Common Demand Response Functions for Heating, Ventilating, and Air Conditioning (HVAC)

A Summary of Demand Response Functionality Discussed in the Industry to Date

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Technical Update, December 2017

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ACKNOWLEDGMENTS

The Electric Power Research Institute (EPRI) prepared this report.

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This report describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

Common Demand Response Functions for Heating, Ventilating, and Air Conditioning (HVAC): A Summary of Demand Response Functionality Discussed in the Industry to Date. EPRI, Palo Alto, CA: 2017. 3002011045.

ABSTRACT

This report serves as a comprehensive guide describing the utility-facing demand response (DR) functions related to residential heating, ventilating, and air-conditioning (HVAC) equipment. A common set of DR functions has been developed using both prior and on-going efforts in this technical area. The current capabilities of existing HVAC equipment have been assessed and mapped to the standardized DR functional requirements. Advanced DR capabilites that are currently under development, but not yet available, are also identified to the extent possible.

The goal of this document is to inform and unify electric utilities, manufacturers, and other stakeholders on residential HVAC DR capabilities that are of most value to utilities. The requirements can serve as a reference for equipment manufacturers, clearly defining the functionality to be achieve while allowing companies to innovate and optimize their product solutions. The guide also provides utilities with a reference for understanding HVAC equipment capabilities and terminology. It is intended that this document will be revised and updated as appropriate to best match the changing utility needs and equipment capabilities.

Keywords

AHRI Standard 1380
CTA-2045
Demand response
Heating, ventilating, and air conditioning (HVAC)
OpenADR
Smart thermostats

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1
INTRODUCTION

Background and Scope

Control of heating, ventilating, and air-conditioning (HVAC) equipment is a key component of utility demand response (DR) programs because of the size of the equipment's electric load and its presence in most homes in North America. When enrolled in DR programs, HVAC system operation is typically reduced during utility peak load periods by adjusting temperature setpoints or by shutting off the equipment for brief periods. While effective in reducing electric load, these approaches may compromise occupant comfort and cause high demand immediately after DR periods end.

Newer technologies like smart thermostats can overcome some of the limitations of conventional DR methods by utilizing adaptive controls, enabled by machine learning, to leverage human behavior patterns and equipment response time to deliver improved energy efficiency and demand response. More advanced HVAC systems with integration of controls between the outdoor unit, indoor unit, and thermostat incorporate additional functionality, such as fully variable-capacity control and Fault Detection and Diagnostics. However, there is untapped potential in utilizing these advanced systems for more customized strategies for achieving DR objectives. Although these advanced capabilities have been identified, HVAC manufacturers describe uncertainty or mixed feedback regarding which of these state-of-the-art DR functions provide greatest value to utilities. Thus, there is a keen need to understand the current capabilities of equipment and map them to standardized DR functional requirements to outline gaps and work with manufacturers to improve DR capability.

This project was conducted to develop a comprehensive guide describing the utility-facing demand response functions relevant to residential HVAC equipment. This document is designed to inform and unify utilities and manufacturers on DR capabilities that have been identified by the industry through either implementation in products to date or in discussions by industry stakeholders. The function definitions are designed to be generic and not reflect any specific implementation of a manufacturer or communication protocol. The benefit of making the functions generic is that it allows the industry to clearly see the core DR functionality provided by HVAC systems.

Prior Bodies of Work

The project developed a common set of functions for utility demand management using prior and ongoing efforts. The following sources were used to inform this document.

- CTA-2045
- OpenADR 2.0 A/B
- AHRI Standard 1380P
- California Title 24
- EPRI Device Specifications

- California Title 24-2016 (JA5)
- EnergyStar Requirements for Connected Thermostat Products
- EPRI Thermostat Data Specification

In addition to the DR functionality defined in the resources above, varying levels of DR and customer control capabilities are currently available from both conventional and advanced HVAC equipment in the market. Therefore, multiple residential HVAC equipment manufacturers were contacted to document clearly the capabilities of their respective equipment for demand response, particularly their advanced variable-capacity systems. As part of this effort, both online research and direct communications with manufacturers were utilized to gauge current equipment capability. The capabilities of existing equipment were then mapped to the common DR functions defined in this document.

Industry Impact

The results of this effort provide HVAC equipment manufacturers with a set of functional requirements that can serve as a reference for the DR functionality that their products can offer to provide value to utilities. This guide similarly provides utilities with a reference for understanding HVAC equipment capabilities and terminology. The intent is to harmonize current DR strategies and inform the development of additional features, future communications protocols, and utility programs for demand management. This guide should also facilitate conversation and development using a common set of ideas and nomenclature. The results of this work will serve as a living document to be shaped and revised as appropriate to best match changing utility needs and equipment capabilities. The results of this project serve as an initial step to advance the development of HVAC that can act as a flexible component of the Integrated Energy Network[1].

Utilities and equipment manufacturers are encouraged to utilize these functional descriptions to aid in the development of requirements for demand response resources. While it is always possible to independently craft new functions, or to design similar functions that work in slightly different ways, such effort does not bring the industry closer to the end goal of off-the-shelf interoperability and ease of system integration. Harmonization of the functionality can help reduce costs to both manufacturers and utilities by reducing the time required to identify and assess functionality on the market today.

It is important to note that these functional definitions are not meant to constrain the development of new ideas and methods but instead capture and recognize these innovations as they occur in the industry.

Report Organization and Language

This report provides a compiled summary of the function descriptions that this initiative has produced thus far. Each function is presented in the form of a proposal, which is the language used by the working group tasked with identifying each function. This reflects the fact that the

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[1] EPRI's Integrated Energy Network (IEN) pathway leads to a more interconnected and integrated energy system that provides customers with increased choice and control; the reliability, safety and affordability they expect; and the additional benefits of a cleaner, electrified environment. More information: http://integratedenergynetwork.com/

functions are not legal standards unless and until they are adopted by a standards development organization (SDO). Equally important is that many demand response functions do not define specific behavior at the device and instead make a request, allowing the device to customize its behavior to realize the request.

This report provides a summary of typical DR control configurations, including a high-level overview and clear definition of the control interfaces that are pertinent to this report. Device enrollment information and metadata reporting requirements are also defined. Furthermore, separate report chapters are used to define each distinct DR function, described in terms of its objective, expected outcome, necessary parameters for control and monitoring, and how the function relates to existing use cases. The proposed functions provide a set of requirements that allow manufacturers to develop innovative approaches to satisfy these outcomes.

This methodology is based on a successful, EPRI-led effort to facilitating an industry collaboration on common functionality in smart inverters. The work has led to industry consensus and recognition of the capabilities smart inverters can provide. Grid codes, standards bodies, manufacturers, and utilities all recognize this functionality, making the process of procuring and integrating these systems simpler than if functionality were to be defined independently.

Roadmap for Document / Ongoing Development

EPRI plans to continue to work with the industry to develop and capture key functionality offered by HVAC systems and other demand response-capable devices. In this first version, the team's goal was to identify existing functionality from current products on the market, standards groups, and communications protocols. In future years EPRI will endeavor to create working groups for industry stakeholders to discuss, refine, and expand the functionality described. The goal is for this document to capture current and future functionality for demand response systems in plain English to help inform manufacturers, standards organizations, utilities, and other industry stakeholders of the discussions in the industry so far. This is a living document that will be updated as necessary.

2 TYPICAL CONTROL CONFIGURATIONS

This document focuses on the functionality that demand response-enabled HVAC systems can provide at the control interface to the device. HVAC systems can provide a variety of functionality at different levels. Some HVAC systems consist of an integrated thermostat that collects requests from utilities and homeowners and then applies proprietary control algorithms to fulfil that request by controlling the compressor and system fans. Others are less sophisticated systems, wherein a thermostat receives a request from a utility or homeowner and simply changes the temperature setpoint. In this document, the focus is on the control interface: the functionality available to a utility or homeowner.

Though it is important to understand how each system fulfils requests received through the control interface, these interfaces are out of scope for this document because they often use proprietary control. Additionally, a utility's command is typically aligned with some grid service to be provided. Distribution system operators are not necessarily concerned with how a device responds to meet the request but care simply that the request is met. For example, it may not matter which of the two examples described above (integrated thermostat vs. less sophisticated system) are used, as long as both systems can provide the demand reduction when requested. Following this approach allows dispatchers not to worry about the specific make or model of a device and instead allows them to focus on the functionality. When a device is properly represented, it allows the dispatcher to focus on capabilities instead of the mechanics of every type of device on the market. This concept is called device abstraction. This is not to downplay the importance of understanding how individual devices function: a utility may likely study the responses from individual makes and models to understand these systems, study potential relationship issues such as customer comfort, validate that the systems are providing the expected response, and collect data for more accurate program design.

The control interface is often described as a physical port on the device but it may also be a wireless connection. An example of a physical interface is the CTA-2045 port on a water heater. An example of a wireless interface is the Wi-Fi connection to a thermostat. At the device interface, the messages are designed to be end-result oriented. They are either a direct request for action/information or inform the device of pricing data to motivate the owner to change behavior. These messages are accepted by the device and may be implemented in a variety of ways but the functionality at the device interface is the same because it focuses on the result.

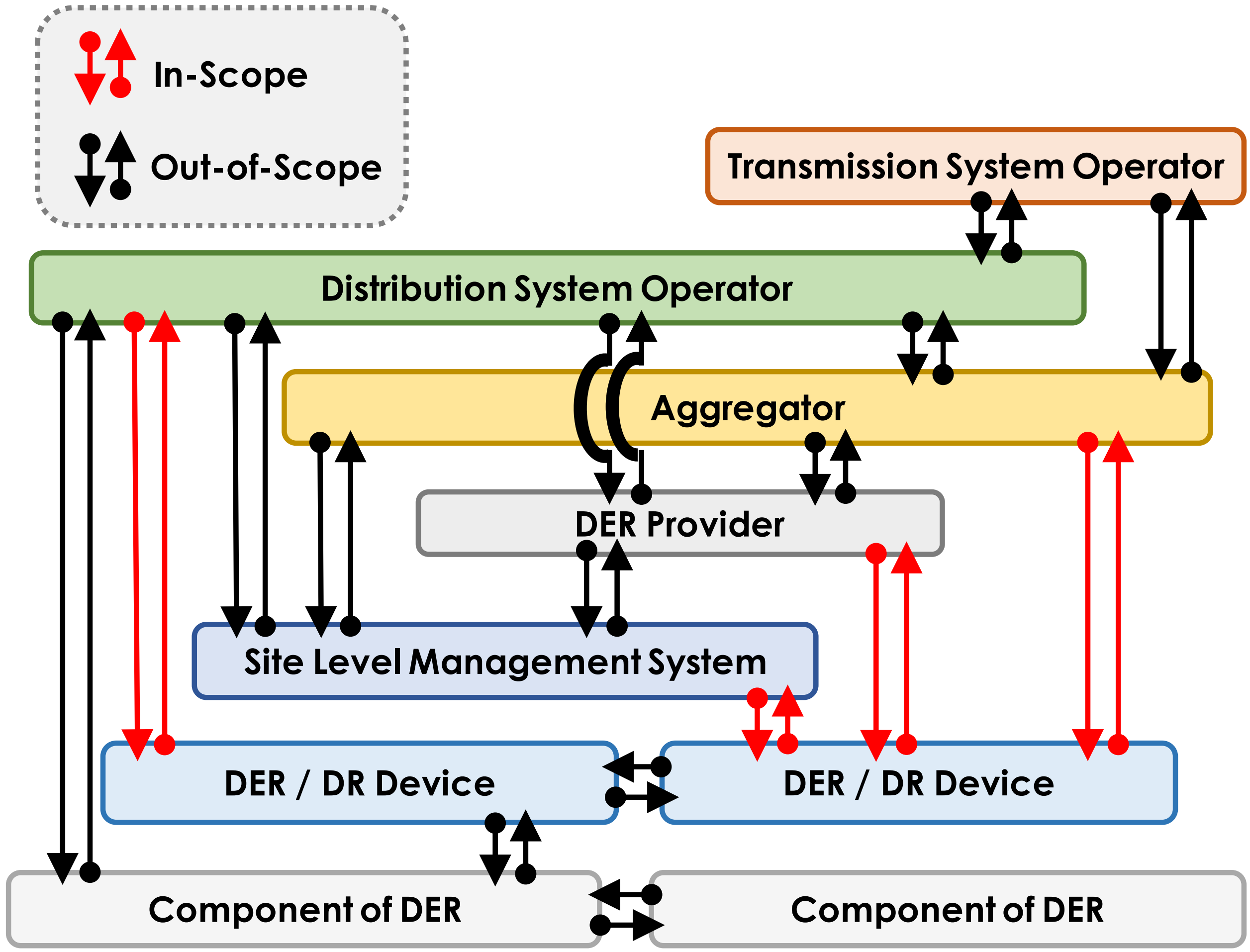

Figure 2-1
Interfaces within scope for this document

It helps to understand the overall control architecture in order to understand the positioning of the device interface. Figure 2-1 shows an overview of a control architecture. It is just an example and there are likely cases where other variants may exist, however, it captures the most common ones.

This document focuses on the device interface. These relationships are shown in Figure 2-1 by red arrows. The figure shows that the device interface is where an entity directly interacts with the device. Any relationship in which an entity is directly interfacing with an individual device is in scope. Functionality between controlling entities (for example, between a utility and an aggregator) and functionality within a device (for example, between a thermostat and a compressor) are out of scope.

Example Control Interfaces

There is debate in the industry on the definition and bounds of a demand response device. The most confusion comes from site-level management systems in which multiple demand response technologies are obscured behind a single site manager. However, there are also instances where HVAC systems have been separated into individual components. Site management systems are not included in this document; however, similar documents may be released in the future focusing on functionality available to these types of systems.

Below are some examples of control interfaces for HVAC systems to clarify the focus of this document.

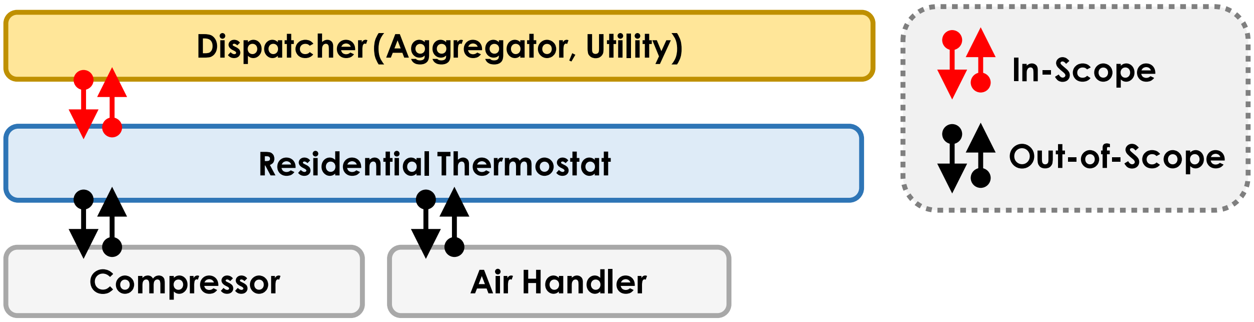

Figure 2-2
Example of a thermostat at the utility/aggregator interface

Figure 2-2 is an example of a residential thermostat using the traditional configuration in which the thermostat turns the compressor and the air handler on and off, depending on the customer's input via the thermostat's user interface. In this case, the interfaces between the thermostat, compressor, and air handler are out of scope. A dispatcher does not have direct access to the compressor or air handler in this case, so the functionality of these devices is obscured by the thermostat. Only the functionality of the thermostat is exposed to the dispatcher, so this functionality will be captured in this case.

Variable-speed HVAC systems, on the other hand, use a different method for controlling system components, as shown in Figure 2-3. Instead of using conventional 24 VAC signals driven primarily by thermostat control logic, variable-speed systems utilize proprietary communications to monitor overall system performance and coordinate the operation of system components. In this case, the conventional thermostat is replaced by a user interface with an integrated temperature sensor that feeds important information to the system controller, which is often located in the outdoor unit. The controller collects information from different system components and controls the HVAC system accordingly.

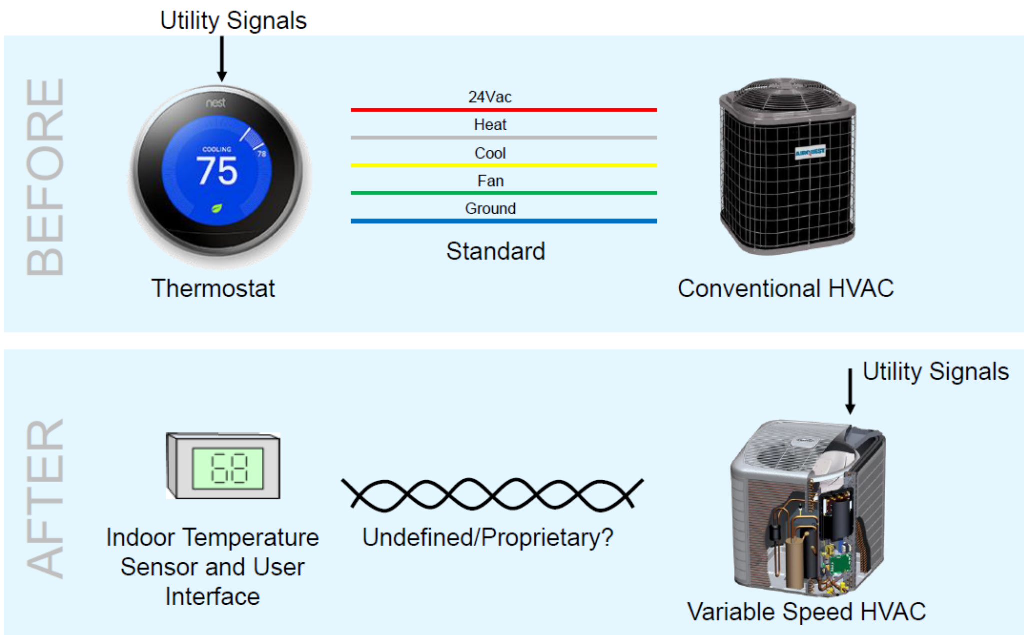

Figure 2-3
Thermostat-centric vs controller-centric HVAC

This difference in methodology impacts where a utility control signal is received in variable-speed systems, as shown in Figure 2-4. Since the central controller is the only control interface exposed to the DR event dispatcher, only the functionality at this interface is captured in this report.

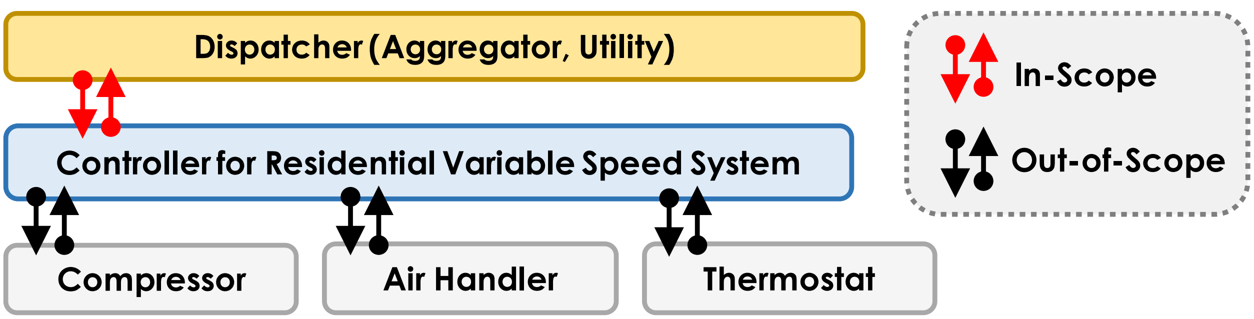

Figure 2-4
Example of a variable speed controller at the utility/aggregator interface

Figure 2-5 shows an example of a typical load control switch. In this example, a dispatcher communicates with the load control switch to disconnect power to a device (the HVAC system in this example). The load control switch has little information about the behavior of the HVAC system. It may have measurement capabilities and be able to read electric current to tell if the device is running, but it is otherwise unaware of the state of the system. Though connected to the HVAC system, the only functionality offered to the dispatcher is the functionality offered by the load control switch.

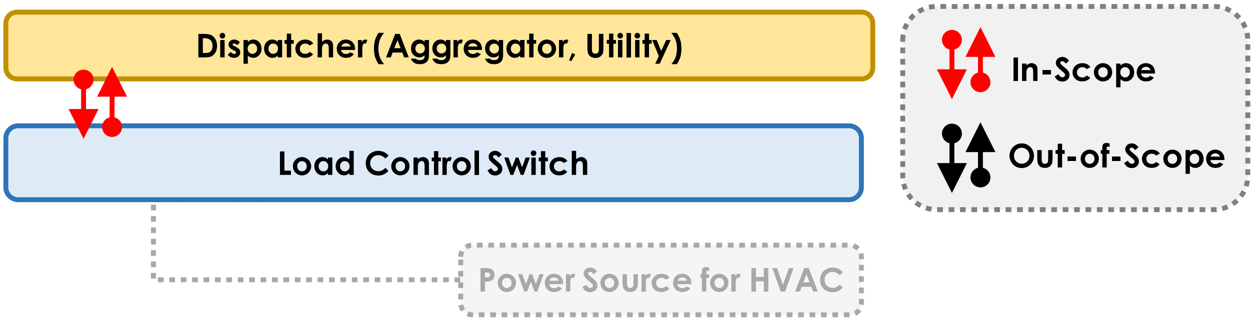

Figure 2-5
Example of a load control switch at utility/aggregator interface

Trends in Utility-Facing Functionality

There are different approaches for categorizing the utility-facing functionality for demand response technologies including HVAC; one approach is based on the type of system control (including indirect and direct) and another on the type of signal sent (requests for device-independent behavior change, setpoint adjustments, and energy price).

Indirect vs. Direct

Direct Control: Direct requests are commands that instruct a device to behave in a specific manner, with a rather direct impact on the electric power use of the device. This includes temperature setpoint adjustments and control signals like load curtailment, load increase, and emergency load control. The devices may each behave differently depending on the type of device, make, or model, regardless of how the request instructs the device to change its behavior.

Indirect Control: Indirect requests are commands that inform and motivate a device or occupant to change their behavior. Currently the only type of indirect request is pricing data. Pricing data does not tell a device how to behave. It informs the device of the current price and motivates the occupant to change the device's behavior. This change may be automatic through predefined setpoints in the device or manual through the occupants' changing their behaviors or adjusting operating parameters of their loads.

Targeted Behavior

Device-Independent Function Changes: Device-independent behavior functions provide the device with generic instructions on how to change their behavior. The key to these signals is that the command changes the behavior of the device through a request, rather than a direct control instruction. While these are typically associated with adjusting power consumption, the mechanism for changing power consumption will vary from device to device. Thermostats may change indoor air temperature setpoints, pool pumps may adjust their speed, and water heaters their water temperature setpoint.

Setpoint Adjustments: Setpoint adjustment functions directly instruct the device to change its operating setpoint to a new value. This is more direct than device-independent functions because it tells the device the mechanism to use to change its behavior. Temperature setpoint adjustments directly relates to thermostats.

Energy Price: Energy pricing functions communicate current or upcoming energy rates to devices to motivate them to change their behavior. This allows the occupant to decide what their threshold for participating in a program will be and when they will act.

Typical Demand Response Program Use Cases

In discussing typical DR control configurations, it is also important to have a basic understanding of common utility DR programs. This discussion is intended to review some of the most common types of utility DR programs, which may be given different names by each utility. It is not intended to be an exhaustive list.

Critical Peak Pricing Programs

A Critical Peak Pricing (CPP) program seeks to reduce peak demand to reduce capital expenditures and energy costs. When utilities observe or anticipate the occurrence of high wholesale market prices (or power system emergency conditions), they may define a critical event during a specified period (for example, 3:00 PM to 6:00 PM on a hot summer weekday). During such periods, the electricity price is substantially higher than usual. The burden of responding to such events falls on the energy consumer, so there is typically no need for feedback to the utility or system operator to confirm a customer's response to the event. Nevertheless, advisory communications regarding availability (and intent) of a resource to participate in an event may be used.

Capacity Bidding Program

A Capacity Bidding Program (CBP) can reduce peak demand and help a system operator meet its resource adequacy obligation. It can also reduce capital expenditures and energy costs. CBPs are used by system operators to obtain pre-committed load-shed capacity from aggregators or customers. This capacity is used when operators observe (or anticipate) the occurrence of high wholesale market prices, power system emergency conditions, or even just as part of normal energy resource use (by calling DR events during a specified time period.[2])

Thermostat Program

A thermostat program is a form of direct load control in which the DR signal directly modifies the behavior of the HVAC system, without a layer of abstraction between receipt of the signal and the specific load-shedding action taken. Thermostat programs are used to reduce peak demand and may reduce capital expenditures and energy costs. When operators observe (or anticipate) high wholesale market prices or power system emergency conditions, they may initiate an event that modifies the behavior of a customer's programmable communicating thermostat (PCT) over a specified time period (for example, from 3:00 PM to 6:00 PM on a hot summer weekday) to reduce energy consumption. The change to the PCT behavior in response to the event may be a simple change in temperature setpoint for the duration of the event or a more complex set of changes, such as precooling, that minimize the impact of the event on the customer's comfort level.

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[2] Note that each aggregator is typically responsible for designing their own event notification mechanism to meet the capacity commitments made by resources as part of this program.

3
BASIC INFORMATION: REGISTRATION AND NAMEPLATE

This section describes several pieces of metadata and enrollment information related to the capabilities of a device that can be useful in utility DR programs. Such information can include basic device type and configuration, providing insight into the capabilities of a device when it is deployed in the field. This information can also be useful when registering equipment in a program and/or verifying response to a DR event.

Use Cases

- Equipment selection, purchasing, or recruiting for DR program participation
- Registration of devices in DR programs

Enrollment Information

In specifying, selecting, or recruiting HVAC equipment to participate in load management programs, it is necessary to understand the features and functionality of equipment to confirm its ability to participate. While it may not be feasible to compile a comprehensive list, there are several aspects of an HVAC system that are important to consider before integrating them into a load control program. Table 3-1 provides a list of some of the important characteristics that a manufacturer should provide on equipment datasheets.

Table 3-1
Device Capabilities to be Included on the Enrollment

Supported DR functions	The common DR functions (defined in this report) that are supported by the system.
Direct addressability	Direct addressability of the device via the communications interface provided (for example, the API [application programming interface]).
Support for locational DR	Ability to support locational control, and level supported (for example to zip code, feeder, or specific device endpoint).
Open communications supported	Hardware interface: Wi-Fi (IEEE 802.11); Communications protocol: OpenADR 2.0 A/B, CTA-2045, or IEEE 2030.5 (SEP 2.0).
Feedback to Load Management Entity	For example: verification/M&V or override notification
Comfort constraints	Measures to limit consumer comfort impacts.
Response configurability/flexibility	How the consumer and/or load management entity can configure the connected device's response to a DR event signal.
Compliance with 2016 California Energy Commission Title 24, Part 6 Joint Appendix 5	Y or N

Device Metadata Reporting

After installation in a home, additional information about the device's installation, configuration, and other static monitoring points could be polled from the device. Table 3-2 lists the metadata that could be reported by a DR-ready system, if available. These points can be useful when taking inventory of the devices registered in a DR program, in device registration itself, or in polling before, during, or after an event to estimate potential impact. Following Table 3-2 are more detailed descriptions of select reporting points listed in the table.

Table 3-2
Reporting Requirements for Device Metadata

Device Identifier	Unique device ID or serial number
Manufacturer Description	Device manufacturer and/or vendor
Model Number	Model number of HVAC system (ASCII string)
Installation Date	Date of device installation
Software Version	Version of the software/firmware installed in the device
ZIP Code	5-digit format
System Ability to Heat	Y or N
Reported Heating System Type	For example, natural gas furnace or heat pump with electric resistance supplemental heater (text)
Reported Number of Heating Stages	Integer value
System Ability to Cool	Y or N
Reported Cooling System Type	Type of cooling system (text)
Reported Number of Cooling Stages	Integer value
Size	Size of the HVAC unit (rated thermal load, in watts)
Unloading Type	Single-speed, continuously variable, or discretely variable
Rated Power (Cooling)	Rated power in cooling mode (in watts)
Rated Power (Heating)	Rated power in heating mode (in watts)

Ability to Heat/Cool

The heating and cooling parameters given in Table 3-2 are applicable to systems that provide heating, cooling or both. For example, a simple air conditioner is not able to provide heating – only cooling is provided. Conversely, these requirements can be applied to a system that only delivers heating. By definition, heat pumps are able to deliver both heating and cooling, and may rely on a second source for supplemental heating (for example, electric resistive “strip” heating elements, natural gas, or propane).

Number of Heating/Cooling Stages

Conventional HVAC systems can employ single or multiple stages of heating and/or cooling without offering continuously variable-speed operation of the refrigerant system. In typical residential applications, the compressor for conventional systems can operate at a single speed or two discrete speeds (high and low). This parameter is intended to describe the number of distinct stages of heating or cooling available. In continuously-variable capacity systems (referring to the ability to operate the compressor at variable speeds), the number of stages should not refer to the ability of the single compressor to operate at multiple operating points. Equipment providers should use *Unloading Type* to define the ability of a variable-capacity system to operate at multiple points, as described below.

Unloading Type

The *Unloading Type* parameter is applicable to variable-capacity HVAC systems, describing the system's ability to operate at different operating levels. Specifically, the unloading levels refer to the amount of control that is available to operate at levels below full speed, whether continuously variable (typically inverter-driven) or discretely variable (such as step-modulated compressor or dual compressor). Continuously variable systems can operate at a wide range of load levels which may be defined to 1% precision. Discretely variable systems have a limited number of operating, which is most often two levels.

This parameter is seen in the proposed AHRI Standard 1380 for variable-capacity systems for residential and small commercial applications. This information can provide program operators with insight into the ability of a variable-capacity system to respond differently to load curtailment events of different magnitude.

Rated Power

The *Rated Power* (in watts) of residential HVAC systems is defined by ANSI/AHRI Standard 210/240, which gives standard test conditions for the rated operating point in cooling and heating modes. In cooling mode, rated power is defined at outdoor conditions of 95°F (35°C) and indoor conditions of 80°F (26.7°C) dry bulb temperature and 67°F (19.4°C) wet bulb temperature. For heat pumps, the rated power of light-load heating is measured at outdoor conditions of 47°F (8.3°C) and indoor conditions of 70°F (21.1°C) dry bulb temperature and 60°F (15.6°C) wet bulb temperature.

The *Rated Power* parameter allows program operators insight into the amount of electric load that can be requested under a DR event. In relating this value to a standard rating, manufacturers have a standardized test procedure and operating conditions, and program operators can be confident in the value that is reported.

4

DEVICE MONITORING AND STATUS

Many functions require monitoring of the status of the HVAC unit, either: 1) periodically; 2) when a value changes significantly; or 3) simply upon request. The mechanisms used by different protocols to implement these reporting requirements are outside the scope of this report. However, at a minimum, support for the reporting of status upon request is expected to be available.

Throughout this document a variety of configuration settings and limits are identified. It is intended that each of these settable parameters can also be monitored or read back at any time.

This section identifies additional quantities (not identified elsewhere in this document) that may also be read from the device. Some of these may be writeable via the communication protocol, while others may be fixed by the manufacturer or settable only with special or local access.

Table 4-1 summarizes the status points that are defined in this Section.

Table 4-1
Status Points

Status Point	Description
Energy/Power Measurements	
Instantaneous Power	In watts
Operational State	See values below
Override State	See values below
Maximum Operating Capacity Level	A mechanism to read the maximum amount of load that can be reduced for a device. A percentage where 100% is a full reduction of load (off).
Operational Settings	
Heating Temperature Setpoint	In degrees (Fahrenheit or Celsius, as agreed)
Cooling Temperature Setpoint	In degrees (Fahrenheit or Celsius, as agreed)
HVAC Mode Setting	Off; Heat; Cool; Auto
Current HVAC Mode	Off; Heat; Cool
Fan Mode Setting	On; Auto
Current Hold Mode	None; Temporary; Permanent
Current Away Mode	Off; On
Conditioned Space Measurements	
Current Conditioned Space Temperature	In degrees (Fahrenheit or Celsius)
Current Conditioned Space Humidity	In percent
System Runtime	
Daily Cooling Equipment Run Time	Minutes
Daily Heating Equipment Run Time	Minutes
Hourly Auxiliary Heat Run Time	Minutes
Hourly Emergency Heat Run Time	Minutes

Energy/Power Measurements Details

Details related to the Energy/Power Measurements status values are provided in this section.

Instantaneous Power

Reported values associated with the power consumption of the HVAC system's components and controls may be measured or estimated. Power should be an "instantaneous" measurement. However, to obtain an accurate power measurement it may be necessary to average instantaneous power readings over some interval. For example, AHRI Standard 1380P (see Section 11 below) specifies that power for variable-speed HVAC systems be reported as the average of twenty instantaneous measurements taken at one-minute intervals to avoid brief compressor "speed-ups" that are used to ensure proper oil return to the compressor.

Operational State

The status values that are returned for the Operational State are defined as follows:

- *Idle Normal* – Indicates that no DR event is in effect and that the HVAC system has either no or insignificant energy consumption.
- *Running Normal* – Indicates that no DR event is in effect and the HVAC system has significant energy consumption.
- *Running Curtailed* – Indicates that a curtailment-type DR event is in effect and the HVAC system has significant energy consumption.
- *Running Heightened* – Indicates that a load-up type of DR event (increase load) is in effect and the HVAC system has significant energy consumption.
- *Idle Curtailed* – Indicates that a curtailment-type DR event is in effect and the HVAC system has either no or insignificant energy consumption.
- *Error Condition* – Indicates that the HVAC is not operating because it needs maintenance or is in some way disabled (for example, it is not responding to communications)
- *Idle Heightened* – Indicates that a heightened-operation type of DR event is in effect and the HVAC system has either no or insignificant energy consumption.
- *Idle, Opted Out* – Indicates that the user of the HVAC system has declined to participate in any DR events and the system has either no or insignificant energy consumption.
- *Running, Opted Out* – Indicates that the user of the HVAC system has declined to participate in any DR events and the system has significant energy consumption.

Override State

This element can have either of two values:

- In override (not participating in DR events)
- Not overridden (participating in DR events)

Operational Settings Details

Details related to several operational settings values are provided in this section.

HVAC Mode Setting

This status value describes the mode of operation specified for the HVAC. The HVAC setting mode can be OFF, wherein unit operation is disabled. In HEAT mode, the system is able to provide space heating as required to maintain the heating temperature setpoint (cooling is disabled). In COOL mode, the system is able to provide space cooling as required to maintain the cooling temperature setpoint (heating is disable). In AUTO mode, the system automatically provides cooling or heating as required based on the current indoor temperature, the cooling temperature setpoint, and the heating temperature setpoint.

Fan Mode Setting

This status value describes the mode of operation specified for the indoor air fan associated with the HVAC system. In the ON mode the fan operates continuously regardless of whether cooling or heating is required. In the AUTO setting, the indoor fan operates only when cooling or heating coils operate, to maintain the defined temperature setpoint(s).

Current Hold Mode

This status value describes whether thermostat setpoint schedules are enabled or if the schedules are being disregarded and the current temperature setpoint is being held constant. If the current hold mode is NONE, then the system is being controlled based on the defined thermostat setpoint schedules. If hold mode is TEMPORARY, then the current thermostat setpoint value will be held constant for a certain period of time before the system automatically reverts to the defined thermostat setpoint schedules. If hold mode is PERMANENT, then the current thermostat setpoint value will be held constant indefinitely (until further notice).

Current Away Mode

This status value indicates whether the system has been notified to operate as if occupants are away from home. If current away mode is ON, then the system can be configured to follow a different mode of operation than when the home is occupied. For example, different setpoint temperatures may be applied during away mode in order to save HVAC energy consumption.

System Runtime Details

Details related to certain HVAC system runtime values are provided in this section.

Auxiliary Heat Runtime

Auxiliary heat is a supplemental heat source (such as an electric strip or natural gas heater) used by a heat pump system to maintain the indoor temperature when heat pump output alone is insufficient. Runtime is the time period (such as minutes) that the auxiliary heat operates over a defined interval of time (such as hourly).

Emergency Heat Runtime

Emergency heat is when heat pump auxiliary heaters are solely used to maintain indoor temperature (the heat pump is disabled). Emergency heat operation is manually enabled by the occupant, normally when the heat pump has malfunctioned. Runtime is the time period (such as minutes) that the auxiliary heat operates over a defined interval of time (such as hourly).

Retrieval of Status Values

The retrieval of status items may be done using a variety of methods that are highly dependent on the particular communications protocol used. Example methods include:

- Retrieval of single status values:
  - *On-Demand* – Returns the status value, upon request
  - *Triggered* – Returns the status value when a triggering event occurs, such as:
    - Upon any change in a value
    - Upon moving out of a deadband (interval in which no action occurs)
    - Upon exceeding a limit
- Retrieval of sets of status values:
  - During initialization of the system, sets of status values could be assigned to one or more "data sets." These data sets could then be used to retrieve information in the following ways:
    - *On-demand* – Return of all the status values in the requested data set, upon request
    - *Periodically* – Return of all the status values in each data set, at recurring intervals
    - *Triggered* – Return of all the status values in the affected data set when a triggering event occurs, such as:
      - Upon change of value of one or more status values
      - Upon one or more status values moving out of a deadband
      - Upon one or more status values exceeding a limit
  - After initialization, using the communications network, data sets could be created, modified, and/or deleted, and the reporting triggers can be established (such as upon demand, periodically, or triggered).

Using an "on-demand" retrieval method, the following command and response actions could be included:

- "On-demand" request:
  - Status command
  - Identity of which status value or which data set should be sent
- Response to an on-demand request:
  - Requested status value(s)
  - Timestamp
  - Failure (plus reason, such as: equipment not available; message error; or security error)

For other retrieval methods, other "unsolicited" information could be transmitted, such as:

- Periodic, or upon change of a status value:
  - Status value(s)
  - Timestamp

Sample Use Cases Monitoring Requirements

Monitoring requirements naturally vary for different use cases. Historical reports could be requested at any time and for any reason. Telemetry (real-time) reports are usually program specific and some typical examples, based on the typical DR programs defined in Section 1 above, are described in this section.

Critical Peak Pricing Programs

Telemetry (real-time) reporting is not typically used with CPP programs, as it is not strictly necessary. Neither is monitoring of temporary availability (via the customer's override status) typically used, though it may be helpful in recording customers' indications of temporary lack of availability when tracking remaining seasonal event days. Nevertheless, some monitoring of HVAC systems in a CPP program might be helpful, such as checking a customer's intention to participate in an event (in order to assess the anticipated response that will occur).

Capacity Bidding Program

Independent System Operator/Regional Transmission Organization (ISO/RTO) CBPs typically require telemetry reports containing real power values (though utility CBPs usually do not do so). Since users have pre-committed their availability by participating in a CBP, there is usually no need for monitoring their participation intentions. However, participation status may be useful as a way to indicate a lack of availability due to unanticipated reasons (such as equipment failure). Participation in an ISO/RTO CBP would typically require hourly reporting of directly-read real power.

Thermostat Program

Although monitoring is not typically used in residential thermostat programs, it may be required for small commercial thermostat programs. At a minimum, these programs usually require monitoring of the current setpoint of the thermostats that control the HVAC resources, as well as tracking their override status. Additional status values that might be monitored include:

- Current Conditioned Space Temperature
- Heating Temperature Setting
- Cooling Temperature Setting
- HVAC Mode Setting
- Current HVAC Mode
- Fan Mode Setting
- Current Hold Mode
- Current Away Mode
- Current Conditioned Space Humidity

A report containing such a set of status values might be generated hourly.

5
LOAD CURTAILMENT CONTROL

This section describes functionality to reduce the electrical load of HVAC equipment on the power system. These functions fall under two broad categories: general load curtailment and critical load curtailment, and are distinct from Emergency Load Control, which is defined in Section 6. This section does not specifically define requirements for participation in a utility DR program. Program requirements may require specific responses to these commands that help utilities and aggregators understand the electrical impact of each device. Any specific requirements should be handled at program enrollment.

Use Cases / Requirements

- Reducing end-use electrical loads to relieve capacity constraints of the distribution system
- Improve power system economics
- Improve the integration of renewable energy sources

Overview

A Load Curtailment event can be requested at one of two tiers, representing a different level of response. These different levels are often characterized by the frequency and priority with which they are called by the controlling entity. Either of these requests is paired with parameters that inform the controlling entity of the device's abilities and current state.

Table 5-1
Load Curtailment Function Parameters

Enable Event Type	General Load Curtailment or Critical Load Curtailment
Load Reduction Target	The amount of reduction in HVAC load requested, as a percent of a reference load.
Maximum Indoor Temperature Offset	(Optional) A parameter set by the program administrator to limit the maximum change in indoor temperature that is allowed during the event.
Customer Override	A mechanism for customers to opt out of an event. This is a state controlled at the device and can be read by the utility.
Randomization Window	A mechanism for the start time of an event to be delayed by a random amount of time before being acted on by the device.
Acknowledgement	A mechanism for the HVAC system to state whether it intends to perform the function (participate), or has declined to perform the function.

General Load Curtailment

A request for reduction in power consumption. It is assumed that this function would be called relatively frequently. The general load curtailment function is used to reduce moderately the energy consumption of HVAC equipment. Such a command is intended to be used periodically, as a means of balancing the supply and demand economics of the power system, for example, to reduce air-conditioning load on peak summer days.

Critical Load Curtailment

A request for reduction in power consumption that is associated with a more significant decrease in power compared to a general load curtailment request. It is assumed that this function would be called relatively infrequently. The critical load curtailment function is used to limit more aggressively the energy consumption of HVAC equipment. This function is designed for infrequent use in response to events of higher criticality to the power system (for example, failure of a large generator).

Load Reduction Target

The reduction in electrical load for the device with respect to a reference value. The reference power is frequently defined as the average power consumed by the device during normal operation; it may also be defined as the nominal rated power at specific conditions. This reference value should be defined by the program administrator.

Maximum Indoor Temperature Offset

The Maximum Indoor Temperature Offset parameter sets a boundary on how far indoor temperature is allowed to deviate from the pre-event setpoint during a load curtailment event. This parameter can be applied to events that are called in both heating and cooling modes of operation. In cooling mode, this offset defines the maximum allowed rise in indoor temperature, while in heating mode it defines the maximum allowed decrease in indoor temperature. When the maximum offset is reached, the system automatically relaxes the load reduction target and holds this temperature as the new setpoint until the end of the event. The default value for this parameter places no limit on indoor temperature deviation. Administrators of DR programs can specify a value for this parameter across many different events to standardize response rates. Alternatively, this parameter can be individually specified for each event to tailor response profiles for the specific needs being addressed.

Example Implementations in Products

Depending on HVAC equipment type, load curtailment can be accomplished by one of two methods (apart from changing the thermostat setpoint temperature, which is described in Section 9). For conventional single-speed equipment, load curtailment can be directly achieved through duty-cycle control. For variable-capacity systems, a power limit can be defined that sets a maximum operating level for the curtailment event.

Duty-cycle control turns a device on and off to manage its average power over a period of time. Under duty-cycle control, a single-speed system will cycle between its full-load power and idle, such that its average power matches the requested level over the given time interval. Variable-speed systems can limit their operation so that average power does not exceed the requested power level. Yet variable-speed systems can also employ cycling behavior to achieve power levels below their minimum operating speed. Figure 5-1 illustrates the difference between duty-cycle and variable control.

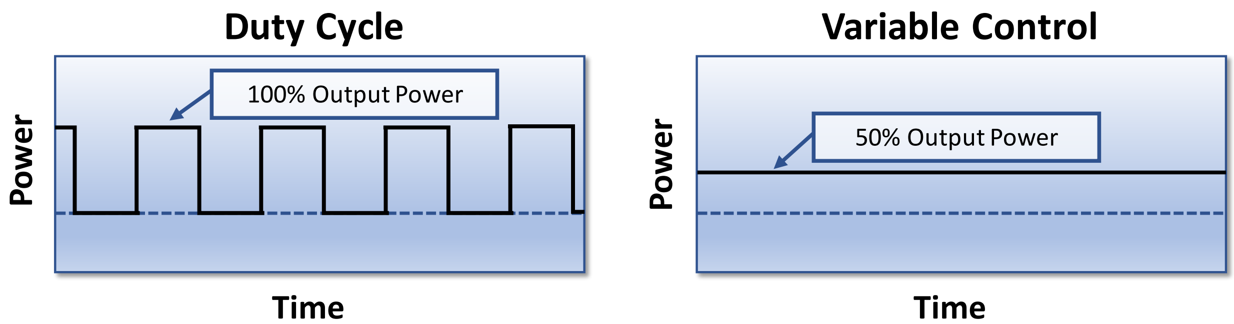

Figure 5-1
Example of the difference between duty cycle and variable control for 50% power

One example of variable control in industry is specified in AHRI Standard 1380P, which defines two Load Curtailment functions. The General Curtailment function is defined as limiting the input power of the HVAC system to no more than 70% of its Benchmark Power (a 30% load reduction target), which is measured at 95°F (35°C) outdoor temperature for cooling mode and at 47°F (8.3°C) in heating mode. When operating under a General Curtailment request, the system must adhere to the maximum indoor temperature offset, if defined, as described above. This function is designed to be compatible with the CTA-2045 and OpenADR open communications protocols. Some protocols (such as OpenADR) may include start and stop times along with the curtailment request, to schedule these events in advance, whereas other protocols (such as CTA-2045) often may not use advanced notification.

The Critical Curtailment function is defined in AHRI 1380P as limiting the input power of the HVAC system to no more than 40% of its Benchmark Power (a 60% load reduction target), which is measured at 95°F (35°C) outdoor temperature for cooling mode and at 47°F (8.3°C) in heating mode. While operating under a Critical Curtailment request, the system must adhere to the maximum indoor temperature offset, if defined, as described above. This function is designed to be compatible with the CTA-2045 and OpenADR open communications protocols. Some protocols (such as OpenADR) may include start and stop times along with the curtailment request to schedule these events in advance, whereas other protocols (such as CTA-2045) often may not use advanced notification.

6

EMERGENCY LOAD CONTROL

The Emergency Load Control function provides a mechanism for a controlling entity to ask devices to provide their most extreme response, often “turn off.” This is called very rarely but when called, is expected to get a response from the end-use device.

Use Cases / Requirements

- Dangerously low voltage on the distribution system
- Dangerously low or high frequency on the distribution system
- System disturbances (such as generator failure, line fault, or overloaded transmission)

Overview

Emergency load control directs an immediate response to a grid command. The grid emergency function is used to reduce HVAC equipment power to near zero, except for any needed auxiliary systems (such as a crankcase heater). This function is designed to be used rarely and only in emergency situations. This function can be applied to variable-capacity equipment of any type, including both continuously variable and equipment with discrete capacity or speeds.

Table 6-1
Emergency Load Function Parameters

Enable Emergency Load Control Event	A request for device to turn off.
Customer Override	A mechanism for customers to opt out of an event. This is a state controlled at the device and can be read by the utility.
Acknowledgement	A mechanism for the HVAC system to state whether it intends to perform the function (participate), or has declined to perform the function.

Example Implementation

In AHRI Standard 1380P, this function is defined as “Turn Off.” The function is designed to be compatible with the CTA-2045 and OpenADR open communications protocols.

7

LOAD INCREASE CONTROL

The Load Increase function provides the utility with a mechanism to increase the short-term energy consumption of the HVAC system. Such a command is intended to shift the timing of HVAC load – for example, to leverage low-cost energy during certain times of day – rather than increasing overall HVAC energy consumption.

Use Cases / Requirements

- Shaping time profile of HVAC load, for example to take advantage of differences in the hourly cost of electricity
- Integration of renewable energy sources

Overview

The Load Increase function calls for an increase in the amount of heating or cooling delivered, using the thermal storage property of a building to reduce HVAC load during a later period of high demand on the electric power system (known as pre-cooling or pre-heating). In addition to specifying the requested load increase target, the program administrator can choose to define a Maximum Indoor Temperature Offset to limit the temperature deviation within the occupied space during the DR event.

Table 7-1
Load Increase Function Parameters

Enable Event	Load Increase: true/false
Load Increase Target	The amount of increase in HVAC load requested, as a percentage of a reference load.
Maximum Indoor Temperature Offset	(Optional) A parameter is set by the program administrator to limit the maximum change in indoor temperature that is allowed during the event.
Customer Override	A mechanism for customers to opt out of an event. This is a state controlled at the device and can be read by the utility.
Randomization Window	A mechanism for the start time of an event to be delayed a random amount of time before being acted on by the device.
Acknowledgement	A mechanism for the HVAC system to state whether it intends to perform the function (participate), or has declined to perform the function.

Load Increase Target

The increase in electrical load for the device with respect to a reference value. The reference power is frequently defined as the average power consumed by the device during normal operation. This reference value should be defined by the program administrator.

Maximum Indoor Temperature Offset

The Maximum Indoor Temperature Offset parameter sets a boundary on how far indoor temperature is allowed to deviate from the pre-event setpoint during an increase load event. This parameter can be applied to events that are called in both heating and cooling modes of operation. In cooling mode, this offset defines the maximum allowed decrease in indoor temperature, while in heating mode it defines the maximum allowed rise in indoor temperature. When the maximum offset is reached, the system automatically relaxes the load increase target and holds this temperature as the new setpoint until the end of the event. The default value for this parameter places no limit on indoor temperature deviation. Administrators of DR programs can specify a value for this parameter across many different events to standardize response rates. Alternatively, this parameter can be individually specified for each event to tailor response profiles for the specific needs being addressed.

Example Implementation

The prototypical example of this function is to increase system operation prior to a load curtailment event, whereby the inherent thermal storage of a building is used to shape the electric load profile of the HVAC system. In the hypothetical example described here, a signal may be sent by the utility or program administrator to request a load increase target (30%) over the system's baseline power consumption (hourly average power over the past 10 days). The request may also include a maximum indoor temperature offset of 3°F (1.7°C) to limit the maximum deviation in indoor temperature, as well as a time duration limit (2 hours).

Note that AHRI Standard 1380P includes a "load up" function which differs from this Load Increase function in that it uses a thermostat setpoint change to increase load (see Section 9, Thermostat Setpoint Control).

8

MOTIVATIONAL FUNCTIONALITY – ENERGY PRICE FUNCTION

The Energy Price function informs devices of new prices to motivate behavior. It is assumed the devices have local interfaces for occupants or building owners to set thresholds for the device to react, or a mechanism to inform the homeowner that a change in price has occurred. This function is considered indirect because the communication of pricing information does not directly control the device, but instead may cause the device to change behavior at the direction of the owner. This price is often a regional wholesale price and may not be the settlement or tariff price paid by the utility customer.

Use Cases / Requirements

- Expose the time-value of electricity consumption, improving power system economics

Overview

Pricing data can be communicated in a variety of ways; however, the differences in the mechanisms must be understood for accurate device response.

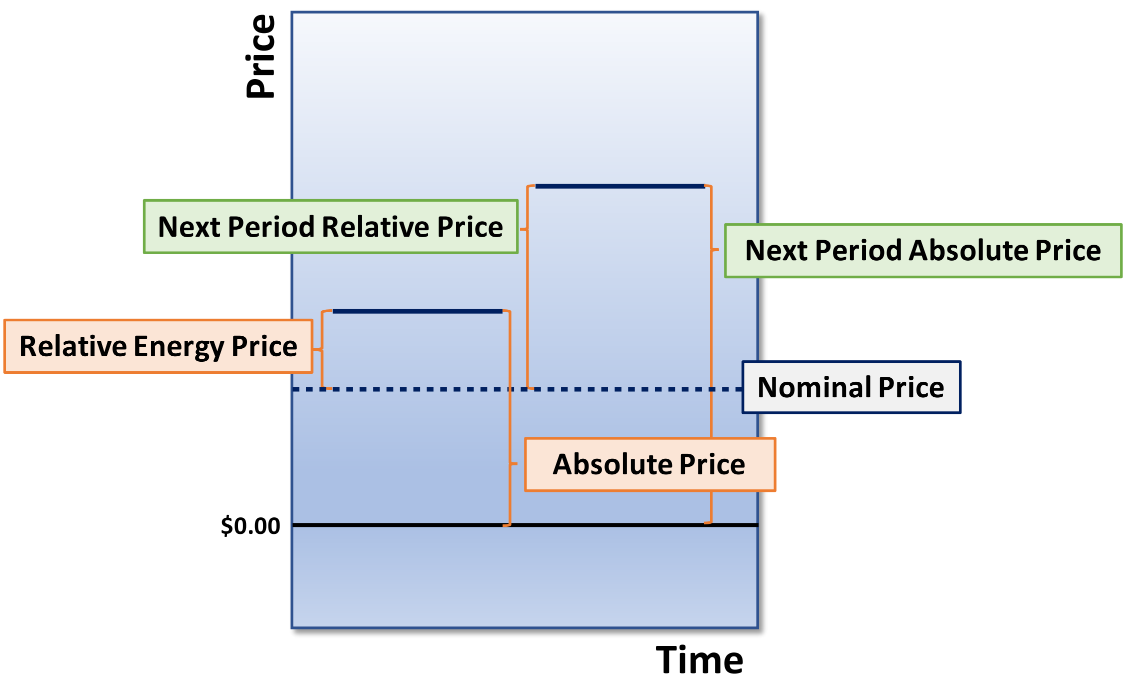

Figure 8-1
Example of pricing terminology

The price communication variants can be broken down into two categories: The first is in the time domain and includes present price or next period price; the second is related to the reference point for pricing and includes absolute or relative. Absolute is a specific price, while a relative price is expressed relative to a reference price (the nominal price outside of an event or the current price).

Table 8-1
Energy Pricing Function Parameters

Relative Energy Price	The difference between current and nominal pricing. Relative pricing can be expressed as a difference (in dollars) or as a multiplier.
Next Period Relative Price	The difference between current and nominal pricing in the next period. This can be expressed in terms of a multiplier or relative difference (in dollars).
Absolute Energy Price	The current energy price expressed in dollars.
Time remaining in current price	The time remaining in the current pricing period.

Example Implementation

In this example, a smart thermostat connected to the internet may be used to control the HVAC equipment. The thermostat accepts an incoming energy price signal from its electric utility company partners and/or related entities. Using the thermostat interface, the occupant can establish an energy price threshold, as well as the thermostat adjustments that will be applied once the incoming energy price signal exceeds the user-defined threshold. Thermostat adjustments applied during a high price period may include changing to new absolute temperature setpoints or applying a temperature setpoint offset to the normal setpoint values. In either case, the setpoint adjustments are applied to reduce HVAC system energy consumption during the high energy price period.

9
TEMPERATURE SETPOINT CONTROL

There are several DR functions that are specific to controlling temperature in the conditioned space. These functions can be used to increase or decrease HVAC electrical load as required by the utility. Load changes are achieved by modifying the HVAC system's thermostat setpoint temperature from its typical value. This section describes two common thermostat-specific functions, which form an important part of HVAC DR control but are not easily translated to device-agnostic commands. The two variants are Absolute Temperature Setpoint and Temperature Setpoint Offset.

Use Cases / Requirements

- Smoothing of electrical demand across a distribution system
- Decreasing HVAC load
- Pre-conditioning (heating or cooling) before a load curtailment event
- Increasing HVAC load

Overview

Intelligent thermostat algorithms and/or utility load management strategies can be used to alter the customer-entered setpoint to change the HVAC system's power consumption during a demand response event. The setpoint temperature can be changed to increase power consumption or reduce power consumption, depending on the strategy employed to smooth electrical demand across the utility distribution system.

A modified temperature setpoint, or temperature setpoint offset, can be sent directly from a controlling entity to the thermostat to override the occupant setpoint. Alternatively, a control event signal can be sent from the controlling entity to the thermostat, and the temperature setpoint can be adjusted by the thermostat itself based on occupant-entered instructions.

Table 9-1
Temperature Setpoint Function Parameters

Enable Event Type	Absolute Temperature Setpoint or Temperature Setpoint Offset
Customer Override	A mechanism for customers to opt out of an event. This is a state controlled at the device and can be read by the utility.
Acknowledgement	A mechanism for the HVAC system to state whether it intends to perform the function (participate), or has declined to perform the function.

Absolute Temperature Setpoint

The Absolute Temperature Setpoint function modifies the thermostat device's current setpoint, replacing it with an absolute temperature setting determined by the DR program administrator or the customer. This function is applied independently to the heating temperature setpoint and to the cooling temperature setpoint. At the end of the DR event, the thermostat setpoint reverts to the normal temperature setpoint (that is, to the setpoint prior to the DR event or normally scheduled setpoint for the time after the DR event ends).

Temperature Setpoint Offset

The Temperature Setpoint Offset function changes the occupant-defined thermostat setpoint temperature by a defined amount (an offset from the current setpoint). The setpoint offset may be determined by the DR program administrator or the customer. This function is applied independently to the heating temperature setpoint and to the cooling temperature setpoint. At the end of the DR event, the thermostat setpoint reverts to the normal temperature setpoint (that is, to the setpoint prior to the DR event or normally scheduled setpoint for the time after the DR event ends).

Example Implementations

In this example, a smart thermostat connected to the Internet may be used to control the HVAC equipment. The thermostat accepts incoming DR signals from its electric utility company partners and/or related entities. The DR signals can instruct the thermostat to enforce discrete or static setpoints (Absolute Temperature Setpoint) or enforce an offset to the occupants' comfort setpoints (Temperature Setpoint Offset). The absolute temperature setpoint and temperature setpoint offset values are entered by the occupant via the thermostat interface. For the example of an absolute temperature setpoint function, the occupant may set the cooling setpoint to 80°F (26.7°C) and the heating setpoint to 65°F (18.3°C). Alternately, for temperature setpoint offset function, the occupant may set the cooling temperature offset to +3°F (+1.7°C) and the heating temperature offset to -5°F (-2.8°C).

A second example is provided in AHRI Standard 1380P, where its "Load Up" function is used to increase HVAC equipment energy use by increasing the thermostat setpoint temperature in heating mode or decreasing the thermostat setpoint temperature in cooling mode. For this standard, the temperature set point offset is defined as 4°F (2.2°C). This function is intended to be applied for a specific time interval (the default is 2 hours), but the period can be extended or terminated early based on additional instructions. This function is designed to be compatible with the CTA-2045 and OpenADR open communications protocols. Some protocols may include start and stop times to schedule these events in advance (such as OpenADR), while other protocols may not usually employ advanced notification (such as CTA-2045).

10
TIME SYNCHRONIZATION

The ability to synchronize DR resources to a standard time is critical to the accurate scheduling of functions and the time-stamping and logging of events. Failure to synchronize can cause end-use devices to respond at incorrect times, which may cause less or no benefit to the power system. Proper synchronization not only improves the value of DR system response, but ensures correct monitoring and compensation for device response.

Use Cases

- Ensure DR devices respond when needed
- Enhance value of DR response
- Ensure accurate monitoring, reporting, and compensation for response

Local Time Zone

As power systems expand and begin to operate in more regionally-dependent ways, it becomes an increasingly common need to consider the difference in time zones between resources on the power system. An HVAC system should account for the time zone in which it is installed, and be able to relate this to a universal standard (GMT). In addition, it is frequently necessary for devices to be informed if or when the local time zone adjusts for Daylight Savings Time. These biannual time adjustments can cause loss of synchronization if not accounted for in some manner.

Synchronization to Reference Clock

In many cases, the chronographic accuracy of internal timing mechanisms may not be sufficient for long-term time keeping. In these cases, it may be necessary to synchronize with a standard reference clock. For example, the National Institute for Standard and Technology (NIST) maintains a number of servers that can be used as reference clocks using Network Time Protocol (NTP), the most common clock synchronization protocol used by internet-connected devices. The primary address that devices can use to synchronize to NIST servers can be found at time.nist.gov.

Research shows that time adjustment may be supported by the specific communication protocols into which these functions will be mapped. In view of this, the recommended approach for time adjustment is to utilize the native time–adjustment mechanism of the specific communication protocol being applied. For example, IEEE 2030.5 has defined time-setting mechanisms that may be used for synchronizing devices. Additional details can be found in the protocol-specific documentation.

11
PREVALENCE IN INDUSTRY

Residential HVAC has played an important role in utility DR programs for some time, providing a valuable resource for electric load reduction during periods when the capacity of the power delivery system is constrained. The primary method of control for these systems has been through limiting the duty cycle of the system, which restricts the unit's runtime. This method of control is particularly useful for residential HVAC, as these systems typically employ a single-speed unit with basic thermostat controller. Duty-cycle control is primarily accomplished with a separate load control switch installed in the conventional 24 VAC control wiring between the thermostat and indoor air handler or between the air handler and outdoor unit. This control signal interruption can be applied to one or multiple heating/cooling stages, as applicable. A second common method for limiting system operation is through changing the temperature setpoint at the thermostat. The setpoint adjustment can be provided via an external signal to the thermostat, which reduces system runtime and, therefore, electric load.

As noted in earlier sections, there are several advanced approaches for limiting the power use of these systems for utility DR. This section is intended to outline the status of efforts to develop and demonstrate control techniques beyond conventional duty cycling or setpoint adjustment control, broken down by manufacturer. While there are many manufacturers working to develop improved DR capabilities for their cooling and heating equipment, the list below is meant to provide a representative sample covering a significant portion of the residential HVAC market.

One step of advancement involves a DR control signal being sent to a terminal block located in the outdoor unit or, for some equipment, the connections are located within the indoor air handler. In most cases, the outdoor unit (compressor and condenser fan) can be disabled via this dedicated load curtailment control signal, which closes or opens an external relay or contactor installed between two control pins. Such control can be utilized as an emergency load control or as a direct load control via duty-cycle limiting. In either case, this terminal block control can be used in much the same way as a conventional duty-cycle load control switch that intercepts the 24 VAC control signal between thermostat and indoor air handler or outdoor unit. Yet this terminal block may enable simpler integration of DR controls into residential HVAC systems, and in some cases, allows control of compressor operation for both cooling and heat pump heating via this single signal connection. Specific details regarding this advanced method are outlined below for HVAC equipment manufacturers that employ this control method.

Carrier

Carrier is part of UTC Climate, Controls & Security (CCS), a unit of United Technologies Corporation. In addition to Carrier, the UTC CCS unit offers a wide array of residential heating and cooling products under several other brands, including Bryant, Payne, Day & Night, Comfortmaker, and Heil.

Carrier's Infinity System Control allows homeowners the ability to configure their system to allow "Demand Response" when a utility curtailment signal is received. Using the thermostat input screen, the homeowner can independently set the system's response to the utility signal for both cooling mode and heat pump heating mode. The system allows two options in response to the DR signal: reduction to low-stage operation (minimum speed for variable speed compressor), or turning the outdoor unit off (compressor and outdoor fan). The utility curtailment signal is transmitted using an external switch closure relay connected within the system's outdoor unit. Upon opening of the external relay switch, the homeowner-specified demand response selection is enabled and "Utility Curtailment Active" is displayed on the thermostat screen.

Daikin (Goodman)

Daikin, a major Japanese manufacturer of HVAC equipment, purchased U.S.-based Goodman in 2012 to become one of the world's largest HVAC manufacturers. Today, Daikin and Goodman branded products are available for ducted central HVAC systems that are traditional in the U.S. residential market.

Daikin/Goodman does not currently offer their own residential DR solution. However, a solution is currently under development, with anticipated release in 2018. Details of the solution are not currently available; however, the communications protocol is likely to be OpenADR 2.0b compatible.

In addition, Daikin has partnered with EPRI to develop and demonstrate advanced DR capabilities of a variable-capacity heat pump, funded by the California Energy Commission under project CEC-EPC-14-021. To date, the project has demonstrated in a laboratory setting the ability of a variable-capacity heat pump to reduce operation to a low-power state in response to an external signal. In addition, the system has utilized OpenADR 2.0b signals transmitted via Wi-Fi to the system controller. Final results from the project, including results from field testing, are expected to be published in late 2018.

Ingersoll-Rand (Trane / American Standard)

Ingersoll-Rand produces the Trane and American Standard lines of residential HVAC products in the U.S. Several of their products offer basic DR capabilities beyond duty- cycle or setpoint control via an external controller, as follows.

For variable speed compressor systems, an external relay can be used to initiate load curtailment control via connection to a terminal block located in the outdoor unit. Upon opening of the external relay switch, load curtailment is enabled, disabling the outdoor unit (compressor and condenser fan) in heating and cooling mode. For a heat pump system in heating mode, load curtailment prevents compressor operation, forcing the system to utilize indoor heat. According to the manufacturer, heating mode load curtailment is primarily targeted toward dual fuel heat pumps (electric heat pump with supplemental heat provided by gas furnace). When in load curtailment mode, the indoor thermostat for a communicating system displays 'Load Shed' to inform the homeowner that the outdoor unit has been turned off intentionally.

For various types of systems, variable speed indoor air handlers can also be used to implement a form of load curtailment. An external relay can be connected to a terminal block located within the air handler. When the relay is opened, both the outdoor unit and indoor air handler will be disabled, or only the outdoor unit will be disabled, depending on air handler controller settings. The specific response to the external relay signal can be independently set for cooling and heating modes via the controller interface. This mode of operation provides two alert indications, although neither is easily accessible to the occupant. The first is an indicator on the control panel located on the exterior of the air handler, and the second is only available in the technician menu on a communicating thermostat.

Beyond the currently-available DR capabilities defined above, Trane has also been developing new advanced DR functionality. For example, EPRI partnered with Trane to demonstrated in a laboratory setting the ability of a Trane variable-capacity heat pump to reduce to low-speed operation in response to an external signal sent via a connected Wi-Fi thermostat controller.

Lennox

Lennox International is a manufacturer of climate control solutions for heating, air conditioning and refrigeration applications. In the residential marketplace, a wide array of equipment is available under the Lennox brand. Additional system offerings are available through the Armstrong Air, Ducane, and Concord brands.

For Lennox systems utilizing a variable speed compressor, an external relay can be used to initiate load curtailment via a terminal block located in the outdoor unit. Upon closure of the external relay switch, load curtailment is enabled. No additional adjustments to the default system settings are required to enable load curtailment. A "Load Shedding" alert is displayed via the thermostat screen in order to notify the homeowner that system operation is being modified based on the exterior control signal.

Mitsubishi Electric US

Mitsubishi offers a variety of ductless cooling and heating products worldwide, including mini-split single zone and multi-zone options. In North America, a more traditional residential ducted air handler option is also offered.

Mitsubishi offers a thermostat "interface" that is compatible with 3rd-party thermostats that utilize traditional 24 VAC control signals. The demand response capabilities that are available via the 3rd-party thermostat (such as thermostat temperature offset) will be applied to the indoor unit. One thermostat and one "interface" are required per indoor unit. Mitsubishi literature indicates that the interface has been tested with thermostats produced by several manufacturers (Nest and Honeywell among them).

Mitsubishi also offers its Diamond Controls solution, primarily for commercial applications, which can be used to manage DR events by adjusting thermostat temperature setpoints, limiting outdoor unit capacity, or both. Diamond Controls communicates with the electric utility or related entity via OpenADR communications. While not often implemented in residences (due primarily to cost), an adapter is available that allows Mitsubishi residential equipment to communicate with this commercial product and take advantage of its DR capabilities.

Beyond these currently-available advanced features, Mitsubishi is also working to develop a more direct solution for advanced DR capabilities through its residential equipment (including thermostat temperature offset and electric power curtailment bounded by maximum temperature offset from setpoint), as well as two-way information transfer using open communication protocols. Product release dates have not yet been announced.

WaterFurnace International

WaterFurnace is one of the leading manufacturers of ground-source heat pumps (geothermal heat pumps) in the U.S. While serving a niche segment of the market, they are nevertheless a leader in high-efficiency heat pumps for the residential market.

Most of WaterFurnace's products include a terminal block for 24 VAC control systems that allows an external relay to provide a DR control signal. The systems can be configured for "Load Shed," which applies load curtailment control by disabling compressor operation. "Emergency Shutdown" is also permitted, wherein both the compressor and indoor fan are disabled. System response to the DR signal is configured by the system installer or service technician.

A second option is available for systems that utilize the Aurora Advanced Control System. A "Smart Grid/On Peak" input signal can be enabled via an external switch closure. The system can be configured by a technician to implement "Load Shed" (load curtailment by disabling compressor operation) or use the Unoccupied Setpoints specified via the thermostat to define a setpoint modification in order to reduce power usage. Reducing compressor speed may also be possible, but the status of implementation is uncertain.

Proposed AHRI Standard 1380

The Air-Conditioning, Heating & Refrigeration Institute (AHRI) is a trade association that represents manufacturers of residential and commercial air conditioning, heating, water heating, and commercial refrigeration equipment sold worldwide. AHRI's member companies account for more than 90 percent of the HVAC, refrigeration, and water heating equipment manufactured and sold in North America.

Based on a number of issues, including the availability of enhanced demand response communication systems and growth of variable capacity air conditioners and heat pumps in the marketplace, AHRI formed a technical committee to develop a new standard, entitled "Demand Response through Variable Capacity HVAC Equipment in Residential and Small Commercial Applications." The purpose of the standard is to establish requirements for variable capacity HVAC systems of 65,000 Btu/hr or less that are capable of supporting DR strategies to benefit the electric grid in a predictable manner and to facilitate end-user participation in DR, price response, or similar incentive programs offered by electric utilities or related entities. The scope of the standard includes:

- Standardized communications between the equipment and electric utility DR programs
- Specifications for communication connections
- Specific HVAC equipment actions to be performed in response to DR utility signals
- Data collection and transmittal to configure the DR-ready equipment and facilitate enrollment in DR programs

The technical committee represented a strong collaboration of many stakeholders, including AHRI members, electric utilities, EPRI, EPA Energy Star, Center for Energy Efficiency (CEE), and others. The draft standard was unanimously approved by the technical committee in September 2017. Review and approval through various AHRI committees will occur in late-2017. Once approved by AHRI, it is anticipated that the standard will be immediately submitted for review and approval by the American National Standards Institute (ANSI).

At this time, several equipment manufacturers have indicated that they are planning to offer products and features that comply with this standard following its publication in final form. However, the exact timing of the release of such products and features is unknown, partly due to uncertainty in the official publication date of Standard 1380.

Market Summary

Table 11-1 summarizes the availability of DR features for residential HVAC products. The table lists conventional, improved, and advanced DR functionality. The list of manufacturers shown is not all-inclusive, but instead represents major equipment manufacturers and is meant to provide a cross-section of DR capabilities available in the marketplace. Given the likely release of AHRI Standard 1380 in the coming months, an "AHRI compliant" entry is also listed to show some of the features that may be available as such products are released.

The table below documents information obtained from published literature from the HVAC equipment manufacturers, as well as personal communications with company representatives. Product development efforts beyond those listed are likely being pursued, but details were not available for disclosure at the present time.

As shown in Table 11-1, all listed manufacturers offer systems that can implement conventional demand response via duty cycling with an external switch or thermostat setpoint control. Several manufacturers also offer systems with load curtailment terminals integrated within the system hardware. These terminals allow load control for both heating and cooling using a single external switch closure. In most cases, this switch closure turns off the outdoor unit (compressor and condenser fan), although some products allow both the indoor supply air fan and outdoor unit to be cycled off. One manufacturer currently allows the occupant to specify via the thermostat if the switch closure turns the outdoor unit off or instead reduces the variable-capacity compressor to its minimum speed. And, as stated previously, several manufacturers are developing advanced DR capabilities primarily driven by AHRI Standard 1380P.

Table 11-1
Residential HVAC Manufacturer Support for DR Functionality

Manufacturer	Conventional		Improved	Advanced[1]				
	Duty Cycle with External Switch	Thermostat Setpoint Control	Integrated Load Curtailment Terminals[2]	Load Curtailment Control	Emergency Load Control	Load Increase Control	Temperature Setpoint Control	Energy Price Function
Carrier	X	X	A					
Daikin (Goodman)	X	X		D				
Ingersoll-Rand (Trane / American Standard)	X	X	B, C	D				
Lennox	X	X	B					
Mitsubishi Electric	X	X		D			D	
WaterFurnace	X	X	C					
AHRI 1380-compliant				X	X		X[3]	X

[1] Advanced functions include DR signal directly delivered to HVAC system and 2-way communications between the utility and the HVAC system.
[2] Electric terminals available within the system for connection to external switch. Single switch may control both heating and cooling operation.
[3]Temperature setpoint control used exclusively for load increase (“Load Up”).
X – feature available
A – DR signal response configurable by the occupant, DR event notification is displayed via thermostat
B – DR signal response not configurable, DR event notification is displayed via thermostat
C – DR signal response configurable by system installer or technician, however, no DR event notification at thermostat
D – feature under development, not yet commercially available

A
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