Lifecycle Technical Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$275,789,493
Energy Cost Impact 30-yr Present Value		$169,146,165
Carbon Impact		1,300,042 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		244,380,907 Therms
30-year Technical Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$827,368,478
Energy Cost Impact 30-yr Present Value		$574,021,372
Carbon Impact		3,900,126 MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		733,142,720 Therms
Estimated Equipment Market Penetration		
90+ AFUE Gas Furnace (South)		27%
90+ AFUE Gas Furnace (North)		70%
30-year Market Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$502,928,772
Energy Cost Impact 30-yr Present Value		$395,249,878
Carbon Impact		2,463,745MTCO2e
Electricity Impact		0 GWh
Natural Gas Impact		463,037,508 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Appendix E: Scenario 2 – Gas Home Common High Efficiency

Appendix E includes each of the six exhibits described in Appendix D. Exhibit E-1 shows an example trade-off that could be done using common high-efficiency equipment to trade down features in gas-heated homes. The values in this Appendix represent national average impacts from equipment trade-offs along with ranges of climate zone average impacts. Climate zone-specific data is available in Appendix B and Appendix C for each scenario.

Exhibit E-1. Gas Furnace - Common High-Efficiency Equipment

	House A (2012 IECC)	House B (Equipment Trade-off)
Natural Gas Furnace	80 AFUE	92 AFUE South / 95 AFUE North
Air Conditioner	13 SEER North / 14 SEER South	15 SEER
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
Wall R-Value*	18	13
Ceiling R-Value*	43	43
Floor R-Value*	19	19
Window U-Factor*	0.35	0.39
Window SHGC*	0.33	0.33
Infiltration ACH50*	3.5	3.5
Energy Code Compliance with Trade-off: Deemed “energy neutral”		
Equipment Trade-off: Shifts $61 of annual costs from equipment to envelope		

*Equivalent national average energy efficiency feature. Each energy feature varies by climate zone; see Appendix B for climate zone-specific energy efficiency features.

Exhibits E-2 and E-3 includes the potential impacts of free ridership trade-offs using common high efficiency heating, air conditioning, and water heating equipment scenario for a single home and on a national basis. Exhibits E-4 and E-5 includes the potential balance of lifecycle impacts for the common high efficiency heating, air conditioning, and water heating equipment scenario for a single home and on a national basis. Each exhibit shows the equipment characteristics, energy cost, present value of the energy cost, carbon impact, electricity impact and the natural gas impact. In addition to showing the national average value, the exhibits also include the range of climate zone averages to provide more context on the potential free ridership impacts across the country.

Exhibit E-2 shows the example of free ridership impacts from for a single home with gas heating, including 20-year net present value costs to the homeowner that are significant, from an average of $1,058 to over $3,500 in the case of common high-efficiency equipment. Exhibit E-4 shows the year 21-30 cost to the homeowner with the installation of both a gas furnace and air conditioner that are high-efficiency but commonly available, the allowable envelope trade-offs would lead to added homeowner costs of $152 to $1,239 (present value) over years 21-30.

For more details and explanation of the individual home and national free ridership impact, see Section 3, and for the individual home and national balance of lifecycle impact, see Section 4.

Exhibit E-2. Individual Home Free Ridership Impact - Gas Furnace - Common High-Efficiency Equipment

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	92 AFUE South / 95 AFUE North
Air Conditioner	13 SEER North / 14 SEER South	15 SEER
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
20 year Impacts for One Home		
Energy Cost Impact - National Average		$1,213
Energy Cost Impact - Range of Climate Zone Averages		$500-4,040
Energy Cost Impact Present Value - National Average		$1,058
Energy Cost Impact Present Value - Range of Climate Zone Averages		$432-3,524
Carbon Impact - National Average		11,964 lbs CO2e
Carbon Impact - Range of Climate Zone Averages		296-54,630 lbs CO2e
Electricity Impact - National Average		640 kWh
Electricity Impact - Range of Climate Zone Averages		40-2,440 kWh
Natural Gas Impact - National Average		1,000 Therms
Natural Gas Impact - Range of Climate Zone Averages		20-4,660 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Exhibit E-3. National Free Ridership Impact - Gas Furnace - Common High-Efficiency Equipment

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	92 AFUE South / 95 AFUE North
Air Conditioner	13 SEER North / 14 SEER South	15 SEER
Water Heater	0.62 Gas DHW	0.62 Gas DHW
20 Year Technical Potential for One Year of Gas Furnace Home Housing Starts		
Energy Cost Impact		$779,993,837
Energy Cost Impact Present Value		$680,299,994
Carbon Impact		3,847,070 MTCO2e
Electricity Impact		412 GWh
Natural Gas Impact		643,107,649 Therms

*See Appendix C for climate zone-specific energy, cost and carbon impacts.

Exhibit E-4. Individual Home Balance of Lifecycle Impact - Gas Furnace – Common High-Efficiency Equipment

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	92 AFUE South / 95 AFUE North
Air Conditioner	13 SEER North / 14 SEER South	15 SEER
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
Year 21-30 Impacts for One Home		
Energy Cost Impact - National Average		$606
Energy Cost Impact - Range of Climate Zone Averages		$250-2,020
Energy Cost Impact Present Value - National Average		$372
Energy Cost Impact Present Value - Range of Climate Zone Averages		$152-1,239
Carbon Impact - National Average		5,982 lbs CO2e
Carbon Impact - Range of Climate Zone Averages		148-27,315 lbs CO2e
Electricity Impact - National Average		320 kWh
Electricity Impact - Range of Climate Zone Averages		20-1,220 kWh
Natural Gas Impact - National Average		500 Therms
Natural Gas Impact - Range of Climate Zone Averages		10-2,330 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Exhibit E-5. National Balance of Lifecycle Impact - Gas Furnace - Common High-Efficiency Equipment

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	92 AFUE South / 95 AFUE North
Air Conditioner	13 SEER North / 14 SEER South	15 SEER
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
Year 21-30 Impacts for One Year of Average Gas Furnace Home Housing Starts		
Energy Cost Impact		$389,996,919
Energy Cost Impact Present Value		$239,191,441
Carbon Impact		1,923,535 MTCO2e
Electricity Impact		205 GWh
Natural Gas Impact		321,553,825 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Exhibit E-6 combines the free ridership and life cycle impacts, calculated in Sections 3 and 4 above, to sum up the full 30-year technical potential for increased homeowner energy bills from using equipment trade-offs. For the combined, 30-year results, we use a present value calculation to bring back this impacts to a current-year perspective.

Exhibit E-6. National Impact - Gas Furnace - Common High-Efficiency Equipment

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	92 AFUE South / 95 AFUE North
Air Conditioner	13 SEER North / 14 SEER South	15 SEER
Water Heater	0.62 EF Gas DHW	0.62 EF Gas DHW
Free Rider Technical Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$779,993,837
Energy Cost Impact 30-yr Present Value		$680,299,994
Carbon Impact		3,847,070 MTCO2e
Electricity Impact		412 GWh
Natural Gas Impact		643,107,649 Therms
Balance of Lifecycle Technical Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$389,996,919
Energy Cost Impact 30-yr Present Value		$239,191,441
Carbon Impact		1,923,535 MTCO2e
Electricity Impact		205 GWh
Natural Gas Impact		321,553,825 Therms
30-year Technical Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$1,169,990,756
Energy Cost Impact 30-yr Present Value		$919,491,435
Carbon Impact		5,770,605 MTCO2e
Electricity Impact		617 GWh
Natural Gas Impact		964,661,474Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Appendix F: Scenario 3 – Gas Home Advanced Efficiency

Appendix F includes each of the six exhibits described in Appendix D. Exhibit F-1 shows an example trade-off that could be done using advanced high-efficiency equipment to trade down features in gas-heated homes. The values in this Appendix represent national average impacts from equipment trade-offs along with ranges of climate zone average impacts. Climate zone-specific data is available in Appendix B and Appendix C for each scenario.

Exhibit F-1. Gas Furnace - Advanced Equipment

	House A (2012 IECC)	House B (Equipment Trade-off)
Natural Gas Furnace	80 AFUE	96 AFUE
Air Conditioner	13 SEER North / 14 SEER South	19 SEER
Water Heater	0.62 EF Gas DHW	0.80 EF Gas DHW
Wall R-Value*	18	5
Ceiling R-Value*	43	34
Floor R-Value*	19	19
Window U-Factor*	0.35	0.49
Window SHGC*	0.33	0.45
Infiltration ACH50*	3.5	3.5
Energy Code Compliance with Trade-off: Deemed “energy neutral”		
Equipment Trade-off: Shifts $99 of annual costs from equipment to envelope		

*Equivalent national average energy efficiency feature. Each energy feature varies by climate zone; see Appendix B for climate zone-specific energy efficiency features.

Exhibits F-2 and F-3 includes the potential impacts of free ridership trade-offs using advanced high efficiency heating, air conditioning, and water heating equipment scenario for a single home and on a national basis. Exhibits F-4 and F-5 includes the potential balance of lifecycle impacts for the advanced high efficiency heating, air conditioning, and water heating equipment scenario for a single home and on a national basis. Each exhibit shows the equipment characteristics, energy cost, present value of the energy cost, carbon impact, electricity impact and the natural gas impact. In addition to showing the national average value, the exhibits also include the range of climate zone averages to provide more context on the potential free ridership impacts across the country.

Exhibit F-2 shows the example of free ridership impacts from for a single home with gas heating, including 20-year net present value costs to the homeowner that are significant, from an average of $1,726 and ranging to over $3,700 in the case of advanced high-efficiency equipment. Exhibit F-4 shows the year 21-30 cost to the homeowner with the installation of both a gas furnace and air conditioner that are advanced high-efficiency, the allowable envelope trade-offs would lead to added homeowner costs of $408 to $1,309 (present value) over years 21-30.

For more details and explanation of the individual home and national free ridership impact, see Section 3, and for the individual home and national balance of lifecycle impact, see Section 4.

Exhibit F-2. Individual Home Free Ridership Impact - Gas Furnace - Advanced Equipment

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	96 SEER
Air Conditioner	13 SEER North / 14 SEER South	19 SEER
Water Heater	0.62 EF Gas DHW	0.80 EF Gas DHW
20 year Impacts for One Home		
Energy Cost Impact - National Average		$1,979
Energy Cost Impact - Range of Climate Zone Averages		$1,320-4,260
Energy Cost Impact Present Value - National Average		$1,726
Energy Cost Impact Present Value - Range of Climate Zone Averages		$1,160-3,723
Carbon Impact - National Average		24,706 lbs CO2e
Carbon Impact - Range of Climate Zone Averages		462-90,568 lbs CO2e
Electricity Impact - National Average		6,080 kWh
Electricity Impact - Range of Climate Zone Averages		120-18,580 kWh
Natural Gas Impact - National Average		1,140 Therms
Natural Gas Impact - Range of Climate Zone Averages		20-4,900 Therms

*See Appendix C for climate zone-specific energy, cost and carbon impacts.

Exhibit F-3. National Free Ridership Impact - Gas Furnace - Advanced Equipment

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	96 SEER
Air Conditioner	13 SEER North / 14 SEER South	19 SEER
Water Heater	0.62 Gas DHW	0.80 Gas DHW
20 Year Technical Potential for One Year of Gas Furnace Home Housing Starts		
Energy Cost Impact		$1,272,624,715
Energy Cost Impact Present Value		$1,109,965,895
Carbon Impact		7,944,309 MTCO2e
Electricity Impact		3,910 GWh
Natural Gas Impact		733,142,720 Therms

*See Appendix C for climate zone-specific energy, cost and carbon impacts.

Exhibit F-4. Individual Home Balance of Lifecycle Impact - Gas Furnace - Advanced Equipment

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	96 SEER
Air Conditioner	13 SEER/14 SEER	19 SEER
Water Heater	0.62 EF Gas DHW	0.80 EF Gas DHW
Year 21-30 Impacts for One Home		
Energy Cost Impact - National Average		$989
Energy Cost Impact - Range of Climate Zone Averages		$660-2,130
Energy Cost Impact Present Value - National Average		$607
Energy Cost Impact Present Value - Range of Climate Zone Averages		$408-1,309
Carbon Impact - National Average		12,353 lbs CO2e
Carbon Impact - Range of Climate Zone Averages		231-45,284 lbs CO2e
Electricity Impact - National Average		3,040 kWh
Electricity Impact - Range of Climate Zone Averages		60-9,290 kWh
Natural Gas Impact - National Average		570 Therms
Natural Gas Impact - Range of Climate Zone Averages		10-2,450 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Exhibit F-5. National Balance of Lifecycle Impact - Gas Furnace - Advanced Equipment

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	96 SEER
Air Conditioner	13 SEER North / 14 SEER South	19 SEER
Water Heater	0.62 EF Gas DHW	0.80 EF Gas DHW
Year 21-30 Impacts for One Year of Average Gas Furnace Home Housing Starts		
Energy Cost Impact		$636,312,358
Energy Cost Impact Present Value		$390,260,703
Carbon Impact		3,972,154 MTCO2e
Electricity Impact		1,955 GWh
Natural Gas Impact		366,571,360 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Exhibit F-6 combines the free ridership and life cycle impacts, calculated in Sections 3 and 4 above, to sum up the full 30-year technical potential for increased homeowner energy bills from using equipment trade-offs. For the combined, 30-year results, we use a present value calculation to bring back this impacts to a current-year perspective.

Exhibit F-6. National Impact - Gas Furnace - Advanced Equipment

	2012 IECC	Equipment Trade-off
Natural Gas Furnace	80 AFUE	96 SEER
Air Conditioner	13 SEER North / 14 SEER South	19 SEER
Water Heater	0.62 EF Gas DHW	0.80 EF Gas DHW
Free Rider Technical Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$1,272,624,715
Energy Cost Impact 30-yr Present Value		$1,109,965,895
Carbon Impact		7,944,309 MTCO2e
Electricity Impact		3,910 GWh
Natural Gas Impact		733,142,720 Therms
Balance of Lifecycle Technical Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$636,312,358
Energy Cost Impact 30-yr Present Value		$390,260,703
Carbon Impact		3,972,154 MTCO2e
Electricity Impact		1,955 GWh
Natural Gas Impact		366,571,360 Therms
30-year Technical Potential Impacts for One Year of Gas Furnace Housing Starts		
Energy Cost Impact		$1,908,937,073
Energy Cost Impact 30-yr Present Value		$1,500,226,598
Carbon Impact		11,916,463 MTCO2e
Electricity Impact		5,865 GWh
Natural Gas Impact		1,099,714,080 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Appendix G: Scenario 4 – Electric Home Common High Efficiency

Appendix G includes each of the six exhibits described in Appendix D. Exhibit G-1 shows an example trade-off that could be done using common high-efficiency equipment to trade down features in electric-heated homes. The values in this Appendix represent national average impacts from equipment trade-offs along with ranges of climate zone average impacts. Climate zone-specific data is available in Appendix B and Appendix C for each scenario.

Exhibit G-1. Air Source Heat Pump - Common High-Efficiency Equipment

	House A (2012 IECC)	House B (Equipment Trade-off)
Air Source Heat Pump	8.2 HSPF	8.5 HSPF
Air Conditioner	14 SEER	15 SEER
Water Heater	0.95 EF Elec DHW	0.95 EF Elec DHW
Wall R-Value*	18	17
Ceiling R-Value*	43	43
Floor R-Value*	19	19
Window U-Factor*	0.35	0.38
Window SHGC*	0.33	0.33
Infiltration ACH50*	3.5	3.5
Energy Code Compliance with Trade-off: Deemed “energy neutral”		
Equipment Trade-off: Shifts $20 of annual costs from equipment to envelope		

*Equivalent national average energy efficiency feature. Each energy feature varies by climate zone; see Appendix B for climate zone-specific energy efficiency features.

Exhibits G-2 and G-3 includes the potential impacts of free ridership trade-offs using high efficiency heating, air conditioning, and water heating equipment scenario for a single home and on a national basis. Exhibits G-4 and G-5 includes the potential balance of lifecycle impacts for the high efficiency heating, air conditioning, and water heating equipment scenario for a single home and on a national basis. Each exhibit shows the equipment characteristics, energy cost, present value of the energy cost, carbon impact, electricity impact and the natural gas impact. In addition to showing the national average value, the exhibits also include the range of climate zone averages to provide more context on the potential free ridership impacts across the country.

Exhibit F-2 shows the example of free ridership impacts from for a single home with electric heating, including 20-year net present value costs to the homeowner that are significant, from an average of $356 in higher energy bills, and range up to $1007 in the case of advanced high-efficiency equipment. Exhibit E-4 shows the year 21-30 cost to the homeowner with the installation of an air source heat pump that is commonly available high-efficiency, the allowable envelope trade-offs would lead to added homeowner costs of $57 to $354 (present value) over years 21-30.

For more details and explanation of the individual home and national free ridership impact, see Section 3, and for the individual home and national balance of lifecycle impact, see Section 4.

Exhibit G-2. Individual Home Free Ridership Impact - Air Source Heat Pump - Common High-Efficiency Equipment

	2012 IECC	Equipment Trade-off
Air Source Heat Pump	8.2 HSPF	8.5 HSPF
Air Conditioner	14 SEER	15 SEER
Water Heater	0.95 EF Elec DHW	0.95 EF Elec DHW
20 year Impacts for One Home		
Energy Cost Impact - National Average		$409
Energy Cost Impact - Range of Climate Zone Averages		$180-1,160
Energy Cost Impact Present Value - National Average		$356
Energy Cost Impact Present Value - Range of Climate Zone Averages		$163-1,007
Carbon Impact - National Average		7,198 lbs CO2e
Carbon Impact - Range of Climate Zone Averages		4,592-13,072 lbs CO2e
Electricity Impact - National Average		3,480 kWh
Electricity Impact - Range of Climate Zone Averages		2,220-6,320 kWh
Natural Gas Impact - National Average		0 Therms
Natural Gas Impact - Range of Climate Zone Averages		0 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Exhibit G-3. National Free Ridership Impact - Air Source Heat Pump - Common High-Efficiency Equipment

	2012 IECC	Equipment Trade-off
Air Source Heat Pump	8.2 HSPF	8.5 HSPF
Air Conditioner	14 SEER	15 SEER
Water Heater	0.95 Elec DHW	0.95 Elec DHW
20 Year Technical Potential for One Year of Air Source Heat Pump Home Housing Starts		
Energy Cost Impact		$262,770,258
Energy Cost Impact Present Value		$229,184,657
Carbon Impact		2,314,544 MTCO2e
Electricity Impact		2238 GWh
Natural Gas Impact		0 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Exhibit G-4. Individual Home Balance of Lifecycle Impact - Air Source Heat Pump - Common High-Efficiency Equipment

	2012 IECC	Equipment Trade-off
Air Source Heat Pump	8.2 HSPF	8.5 HSPF
Air Conditioner	14 SEER	15 SEER
Water Heater	0.95 EF Elec DHW	0.95 EF Elec DHW
Year 21-30 Impacts for One Home		
Energy Cost Impact - National Average		$204
Energy Cost Impact - Range of Climate Zone Averages		$90-580
Energy Cost Impact Present Value - National Average		$125
Energy Cost Impact Present Value - Range of Climate Zone Averages		$57-354
Carbon Impact - National Average		3,599 lbs CO2e
Carbon Impact - Range of Climate Zone Averages		2,296-6,536 lbs CO2e
Electricity Impact - National Average		1,740 kWh
Electricity Impact - Range of Climate Zone Averages		1110-3,160 kWh
Natural Gas Impact - National Average		0 Therms
Natural Gas Impact - Range of Climate Zone Averages		0 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Exhibit G-5. National Balance of Lifecycle Impact - Air Source Heat Pump - Common High-Efficiency Equipment

	2012 IECC	Equipment Trade-off
Air Source Heat Pump	8.2 HSPF	8.5 HSPF
Air Conditioner	14 SEER	15 SEER
Water Heater	0.95 EF Elec DHW	0.95 EF Elec DHW
Year 21-30 Impacts for One Year of Average Air Source Heat Pump Home Housing Starts		
Energy Cost Impact		$131,385,129
Energy Cost Impact Present Value		$80,580,635
Carbon Impact		1,157,272 MTCO2e
Electricity Impact		1,119 GWh
Natural Gas Impact		0 Therms

*See Appendix C for climate zone-specific energy, cost and carbon impacts.

Exhibit G-6 combines the free ridership and life cycle impacts, calculated in Sections 3 and 4 above, to sum up the full 30-year technical potential for increased homeowner energy bills from using equipment trade-offs. For the combined, 30-year results, we use a present value calculation to bring back this impacts to a current-year perspective.

Exhibit G-6. National Impact - Air Source Heat Pump - Common High-Efficiency Equipment

	2012 IECC	Equipment Trade-off
Air Source Heat Pump	8.2 HSPF	8.5 HSPF
Air Conditioner	14 SEER	15 SEER
Water Heater	0.95 EF Elec DHW	0.95 EF Elec DHW
Free Rider Technical Potential Impacts for One Year of Air Source Heat Pump Housing Starts		
Energy Cost Impact		$262,770,258
Energy Cost Impact 30-yr Present Value		$229,184,657
Carbon Impact		2,314,544 MTCO2e
Electricity Impact		2238 GWh
Natural Gas Impact		0 Therms
Balance of Lifecycle Technical Potential for One Year of Air Source Heat Pump Housing Starts		
Energy Cost Impact		$131,385,129
Energy Cost Impact 30-yr Present Value		$80,580,635
Carbon Impact		1,157,272 MTCO2e
Electricity Impact		1,119 GWh
Natural Gas Impact		0 Therms
30-year Technical Potential Impacts for One Year of Air Source Heat Pump Home Housing Starts		
Energy Cost Impact		$394,155,387
Energy Cost Impact 30-yr Present Value		$309,765,292
Carbon Impact		3,471,816 MTCO2e
Electricity Impact		3,357 GWh
Natural Gas Impact		0 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Appendix H: Scenario 5 – Electric Home Advanced Efficiency

Appendix H includes each of the six exhibits described in Appendix D. Exhibit H-1 shows an example trade-off that could be done using common high-efficiency equipment to trade down features in electric-heated homes. The values in this Appendix represent national average impacts from equipment trade-offs along with ranges of climate zone average impacts. Climate zone-specific data is available in Appendix B and Appendix C for each scenario.

Exhibit H-1. Scenario 5: Air Source Heat Pump - Advanced Equipment

	House A (2012 IECC)	House B (Equipment Trade-off)
Air Source Heat Pump	8.2 HSPF	9.2 HSPF
Air Conditioner	14 SEER	19 SEER
Water Heater	0.95 EF Elec DHW	1.15 EF Elec DHW
Wall R-Value*	18	9
Ceiling R-Value*	43	36
Floor R-Value*	19	19
Window U-Factor*	0.35	0.67
Window SHGC*	0.33	0.49
Infiltration ACH50*	3.5	3.5
Energy Code Compliance with Trade-off: Deemed "energy neutral"		
Equipment Trade-off: Shifts $70 of annual costs from equipment to envelope		

*Equivalent national average energy efficiency feature. Each energy feature varies by climate zone; see Appendix B for climate zone-specific energy efficiency features.

Exhibits H-2 and H-3 includes the potential impacts of free ridership trade-offs using advanced high efficiency heating, air conditioning, and water heating equipment scenario for a single home and on a national basis. Exhibits H-4 and H-5 includes the potential balance of lifecycle impacts for the advanced high efficiency heating, air conditioning, and water heating equipment scenario for a single home and on a national basis. Each exhibit shows the equipment characteristics, energy cost, present value of the energy cost, carbon impact, electricity impact and the natural gas impact. In addition to showing the national average value, the exhibits also include the range of climate zone averages to provide more context on the potential free ridership impacts across the country.

Exhibit H-2 shows the example of free ridership impacts from for a single home with electric heating, including 20-year net present value costs to the homeowner that are significant, from an average of $1,225 and up to $3,642 in the case of advanced high-efficiency equipment. Exhibit H-4 shows the year 21-30 cost to the homeowner with the installation of both a gas furnace and air conditioner that are advanced high-efficiency, the allowable envelope trade-offs would lead to added homeowner costs of $184 to $1,280 (present value) over years 21-30.

For more details and explanation of the individual home and national free ridership impact, see Section 3, and for the individual home and national balance of lifecycle impact, see Section 4.

Exhibit H-2. Individual Home Free Ridership Impact - Air Source Heat Pump - Advanced Equipment

	2012 IECC	Equipment Trade-off
Air Source Heat Pump	8.2 HSPF	9.2 HSPF
Air Conditioner	13 SEER North / 14 SEER South	19 SEER
Water Heater	0.95 EF Elec DHW	1.15 EF Elec DHW
20 year Impacts for One Home		
Energy Cost Impact - National Average		$1,404
Energy Cost Impact - Range of Climate Zone Averages		$601-4,180
Energy Cost Impact Present Value - National Average		$1,225
Energy Cost Impact Present Value - Range of Climate Zone Averages		$522-3,642
Carbon Impact - National Average		24,698 lbs CO2e
Carbon Impact - Range of Climate Zone Averages		0-33,676 lbs CO2e
Electricity Impact - National Average		11,940 kWh
Electricity Impact - Range of Climate Zone Averages		0-16,280 kWh
Natural Gas Impact - National Average		0 Therms
Natural Gas Impact - Range of Climate Zone Averages		0 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Exhibit H-3. National Free Ridership Impact - Air Source Heat Pump - Advanced Equipment

	2012 IECC	Equipment Trade-off
Air Source Heat Pump	8.2 HSPF	9.2 HSPF
Air Conditioner	13 SEER North / 14 SEER South	19 SEER
Water Heater	0.95 Elec DHW	1.15 Elec DHW
20 Year Technical Potential for One Year of Air Source Heat Pump Home Housing Starts		
Energy Cost Impact		$903,197,463
Energy Cost Impact Present Value		$787,978,144
Carbon Impact		7,941,736 MTCO2e
Electricity Impact		7,678 GWh
Natural Gas Impact		0 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Exhibit H-4. Individual Home Balance of Lifecycle Impact - Air Source Heat Pump - Advanced Equipment

	2012 IECC	Equipment Trade-off
Air Source Heat Pump	8.2 HSPF	9.2 HSPF
Air Conditioner	13 SEER North / 14 SEER South	19 SEER
Water Heater	0.95 EF Elec DHW	1.15 EF Elec DHW
Year 21-30 Impacts for One Home		
Energy Cost Impact - National Average		$702
Energy Cost Impact - Range of Climate Zone Averages		$300-2,090
Energy Cost Impact Present Value - National Average		$431
Energy Cost Impact Present Value - Range of Climate Zone Averages		$184-1,280
Carbon Impact - National Average		12,349 lbs CO2e
Carbon Impact - Range of Climate Zone Averages		0-16,838 lbs CO2e
Electricity Impact - National Average		5,970 kWh
Electricity Impact - Range of Climate Zone Averages		0-8,140 kWh
Natural Gas Impact - National Average		0 Therms
Natural Gas Impact - Range of Climate Zone Averages		0 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Exhibit H-5. National Balance of Lifecycle Impact - Air Source Heat Pump - Advanced Equipment

	2012 IECC	Equipment Trade-off
Air Source Heat Pump	8.2 HSPF	9.2 HSPF
Air Conditioner	13 SEER North / 14 SEER South	19 SEER
Water Heater	0.95 EF Elec DHW	1.15 EF Elec DHW
Year 21-30 Impacts for One Year of Average Air Source Heat Pump Home Housing Starts		
Energy Cost Impact		$451,598,731
Energy Cost Impact Present Value		$277,050,774
Carbon Impact		3,970,868 MTCO2e
Electricity Impact		3,839 GWh
Natural Gas Impact		0 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Exhibit H-6 combines the free ridership and life cycle impacts, calculated in Sections 3 and 4 above, to sum up the full 30-year technical potential for increased homeowner energy bills from using equipment trade-offs. For the combined, 30-year results, we use a present value calculation to bring back this impacts to a current-year perspective.

Exhibit H-6. National Impact - Air Source Heat Pump - Advanced Equipment

	2012 IECC	Equipment Trade-off
Air Source Heat Pump	8.2 HSPF	9.2 HSPF
Air Conditioner	13 SEER North / 14 SEER South	19 SEER
Water Heater	0.95 EF Elec DHW	1.15 EF Elec DHW
Free Rider Technical Potential Impacts for One Year of Air Source Heat Pump Home Housing Starts		
Energy Cost Impact		$903,197,463
Energy Cost Impact 30-yr Present Value		$787,978,144
Carbon Impact		7,941,736 MTCO2e
Electricity Impact		7,678 GWh
Natural Gas Impact		0 Therms
Balance of Lifecycle Technical Potential for One Year of Air Source Heat Pump Home Housing Starts		
Energy Cost Impact		$451,598,731
Energy Cost Impact 30-yr Present Value		$277,050,774
Carbon Impact		3,970,868 MTCO2e
Electricity Impact		3,839 GWh
Natural Gas Impact		0 Therms
30-year Technical Potential Impacts for One Year of Air Source Heat Pump Home Housing Starts		
Energy Cost Impact		$1,354,796,194
Energy Cost Impact 30-yr Present Value		$1,065,028,918
Carbon Impact		11,912,604 MTCO2e
Electricity Impact		11,517 kWh
Natural Gas Impact		0 Therms

*See Appendix C for climate zone-specific energy, cost, and carbon impacts.

Appendix I: National Technical Potential Analysis

Appendix I includes the total technical potential energy impacts from both the gas home and electric home cases detailed in Appendices E to H, when combining both the free ridership and life cycle impacts. The resulting total technical potential impacts from the common high efficiency cases are shown in exhibits I-1 and the total impacts from the advanced equipment are shown in exhibit I-2. For homes with common high efficiency equipment the 30-year present value potential impact is approximately $1.2 billion per year of housing starts. For the advanced practice equipment scenarios for both gas and electric homes the energy impact to homeowners would be approximately $2.5 billion per year of housing starts. It should be noted that the estimates in this Appendix (and E to H) are estimates of technical potential and have not been adjusted by estimates of market penetration to determine reasonable estimated market potential impacts described in Section 3, Section 4 and Appendix D for the 90 AFUE scenario.

Exhibit I-1. National Technical Potential – All Homes with Common High-Efficiency Equipment

Total Technical Potential Impacts - One Year of Average Housing Starts	
Energy Cost Impact	$1,564,146,143
Energy Cost Impact 30-yr Present Value	$1,229,256,727
Carbon Impact	9,242,421 MTCO2e
Electricity Impact	3,974 GWh
Natural Gas Impact	964,661,474 Therms

Exhibit I-2. National Technical Potential – All Homes with Advanced Equipment

Total Technical Potential Impacts - One Year of Average Housing Starts	
Energy Cost Impact	$3,263,733,267
Energy Cost Impact 30-yr Present Value	$2,565,255,516
Carbon Impact	23,829,067 MTCO2e
Electricity Impact	17,382 GWh
Natural Gas Impact	1,099,714,080 Therms

Appendix J: Example Energy Use Impacts

Appendix J includes analysis that was completed to look at 5 example scenarios to determine the potential shift of energy from efficient non-equipment measures to efficient equipment measures. The following table examines the impact of the 90 AFUE trade-off that could be caused by allowing equipment trade-offs in residential building energy codes.

Exhibit J-1. Example 1 – Natural Gas (90 AFUE Only)

			Increase in Energy Use	
	2015 Federal Minimum Equipment Efficiency	90 AFUE Gas Furnace Equipment	National Average	Climate Zone Average Range
Example 1 - Natural Gas (90 AFUE Only)				
Natural Gas Furnace	80 AFUE	90 AFUE	6%	0-9%
Air Conditioner	13 SEER/14 SEER	13 SEER/14 SEER	0%	0-0%
Water Heater	0.62 Gas DHW	0.62 Gas DHW	0%	0-0%
		National Average	6%	0-9%

The national average percentage numbers in the table indicate the amount of energy savings at risk if a builder uses readily available mechanical equipment as a means of "trading-off" elements of the thermal building envelope such as insulation or windows. The following tables show four different trade-off examples that further illustrate the magnitude of the resulting trade-off loophole that will reduce the long-term energy efficiency of the building simply from installing moderate or higher efficiency equipment that is readily available:

Exhibit J-2. Example 2 – Natural Gas (Moderate Efficiency Equipment)

			Increase in Energy Use	
	2015 Federal Minimum Equipment Efficiency	Commonly-Installed Equipment Efficiency	National Average	Climate Zone Average Range
Example 2 - Natural Gas (Moderate Efficiency Equipment)				
Natural Gas Furnace	80 AFUE	92 AFUE	7%	0-11%
Air Conditioner	13 SEER/14 SEER	16 SEER	2%	0-7%
Water Heater	0.62 Gas DHW	0.67 EF Gas DHW	2%	1-4%
		National Average	11%	8-12%

Exhibit J-3. Example 3 – Natural Gas (High Efficiency Equipment)

			Increase in Energy Use	
	2015 Federal Minimum Equipment Efficiency	Advanced Equipment Efficiency	National Average	Climate Zone Average Range
Example 3 - Natural Gas (High Efficiency Equipment)				
Natural Gas Furnace	80 AFUE	96 AFUE	9%	0-14%
Air Conditioner	13 SEER/14 SEER	19 SEER	4%	0-15%
Water Heater	0.62 Gas DHW	0.80 Gas EF DHW	9%	4-15%
		National Average	22%	18-30%

Exhibit J-4. Example 4 – Electric (Moderate Efficiency Equipment)

	2015 Federal Minimum Equipment Efficiency	Commonly-Installed Equipment Efficiency	Increase in Energy Use: National Average	Increase in Energy Use: Climate Zone Average Range
Example 4 - Electric (Moderate Efficiency Equipment)				
Heat Pump	8.2 HSPF	8.5 HSPF	1%	0-7%
Air Conditioner	14 SEER	16 SEER	2%	0-7%
Water Heater	0.95 Elec DHW	0.95 EF Elec DHW	0%	0-0%
		National Average	3%	5-8%

Exhibit J-5. Example 5 – Electric (High Efficiency Equipment)

	2015 Federal Minimum Equipment Efficiency	Advanced Equipment Efficiency	Increase in Energy Use: National Average	Increase in Energy Use: Climate Zone Average Range
Example 5 - Electric (High Efficiency Equipment)				
Heat Pump	8.2 HSPF	9.2 HSPF	3%	0-4%
Air Conditioner	14 SEER	19 SEER	4%	0-15%
Water Heater	0.95 Elec DHW	1.15 EF Elec DHW	10%	6-15%
		National Average	18%	10-26%

Appendix K: U.S. Department of Energy Citations

2009 IECC Determination Citations:

DEPARTMENT OF ENERGY [Docket No. EERE–2010–BT–DET–0030] RIN 1904–AC17

Updating State Residential Building Energy Efficiency Codes

"Another change does not directly alter code stringency in the performance path but may ultimately result in some energy savings is the removal of the option to trade high-efficiency HVAC equipment for reductions in other requirements in the code, such as reduced envelope insulation. Because building envelopes have substantially longer lives than HVAC and/or water heating equipment, energy savings from envelope improvements may persist for many more years than comparable equipment improvements. Also, because high-efficiency equipment is already the predominant choice in many markets, disallowing envelope/equipment tradeoffs is likely to result in improved overall efficiency in many situations."

2012 IECC Determination Citations:

DEPARTMENT OF ENERGY [Docket No. EERE-2011-BT-DET-0057] RIN 1904-AC59

Updating State Residential Building Energy Efficiency Codes

D. DOE's Final Determination Statement

"The 2012 IECC has a substantial variety of revisions compared to the 2009 IECC. Most of these revisions appear to directly improve energy efficiency that, on the whole, would result in a significant improvement in efficiency to homes built to the code. Therefore, the Department concludes that the 2012 edition of the IECC receives an affirmative determination under Section 304(a) of ECPA."