

History of Residential Energy Code Progress Toward Net-Zero

V. Robert Salcido, Pacific Northwest National Laboratory (PNNL)

Yan Chen, Pacific Northwest National Laboratory (PNNL)

YuLong Xie, Pacific Northwest National Laboratory (PNNL)

Michael Rosenberg, Pacific Northwest National Laboratory (PNNL)

ABSTRACT

Beginning in early 2000, the Pacific Northwest National Laboratory (PNNL) began tracking the historic progression of efficiency improvement in residential building energy codes. This progression has been captured in a graph that shows the improvement in energy code efficiency over time. However, early approximations of energy code efficiency were based on review of various disparate analyses conducted by the Department of Energy (DOE) since the beginning of their Building Energy Codes Program. Those analyses included published residential determinations and other unpublished analyses. These efficiency estimates were based on energy simulations; however, over many years used a series of differing simulation programs, residential prototypes, weather files and construction types.

In the campaign to develop a pathway to net-zero energy buildings, it is necessary to track the progression of the U.S. residential energy code efficiency from inception to the latest edition of the International Energy Conservation Code (IECC). Such a tracking system can inform policy makers of the effort needed to meet progressive energy targets. ASHRAE 90-1975 was the first voluntary building consensus energy standard published in the U.S. In ensuing years, energy codes have changed titles, adapted to modern building practices and reduced energy use.

The objective of this study is to develop and implement a strategy for a consistent analytical approach to compare the efficiency levels of all residential energy codes from 1975 to 2021. The outcome is a residential energy code progress indicator to identify the performance gap between energy code editions, relative to current codes with an eye toward net-zero energy.

Introduction

The PNNL Building Energy Codes Program's (BECPP) has maintained a residential energy code graph, highlighting improvements in energy code efficiency for more than 10 years. This residential energy code graph began with the ASHRAE 90-75 energy code to show the progression of energy code efficiency up to the latest energy code – the 2021 IECC (ICC 2021) published on January 29, 2021. The energy efficiency levels of the most recent energy code editions (2006 – 2021 IECC) were based off the DOE determination analyses as required by federal law. With each new edition of the IECC, DOE is required by statute to issue a determination as to whether the updated edition will improve energy efficiency in residential buildings (42 U.S.C. 6833). The determination analyses followed a consistent and rigorous methodology allowing accurate comparison of the energy codes evaluated between 2006 and 2021. Although the efficiency levels of the earlier energy code editions were also verified by simulation analysis, over the years the different comparative analyses used a series of differing simulation programs, residential prototypes, weather files and construction weighting. Therefore, the stepwise progress of the pre-2006 codes was estimated by adding the savings of each step

relative to the previous codes. This resulted in a valid comparison of two consecutive editions of the code but was less accurate for establishing the stepwise progression over multiple code cycles.

The objective of this study is to develop and implement a strategy to update the residential energy code graph for all residential energy codes from 1975 to 2021 by using a consistent analytical approach based on the DOE established methodology (Taylor, Mendon, and Fernandez 2015). While most recent residential energy code editions are published online, most earlier codes exist only in hard copies and not in electronic form. In contrast, ASHRAE 90-75 and 1980A both exist online as PDF's. Compiling all earlier energy codes required extensive outreach to energy code stakeholders. Figure 1 shows the updated residential energy code graph version developed from this analysis.

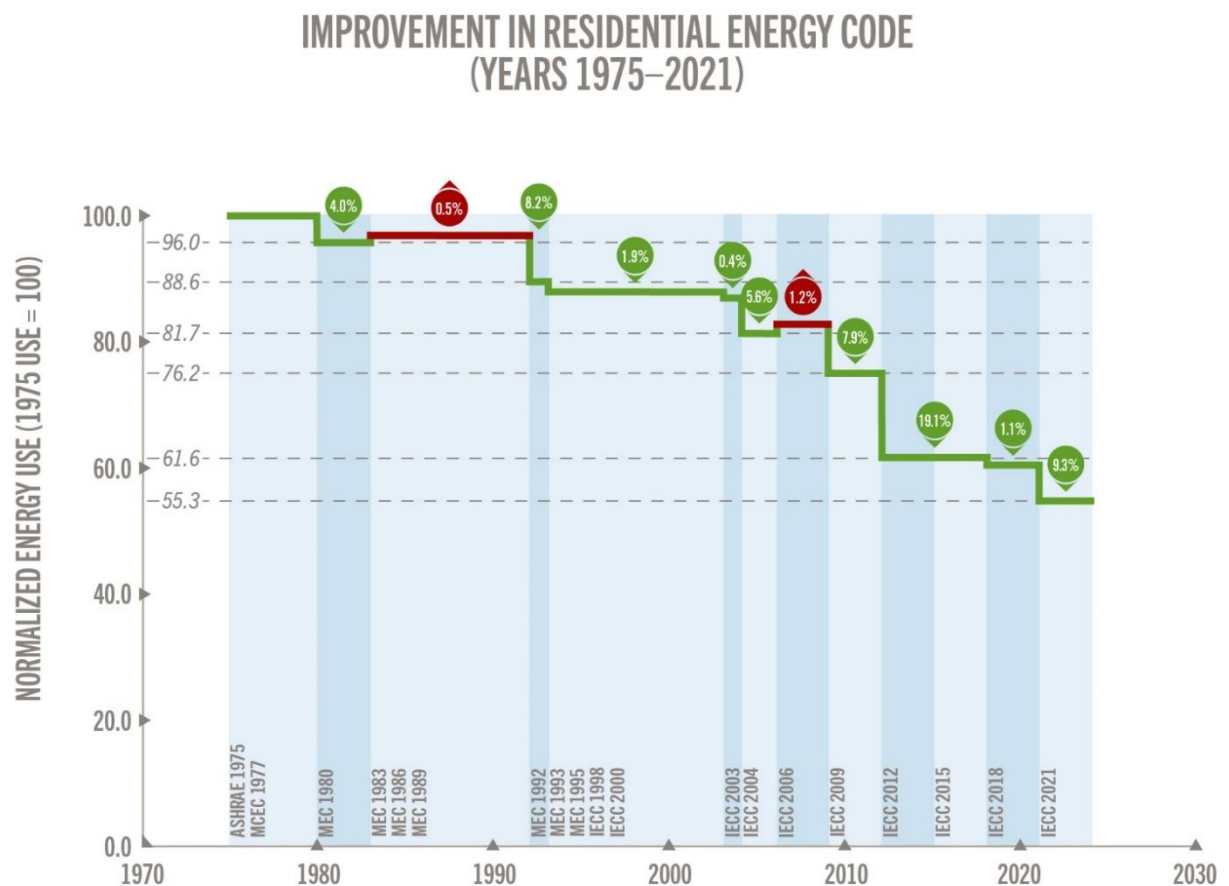


Figure 1. Residential Energy Code Graph, 1975 - 2021. Horizontal lines show energy use as a percentage of ASHRAE 90-1975 energy use. Source: PNNL 2021.

In order to develop the residential simulation models, it was necessary to determine the best approach to compare the early code editions with the modern energy codes. It was decided that each energy code edition would be analyzed as if a home were being constructed today to the prescriptive levels. That means the appliances, receptacle loads, hot water fixture flow, and any other equipment not regulated directly by the energy code are assumed to match those installed in a home built today. This strategy isolates the improvement of only the code regulated items. In addition, the efficiency provisions of HVAC and service water heating equipment are

based on current federal standards due to the National Appliance Energy Conservation Act (NAECA) (NAECA 1987). A full discussion on the procedures utilized in the development of the energy models is described in the Methodology section.

History of the Residential Energy Code Graph

DOE interest in the residential energy code graph paralleled the development of a commercial energy code graph starting around 2008. This graph was envisioned as a way to track progress towards a joint DOE and ASHRAE goal to achieve 30% savings in commercial buildings from Standard 90.1-2010 relative to Standard 90.1-2004 (Thornton et al. 2010).

With the development of the commercial energy code graph and the successful achievement of the 30% savings goal, DOE attention turned to the residential energy code. Historically, many early DOE residential energy code determinations focused solely on whether or not the new energy code saves energy compared to its predecessor, with no formal attempt at quantification of those savings. Eventually, DOE began quantifying residential energy code savings and the basis of this graph emerged. However, because DOE had not formally quantified the saving of many of the earlier residential energy codes, the estimates were based on informal and unpublished analyses.

The earliest copy of the residential energy code graph known to the authors of this document shows up in an internal document and spreadsheet dated in 2011. The first formal representation of the residential energy code graph shows up in the Building Energy Codes Program National Benefits Assessment, 1992-2040. (Livingston et al, 2014).

Methodology

Strategy

To assemble the updated residential energy code improvement graph, it was necessary to develop a strategy for how each energy code edition would be assessed. Prescriptive envelope specifications in energy codes are easy to understand and implement in energy simulation models. There are no federal statutes that change or overrule the envelope specifications in the energy code. That is not the case for residential HVAC and service water heating equipment efficiency. Early editions of the energy codes prior to NAECA specified residential HVAC efficiency levels as a minimum prescriptive requirement. However, with the passage of NAECA in 1987, residential HVAC equipment efficiency in energy codes cannot pre-empt federal minimum efficiency requirements.

NAECA instituted minimum energy efficiency standards for many household appliances. Congress set the initial federal energy efficiency standards and inaugurated schedules for DOE to review and update these standards. The Energy Policy Act of 1992 (EPAct) added standards for lighting, plumbing products, electric motors, commercial water heaters, and heating, ventilation, and air conditioning (HVAC) systems (EERE 2022). Since NAECA does not allow the manufacture or sale of this equipment below the federal minimum efficiency standards such as those specified in energy code editions prior to 1987, all energy codes were simulated with the current federal minimum HVAC efficiencies (CFR 2022). When new residential energy efficiency measures became regulated in the energy code (envelope and duct tightness, lighting,

ventilation, etc.), prior energy codes would either show no regulation of these measures or were set to the minimum efficiency level of the first code to regulate the measure. This strategy allowed a consistent framework for the comparison of the energy efficiency of all residential energy code editions from 1975 to 2021.

Analysis Tools

The simulation analysis to reconstruct the residential energy code graph was conducted using the PNNL residential prototype models following the DOE established methodology (Taylor, Mendon, and Fernandez 2015). EnergyPlus version 9.5 (DOE 2020) was used to conduct the building energy simulation. DOE's established methodology utilizes a suite of representative residential prototype buildings, including a single-family and a low-rise multifamily residential building, each with four foundation types (i.e., slab-on-grade, vented crawlspace, heated basement, unheated basement) and four heating system types (i.e., gas furnace, electric resistance, heat pump, fuel oil furnace). The entire set of configurations is designed to represent the majority of the new residential building construction stock in the United States and was created based on construction data from the U.S. Census (Census 2010), the Residential Energy Consumption Survey (RECS 2013) and the National Association of Home Builders (NAHB 2009).

Thus, a total of 32 prototype buildings and configurations are represented (i.e., two building types, four foundation types, and four fuel/equipment types) resulting in 576 individual energy simulation models modeled across 18 representative cities with the corresponding TMY3 weather data (BECF 2022). Detailed descriptions of the prototype building models and their representative operational assumptions are documented by Mendon et al. (2013, 2015) and Mendon and Taylor (2014). Based on this simulation structure, the result was an aggregated energy use index (EUI) in kBtu/ft² of total building energy for each energy code edition.

Energy Code Editions

Nineteen residential energy code editions were reviewed and simulated for the updated residential energy code graph. The code editions are listed below.

- 1975 ASHRAE 90 (ASHRAE 1975)
- 1977 Model Code for Energy Conservation (MCEC 1977)
- 1980 ASHRAE 90A (ASHRAE 1980A)
- 1983 Model Energy Code (MEC 1983)
- 1986 Model Energy Code (MEC 1986)
- 1989 Model Energy Code (MEC 1989)
- 1992 Model Energy Code (MEC 1992)
- 1993 Model Energy Code (MEC 1993)
- 1995 Model Energy Code (MEC 1995)
- 1998 International Energy Conservation Code (ICC 1998)
- 2000 International Energy Conservation Code (ICC 2000)
- 2003 International Energy Conservation Code (ICC 2003)
- 2004 International Energy Conservation Supplement (ICC 2004)
- 2006 International Energy Conservation Code (ICC 2006)

- 2009 International Energy Conservation Code (ICC 2009)
- 2012 International Energy Conservation Code (ICC 2012)
- 2015 International Energy Conservation Code (ICC 2015)
- 2018 International Energy Conservation Code (ICC 2018)
- 2021 International Energy Conservation Code (ICC 2021)

The early residential energy code editions (1975 – 2003) consisted of prescriptive specifications primarily for envelope components. Air leakage requirements were initially for windows and doors only and not the whole building. These code editions quantified wall, ceiling, floor and slab on grade U-factors from graphs based on heating degree days base 65°F. Windows and doors were considered integral to the walls with no separate U-factor requirements, and so a whole-wall U-factor was specified the same as for envelopes of commercial buildings.

As energy codes matured, windows and doors were extracted from the walls with specific requirements for U-factors and solar heat gain coefficients (SHGC). The energy code editions since 2004 provided two tables for envelope R-values as well as U-factors and SHGCs based on climate zone designation. Energy code editions since 2009 added requirements for building envelope tightness and duct tightness, as well as ventilation and lighting requirements. The changing format and additional efficiency measures in later editions of energy codes made it challenging to align all the energy codes to the latest format. The process of aligning the early energy code editions with the modern energy codes is discussed in the following sections.

Procurement of Energy Codes

The first step for updating the residential energy code graph was compiling electronic or hard copies of all energy code editions beginning with ASHRAE 90-1975 through the 2021 IECC. This required extensive outreach within the PNNL BECP as well as with energy code stakeholders. Older energy code editions were not available for download or purchase from Building Officials and Code Administrators, the International Conference of Building Officials nor the Council of American Building Officials. In the end, it was the individual stakeholders who had maintained hard copies of early energy code editions as well as online searching that made the collection successful.

The next step consisted of collecting and organizing all residential prescriptive requirements for each energy code edition. The data was formatted according to the prescriptive requirements of the 2021 IECC as the latest published energy code. The specifications for each code edition were separated by envelope component as required for energy simulation. The building components compiled for this analysis are shown below. Any building component not listed was held constant through all energy code editions.

- | | |
|---------------------------------|---|
| • Fenestration U-Factor | • Floor Insulation R-Value |
| • Fenestration SHGC | • Basement Wall Insulation R-Value |
| • Skylight U-Factor | • Slab Insulation R-Value and Depth |
| • Skylight SHGC | • Crawlspace Wall Insulation R-Value |
| • Ceiling Insulation R-Value | • Envelope Air Leakage (ACH50) |
| • Opaque Wall Sheathing R-Value | • Duct Leakage (CFM25/100 ft ²) |

- Duct Insulation R-Value
- High-Efficacy Lighting (%)
- Heat Pump Cooling SEER*
- Heat Pump Heating HSPF*
- Gas Furnace AFUE*
- Oil Furnace AFUE*
- Service Water Heating EF*
- Mechanical Ventilation Flow (CFM)

** Uses federal minimum efficiency requirements across all energy code editions.*

The earliest energy codes (1975 to 2003) included requirements for envelope U-factors based on heating degree days (base 65°F) from several graphs within the code. The specified wall U-factor requirements included both above and below grade walls as well as windows and doors. Energy code editions starting in 2004 became more granular in their prescriptive envelope requirements, specifying the U-factor for each envelope component

The 2004 IECC became the first energy code to specify prescriptive envelope components from a climate zone map containing 8 climate zones determined by heating degree days at base 65°F and cooling degree days at base 50°F. Climate zones are divided into moist (A), dry (B), and marine (C) regions. However, not all the moisture regimes apply to all climate zones in the United States, and some zones have no moisture designations at all (zones 7 and 8 in the United States). The IECC further defines a warm-humid region in the southeastern United States. This region is defined by humidity levels, whereas the moist (A) regime is more closely associated with rainfall. The warm-humid distinction affects only whether basement insulation is required in climate zone 3. All energy code editions since 2004 IECC have used the same prescriptive R-Value and U-factor tables for prescriptive compliance based on climate zone with improving levels of efficiency. The 2015 IECC added tropical zone requirements for locations in the tropical zone with elevation below 2,400 ft above sea level.

The 2021 IECC incorporated several climate zone changes introduced by the 2013 edition of ASHRAE Standard 169, Climatic Data for Building Design Standards (ASHRAE 2013). ASHRAE 169-2013 redefined climate zones and moisture regimes based on a more recent period of weather data. As a result, a number of U.S. counties were reassigned to different zones/regimes, and a new, extremely hot climate zone 0, which does not occur in the United States, was added. Approximately 400 U. S. counties out of more than 3,000 were reassigned, most to warmer climate zones (Athalye et al. 2016). The 2021 IECC aligned the climate zone map with that of ASHRAE 90.1, ASHRAE 90.2, and the International Green Construction Code (IgCC). Standard 169-2013 includes nine thermal zones and three moisture regimes.

Alignment of Energy Code Provisions

Given the growth and expansion of regulated efficiency measures in residential energy code editions, it was necessary to extract and specify all building component requirements from the older code editions to match the building component requirements of the latest energy codes. The following sections describe the processes to align the earlier energy codes with the later energy codes by component type. As mentioned earlier in the methodology, all energy code editions were analyzed as if homes were being built today, to the requirements of each code.

Envelope. Prior to the 2004 IECC, energy codes only specified the U-factors of the major envelope components of the envelope (above grade walls, ceilings, floors, slab on grade,

basement walls and crawlspace walls). Prior to 1992 MEC, wall U-factors included above and below grade walls. Since windows and doors were included as part of the wall U-factors, any combination of realistic wall insulation R-values as well as window and door U-factors could be designed to meet the overall wall U-factor. This required the use of the PNNL prototype surface areas to extract and isolate the individual wall components and calculate their efficiency levels to meet the energy code edition required wall U-factor.

For the purpose of separating the efficiency requirements of the opaque and non-opaque wall components, the opaque wall (above and below grade) insulation R-values were assumed based on market standards at the time of the energy code edition. The wall insulation R-values were assumed based on climate zone and the required wall U-factors. Once the wall insulation R-values were determined, the window and door U-factors were calculated using the PNNL prototype surface areas such that the overall wall met the required U-factor. Minor adjustments to the wall insulation R-values were necessary in order to produce realistic window and door U-factors that were indicative of the energy code year.

Once the opaque wall insulation R-values and U-factors for the above grade and below grade walls as well as the window and door U-factors of the early energy codes were calculated and verified to be reasonable, they could be aligned and directly compared with the same components in modern energy codes. The envelope R-values and U-factors were directly input into the residential simulation infrastructure for the parametric analysis of all energy code editions.

Heating, ventilating and air conditioning (HVAC) and service hot water (SHW). As stated earlier, NAECA sets federal energy efficiency standards for HVAC and SHW systems that cannot be pre-empted by national, state or local energy codes. With the assessment of the energy code editions as if they were adopted today and HVAC and SHW equipment efficiency being mandated by federal law, the current federal minimum HVAC and SHW efficiencies were simulated for all energy code editions. All energy codes were modeled with prototype buildings containing 80 AFUE gas furnaces, 78 AFUE oil furnaces, 8.2 HSPF/14 SEER heat pumps and 13 SEER air conditioners.

Air leakage and duct tightness. Prior to the 2009 IECC, the energy codes specified various prescriptive strategies for air sealing the building thermal envelope and the duct system. These energy codes indicated the elements of the thermal envelope or duct systems that needed to be sealed. However, there was not any requirement to test and verify the envelope or duct tightness. The 2009 IECC was the first residential energy code to require a performance test to measure the building envelope tightness with a blower door test or prove the tightness by a visual inspection. The 2009 IECC also added a requirement for duct tightness testing with limits based on phase of construction (rough-in or post construction). For the reconstruction of the residential energy code graph, the building thermal envelope air leakage and duct system air leakage requirements specified in each code were used for the 2009 IECC and all later energy codes.

For energy codes prior to 2009 IECC without envelope tightness requirements, the building thermal envelope tightness was assumed to be 8 ACH50 (air changes per hour at 50 Pa). The duct system tightness for earlier code editions was assumed to be 18.75 CFM25/100 ft² of shell area. These two leakage values were set for the 2006 IECC analysis based on assumptions in the *Cost Effectiveness Analysis of the 2009 and 2012 IECC Residential Provisions – Technical Support Document* (Mendon, Lucas, and Goel 2013). Given that no air leakage testing was

required in all prior energy code editions, no assumption was made for improving air sealing techniques.

High efficacy lighting and ventilation. Starting with the 2009 IECC, a high efficacy lighting requirement was added that initially set the minimum percentage of high-efficacy lamps installed in permanent lighting fixtures at 50%. High efficacy lamps required a minimum of 65 lumens per Watt. The remained light fixtures were assumed to contain incandescent lamps (efficacy of 15 lumens per Watt). Later energy codes increased the minimum percentage of high efficacy lamps up to 100% by the 2021 IECC. Energy code editions prior to the 2009 IECC were simulated with 100% incandescent lamps in the prototype home thus lighting efficiency gains were only confirmed in energy codes after the 2009 IECC.

The 2012 IECC added a provision that mechanical ventilation volumetric flow in cubic feet per minute (CFM) must meet the requirements of the International Residential Code (IRC) or the International Mechanical Code (IMC). Volumetric flow was determined based on size of the home and number of bedrooms. The ventilation could be provided by any means such as exhaust only, supply only, balanced system or any approved means of ventilation. In addition, mechanical ventilation fans were required to meet the fan efficacy requirements based on fan type. For the 2012 IECC and later energy codes, prototype models were simulated with exhaust only ventilation at 60 cfm for single family and 45 cfm for multifamily dwelling units. Fan efficacies met the requirements of the energy code editions. Prototype models for energy codes prior to the 2012 IECC were simulated without mechanical ventilation.

2021 IECC. As the latest published energy code, the 2021 IECC added new requirements that were not part of any earlier energy codes. The first new requirement mandated the installation of heat recovery ventilators (HRV) as part of the mechanical ventilation systems for residential buildings in climate zones 7 and 8. The second new requirement authorized the selection of an additional efficiency option meant to improve overall building efficiency by approximately 5%. There are five additional efficiency options for envelope efficiency, HVAC efficiency, SHW efficiency, envelope tightness and duct system tightness. The prescriptive compliance path requires the selection of at least one additional efficiency option. For the 2021 IECC, the prototype mechanical ventilation systems in climate zones 7 and 8 included the HRV as required. The additional efficiency option modeled for the 2021 IECC was for SHW efficiency utilizing a heat pump water heater with a 2.0 Energy Factor (EF). No earlier energy code editions included HRVs nor additional efficiency options in the simulations.

Simulation of Energy Codes

Once the building component requirements for all energy code editions were aligned, verified, and organized, each code year was simulated using the PNNL prototype models for the 18 representative cities across every climate zone, moisture regime and humidity designation. The national level results of the simulations produced energy use indices (EUI) of the total energy in kBtu/ft². The EUIs were aggregated down to a single national value that represents the weighted total energy based on four foundation types, four system types and two building types over all climate zones. The PNNL prototype weights were used from the 2021 IECC Determination analysis (Salcido et al. 2021). Using the weighted average EUI for each energy code edition, the updated residential energy code graph was reconstructed to show the progression in energy efficiency by quantitative analysis.

Results

Residential Energy Code Graph

The reconstructed residential energy code graph is shown in Figure 2 below. Each horizontal line of the code reflects the percent reduction in energy use of the energy code edition relative to the baseline ASHRAE 90-1975 energy code. The bubbles in the graph show the improvement for each jump in efficiency based on the prior energy code edition. There are two energy code editions that rollback efficiency. The 1983 MEC had slightly relaxed window U-factors that shows a half percentage decrease in energy efficiency that lasted until the 1992 MEC. The 2006 had slightly lower wall insulation requirements for climate zones 3 – 6 (R-15 in 2015 and R-13 in 2006) which reduced efficiency by 1.2%. Overall, there has been a general increase in efficiency since 1975 which cumulatively results in 45% efficiency improvement by 2021 IECC.

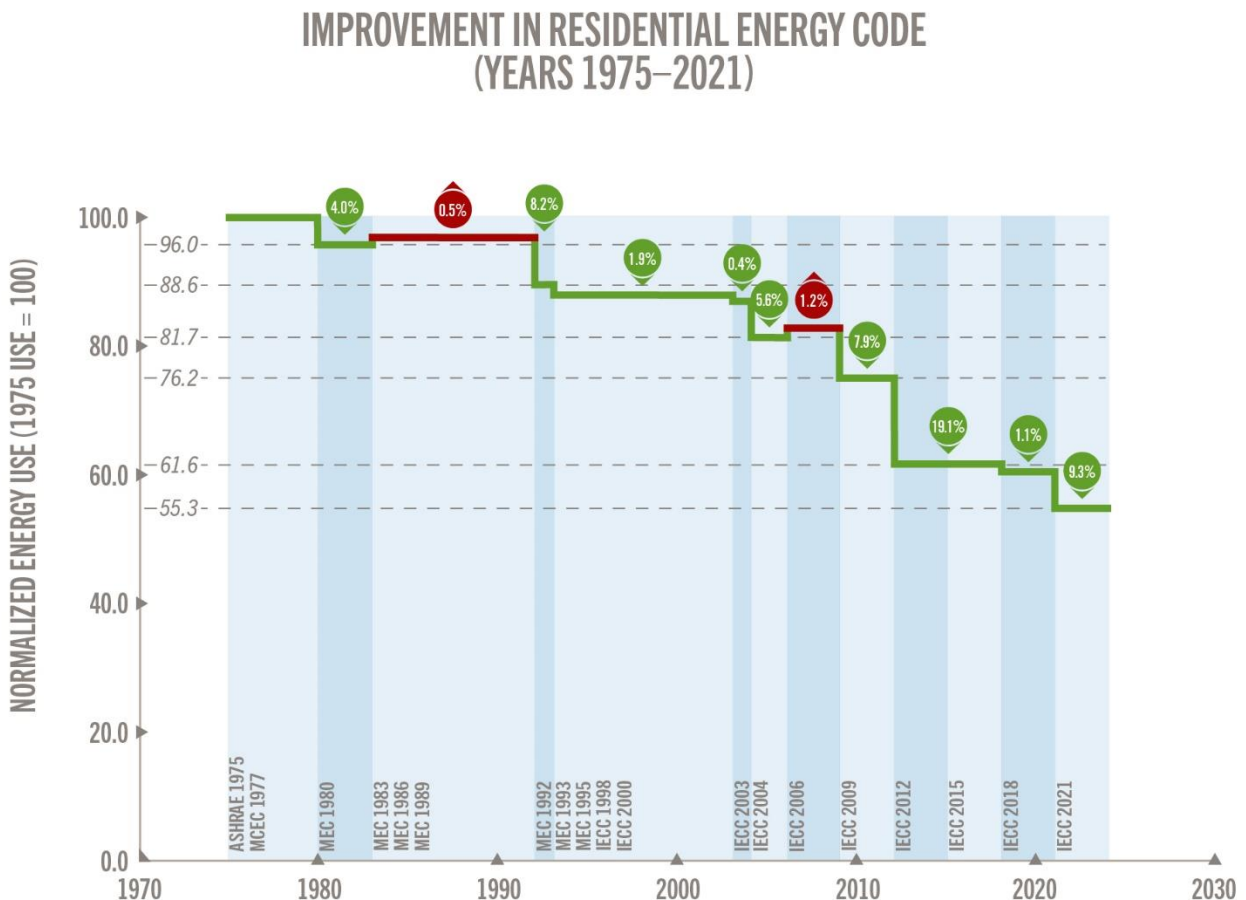


Figure 2. Residential Energy Code Graph, 1975 - 2021. Horizontal lines show energy use as a percentage of ASHRAE 90-1975 energy use. Source: PNNL 2021.

Comparing Graphs

Figure 3 overlays the energy code efficiency levels from the updated residential energy code graph with the efficiency levels from the original residential energy code graph. The green line represents the updated efficiency levels while the red line represents the original levels. Figure 3 emphasizes the differences in the energy code comparative efficiency levels of the original residential energy code graph with the reconstructed version. The green line representing the original graph underestimated the efficiency gains of the early energy code editions. The red line of the updated residential energy code graph shows a combined 10% improvement in energy efficiency in the 1992 and 1993 MEC that was not fully accounted for in the original residential code graph. The original code graph missed efficiency improvements in the 2003 and 2004 IECC as well. Starting with the 2006 IECC, the original graph used the same, consistent methodology as the reconstructed graph and the two lines are parallel. The reconstructed residential code graph shows the 2021 IECC approximately 3.5% more efficient than the original energy code graph.

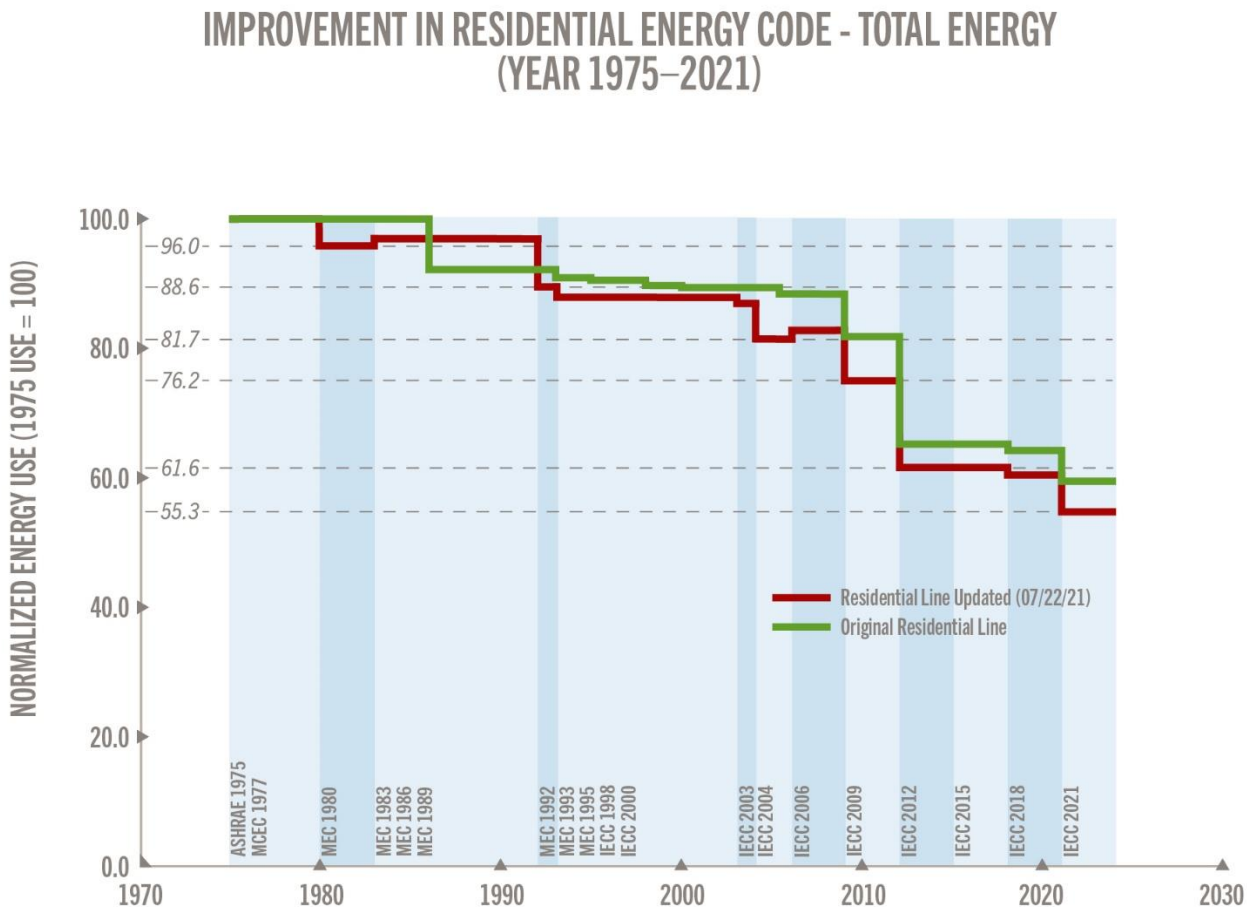


Figure 3. Comparison of original residential energy code graph to the updated energy code graph. 1975–2021. Source: PNNL 2022.

Energy Targets Graph

The purpose of the residential energy code graph is to show the progression of efficiency improvements in energy code editions as well as assist in establishing future efficiency goals. The residential energy code graph illustrates that energy codes starting from the 2021 IECC will need to improve drastically in nine years to reach net zero energy by 2030. In Figure 4, a couple of lines were added to the graph representing the efficiency level of a prototype home meeting the Passive House 2021 prescriptive requirements. The second added line is the residential solar potential line representing the rooftop solar power generation capability of newly constructed residential buildings in the U.S. (Franconi et al. 2022). Since net zero energy homes will require renewable energy generation, the path to net zero energy highlights the improvements in design efficiency needed to reach the residential solar capacity line. In order to reach net zero energy, the graph highlights the levels of efficiency improvements required in the next three code cycles (2024, 2027 and 2030 IECC) to reach the solar potential line. To give some perspective, since 1975, energy codes have improved 45% in 46 years. To reach net zero energy in nine years, energy code efficiency will need to improve by 27%. This correlates to an efficiency improvement at roughly three times the pace of the past energy codes.

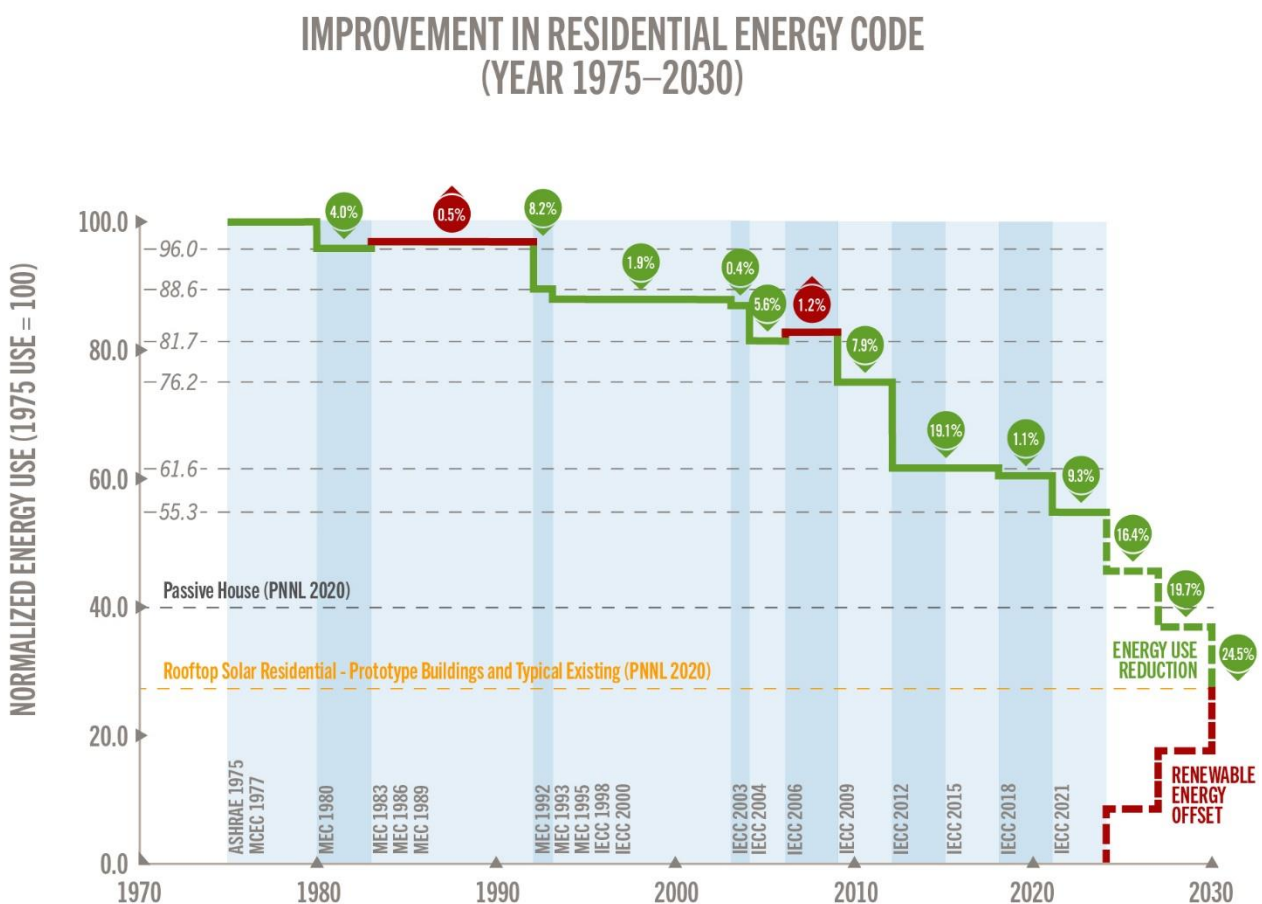


Figure 4. Residential energy code graph showing glide path to net zero energy by 2030. Source: PNNL 2022.

References

- 42 USC 6833. Chapter 42, U.S. Code, Section 6833. Available at <http://www.gpo.gov/fdsys/pkg/USCODE-2011-title42/pdf/USCODE-2011-title42-chap81-subchapII.pdf>.
- ASHRAE 1975. ANSI/ASHRAE Standard 90-1975. *Energy Conservation in New Building Design*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, Georgia.
- ASHRAE 1980. ANSI/ASHRAE Standard 90A-1980. *Energy Conservation in New Building Design*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, Georgia.
- ASHRAE 2013. ANSI/ASHRAE Standard 169-2013. *Climatic Data for Building Design Standards*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, Georgia.
- Athalye, A, ZT Taylor, and B. Liu. 2016. 2015 IECC: Impact of ASHRAE Standard 169-2013 on Building Energy Codes and Energy Efficiency. ASHRAE/IBPSA-USA Bldg Simulation Conf, 2016.
- BECP – Building Energy Codes Program. Department of Energy. *Prototype Building Models*. 2022. Washington, D.C. <https://www.energycodes.gov/prototype-building-models>
- Census – U.S. Census. 2010. *Characteristics of New Housing*. U.S. Census Bureau, Washington, D.C. Available at <http://www.census.gov/construction/chars/completed.html>
- CFR – Code of Federal Regulations. 2022. *Part 430 – Energy Conservation Program for Consumer Products*. Washington, D.C. <https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-430#sp10.3.430.c>
- DOE – U.S. Department of Energy. 2020. EnergyPlus Energy Simulation Software, Version 9.4. U.S. Department of Energy, Washington, D.C. [Available at https://energyplus.net/downloads](https://energyplus.net/downloads)
- EERE – Energy Efficiency & Renewable Energy. 2022. *Appliance & Equipment Standards – History and Impacts*. Washington, D.C. <https://www.energy.gov/eere/buildings/history-and-impacts>
- Franconi, Ellen, Jeremy Lerond, Chitra Nambiar, Dongsu Kim, David Winiarski, and Michael Rosenberg. 2022. *Filling the Efficiency Gap to Achieve Zero Energy Buildings with Energy Codes*. PNNL-30547. Pacific Northwest National Laboratory.
- ICC 1998 – International Code Council. 1998. *1998 International Energy Conservation Code*. Washington, D.C.
- ICC 2000 – International Code Council. 2000. *2000 International Energy Conservation Code*. Washington, D.C.

ICC 2003 – International Code Council. 2003. *2003 International Energy Conservation Code*. Washington, D.C.

ICC 2004 – International Code Council. 2004. *2004 International Energy Conservation Code Supplement Edition*. Washington, D.C.

ICC 2006 – International Code Council. 2006. *2006 International Energy Conservation Code*. Washington, D.C.

ICC 2009 – International Code Council. 2009. *2009 International Energy Conservation Code*. Washington, D.C.

ICC 2012 – International Code Council. 2012. *2012 International Energy Conservation Code*. Washington, D.C.

ICC 2015 – International Code Council. 2015. *2015 International Energy Conservation Code*. Washington, D.C.

ICC 2018 – International Code Council. 2018. *2018 International Energy Conservation Code*. Washington, D.C.

ICC 2021 – International Code Council. 2021. *2021 International Energy Conservation Code*. Washington, D.C.

Livingston OV, DB Elliott, PC Cole, and R Bartlett. 2014. *Building Energy Codes Program: National Benefits Assessment, 1992-2040*. PNNL-22610, Rev 1, Pacific Northwest National Laboratory, Richland, Washington. Available at https://www.energycodes.gov/sites/default/files/2021-07/BenefitsReport_Final_March20142.pdf.

MCEC 1977 – *Model Code for Energy Conservation in New Building Construction*. 1977. Council of American Building Officials. Falls Church, VA.

MEC 1983 – Model Energy Code. 1983. Council of American Building Officials. Falls Church, VA.

MEC 1986 – Model Energy Code. 1986. Council of American Building Officials. Falls Church, VA.

MEC 1989 – Model Energy Code. 1989. Council of American Building Officials. Falls Church, VA.

MEC 1992 – Model Energy Code. 1992. Council of American Building Officials. Falls Church, VA.

MEC 1993 – Model Energy Code. 1993. Council of American Building Officials. Falls Church, VA.

MEC 1995 – Model Energy Code. 1995. Council of American Building Officials. Falls Church, VA.

Mendon VV, RG Lucas, and SG Goel. 2013. *Cost-Effectiveness Analysis of the 2009 and 2012 IECC Residential Provisions – Technical Support Document*. Pacific Northwest National Laboratory, Richland, Washington. Available at https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22068.pdf.

Mendon VV and ZT Taylor. 2014. *Development of Residential Prototype Building Models and Analysis System for Large-Scale Energy Efficiency Studies Using EnergyPlus*. 2014 ASHRAE/IBPSA-USA Building Simulation Conference, Atlanta, Georgia.

Mendon VV, ZT Taylor, SU Rao, and YL Xie. 2015. *2015 IECC: Energy Savings Analysis*. Pacific Northwest National Laboratory, Richland, Washington. Available at https://www.energycodes.gov/sites/default/files/documents/2015_IECC_FinalDeterminationAnalysis.pdf

NAECA – National Appliance Energy Conservation Act. 1987. U.S. 100th Congress. Washington, D.C. <https://www.govinfo.gov/content/pkg/STATUTE-101/pdf/STATUTE-101-Pg103.pdf>

NAHB – National Association of Home Builders. 2009. *Builder Practices Reports*. National Association of Home Builders, Upper Marlboro, Maryland. Available at http://www.homeinnovation.com/trends_and_reports/data/new_construction

RECS – Residential Energy Consumption Survey. 2013. *2009 RECS Survey Data*. U.S. Energy Information Administration. Washington D.C. Available at <https://www.eia.gov/consumption/residential/data/2009/>

Salcido V. Robert, Y Chen, Y Xie and ZT Taylor. 2021. *Preliminary Energy Savings Analysis: 2021 IECC for Residential Buildings*. Pacific Northwest National Laboratory, Richland, Washington. April 2021. https://www.energycodes.gov/sites/default/files/2021-07/ColoradoResidentialCostEffectiveness_2021_0.pdf

Taylor ZT, VV Mendon, and N Fernandez. 2015. *Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes*. Pacific Northwest National Laboratory, Richland, Washington. Available at https://www.energycodes.gov/sites/default/files/documents/residential_methodology_2015.pdf

Thornton BA, MI Rosenberg, EE Richman, W Wang, Y Xie, J Zhang, and H Cho, et al. 2011. *Achieving the 30% Goal: Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010*. PNNL-20405. Pacific Northwest National Laboratory, Richland, Washington. Available at https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20405.pdf.