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Demand Response-Ready Programmable Thermostat Specification

Preliminary Requirements for CEA-2045 Field Demonstration

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ABSTRACT

This document is a specification for a programmable communicating thermostat with built-in demand response (DR) capabilities and a standard communication interface. The context for the development of this specification is a field demonstration project that EPRI is facilitating regarding the ANSI/CEA-2045 modular communication standard. In this project, utilities are fielding consumer end-use products and integrating them into a wide range of DR systems in order to assess the standard and determine the degree to which interoperability is achieved.

The project plan required that all of the field tests of a given product type be carried out using the same design, so that there is no regional customization, and the concept of a mass-producible product is directly evaluated. This required that utilities work together to develop a common set of requirements that are sufficient for supporting each DR program. This collaborative process was conducted early in the project, resulting in the preliminary specification represented in this document. The project plan anticipates updating this specification later in order to incorporate any new requirements or adjustments that are identified during the field testing.

Keywords
CEA-2045
Demand response
DR-Ready
Programmable Thermostat
Communication
Smart Grid

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INTRODUCTION

In 2013 the Consumer Electronics Association released the ANSI/CEA-2045 standard. This standard defines a modular communication interface intended to be designed into end-use loads to enable demand response (DR). The CEA-2045 standard has been described in detail in EPRI report 3002004020, Introduction to the CEA-2045 Standard, EPRI, Palo Alto, CA 2014[1].

Utilities and manufacturers are assessing this new standard to determine the degree to which it meets the needs of consumers, aggregators, and utilities. EPRI is facilitating a collaborative project that is specifically studying the extent to which CEA-2045 provides compatibility and interoperability with the wide range of systems into which consumer loads might be connected. If a modular interface works as intended, achieving interoperability and being self-installable by consumers, it could significantly advance the state of demand response worldwide. A detailed description of the CEA-2045 Field Demonstration project, including its goals and plan, has been provided in EPRI report 3002004009, ANSI/CEA-2045 Field Demonstration Project Description[2].

The project plan required that all of the field tests of a given product type be carried out using the same design, so that there is no regional customization and the concept of a mass-producible product is directly evaluated. This required that utilities work together to develop a common set of requirements that are sufficient for supporting each DR program. This collaborative process was conducted early in the project, resulting in the preliminary thermostat specification represented in this document. The project plan anticipates updating this specification later in order to incorporate any new requirements or adjustments that are identified during the field testing.

[1] http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004020

[2] http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004009

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MECHANICAL AND ELECTRICAL REQUIREMENTS

HVAC Types

- **REQ.ME1** Minimum, three-stage heat for heat pump applications and dual stage cooling for conventional systems.
- **REQ.ME2** Basic functional requirements of a typical programmable thermostat.

CEA-2045 Port Characteristics

- **REQ.ME2** The PCT shall support the DC form factor described in Appendix A of the CEA-2045 standard.
- **REQ.ME3** The PCT should accommodate the maximum allowable dimensions for the DC form factor enclosure.

User Interface Characteristics

The PCT shall include a user interface that, at a minimum, supports the following features:

- **REQ.UI0** An indicator of successful communication connectedness (based on the CEA "Outside Comm Connection Status" message)
- **REQ.UI1** An indicator of when the PCT is operating in a curtailed or heightened fashion based on a request received from the UCM
- **REQ.UI2** An event override button (note also monitoring requirement REQ.M1)
- **REQ.UI3** The PCT display must be capable of displaying Real-time Price and Whole Home Energy Usage information $/Wh, W and Wh.
- **REQ.UI4** (Optional) The PCT display must be capable of supporting both: 1) displaying the current temperature offset and 2) enabling the user to change the temperature offset.
- **REQ.UI5** (Optional) If Price Relative or Actual Price is available, the PCT should allow the user to assign an offset to different Relative Price or Actual Price thresholds.

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CEA-2045 COMMUNICATION REQUIREMENTS

The communication requirements are described in three groups: Link-Layer, Control, and Monitoring as detailed in the following sub-sections.

Link-Layer Requirements

Table 3-1
Link-Layer Requirements

Requirement	CEA-2045 Message	Thermostat Implementation
REQ.LL1	Link ACK	Supported. Required per the standard.
REQ.LL2	Link NAK	Supported. Required per the standard. PCT shall detect and report all the standard NAK codes.
REQ.LL3	Request Different Power Mode	Supported. This function is required to support Wi-Fi UCMs that may require more energy to operate.
	Request Different Bit Rate	Not required. Default Bit Rate is acceptable.
REQ.LL4	Query & Response: Maximum Payload Length	Supported. In order to support the messages identified herein (Get_Information is the longest), the unit must support negotiation of up to 64 bytes message length.
	Query & Response: Get SGD Slot Number	Not supported. Not applicable with only one slot on the device.
	Query and Response: Get Available Slot Numbers	Not supported. Not applicable with only one slot on the device.
	Send Next Command to Slot	Not supported. Not applicable with only one slot on the device.

Control Requirements

This section identifies the CEA-2045 control messages that must be supported and the associated PCT responses. Any one of these message/response combinations may be utilized by any number of utility program strategies. Several examples of such strategies are identified in a later section of this report.

The responses defined herein are designed to achieve a somewhat predictable behavior so that the contribution of thermostats can be properly valued. The graphic in Figure 3-1 is provided to show the different control and operational modes of a PCT.

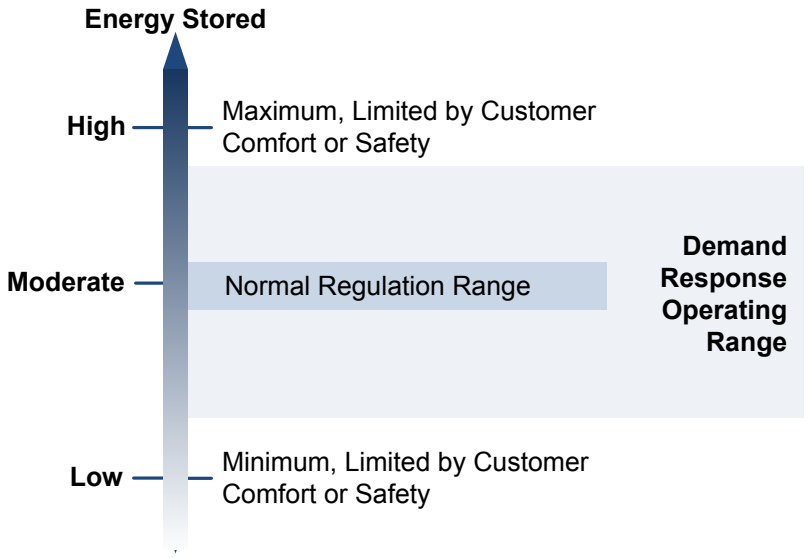

Figure 3-1
PCT Temperature Control Range

A PCT, or thermostat, is a component of an HVAC (heating, ventilation and air conditioning) system that's designed to automatically govern the operation of equipment to control the temperature and humidity in buildings. The diagram in Figure 3-1 represents the stored energy related to the energy required to support the zone in which the thermostat is controlling. The upper and lower tic marks represent the zone's energy envelope, while the middle of this range marked "moderate," represents the typical energy storage level maintained by the zone when the thermostat is controlling the temperature at a set point. The "normal regulation range," indicated by the dark shaded region, represents the typical range of stored energy of the zone as determined by the thermostat's dead band. The lighter shaded area, "demand response operating range," represents the potential range of stored energy that the zone and thermostat can manage. This document is designed to define the manner in which a thermostat with a CEA-2045 port utilizes messages received through the port to manage the stored energy of its zone.

- **REQ.C1** The PCT logic shall be such that all curtailment requests expire and the PCT returns to the previous customer-chosen mode of operation (normal operation) after twelve hours, unless another request is received within that time.
- **REQ.C2** The PCT logic shall be such that upon power cycle, all operational settings shall return to normal. Any non-default settings must be renegotiated. For example, if power is cycled while a curtailment event is active, the PCT should return to a normal operating state and should not restart in the curtailed state. If the PCT needs to be placed back into the curtailed state, the UCM would need to resend the curtailment request to the PCT.

Table 3-2
Control Requirements

Requirement	CEA-2045 Message	Usage	Thermostat (PCT) Response
REQ.C3	<Basic> Application ACK	As Specified	The PCT will support the application ACK as described in the CEA-2045 specification.
REQ.C4	<Basic> Application NAK	As Specified	The PCT will support the application NAK as described in the CEA-2045 specification.
REQ.C5	<Basic> Outside Comm Connection Status	As Specified	The PCT must use this message as a "heartbeat" signal. If not received within 15 minutes, the PCT will return to the previous customer-chosen mode of operation, unless the heartbeat is lost during a curtailment event with a known duration. In this case, the event should be processed to its conclusion. If the heartbeat has not returned by the end of the active event, the PCT should revert back to its normal operating state.
REQ.C6	<Basic> End Shed/Run Normal	As Specified	Upon receipt, the PCT should revert back to its normal operating mode or user-defined operating schedule.
REQ.C7 Optional	<Basic> Present Relative Price	As Specified	The Relative Price command is used in association with a range of price-based programs and lends strongly to consumer-configurability of response (i.e., no particular response is mandatory from a utility perspective). This demonstration project DOES require support of this message and a response to it, but the PCT manufacturer may propose the response and method by which customer adjustability is provided (if any). A simple example of how a PCT could respond to the relative price signal is as follows: • Offer consumers configurability of a "Low Price Threshold" and a "High Price Threshold." • If Present Relative Price is < "High Price Threshold": – the PCT should operate normally. • If Present Relative Price is above "High Price Threshold": – the PCT will act to reduce demand of the HVAC system to the minimum temperature, limited by consumer comfort.

Table 3-2 (continued)
Control Requirements

Requirement	CEA-2045 Message	Usage	Thermostat (PCT) Response
REQ.C8	<Basic> Shed	The optional "Event Duration" field may be provided by a UCM. If supported see REQ C14	Shed Events are used as part of fixed-incentive based programs and require a predictable response: The offset should be set to 4ºF. Example (Cooling Mode) • Temperature Set point prior to Shed: 72 ºF • Temperature Set point after receipt of Shed: 76 ºF • Temperature Set point after receipt of End Shed/Run Normal: 72 ºF
REQ.C9	<Basic> Critical Peak Event	The optional "Event Duration" field may be provided by a UCM. If supported see REQ C14	Critical Peak Events are typically used as part of fixed-incentive based programs and require a predictable response. These events are typically infrequent (only a few times a year) so responses are more aggressive. The offset should be set to 8ºF. Example (Cooling Mode) • Temperature Set point Prior to Critical Peak Event: 72 ºF • Temperature Set point after receipt of Critical Peak Event: 80 ºF • Temperature Set point after receipt of EndShed/Run Normal: 72 ºF
REQ.C10	<Basic> Grid Emergency	The optional "Event Duration" field may be provided by a UCM. If supported see REQ C14	During an emergency event, the PCT shall immediately shutdown the system. For grid emergencies, the PCT may time out and resume operation after one hour. Note: Customer overrides shall be allowed, even for grid emergencies.
REQ.C11	<Intermediate> Set/Get TemperatureOffset	As specified	The temperature offset parameter is used to either increase or decrease the temperature set point of the PCT independent of the mode of operation. Example (Cooling Mode) Operating Mode: Cooling Mode • Temperature Set point: 72 ºF • TemperatureOffset = 6ºF • Temperature Set point After receipt of TemperatureOffset: 78 ºF • TemperatureOffset = 0ºF • Temperature Set point: 72 ºF

Table 3-2 (continued)
Control Requirements

Requirement	CEA-2045 Message	Usage	Thermostat (PCT) Response
REQ.C12	<Basic> Load Up NEW message, not included in current version of the CEA-2045 standard Opcode 1 = 0x17 Opcode 2 = Duration	The optional "Event Duration" field may be provided by a UCM. If supported see REQ C14	The intent of this message is to use the zone to immediately store the maximum allowable amount of energy. A Shed message could be used prior to the Ramp Up command to maximize the storage capacity. For example, referring to Figure 3-1, if a thermostat has a 1 degree dead band and if the actual stored energy is approaching the lower limit of this dead band, the Load Up command could be used to request that the PCT immediately go to the top of this dead band. The intent is NOT to increase the total energy usage of the zone.
REQ.C13	<Intermediate> Get/Set Set Point	As specified	The intent of this message is to provide the UCM with the tools necessary to monitor and manage the PCT set point as determined by the DR program.

- **REQ.C14** If the UCM provides an "Event Duration" in association with any energy management function, then the thermostat shall assume that the event has ended when EITHER the duration expires or an "End Shed" is received, whichever comes first.

Feedback/Reporting Requirements

This section identifies the CEA-2045 monitoring messages that must be supported, in addition to the ACK and NACK application layer messages that must be supported.

- **REQ.M0** The data update time of the following messages must be less than one second.

Table 3-3
Monitoring Requirements

Requirement	CEA-2045 Message	Usage	Thermostat (PCT) Response
REQ.M1	<Basic> Customer Override	As Specified	The PCT must provide consumers with an event only override option. If pressed, the PCT must report the override to the UCM using this message. If an event override occurs, the PCT shall return to normal operations and ignore any new curtailment messages for the next 4 hours. The PCT shall provide a simple mechanism to override current and future curtailment events for up to 24 hours. This could be pressed prior to the receipt of an event (proactively).
REQ.M2	<Basic> Query & Response: What is your Operational State	As Specified	The PCT shall support these messages. Reporting: 0 – Idle Normal, when the PCT is in a normal mode of operation and not calling for Cooling or Heating (i.e., Compressor is not running) 1 – Running Normal, when the PCT is in normal operations and is calling for Cooling or Heating. 2 – Running Curtailed Grid, when the PCT is using a CEA-2045 command to operate and is calling for Cooling or Heating 3 – Running Heightened Grid, if a request has been made to cause the system to operate during a time or state in which it typically wouldn't be operating 4 – Idle Grid, when the PCT is using a CEA-2045 command to operate and is NOT calling for Cooling or Heating 5- SGD Error Condition, if anything is internally faulted.
REQ.M4	<Intermediate> Query & Response: Info Request		PCT shall support, at a minimum, all mandatory device information plus the model number and serial number optional fields associated with the Info Request. Device Type shall be reported as a 0x0004 "Central AC – Heat Pump."

Table 3-3 (continued)
Monitoring Requirements

Requirement	CEA-2045 Message	Usage	Thermostat (PCT) Response
REQ.M5	<Intermediate> Get/Set Commodity Read Request and Get/Set Commodity Read Reply	Energy Usage Information Display and Energy Storage Capacity	The PCT shall support the following: • Whole Home Energy Usage Display PCT shall request building energy usage from the UCM for display purposes; (present consumption rate) and cumulative lifetime energy consumed. Commodity Code = 0 "Electricity Consumed" to the UCM. – *Total Energy Storage Capacity Commodity Code = 6 – *Present Energy Storage Capacity Commodity Code = 7[3] – *Total Energy Storage Capacity and Present Energy Storage Capacity are new messages defined in the "Recommended Changes to the ANSI/CEA-2045 Standard." • Optional - PCT should also provide electric power (present consumption rate) and cumulative lifetime energy consumed. Commodity Code = 0 "Electricity Consumed" to the UCM. Power calculations: TBD These values can be estimates based on operating state; metering electronics are not required.
REQ.M6 (Optional)	<Intermediate> Get Energy Price	Energy Usage Information Display	PCT shall request Energy Price from the UCM for use in display. Could be used to show published rate or used to calculate actual or projected costs.

[3] New Energy Storage Commodity codes are included in the latest CEA-2045 draft. For details see: http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002003988

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EXAMPLE UTILITY CONTROL STRATEGIES

This section is included for informational purposes only. It describes several example utility program types and identifies the messages that may be used in association with these programs. From the PCT design perspective, this information is irrelevant. Only the message-to-response mappings provided in the previous sections matter.

Direct Load Control

Utility Direct Load Control programs have traditionally used external relays to control the power to end-use devices. These are simple control methods and are commonly used for water heating and pool pump control. A predictable response is needed for these programs. Messages potentially used in conjunction with this control strategy include:

Table 4-1
Example Messages Related to Direct Load Control

CEA-2045 Message	How Used
<Basic> Shed	To inform devices that a control event is in effect
<Basic> End Shed/Run Normal	To inform devices to return to normal at the close of an event

Time of Use (TOU)

Utility Time-of-Use programs involve an energy price that varies with time. For residential programs, the schedules for these price variations are fixed and known to consumers in advance. Advanced meters capture and report the consumption during each time interval of the day, allowing for bill calculation.

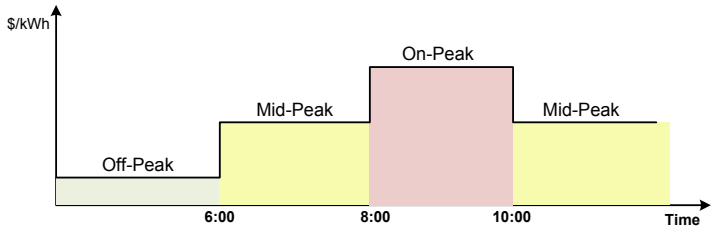

Figure 4-1
Time-of-Use Example

To aid consumers in managing their consumption patterns, price information can be provided to end-use devices. Messages potentially used in conjunction with this control strategy include:

Table 4-2
Example Messages Related to Time-of-Use

CEA-2045 Message	How Used
<Basic> Present Relative Price	The Present Relative Price signal to the PCT is varied according to what is currently in effect.

Critical Peak Pricing (CPP)

Critical Peak Pricing programs are a dispatchable form of Time of Use. Critical Peak events are called, usually with day-ahead notification, to the consumer. Typically, CPP program agreements limit the number of event days per year to a small number (e.g., 10) and involve prices that are substantially higher than normal. Critical peak events may be used in conjunction with regular daily TOU. Messages potentially used in conjunction with this control strategy include:

Table 4-3
Example Messages Related to Critical Peak Pricing

CEA-2045 Message	How Used
<Basic> Critical Peak Event	To inform devices that an infrequent Critical Peak event is in effect
<Basic> End Shed/Run Normal	To inform devices to return to normal at the close of an event

Grid Emergencies

Grid emergencies are not a part of any normal program. Grid emergency messages would only be sent to end devices during emergency situations when complete power outages are the alternative. Messages potentially used in conjunction with this control strategy include:

Table 4-4
Example Messages Related to Grid Emergencies

CEA-2045 Message	How Used
<Basic> Grid Emergency	To request that devices shut down due to a grid emergency
<Basic> End Shed/Run Normal	To inform devices to return to normal once the emergency condition is over

Cycling-Based Managed Load Operation

Managed Load Operation represents a number of control strategies in which the water heater may be requested to operate at particular times (to absorb energy), in addition to avoiding operations at other times. Use cases associated with this kind of management include following variable generation resources such as wind energy. Messages potentially used in conjunction with this control strategy include:

Table 4-5
Example Messages Related to Cycling-Based Managed Load Operation

CEA-2045 Message	How Used
<Basic> Shed	To put the thermostat / HVAC system in a state such that its capacity to store energy is increased or maximized
<Intermediate> Start Autonomous Cycling	To request that the thermostat / HVAC system absorb energy at an average rate (over a one hour cycle) determined by the specified duty cycle
<Intermediate> Terminate Autonomous Cycling	To inform the thermostat / HVAC system to return to normal operation, once the managed load operation is past

Up/Down Energy Storage Management

The number of scenarios in which end-use loads could be used to store energy is growing with increases in variable generation such as wind and solar. Thermostat / HVAC systems could be used to absorb excess energy to compensate for this variable resource. One way in which this could be performed is by scheduling a curtailment event to reduce the conditioned space's stored energy prior to the time when storage is needed. Messages potentially used in conjunction with this control strategy include:

Table 4-6
Example Messages Related to Up/Down Energy Storage Management

CEA-2045 Message	How Used
<Basic> Shed	To put the thermostat / HVAC system in a state such that its capacity to store energy is increased or maximized
<Basic> Load Up	To request that the thermostat / HVAC system absorb energy to the extent possible
<Basic> End Shed/Run Normal	To inform the thermostat / HVAC system to return to normal operation once the managed load operation is past.

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