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Demand Response in Residential Energy Code

Technical Brief

September 2021

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U.S. DEPARTMENT OF ENERGY
Prepared for the U.S. Department of Energy
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Pacific Northwest National Laboratory
Richland, Washington 99354

Preamble

The U.S. Department of Energy (DOE) and Pacific Northwest National Laboratory (PNNL) are developing a series of technical briefs supporting national, state, and local initiatives to update and advance building energy codes. These technical briefs represent specific technologies, measures, or practices that can be incorporated as module-based "plug-ins" via the national model energy codes, such as the International Energy Conservation Code (IECC) or ASHRAE Standard 90.1, or can be adopted directly by state and local governments pursuing advanced energy savings and greenhouse gas emissions reductions. The collection of briefs is part of a larger effort to provide technical assistance supporting states and local governments and to help them realize their policy goals.

This technical brief provides requirements for demand-responsive thermostats and water heaters that could be incorporated into model residential energy codes. It provides background on the benefits of these devices, impacts on the cost of construction, and model code language that can be plugged into the IECC or adapted into other energy codes.

Additional assistance may be available from DOE and PNNL to support states and local governments who are interested in adding demand response and other "stretch" provisions to their building codes. Assistance includes technical guidance, customized analysis of expected impacts (e.g., based on state-specific building stock, climate considerations, or utility prices), and further tailored code language to overlay state building codes or other standards. DOE provides this assistance in response to the Energy Conservation and Production Act, which directs the Secretary of Energy to provide technical assistance "to support implementation of state residential and commercial building energy efficiency codes" (42 USC 6833). PNNL supports this mission by evaluating concepts for future code updates, conducting technical reviews and analysis of potential code changes, and assisting states and local jurisdictions who strive to adopt, comply with, and enforce energy codes. This helps assure successful implementation of building energy codes, as well as a range of advanced technologies and construction practices, and encourages building standards that are proven to be practical, affordable, and efficient.

DOE Building Energy Codes Program

DOE supports the advancement of building energy codes. Modern building codes and standards offer cost-effective solutions, contributing to lower utility bills for homes and businesses and helping mitigate the impacts of climate change. Learn more at energycodes.gov.

Executive Summary

As buildings account for over 70% of U.S. electricity use, effectively managing their loads can greatly facilitate the transition towards a clean, reliable grid. Grid-interactive efficient buildings (GEBs) combine efficiency and demand flexibility with smart technologies and communication to provide occupant comfort and productivity while serving the grid as a distributed energy resource (DER). In turn, GEBs can play a key role in ensuring access to an affordable, reliable, sustainable and modern U.S. electric power system. Their national adoption could provide $100-200 billion in U.S. electric power system cost savings over the next two decades. The associated reduction in CO_2 emissions is estimated at 6% per year by 2030.[1]

Building codes represent standard design practice in the construction industry and continually evolve to include advanced technologies and innovative practices. Historically, national model energy codes establish minimum efficiency requirements for new construction.[2] Expanding codes to support GEB capabilities is a pivotal step towards realizing demand flexibility in support of a clean grid by addressing capabilities to improve interoperability between smart building systems, the grid, and renewable energy resources. Realizing GEBs requires buildings with automated demand response (DR) capabilities that enable standardized control, subject to explicit consumer consent, of energy smart appliances on an electricity network. This is achieved through communication between appliances and a controlling entity that is in communication with the consumer participants.

Energy codes can support DR communication standardization and advance the deployment of flexible load technologies such as smart home energy management systems, energy storage, behind-the-meter generation, and electric vehicles (EVs). Incorporating automated DR capabilities in energy codes provides many benefits to consumers and society. Specifically, it matches intermittent renewable energy sources to building electric loads, decreases peak load on the electric grid, allows buildings to respond to utility price signals, supports electrical network reliability and market growth of products and processes aligned with clean economic growth.

The incorporation of DR into the model residential energy codes was considered for the 2021 International Energy Conservation Code (IECC) code development cycle. The approved DR measures were later removed in response to appeals.[3] This technical brief updates the proposed DR components such that they can be considered by states and local governments for direct incorporation into their codes, as well as for future IECC energy code development. The proposal refinements are intended to support consistency in approach and provide a degree of certainty for building owners, designers, contractors, manufacturers, and building and fire safety professionals. The scope of this technical brief includes two strategies for DR in

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[1] DOE (U.S. Department of Energy). 2021. *A National Roadmap for Grid-Interactive Efficient Buildings*. Washington DC. Accessed on June 9, 2021 at https://gebroadmap.lbl.gov/

[2] While advanced codes can be considered model codes, in this document, the term "model energy code" refers to the current published version of the International Energy Conservation Code-Residential and ASHRAE Standard 90.1, as those documents are referenced by the Energy Conservation and Production Act, as modified by the Energy Policy Act of 1992, as the minimum requirements for states adopting energy codes. https://www.govinfo.gov/content/pkg/USCODE-2011-title42/pdf/USCODE-2011-title42-chap81-subchapII.pdf.

[3] https://www.iccsafe.org/building-safety-journal/bsj-technical/code-development-a-process-of-evolution-and-improvement/

residential buildings: 1) smart thermostats with demand-responsive control and 2) electric water heating incorporating demand-responsive controls and communication.

Contents

1.0 Demand Response in Residential Energy Codes

A rapid transition of the U.S. power system is underway that is reshaping the operation and performance of the electric grid. Persistent growth in renewable energy resources—driven by declining costs, improved performance, and decarbonization policies[1]—is starting to noticeably impact the electricity system.[2] As buildings account for over 70% of U.S. electricity use, effectively managing their loads can greatly facilitate this transition towards a clean, reliable grid. Grid-interactive efficient buildings (GEBs) combine efficiency and demand flexibility with smart technologies and communication to provide occupant comfort and productivity while serving the grid as a distributed energy resource (DER). In turn, GEBs can play a key role in ensuring access to an affordable, reliable, sustainable and modern U.S. electric power system. Their national adoption could provide $100-200 billion in U.S. electric power system cost savings over the next two decades. The associated reduction in CO_2 emissions is estimated at 6% per year by 2030. DOE's national GEB vision is to triple energy efficiency (EE) and demand flexibility[3] (DF) of the buildings sector by 2030 relative to 2020 levels.[4]

Building codes represent standard design practice in the construction industry and continually evolve to include advanced technologies and innovative practices. Historically, national model energy codes establish minimum efficiency requirements for new construction.[5] Expanding codes to support GEB capabilities is a pivotal step towards realizing DF in support of a clean grid by addressing capabilities to improve interoperability between smart building systems, the grid, and renewable energy resources. Realizing GEBs requires buildings with automated demand response (DR) capabilities that enable standardized control, subject to explicit consumer consent, of energy smart appliances on an electricity network. This is achieved through communication between appliances and a controlling entity that is in communication with the consumer participants. Energy codes can support DR communication standardization and advance the deployment of flexible load technologies such as smart home energy management systems, energy storage, behind-the-meter generation, and electric vehicles (EVs).

Incorporating GEB considerations in energy codes can benefit all consumers by providing the following impacts:

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[1] Thirty-seven states representing 80% of the U.S. population have enacted renewable portfolio standards or goals.

[2] GridWise Architecture Council. 2015. *GridWise Transactive Energy Framework Version 1.0*. PNNL-22946, Ver 1.0. Accessed on September 27, 2018 at https://www.gridwiseac.org/pdfs/te_framework_report_pnnl-22946.pdf.

[3] Capability provided by DERs to reduce, shed, shift, modulate or generate electricity; energy flexibility and load flexibility are often used interchangeably with demand flexibility.

[4] DOE (U.S. Department of Energy). 2021. *A National Roadmap for Grid-Interactive Efficient Buildings*. Washington DC. Accessed on June 9, 2021 at https://gebroadmap.lbl.gov/

[5] While advanced codes can be considered model codes, in this document, the term "model energy code" refers to the current published version of the International Energy Conservation Code-Residential and ASHRAE Standard 90.1, as those documents are referenced by the Energy Conservation and Production Act, as modified by the Energy Policy Act of 1992, as the minimum requirements for states adopting energy codes. https://www.govinfo.gov/content/pkg/USCODE-2011-title42/pdf/USCODE-2011-title42-chap81-subchapII.pdf.

- Match the short-term availability of intermittent renewable energy sources, such as wind and solar, with building electric loads
- Decrease the peak load on the electrical transmission and distribution networks to alleviate the need for network upgrades to handle new electric loads
- Allow buildings to respond to utility price signals and provide grid services that control network characteristics, such as line frequency, system inertia and network voltage, and help prevent network and generation outages
- Allow electricity suppliers to offset their short-term market imbalance by controlling flexible load on the network
- Provide a market signal to companies and investors to develop products and processes that align buildings with the transition towards clean economic growth.

The incorporation of DR into the model residential energy codes was considered for the 2021 International Energy Conservation Code (IECC) code development cycle. The approved DR measures were later removed in response to appeals.[1] DOE developed this technical brief to update the DR concept such that it can be considered by states and local governments for direct incorporation into their codes, as well as for future IECC energy code development. The DR requirements specified in this technical brief build upon the language considered for the 2021 IECC, as well as that contained in the New Buildings Institute's Building Decarbonization Code (NBI 2021). In addition to sample code language, this technical brief adds further information and analysis developed by Pacific Northwest National Laboratory (PNNL). These requirement refinements are intended to support consistency in approach and provide a degree of certainty for building owners, designers, contractors, manufacturers, and building and fire safety professionals.

The scope of this technical brief includes two strategies for DR in residential buildings:

- Smart thermostats with demand-responsive control
- Electric water heating incorporating demand-responsive controls and communication.

1.1 Smart Thermostats with DR Control

Thermostats have evolved over the many years since their first introduction for scheduling and control of heating, ventilation, and air conditioning (HVAC) equipment. The first programmable thermostat was released to the market in 1906 with additional features and functionality added over the ensuing decades (DOE 2016). The first digital programmable thermostats were introduced in the mid-1980s. In the 1990s and into the 2000s, thermostats continued to evolve with additional sophistication such as individual day scheduling, equipment control choices, and ancillary services such as humidification, dehumidification, and ventilation. Programmable thermostats were projected to reduce HVAC energy use by 30% (Pang et al. 2020). However, expected levels of energy savings from programmable thermostats were not achieved because of consumer frustration or apathy on the intricacies of programming the thermostat (DOE 2016). Savings projections were based on correct and optimal use of programming functionality.

In response to the usability issues of programmable thermostats, connected (smart) thermostats with improved interfaces and learning algorithms were brought into the market. Smart thermostats capitalized on advancement of data and communication technologies as well as

[1] https://www.iccsafe.org/building-safety-journal/bsj-technical/code-development-a-process-of-evolution-and-improvement/

simplifying the scheduling process (DOE 2016). Today's smart thermostat market is under 15 years old and has evolved quickly through rapid growth and innovation. The interaction of smart thermostats with a smart home can enhance security, comfort, and convenience. The next generation of smart thermostats will communicate with the grid for demand-responsive control.

Smart thermostats with DR control for heating and cooling systems are designed to communicate with the utility grid and adjust heating and cooling setpoints to preprogramed levels during times of high demand or high energy prices. Thermostats with DR control allow grid operators to reduce residential heating and cooling demand on the grid and keep expensive and high-pollution-generating systems offline.

California's Title 24 Residential Code stipulates that heating, cooling, and ventilation systems have thermostatic control with the ability to:[1]

1. Automatically adjust temperature setpoints by +/- 4° Fahrenheit from a central point
2. Return the system to its original setpoint after the event
3. Provide an adjustable rate of change
4. Provide three modes of operation: automated demand shed, manual, and disabled.

Residential smart thermostat requirements described in the sample code language do not include all the controls of a Title 24 compliant thermostat, but a Title 24 compliant thermostat meets the residential DR control requirements prescribed in this technical brief.

1.2 Water Heating with DR Control

Water heating accounts for 19% of the annual energy consumption in the U.S. residential building stock.[2] Electric storage water heaters provide an excellent opportunity for load shedding/shifting due to the energy storage capacity of the hot water. Heat pump water heaters (HPWHs) have the potential to reduce the annual energy consumption of residential water heating by 60% when compared to electric resistance water heating (Mayhorn et al. 2015). HPWHs can be loaded (increase in water temperature) or turned down or off to take advantage of lower utility pricing and lower hourly carbon emission rates during periods of low demand. A study conducted by PNNL developed typical load shapes of HPWHs in the Pacific Northwest (Hunt et al. 2021). The HPWH load shapes can help utilities and DR aggregators establish baseline behavior and improve load forecasting algorithms.

Water heaters require a minimum storage capacity of 20 gallons to provide sufficient energy storage for adequate load flexibility. Four potential strategies for water heating demand-responsive control with various levels of sophistication and regulation are described below. The grid-connected strategy allows full DF in response to a real-time price signal or demand on the grid.

- Manual Control – manual adjustment of appliance loads
- On/Off Control – controlled on a fixed price time-of-use schedule
- Load Up/Shed – load up water heater over setpoint temperature during demand trough and shed on peak demand

[1] https://energycodeace.com/site/custom/public/reference-ace-2016/index.html#!Documents/ja52requiredfunctionalresources.htm
[2] https://www.eia.gov/todayinenergy/detail.php?id=37433

- Grid Connected – water heater control based on future forecasting of demand from utility.

Water heaters with demand-responsive control must be supplied with a communication link that meets the Consumer Technology Association Standard 2045 (CTA-2045) for communication with the electric grid or DR signal providers.[1] The CTA-2045 communication protocol stipulates controls to allow an HPWH to overload the tank temperature and increase storage capacity. The communication interface is analogous in concept to a USB socket on computers and other electronic equipment, but this socket is specifically designed for appliances.[2] CTA-2045 is the industry standard for demand-responsive control in water heaters but allows other communication protocols approved by a building official or other authority having jurisdiction.

1.3 Benefits of Demand Response

DR provides substantial benefits to the consumer, utilities, and society (Xing et al. 2018). Consumers can reduce energy consumption during peak demand, take advantage of time-of-use or real-time pricing, and lower electric utility bills. Utilities can reduce capital costs, reduce fuel consumption and operating costs, and increase productivity and profit margins while operating power plants at optimized speeds. Societal benefits include enhanced grid resilience and stability, lower carbon emissions, and higher penetration of renewable energy resources. It is difficult to place a value on the utility and consumer benefits of DR, but it appears to be a win-win situation for all. A more complete list of benefits is shown below.

Consumer Benefits

- Take advantage of time-of-use or real-time pricing
- Less rolling blackouts
- Reduced energy consumption during peak demand
- Reduced wholesale energy prices and prices paid by consumers
- Lower utility bills

Utility Benefits

- Reduced capital cost
- Reduced carbon emissions
- Reduced fuel consumption and operating costs
- Increased productivity and profit margins
- Operate power plants at optimized speeds
- Grid resilience and stability
- Enhanced voltage stability
- Balanced fluctuations in renewable energy generation

[1] https://www.techstreet.com/standards/cta-2045-a?product_id=2002822
[2] https://www.bpa.gov/EE/Technology/demand-response/Pages/CTA2045-DataShare.aspx

Societal Benefits

- Enhanced grid resilience and stability
- Reduced carbon emissions
- Higher penetrations of renewable energy resources

2.0 Economic Analysis

The costs associated with installing residential DR control strategies highlighted in this technical brief are discussed below. The installed costs for smart thermostats and electric water heaters with DR control are modest and depend on the design of the home.

The cost of a standard programmable thermostat required in the 2021 IECC ranges from $20 to $100 based on costs at local home improvement stores. A smart thermostat can range from $120 to $400 based on brand, model, and level of sophistication. The cost to install a programmable or smart thermostat ranges from $112 to $255, with the national average cost of $175.[1] Thus, the incremental cost of upgrading from a standard programmable thermostat to a smart thermostat with DR controls is anywhere between $100 and $200.

Electric resistance water heaters supplied with CTA-2045 communication have been manufactured but are not widely available. HPWHs have taken over the energy efficiency segment of the water heater market, and brands at local home improvement stores include the CTA-2045 communication ports. The average cost for a 50-gallon electric resistance heater is $400, while the average cost for a 50-gallon HPWH is $1,300 at local home improvement stores (Salcido et al. 2021). The incremental cost of $900 plus additional condensate removal equipment of $75 results in a total cost differential of $975. Therefore, for buildings already including HPWHs in the original design, the incremental increase in cost is $0. If the building specified an electric resistance water heater, the most straightforward way to implement the CTA-2045 communication for DR control is to switch to an HPWH with an incremental cost of $975.

While DR control functionality will reduce costs to utilities as well as electric costs to consumers, it is difficult to estimate or calculate the actual cost savings. DR will present cost-saving opportunities for buildings as more homeowners take advantage of time-of-use or real-time pricing controls as they become more widely available. Adding DR controls in model energy codes can help homeowners have the capability of participating in DR programs with alternative utility pricing structures whether they exist now or in the future. When DR requirements are part of the model energy code, it will not require homeowners or buildings to participate in any DR programs but will guarantee that residential buildings are capable of participating in DR programs.

[1] https://www.homeadvisor.com/cost/heating-and-cooling/install-a-thermostat/

3.0 Sample Code Language

This section contains model code language for any state or local government to overlay the 2021 IECC or that can be adapted to other existing residential energy codes.

3.1 Definitions

The following definition shall be added to Section R202 of the 2021 IECC residential energy code.

DEMAND-RESPONSIVE CONTROL. An automatic control that can receive and automatically respond to DR requests from a utility, electrical system operator, or third-party DR program provider.

3.2 Demand-Responsive Thermostats

The following DR requirements shall be placed in Section R403.1.1 of the 2021 IECC residential energy code or analogous location of other existing code.

R403.1.1 Programable thermostat. The thermostat controlling the primary heating or cooling system of the dwelling unit shall be capable of controlling the heating and cooling system on a daily schedule to maintain different temperature setpoints at different times of the day and different days of the week. This thermostat shall include the capability to set back or temporarily operate the system to maintain zone temperatures of not less than 55 °F (13 °C) to not greater than 85 °F (29 °C). The thermostat shall be programmed initially by the manufacturer with a heating temperature setpoint of not greater than 70 °F (21 °C) and a cooling temperature setpoint of not less than 78 °F (26 °C). The thermostat shall be provided with Demand-Responsive Control capable of increasing the cooling setpoint by no less than 4 °F (2.2 °C) and decreasing the heating setpoint by no less than 4 °F (2.2 °C) in response to a DR request.

1. All demand-responsive controls shall be either:
    a. A certified OpenADR 2.0a or OpenADR 2.0b Virtual End Node (VEN), as specified under Clause 11, Conformance, in the applicable OpenADR 2.0 Specification[1], or
    b. Certified by the manufacturer as being capable of responding to a DR signal from a certified OpenADR 2.0b Virtual End Node by automatically implementing the control functions requested by the Virtual End Node for the equipment it controls, or

[1] The Sample Code Language provided for OpenADR and the communication pathway requirements is based on language published in Title 24 2019 Energy Code and the 2020 Nonresidential Grid Integration CASE report accessed on September 22, 2021 at https://www.energy.ca.gov/2018publications/CEC-400-2018-020/CEC-400-2018-020-CMF.pdf and https://title24stakeholders.com/wp-content/uploads/2020/08/NR-Grid-Integration_Final-CASE-Report_Statewide-CASE-Team.pdf

c. Comply with IEC 62746-10-1, an international standard for the open automated DR system interface between the smart appliance, system, or energy management system and the controlling entity, such as a utility or service provider[1], or

d. Comply with the communication protocol required by a controlling entity, such as a utility or service provider, to participate in an automated DR program.

2. All demand-responsive controls shall be capable of communicating to the VEN using one or more of the following: Wi-Fi, ZigBee, BACnet, Ethernet, or hard-wiring any other bi-directional communication pathway.

3. When communications are disabled or unavailable, all demand-responsive controls shall continue to perform all other control functions provided by the control.

3.3 Demand-Responsive Water Heating

The following DR requirements shall be placed in Section R403.5.4 of the 2021 IECC residential energy code or analogous location of other existing code.

R403.5.4 Demand-responsive water heating. All electric storage water heaters with a storage tank capacity greater than 20 gallons (76 L) shall be provided with demand-responsive controls that comply with CTA-2045 or another demand-responsive control approved by the Authority Having Jurisdiction.

[1] IEC 62746-10-1(E) specifies a minimal data model and services for demand response (DR), pricing, and distributed energy resource (DER) communications. It specifies how to implement a two-way signaling system to facilitate information exchange between electricity service providers, aggregators, and end users. The DR signaling system is described in terms of servers (virtual top nodes or VTNs), which publish information to automated clients (virtual end nodes, or VENs), which in turn subscribe to the information. Note the OpenADR 2.0b Profile Specification is known as IEC 62746-10-1 ED1.

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