

REFERENCE JOINT APPENDIX JA5

Technical Specifications

**For Programmable Communicating Thermostats
Compliant with Title 24-2008**

JOINT APPENDIX 5

Technical Specifications For Programmable Communicating Thermostats

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5.1 Introduction

This document provides a high level technical specification for a programmable communicating thermostat (PCT) that is compliant with the 2008 Update to the Title 24 Building Energy Efficiency Standards. All PCTs shall comply with the specifications set forth in this document or specification approved by the Executive Director. This specification focuses on four interfaces that the CEC has determined must be supported by all PCTs:

1. HVAC System Interface
2. Communications Interface
3. Expansion Interface
4. Human-Machine Interface

Sections within this document address each interface in terms of its hardware and software characteristics. In general and unless otherwise specified, this specification is compatible with NEMA Standards Publication DC 3-2003 – “Residential Controls – Electrical Wall-Mounted Thermostats”.

The Communications Interface is defined as a set of logical services that may be performed either over the mandatory wide area communications interface (e.g. Radio Broadcast Data System -RBDS-) of the PCT, or over an optional external physical network interface connected to the Expansion Interface.

These interfaces are designed to permit a variety of intended uses for PCTs that have been defined in other publications (see references in Annex C). To the extent possible, this document strives to be upward compatible with related efforts underway (e.g. the Joint California IOU PCT effort and the OpenHAN use case and requirements development effort) that intend to construct extended capabilities on the Title 24 foundation. Upward compatibility will be facilitated by not specifying any capability or feature that can be foreseen to contradict or impede the clear direction of those related efforts.

The specifications in this document are based on the Reference Design for Title 24 PCT's² and are compatible with the architectural principles set forth in the CEC PIER Strawman Reference Design for Demand Response Information Exchange³.

PCT Vendors should use Title 24 code language, this document, and the documents they reference to make early design decisions on physical design (e.g. mold plastic to support connectors), processing power, code space, working memory, and code licensing. These documents provide enough information to make these decisions. It is expected that only

² E. W. Gunther, “A Reference Design for the California Title 24 Programmable Communicating Thermostat”, CEC PIER Consultants Report, November, 2007

³ E. W. Gunther, “A Strawman Reference Design For Demand Response Information Exchange”, CEC PIER Consultants Report, October, 2004

firmware changes to a compatible platform will be necessary during 2008 to ensure interoperability with the statewide communications system and compatibility with CEC goals and policy requirements. The following elements are addressed in this document and are considered the key requirements that gate early design and decision making:

- Support of the MMC/SDIO expansion port (physically and logically) – see the reference given for the specification to support BlueTooth over an SDIO interface. If you can handle that specification, you can support the “worst case”.
- Support for MMC/SDIO card based firmware upgrade – for example, the use case infers that you need to be able to buffer a candidate firmware upgrade without losing the last known good firmware.
- Support for the core cryptographic primitives described in this document which include:
 - Support Elliptic Key and other cryptographic primitives sufficient to support the Digital Signature Standard as defined in ANSI X9.62-2005 and FIPS 186-2 for a key size of 256 bits.
 - Support buffering the last 500 message ID’s (nonce’s) sent to detect replay.
 - The ability to carry out the PCT registration use case defined in Annex A of this document.
- The ability to generate and embed in the PCT at manufacturing time a random number of up to 256 bits in size to be used for the registration process.
- Support for an internal clock that can be updated using the communications network as defined herein.
- Support for the RBDS radio and the ability to decode T24 messages from that source
- Support for the Basic HVAC terminal interface specification

The following sections describe these and other elements of the specification in more detail.

5.1.1 Required Functional Resources

The following PCT functional resources are required by Section 122(c) of the Standards:

- a) A default, non-removable, **one-way communications device** that is compatible with the statewide DR communications system (RBDS protocol standard⁴).
- b) An industry-standard **Expansion/Communication port** (Based on MMC / SD / SDIO standards⁵).
 - a. This port is available to be used by either a memory module or a module supporting two-way communications with the statewide RBDS DR communications system. Refer to Section 3 for more information.
- c) An industry-standard **display facility** that shall be used to display the following:

⁴ United States RBDS Standard NRSC-4-A, National Radio Systems Committee, April 2005

⁵ SD Specifications Part 1: Physical Layer Simplified Specification, Version 2.00, September 25, 2006; SD Specifications Part E1: SDIO Simplified Specification, Version 2.00, February 8, 2007

- a. The current **communications status**, indicating whether status is normal or abnormal (always displayed).
 - b. The **type of event in progress**: Emergency event, price event, or no event (always displayed).
 - c. **Maintenance-related information**: Icons and/or error codes (always displayed).
 - d. The **current temperature** (always displayed)
 - e. **Thermostat settings** (under customer control)
 - f. **Hex character strings are strings that** are entered by a customer or installer to represent the PCT's system address, elected DR options, and possibly a public security key. Such strings may be 26 to 28 characters long. It is recommended that these strings be broken into 4 character fields separated by spaces to aid readability and verification.
- d) One or more setting mechanism(s) that allow a customer to change the following thermostat settings at any time except during emergency events:
- a. A **temperature setpoint** and associated starting time used during normal operation.
 - i. The PCT shall provide a separate pair of parameters for at least four operating periods that collectively govern thermostat operation during the 24-hour day.
 - b. **Temperature offsets** used during price events:
 - i. The PCT shall provide one price-event offset for heating. The PCT shall be shipped with a default value of -4°F. Only negative values are allowed.
 - ii. The PCT shall provide one price-event offset for cooling. The PCT shall be shipped with a default value of +4°F. Only positive values are allowed.
- e) An **entry mechanism** for hex character strings, used to represent the PCT's system address, elected DR options, and possibly a public security key.
- f) A **clock mechanism** that allows the PCT to execute temperature setpoints scheduled by the customer and to respond to events.
- g) A data entity representing the **currently sensed temperature**.

5.1.2 Required Functional Behavior

The following describes how the PCT needs to behave and use the functional resources specified above to comply with Title 24 requirements.

a) One-Way Communications Device

1. The PCT shall receive incoming messages from the statewide DR communications system through its one-way communications device. The PCT

shall follow the instructions in those messages to perform temperature control during price events and emergency events.

2. A PCT shall be addressable by utility, area, substation, feeder, billing point, or demand response (DR) program.
3. A PCT shall automatically disable operation of the default, one-way communications device if a communications module occupies the Expansion Interface and the PCT detects a received communications signal.

b) Clock Operation

The clock mechanism enables the PCT to execute temperature setpoints scheduled by the customer. It also supports other timing functions such as start- and stop-time coordination for events; delay measurements after events expire.

Accuracy to a precision of one minute is acceptable for this operating environment and the applications being considered.

The PCT clock may be set and resynchronized by two means: (1) through system communications messages and (2) by the customer, using the PCT's human interface. Such action by either source will override a prior setting, regardless of which source set it. So in practice they override each other, an approach that serves the needs of the system and the customer in a balanced way. Either method may be used at any time, although the system will likely do so infrequently, one to four times a day. One system update time should be 2 AM, as that is frequently the official time used for changes to and from daylight-savings time.

The system may also elect to update PCT clocks just prior to an event and perhaps at intervals during an event, to prevent customers from gaming the system.

c) Normal Operation

Normal operation is defined to be the PCT's prevailing mode of operation as determined by the customer's prior settings and use of features⁶ provided by the PCT vendor's design. Aspects of normal operation may be modified or interrupted while price events or emergency events are in progress, but only to the extent required by those events.

To the extent such actions are not prohibited by event requirements or the PCT vendor's design, a customer may change PCT settings or use other features of a PCT vendor's design during an event. Those changes may alter what is considered to be the prevailing mode of operation when an event is terminated and the PCT returns to normal operation.

The PCT is mandated to provide a mode of operation whereby it controls temperature by following the scheduled temperature setpoints. Because price events and emergency events use this mode, the PCT shall require the customer to provide initial settings for temperature setpoints covering the full 24-hour day and temperature offsets (heating and cooling, as applicable) before PCT operation is allowed to commence. This requirement shall be re-imposed following any loss of PCT settings.

⁶ The specific design of such features (e.g. HOLD, OVERRIDE) is defined by individual vendors and not by this document.

d) Price Events

Upon receiving a price-event signal, the PCT shall normally adjust the currently applicable temperature setpoint by the number of degrees indicated in the temperature offset (heating or cooling, as appropriate) for the duration of the event.

Exception: Title 24 allows a customer to override any individual price event through use of an override function provided by the PCT vendor's design. If so used by a customer, the override shall be reset when the PCT returns to normal operation.

Summarizing, price events only constrain the operating range of the thermostat. They do not otherwise affect the operation and use of features provided by the vendor's design.

When the price event expires, the PCT shall return to normal operation after a delay. The delay shall randomly occur between 0 and 30 minutes, determined by a process that yields a uniform distribution of return times for a large number of PCTs.

The PCT shall also be equipped with the capability to allow customers to define setpoints for heating and cooling in response to price signals as an alternative to temperature-offsetting response as follows:

1. The default setpoint in the cooling mode shall be 88 °F. The PCT shall allow the user to change the default setpoint to any other value. The PCT shall ignore a temperature setpoint lower than the prevailing temperature entered by the customer just before the DR event.
2. The default setpoint in the heating mode shall be 64 °F. The PCT shall allow the user to change the default setpoint to any other value. The PCT shall ignore a temperature setpoint higher than the prevailing temperature entered by the customer just before the DR event.

e) Emergency Events

Upon receiving an emergency signal, the PCT shall respond to commands contained in the emergency signal, including (a) adjusting the PCT's currently applicable temperature setpoint with a signal-specified offset or (b) overriding the PCT's currently applicable temperature setpoint with a signal-specified temperature setpoint.

A PCT vendor's design may allow customers to specify new thermostat settings (i.e. temperature setpoints and temperature offsets) during emergency events, but the new settings shall not take effect until the PCT returns to normal operation. In such cases, it is the vendor's responsibility to determine how prevailing and pending settings are displayed.

Protective rules for remotely operating thermostats:

- A. For heating, a PCT shall ignore an emergency signal that specifies a temperature setpoint higher than the prevailing temperature setpoint entered by the customer just before the DR event.
- B. Similarly for cooling, a PCT shall ignore an emergency signal that specifies a temperature setpoint lower than the prevailing temperature setpoint entered by the customer just before the DR event.

- C. Any temperature offset provided by an emergency signal shall be specified as an unsigned value and always interpreted by a PCT as a change to the prevailing temperature setpoint in the direction that saves energy, regardless of whether heating or cooling mode is in effect.

This deals with the situation where some PCTs receiving an emergency signal are heating and others are cooling, particularly where the PCTs reside in different microclimates.

- D. Additionally, thermostats shall not be remotely set above 90°F or below 62°F. This measure protects customer premises from extreme temperatures that might otherwise be imposed using emergency offsets, should the customer already have a very high or low temperature setpoint in effect.

Summarizing, emergency events only constrain the operating range of the thermostat and prevent the customer from putting new thermostat settings (i.e. temperature setpoints and temperature offsets) into effect while an event is in progress. They do not otherwise affect the operation and use of features provided by the vendor's design.

When an emergency event expires, the PCT shall return to normal operation after a delay. The delay shall randomly occur between 0 and 30 minutes, determined by a process that yields a uniform distribution of return times for a large number of PCTs.

5.2 The HVAC System Interface

The physical connector on the PCT to be presented to the HVAC system shall be one or two screw terminal block headers (of a type chosen by the manufacturer) for direct control applications. The following sections describe each interface. Alternatively, a PCT may present a digital interface in a vendor dependent manner and is not described in this document.

5.2.1 Minimal Direct Control Interface

The PCT is required to support at least one 5 terminal connector for basic HVAC and heat pump systems. The terminal numbering and definitions for this connector is shown in Table 5.2-1. The terminal designations are from NEMA DC 3-2003⁷.

Table 5.2-1: Terminal Block 1 - Basic Thermostat Terminal Mapping (Required)

Term #	Signal Name	Normal Color	Notes
1	(Conventional) Y: Cooling	Yellow	Conventional - First stage cooling
	(Heat Pump) Y: Compressor		Heat Pump - First stage compressor. Will heat and cool based on the output of terminal 2 - O/B
2	(Conventional) W: Heating	White	Conventional - First stage heating
	(Heat Pump) O/B: Compressor		Heat Pump – Configurable option to energize the terminal for cooling (O option) or heating (B option)
3	G: Fan	Green	Fan switch on thermostat or on a call for cooling or heat pump
4	C: 24 Vac Common	Black	24Vac transformer neutral
5	R: 24 Vac Power	Red	24Vac transformer power. In a two source transformer installation, this terminal becomes Rh.
6 (opt)	Rc: 24 Vac Power	Red	OPTIONAL. Cooling transformer power for two source transformer installations. This terminal can be tied to terminal #2 in single transformer installations.

⁷ NEMA DC 3-2003 - <http://www.nema.org/redirect/redirectFile.cfm?ID=3528&user=109127&filename=/DC3.pdf>

5.2.2 Advanced Thermostat Direct Control Interface

Thermostats designed to support advanced HVAC systems such as multi-stage configurations will support a second terminal block. The terminal numbering and definitions for this connector are shown in Table 5.2-2. Note that the terminal numbering starts with 7 to minimize confusion with the mandatory terminal block. This will also facilitate use of a single, standardized connector in the future.

Table 5.2-2: Terminal Block 2 - Advanced Thermostat Terminal Mapping (Optional)

Term #	Signal Name	Normal Color	Notes
7	(Conventional) W2: Second Stage Heating	Various	Conventional - Second stage heating
	(Heat Pump) Aux/E: Auxiliary Heating		Heat Pump – Auxiliary and emergency heating control relay.
8	Y2: Second Stage Cooling	Blue or Orange	Second stage cooling for both Conventional and Heat Pump configurations
9	L: Equipment Fault	Various	<p>Installed as an input based on equipment type. When configured as in input, activation of the external generated signal informs the user via icon or LED enunciation, that the heat pump system is not available.</p> <p>Installed as an output based on equipment type. This output is used to “inform” zoning equipment that the system is in emergency heat mode. In this situation the secondary piece of equipment (zoning panel) will disable a call for heat pump.</p>
10	(Conventional) W3: Third Stage Heating	Various	Conventional - Third stage heating
	(Heat Pump) Aux2: Second Stage Auxiliary Heating		Heat Pump – Second stage auxiliary heating

Note that the optional connector may be extended in a vendor-dependent manner to support additional functionality. These terminals should use industry standardized designations, if appropriate, from those defined in Table 5.2-3 below.

Table 5.2-3 – Terminal Markings for Low-Voltage Class 2 Controls⁷

Heating	W
1 st Stage	W1
2 nd Stage	W2
3 rd Stage	W3
Cooling	Y
1 st Stage	Y1
2 nd Stage	Y2
3 rd Stage	Y3
Fan	G
Switched Side, Class 2 Power (Single Source)	R
Switched Side, Class 2 Power, Heating	RH
Switched Side, Class 2 Power, Cooling Side	RC
Unswitched Side, Class 2 Power (Number Sequentially)	C <input type="text"/>
Damper (heat); Reversing Solenoid (heat)	B
Damper (cool); Reversing Solenoid (cool)	O
General Purpose (Any Number)	A
Lockout Reset	X
One Side, Class 2 Circuit Switch-Heat	TT
Other Side, Class 2 Circuit Switch-Heat	TT
Indicator Circuits; System Monitors (Number Sequentially)	L <input type="text"/>
Switched Side, Second Source-Class 2 Power	K1
Unswitched Side, Second Source-Class 2 Power	K2
Defrost	DF
Emergency Heat Relay	E
Outdoor Thermistor	T

5.3 Expansion Interface

The expansion interface shall be available to extend the communication capabilities of the thermostat as well as to provide an external means of memory storage, logging, and firmware upgrade. The requirements associated with the expansion interface are:

- The physical interface (Figure 1) shall be implemented by using the Multi-Media Card (MMC) format as defined in the MMC System Specification Version 3.31⁸.
- The logical interface shall utilize the Serial Peripheral Interface (SPI) standard as defined in the MMC System Specification version 3.31. The MMC System Specification indicates that the SPI is optional for MMC devices, but it will be mandatory for the PCT Expansion Interface.
- PCT manufacturers may optionally support other physical and logical interfaces that provide backwards compatibility with the MMC version 3.31. Examples are MMC version 4.1 and SDIO version 2.0.
- It is desirable, but not mandatory, for the PCT to support the SDIO 2.0 standard such that off-the-shelf memory cards and other SDIO devices may be utilized by the PCT (if supported by the vendor). An example of a full featured device that could be supported by the SDIO interface is a Bluetooth radio built to Part E2 of the SD Specifications⁹.
- The interface shall be capable of recognizing whether a communications network interface MMC card or a memory card has been placed in the Expansion Interface. It shall also be able to identify which type of communications interface is installed.
- If a communications MMC card has been inserted and found to be valid and operational by the PCT, this interface shall be used in lieu of the internal, default, one-way communications capability in the PCT itself.
- Regardless of whether communications takes place over an internal or external interface, the communications shall take place in accordance with the specifications set forth in section Communications Interface.
- The expansion port shall be capable of being used to perform a local firmware upgrade to the PCT. The specific scenario that the PCT must support is described in Annex A, Scenario 9.

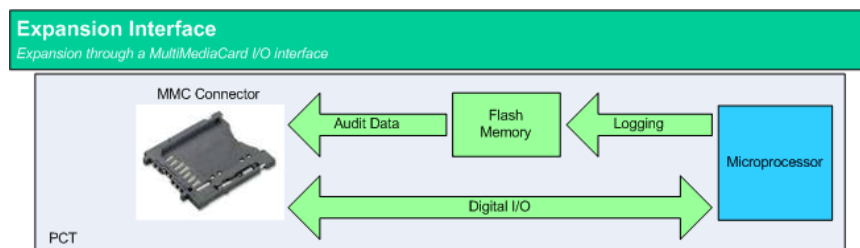


Figure 1 MMC Interface and Card Examples

⁸ MultiMediaCard Specification Summary Version 3.31 March 2003 - http://www.mmca.org/compliance/buy_spec/MMC-System-Summary-v3.31.pdf

⁹ SD Specifications Part E2: SDIO Card Bluetooth Type-A Simplified Specification, Version 1.00, April 3 2006

5.4 Communications Interface

The communications interface has two aspects – the physical interface and the logical interface.

The physical communications interface is has up to two components:

- A mandatory, internal interface supporting the US Radio Broadcast Data System (RBDS – NRSC-4-A) standard¹⁰;
- An optional one- or two-way communications interface connected through the Expansion Interface as selected and specified by a load serving entity.

The logical interface is described in the following section and consists of the information model used to represent messages sent to the PCT. The semantics of this model are derived from numerous existing standards and industry agreements in an effort to be as consistent and compatible with existing technology and implementations as possible. Note that the representation of the model is a logical representation only (i.e. it only defines the information exchanges; not the actual form of the exchange itself).

5.4.1 PCT Messages and Attributes

This section describes the messages and associated data payloads necessary to implement the functionality of the PCT as specified in Section 122(c) of the Standards while being compatible with the Joint California IOU PCT business requirements, revision 7,¹¹ and the use cases and requirements developed by the OpenHAN task force¹² of the UtilityAMI working group¹³. Each of the documents describes different sets of messages. The Section 122(c) specification is used as the base document for the purposes of describing the minimum functionality of a one-way DR system. The functionality described in the Joint California IOU PCT document extends the Title 24 requirements to include usability features which can increase the response to calls for short-term energy conservation. Proposed messages necessary to support additional functionality are included as an informative annex to this document. Note that it is expected that the messages designed herein may need to be updated (e.g. message ID's and enumerated constants) and/or new messages added as vendors begin implementation and the CEC conducts system level testing. Such changes will be reflected through various mechanisms as approved by the Executive Director.

If a message is received and validated, but it conflicts with a prior message, the newer message is executed and any continuing action for the prior message is automatically terminated by the PCT.

¹⁰ Developed by the Radio Broadcast Data System (RBDS) Subcommittee of the National Radio Systems Committee (NRSC) - <http://www.nrsstandards.org/SG.asp>

¹¹ Available at <http://sharepoint.californiademandresponse.org/pct/> in the document library.

¹² <http://sharepoint.ucaiug.org/OpenHAN/>

¹³ <http://sharepoint.ucaiug.org/OpenAMI/>

5.4.1.1 Event Modes

The PCT specifications recognize the following two basic system event modes:

1. Price Events, which can be overridden by the customer
2. Emergency Events, which may force an involuntary reduction in load.

In order to facilitate future changes in tariffs and regulations, the messages and data payloads that support these events have been designed to provide sufficient flexibility and information to handle such changes. To provide this flexibility, while ensuring consistency, several common data classes are defined below. These data classes are used by most messages for addressing, event identification, and time stamping. Event ID's are particularly important, because they are used to cancel events and to allow multiple event transmissions for message-transport reliability purposes. The addressing scheme may be used to enable regional or even PCT-level control resolution.

5.4.1.1.1 Price Events

This event allows the utility or another controlling entity to send a signal indicating that a super peak rate period is in effect. The controlling entity may wish to simply send a message that a peak price is in effect or send an explicit price.

Price Event Attributes and Requirements:

- The price event message defined below specifies a start and stop time for which the price event is in effect as well as the price itself.
- If the price field is set to zero, then this is a generic super-peak event with no specific price.
- The customer's PCT will have a default response to receiving a price event, but the owner may override that programming.
- PCT vendors are free to provide whatever flexibility they desire in allowing the owner to respond to the event alone or to the event and price.

5.4.1.1.2 Emergency (Grid Reliability) Events

This event class allows the utility or another controlling entity to issue specific directives to the PCT in order to address a grid reliability situation.

Grid Reliability Event Attributes:

- Provide a start and stop time as does a price event which allows them to be scheduled in advance.
- There are two flavors of the basic reliability event – change temperature and set temperature. The controlling entity may specify an arbitrary temperature increase or decrease from the PCT's current setpoint or simply specify a specific set point.

- The ability to specify an explicit setpoint is required by Title 24 to have the flexibility to mitigate the situation where customers change the setpoint just prior to the start of a reliability event in order to “game” the system.

5.4.1.2 Common Data Classes

All of the defined messages below make use of one or more common data classes. These common classes (types) are used to represent addressing information, date time stamps, and other common information.

Addressing <ADDR>

Common Addressing Information <ADDR>			
Attribute Name	Attr. Type	Explanation	M/O
Data			
Utility_ID	INT8U	Identifies the utility / DisCo that controls the PCT (Ex: 5=SCE)	M
Program_ID	INT8U	Demand response program identifier (Ex: 3=CPP, 1=non-curtailable)	M
Loc_ID	INT16U	Locates customer (Ex:0=ALL, 1..999 identifies an 'area', 1000 up identifies a substation)	M
Feeder_ID	INT8U	Feeder number within a substation (0 = all feeders, 1..N = feeder)	M
Cust_ID	INT64U	Identifies individual customer (Ex: 0=ALL)	O

Note: This addressing scheme may be updated to coordinate with IPV6 terminology and be suitable for use as a subset of a valid IPV6 address. Another potential update is to interpret the Loc_ID field as a Postal Zip Code.

The addressing scheme may be used to enable regional or even PCT-level control resolution. Note that the common data class and information models that implement it allows an addressing scheme to be implemented but this specification does not specify how it should be implemented nor how it should be used.

Date/Time Stamp <DTIME>

Common Date/Time Information <DTIME>			
Attribute Name	Attr. Type	Explanation	M/O
Data			
NTP_Seconds	INT32U	Seconds since 0h January 1, 1900 UTC	M
NTP_Fraction	INT32U	Fractional seconds	O

Note: All time stamps are in Universal Coordinated Time (UTC) using the SNTP Version 4 format as defined in RFC 4330. SNTP uses the NTP timestamp format which is represented as a 64-bit unsigned fixed-point number, in seconds relative to 0h on 1 January 1900. The integer part is in the first 32 bits and the fractional part in the last 32 bits. In the fractional part, all bits should be set to 0. When rollover of the NTP_Seconds field occurs in 2036 to start a new NTP era, context is sufficient to detect the new epoch (e.g. a second field less than the time stamp of the date of manufacture is implicitly defined in a new NTP epoch)¹⁴

¹⁴ See <http://www.ece.udel.edu/~mills/y2k.html> - “The NTP Era and Era Numbering”, L. Frank Baum.

Message Identification <MSG_ID>

Common Event Identifier <EV_ID>			
Attribute Name	Attr. Type	Explanation	M/O
Data			
Message_ID	INT16U	Used to uniquely identify each message and prevent replay.	M

Note: The ID may be a nonce to further prevent replay attacks. The PCT shall be capable of storing the last 512 or more message IDs received for comparison with newly received message IDs to verify that replay has not occurred.

Event Identification <EV_ID>

Common Event Identifier <EV_ID>			
Attribute Name	Attr. Type	Explanation	M/O
Data			
Event_ID	INT16U	Used to provide a single, unique event identifier for all messages associated with the same event. Cancellation events will reference this ID.	M

Event Price <PRICE>

Common Event Identifier <EV_ID>			
Attribute Name	Attr. Type	Explanation	M/O
Data			
Event_Price	INT16U	\$ / KWH * 0.0001 (Ex:2000 = \$0.20 / KWH)	M123
Event_Price_Ratio	INT16U	Event price is normal price x this_value / 100 (i.e. 200 means 2x price)	M123
Event_Price_Tier	INT8U	Indicator of relative price (ex:1=normal, 2=high, 3=very high, >1000 is a Tier ID)	M123

Note: One of the three M123 elements is mandatory

Cryptographic Signature <CRYPTO>

Common Crypto Hash Value <CRYPTO>			
Attribute Name	Attr. Type	Explanation	M/O
Data			
Sig_ID	INT8U	An energy commission assigned ID indicating the security domain parameter set used for this message	M
Sig_r	INT256U	r component of a FIPS 186-2 digital signature	M
Sig_s	INT256U	s component of a FIPS 186-2 digital signature	M

Note: The use of a digital signature for all messages is required. The signature is based on FIPS 186-2 and utilizes the ECDSA algorithm as defined in ANSI X9.62.

5.4.1.3 Message Commands for Minimum Title 24 PCT Functionality

Clock Set Command

Clock Set Command			
Attribute Name	Attr. Type	Explanation	M/O
Data			
Message_ID	<MSG_ID>	ID for this message	M
Cmd_ID	INT8U	Clock set command (ex: 1)	M

Address	<ADDR>	Which PCTs should use this information (this may be ignored)	M
Now	<DTIME>	Present time (Universal Coordinated Time – UTC)	M
DST_Next	<DTIME>	Time of next DST/SummerTime shift (ex:2006 302 7200)	M
DST_Offset	INT8S	Number of minutes (ex: -60 for USA change away from DST)	M
Crypto	<CRYPTO>	Message integrity value	O

Price Event Command

Price Event Notification			
Attribute Name	Attr. Type	Explanation	M/O
Data			
Message_ID	<MSG_ID>	ID for this message	M
Cmd_ID	INT8U	(ex: 2)	M
Address	<ADDR>	Which PCTs should use this information (this may be ignored)	M
Start_Time	<DTIME>	Event begin time	M
Stop_Time	<DTIME>	Event end time	M
Event_ID	<EV_ID>	Identifier of this price event (used for cancellation)	M
Event_Price	<PRICE>	One of three possible price options – see <PRICE>	M
Crypto	<CRYPTO>	Message integrity value	O

Price Schedule Command

Price Schedule Command			
Attribute Name	Attr. Type	Explanation	M/O
Data			
Message_ID	<MSG_ID>	ID for this message	M
Cmd_ID	INT8U	(ex: 23)	M
Address	<ADDR>	Which PCTs should use this information (this may be ignored)	M
Number_of_Prices	INT8U	number of triple entries	M
1 st _Price	<PRICE>	One of three possible price options – see <PRICE>	M
1 st _Start_Time	<DTIME>	Time that this price become effective	M
1 st _End_Time	<DTIME>	Time that this price is no longer effective	M
2 nd _Price	<PRICE>		O
2 nd _Start_Time	<DTIME>		O
2 nd _End_Time	<DTIME>		O
...			O
Crypto	<CRYPTO>	Message integrity value	O

Change Temperature Command

Change Temperature Command			
Attribute Name	Attr. Type	Explanation	M/O
Data			
Message_ID	<MSG_ID>	ID for this message	M
Cmd_ID	INT8U	(ex: 5)	M
Address	<ADDR>	Which PCTs should use this information (this may be ignored)	M
Start_Time	<DTIME>	Event begin time	M
Stop_Time	<DTIME>	Event end time	M
Event_ID	<EV_ID>	Identifier of this price event (used for cancellation)	M
Temp_Change	INT8U	Amount to change setpoint in 0.1 degree Celsius	M
Crypto	<CRYPTO>	Message integrity value	O

Note: Setpoint change sign is not specified – the thermostat knows which direction to change based on current mode for energy savings. Some PCTs receiving the message may be in heating mode while others are in cooling mode, particularly where the PCTs reside in different microclimates.

Set Temperature Command

Set Temperature Command			
Attribute Name	Attr. Type	Explanation	M/O
Data			
Message_ID	<MSG_ID>	ID for this message	M
Cmd_ID	INT8U	(ex: 6)	M
Address	<ADDR>	Which PCTs should use this information (this may be ignored)	M
Start_Time	<DTIME>	Event begin time	M
Stop_Time	<DTIME>	Event end time	M
Event_ID	<EV_ID>	Identifier of this price event (used for cancellation)	M
New_Temperature	INT16U	New temperature setpoint, in tenths of a degree Celsius	M
Crypto	<CRYPTO>	Message integrity value	O

Display Message Command

Display Message Command			
Attribute Name	Attr. Type	Explanation	M/O
Data			
Message_ID	<MSG_ID>	ID for this message	M
Cmd_ID	INT8U	(ex: 7)	M
Address	<ADDR>	Which PCTs should use this information (this may be ignored)	M
Message Length	INT8U	Number of characters in message	M
Message	STRING[n]	Message to display on display	M
Crypto	<CRYPTO>	Message integrity value	O

Cancel Event

Cancel Event			
Attribute Name	Attr. Type	Explanation	M/O
Data			
Message_ID	<MSG_ID>	ID for this message	M
Cmd_ID	INT8U	(ex: 9)	M
Address	<ADDR>	Which PCTs should use this information (this may be ignored)	M
Event_ID	<EV_ID>	Identifier of this price event (used for cancellation)	O
Crypto	<CRYPTO>	Message integrity value	O

Keep Alive

Keep-alive Command			
Attribute Name	Attr. Type	Explanation	M/O
Data			
Message_ID	<MSG_ID>	ID for this message	M
Cmd_ID	INT8U	(ex: 21)	M
Address	<ADDR>	Which PCTs should use this information (this may be ignored)	M
Crypto	<CRYPTO>	Message integrity value	O

5.4.2 Implementation Profiles

An implementation profile for a communications interface describes how the logical information models and transactions necessary to support it are actually implemented using a specific standard via the enabling services layer. The logical information models specify the attributes that can be read and written from the PCT and their expected behavior when transactions occur. The implementation profiles define the details of how the underlying protocol is used to implement the model, services, and transaction model. This specification does not specify a particular implementation profile – this is described in a separate CEC publication.

5.4.3 Security

The PCT communications system must be secure from a variety of cyber attacks. A thorough discussion of issues leading to the requirements and recommendations of this section may be found at <http://sharepoint.californiademandresponse.org/pct/>.

There are two attack mitigation types where specific requirements and guidelines can be defined for Title 24 compliant PCT's – business logic mitigation and cryptographic mitigation. The following sections provide the requirements and recommendations associated with this specification for each of these two mitigation types.

5.4.3.1 Business Logic

1. Thermostats shall not accept remote commands to increase energy usage except the cancel event message, discussed below.
2. Thermostats shall have hard-coded limits on what set points will be accepted via remote commands, to prevent unsafe set points.
3. Thermostats shall randomly delay for up to 30 minutes after being instructed to normally end or cancel an energy reduction event, avoiding sudden increases in load on the grid. The display of the thermostat shall not indicate the end of the event until after the random delay.
4. Thermostats will never automatically increase energy usage at the end of an event by any more than they originally reduced it.
5. Time synchronization commands received via the remote network shall override any time set locally.

5.4.3.2 Cryptographic Methods

Confidentiality of PCT message contents is not a requirement. For this reason, message packets are not encrypted but are instead signed using a method consistent with the FIPS 186-2 Digital Signature Standard. The Elliptic Curve Digital Signature Algorithm (ECDSA) as defined in

FIPS 186-2 and ANSI X9.62 shall be utilized. The PCT shall be capable of supporting a public key length of 256 bit or larger.

The PCT shall link each message with a timestamp and a non-sequential message identifier. The timestamp shall be accurate to within one minute per section 5.1.2 Required Functional Behavior c) Clock Operation. The PCT shall store the last 512 message identifiers received and compare each incoming message ID with the stored set. The PCT shall only accept messages with identifiers not in the stored set, and ignore messages with duplicated identifiers.

The general concept behind the PCT secure messaging scheme is to put a unique, random number into each PCT at the time of manufacture. This number is subsequently used in the installation process to register the PCT (see the registration scenario in the Appendix), as well as facilitate the transmission of cryptographic key information (a public key) to the device which will be used to verify the signatures of incoming messages.

Details associated with the specific cryptographic domain parameters (e.g. as elliptic curve family, key size, etc.) and other parameters necessary to ensure interoperability between the PCT and the statewide communication system are expected to be developed during 2008 and documented in a separate compliance manual. PCT vendors may base their processor capability, code size, memory space, and other parameters on the general requirements of this section.

5.5 Human-Machine Interface

This section discusses the interface between humans and the PCT. All core functional requirements for the Human-Machine Interface are defined in Section 122(c) of the Title 24 Standards. The following section addresses requirements for terminology.

5.5.1 Terminology

The only human-machine interface standardization required to support the Title 24 requirements is a clear definition of terminology. All other standard features of the PCT are up to the discretion and innovative talents of the thermostat manufacturers. **NOTE:** Minimum programming requirements shall meet the current Energy Star specifications.

PCT user interface and documentation shall use the following terminology.

Reliability Event / Emergency Event	Refers to a Stage 1 Emergency or Stage 2 Emergency message from the utility. Upon receiving an emergency event, the PCT shall adjust its settings according to the Title 24 requirements.
Price Event	Refers to a change in pricing sent to the PCT from the utility.
Stage 1 Emergency	The lowest level of the emergency events.
Stage 2 Emergency	The highest level of the emergency events.
Critical Peak Pricing Event (CPP)	A type of price event. When a CPP is received by the PCT, the device should take appropriate behavior as defined by the settings configured by the customer.
Over-Ride	Refers to a person adjusting the functional behavior of the PCT to ignore a State 1 emergency message. Upon receiving a Stage 2 emergency message, a PCT shall act normally and ignore the Over-Ride setting.
Provision	Describes the commissioning or binding process of connecting a PCT to the wide area network or to an in-premise network. NOTE: This process depends critically on the data security solution chosen, as described in section Error! Reference source not found.
Pending Event	Refers to a price event or emergency event that is scheduled but has not yet happened.
Active Event	Refers to a price event or emergency event that is underway.

Annex A: PCT Use Cases

These use cases were used to help identify requirements that are reflected in the main portion of the specification.

Scenario 1: Customer Installs PCT

- 1 Installer installs PCT in a new home or a qualifying re-model.
Installer connects any required devices (antenna, external communication module, etc.) to
- 2 PCT to support one-way communications
- 3 Installer puts PCT into Provisioning Mode to receive security and address information
- 4 Installer calls phone number to initiate PCT security and address registration
Installer provides the PCT's unique identifier number to automated system or phone
- 5 service personnel
Utility system transmits PCT specific data in a Provisioning Message over the Utility
- 6 Communication Infrastructure which is only acted on by the PCT being installed
PCT receives Provisioning Message and uses message data to complete configuration of
- 7 security keys and address information
- 8 PCT provides visual feedback to Installer that provisioning is successful

\
Notes Installer can be home builder, contractor, customer or other.

Primary Actor: Installer

Goal: Register a Programmable Communicating Thermostat with the Title 24 One-Way Broadcast System.

Stakeholders and Interests:

Installer: Wants confirmation of successful PCT registration with minimal time and hassle.

System Owner: Wants to have primary and backup public keys installed in the PCT.

System Operator: Wants to have public key installed in the PCT. Wants to be able to place PCT in a specific operational group (e.g.: region, substation, neighborhood, etc...).

Initial Conditions:

- a) The PCT is physically located inside a residence and has yet to be activated.
- b) The Manufacturer has embedded a 160-bit random number in the PCT.
- c) The System Owner has primary and backup public/private key pairs, and is known to the System Operator.
- d) The System Operator has a public/private key pair, and is known to the System Owner.
- e) The Installer has access to the out-of-band communications channel.

Minimal Guarantees:

- a) PCT remains capable of being registered on the system.
- b) No private keys are compromised.

- c) The PCT does not have increased vulnerability.

Success Guarantees:

- a) PCT is capable of receiving price or emergency signals.
- b) PCT can determine signals are authentic.
- c) PCT can be re-registered.
- d) System Owner and System Operator may distribute new public keys to the PCT.

Trigger: Homeowner summons Installer to residence (or becomes Installer) for the purpose of installing a PCT.

Main Success Scenario:

1. Installer retrieves random number from PCT.
2. Installer contacts System Operator via out-of-band channel.
3. Installer relays PCT random number to System Operator.
4. System Operator relays PCT random number to System Owner.
5. System Owner performs two XOR operations:
 - a) With PCT random number and System Owner's primary public key
 - b) With PCT random number and System Owner's backup public key.
6. System Owner sends results of XOR operations to System Operator.
7. System Operator performs XOR operation with PCT random number and System Operator's public key.
8. System Operator transmits registration signal including the labeled results of all three XOR operations to PCT.
9. PCT performs XOR operation with its random number and each of the three result numbers received via registration signal, recovering three labeled public keys.
10. System Owner signs activation message with System Owner's primary private key.
11. System Owner sends (signed) activation message to System Operator.
12. System Operator signs activation message (including signature) with System Operator's private key.
13. System Operator transmits (doubly signed) activation message to PCT.
14. PCT authenticates activation message: first with System Operator's public key; second with System Owner's primary public key.
15. PCT activates.

Manufacturer	The entity responsible for production of the PCT. This entity must have the capacity to build all required cryptographic capability into the PCT.
Installer	The entity responsible for placing the PCT in service within the home. This entity may or may not have technical training or expertise.
PCT	The Programmable Communicating Thermostat in the home.

Scenario 2: Customer programs PCT

- 1 Customer can set the time on the PCT but the time should be changed upon receipt of a valid time signal from the Utility Communication Infrastructure
 - 2 Customer programs PCT for normal desired temperature for different times of day and for different days. (This is functionally identical to current programmable thermostats)
 - 3 Customer can optionally change the default PCT program on its response to Price Events and Stage 1 Emergency Events
 - 3.1 Customer can change the temperature offset for cooling upon receipt of a Price Event
 - 3.2 Customer can change the temperature offset for heating upon receipt of a Price Event
 - 3.3 Customer can change the price level response based on the signals that the customer's utility sends and the capabilities of the specific model of PCT
 - 3.4 Customer can change the temperature offset for cooling upon receipt of a Stage 1 Emergency Event
 - 3.5 Customer can change the temperature offset for heating upon receipt of a Stage 1 Emergency Event
 - 4 Customer pushes "Run Program" button to activate normal PCT schedule
 - 5 PCT sets temperature according to the day and time of the programmed schedule
 - 6 PCT adjusts time when it receives a Clock Set message from the Utility Communication Infrastructure
- Notes

Scenario 3: PCT responds to 'Price Event' message

- 1 Utility sends Price Event message
- 1.1 Utility includes at least one form of pricing information in Price Event message (price / kW hour, price ratio, price tier)
- 2 PCT receives Price Event message from the Utility Communication Infrastructure
- 3 PCT responds to the Price Event message based on pricing information and the PCT's programmed response (Many options here. Assuming a basic response)
- 4 PCT adjusts the thermostat setting equal to the programmed temperature offset setting for a Price Event
- 5 PCT remains responsive to customer input to override the setback temperature setting
- 6 PCT waits until the Event End Time as indicated by the Price Event message

PCT returns to the operating state that existed prior to the Price Event message (Could be normal programmed schedule, holding a specific temperature, etc.)
7
Notes PCT will also respond to a Cancel Event message prior to the Event End Time

Scenario 4: PCT responds to 'Price Event' message based on price

1 Utility sends Price Event message
Utility includes at least one form of pricing information in Price Event message (price /
1.1 kW hour, price ratio, price tier)
2 PCT receives Price Event message from the Utility Communication Infrastructure
PCT responds to the Price Event message based on pricing information and the PCT's
3 programmed response
PCT chooses not to respond to Price Event because the programmed response is to ignore
4 events under a specific threshold price
Utility measures response to Price Event and determines that it does not meet the Utility's
5 needs
6 Utility has to purchase additional power at higher prices to meet demand
7 Utility sends new Price Event message with increased pricing level information
8 PCT receives Price Event message from the Utility Communication Infrastructure
PCT responds to Price Event message based on pricing information and the PCT's
9 programmed response
PCT now chooses to respond to Price Event message because the programmed response's
10 threshold has been met
PCT adjusts the thermostat setting equal to the programmed temperature offset setting for
11 a Price Event
12 PCT remains responsive to customer input to override the setback temperature setting
13 PCT waits until the Event End Time as indicated by the Price Event message
PCT returns to the operating state that existed prior to the Price Event message (Could be
14 normal programmed schedule, holding a specific temperature, etc.)
For a customer to realistically respond to different price levels received from the one way
Notes communication system, the customer will need to have an installed Time of Use meter
PCT will also respond to a Cancel Event message prior to the Event End Time

Scenario 5: PCT responds to Reliability Event message

1 Utility sends Reliability Event messages
Utility sends Reliability Event - Change Temperature message that includes a
1.1 temperature offset change value
Utility sends Reliability Event - Set Temperature message that includes an absolute
1.2 temperature set point value
2 PCT receives Reliability Event message from the Utility Communication Infrastructure
3 PCT responds to the Reliability Event message based on the PCT's programmed response
PCT adjusts the thermostat setting to save the most energy based on the received
Reliability Event messages (default response) or to the customer's programmed response
4 for a Reliability Event

- 5 PCT remains responsive to customer input to override the Reliability Event temperature setting
- 6 PCT waits until the Event End Time as indicated by the Reliability Event message
- 7 PCT returns to the operating state that existed prior to the Reliability Event message (Could be normal programmed schedule, holding a specific temperature, etc.)
- Notes PCT will also respond to a Cancel Event message prior to the Event End Time
- With two temperature setting messages, the desired default response and acceptable programmable responses need to be well defined

Scenario 6: PCT does not respond to Reliability Event message

- 1 Utility sends Reliability Event messages
- Utility sends Reliability Event - Change Temperature message that includes a
- 1.1 temperature offset change value
- Utility sends Reliability Event - Set Temperature message that includes an absolute
- 1.2 temperature set point value
- 2 PCT receives Reliability Event message from the Utility Communication Infrastructure
- 3 PCT responds to the Reliability Event message based on the PCT's programmed response
- PCT chooses not to respond to the Reliability Event because the programmed response is
- 4 to ignore Reliability Events

Scenario 7: PCT responds to Emergency Event message

- 1 Utility sends Emergency Event messages
- Utility sends Emergency Event - Change Temperature message that includes a
- 1.1 temperature offset change value
- Utility sends Emergency Event - Set Temperature message that includes an absolute
- 1.2 temperature set point value
- 2 PCT receives Emergency Event message from the Utility Communication Infrastructure
- PCT adjusts the thermostat setting to save the most energy based on the received
- 3 Emergency Event messages
- PCT is not responsive to customer input to override the Emergency Event temperature
- 4 setting
- 5 PCT waits until the Event End Time as indicated by the Emergency Event message
- PCT returns to the operating state that existed prior to the Emergency Event message
- 6 (Could be normal programmed schedule, holding a specific temperature, etc.)
- Notes PCT will also respond to a Cancel Event message prior to the Event End Time
- With two temperature setting messages, the desired default response and acceptable programmable responses need to be well defined

Scenario 8: PCT receives Event message with address information

- 1 Utility sends Event Message(s) with Addressing data in the message body (The exact message type is irrelevant for this use case)
- PCT receives Event Message with Addressing information from the Utility
- 2 Communication Infrastructure

- 3 PCT compares received Addressing data with the PCT's stored address information
 - 4 PCT determines that it is an intended Event Message recipient
 - 5 PCT responds to Event Message according to the message type and the PCT's programming
- Notes Title 24 indicates that accepting and acting on Addressing data is mandatory for the PCT.
The utility is not required to send Addressing data.
"Addressing data" refers to the Common Data Class that is included as part of messages sent by utilities to invoke a power saving response
"address information" refers to the information that must be input into a PCT that defines a particular PCT's actual address

Scenario 9: Firmware update via expansion port

- 1 User inserts SD memory card into expansion interface
- 2 PCT recognizes memory card and looks if a PCT vendor specific file is on the card
- 3 If so, the PCT validates the vendor proprietary information on that card through a vendor specified process (e.g. cryptographic hash or other signature)
- 4 If the vendor specific file contains a firmware image, the PCT will request acknowledgement from the user to replace the existing firmware with the update using the PCT's user interface in a vendor specified manner (e.g. push the red button three times in three seconds).
- 5 If the PCT does not successfully load the new firmware in a vendor specified amount of time, a watchdog timer or other mechanism will cause a reset and the PCT will resume normal operation using the original firmware (implies the ability to reliably retain the original firmware image and all configuration information)
- 6 The PCT utilizes its user interface in a vendor specified manner to signal success, failure, and recovery from failure.
- 7 Optionally, a log of the operation is written in clear text to the SD card for auditing purposes

Annex B: Glossary

Acronyms

▪ A/C	Air Conditioning
▪ ACSI	Abstract Communications Service Interface
▪ AMI	Advanced Metering Infrastructure
▪ AW	Advisory Warning
▪ CDC	Common Data Class
▪ CEC	California Energy Commission
▪ CI	Commercial / Industrial
▪ CIS	Customer information System
▪ CPP	Critical Peak Pricing
▪ CPUC	California Public Utility Exchange
▪ DES	Data Encryption Standard
▪ DR	Demand Response
▪ DRI	Demand Responsive Infrastructure
▪ EE	Energy Efficiency
▪ HVAC	Heating, Ventilation, and Air Conditioning
▪ IETF	Internet Engineering Task Force
▪ IOU	Investor Owned Utility
▪ ISO	Independent System Operator
▪ LCD	Liquid Crystal Display
▪ LED	Light Emitting Diode
▪ MD5	Message Digest 5
▪ MMC	Multi-Media Card
▪ NEMA	National Electrical Manufacturers Association
▪ NRSC	National Radio Systems Committee
▪ NTP	Network Time Protocol
▪ PAM	Price Alert Map
▪ PCT	Programmable Communicating Thermostat
▪ PRD	Price Responsive Device
▪ RFC	Request for Comments
▪ SDIO	Secure Digital Input / Output
▪ RBDS	Radio Broadcast Data System
▪ RX	Receive
▪ SHA1	Secure Hash Algorithm 1
▪ SNTP	Simple Network Time Protocol
▪ SPMS	Statewide Power Management System
▪ SPI	Serial Peripheral Interface
▪ TX	Transmit
▪ UCI	Utility Communications Interface
▪ UML	Unified Modeling Language
▪ XML	eXtensible Mark-up Language

Terms

- **Emergency Event:** An emergency event is issued through the utility communications network to PCTs when energy system reliability problems require a curtailment of residential energy use through temporary adjustment of thermostat settings. Emergency events make a temporary adjustment to a customer's temperature setpoint to lower energy use during a specified period.
- **Hash:** A hash value (or simply hash), also called a message digest, is a number generated from a string of text. The hash is substantially smaller than the text itself, and is generated by a formula in such a way that it is extremely unlikely that some other text will produce the same hash value.
- **Heat Pump:** A device that warms or cools a building by transferring heat from a relatively low-temperature reservoir to one at a higher temperature.
- **Implementation Profile:**
- **Price Event:** A price event is issued through the utility communications network to PCTs when energy supplies become tight when compared with energy demand. Customer PCTs receive this event and use pre-programmed adjustments provided by customers to lower energy use during such periods. In the future, once a smart meter has been installed at the customer's premises, energy charges may be raised during price events to reflect higher energy costs that the utility must pay to increase energy supply.

Annex C: Other Publications

The following publications are related to the security methods described in the specification.

ANSI X9.62-2005 – The Elliptic Curve Digital Signature Algorithm (ECDSA)
RFC 4050 - Using the Elliptic Curve Signature Algorithm (ECDSA) for XML Digital Signatures
FIPS 140-2 – Security Requirements for Cryptographic Modules
FIPS 180-2 – Secure Hash Standard
FIPS 186-2 – Digital Signature Standard with Change Notice 1

Rob Lambert, “Understanding elliptic-curve cryptography”, Embedded Systems Design
http://www.embedded.com/columns/technicalinsights/177101463?_requestid=312619

The following publications are useful to fully understand aspects of the specification.

PIER Project Report - Technical Review of Residential Programmable Communicating Thermostat Implementation for Title 24-2008, University of California, Berkeley.
<http://drrc.lbl.gov/pct/index.html>

PIER Project Report – “A Reference Design for the California Title 24 Programmable Communicating Thermostat”, E. W. Gunther
<http://drrc.lbl.gov/pct/index.html>

