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Draft Report
Demand Responsive Control of Air Conditioning via Programmable Communicating Thermostats (PCTs)

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Overview

This report describes the economic, technical, cost-effectiveness and feasibility issues associated with a Title 24 energy code requirement that would mandate the use of Programmable Communicating Thermostats (PCTs) in all new California buildings. PCTs are thermostats that receive a price based or system reliability based load curtailment signal and automatically reduce energy consumption by setting up the air conditioning setpoint.

Most of the reduction in energy consumption in response to a higher thermostat setpoint is temporary as the temperature in the space eventually rises to the higher setpoint temperature and the air conditioner resumes energy consumption at a similar level prior to the load curtailment signal. This temporary reduction in air conditioner energy consumption is a valuable method of reducing energy costs and increasing system reliability.

Air conditioner loads are highly coincident with peak energy consumption. At 15% of peak demand or 8,139 MW, nonresidential air conditioning is the largest single contributor to peak demand followed closely by residential air conditioning which at 7,917 MW accounts for 14% of peak demand.[1] Thus as a single measure, setting back thermostats just a couple of degrees statewide would have a tremendous impact on peak demand. As shown later in this report, the statewide impacts are approximately 900 MW after 10 years of adoption of this proposal depending upon the assumptions one uses for the number of new buildings and homes that are enabled each year to reduce peak demand with PCTs. These savings figure could be approximately doubled if the thermostat serving an air conditioner must be replaced by a PCT when the air conditioner is replaced or undergoes major repairs.

Controlling peak demand is important for several reasons:

- The capacity of the electric power system is determined by the maximum peak demand that the California electric system is called on to deliver. This capacity determines the number of power plants and peak period imports into California that are needed and the size of the transmission and distribution system that must deliver this power. Controlling peak demand is an effective tool when balancing the electrical needs of a growing population against the economic, environmental and other constraints.

- The cost of electricity is highest during times of peak demand. Reducing peak demand decreases the average cost of electricity and increases economic efficiency.

- System reliability (ability to provide power) is increased if consumption can be reduced in a real time manner. When demand outstrips supply, California utilities must resort to rotating outages or blackouts to maintain acceptable system voltage and frequency. The total loss of power in a blackout results in substantial negative impacts to California consumers and industry.

- During system peaks, inefficient and marginal power plants are brought on line. These power plants emit more pollutants per kWh and thus controlling peak demand reduces the air emissions. Typically peak demand occurs during hot summer afternoons when the build-up of nitrogen oxides and photochemical smog is the highest. Thus controlling peak demand reduces air emissions when the need to curtail emissions is high.

The California electricity market shows considerably higher prices during a few critical hours in the year. In addition, there is a capacity market emerging in California and corresponding resource adequacy ruling that requires utilities to purchase capacity to meet the system peak load at potentially considerable cost. The critical peak hours are not during fixed time periods as is the case for Time-Of-Use (TOU) rates but rather in response to the availability of electricity relative to the system wide demand. In the most prevalent rate designs in California these higher costs are averaged into the summer or summer peak period. However, there are several demand response

[1] 2001 California Peak Demand, spreadsheet published by CEC demand office.

rates that are being considered in California including Critical Peak Pricing (CPP) that pass the higher prices during these critical periods to customers and provide correspondingly lower prices at other times. The programmable communicating thermostat (PCT) is the enabling technology that allows customers to automatically control their air conditioning setpoint in response to the critical price or dispatch signal.

Description

In its broadest interpretation, this proposal would require that all temperature control of all new spaces and all spaces served by a retrofit HVAC system would include the capability to receive a curtailment signal from the local utility or Independent System Operator (ISO) and be able to set-up the cooling setpoint while receiving the curtailment signal. For those situations when there is a shortfall of capacity in the winter, the PCT shall also be able to lock-out the electric resistance supplemental heating in heat pumps.

These code language changes would place the communicating nature of temperature controls on the same footing as the requirement for thermostats to be programmable. In fact the communication requirements would be placed in the same sections as the programmable nature of thermostat schedules namely Section 122(e) for nonresidential thermostats and Section 150(i) for residential thermostats. This would render the communication requirement as a mandatory requirement, something that could not be traded away for another building feature. The exemptions that apply for programmable thermostats would also apply to PCTs.

Though the effectiveness of PCTs is subject to how they are installed and configured, it is likely that much of the configuration activities will be automated and diagnosis will be relatively straightforward. As a result this measure will not require acceptance tests and associated paperwork.

Energy Benefits

The energy benefit of the PCT is small relative to the capacity savings benefit because the PCT is expected to operate in only the critical hours per year. In addition, some of the amount of energy saved during the curtailment period is offset by increased energy consumption after the curtailment signal is released. During the curtailment period, since the thermostat setpoint is higher, the loads are lower even when one is not considering the amount of thermal energy stored in the building thermal mass. In the case of office spaces, the load curtailment release occurs as the loads in the office are dropping due to normal schedules of people leaving for the night. In all other spaces, loads are dropping in the evening as the ambient temperature drops and solar radiation decreases. Air conditioning efficiency also rises as ambient temperature drops.

The Results section details the energy, demand and life cycle cost savings for PCTs under a variety of scenarios containing different assumptions. The table below summarizes the same information for “base case” scenario that picks a middle set of assumptions that reflect the likely performance of PCTs. The savings for each building type represents the savings per thermostat. For the office and retail occupancies, it is assumed that a thermostat is installed for each 2,000 sf of floor area.

The energy savings reflect the energy saved by participating users for a voluntary cost based program that sends out a curtailment or price signal for maximum number of hours per year. In the base case we assume a maximum of 15 days per year and four hours per day. However, we have evaluated a range of scenarios to reflect a range of demand response rate and program designs as well as customer participation approaches (‘opt-in’, ‘opt-out’, and mandatory). In addition to voluntary portion, our analysis assumes all PCT thermostats will set up the setpoint during an emergency or reliability event regardless of user preferences or overrides. This yields significant incremental demand savings during system emergencies such as California ISO Stage 2 or 3 emergencies. The savings associated with voluntary user activities to save peak energy costs are associated with “Resource Savings“ are computed in the same manner as other Title 24 measures using Time-dependent Valuation. The additional improvement in ‘Reliability Benefits’ during system emergencies associated with disabling the override feature of the PCT is based upon the Value of Lost Load (VOLL). Note that all resource and reliability benefits are net of the loss in productivity or the value of the loss of comfort suffered by having the thermostat set-up during these periods.

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Table 1: Base Case Savings per Tstat for Residential Buildings

Base Case Cost, Energy & Demand Savings per Tstat Estimates for Res New Construction

Title 24 California CTZ	Total Value per Tstat ($/Tstat)	Resource Value per Tstat ($/Tstat)	Emergency Value per Tstat ($/Tstat)	Non-Emergency Avg Demand Savings per Tstat (kW/Tstat)	Emergency Avg Demand Savings per Tstat (kW/Tstat)	Energy Savings per Tstat (kWh/Tstat)
1	$144	$110	$34	0.17	0.02	9.45
2	$290	$221	$69	0.33	0.04	15.88
3	$250	$187	$63	0.31	0.03	13.42
4	$311	$238	$73	0.36	0.04	17.28
5	$306	$242	$65	0.31	0.03	20.12
6	$239	$174	$66	0.32	0.04	13.70
7	$331	$258	$73	0.36	0.04	17.75
8	$277	$207	$70	0.34	0.04	14.74
9	$426	$325	$102	0.49	0.05	23.25
10	$338	$252	$86	0.41	0.05	19.68
11	$436	$341	$95	0.46	0.05	20.75
12	$408	$314	$94	0.45	0.05	20.17
13	$404	$306	$98	0.48	0.05	22.59
14	$449	$340	$109	0.53	0.06	24.48
15	$529	$394	$134	0.65	0.07	29.74
16	$318	$245	$72	0.35	0.04	15.87

Table 2: Base Case Savings per Tstat for Nonresidential Buildings

Base Case Cost, Energy & Demand Savings Estimates per Tstat - Nonresidential New Construction

Title 24 California CTZ	Total Value per Tstat (PV$/Tstat)		Resource Value per Tstat (PV$/Tstat)		Emergency Value per Tstat (PV$/Tstat)		Non-Emergency Avg Demand Savings per Tstat (kW/Tstat)		Emergency Avg Demand Savings per Tstat (kW/Tstat)		Energy Savings per Tstat (kWh/Tstat)	
	Office	Retail	Office	Retail	Office	Retail	Office	Retail	Office	Retail	Office	Retail
1	$442	$400	$335	$305	$107	$95	0.85	0.76	0.09	0.08	40.41	37.74
2	$475	$381	$363	$293	$113	$88	0.90	0.70	0.10	0.08	39.65	33.56
3	$404	$311	$304	$235	$100	$76	0.80	0.61	0.09	0.07	34.59	27.95
4	$467	$389	$358	$299	$109	$90	0.87	0.71	0.10	0.08	40.19	35.09
5	$409	$340	$305	$256	$103	$85	0.82	0.67	0.09	0.07	37.07	31.81
6	$439	$370	$325	$276	$114	$94	0.91	0.75	0.10	0.08	41.96	36.64
7	$497	$417	$382	$321	$114	$96	0.91	0.77	0.10	0.09	44.02	39.27
8	$423	$347	$320	$264	$103	$83	0.82	0.66	0.09	0.07	37.68	32.87
9	$471	$389	$361	$300	$110	$89	0.87	0.71	0.10	0.08	41.03	36.15
10	$479	$382	$361	$290	$118	$92	0.94	0.73	0.10	0.08	43.28	36.84
11	$554	$455	$434	$360	$120	$95	0.95	0.76	0.11	0.08	42.86	38.84
12	$542	$448	$421	$350	$121	$97	0.97	0.78	0.11	0.09	44.95	39.77
13	$505	$424	$384	$325	$122	$98	0.97	0.78	0.11	0.09	45.24	41.03
14	$525	$441	$400	$339	$125	$102	1.00	0.81	0.11	0.09	44.28	39.67
15	$543	$445	$409	$339	$134	$106	1.07	0.84	0.12	0.09	47.51	41.63
16	$456	$363	$353	$282	$103	$81	0.82	0.64	0.09	0.07	35.85	29.97

As can be seen from the residential results in Table 1, the total life cycle energy cost savings per single family home ranges between $144 and $529. As can be seen from the nonresidential savings results in Table 2, the present valued total life cycle energy cost savings for offices range between $404 and $554 per thermostat and for retail between $311 and $455 per thermostat. In both building models it is assumed that there is a thermostat f serving each 2,000 sf zone. These savings more than pay for the incremental equipment cost of a one-way communicating thermostat.

Non-energy Benefits

In addition to the energy benefits and system reliability benefits previously described, we have calculated the expected reduction in air emissions associated with PCTs. Since the PCT will not operate in a significant number of hours the air emissions reductions from power plants is relatively small, but positive. See the Environmental Impact section for more discussion.

There are also negative non-energy benefits associated with PCTs. Raising the thermostat setpoint above its accustomed settings while the spaces are occupied will cause discomfort for some occupants. The calculation of total cost savings takes in to account both the financial benefits of increased reliability and the financial impacts of reduced productivity or comfort.

Statewide Energy Impacts

A detailed analysis found that the first year's implementation of the PCT requirements would reduce electricity energy consumption by 3.9 Gigawatt/hr per year, and reduce electrical demand coincident with utility system peak by 93.3 Megawatts. The discounted life cycle energy cost savings (3% discount rate, 15 year period) is $61 Million for one year's new construction. After 10 years of this code measure the savings would be approximately tenfold or about $610 Million of primarily demand cost savings that accrue over the life of these buildings. These values could be approximately doubled if the requirements for PCTs also applied to buildings and homes where the air conditioner is being replaced or undergoing major repairs.

Table 3: Statewide Energy, Demand and Cost Savings Summary

Building Category	Number dwelling units or sf nonresidential bldg	Energy Savings MWh/yr	Emergency Demand Impact MW	Non-Emergency Demand Impact MW	Total Value PV$Millions
1st year New residential	122,963	2,432	5.8	52.0	$ 44.16
1st year New nonresidential	76,832,749	1,507	3.5	31.9	$ 17.00
Total first year new construction		3,939	9.3	84.0	$ 61.16

The residential statewide savings estimate was based upon energy simulation of the impact of thermostat set-up in simulations of single family homes each of the 16 Title 24 climate and temperature zones (CTZs) and expanded up to the population of dwelling units with air conditioners as contained in the "California Energy Demand 2003-2013 Forecast Staff Report." The nonresidential statewide savings estimate was based upon energy simulations of thermostat set-up during the curtailment period in small office and small retail prototypes and expanded up to the population of one year's new construction which is estimated to be 108.3 Million square feet per year for all nonresidential building types excepting amusement and storage. However, approximately 71% of conditioned floor area, or 77 Million sf, is served by single zone packaged air conditioners that could be impacted by stand alone PCTs, thus our estimates of air conditioning load curtailment are multiplied by a factor of 71%. The remaining 29% of nonresidential demand response savings could be captured by energy management systems that respond to a demand response signal. These systems are likely even more cost-effective but not in the scope of this report. Estimates of nonresidential new construction activities are an average of four years' nonresidential construction data from the McGraw-Hill Dodge construction database. See the Results section and Appendices 4 though 6 of this report for a detailed description of how the statewide energy impacts were calculated.

Environmental Impact

The types of materials used in programmable communicating thermostats are the same as are used in standard electronic thermostats. Thus there is expected to negligible incremental environmental impacts from the manufacture of PCTs as compared to the thermostats they are replacing, programmable digital thermostats. Since the operation of the PCT differs from the base case of the programmable thermostat only during the approximately 50 hours per year when curtailment is desired, the air emissions reductions from power plants is relatively small, but positive, compared with efficiency measures that save energy in significant number of hours. The air emissions reductions are tabulated in Table 4 and are comparable to removing 472 cars from the road for CO2 emissions and comparable to removing 21 cars from the road for Nitrous Oxides[2].

Table 4 Annual air emissions reductions from first year of PCT standard

Building Category	Statewide NOx Reduction (Lbs)	Statewide PM10 Reduction (Lbs)	Statewide CO2 Reduction (Tons)
1st year New residential	513	207	1,673
1st year New nonresidential	317	128	1,035
Total first year new construction	830	335	2,708

Type of Change

By recommending that the requirements for PCTs be placed in the same sections (§122(e) and §150(i)) of Title 24, we are proposing that the requirements for PCTs be mandatory. That is PCTs are required and cannot be traded off against other building measures. As a result, there is not a requirement that PCTs be simulated as stipulated by a specific rule set in the ACM Manual.

However, if it is desired that the PCTs be simulated, then we recommend that the PCTs be simulated in one of two ways.

1. Assuming reliability response only – the thermostats are set up from on two hours on either side of the hour with the highest TDV costs. This will vary by climate zone.

2. Assuming economic and reliability response – in addition to the hours setup as described above, the rest of the top 50 hours with the highest TDV values are also set-up. The hours selected will vary by climate zone.

Mandatory Measure	**The change would add or modify a mandatory measure. Mandatory measures must be satisfied with either the prescriptive or performance compliance methods.**

[2] Automobiles emit a greater proportion of nitrous oxides to carbon dioxide than do electric generation stations. The typical passenger car emits 38.2 lbs/yr of Nitrous Oxides and 5.7 tons of CO2 during a typical year's driving (12,500 miles). From USEPA "Emission facts" http://www.epa.gov/otaq/consumer/f00013.htm..

Technology Measures

If the measure requires or encourages a particular technology, address the following subsections.

Measure Availability and Cost

On behalf of this project, E-Source/Platts contacted eight manufacturers of PCTs to provide price estimates of PCTs under various scenarios of sales volume. Five of the manufactures participated in the survey; the results in Table 5 summarize the range of their responses on the likely cost at the retail and wholesale level. Not surprisingly, the cost of the PCT drops with greater sales volumes due presumably to economies of scale and greater competition. See Appendix 2 – PCT Capabilities and Pricing Survey, for more details about this survey and the specifications of PCTs that are the basis of these price estimates.

Table 5 Hardware and installation costs for PCTs capable of emergency and price responsiveness

Sales Channel	**Retail**				**Wholesale to Contractors**			
	Hardware Cost		**Installation Cost**		**Hardware Cost**		**Installation Cost**	
Annual Volume	Emergency Response	Price Response	Emergency Response	Price Response	Emergency Response	Price Response	Emergency Response	Price Response
50,000	$90 to $200	$95 to $200	Little incremental cost relative to conventional thermostat. $75 to $100 total.		$75 to $160	$75 to $160	Little incremental cost relative to conventional thermostat. $75 to $100 total.	
100,000	$80 to $170	$80 to $170			$60 to $135	$60 to $135		
250,000	$60 to $125	$60 to $125			$45 to $100	$45 to $100		

Given that standard thermostats cost have an approximate cost of $30 to $150 and are simpler to install, assuming the PCT takes 10 more minutes to install, the retail incremental costs are approximately $60 depending upon the quotes and sales volume. These estimates are for one-way communicating thermostats – thermostats that receive messages from the utility but do not respond back in return.

Two-way thermostats receive information from the utility and transmit information back indicating whether the curtailment request was executed as well as other pertinent information (indoor temperature, override of thermostat, cycling rate etc.) As described in Appendix 2 – PCT Capabilities and Pricing Survey, the cost of two-way thermostats are essentially double those of the one-way thermostats. In addition, the two systems are not necessary on a broad basis, installing a smaller sample of two way thermostats would provide sufficient accuracy at a lower cost. Thus the cost-effectiveness evaluation of PCTs will be based upon the cost of one-way PCTs.

Useful Life, Persistence and Maintenance

The PCT's are considered electronic controls similar to other forms of electronic controls including the standard programmable thermostats the PCTs would be replacing. Thus it seems likely that the service life of the PCT would be very similar to that of the standard programmable thermostat. The 1999 ASHRAE Applications Handbook estimates that the life of electronic controls is approximately 15 years[3]. We use this same assumption for estimating replacement period for residential and nonresidential PCTs.

Performance Verification

Programmable communicating thermostats (PCTs) are different from standard thermostats in one way – they communicate with the utility demand response system. As a result, an additional step is required to assure that PCTs increase electric systems reliability and provide cost-savings to the user; the communications link between the utility and PCT must be verified. Ideally, this verification would do more than merely indicate that the PCT was receiving the signal, it could show that it is responding to the test signals of the local utility. These test signals would include one test signal that simulates a high cost period and another signal that simulates a system reliability emergency signal.

For the overall demand response system to work, the utility demand response communication system AND the PCT both have to work. Thus it is important that the system is exercised regularly to assure it works. Since the system reliability is expected to be affected only one day out of every ten years, it is important that many PCT systems are responding to economic signals and that the emergency system is tested at least once a year.

Cost Effectiveness

As described in the Methodology section of this report, the savings calculated from PCTs is dependent upon the assumptions one uses for participation rates, rate design etc. Thus we have developed five scenarios from a pessimistic estimate of savings to a very optimistic estimate of savings. Along this continuum in the middle is the "base" scenario which we believe to be a reasonably likely outcome of the statewide application of thermostats and a supporting utility rate design which returns most of the resource acquisition value to PCT owners who allow their thermostat to be set-up during the curtailment periods.

Assuming the incremental cost of the PCT to be approximately $60 in residential buildings and that a PCT will have to be replaced in 15 years the discounted, incremental life cycle equipment cost of PCTs is $100. For the base case assumptions, the residential, benefit cost ratio is above 1.4 in all climate zones. On average the base case benefit cost ratio is 3.5 to 1. Pessimistic assumptions render PCTs not cost-effective and optimistic assumptions render PCTs more cost-effective. More detailed results are in the Results section of this report.

PCTs are more cost effective for nonresidential buildings as loads are higher for the same equivalent area. Since the life of the thermostat is the same as the period of analysis – 15 years, the present value of the incremental equipment cost is the same as the incremental first cost or $60. For the base case assumptions the PCTs are cost-effective in all climate zones and on average across all climate zones has a benefit cost ratio of 7.3 to 1.

Thus given the base case assumptions, PCTs are a cost-effective measure in new homes and in new nonresidential buildings. When demand response is applied to nonresidential spaces where multiple zones are controlled by an energy management and control system (EMCS), the benefit to cost ratios should be even higher. These systems are more thoroughly discussed in CASE studies describing DDC control to the zone level (PG&E CASE study) and global temperature adjustment or GTA (LBNL PIER CASE study).

Given that the total cost of a PCT is twice that of its incremental cost, is approximately two and a half times that of the incremental cost, requiring PCTs upon major repair or replacement of the air conditioner should also be considered. This would approximately double the statewide savings.

[3] Table 3 "Estimates of service Lives of Various System Components." P. 35.3, 1999 ASHRAE Applications Handbook, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

Analysis Tools

As this measure is proposed as a mandatory measure, there is not necessarily a need to model PCTs in the Alternative Compliance Method (ACM) performance software. However, if it was deemed necessary to provide more accuracy when in consideration of other demand response measures that impact air conditioning (such as thermal storage), the PCT curtailment could be modeled as a temperature set-up during the top 50 hours of TDV values. These top 50 values change with respect to Title 24 climate zone.

Relationship to Other Measures

In general, the PCT measure does not affect other energy efficiency measures. It may impact the analysis of other air conditioning demand response measures such as thermal storage. This would have to be addressed by an exceptional calculation method submittal for thermal storage systems.

Methodology

The following process was used to evaluate the energy savings, demand reduction, and cost savings that result from statewide requirements for PCTs in every new conditioned space and for every space where the air conditioning unit is being replaced or receiving major repairs.

- DOE-2.2 simulation models created for single family homes, small office buildings and small retail buildings for each of the 16 climate temperature zones (CTZs) as defined in the Title 24 building efficiency standards. These three prototypes are considered to be mostly representative for all buildings in California. These simulation models were created for three residential thermostat schedules and two nonresidential thermostat schedules. In all models there are 21 different curtailment schedules from a 1 hour curtailment to a 4 hour curtailment between the hours of noon and 6 pm. The base case model with no curtailment is compared with the curtailment model to generate hourly energy savings for the hottest day of the year and the tenth hottest day of the year. Thus these DOE-2 models are used develop the technical demand and energy savings potential estimates.

- Revised Time Dependent Valuation (TDV) files developed for the 2008 Title 24 building efficiency standards, contain present valued cost estimates of the cost of a kWh of electricity for each hour of the year for residential (30 year present valued series) and nonresidential (15 year present valued series) buildings for each one of the 16 climate temperature zones (CTZs). These revised TDV estimates include the residual capacity costs for a new combustion turbine allocated to the top 100 hours where excess capacity is the least (demand is close to outstripping demand). The TDV costs are sorted from highest cost day to lowest cost day. Starting with the highest cost day, the TDV values are multiplied by the hourly energy savings over the duration of the specified curtailment program. Thus if one wanted to evaluate a program that would curtail for 10 days one might select the ten top days of TDV values and multiply this by the hourly savings from the DOE-2 simulation models.

- The DOE-2 simulations and the TDV cost savings models are combined in different ways depending upon various scenarios that are include a variety of different assumptions about how people behave and the rules that might be applied to economic and emergency use of the set-up capabilities of the PCTs.

- Statewide population estimates of homes and business with air conditioning are applied to the appropriate building model and economic/behavioral scenario to yield statewide estimates of energy and demand savings and societal cost savings.

- Inefficient, more polluting and more expensive power plants are dispatched during times of high demand and high electricity cost. Hourly emissions factors (lbs of NOx, lbs of particulate matter or Tons of CO2 per kWh) are also multiplied by the hourly energy savings estimates to yield an estimate of environmental benefits of PCTs.

Calculation of Avoided Costs and Value of Reliability

The calculation of the lifecycle value of PCTs is completed using the methodology described in the Life Cycle Cost Methodology report for the 2008 Title 24 prepared by Architectural Energy Corporation, and the 2008 Title 24 TDV Methodology (Section 3.8) prepared by Energy and Environmental Economics, Inc.

The analysis consists of two components, the first is a measurement of the ‘resource value’ and is calculated using the same approach used for all building measures with TDV; multiplying the expected load reduction in each hour based on the technology and the weather for each climate zone by the hourly TDV value (in lifecycle $/kWh). The second component measures the incremental ‘reliability value’ for additional load reduction, if any, that can be achieved from operation of the PCTs during a system emergency (E.g. California ISO Stage 2 or 3). As noted in the referenced 2008 Title 24 TDV Methodology document, the ‘resource value’ and the ‘reliability value’ do not apply to the same kW of load reduction and the analysis is careful not to double count load reduction for both a resource savings AND reliability improvement.

Assumptions Associated with Scenarios

Given the large range of potential applications of PCTs the calculations are made for each of five scenarios described above with different sets of assumptions ranging from very pessimistic to very optimistic. The savings available from programmable communicating thermostats (PCTs) vary considerably depending upon the requirements of demand response programs and the response rates of participants.

Table 6: PCT analysis scenarios from very pessimistic to very optimistic

	(--) Very Pessimistic	**(-) Pessimistic**	**(=) Base Case**	**(+) Optimistic**	**(++) Very Optimistic**
Annual Days of Operation	5	10	15	15	20
Time Period of Dispatch	2pm to 4pm	2pm to 4pm	2pm to 6pm	2pm to 6pm	2pm to 6pm
Temperature Set-up	4 deg	4 deg	4 deg	4 deg	4 deg
Override Possible during non-emergency event	Yes	Yes	Yes	Yes	Yes
'Emergency' Operations Rule	No Emergency	Only Participants	All PCT Owners	All PCT Owners	All PCT Owners
Dispatch of PCT	Alternate TDV cost days	Alternate TDV cost days	Highest cost TDV days	Highest cost TDV days	Highest cost TDV days
Dispatch Weather Assumption	10th Hottest Day	10th Hottest Day	10th Hottest Day	Hottest Day	Hottest Day
Fraction of Population participating	DR or CPP 'opt-in' 20%	DR or CPP 'opt-in' 20%	CPP 'opt-out' 70%	CPP Mandatory 100%	CPP Mandatory 100%
Economic signal for participants	Reset with option to override	Reset with option to override	Reset with option to override	Reset with option to override	Reset with option to override
Residential: Fraction with T-stat ON	From RAS by climate zone				
Nonresidential: Fraction with T-stat ON	100%	100%	100%	100%	100%
Fraction overriding voluntary signal residential	30%	20%	10%	10%	5%
Fraction overriding voluntary signal nonresidential	20%	20%	10%	10%	10%
Useful life of PCT	15 yrs	15 yrs	15 yrs	15 yrs	15 yrs
Thermostat schedules res	T-24	76°F	76°F	74°F	74°F
Thermostat schedules nonres	74°F	74°F	74°F	72°F	72°F
Productivity loss	50%	35%	20%	20%	10%
Value of loss of service ($/kWh)	N/A	$30	$42	$100	$200

Table 6 lists the description of scenarios considered for evaluating the benefits of PCTs. To bound the widest possible range of outcomes from PCTs, the scenarios range from very pessimistic inputs, resulting in a low estimate of savings, to very optimistic inputs with high savings estimates. However, if the range of estimates that are so wide the worst case doesn't meet the threshold of approval and the best case does, then this methodology would not give much guidance. Thus we have also included a "base case" that is our best estimate of the most likely outcome. Each of the variables that are changed in the scenarios is described further, below.

- Annual Days of Operation –the number of days per year that a curtailment signal is sent to the average PCT.

- Time Period of Dispatch – this is the time period during which the curtailment signal is sent. This analysis considers a two hour curtailment for the pessimistic scenarios and 4 hours for all other scenarios.

- Temperature Set-up – how many degrees F is the thermostat setpoint increased during the curtailment period. The setpoint is increased by 4°F under all scenarios.

- Override Possible during non-emergency event – there are two reasons for curtailing loads with PCTs: non-emergency (economic) and emergency (reliability). The motivation for curtailing air-conditioning loads during non-emergency events is to save money for both the customer and the utility by minimizing energy consumption during high priced periods. Some programs are designed to curtail power without possibility of customer override even during non-emergency periods when system reliability is not threatened. In all of these scenarios, the occupant is capable of overriding the thermostat automatic set-up during non-emergency curtailment events.

- 'Emergency' Operations Rule – this describes whether the occupant can override the thermostat set-up when the PCT receives a curtailment signal to maintain system reliability. In the "very pessimistic" scenario, participants or non-participants in utility demand response programs or rates are able to override the PCT curtailment set-up even when it is in response to a system emergency that threatens system reliability. In the "pessimistic scenario" only the participants in utility demand response rates or programs cannot override the emergency signal; non-participants receive the signal but can choose if they want to save energy. In the base case and optimistic scenarios, all owners of PCTs cannot override the emergency curtailment signal.

- Dispatch of PCT – this describes how well the utility is able to match their curtailment schedule with the costs of energy. Since there is a limited number of days one can dispatch one does not want to curtail one day if they believe the next day is going to be even more expensive. The pessimistic scenarios assume that the utility is able to dispatch correctly half of the time so that alternate days of TDV price are curtailed; the first, third, fifth etc highest priced days are modeled as being curtailed. The base case an optimistic scenarios assume that the all of the highest priced days are curtailed.

- Dispatch Weather – the energy simulations of the "curtailed days" include both the hottest day and the tenth hottest day. The energy results from these two days are multiplied by the hourly electricity costs of the highest priced days for the duration of annual curtailment program. The energy results are repeated and multiplied by different cost numbers associated with different days. The base case and pessimistic scenarios use the tenth hottest day for the energy simulation and the optimistic scenarios use the hottest day for weather inputs into these simulations.

- Fraction of Population participating – this is expected to vary depending upon the future conditions of service as decided by the California Public Utilities Commission. The pessimistic scenarios assume that participation in demand response programs are something that the customer has to pursue by deciding to change their rate or otherwise "opt-in" to a demand response program. Our assumption is that given the effort to change rates, only the most cost-sensitive and pro-active customers will pursue this with a participation rate of 20%. The base case scenario assume that at a certain time all customers will be automatically be enrolled in the demand response program and only customers who actively dislike DR rates (expected to be around 30%) will "opt-out" of the program netting approximately a 70% participation rate. The optimistic scenarios assume that all customers will be required to be on a critical peak pricing rate (CPP) without any other options.

- Economic signal for participants – this is similar to the override possible during non-emergency event. During curtailment for economic reasons (non-emergency curtailment) the PCT is set-up with the occupant having the capability to override the set-up.

- Residential: Fraction with T-stat ON – The amount of t-stats on during the curtailment period a function of climate zone. This is supported by the RASS (residential appliance saturation survey) study. For those climate zones that did not have a significantly significant sample in the RASS t-stat survey, we will map the results from the closest climate zone. Climate zone 16 in the mountains was mapped to the North Coast Region. The fraction of thermostats set to OFF as identified in the RASS study and the fraction ON that we will be using in our analysis are given in Table 7.

Table 7: RASS study of programmable residential thermostats ON between 9 am and 5 pm[4]

T24-CZ	Region	Programmable Thermostat % Set to OFF	Programmable Thermostat % Set to ON
CZ 1-5, 16	North Coast	31%	69%
CZ 6-8	South Coast	37%	63%
CZ 9,10	South Inland	20%	80%
CZ 11-13	Central Valley	15%	85%
CZ 14, 15	Desert	10%	90%

- Nonresidential: Fraction with T-stat ON – we were unable to find good information on this and have used the assumption that in most cases nonresidential thermostats will be active during the hottest summer afternoons. Thus 100% of thermostats ON is assumed for all of the scenarios.

- Fraction overriding voluntary signal residential - From the E-Source literature review of residential DR projects in other parts of the country, typical override rates are 5% to 30%[5]. We think this should be the basis of the base case with other factors accounting for the level of optimism or pessimism in the sensitivity analysis.

- Fraction overriding voluntary signal nonresidential - Southern California Pilot project for non-residential customers shows an average of 20% (high 21%, low 18%) override during their events. This value is used as the pessimistic estimate for non-residential customers. This reflects the belief that override rates will decline once greater expertise is developed in timing and spreading out the curtailment amongst a larger pool of participants.

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[4] Table 6. *Percent of Programmable Thermostats set to "Off"* in SCE internal report reviewing the RASS study *Programmable Thermostats Installed into Residential Buildings: Predicting Energy Saving Using Occupant Behavior & Simulation*

[5] P.10, Rachel Reiss, E-Source, "Two-Way Thermostats Creating New Markets for Residential Load Control Programs," ER – 02, 4 March 2002

- Useful life of PCT - The 1999 ASHRAE Applications Handbook estimates that the life of electronic controls is approximately 15 years[6]. This assumption was used for estimating replacement period for residential and nonresidential PCTs

- Thermostat schedules residential – this describes the thermostat schedule of temperatures for the residential building models. The very pessimistic scenario assumes that the Title 24 schedule is used which sets-up the thermostat during the day. The pessimistic and base case scenarios assume the thermostat schedule is a constant 76ºF and the optimistic cases assume that the thermostat is set to a constant 74°F.

- Thermostat schedules nonresidential - similar to the residential thermostat schedules the more pessimistic schedules assume higher thermostat settings (74ºF) and the more optimistic assume a lower setpoint (72°F). When the setpoint is lower, the loads on the building are higher and thus there is more load to curtail.

- Productivity loss – There are two approaches in the evaluation methodology to make sure that customer savings are net of lost productivity and comfort. For a 'voluntary' program (e.g. customer has the ability to override, but does not) the productivity loss is calculated as the fraction of the expected customer bill savings that would compensate the occupants for their discomfort or reduced productivity. For example, if the bill savings for an operation is $2 for the day and the productivity loss is 50%, the customer nets $1 savings and the other $1 offsets their productivity and comfort loss[7]. The assumption on voluntary programs is that the customer bill savings is always greater than the discomfort or the occupant would override the PCT dispatch. For a mandatory type program a different approach is used. In this case the comfort and productivity loss is assumed to be $2.50/kWh in all of the scenarios. The value is derived from value of service studies from customers which assess a customer's willingness to pay to avoid an interruption of the cooling[8].

- Value of loss of service ($/kWh) – this is the value that is gained by preventing an outage. This value is only ascribed to the PCT only for those spaces that are NOT participating in a voluntary resource acquisition plan. This is because those who are participating in a demand response program are being paid on the basis that fewer power plants have to be purchased to maintain the same system reliability. This additional emergency value is ascribed to the additional demand savings that can be squeezed out during emergency events beyond those already subscribed to curtail load.

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[6] Table 3 "Estimates of service Lives of Various System Components." P. 35.3, 1999 ASHRAE Applications Handbook, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

[7] This approach was presented at the 'Other Benefits' workshop on August 5th, 2005 by Carl Silsbee of SCE and separately by C.K. Woo of E3. For academic reference see; Acton, Jan Paul and Bridger M. Mitchell, Welfare Analysis of Electricity Rate Changes, Rand Note N-201-HF/FF/NSF, May 1983; and Borenstein, Severin, Michael Jaske and Arthur Rosenfeld, Dynamic Pricing, Advanced Metering and Demand Response in Electricity Markets, University of California Energy Institute, Center for the Study of Energy Markets, Working Paper CSEM WP 105, October 2002/

[8] See Keane DM, McDonald D, Woo CK (1988) "Estimating residential partial outage cost with market research data," *Energy Journal–Reliability Special Issue*, 9: 151-172 which provides a value of $2.60/kWh in 2004$ however this study is an assessment of A/C cycling rather than PCT, or see Southern California Edison Appendix F: Customer Value of Service Reliability Study, March 1st 1999, Exhibit 2.1 A/C Cycling Program on page range of $1998 range of $2.01 to $5.02 assuming 6 interruptions per year.

Energy Simulation of PCTs

The energy impacts of PCTs are calculated by simulating a representative building or collections of buildings and temporarily setting the thermostat higher during the curtailment period. These simulations are performed on either the hottest day in the weather file or the tenth hottest day depending upon the scenario being modeled. The residential simulation models are two single family homes: a single story home and a two story home. These simulation models are rotated and the results averaged to yield average impacts of PCTs on the single family market.

Two models were developed for estimating the impacts of PCTs in the nonresidential sector: a small office building with ten 2,000 sf zones and a retail model with three 2,000 sf sales area zones and a 2,000 warehouse zone. The small office building has zones that are facing in all directions and is essentially an average model. The retail model has most of the windows on one side of the building, thus the model is rotated in each of the cardinal directions (North, South, East, and West) and the results averaged to yield the average energy impacts of PCTs on the small retail market.

The energy and demand savings of the PCT is evaluated by taking the energy results of these prototype buildings with a given thermostat schedule and comparing these results to the same building model except the thermostat schedule has a "curtailment period" where the thermostat setpoint schedule is increased by four degrees and then at the end of the period, the setpoint is brought back down to its normal setpoint.

Calculation of Load Reduction and Reliability Value

Technical Load Reduction and Resource Savings

The energy savings estimate from comparing the energy consumption of the base case simulation to the simulation where the PCT is dispatched. This energy savings estimate is considered for all hours of the day. To estimate average demand savings, the average change in energy consumption is averaged over the hours of 12 noon to 6 pm, the hours the ISO considers to be a likely peak demand period. The peak demand savings considers the hour with the largest savings from the PCT.

The capacity cost savings are calculated by taking the energy results from the building simulation and multiplying them by the hourly values as contained in the TDV files. Depending upon the scenario selected, the hourly energy savings are multiplied by the TDV values of the days with the highest TDV costs, or to model imperfect dispatch, multiplied by the hourly TDV cost values of the odd highest (first, third, fifth…) cost days. This yields the simulation or technical demand, energy and cost savings potential. Figure 1 is an example of the hourly electricity savings and the TDV electricity costs per kWh for the highest cost day. Note that the curtailment period 2 pm to 6 pm coincides well with the costs of electricity. The product of these two lines yields the technical cost savings associated for operating the PCT on this high cost day.

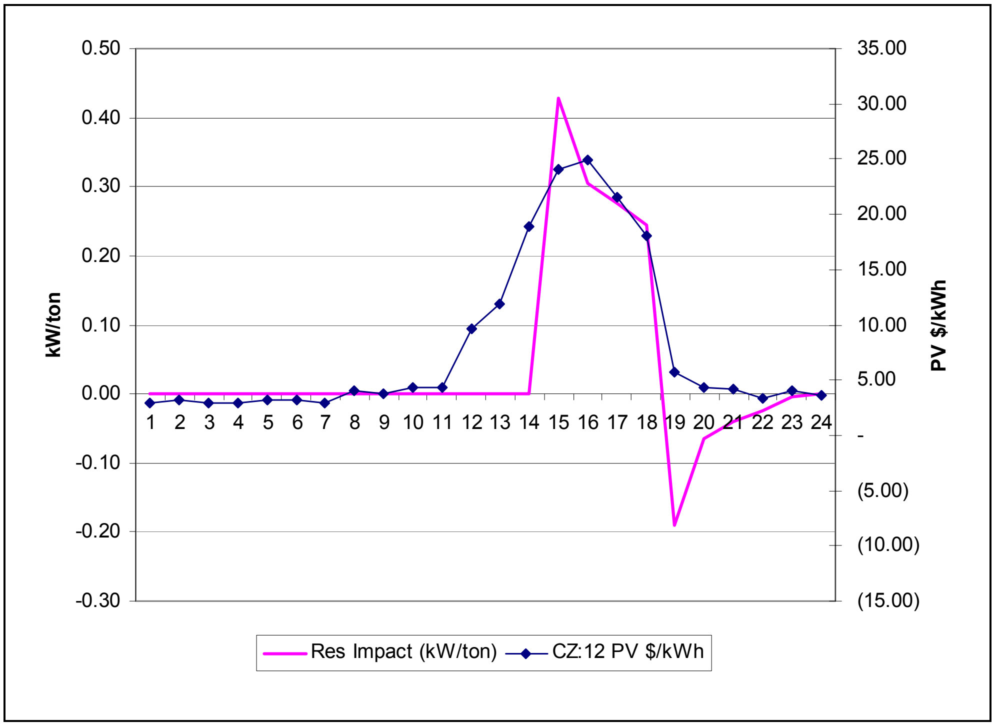

Figure 1: PCT demand savings and TDV energy costs on peak cost day

The technical energy and cost savings results from the simulations have to be de-rated by the fraction of PCTs that are actually saving energy. Some fraction of the PCTs is not saving energy due to a number of reasons: the PCT is not receiving the signal, the owner may not be participating in the demand response program, the thermostat may be normally OFF during the curtailment period, the owner may override the operation of the PCT etc. The following section describes how the savings values are de-rating due to these economic and human factors.

From Technical Potential to Market Potential

The number of hours the PCT operates and how frequently the PCTs are overridden is a complex interaction between rate design, public policy and curtailment strategy. The various choices that are made along these lines and projected population responses make up the assumptions as outlines in the Assumptions Associated with Scenarios section earlier in this report. The base case assumptions were considered the most likely outcomes and are bounded on either side by progressively more pessimistic and optimistic scenarios.

The example below considers a base case scenario for a single family home in climate zone 12 (Central Valley near Sacramento). In this case, the PCT is set-up for four hours between 2 pm and 6 pm for 15 relatively hot days as represented by the tenth hottest day on the California Energy Commission CTZ12 WYEC2 (weather year for energy calculations) hourly weather file used in the energy simulations.

Participation Estimate - Voluntary Program			Example Calculation
Row	*Calculation*	*Description*	*Base Case: CZ 12*
A	Input	Percentage of AC that are on and below set point	85%
B	Input	Percentage that receive and can act upon the signal	97%
C	Input	Percentage that do not override	90%
D	A*B*C	Technical potential	74%
E	Input	Percentage w/ PCT participating in program	70%
F	D*E	Overall fraction of potential including participation	**52%**
Impact Estimates			
G	Simulation	Average simulated kW reduction	0.87
H	F*G	Average kW reduction per Tstat installed	0.45

Figure 2: Fraction of Response to Voluntary Program

As shown in Figure 2, the *Percentage of AC that are on and below set point*, the *Percentage that receive and can act upon the signal* and the *Percentage that do not override* are multiplied to yield *Technical potential* that is likely to be realized by the **participants in the voluntary program** envisioned for our base case. This voluntary program for the base case is a critical peak pricing program that all customers are assigned initially unless they consciously "opt-out" by contacting their utility and asking to be placed on another rate. The *Overall fraction of potential including participation* is the product of the participant faction of technical savings and the participation rate. This overall market potential fraction indicates what fraction of the technical potential is going to be realized by a given customer segment as a whole. In this example, 52% of all PCTs installed in residences in climate zone 12 are assumed to operate in response to a voluntary call.

As described above in the *Technical Load Reduction and Resource Savings* section, the hourly energy savings from PCTs is multiplied by the hourly TDV factors to yield the Avoided Cost Value (PV$/ton)[9], shown in Figure 3. This value is multiplied by the *tonnage of the air conditioner* and the *overall market potential fraction* to yield the *value per thermostat (PV$/tstat).* The value per thermostat is average value of the thermostats in the population of which 52% are participating. The net savings is then calculated by subtracting the assumed productivity losses and discomfort to estimate the total net resource value of the PCT.

Resource Value		Best Dispatch
Avoided Cost Value	1	
Avoided Cost Value (PV$/ton)		$ 271.30
AC tons per thermostat		2.79
Value per thermostat (PV$/tstat)		$ 392.59
Comfort and productivity loss		
Comfort loss as a percentage of avoided cost		20%
Comfort loss ($PV/tstat)		$ (78.52)
Net Resource Value		**$ 314.07**

Figure 3: Resource (Non-emergency) Value Impacts

For reporting purposes, we also compute the expected peak and average load reductions for each scenario. In Figure 4, one can observe how the technical peak demand savings potential of 1.2 kW per home is reduced to 0.89 kW per home for participants and 0.62 kW per home for the population as a whole by applying the participant fraction and market fractions respectively.

[9] Present Valued (30 year analysis at 3% discount rate) dollars per ton of air-conditioning

Operating Summary

Non Emergency Impact

	Simulation Result	Adjusted Results Participants	Tstat Population
Peak Reduction (kW/tstat)	1.19	0.89	0.62
Average Reduction (kW/tstat)	0.87	0.65	0.45
Hours per Operation	4		
Total Hours of Operation/yr	60		

Figure 4: Non EmergencyDemand Impacts

Emergency Load Reduction and Value of Reliability

In addition to the resource value, we compute the value of reliability improvement of additional load reduction that can be achieved during an emergency. The additional load reduction is captured by disabling the override feature of the PCT during an emergency. In order not to double count, the emergency load reduction value only applies to the additional load reduction and not the total PCT load reduction assumed for the voluntary resource value features of the PCT. Depending on the scenario, either all PCT owners much participate in the emergency program, or only those that sign up for a utility program participate in the emergency program.

The calculation of the additional emergency load reduction is done in a similar fashion to the voluntary program. An example is shown for the same climate zone 12, base case example in Figure 5, below. For the base case, in which all PCT owners would participate in the emergency program, the incremental emergency impact is calculated as the product of *Percentage of AC that are on and below the set point*, the *Percentage that receive and can act upon the signal*, and the percentage of customers who would have overridden the dispatch signal if possible, (1-*Percentage that do not override*). In the base case for climate zone 12 this is an additional 8% load reduction, or an average of 0.07kW per installed residential climate zone 12 PCT.

Participation Estimate - Emergency Program			*Example Calculation*
Row	*Calculation*	*Description*	*Base Case: CZ 12*
A	Input	Percentage of AC that are on and below set point	85%
B	Input	Percentage that receive and can act upon the signal	97%
C	Input	Percentage that do not override	90%
D	A*B*C	Technical potential	74%
E	Input	Percentage w/ PCT participating in program	70%
F	A*B*(1-C)*E	Incremental Emergency kW/ Tstat (Participants Only)	**6%**
G	A*B*(1-C)	Incremental Emergency kW/ Tstat (All PCT Owners)	**8%**
Impact Estimates			
H	Simulation	Average simulated kW reduction	0.87
J	F*H	Incremental Emergency kW per Tstat (Participants Only)	0.05
K	G*H	Incremental Emergency kW per Tstat (All PCT Owners)	0.07

Figure 5: Fraction of Technical Potential Associated with Emergency Impact

The calculation of the emergency value in the base case is shown in Figure 6, below. We calculate the emergency value as the *Class Weighted Average VOS*, net of the *Comfort and Productivity Loss*, by the *Expected outage hours per year* and the Average reduction per t-stat. The lifecycle value of the emergency load reduction for residential climate zone 12 customer is $130.07/t-stat.

Emergency Value

Class Weighted Average VOS ($/kWh)		$ 42.00	
Comfort and Produtivity Loss ($/kWh)		$ 2.50	
Net Gain of reduced outages costs ($/kWh)		$ 39.50	
Reliability Target (1 Day in X Years)		10	
Expected Outage Hours (hours per year)		2.4	
Reduced Outage Cost $/kW-yr		$ 94.80	
Present Value Factor		19.60	
Real Discount Rate	3%		
Number of Years	30		
Reduced Outage Cost ($PV/kW)		$ 1,858.12	
Average reduction per t-stat (kW/t-stat)		0.05	
Reduced Outage Cost ($/t-stat)			**$ 93.52**

Figure 6: Reliability Value per Thermostat

Results

Describe the results of the research. What was learned? How is it relevant to the standards? Results are not all computational. Some results are based on market share of equipment and applicability of measure limited to certain applications.

Energy and Cost Savings

This section contains detailed energy and cost savings results that are summarized in the energy benefits section of the report

Residential Results

Residential Results per Thermostat

Table 8: Base Case Energy, Demand & Cost Savings Estimates per Tstat – Residential

Base Case Cost, Energy & Demand Savings per Tstat Estimates for Res New Construction

Title 24 California CTZ	Total Value per Tstat ($/Tstat)	Resource Value per Tstat ($/Tstat)	Emergency Value per Tstat ($/Tstat)	Non-Emergency Avg Demand Savings per Tstat (kW/Tstat)	Emergency Avg Demand Savings per Tstat (kW/Tstat)	Energy Savings per Tstat (kWh/Tstat)
1	$144	$110	$34	0.17	0.02	9.45
2	$290	$221	$69	0.33	0.04	15.88
3	$250	$187	$63	0.31	0.03	13.42
4	$311	$238	$73	0.36	0.04	17.28
5	$306	$242	$65	0.31	0.03	20.12
6	$239	$174	$66	0.32	0.04	13.70
7	$331	$258	$73	0.36	0.04	17.75
8	$277	$207	$70	0.34	0.04	14.74
9	$426	$325	$102	0.49	0.05	23.25
10	$338	$252	$86	0.41	0.05	19.68
11	$436	$341	$95	0.46	0.05	20.75
12	$408	$314	$94	0.45	0.05	20.17
13	$404	$306	$98	0.48	0.05	22.59
14	$449	$340	$109	0.53	0.06	24.48
15	$529	$394	$134	0.65	0.07	29.74
16	$318	$245	$72	0.35	0.04	15.87

Statewide Residential Results

The statewide estimates of energy, demand and cost savings are developed by multiplying the savings per thermostat in the above section and multiplying by an estimate of the number of thermostats statewide. The data source for statewide estimates of residential air conditioners is from the "California Energy Demand 2003-2013 Forecast Staff Report." For more background information concerning the population estimates please turn to Appendix 3 – Statewide Estimates of Air-Conditioned Dwelling Units or Commercial Floor Space.

Table 9: Statewide Energy, Demand & Cost Savings Estimates– Residential

Statewide Cost, Energy and Demand Savings Estimates for Residential New Construction

Utility	CEC Forecast CZ	Title 24 California CTZ	Res New Construction Homes/Yr	Statewide Total Value ($)	Statewide Resource Value ($)	Statewide Emergency Value ($)	Statewide Non-Emergency Average Demand Savings (kW)	Statewide Emergency Average Demand Savings (kW)	Statewide Energy Savings (kWh)
PG&E	1	2	2,251	653,443	497,962	155,481	753	84	35,751
PG&E	5	3	968	242,345	180,987	61,358	297	33	12,989
PG&E	4	4	11,339	3,526,536	2,695,080	831,456	4,027	447	195,933
SCE	8	6	12,811	3,067,179	2,227,596	839,583	4,067	452	175,539
LADWP	11	6	1,869	447,472	324,985	122,487	593	66	25,609
SDG&E	13	7	7,674	2,542,008	1,978,176	563,832	2,731	303	136,214
SCE	9	9	14,301	6,093,817	4,640,694	1,453,123	7,038	782	332,484
LADWP	12	9	2,839	1,209,730	921,259	288,470	1,397	155	66,004
BDP	16	9	748	318,731	242,727	76,004	368	41	17,390
SCE	10	10	26,846	9,064,067	6,767,179	2,296,888	11,125	1,236	528,413
PG&E	2	12	7,908	3,223,209	2,483,664	739,545	3,582	398	159,504
SMUD	6	12	8,531	3,477,137	2,679,330	797,807	3,864	429	172,070
PG&E	3	13	18,855	7,622,780	5,770,926	1,851,854	8,970	997	425,881
SCE	7	13	3,121	1,261,771	955,240	306,531	1,485	165	70,494
Other	15	15	2,298	1,215,213	906,271	308,942	1,496	166	68,319
Other	14	16	605	192,185	148,405	43,780	212	24	9,600
			122,963	**44,157,624**	**33,420,482**	**10,737,142**	**52,006**	**5,778**	**2,432,195**

Nonresidential Results

Nonresidential results per thermostat

Table 10: Base Case Energy, Demand & Cost Savings per Tstat - Nonresidential

Base Case Cost, Energy & Demand Savings Estimates per Tstat - Nonresidential New Construction

Title 24 California CTZ	Total Value per Tstat (PV$/Tstat)		Resource Value per Tstat (PV$/Tstat)		Emergency Value per Tstat (PV$/Tstat)		Non-Emergency Avg Demand Savings per Tstat (kW/Tstat)		Emergency Avg Demand Savings per Tstat (kW/Tstat)		Energy Savings per Tstat (kWh/Tstat)	
	Office	Retail	Office	Retail	Office	Retail	Office	Retail	Office	Retail	Office	Retail
1	$442	$400	$335	$305	$107	$95	0.85	0.76	0.09	0.08	40.41	37.74
2	$475	$381	$363	$293	$113	$88	0.90	0.70	0.10	0.08	39.65	33.56
3	$404	$311	$304	$235	$100	$76	0.80	0.61	0.09	0.07	34.59	27.95
4	$467	$389	$358	$299	$109	$90	0.87	0.71	0.10	0.08	40.19	35.09
5	$409	$340	$305	$256	$103	$85	0.82	0.67	0.09	0.07	37.07	31.81
6	$439	$370	$325	$276	$114	$94	0.91	0.75	0.10	0.08	41.96	36.64
7	$497	$417	$382	$321	$114	$96	0.91	0.77	0.10	0.09	44.02	39.27
8	$423	$347	$320	$264	$103	$83	0.82	0.66	0.09	0.07	37.68	32.87
9	$471	$389	$361	$300	$110	$89	0.87	0.71	0.10	0.08	41.03	36.15
10	$479	$382	$361	$290	$118	$92	0.94	0.73	0.10	0.08	43.28	36.84
11	$554	$455	$434	$360	$120	$95	0.95	0.76	0.11	0.08	42.86	38.84
12	$542	$448	$421	$350	$121	$97	0.97	0.78	0.11	0.09	44.95	39.77
13	$505	$424	$384	$325	$122	$98	0.97	0.78	0.11	0.09	45.24	41.03
14	$525	$441	$400	$339	$125	$102	1.00	0.81	0.11	0.09	44.28	39.67
15	$543	$445	$409	$339	$134	$106	1.07	0.84	0.12	0.09	47.51	41.63
16	$456	$363	$353	$282	$103	$81	0.82	0.64	0.09	0.07	35.85	29.97

Nonresidential Statewide Results

The statewide estimates of energy, demand and cost savings are developed by multiplying the savings per thermostat in the above section and multiplying by an estimate of the number of thermostats statewide. The estimate for the number of thermostats in nonresidential buildings is based on an average of the last 4 years of construction activity. We assume that there is a thermostat for every 2,000 sf of floorspace and all new air conditioned spaces have a demand control. If we are considering only those spaces that would be served with a stand alone thermostat or PCT then we would only consider single zone systems. Single zone systems account for 71% of all conditioned floor space served. For more information about the estimates of new nonresidential floor space or the fraction of floor space served by single zone systems please see Appendix 3 – Statewide Estimates of Air-Conditioned Dwelling Units or Commercial Floor Space.

Table 11: Statewide Energy, Demand & Cost Savings – Nonresidential

Statewide Cost, Energy and Demand Savings Estimates for Nonresidential New Construction

Title 24 California CTZ	Statewide Avg. Annual New Construction Area (sf)	Statewide Total Value (PV$)	Statewide Resource Value (PV$)	Statewide Emergency Value (PV$)	Non-Emergency Average Demand Savings	Emergency Average Demand Savings (kW)	Statewide Energy Savings (kWh)
1	243,843	$52,887	$40,121	$12,765	102	11	4,862
2	1,376,745	$313,325	$239,423	$73,902	588	65	26,396
3	12,822,400	$2,361,494	$1,778,622	$582,872	4,635	515	205,343
4	9,490,575	$2,071,365	$1,590,207	$481,158	3,826	425	181,202
5	1,378,275	$264,782	$198,286	$66,496	529	59	24,260
6	7,724,368	$1,573,690	$1,168,741	$404,949	3,220	358	152,566
7	4,161,900	$967,252	$744,238	$223,015	1,774	197	87,626
8	12,008,175	$2,324,255	$1,762,553	$561,702	4,467	496	212,470
9	7,383,638	$1,589,231	$1,221,035	$368,196	2,928	325	142,646
10	9,455,800	$2,065,819	$1,560,883	$504,936	4,016	446	191,405
11	3,173,625	$812,464	$639,155	$173,309	1,378	153	65,300
12	14,837,825	$3,728,366	$2,902,041	$826,325	6,571	730	317,279
13	3,725,475	$880,808	$671,297	$209,511	1,666	185	81,139
14	12,239,230	$2,971,426	$2,272,987	$698,439	5,554	617	257,759
15	6,020,158	$1,512,318	$1,143,435	$368,884	2,934	326	135,708
16	2,277,345	$478,534	$371,340	$107,194	852	95	38,271
Total AC DR	**108,319,375**	**$23,968,017**	**$18,304,364**	**$5,663,652**	**45,040**	**5,004**	**2,124,231**
Single Zone PC	**76,832,749**	**$17,000,916**	**$12,983,593**	**$4,017,323**	**31,948**	**3,550**	**1,506,753**

Residential Air Emission Impacts

Table 12: Base Case Pollution Savings per Tstat – Residential

Base Case Pollution Savings Estimates per Tstat for Residential New Construction			
Title 24 California CTZ	NOx Reduction per Tstat (Lbs/Tstat)	PM10 Reduction per Tstat (Lbs/Tstat)	CO2 Reduction per Tstat (Tons/Tstat)
1	0.0022	0.0008	0.0069
2	0.0034	0.0014	0.0110
3	0.0030	0.0012	0.0096
4	0.0036	0.0015	0.0119
5	0.0042	0.0017	0.0137
6	0.0030	0.0012	0.0096
7	0.0033	0.0014	0.0114
8	0.0030	0.0012	0.0100
9	0.0043	0.0018	0.0147
10	0.0043	0.0017	0.0138
11	0.0046	0.0018	0.0148
12	0.0047	0.0018	0.0148
13	0.0049	0.0020	0.0158
14	0.0056	0.0022	0.0176
15	0.0064	0.0026	0.0206
16	0.0036	0.0014	0.0115

Table 13: Statewide Pollution Savings – Residential

Statewide Pollution Savings Estimates for Residential New Construction

Utility	CEC Forecast CZ	Title 24 California CTZ	Res New Construction Homes/Yr	Statewide NOx Reduction (Lbs)	Statewide PM10 Reduction (Lbs)	Statewide CO2 Reduction (Tons)
PG&E	1	2	2,251	8	3	25
PG&E	5	3	968	3	1	9
PG&E	4	4	11,339	41	17	135
SCE	8	6	12,811	38	15	123
LADWP	11	6	1,869	6	2	18
SDG&E	13	7	7,674	26	11	87
SCE	9	9	14,301	61	26	210
LADWP	12	9	2,839	12	5	42
BDP	16	9	748	3	1	11
SCE	10	10	26,846	115	46	370
PG&E	2	12	7,908	37	14	117
SMUD	6	12	8,531	40	15	126
PG&E	3	13	18,855	92	37	298
SCE	7	13	3,121	15	6	49
Other	15	15	2,298	15	6	47
Other	14	16	605	2	1	7
			122,963	**513**	**207**	**1,673**

Nonresidential Air Emission Impacts

Table 14: Base Case Pollution Savings per Tstat– Nonresidential

Pollution Savings Estimates per Tstat - Nonresidential New Construction

Title 24 California CTZ	Statewide NOx Reduction (Lbs/Tstat)		Statewide PM10 Reduction (Lbs/TStat)		Statewide CO2 Reduction (Tons/Tstat)	
	Office	Retail	Office	Retail	Office	Retail
1	0.009	0.008	0.004	0.003	0.029	0.026
2	0.008	0.007	0.003	0.003	0.027	0.023
3	0.008	0.006	0.003	0.002	0.025	0.019
4	0.009	0.007	0.003	0.003	0.028	0.024
5	0.008	0.007	0.003	0.003	0.026	0.022
6	0.008	0.007	0.003	0.003	0.028	0.024
7	0.008	0.007	0.003	0.003	0.027	0.025
8	0.008	0.007	0.003	0.003	0.026	0.022
9	0.008	0.007	0.003	0.003	0.027	0.023
10	0.010	0.008	0.004	0.003	0.031	0.026
11	0.009	0.008	0.004	0.003	0.030	0.027
12	0.010	0.008	0.004	0.003	0.033	0.026
13	0.010	0.008	0.004	0.003	0.031	0.027
14	0.009	0.009	0.004	0.004	0.031	0.029
15	0.010	0.008	0.004	0.003	0.033	0.027
16	0.007	0.007	0.003	0.003	0.024	0.021

As described earlier, 71% of nonresidential floor area is served by single zones systems that could be controlled by stand-alone thermostats and thus easily by PCTs. Thus the pollution savings from PCTs is 71% of the total demand responsive air conditioning savings based upon temperature setpoint set-up.

Table 15: Statewide Pollution Savings – Nonresidential

Statewide Pollution Savings Estimates for Nonresidential New Construction

Title 24 California CTZ	Statewide Avg. Annual New Construction Area (sf)	Statewide NOx Reduction (Lbs)	Statewide PM10 Reduction (Lbs)	Statewide CO2 Reduction (Tons)
1	243,843	1.1	0.4	3.5
2	1,376,745	5.4	2.2	17.8
3	12,822,400	45.1	17.9	144.9
4	9,490,575	38.4	15.5	125.0
5	1,378,275	5.2	2.1	16.9
6	7,724,368	29.7	12.5	99.8
7	4,161,900	15.6	6.9	54.4
8	12,008,175	43.5	17.8	143.4
9	7,383,638	27.3	11.6	92.3
10	9,455,800	42.3	16.7	135.7
11	3,173,625	14.0	5.6	45.4
12	14,837,825	69.3	27.5	223.1
13	3,725,475	16.6	6.8	54.8
14	12,239,230	56.8	22.5	182.2
15	6,020,158	28.4	11.5	93.0
16	2,277,345	8.1	3.3	26.4
Total AC	**108,319,375**	**447**	**181**	**1,458**
Zone PCT	**76,832,749**	**317**	**128**	**1,035**

Cost-effectiveness

The savings calculated from PCTs is dependent upon the assumptions one uses for participation rates, rate design etc. Thus we have developed five scenarios from a pessimistic estimate of savings to a very optimistic estimate of savings. Along this continuum in the middle is the "base" scenario which we believe to be a reasonably likely outcome of the statewide application of thermostats and a supporting utility rate design which returns most of the resource acquisition value to PCT owners who allow their thermostat to be set-up during the curtailment periods.

The incremental first cost of a PCT is approximately $60 more than a standard programmable thermostat. Since the period of analysis for residential buildings is 30 years and the PCT will have to be replaced in 15 years, the discounted (3% real rate), incremental life cycle equipment cost of PCTs is $100.

What the results in Table 16 indicate is that cost-effectiveness is dependent on climate zone but is even more highly dependent upon the scenario of assumptions used to calculate savings. Our best estimate at predicting savings indicates that PCTs are cost-effective. However the results are dependent upon the rules that are created for demand response programs and how people respond.

Table 16 Residentail Cost-Effectiveness by CTZ and Scenario

ResidentialBenefit/Cost Ratio					
	Residential New Construction				
Climate Zone	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5
1	0.0	0.2	1.46	5.1	6.3
2	0.1	0.5	2.9	6.0	7.5
3	0.1	0.4	2.5	5.7	6.9
4	0.1	0.5	3.2	6.9	8.4
5	0.1	0.4	3.1	5.3	6.3
6	0.1	0.5	2.4	5.3	6.4
7	0.1	0.6	3.4	6.0	7.5
8	0.1	0.5	2.8	5.8	7.1
9	0.1	0.8	4.3	9.7	12.1
10	0.1	0.6	3.4	7.3	9.1
11	0.1	0.7	4.4	8.5	10.6
12	0.1	0.6	4.1	8.5	10.7
13	0.1	0.7	4.1	8.4	10.2
14	0.1	0.7	4.6	9.4	11.5
15	0.1	0.9	5.4	10.8	13.4
16	0.1	0.5	3.2	6.8	8.3

In nonresidential buildings, the life of the thermostat is the same as the period of analysis, 15 years. As a result, the present value of the incremental equipment cost is the same as the incremental first cost or $50. The results in Table 17 indicate that cost-effectiveness of PCTs is greater in nonresidential spaces than in residential homes. Whether PCTs are cost-effective is dependent on scenario, but under the base scenario, PCTs are very cost-effective.

Table 17: Nonresidential Cost-Effectiveness by CTZ and Scenario

Nonresidential Benefit/Cost Ratio										
	Office					Retail				
Climate Zone	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5
1	0.2	1.2	7.4	9.6	15.8	0.2	1.0	6.7	10.0	16.3
2	0.2	1.3	7.9	11.8	19.3	0.2	1.0	6.3	12.2	19.8
3	0.2	1.2	6.7	10.1	16.5	0.1	0.8	5.2	10.1	16.3
4	0.2	1.3	7.8	11.7	19.0	0.2	1.0	6.5	12.0	19.4
5	0.2	1.2	6.8	9.4	15.2	0.1	0.9	5.7	9.5	15.3
6	0.2	1.3	7.3	9.7	16.1	0.2	1.0	6.2	10.1	16.6
7	0.3	1.5	8.3	10.9	17.9	0.2	0.9	7.0	11.1	18.2
8	0.2	1.2	7.1	10.9	18.0	0.2	0.9	5.8	10.7	17.5
9	0.2	1.3	7.8	12.4	20.4	0.2	1.0	6.5	12.7	20.8
10	0.2	1.4	8.0	11.8	19.6	0.2	1.0	6.4	12.3	20.3
11	0.2	1.5	9.2	12.9	20.8	0.2	1.1	7.6	12.8	20.6
12	0.2	1.4	9.0	13.1	21.5	0.2	1.1	7.5	13.6	22.3
13	0.2	1.4	8.4	12.6	20.2	0.2	1.1	7.1	12.7	20.3
14	0.2	1.4	8.8	12.1	19.8	0.2	1.1	7.3	12.2	19.7
15	0.2	1.5	9.0	13.7	22.6	0.2	1.2	7.4	13.6	22.2
16	0.2	1.3	7.6	11.8	19.0	0.2	0.9	6.0	12.1	19.5

Recommendations

Proposed Standards Language

Proposed Language for Definitions Section of the Building Efficiency Standards

SECTION 101 – DEFINITIONS AND RULES OF CONSTRUCTION

(a) **Rules of Construction.**

1. Where the context requires, the singular includes the plural and the plural includes the singular.
2. The use of "and" in a conjunctive provision means that all elements in the provision must be complied with, or must exist to make the provision applicable. Where compliance with one or more elements suffices, or where existence of one or more elements makes the provision applicable, "or" (rather than "and/or") is used.
3. "Shall" is mandatory and "may" is permissive.

(b) **Definitions**. Terms, phrases, words and their derivatives in Title 24, Part 6, shall be defined as specified in Section 101. Terms, phrases, words and their derivatives not found in Section 101 shall be defined as specified in Title 24, Part 2, Chapter 2 of the California Code of Regulations. Terms, phrases, words and their derivatives not found in either Title 24, Part 6, or Chapter 2 shall be defined as specified in Title 24, Part 2, Chapter 2 of the *California Building Code*. Where terms, phrases, words and their derivatives are not defined in any of the references above, they shall be defined as specified in *Webster's Third New International Dictionary of the English Language, Unabridged* (1987 edition), unless the context requires otherwise.

DEMAND RESPONSE PERIOD is a period of time during which the local utility is curtailing electricity loads by sending out a demand response signal.

DEMAND RESPONSE SIGNAL is an electronic signal sent out by the local utility indicating a request to their customers to curtail electricity consumption.

Proposed Nonresidential Standards Language

SUBCHAPTER 3 NONRESIDENTIAL, HIGH-RISE RESIDENTIAL, AND HOTEL/MOTEL OCCUPANCIES—MANDATORY REQUIREMENTS FOR SPACE-CONDITIONING AND SERVICE WATER-HEATING SYSTEMS AND EQUIPMENT

SECTION 122 – REQUIRED CONTROLS FOR SPACE-CONDITIONING SYSTEMS

Space-conditioning systems shall be installed with controls that comply with the applicable requirements of Subsections (a) through (h).

(e) **Shut-off**, ~~and~~ **Reset** and Demand Response **Controls for Space-conditioning Systems**. Each space-conditioning system shall be installed with controls that comply with Items 1, ~~and~~ 2 and 3 below:

1. The control shall be capable of automatically shutting off the system during periods of nonuse and shall have:

   A. An automatic time switch control device complying with Section 119 (c), with an accessible manual override that allows operation of the system for up to four hours; or

   B. An occupancy sensor; or

C. A four-hour timer that can be manually operated.

EXCEPTION to Section 122 (e) 1: Mechanical systems serving retail stores and associated malls, restaurants, grocery stores, churches, and theaters equipped with 7-day programmable timers.

2. The control shall automatically restart and temporarily operate the system as required to maintain:

A. A setback heating thermostat setpoint if the system provides mechanical heating; and

EXCEPTION to Section 122 (e) 2 A: Thermostat setback controls are not required in areas where the Winter Median of Extremes outdoor air temperature determined in accordance with Section 144 (b) 4 is greater than 32°F.

B. A setup cooling thermostat setpoint if the system provides mechanical cooling.

EXCEPTION to Section 122 (e) 2 B: Thermostat setup controls are not required in areas where the Summer Design Dry Bulb 0.5 percent temperature determined in accordance with Section 144 (b) 4 is less than 100°F.

EXCEPTION 1 to Section 122 (e) 1& 2**:** Where it can be demonstrated to the satisfaction of the enforcing agency that the system serves an area that must operate continuously.

EXCEPTION 2 to Section 122 (e) 1& 2**:** Where it can be demonstrated to the satisfaction of the enforcing agency that shutdown, setback, and setup will not result in a decrease in overall building source energy use.

EXCEPTION 3 to Section 122 (e) 1& 2**:** Systems with full load demands of 2 kW or less, if they have a readily accessible manual shut-off switch.

EXCEPTION 4 to Section 122 (e) 1& 2**:** Systems serving hotel/motel guest rooms, if they have a readily accessible manual shut-off switch.

3. If the building is provided a demand response signal by the local utility, the control shall comply with the communication requirements of the local utility and be capable and installed to set up the cooling setpoint by 4°F during the demand response period. If the control is controlling a heat pump, the control shall also be capable and installed to turn off supplementary resistance heating during the demand response period.

EXCEPTION to Section 122 (e) 3: Systems serving zones that must have constant temperatures for patient health or to prevent degradation of materials, a process, or plants or animals.

Note this language in this exception is the same as the language used in the Exception to Section 122(b) "Criteria for Zonal Thermostatic Controls." This language should be reviewed to see if it is too broad.

Proposed Residential Standards Language

SUBCHAPTER 7 LOW-RISE RESIDENTIAL BUILDINGS – MANDATORY FEATURES AND DEVICES

SECTION 150 – MANDATORY FEATURES AND DEVICES

Any new construction in a low-rise residential building shall meet the requirements of this Section.

(i) Setback and Demand Responsive Thermostats. All heating and/or cooling systems other than wood stoves shall have an automatic thermostat that complies with items 1 and 2 below.

1. Thermostat shall have ~~with~~ a clock mechanism or other setback mechanism approved by the executive director that shuts the system off during periods of nonuse and that allows the building occupant to automatically set back the thermostat set points for at least two periods within 24 hours. Setback thermostats for heat pumps shall meet the requirements of Section 112 (b).

2. If the building is provided a demand response signal by the local utility, the control shall comply with the communication requirements of the local utility and be capable and installed to set up the cooling setpoint by 4°F during the demand response period. If the control is controlling a heat pump, the control shall also be capable and installed to turn off supplementary resistance heating during the demand response period.

EXCEPTION to Section 150 (i): Gravity gas wall heaters, gravity floor heaters, gravity room heaters, noncentral electric heaters, room air conditioners, and room air-conditioner heat pumps need not comply with this requirement. Additionally, room air-conditioner heat pumps need not comply with Section 112 (b). The resulting increase in energy use due to elimination of the setback thermostat shall be factored into the compliance analysis in accordance with a method prescribed by the executive director.

PCT Specifications in the Title 24 Standards

LBNL (Lawrence Berkeley National Laboratory) is conducting PIER sponsored research into a flexible PCT platform which can be reconfigured over time. The outcome of this research will include a specification for PCTs that could be incorporated into the above sections of the Standard or into the Joint Appendices of the Standard. Since the PCT is but one piece of the larger statewide utility communications infrastructure and must be readily manufactured by multiple vendors, this specification will be the subject of a collaborative effort between LBNL, the CEC, the California Utilities and equipment manufacturers.

Alternative Calculation Method Manual

If the Commission desires to model the action of the PCT thermostats in the performance method, a listing of the hours that thermostats are set-up could be added to the ACM Manual. These hours would be for a predetermined number of days and likely a fixed number of hours on these days. This is within the capabilities of the current reference program DOE-2.1E.

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Appendix 1 - Building Energy Simulation Description

Introduction

This document describes the procedures used to determine the technical potential of demand controlled thermostats applied to residential and small commercial HVAC systems in California. The work was directed by Carlos Haiad. Accompanying spreadsheets provide the detailed results and interactive graphics that form the main deliverable of this project.

Project Scope

Phase 1 of this project concentrates on the most common applications for demand-controlled thermostats: residential systems in the range of 2 – 5 tons and small commercial packaged systems in the range of 5 – 10 tons. For these combinations of buildings and HVAC types, a range of building shells and HVAC configurations are examined for the sixteen standard California climate zones. The combination of shell and HVAC options used are intended to capture the range of cooling loads that will be encountered during a given demand period.

Twenty-one thermostat control periods, defined by a starting hour and a duration, are applied to each of the building/HVAC combinations for both the hottest day and tenth hottest day of each climate zone. All of these options lead to a total of more than 169,000 individual results derived from more than 48,000 simulations.

Table 18: Simulation options for each building type

Building Types	Individual Buildings	Zones per Building	Building Shells (Vintages)	HVAC Sizing Options	Base T-Stat Options	Demand period Options	Demand day Definitions	Climate Zones	number of simulations	number of results
Small Office	1	10	3	2	2	22	2	16	8448	80640
Small Retail	4	2	3	2	2	22	2	16	33792	64512
Single Family	4	1	3	1	3	22	2	16	6336	24192
								totals:	48,576	169,344

Building Types and HVAC systems

The three building types used for this study were chosen from a larger list of buildings types that are likely candidates for controllable thermostats. These three building types are the most common application of the HVAC systems of interest to this study.

Small Office:

- 2 stories,
- 20,000 square feet total area,
- square footprint (aspect ratio = 1),
- each floor has 4 perimeter zones and one core zone,
- 22.5' perimeter depth, (core = 30% of total area),
- a single HVAC unit serves each of 10 zones.

Small Retail:

- 2 zones per building: sales (80% of total area) and storage,
- 4 buildings: front wall with display windows facing each cardinal direction,
- 8,000 square feet total area per building,
- aspect ratio = 1.5, (approx 73' x 100'),
- three HVAC units serve the sales area; a single system serves the storage.

Single Family:

- Two 2-story models (one facing East-West, one facing North-South),
- two 1-story models (one facing East-West, one facing North-South),
- total area of each house varies with vintage and climate zone,
- each of 4 houses served by a single HVAC system.

Building Shells

Typical building construction models from three time periods are used to capture the variety of building shells that are associated with the three building types. Definitions for an old vintage (pre-1975), a mid-1990s vintage (1993 – 2001) and a new vintage for each of the building types are taken from the 2005 DEER Update Study. The definition includes insulation levels, glass type, total window area as well as internal loads such as lighting and equipment levels.

HVAC Sizing Options

The HVAC sizing methodology used in the 2005 DEER Update Study is repeated for this analysis. For residential simulations, this means using fixed HVAC capacities that have been determined for each climate zone based on vintage and house size. For the commercial simulations, design days are used to determine peak loads. Cooling and heating HVAC capacities are then calculated as the peak design day load multiplied by a sizing factor. The DEER study used a sizing factor of 1.3 for cooling. For this analysis, separate simulations are conducted with a cooling sizing factor of 1.3 and 1.5 used to determine the cooling capacities. An earlier study of similar building types found that installed cooling capacities typically fall between 1.2 and 1.6 times the design day peak loads.

Base Thermostat Options

Each of the commercial building types have two options for the cooling thermostat schedule used during normal (i.e. non demand-controlled) operation. The small office uses either a constant 72 °F or 74 °F from 7a.m. to 8p.m. while the small retail uses these same temperatures from 8a.m. to 10p.m. Both of these building types assume the nighttime cooling thermostat set point is set up to 85 °F.

The residential models use a daytime cooling thermostat set point of 74 °F or 76 °F from 8a.m. to 10p.m., with a nighttime set point of 78 °F. A third option for the residential models uses the Title-24 residential cooling thermostat schedule, which assumes a set point of 83 °F from 7a.m. to 1p.m., followed by a decrease of 1°F each hour until the set point hits 78 °F at 5p.m. and stays there until 7a.m. the following day.

Demand Period Options

The limits for the demand control period for this analysis are noon and 6p.m. A control period can start at any hour from noon to 5p.m. and last as little as one hour or last until 6p.m. Table 2 shows all of the potential control periods given these limitations. The first row of this table, with an index of zero, represents the simulation that has no demand control (also referred to as the "baseline" run).

Table 19: Demand Period Definitions

Index	Start Time	Duration	End Time
0	na	na	Na
1	noon	1 hr	1:00 PM
2	noon	2 hrs	2:00 PM
3	noon	3 hrs	3:00 PM
4	noon	4 hrs	4:00 PM
5	noon	5 hrs	5:00 PM
6	noon	6 hrs	6:00 PM
7	1:00 PM	1 hr	2:00 PM
8	1:00 PM	2 hrs	3:00 PM
9	1:00 PM	3 hrs	4:00 PM
10	1:00 PM	4 hrs	5:00 PM
11	1:00 PM	5 hrs	6:00 PM
12	2:00 PM	1 hr	3:00 PM
13	2:00 PM	2 hrs	4:00 PM
14	2:00 PM	3 hrs	5:00 PM
15	**2:00 PM**	**4 hrs**	**6:00 PM**
16	3:00 PM	1 hr	4:00 PM
17	3:00 PM	2 hrs	5:00 PM
18	3:00 PM	3 hrs	6:00 PM
19	4:00 PM	1 hr	5:00 PM
20	4:00 PM	2 hrs	6:00 PM
21	5:00 PM	1 hr	6:00 PM

The accompanying spreadsheets contain results for each of these control periods, but the summary tables use only the demand period that begins at 2p.m. and lasts until 6p.m., as this is considered to be the demand period of most interest.

Demand Day Definitions

The demand control periods defined above are applied to two days each year: the hottest day and the 10th hottest day. To determine the hottest days, each day is ranked by the average temperature from noon to 6p.m. plus the maximum temperature from noon to 6p.m. Table 3 shows the dates for these two hot days for each climate zone.

Table 20: Control Days used in the analysis (hottest and 10th hottest days)

Climate Zone	Year	Annual Max (°F)	Hottest Day				10th Hottest Day			
			Month	Day	Ave T (°F)	Max T (°F)	Month	Day	Ave T (°F)	Max T (°F)
CZ01	1991	80	OCT	1	71	80	AUG	29	71	72
CZ02	1998	99	JUL	23	96	99	SEP	16	93	96
CZ03	1994	91	SEP	28	87	91	OCT	3	82	84
CZ04	1998	97	AUG	27	93	97	SEP	21	86	90
CZ05	1995	93	SEP	4	84	93	SEP	27	76	82
CZ06	1998	89	AUG	31	83	87	OCT	2	77	83
CZ07	1993	92	OCT	27	85	90	JUL	21	81	86
CZ08	1998	98	SEP	24	91	98	JUL	20	88	92
CZ09	1993	102	SEP	24	98	102	JUL	12	92	97
CZ10	1991	104	AUG	13	101	104	SEP	3	96	101
CZ11	1998	105	JUL	15	103	105	JUL	1	99	100
CZ12	1991	103	AUG	20	102	103	JUL	12	98	100
CZ13	1991	106	AUG	1	104	106	AUG	19	101	104
CZ14	1994	106	JUL	11	104	106	AUG	9	101	103
CZ15	1998	115	JUL	7	113	115	AUG	17	111	113
CZ16	1991	96	JUL	5	93	95	AUG	5	88	91

The year shown in this table was chosen such that both the hottest day and the 10th hottest day fall on weekdays. The simulations use this year to assure that the building models will be using occupied schedules for the control days.

More details regarding the criteria used to choose the hot days and the actual hot day temperature profiles are available in the accompanying "Peak Day Definition" spreadsheet.

Analysis Procedure

The 2005 DEER Update Modeling Tool was used to create the climate zone and vintage dependent DOE2 building models described above. Batch procedures and manual editing were used to modify the DOE2 models to accommodate the thermostat and HVAC modeling needed for this analysis.

Modifications to the 2005 DEER small retail model include:

- Removing the windows from all but the front wall,
- setting an aspect ratio of 1.5, with the front having the smaller side,
- creating 4 separate building by rotating the model to face each cardinal direction,
- replacing the HVAC specifications with detailed SEER-10 packaged system performance curves.

Modifications to the 2005 DEER small office model include:

- Changing the total area from 10,000 ft^2 to 20,000 ft^2,
- increasing the perimeter depth from 15 to 22.5 feet to better accommodate the HVAC sizes of interest,
- replacing the HVAC specifications with detailed SEER-10 packaged system performance curves.

Modifications to the 2005 DEER single-family residential model include:

- Replacing the SEER 8.5 unit in the "pre-1975" vintage with SEER 10 unit specifications.

HVAC modeling

This analysis utilizes the detailed residential HVAC performance curves developed for the 2005 DEER Update Study. Instead of relying on DOE2 default values for HVAC performance, expanded engineering data for actual residential split systems are used. The process used to choose the typical HVAC unit within each SEER level is documented in the SCE report "DEER Residential SEER-Rated Units Performance Maps Phase2". This report is available from the 2005 DEER documentation as "DEER-SEERUnitPerformanceMapsPhase2_2005-04-07b.pdf". The residential models use the median performing SEER 10 and SEER 13 performance maps.

The development of detailed HVAC performance maps was expanded to include small commercial packaged units. Detailed performance curves were derived for a wide range of SEER and cooling capacity levels. For this application, the data were filtered down to units with a SEER level between 9.7 and 10.3, and with rated cooling capacities between 55,000 and 100,000 BTU/hr (approximately 4.5 to 8.5 tons). The performance curves of the median unit were chosen as the basis for the commercial simulations for this analysis.

Thermostat Modeling

The base case thermostat schedules described above were used to establish the HVAC demand in the absence of thermostat control. For each base case thermostat simulation, 21 additional simulations were conducted that increase thermostat setpoint by 4 degrees during the control periods described in table 2. Figures 1 and 2 below show the base case and controlled case cooling thermostat schedules for two of the residential scenarios. In these examples, the control period is from 2p.m. to 6p.m. The commercial thermostat schedules are similar in shape to those shown in figure 1, with different daytime and nighttime set points.

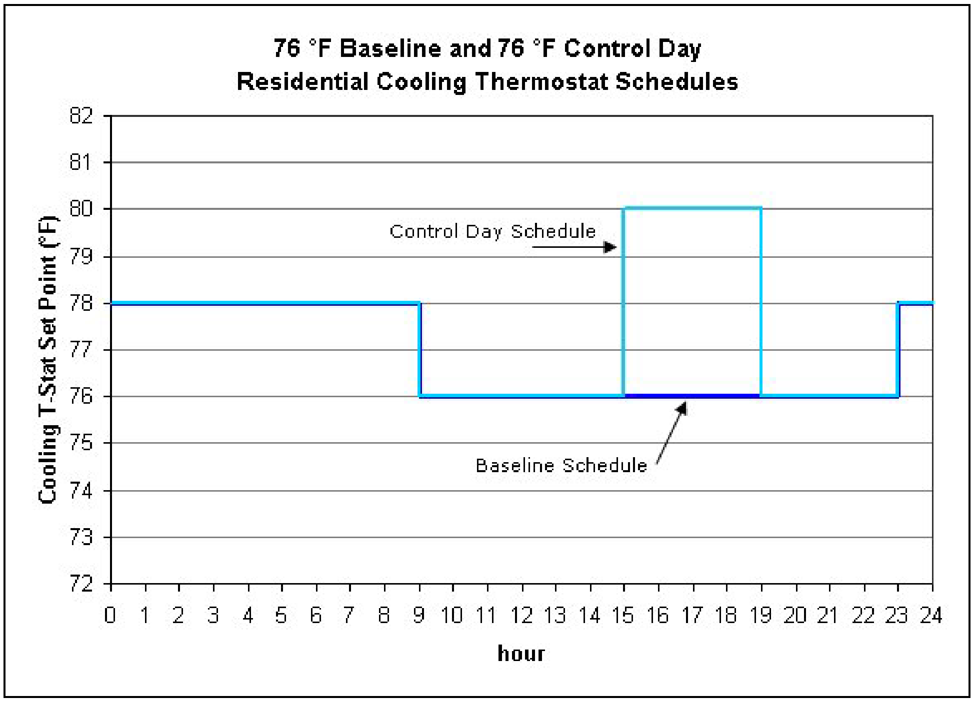

Figure 7. Residential Baseline and Control day cooling thermostat schedule

Calculation of Demand Reduction

The demand reduction is determined by comparing the baseline hourly demand to the hourly demand of the control day using the modified thermostat schedule. Two definitions of demand reduction are presented in the results spreadsheets. The first definition is referred to as "average demand reduction" with the units of kWh/hr-ton. These values are calculated as the simple difference in hourly energy use from one scenario to the other, normalized by the cooling capacity in tons.

The second demand definition is referred to as "run-time demand reduction" with units of kW/ton. These values are calculated as the demand reduction during the fraction of the hour when the baseline HVAC compressor was operating, normalized by the cooling capacity in tons. These values are always greater than or equal to the average demand reduction.

Simulation Results

The challenge of presenting nearly 170,000 sets of results is how to present the results in a meaningful and useful way without overwhelming the viewer with too many tables and graphs. The spreadsheets accompanying this report filter the results down to a single table for each building type. The spreadsheets also present interactive graphs that allow for the examination and comparison of each individual set of results.

Average Results

The summary table for "average demand reduction" for the small office building type is shown below. This table presents the values of most interest along with some indications of reliability.

Table 21 Summary Results for Small Office

	Whole Building Average Demand Reduction (kWh/hr-ton)							Ind. Zones	
Climate Zone	**Control Period = 2pm - 6pm**				period Average	First Hour		First Hour	
	1st hr	2nd hr	3rd hr	4th hr		Min	Max	Min	Max
CZ01	**0.29**	0.23	0.18	0.17	0.22	0.21	0.37	0.12	0.62
CZ02	**0.26**	0.16	0.14	0.12	0.17	0.18	0.35	0.12	0.56
CZ03	**0.25**	0.16	0.13	0.12	0.17	0.18	0.34	0.11	0.58
CZ04	**0.25**	0.16	0.14	0.13	0.17	0.17	0.34	0.11	0.57
CZ05	**0.25**	0.16	0.13	0.12	0.17	0.18	0.33	0.11	0.60
CZ06	**0.23**	0.14	0.12	0.11	0.15	0.16	0.31	0.10	0.60
CZ07	**0.25**	0.17	0.15	0.13	0.17	0.18	0.34	0.10	0.72
CZ08	**0.25**	0.15	0.13	0.11	0.16	0.17	0.33	0.11	0.56
CZ09	**0.24**	0.16	0.14	0.12	0.16	0.17	0.33	0.11	0.61
CZ10	**0.25**	0.16	0.13	0.12	0.16	0.18	0.34	0.11	0.53
CZ11	**0.25**	0.16	0.13	0.12	0.16	0.17	0.33	0.11	0.53
CZ12	**0.25**	0.16	0.14	0.13	0.17	0.17	0.33	0.11	0.54
CZ13	**0.24**	0.16	0.14	0.13	0.17	0.17	0.33	0.11	0.55
CZ14	**0.23**	0.15	0.13	0.12	0.16	0.16	0.31	0.10	0.49
CZ15	**0.24**	0.15	0.14	0.13	0.16	0.16	0.32	0.11	0.53
CZ16	**0.27**	0.17	0.14	0.13	0.18	0.18	0.37	0.11	0.65

The results presented in this table are for a single demand control period: from 2p.m. to 6p.m., and are averaged across 240 combinations of building shell and HVAC configurations:

- 10 zones: 4 perimeter and 1 core for each of two floors
- 3 vintages: pre-1975, 1993 – 2001 new
- 2 base cooling setpoints: 72F, 74F
- 2 control days: hottest day, 10th hottest day
- 2 cooling equipment sizing ratios: 1.3, 1.5

These are "whole building" results in that the individual results for each HVAC system in the 10-zone building are averaged together. The whole building results are further averaged across the various vintages, base cooling thermostats, cooling equipment sizing ratios and control day definitions. Some of these variables may have weights that can be applied, as opposed to simply averaging the results. Alternative methods of combining the data can be applied to the individual sets of results that are also included in the spreadsheets.

Columns 2 through 5 of this table present the average demand reduction per ton of cooling capacity for each of the hours of the control period; column 6 is the average demand reduction across all four hours of the control period. Columns 7 and 8 bracket the range of whole building first hour demand savings across the various vintages, base cooling thermostat set points, control days and cooling equipment sizing factors.

In climate zone CZ01, for example, the average whole building demand savings is 0.29 kWh/hr-ton in the first hour of the control period. The minimum whole building demand savings for any vintage, base cooling set point, equipment sizing ratio or control day is 0.21 kWh/hr-ton while the maximum savings across these model variations is 0.37 kWh/hr-ton. The minimum and maximum first hour savings for any particular HVAC system across these variables is given in columns 9 and 10 and is necessarily a wider range of results than the whole building minimum and maximum values.

Table 22 presents a similar set of results for the small retail building. In this case, "whole building" refers to the combination of sales and storage areas.

Table 22 . Summary Results for Small Retail

	Whole Building Average Demand Reduction (kWh/hr-ton)							Ind. Zones	
Climate	**Control Period = 2pm - 6pm**				period	First Hour		First Hour	
Zone	1st hr	2nd hr	3rd hr	4^{th} hr	Average	Min	Max	Min	Max
CZ01	**0.26**	0.30	0.25	0.25	0.27	0.19	0.36	0.18	0.39
CZ02	**0.23**	0.20	0.18	0.16	0.19	0.19	0.27	0.17	0.29
CZ03	**0.21**	0.21	0.17	0.16	0.19	0.17	0.26	0.16	0.28
CZ04	**0.23**	0.22	0.18	0.18	0.20	0.19	0.26	0.17	0.29
CZ05	**0.22**	0.21	0.18	0.17	0.20	0.18	0.26	0.16	0.29
CZ06	**0.20**	0.19	0.16	0.16	0.18	0.17	0.23	0.15	0.25
CZ07	**0.22**	0.22	0.19	0.17	0.20	0.17	0.27	0.16	0.29
CZ08	**0.22**	0.18	0.16	0.15	0.18	0.18	0.27	0.16	0.31
CZ09	**0.22**	0.19	0.18	0.16	0.19	0.17	0.27	0.14	0.29
CZ10	**0.21**	0.18	0.16	0.15	0.18	0.18	0.26	0.15	0.27
CZ11	**0.21**	0.18	0.16	0.15	0.17	0.17	0.25	0.15	0.27
CZ12	**0.21**	0.19	0.17	0.16	0.19	0.17	0.26	0.15	0.27
CZ13	**0.20**	0.18	0.16	0.16	0.17	0.15	0.25	0.08	0.26
CZ14	**0.20**	0.17	0.15	0.15	0.17	0.14	0.24	0.07	0.25
CZ15	**0.17**	0.15	0.14	0.14	0.15	0.10	0.23	0.00	0.24
CZ16	**0.25**	0.22	0.19	0.17	0.21	0.21	0.30	0.18	0.31

These results are averaged across 192 combinations of building shell and HVAC configurations:

- 4 orientations: front facing North, East, South, West
- 2 zones: sales and storage
- 3 vintages: pre-1975, 1993 – 2001 new
- 2 base cooling setpoints: 72F, 74F
- 2 control days: hottest day, 10th hottest day
- 2 cooling equipment sizing ratios: 1.3, 1.5

Compared to the Small Office results, savings for the retail building are somewhat smaller, but with a smaller range between first hour minimum and maximum savings.

The summary results for the single-family building are presented in Table 23. For this building type, the results are averaged across 72 combinations of building shell and HVAC configurations:

- 2 building sizes: 1 story, 2 story
- 2 building orientations: windows facing East & West, windows facing North & South
- 3 vintages: pre-1975, 1993 - 2001 new
- 3 base cooling setpoints: 74F, 74F, Title-24 schedule
- 2 control days: hottest day, 10th hottest day

Columns 7 and 8 of Table 23 are the minimum and maximum demand savings for any of the configurations listed above. Unlike the results for the small office and small retail buildings, the "whole building" and "individual zone" results are the same, so there is no need for the second set of Min/Max results.

Table 23. Summary Results for Single-Family

	Average Demand Reduction (kWh/hr-ton)						
Climate	**Control Period = 2pm - 6pm**				period	First Hour	
Zone	1st hr	2nd hr	3rd hr	4th hr	Average	Min	Max
CZ01	**0.22**	0.20	0.14	0.16	0.18	0.00	0.50
CZ02	**0.34**	0.23	0.20	0.17	0.24	0.20	0.48
CZ03	**0.28**	0.18	0.15	0.13	0.18	0.20	0.33
CZ04	**0.32**	0.21	0.17	0.15	0.21	0.28	0.41
CZ05	**0.26**	0.19	0.16	0.14	0.19	0.00	0.35
CZ06	**0.25**	0.16	0.13	0.12	0.17	0.20	0.29
CZ07	**0.31**	0.21	0.18	0.16	0.21	0.24	0.41
CZ08	**0.29**	0.17	0.15	0.13	0.19	0.05	0.35
CZ09	**0.34**	0.22	0.18	0.16	0.23	0.09	0.44
CZ10	**0.35**	0.21	0.17	0.16	0.23	0.20	0.46
CZ11	**0.37**	0.22	0.18	0.15	0.23	0.27	0.45
CZ12	**0.37**	0.24	0.21	0.19	0.25	0.26	0.47
CZ13	**0.36**	0.23	0.19	0.16	0.24	0.14	0.49
CZ14	**0.34**	0.23	0.20	0.18	0.24	0.22	0.42
CZ15	**0.35**	0.21	0.19	0.17	0.23	0.09	0.45
CZ16	**0.29**	0.18	0.16	0.13	0.19	0.23	0.35

Individual Results

The results spreadsheets include all of the sets of individual simulation results produced for this analysis (which explains why the spreadsheets are so large). Summary tables like the ones presented above are included in the spreadsheet, as are tables with greater detail and less averaging across the building configurations. In the small retail results spreadsheet, for example, the tab labeled "AllRes 2p-6p" presents the demand savings results for the control period defined from 2p.m. to 6p.m. for all whole-building configurations in a table 384 rows long and 51columns wide.

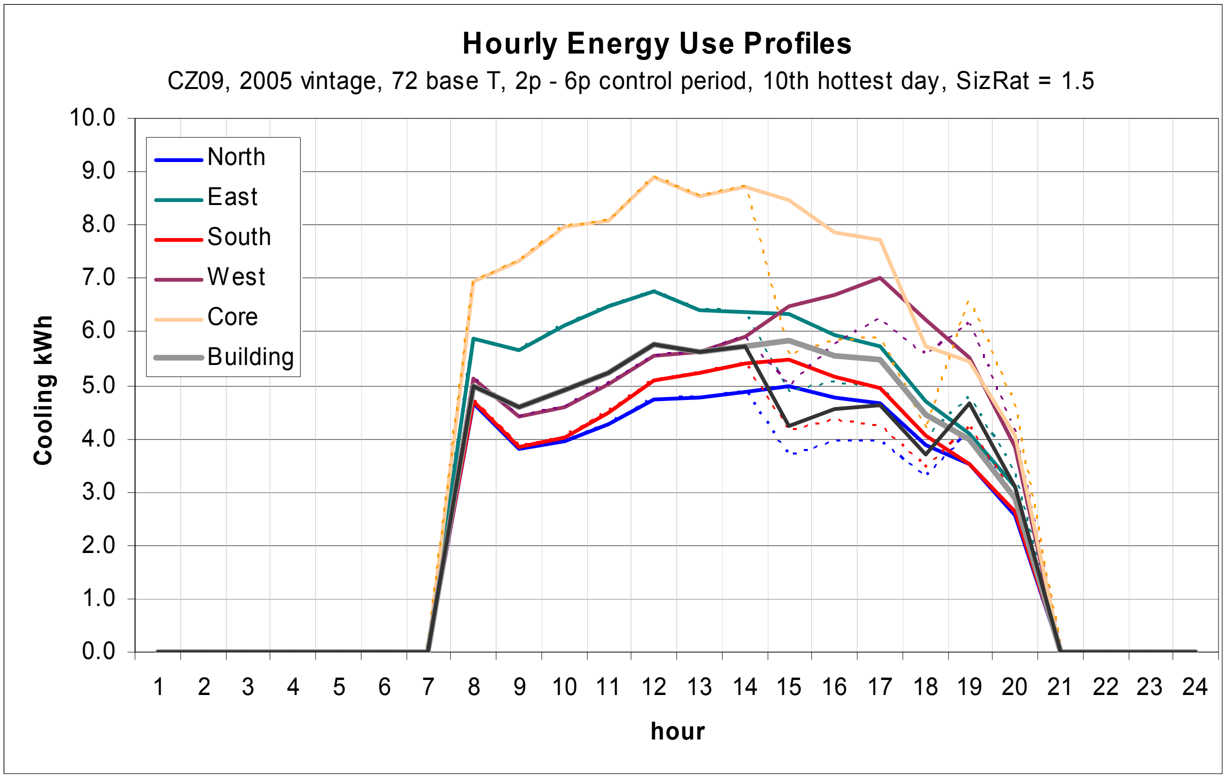

Figure 8 Small Office Energy Use Profile for a specific building configuration

Even greater detail is available on the interactive graphics tab, where the results of all zones and all control periods can be viewed. Diagnostic results, such as interior temperatures for each zone and hourly HVAC energy use, provide insight to how the simulation models are working. Figure 8 Small Office Energy Use Profile for a specific building configuration shows an example of the hourly energy use profile graph. The dotted lines show the effect of the demand control cooling schedule on the hourly HVAC energy use.

The "hourly average reduction" graph shows the demand savings for each zone and for each hour of a particular building configuration. The increase in HVAC energy use (negative savings values) after the control period ends can be seen in these results.

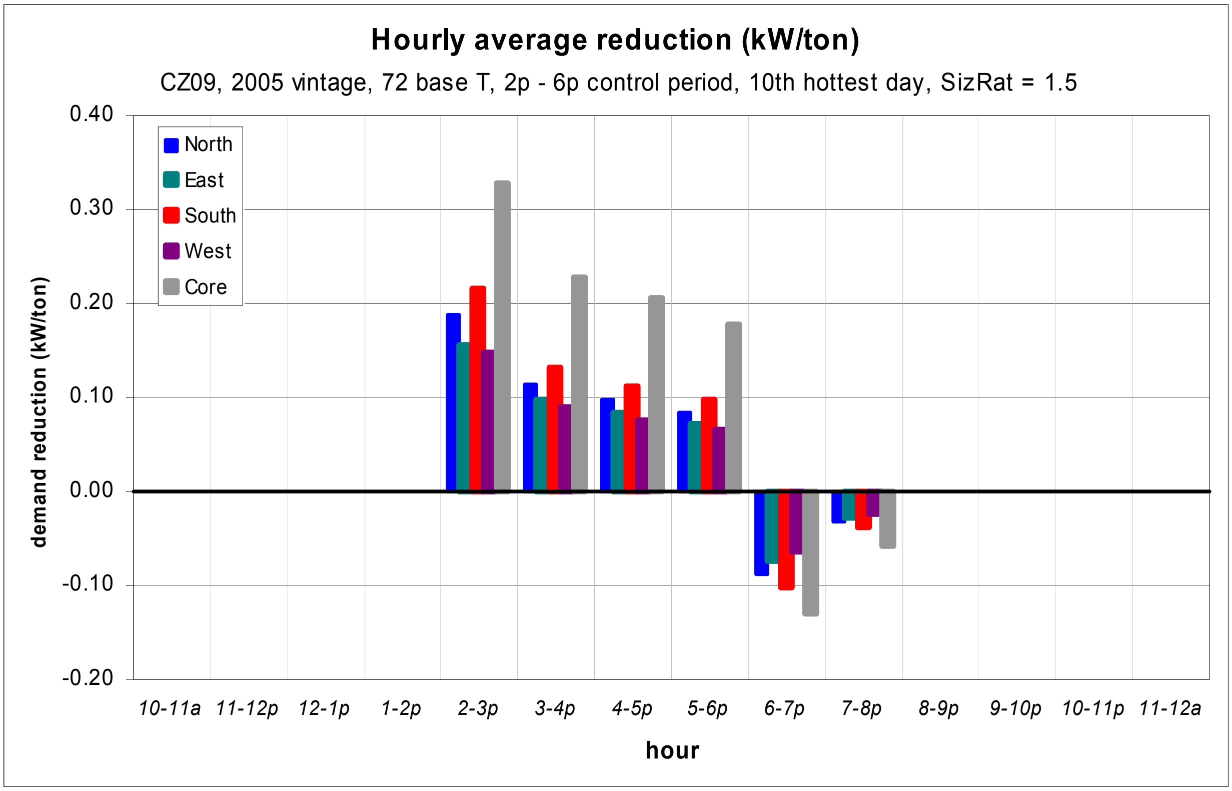

Figure 9 Small Office Demand Savings for each zone and all hours for a specific building configuration

Additional Analysis

This work could be expanded to study the sensitivity of demand reduction to residential cooling capacity. Currently, there is some diversity in the cooling sizing factor built into the residential models, but the sensitivity of demand savings to the cooling sizing factor has not been explicitly examined.

This analysis includes only the two most common commercial building types that use small packaged HVAC systems and single-family residences. The building types listed below also use the HVAC system types of interest to this study:

Residential – Multifamily
Residential - Double-Wide Mobile
Assembly
Education - Primary School
Education - Secondary School
Education - Community College
Education - Relocatable Classroom
Manufacturing - Bio/Tech
Manufacturing - Light Industrial
Restaurant - Sit-Down
Restaurant - Fast-Food
Retail - Single-Story Large

Sensitivity of demand reduction during control periods to the actual HVAC unit used has not been examined. This analysis uses the "median performing" unit, determined by annual energy use. Performance characteristics for a range of HVAC units within each SEER level have already been developed and could be used to determine the impact of unit selection on demand savings.

Appendix 2 – PCT Capabilities and Pricing Survey

Preliminary PCT Specification

The initial starting point for the PCT functionality specification was provided by the CEC and is presented below in Figure 10 Preliminary PCT Specification. Although this specification is slightly different from that used in the earliest stakeholder interviews conducted under this project, we believe the CEC specification is sound, well supported by the documents included in the literature review as well as our previous research, and consistent with the opinions of the majority of relevant industry stakeholders. We therefore adopted this specification as the basis for our investigations into PCT costs, benefits, and stakeholder positions in all communications subsequent to the technology planning meeting held at Southern California Edison's Customer Technology Applications Center on July 15, 2005.

Figure 10 Preliminary PCT Specification

Necessary Functions for Emergency Response

- Receive at least one type of communication signal to control thermostat set point
- Respond automatically to emergency signals
- Indicate the emergency state

Necessary Functions for Price Response

- Receive at least one type of communication signal to which the PCT can respond based upon customer's preference
- Be programmed by the customer to respond according to desired temperature changes at desired price thresholds.
- Be capable of customer override during events
- Indicate the critical peak pricing state

Necessary Functions for Verification

- Transmit acknowledgement signal back with time stamp. (Note: Final determination of this function as being necessary for the standards is pending.)

Potential Functions for Emergency Response

- Provide system operators with the ability to target specific geographic locations and select only the amount of load necessary to address individual shortage situations

Potential Functions for Price Response

- Ship the PCT with default heating and cooling setpoints at pre-programmed electric rate thresholds.
- Provide information to the user on energy usage and cost per hour/day/month from AC system
- Provide information to the user on energy usage and cost per hour/day/month from meter for total consumption

Potential Functions for Verification

- Transmit information to the utility on the operating state of the controlled HVAC equipment
- Transmit information to the utility on actual temperature and temperature settings

Other Potential Functions

- Remote programming and customer override/control via web or phone
- Relay information signals to other appliances, pool pump, water heater, dryer or lighting.
- Bundle the 5 wires between the HVAC system to the thermostat into one common plug, similar to a phone cord system. This would allow for plug and play capability.

Table 24 Hardware and installation costs for PCTs capable of emergency and price responsiveness.

Sales Channel	Retail				Wholesale to Contractors			
	Hardware Cost		Installation Cost		Hardware Cost		Installation Cost	
Annual Volume	Emergency Response	Price Response	Emergency Response	Price Response	Emergency Response	Price Response	Emergency Response	Price Response
50,000	$90 to $200	$95 to $200	Little incremental cost relative to conventional thermostat. $75 to $100 total.		$75 to $160	$75 to $160	Little incremental cost relative to conventional thermostat. $75 to $100 total.	
100,000	$80 to $170	$80 to $170			$60 to $135	$60 to $135		
250,000	$60 to $125	$60 to $125			$45 to $100	$45 to $100		

We draw the following conclusions from these responses:

- Not surprisingly, the data in the table demonstrate that annual sales volume can play a significant role in the cost of a PCT.
- Cost estimates vary by a factor of approximately 2 regardless of sales channel or volume. This appears to be primarily linked to manufacturer assumptions regarding the type of communications receiver integrated into the PCT.
- These responses suggest that the market price of a PCT capable of responding to both emergency and price signals would be only slightly higher than the market price of a PCT able to respond to only one of these signals.
- PCTs can be installed at little if any incremental cost relative to conventional thermostats.

We also asked manufacturers to estimate the costs of PCTs that could acknowledge receipt of emergency and price signals in addition to responding to those signals. The range of responses is presented in Table 25 for the same sales channels and annual sales volumes as above. As above, the costs indicated in the table reflect hardware and installation costs only, and explicitly do not include costs related to sending signals to or receiving responses from installed PCTs.

From these responses we conclude that:

- Moving from one-way to two-way communication adds considerable hardware and installation cost to a PCT.
- Manufacturers' assumptions about how return path communications (PCT to utility) is established lead to very different cost estimates among vendors for two-way communication. This results in the much broader range of price estimates than was the case for one-way PCTs.
- Installation costs increase due to the need to verify two-way communication and in some cases due to installation of additional equipment.

Table 25 . Hardware and installation costs for two-way PCTs

Sales Channel	Retail				Wholesale to Contractors			
	Hardware Cost		Installation Cost		Hardware Cost		Installation Cost	
Volume	Emergency Response	Price Response	Emergency Response	Price Response	Emergency Response	Price Response	Emergency Response	Price Response
50,000	$110 to $545	$110 to $545	2-way communication adds from $30 to $80 to installation costs, relatively insensitive to volume.		$100 to $435	$100 to $435	2-way communication adds from $30 to $80 to install costs, relatively insensitive to volume.	
100,000	$105 to $515	$109 to $515			$93 to $410	$93 to $410		
250,000	$100 to $470	$100 to $470			$86 to $375	$86 to $375		

Communication costs.

Our initial investigation into the communication-related costs of operating a PCT network resulted in the consistent message that cost structures are very flexible and highly dependent on the size, frequency, and timing of the communications. None of the communications providers we interviewed were willing or able to provide cost estimates in the abstract. Several providers indicated that they offer a variety of pricing structures that can be adapted to particular applications. With the exception of the case in which utilities own and operate the communications network, as could be the case with a power line carrier technology, our view is that the actual pricing of the communications service is likely to be the result of a negotiation between the utility and the provider for a specific application.

Subsequent to the technology planning meeting, we sent questionnaires to a set of 14 communications providers, intended to elicit better information on the range of costs necessary to establish (where a network doesn't already exist) and operate a network capable of supporting the communications requirements of a growing population of installed PCTs. The communications providers we contacted included companies operating networks based on paging, cellular, satellite, PLC, BPL, and conventional VHF technologies. Unfortunately, response to this questionnaire was substantially less robust than the response provided by PCT manufacturers, despite our repeated attempts to encourage the communications companies to respond. Only four communications providers, two satellite communications providers, one paging provider and one FM VHF provider, contributed substantive responses that yield insight into the cost of establishing and operating a communications network to support PCT demand responsiveness.

Because we were unable to gather robust information on the potential communication-related costs of a statewide PCT network for some of the most prominent communications technologies within the time constraints of this project, we are currently unable to provide guidance on the potential range of these costs. Information on the cost of communicating with the population of PCTs is obviously critical to the determination of cost effectiveness of a Title

24 requirement for PCTs in new construction. We therefore recommend that the CEC undertake additional research into this question.

Refining the preliminary PCT functions and costs based on manufacturer and industry feedback.

Our primary role in this project was to gather information and opinions from relevant stakeholders regarding the preliminary PCT specification, the existing and potential future market for these devices, and the costs and benefits of PCTs incorporating different sets of functions. We solicited this information and opinion in three ways: via telephone interviews conducted in late June and early July 2005, via "Post-It" notes and limited discussion during the afternoon session of the July 15, 2005 technology planning meeting at SCE's Customer Technology Application Center in Irwindale, CA, and in written responses to three sets of questions distributed in August 2005.

As one would expect when soliciting opinion from a variety of stakeholders with a variety of capabilities and (sometimes opposing) interests, there is no consensus among this group of the optimal functionality that should be included in a minimum PCT specification. The good news, however, is that the majority of stakeholders largely support the preliminary PCT specification presented by the CEC, and the project in general.

One of the main points of disagreement among vendors was with the requirement that all PCTs be capable of sending an acknowledgment in response to emergency or price signals from the utility. Several vendors see this as a more appropriate function for the AMI meter, which could provide an estimate of load reduction in addition to acknowledging receipt of the signal. Others suggest that it would be more economical to include this functionality only in a statistically valid sample of installed PCTs.

The necessity of a verification signal must be considered in the context of the ongoing Advanced Metering Initiative (AMI) proceeding. If networks of remotely readable interval recording meters are built through AMI, then we agree with those PCT vendors and others who argue that the PCT is the wrong place to verify that curtailment occurred. Data collected from the meter can not only determine whether load was shed at a home or business, but also the amount of load reduction—information a PCT could not easily (or inexpensively) provide. In the event that AMI networks are not built, or are built only in some utility service areas, a requirement that PCTs be capable of acknowledging emergency or CPP signals becomes more reasonable, but in our view, this functionality remains unnecessary in this case as well. Instead, data on receipt of curtailment signal and load curtailment can be achieved by installing two-way communicating PCTs and/or additional data acquisition equipment at a statistically significant sample of homes and businesses at far lower societal cost than a requirement that each PCT be capable of acknowledging receipt of a curtailment signal. *We therefore recommend that the CEC not require PCTs to be capable of acknowledging receipt of emergency or price signals.*

A few stakeholders also expressed the opinion that the CEC specification did not go far enough in defining necessary PCT functionality, and suggested that additional functionality be required, such as

- The ability to display additional information (such as energy consumption by the HVAC system, total energy consumption, the state that the thermostat is in (cooling, heating, curtailment, etc.), the current price of electricity or price period (low, medium, high, CPP));
- The ability to receive and respond to control signals based on geographic location
- The ability to program and control PCTs remotely via a web page.
- The ability to control the HVAC system by both temperature setback and cycling
- Controls should have pre-set temperature setpoints at different prices
- Controls should be able to provide estimates of curtailable load

In our view, only two of these nominations for necessary PCT functionality merit that status. These are 1) the ability to address PCTs based on their geographical location, and 2) the ability to curtail load via both temperature setback and compressor cycling.

Although it is certainly possible to implement both emergency and price response without this geographic addressability, inability to dispatch PCTs by location would render the demand response resource they represent a rather blunt instrument, with the potential to cause unnecessary consumer discomfort when system-wide curtailment is implemented to respond to a localized problem. Moreover, geographic addressability is already a feature of many PCTs that are on the market, and none of the manufacturers have indicated that this feature is a significant driver of PCT cost.

In our view, it is important to add the capability to duty cycle air conditioners via the thermostat primarily because duty cycling yields a more sustained load reduction. Duty cycling produces consistent load shed over the duration of the curtailment period because the air conditioners shut off for the same percentage of time each hour. Temperature offset only delivers short-term load reductions. Since temperature offset produces most of its load reduction during the first hour, it's a good strategy for short events such as brief transmission constraints or local distribution problems.

While many of the other nominations for required functionality would be useful or advantageous for the consumer, and some have the potential of enhancing demand responsiveness (such as displaying the current electricity price, which could encourage consumers to manually control additional end-uses), in our view none are essential to the CEC's stated goal of enabling emergency and price responsiveness in residential and commercial HVAC systems. Many of these nominated functions are already available in commercial PCTs, and/or will likely be incorporated in future models. *Our recommendation is that the CEC allow the market to dictate PCT functionality beyond the minimum functions that are necessary to procure this resource and operate it efficiently. We believe that geographic addressability and compressor cycling are necessary for the efficient operation of a PCT network and that the market does currently and will in the future provide these functions at little or no additional cost. We therefore recommend that these functions be added to the CEC's PCT specification.*

Final Recommended PCT Specification

As discussed above, we recommend that one function listed as "Necessary" in the preliminary PCT specification—transmitting an acknowledgment signal—be eliminated, and that both geographic addressability and cycling capability be required by the CEC. Our proposed final PCT specification is presented in Figure ES-2. Our recommendation is that the CEC allow the market to dictate PCT functionality beyond the minimum functions identified in the figure.

Other Potential Demand-responsive Technologies

There are a limited number of additional technologies that the CEC may wish to consider integrating into building energy/Title 24 standards in the future. These technologies fall into four categories: lighting controls, building automation systems, direct load control switches, and frequency and voltage protection controllers.

In the category of lighting controls, we considered systems based on the Digitally Addressable Lighting Interface, wireless lighting control systems, and lighting power reducers. We find that cost and in some cases availability barriers preclude these technologies from eligibility for incorporation into the Title 24 standards.

Necessary Functions for Emergency Response

- Receive and respond to communication signals to control thermostat set point
- Receive and respond to communication signals to cycle the air conditioner compressor
- Respond automatically to emergency signals
- Indicate the emergency state
- Provide system operators with the ability to target specific geographic locations and select only the amount of load necessary to address individual shortage situations

Necessary Functions for Price Response

- Receive at least one type of communication signal to which the PCT can respond based upon customer's preference
- Be programmed by the customer to respond according to desired temperature changes at desired price thresholds.
- Be capable of customer override during events
- Indicate the critical peak pricing state

Provide system operators with the ability to target specific geographic locations and select only the amount of load necessary to address individual shortage situations

Figure 11 Proposed Final PCT Specification

Many BASs have demand-limiting or load-shedding functions. Traditionally, BASs have operated on a network dedicated to that system, but now a utility can connect its demand response system into a BAS for automated load reduction. Facility managers can also respond to load curtailment signals more quickly, and while preserving occupant comfort. Past research reveals that BASs are cost-effective for demand response, and we recommend that the CEC investigate requiring demand response functionality in BASs as a Title 24 requirement.

Direct load control (DLC) switches are inexpensive and utilities have used them for decades on such end uses as electric water heaters, air conditioners, and pool pumps. DLC switches are simply electrical relays that reside in electrical circuits between an end use and its power supply. Upon receipt of a control signal, load switches interrupt power for a duration specified in the control signal. This technology is proven reliable and effective, provided a reliable communication network. We recommend that the CEC consider a Title 24 revision requiring that load switches be incorporated into all new pool pumps, room air conditioners (those not controlled by a central thermostat), and electric water heaters sold in the state.

Frequency and voltage protection can be built into appliances and/or load switches. Pacific Northwest National Laboratory (PNNL) developed a controller (essentially a chip) called the Grid Friendly™ Appliance Controller that goes into directly appliances to automatically sense and respond to grid fluctuations. The appliance cuts power to the sub-end-uses that can be postponed. Dryers, water heaters, refrigerators, clothes washers, and dishwashers are all good candidates for appliance controllers. At some point in the future, frequency and voltage protection may well be a viable candidate for incorporation into California's appliance standards. However, the technology is currently neither mature nor commercially available, and so not yet ripe for incorporation into the standards.

Introduction

This document reports on the results of our work to characterize the attributes of existing and potential programmable communicating thermostats (PCTs), to assess utility program experience, PCT hardware, installation, and communication-related costs, and to evaluate the minimum PCT functionality necessary to make the heating, ventilating, and air conditioning (HVAC) equipment in new buildings within the state of California responsive to broadcast emergency and price signals.

This project was one of three projects designed to provide information the California Energy Commission (CEC) requires in its investigation into the cost-effectiveness of a proposed modification to California's Title 24 building standards which would mandate that the HVAC systems in all new residential and commercial buildings be controlled by a PCT. The other two projects, conducted by Energy and Environmental Economics, Inc. and the Heschong-Mahone Group, Inc. respectively, are designed to 1) establish a framework for evaluating the economic benefits of demand response, and 2) develop a codes and standards enhancement initiative for PCTs, which will utilize the cost information presented in this report and the demand response benefits information provided by Energy and Environmental Economics, Inc. to assess the cost-effectiveness of PCTs.

The specific tasks specified for this project were to:

1. Conduct a literature and feasibility review of past related work;
2. Identify the preliminary PCT functions and determine the cost and benefits;
3. Refine the preliminary PCT functions and costs based on manufacturer and industry feedback; and
4. develop a final recommended PCT specification

We conducted this information gathering and analysis process by reviewing relevant literature specified by the CEC and others, reviewing prior E SOURCE reports and interviews, and by soliciting additional information and opinion from industry stakeholders, including PCT manufacturers, communication providers, utility demand response program managers, HVAC manufacturers, meter manufacturers, PCT installers, and demand response system integrators. We gathered stakeholder input in three ways:

- Via interviews conducted in late June and early July with small numbers of stakeholders in each of these groups;
- At a technology planning meeting held on July 15, 2005 at Southern California Edison's Customer Technology Application Center in Irwindale, CA (henceforth the "technology planning meeting"); and
- Via industry-specific questionnaires focusing on PCT manufacturers and communication providers.

Organization of this report

This report is organized roughly along the lines of the tasks we were asked to accomplish. Following the literature review, which begins on the next page, we present the preliminary PCT specification proposed as a starting point by the CEC. We used this specification as the basis for the vast majority of our interactions with the various stakeholder groups, the results of which are described in the following three sections: "Information and Opinion from Stakeholders", "Costs of PCT Hardware and Installation", and "Communication Costs". A subsequent section, "Proposed Final PCT Specification", presents our recommendations for the minimal PCT functionality that the CEC should specify in the 2008 Title 24 revisions. A final section provides information and our recommendations regarding a limited set of additional technologies that can provide demand responsiveness, and which the CEC may wish to consider for integration into Title 24, either for the 2008 revisions or further into the future.

Literature Review

As part of Task 1, we were to perform a literature and feasibility review of past related work. The overall themes of the literature review are:

- The current demand response system isn't fair to all customers and it's economically inefficient.

- Two types of demand response programs are necessary: 1) voluntary price response program and 2) mandatory reliability/emergency rate-based program.

- Customers should have control over their thermostat for price response programs, but they should not be able to override emergency signals.

- Advanced metering is necessary.

What follows is a summary of each paper as well as responses to the CEC's specific questions about the literature.

Summary of the literature

<u>Herter, K., Levy, R., Wilson, J. and Rosenfeld, R., 2002. Rates and Technologies for Mass-Market Demand Response</u>

The main point of this paper is that demand response should be an element of the utilities' obligation to serve and customer service, not just a series of event-driven utility programs that sprout and wither with the times. Programs should be bundled, providing automatic load management through customer-programmed price response. This would require customers to pay for the resources that fulfill the service commitment. The utility could preferentially serve loads able to respond to contingencies. This would be based on the fact that energy prices are time-variant and that customers should pay for and be held accountable for their cost of service. It is better for a utility to cover its costs via cost of service than through program costs. For example, metering is a cost of service, not a component of demand response. This new approach could shed load on specific end-uses during emergencies rather than shutting off half of all customers completely. For a statewide demand response program, the authors propose a demand response rate (not fixed or TOU) in conjunction with thermostats given to residential and small commercial customers.

<u>Herter, K., Levy, R., Wilson, J. 2002. Proposal for Improved Demand Response in California</u>

The authors present several ideas for how to improve demand response in CA. They propose making demand response an integrated service offering with advanced metering, time-differentiated rates, and customer education about their usage all as necessary components. New demand response programs should encourage load shifting at all times of the day, not just at peak. With price-response, customers can have full control over the functioning of the thermostat and customers choose the default action of the thermostat when it receives a signal.

The authors also include the perceived barriers for why the CA PUC and utilities haven't enthusiastically supported demand response. The barriers include: insufficient documentation of successful programs, high perceived costs, perceived customer resistance, lack of wholesale market, reluctance of utilities to incur costs without cost recovery assurance, and uncertainty over the future role of the utility distribution company in retail services such as metering and demand response programs.

<u>Herter, K., Levy, R., Wilson, J., and Rosenfeld, A. Rates and Technologies for Mass-Market Demand Response (presentation)</u>

Critical Peak Pricing (CPP) should be a demand response tool because it combines efficiency and demand response. Customers can choose end-uses, control technologies and savings-comfort tradeoffs that they want to endure. With CPP, the incentives become proportional to load reduction, which would remedy one "broken" part of current demand response programs. Instead of a demand response program that targets the entire customer load on only half of the customers, CPP creates a partial outage program that targets non-essential loads on all customers. This is more equitable and less expensive.

<u>Herter, K., 2005. Notable Thermostat Programs in the US (Table)</u>

The programs covered include: Austin Energy (one-way thermostat), SMUD (one-way thermostat and gateway system), SCE (two-way thermostat), SDG&E (two-way thermostat), Gulf Power (gateway system), and Allegheny Power, though no information is listed for this program. The table covers whether the program is a pilot or full-scale program, sector, points (number of installed thermostats), customer charge, cash incentives, non-cash incentives, event trigger, and hardware. All were pilots except for Austin Energy and Gulf Power, and all were residential, except for SCE, which is small commercial. Gulf charges its customers $4.95 to participate in the program. All the programs give away a free thermostat, or any necessary hardware. In each case the event trigger is high temperatures, a system emergency (stage 2 for SDG&E), or operator discretion. The hardware costs listed in the table are summarized in the Feasibility review below, under PCT availability, functionality, and costs.

<u>SCE 2005 Advice Filing Renewing Proposal to Expand the SCE Energy$mart Thermostat Program</u> (Advice 1875E (U338-E))

The SCE Energy$mart Thermostat^{SM} (E$T) program provides small commercial/ industrial customers in SCE's service territory with two-way programmable thermostats at no cost. The advice filing came about because SCE wanted to renew its proposal to expand program for small commercial and industrial customers in hot/rural areas, based on the success of the 2004 program. The original E$T program calls for enrollment on 9,000 thermostats, and the advice filing states that SCE wants to add 5,500 more thermostats, for a total of 14,500 thermostats. No additional funding is needed. (Note that as of Sept 2005, 8,250 thermostats are installed.)

2004 program results include 12 curtailment events. SCE's demand response program exceeded its curtailment goal (4 MW) by 125 percent during the summer of 2004. The impact estimates for this program are quantified on a kW and kWh per ton basis. Assuming a total controlled tonnage of 18,322 tons, the average first hour energy savings due to the curtailments in 2004 were about 6.0 MWh, and the total energy savings in the second hour was about 3.9 MWh. The initial (15 minute) program peak demand reduction was about 9 MW.

<u>Levy, R. and Rosen, K., 2001. Mandating Demand Responsiveness in Appliance Standards through Controllable Thermostats</u>

Mandating remotely controllable thermostats provides an opportunity to expand customer choice through optional demand response programs that can be tailored to individual customers' preferences. In addition to increased program acceptance (because customers have the ability to override), mandating thermostats would also yield more equitable comfort impacts than direct load control programs. Currently, demand response is a reactive effort, isn't integrated into the customers' underlying rate, and load impacts and customer incentives are based on engineering estimates, which are unfair to some parties.

This paper consists of a proposal to test the feasibility of a voluntary program that combines a price-based control signal with a time-varying rate incentive. It provides a functional specification in the paper. To have an effective voluntary program, customers should be able to fulfill two basic requirements: 1) take service under a TOU rate with a distpatchable component that will provide one or more super-peak price signals to automatically dispatch customer pre-programmed control strategies, and 2) install and maintain an advanced interval meter with communication capability. The technology should be widely available through retail outlets and/or energy service providers. There should also be standardized communication and operating protocols. Existing commercially available remotely controlled thermostats do not currently satisfy the anticipated design and operating standards. Developing new technologies in conjunction with vendors and investigating system security were also part of the proposed technology review.

<u>Herter, K. and Levy, R., 2002. Mandating Demand Responsiveness in Buildings: Requiring Controllable Thermostats through CEC Load Management Standards</u>

This document outlines a proposal for the CEC to establish a specification for PCTs. No existing thermostat currently satisfies the anticipated requirements. Mandating PCTs will help ensure CA system reliability. The PCT should have the ability to target specific geographic locations (either at the distribution level or customer level) and reduce only the amount of load needed to manage any expected shortage. A statewide mandated program could produce about 10 GW of load response. With such a large amount of controllable units, effects on each individual unit can be minimized. Focus should be on the residential and small business sector because typically those sectors haven't contributed to system reliability. Another important function of the mandatory PCT should be that customers can install it and that it is active upon installation. Communications outbound from the thermostat is preferred but not required. The authors envision that the same equipment used to provide system protection functions can also be used to support a voluntary customer bill management option. Under the bill management option, customers will have the ability to override any control action. The thermostat should have an "alert indicator" on the face to specify, at a minimum, whether system protection is activated. Bill management functionality for the PCT requires the same functions as system protection, but also requires interval metering, setup software, and an event indicator.

SDG&E 2003 Smart Thermostat Program Impact Evaluation

2003 was the second summer of the residential Smart Thermostat pilot program. While SDG&E didn't operate the full program in 2003 (likely because program operators only invoked curtailment once in 2002), 92 customer premises that had advanced metering and smart thermostats were controlled during 12 critical peak days as part of the California Statewide Pricing Pilot. Savings per unit enrolled in the program averaged over the re-set periods was 0.33 kW. For any particular event, the total impact can be very small—1.7 MW—or more significant on the best control day—5.9 MW. About 96% of thermostats in the program appeared to operate correctly during the events. The average override rate was 19%, but the override rate increases as the temperature increased. For example, the highest override rate (47%) occurred on the hottest day. Between 75°F and 85°F, each 1°F increase in temperature is estimated to increase the over-ride rate by 3.6%. This raises concerns about the effectiveness of the program when it is likely to be most needed. Only about 60% of the participating units actually contribute to load reduction as a result of signal failure, overrides, and non-use in mild weather. In SDG&E's territory, 20% of the air conditioning units are never used during the summer. Statewide emergency conditions don't necessarily coincide with hot weather in the San Diego area; therefore SDG&E control events should only be locally-triggered.

SDG&E 2002 Smart Thermostat Program Process Evaluation Report

This process evaluation was conducted from February to November 2002. The program was designed to test 5,000 residential customers' air conditioning use (representing a combined load of about 4 MW) with PCTs that allow customer to override a request for curtailment. Overall the customer reactions to the program were positive. Of particular relevance to this project, a few problems arose. Customer survey results indicate that only 25% of program participants are using the programmable features of their new thermostats—the rest were manually adjusting them. The program also suffered from lags in the installation process; in some cases it took more than a month between when the application was received and when installation was completed. Because the main installer—Carrier—lacked enough installers, they then hired Honeywell DMC to help with the installation process. Customer satisfaction of time to install thermostat after they sent in an application improved over the course of the program. Participants rated themselves to only be moderately knowledgeable about how to program their new thermostats. Only 8% of survey respondents indicated that they were aware SDG&E had remotely controlled their thermostats. 22% felt that better instructions on how to use the new thermostat needed to be developed and/or the installation reps needed to be better trained on how to educate participants on how to use the new thermostats.

Feasibility review based on the literature

PCT availability, functionality, and costs. One paper, "Rates and Technologies for Mass-Market Demand Response", claims that technologies are available today that are capable of completely automating response to contingency or price signals, relegating customer decision making to the one-time effort of programming these technologies to respond as desired. However papers "Mandating Demand Responsiveness in Appliance Standards through Controllable Thermostats" and "Mandating Demand Responsiveness in Buildings: Requiring Controllable Thermostats through CEC Load Management Standards" claim that existing commercially available remotely controlled thermostats do not currently satisfy the anticipated design and operating standards, which includes responding to both emergency- and price-oriented signals. Note that the functional specification on which they are basing that claim is different, and more detailed, than the minimum specification used for this project.

Based on our research, it is evident that several products are available to meet the specified minimum functionality, and that manufacturers are likely to develop additional products that will comply with a PCT specification in Title 24. According to the "Notable Thermostat Programs in the US" table, system costs are as follows: $150 for basic load control thermostat; $400 for Carrier ComfortChoice thermostat, and $1000 for Comverge Maingate with thermostat. Advanced meters are estimated at $100, whereas a standard meter and a standard thermostat are estimated at $20 $30, respectively, for $50 total.

Additional cost and functionality information obtained from PCT manufacturers as part of this project is outlined later in this report.

Problems with PCTs. The SDG&E Smart Thermostat program process and impact evaluation reports revealed a few problems that the utility experienced with PCTs. For example, only 25% of program participants are using the programmable features of their new thermostats. The rest were operating it manually. Similarly, program participants rated themselves only moderately knowledgeable about how to use the thermostat correctly and many felt that better instructions should be developed.

Keeping up with installations has also been a problem with past PCT programs. Part of the problem is that in a retrofit situation, installers have to schedule appointments with homeowners to get inside the house to install the thermostat. This problem is unlikely to arise in the new construction market targeted by the current proceeding.

Other potential problems with PCTs that Herter and Levy outline in their papers include the fact that there are so many unknowns about the technology. The unknowns include: what communication technologies to use; whether a low cost communication medium exists that can provide mass-market coverage, individual customer addressability, reliable signal reception, and tamper protection; if the hardware can allow for both overrideable signals and non-overrideable signals; if system operators can target specific geographic areas. Based on our research for this project, it is evident that technology exists that can satisfy all those requirements.

Relevant communication and control technologies. The CEC asked us to identify communication and control technologies that can support mandated system protection strategies (no customer override) and customer bill management strategies (provides customer override). The literature we reviewed outlines the technologies behind Southern California Edison's and San Diego Gas & Electric's smart thermostat programs, which includes two-way communicating thermostats manufactured by Carrier and two-way paging from SkyTel. The literature doesn't present any other technology options.

However, based on our research, it is clear that the thermostats on the market today for utility use can support both system protection and customer bill management strategies. Further technology development is not needed. Similarly, traditional communications channels can support both of these program options, including paging, RF, VHF, and two-way paging. Satellite, power line carrier, and broadband over power line communication technologies could also support the necessary features for emergency and price response and verification. While utilities haven't yet used satellite for demand response, it is attractive in the sense that it provides ubiquitous coverage. More information about the technologies and communications methods is presented later in this report.

Preliminary PCT Specification

The initial starting point for the PCT functionality specification was provided by the CEC and is presented below. Although this specification is slightly different from that used in the earliest stakeholder interviews conducted under this project, we believe the CEC specification is sound, well supported by the documents included in the literature review as well as our previous research, and consistent with the opinions of the majority of relevant industry stakeholders. We therefore adopted this specification as the basis for our investigations into PCT costs, benefits, and stakeholder positions in all communications subsequent to the technology planning meeting held at Southern California Edison's Customer Technology Applications Center on July 15, 2005.

Minimum requirements for PCTs – Stakeholder comments

Necessary Functions for Emergency Response

- Receive at least one type of communication signal to control thermostat set point
- Respond automatically to emergency signals
- Indicate the emergency state

Necessary Functions for Price Response

- Receive at least one type of communication signal to which the PCT can respond based upon customer's preference
- Be programmed by the customer to respond according to desired temperature changes at desired price thresholds.
- Be capable of customer override during events
- Indicate the critical peak pricing state

Necessary Functions for Verification

- Transmit acknowledgement signal back with time stamp. (Note: Final determination of this function as being necessary for the standards is pending.)

Potential Functions for Emergency Response

- Provide system operators with the ability to target specific geographic locations and select only the amount of load necessary to address individual shortage situations

Potential Functions for Price Response

- Ship the PCT with default heating and cooling setpoints at pre-programmed electric rate thresholds.
- Provide information to the user on energy usage and cost per hour/day/month from AC system
- Provide information to the user on energy usage and cost per hour/day/month from meter for total consumption

Potential Functions for Verification

- Transmit information to the utility on the operating state of the controlled HVAC equipment
- Transmit information to the utility on actual temperature and temperature settings

Other Potential Functions

- Remote programming and customer override/control via web or phone
- Relay information signals to other appliances, pool pump, water heater, dryer or lighting.
- Bundle the 5 wires between the HVAC system to the thermostat into one common plug, similar to a phone cord system. This would allow for plug and play capability.

Our primary role in this project was to gather information and opinions from relevant stakeholders regarding the preliminary PCT specification, the existing and potential future market for these devices, and the costs and benefits of PCTs incorporating different sets of functions. We solicited this information and opinion in three ways: via telephone interviews conducted in late June and early July 2005, via "Post-It" notes and limited discussion during the afternoon session of the July 15, 2005 technology planning meeting, and in written responses to three sets of questions distributed in August 2005. Following brief descriptions of these three modes of information gathering below, subsequent sections integrate responses from all three modes into conclusions about PCT functionality and costs.

Telephone Interviews. E-Source/Platts conducted a total of 17 interviews in preparation for the technology planning meeting. The breakdown of these interviews by stakeholder type is shown in Table 26. Given the compressed timeframe of this project, these interviews were not intended to be comprehensive, but rather to elucidate the most important issues on which to gain further input at and after the technology planning meeting. The interviews were also important for introducing the CEC proposal of incorporating demand response into Title 24 to the industry and to invite relevant stakeholders to the meetings.

The interview transcripts and contact information for each interviewee are contained in Appendix A.

Table 26: Number of interviews conducted by stakeholder type

Type of Stakeholder	Number of interviews conducted
PCT manufacturer	5
Communication provider	5
Utility demand response program manager	2*
HVAC manufacturer	1
Demand response equipment installer	2
Meter manufacturer	1
System integrator	1

*We also incorporated information from interviews with 18 utility program managers conducted prior to this project.

The technology planning meeting. During our presentation at the July 15 meeting, we outlined the potential functional specification, presented preliminary findings resulting from our interviews, and described the especially controversial issues to be resolved before the CEC could mandate PCTs via standards. Meeting attendees were asked to respond to the questions presented in Table 2. Due to the large number of stakeholders present at the meeting and attending by phone, the charged nature of some of the issues presented, and the very limited time available for discussion of the issues, the meeting facilitator asked participants to respond to these questions on Post-It notes, which SCE staff then collected and later assembled into a single document.

Although this mode of communication did allow for the collection of a lot of information, and was probably necessary given the time constraints of the meeting, it effectively prevented substantive dialog on the questions we asked or exploration of opposing points of view. The written format, small space, and limited time provided for meeting participants to reply to our questions led to hasty, poorly supported, often confusing comments. For these reasons, we found that the comments collected at the technology planning meeting were of little value in drawing conclusions for most of the questions we asked.

Table 27 Questions asked of participants at the technology planning meeting.

What should the minimum requirements of the PCT specification be?
What are the most important attributes of a communication channel to be used for demand response?
Should communication with all demand response devices use the same channel?
Is it critical that the selected channel(s) be capable of reaching demand response devices across the entire state?
How can the retail purchase of PCTs by construction firms/HVAC contractors be reconciled with utility service area geography and the communication channel(s) selected by the local utility?
Does the channel used for demand response communication need to be the same as that used for AMI?
Given the minimum PCT functionality and PCT communication infrastructure, when would these products be available (please provide timeline)? Why?
What would speed up the process?
What are the deployment costs for hardware, installation, communication with devices, communication infrastructure build out, and systems integration?

The compiled Post-It responses and a summary of our conclusions from those responses are included in Appendix C.

Responses to Questionnaires. In an attempt to augment the information we gathered via telephone interviews and at the technology planning meeting, we developed and distributed two questionnaires, one for PCT manufacturers, and the other for communication service providers. The questionnaire for PCT manufacturers probed their opinions about the minimum necessary functionality for PCTs, their thoughts about existing and potential future market demand for additional functionality, their estimates of the hardware and installation costs associated with different sales volumes and market delivery channels for one- and two-way communicating thermostats capable of emergency and price responsiveness, and their ideas for other types of demand-responsive equipment that might be suitable for inclusion in the Title 24 standard.

The questionnaire for communication service providers asked them to consider several scenarios regarding the population of installed PCTs and the way in which those PCTs would be operated. The intent was to elicit cost estimates for a variety of scenarios thought to bracket the range of possibilities for the growth of the PCT population over the course of 15 years following a decision by the CEC to require their installation in all new construction.

Following receipt of responses to these questionnaires, we created a third document which summarized the responses regarding potential PCT costs, drew a set of draft conclusions, and posed a small set of additional questions. We circulated this document to back to the PCT manufacturers for comment. The intent of this exercise was to ensure that the responses we received to the questionnaires accurately represented the range of possible costs and to identify areas of significant disagreement between stakeholders.

The two questionnaires, responses received, and the summary / draft conclusions document are included as Appendices D - F. Stakeholder contact information is listed in Appendix G.

Response to Preliminary PCT Specification

As one would expect when soliciting opinion from a variety of stakeholders with a variety of capabilities and (sometimes opposing) interests, there is no consensus among this group of the optimal functionality that should be included in a minimum PCT specification. The good news, however, is that the majority of stakeholders largely support the preliminary PCT specification presented by the CEC, and the project in general. No vendors that we contacted refused to participate, though some were more eager than others.

In our initial interviews, the questions posed at the technology planning meeting, and in the questionnaires we sent out following that meeting, we asked stakeholders for their thoughts about PCT functionality that was necessary for emergency and price responsiveness and for validation. We also asked whether functionality listed as necessary in the specification was optional in their view.

Functionality seen as unnecessary in CEC specification

The majority of respondents agree that those functions listed as "Necessary" in the CEC specification are indeed necessary minimal functions to provide emergency and price responsiveness and verification. There were, however, a few stakeholders that took issue with a few requirements.

Verification. One of the main points of disagreement among vendors was with the requirement that all PCTs be capable of sending an acknowledgment in response to emergency or price signals from the utility. Lightstat, DCSI, and Honeywell see this as a more appropriate function for the AMI meter, which could provide an estimate of load reduction in addition to acknowledging receipt of the signal. Honeywell and Orbcomm suggest that it would be more economical to include this functionality only in a statistically valid sample of installed PCTs.

As the minimum functionality for verification, the specification calls for including a timestamp for the acknowledgement signal. However, Venstar points out that it would be preferable that the system receiving the acknowledgment message add the timestamp, rather than it being part of the message that the PCT sends. This would both cut down on the size of the acknowledgment messages and eliminate the error introduced by PCT clock drift. (Note clock drift is a common problem for all types of programmable thermostats.)

The necessity of a verification signal must be considered in the context of the ongoing Advanced Metering Initiative (AMI) proceeding. If networks of remotely readable interval recording meters are built through AMI, then we agree with those PCT vendors and others who argue that the PCT is the wrong place to verify that curtailment occurred. Data collected from the meter can not only determine whether load was shed at a home or business, but also the amount of load reduction—information a PCT could not easily (or inexpensively) provide. Therefore, in our view, if AMI networks are built, there is simply no reason for the CEC to require the considerable additional expense necessary (see "Costs of PCT hardware and installation" below) to make PCTs capable of acknowledging receipt of an emergency or price signal. Moreover, if these meter networks are built, acknowledgement may not even be necessary because utility demand response program designs that offer seasonal or per-event incentives to consumers in exchange for voluntary load curtailment will most likely be replaced by programs that rely on price-responsive demand—it will no longer be necessary to determine whether a particular customer curtailed load and is therefore due an incentive payment. Over time, it will be desirable to identify individual PCTs that are no longer curtailing load in response to emergency or price signals, but again, meter data (particularly that collected during an emergency event) can be instrumental in identifying malfunctioning PCTs or communication links.

In the event that AMI networks are not built, or are built only in some utility service areas, a requirement that PCTs be capable of acknowledging emergency or CPP signals becomes more reasonable, but in our view, this functionality remains unnecessary in this case as well. Where consumers do not have the ability to receive and act on time-varying electricity prices (i.e. where consumers do not have the option of deciding how much amenity to purchase at each electricity price level), utilities may continue to operate demand response programs that pay incentives for load curtailment during individual events. Although with this type of program design the ability to identify program participants that did and did not receive the curtailment request is certainly useful for determining which participants should or should not receive incentive payments, the acknowledgment signal itself would be no guarantee of actual curtailment. And although it will certainly be necessary in such programs to evaluate the amount of load shed in order to determine program cost-effectiveness, this information will be available at the feeder, substation, and transmission line levels where data acquisition equipment already exists. In addition, as several stakeholders have pointed out, finer resolution data on receipt of curtailment signal and load curtailment can be achieved by installing two-way communicating PCTs and/or additional data acquisition equipment at a statistically significant sample of homes and businesses at far lower societal cost than a requirement that each PCT be capable of acknowledging receipt of a curtailment signal.

Finally, where utilities wish to identify individual demand response program participants that choose to opt out of individual curtailment events, practical and proven means to provide this function exist that are likely to be far less expensive than a requirement that all PCTs be capable of two-way communications. One such option, which has been implemented by several utilities, is to provide a web site and/or automated telephone voice response system at which the participant can override the curtailment request. Upon receipt of the override command, the utility system initiates a signal to the individual consumer's PCT that terminates the curtailment event. Note that for this method to be effective, even voluntary (i.e. non-emergency) curtailment events would have to disable the participant's ability to override the curtailment at the PCT.

To summarize, where AMI networks are deployed, we see no value in a requirement that PCTs be able to acknowledge receipt of a curtailment signal. Where such networks are not deployed, an acknowledgement would have value, but in our view, that value can be obtained far more cost-effectively through other means. *We therefore recommend that the CEC not require PCTs to be capable of acknowledging receipt of emergency or price signals.*

Bundling conductors. We also received comments during our interviews and at the technology planning meeting regarding functionality listed as "Potential" in the CEC specification that stakeholders view as problematic or unlikely to add value. Among these, the most consistent reaction was an almost uniform objection to the concept of bundling the conductors that run from the thermostat to the HVAC system into a standard, modular plug like those used for telephones. A common manufacturer objection to this concept is that there is a very wide variety of HVAC equipment available, and a given design may utilize anywhere from 4 to 7 conductors, so a requirement to standardize these cables and their connection to the thermostat would inevitably create problems for installers. Another problem is that PCT retailers would object to stocking models designed to accommodate the modular plug as well as retrofit models designed to replace thermostats in existing homes and businesses. *Our view is that these objections are well founded, and we recommend that this functionality not be included in the final PCT specification.*

Relaying signals to other devices. Several vendors also expressed skepticism and/or reservations about the concept of using the PCT to relay control signals on to other devices. Such capability would essentially turn the thermostat into a gateway, which in their view is an expensive and complicated way to implement demand responsiveness. One vendor promotes a radio-controlled device with multiple, individually addressable switches as a more cost-effective way to provide the same functionality. Our view is that although specific segments of the market may ascribe sufficient value to this functionality to justify its additional costs, it is certainly not a function that is necessary to enable demand response in HVAC systems, but it would likely add significant cost to the PCT. *Our recommendation is therefore that the ability to relay signals to other devices not be a required function at this time.* If in the future the market produces PCTs that can provide this function cost-effectively, the CEC can reconsider this issue.

Additional functionality seen as necessary

A few stakeholders also expressed the opinion that the CEC specification did not go far enough in defining PCT functionality, and offered the following suggestions for an expanded list of necessary PCT functionality:

Information display. Several PCT manufacturers thought it should be necessary to provide information to the user via a display on the thermostat. For example, Comverge thinks it is necessary to provide information on air conditioning energy consumption and total consumption on the PCT display. Lightstat contends that the display should show the state that the thermostat is in: whether it is calling for cooling, curtailment, etc. suggesting that this can be accomplished either with text or with colored lights. Several commenters at the technology planning meeting, during the course of interviews, or in response to our questionnaires also urged that the PCTs be able to display current price period to the consumer, either low / medium / high / CPP or display the actual $/kWh rate.

Geographic addressability. The original specification calls for targeting specific geographic locations as a potential function for emergency response. However, E-Radio contends that geographic addressability should be a necessary rather than potential function. Venstar agrees that geographic targeting must be required instead of being a "potential" function. According to Venstar, geographic addressability is a standard feature of most systems.

Remote access. Honeywell states that web access to the device for both the customer and utility should be considered as a "necessary" function for program, retention, and economic reasons.

Other functions seen as necessary:

- Require that the PCT be capable of both temperature setback and compressor cycling (Comverge).
- Demand response box should be shipped with default price setpoints (DSCI).
- Demand response system should also provide an estimate of curtailable load (DCSI).

In our view, only two of these nominations for necessary PCT functionality merit that status. These are 1) the ability to address PCTs based on their geographical location, and 2) the ability to curtail load via both temperature setback and compressor cycling.

Although it is certainly possible to implement both emergency and price response without this geographic addressability, inability to dispatch PCTs by location would render the demand response resource they represent a rather blunt instrument, with the potential to cause unnecessary consumer discomfort when system-wide curtailment is implemented to respond to a localized problem. Moreover, geographic addressability is already a feature of many

PCTs that are on the market, and none of the manufacturers have indicated that this feature is a significant driver of PCT cost.

We believe it is important to add the capability to duty cycle air conditioners via the thermostat primarily because duty cycling yields a more sustained load reduction. (Duty cycling limits the runtime of the air conditioner for a fixed percentage of time. For example, if a utility uses a 50% duty cycle, the compressor in the air conditioner will only be allowed to run for 15 minutes in each half-hour period.) Temperature offset is a beneficial strategy for load control because it delivers at least minimal load reduction. As long as the signal to raise the setpoint reaches the thermostat, that customer's air conditioner will automatically run less frequently, allowing the internal temperature to drift up to the new setpoint, thus yielding load reduction. However, temperature offset only delivers short-term load reductions.

With temperature offset, the load reduction mainly occurs in the first hour of a curtailment period, because it takes almost a full hour for the temperature inside individual houses to rise to the specified setpoint; during subsequent hours in the curtailment period, the air conditioners run, but not as much as they otherwise would have. Toward the end of the curtailment, the thermostats start to kick in more frequently to maintain the temperature and then to return the house to the lower programmed setpoint after the event is over. Because temperature offset produces most of its load reduction during the first hour, it's a good strategy for short events such as brief transmission constraints or local distribution problems. It's important to keep in mind though that duty cycling produces consistent load shed over the duration of the curtailment period because the air conditioners shut off for the same percentage of time each hour.

Note that only a few utilities that we know of use temperature offset in their load control activities; all others that have installed thermostats for load control programs appear to operate the thermostats like load switches by cycling them. Note also that for PCTs capable of setback, cycling capability can be added at little to no cost.

While many of the other nominations for required functionality would be useful or advantageous for the consumer, and some have the potential of enhancing demand responsiveness (such as displaying the current electricity price, which could encourage consumers to manually control additional end-uses), in our view none are essential to the CEC's stated goal of enabling emergency and price responsiveness in residential and commercial HVAC systems. As the next section will demonstrate, many of these nominated functions are already available in commercial PCTs, and/or will likely be incorporated in future models. *Our recommendation is that the CEC allow the market to dictate PCT functionality beyond the minimum functions that are necessary to procure this resource and operate it efficiently. We believe that geographic addressability and compressor cycling are necessary for the efficient operation of a PCT network and that the market does currently and will in the future provide these functions at little or no additional cost. We therefore recommend that these functions be added to the CEC's PCT specification.*

PCT Functionality Currently Provided by the Market

In order to assess PCT manufacturer beliefs about current market demand for thermostat functionality, we asked "If your company were to design a product today satisfying the minimum "Necessary Functions" with the above specification [the CEC's Preliminary PCT Specification], what other functions (whether listed in the specification as "potential" or not) would you be likely to incorporate?" In response to this question, PCT manufacturers indicate that they intend to produce PCTs with a wide variety of functionality in addition to that listed as "Necessary" in the Preliminary Specification. The list of added features includes:

- Display of either electricity price tier (low, medium, high, critical) or the specific rate broadcast by the utility (listed by 4 of 9 respondents),
- Ability to control additional devices (3 of 9 respondents),
- Compressor cycling in addition to setpoint adjustment (1 of 9 respondents),
- A large back-lit LCD display for improved readability, even in a dark hallway (1 of 9 respondents),
- Battery-free operation (1 of 9 respondents),
- Remote programming via a web interface (5 of 9 respondents),

- A messaging area to inform the customer including telephone number for customer service and can be upgraded to incorporate other messages (bill month to date, KWH month to date, etc.) (1 of 9 respondents)
- Geographic addressability (listed by 2 of 9 respondents, though several manufacturers already offer this feature and would presumably continue to do so)
- Remote ability to inform building occupants of emergency issues with heating/cooling equipment (1 of 9 respondents),
- Remote ability for occupants to monitor energy usage, and to determine energy or cost savings from participation in setbacks (1 of 9 respondents),
- Audible notification for price changes or curtailment periods (1 of 9 respondents),
- In-home gateway capability (1 of 9 respondents),

Their stated intention to offer these additional features indicates that manufacturers believe they will be able to incorporate these features at a price that the market will bear. This list also suggests that mandating the functionality presented as "Necessary" in the Preliminary Specification will not constrain manufacturers from adding features that will distinguish their products from those of their competitors—i.e. it will not put a damper on manufacturer creativity. The fact that the above list contains many functions included as "Potential Functions" in the Preliminary Specification reinforces the notion that these functions need not be mandated by the CEC in its revisions to Title 24.

Market Evolution

In the questionnaires we sent to PCT manufacturers, we also asked the following question designed to elicit their thoughts about how the PCT market might change in the future: "What is your view on how the PCT market is likely to evolve in the future? What changes in PCT functionality do you envision in the future?"

Responses to this question revealed some striking differences of opinion about where this market is headed. Our view is that these differences are largely dictated by differences in the manufacturer's current capabilities and their aspirations. For example, some manufacturers believe that the PCT will evolve into a gateway, with occupants using the device to interact with and control end uses such as pool pumps, water heaters, and dishwashers in addition to their HVAC systems. Others view this functionality as belonging to a separate gateway that would communicate with the PCT.

Another point of contention about the future role of the PCT is whether or not it would become an important customer interface point and information display for utilities. Some manufacturers see the PCT evolving into a source of information not only about electric rates, but also the local water and gas rates, and other information such as outside temperature, the UV index, etc. Others believe that customers won't have much interaction with the PCT beyond the occasional reprogramming for price-responsive setpoints.

One manufacturer (Honeywell) expressed the opinion that the use of PCTs to enable price-responsive demand would be limited due to the inability of most utility customer information systems to differentiate energy consumption by time period. Another (Venstar) sees the PCT market evolving toward the use of TCP/IP for communications.

Modifying the functionality of installed PCTs

Because both technology and utility needs change over time, the flexibility to incorporate new features and capabilities into PCTs is an important consideration. Through the questionnaires sent to PCT manufacturers, we investigated the likelihood that future enhancements in functionality could be implemented remotely via a software change or whether a physical replacement of the PCT would be necessary and cost-effective.

Modifying functionality via remote firmware change. To assess the degree to which PCTs could gain new functionality by downloading new software we asked PCT manufacturers the following question: "Given your views on how the PCT market and PCT functionality will evolve, do you believe it would be possible to retrofit installed PCTs with any such functionality remotely via a software change?" Most (though not all) of the respondents to this question indicated that given a reliable communications network, it would be possible to remotely modify PCT software to enhance functionality. A caveat though, is that the PCT would have to be designed from the outset to accommodate such modifications. Several manufacturers also stressed that this capability would be dependent on the communications link, as a software upgrade involves considerably more data transfer than an emergency or price signal. So although it may be technically possible to enhance the functionality of installed PCTs remotely via a software change, this may not be possible from a practical standpoint, as one could not guarantee a successful download of the revised software to all PCTs.

Modifying functionality via physical replacement of installed PCTs. If it is not possible to upgrade functionality remotely via a software change, any such upgrades would require physical replacement of the PCT, either by the occupant or a service person. To elicit opinions about the cost effectiveness of physical replacement of the PCT to enhance functionality (the additional functionality manufacturers identified above under Market Evolution), we asked PCT manufacturers "Do you believe that any such expanded functionality would make it economically advantageous to physically replace an installed PCT satisfying the "Necessary Functions" with one that has expanded functionality?"

Responses to this question were about evenly split between those that believe additional functionality will have sufficient value to justify replacement and those that don't. Because each respondent to this question had his or her own conception of what the "expanded functionality" might be, each was in effect answering a somewhat different question. However, it is possible to make the general statement that those manufacturers that see the PCT evolving into a gateway that would offer control of multiple devices and perhaps additional services like security monitoring tend to believe that there will be sufficient economic justification to physically replace an installed PCT. Manufacturers that don't see the PCT evolving into a gateway or that promote a separate home automation gateway express skepticism that sufficient additional functionality can be built into PCTs to make it attractive to replace them.

Retrofitting two-way capability into one-way PCTs. The CEC was particularly interested in whether industry players would be able to add two-way communications capabilities to their products at a later time, if the CEC were initially to require one-way communications. The market already offers several two-way PCT solutions, so it is clear that if the CEC were to first require one-way communications and subsequently to require two-way communications for PCTs in new construction, the market would have no problem responding with qualifying products.

What is less clear is whether it would be cost-effective to retrofit installed PCTs capable of only one-way communications with modules that would enable two-way communication, or to replace them with PCTs designed for two-way communication. To assess this question, we asked PCT manufacturers the following question: "If the CEC were to require only one-way communication to the PCTs, would it be possible to retrofit two-way capability into installed thermostats at a later date, or would this be cost-prohibitive?"

All but one of the nine PCT manufacturers that offered a substantive response to this question indicated that a retrofit or replacement to enable two-way communications would be cost-prohibitive, and in the case of retrofit, that the PCT would have to be designed for two-way communications from the outset. However, several manufacturers suggest that a more economically viable alternative would be to ship and install PCTs with two-way capability, even if only one-way capability is to be used initially. According to Invensys, "With today's technology, the cost of two-way radio today would have a negligible cost impact on the overall PCT cost." Venstar comments that "If there is even a slight possibility of needing to retrofit or replace the PCT in the field, it is far more cost effective to start with 2 way communication [than to retrofit or replace a one-way PCT]."

As discussed above, our recommendation is that the CEC not require that PCTs be capable of acknowledging curtailment signals. Furthermore, information provided by most PCT manufacturers (see following section) indicates that two-way communication capability adds considerably to the cost of a PCT and to its installation cost. Unless and until the costs to enable and operate two-way communications drop substantially, our recommendation is that the CEC require only one-way communication capability.

Costs of PCT Hardware and Installation

Costs for emergency and price responsiveness

We asked PCT manufacturers to provide estimates of the hardware and installation costs of PCTs that could respond to emergency and price signals, but that were not capable of acknowledging receipt of such signals (i.e. one-way PCTs). We asked for cost estimates for PCTs sold to installers or consumers through retail channels and wholesale channels to installers at annual volumes of 50,000; 100,000; and 250,000. We received substantive cost responses from five thermostat manufacturers, with the results shown in Table 28. Three additional manufacturers declined to provide cost information for a variety of reasons. Individual company responses are provided in Appendix D. Note that the costs included here do not include communications-related costs, other than the cost of the receiver itself.

Table 28: Hardware and installation costs for PCTs capable of emergency and price responsiveness.

Sales Channel	Retail				Wholesale to Contractors			
	Hardware Cost		Installation Cost		Hardware Cost		Installation Cost	
Annual Volume	Emergency Response	Price Response	Emergency Response	Price Response	Emergency Response	Price Response	Emergency Response	Price Response
50,000	$90 to $200	$95 to $200	Little incremental cost relative to conventional thermostat. $75 to $100 total.		$75 to $160	$75 to $160	Little incremental cost relative to conventional thermostat. $75 to $100 total.	
100,000	$80 to $170	$80 to $170			$60 to $135	$60 to $135		
250,000	$60 to $125	$60 to $125			$45 to $100	$45 to $100		

We draw the following conclusions from these responses:

- Not surprisingly, the data in the table demonstrate that annual sales volume can play a significant role in the cost of a PCT.
- Cost estimates vary by a factor of approximately 2 regardless of sales channel or volume. This appears to be primarily linked to manufacturer assumptions regarding the type of communications receiver integrated into the PCT.
- These responses suggest that the market price of a PCT capable of responding to both emergency and price signals would be only slightly higher than the market price of a PCT able to respond to only one of these signals.
- PCTs can be installed at little if any incremental cost relative to conventional thermostats.

Assuming an installation cost of $100 per PCT, the hardware costs in Table 28 result in the annual installed cost estimates presented in Table 29.

Table 29 . Annual installed costs for one-way PCTs capable of emergency and price responsiveness.

Sales Channel	Retail ($million)	Wholesale ($million)
Annual Volume		
50,000	9.75 to 15	8.75 to 13
100,000	18 to 27	16 to 23.5
250,000	40 to 56	36 to 50

Additional costs for verification

We also asked manufacturers to estimate the costs of PCTs that could acknowledge receipt of emergency and price signals in addition to responding to those signals. The range of responses is presented in Table 30 for the same sales channels and annual sales volumes as above. As above, the costs indicated in the table reflect hardware and installation costs only, and explicitly do not include costs related to sending signals to or receiving responses from installed PCTs. Again, individual manufacturer responses are included in Appendix D.

Table 30 Hardware and installation costs for two-way PCTs

Sales Channel	Retail				Wholesale to Contractors			
	Hardware Cost		Installation Cost		Hardware Cost		Installation Cost	
Volume	Emergency Response	Price Response	Emergency Response	Price Response	Emergency Response	Price Response	Emergency Response	Price Response
50,000	$110 to $545	$110 to $545	2-way communication adds from $30 to $80 to installation costs, relatively insensitive to volume.		$100 to $435	$100 to $435	2-way communication adds from $30 to $80 to install costs, relatively insensitive to volume.	
100,000	$105 to $515	$109 to $515			$93 to $410	$93 to $410		
250,000	$100 to $470	$100 to $470			$86 to $375	$86 to $375		

From these responses we conclude that:

- Moving from one-way to two-way communication adds considerable hardware and installation cost to a PCT.
- Manufacturers' assumptions about how return path communications (PCT to utility) is established lead to very different cost estimates among vendors for two-way communication. This results in the much broader range of price estimates than was the case for one-way PCTs.
- Installation costs increase due to the need to verify two-way communication and in some cases due to installation of additional equipment.

Assuming an installation cost of $155 per PCT, the hardware costs in Table 5K result in the annual installed cost estimates presented in Table 31.

Table 31 Annual installed costs for two-way communicating PCTs.

Sales Channel	**Retail ($million)**	**Wholesale ($million)**
Annual Volume		
50,000	13 to 35	13 to 29.5
100,000	26 to 67	25 to 56.5
250,000	64 to 156	60 to 132.5

Table 32 presents the ranges of estimated incremental costs for adding two-way communication capability to PCTs. This table is based on comparisons between individual manufacturers' cost estimates for one- and two-way PCTs and assumes installation costs of $100 and $155 for one- and two-way PCTs respectively.

Table 32 Annual incremental installed costs for two-way communicating PCTs.

Sales Channel	Retail ($million)	Wholesale ($million)
Annual Volume		
50,000	6.25 to 20	4 to 16.5
100,000	12.5 to 40	8 to 35.5
250,000	28.75 to 100	20.25 to 82.75

Key cost drivers

The two factors that were cited consistently by almost all PCT manufacturers as the most important determinants of the cost of a PCT are volume and the type of infrastructure used to establish communications. The impact of volume production can be seen clearly in Table 28, which demonstrates that increasing sales volume from 50,000 to 250,000 units would result in a cost reduction of about one-third.

The selection of one-way or two-way communications has a substantial impact on the cost of a PCT, as demonstrated by the difference in the price ranges shown in Table 28 and Table 30. In addition, once one- or two-way communication has been specified, differences in the hardware required at the PCT for different communication media result in very different hardware costs. For example, paging receivers are substantially more expensive than simple RF receivers. We did not explicitly request data on the cost of receivers or transceivers; however, we did ask manufacturers to specify their assumptions regarding communications hardware in their cost estimates. This information is available in Appendix D of the E-Source PCT report for SCE.

Communication Costs

In late June and early July 2005, we conducted telephone interviews with five communications providers to gather initial responses to the preliminary PCT specification and information on the likely costs of communicating with large numbers of PCTs. Transcripts of these interviews are contained in Appendix A. Through the interviews, we attempted to characterize the services that each company provides, the experience each company has in supporting demand response programs, the extent of each company's network coverage within California, and the costs of providing and extending that coverage. Those interviews reflected the fact that some providers already have extensive networks in the state, while others currently have little to no established network. Existing network capabilities are listed in Table 33.

Table 33 Existing communication networks for a sample of communications providers.

Communication provider	Communication medium	Claimed existing coverage in California
SkyTel	2-way paging	All cities with population > 70,000
Orbcomm	Satellite	Entire state
Verizon Wireless	Cellular	Over 80 percent of population
Current Technologies	Broadband over power line	No existing network
Hunt Technologies	Power line carrier	Limited

As this table indicates, networks making use of paging, cellular, or satellite communication technologies enjoy the advantage of having well established networks, whereas broadband over power line (BPL) and power line carrier (PLC) networks would essentially have to be built from the ground up. One additional technology not included in the initial interviews is the use of existing commercial FM radio sub carrier frequencies. The sole company representing this technology that contributed to our information gathering process, e-Radio Inc., has an existing network limited to the San Francisco Bay area, though the vast majority of the physical infrastructure necessary to support a much larger network already exists in the FM broadcast towers that already reach most of the state. In this case, network "build-out" would involve contracting with the owners of broadcasting licenses rather than physically adding new broadcasting capability.

Our initial investigation into the communication-related costs of operating a PCT network resulted in the consistent message that cost structures are very flexible and highly dependent on the size, frequency, and timing of the communications. None of the communications providers we interviewed were willing or able to provide cost estimates in the abstract. Several providers indicated that they offer a variety of pricing structures that can be adapted to particular applications. With the exception of the case in which utilities own and operate the communications network, as could be the case with a power line carrier technology, our view is that the actual pricing of the communications service is likely to be the result of a negotiation between the utility and the provider for a specific application.

Subsequent to the technology planning meeting, we sent questionnaires to a set of 14 communications providers, intended to elicit better information on the range of costs necessary to establish (where a network doesn't already exist) and operate a network capable of supporting the communications requirements of a growing population of installed PCTs. The communications providers we contacted included companies operating networks based on paging, cellular, satellite, PLC, BPL, and conventional VHF technologies.

The questionnaire, which is included along with provider responses Appendix F, presented a set of potential communication scenarios based on usage cases and the installed PCT population at some future date. The scenarios were intended to bracket the range of possible communication volumes anticipated over 15 years subsequent to the implementation of a Title 24 mandate of PCTs in all new construction. These scenarios were developed in consultation with knowledgeable personnel from California electric utilities.

Unfortunately, response to this questionnaire was substantially less robust than the response provided by PCT manufacturers, despite our repeated attempts to encourage the communications companies to respond. Only four communications providers, two satellite communications providers, one paging provider and one FM VHF provider, contributed substantive responses that yield insight into the cost of establishing and operating a communications network to support PCT demand responsiveness.

There are several potential reasons for the poor response rate among communications providers. One provider cited ongoing negotiations as the reason it could not provide the requested information. Another provider, a company that focuses on broadband over power lines, explained that that technology is too new and existing applications too few to provide reasonable cost estimates. For BPL in particular, and to a lesser degree for power line carrier communications, the cost of establishing the networks that would be needed to support PCT communications will be shared among a variety of applications (such as meter reading, high-speed Internet access, capacitor switching, power quality monitoring, etc.), and the way in which network costs are distributed across these potential applications may vary from one utility to the next, so estimating the cost for PCT communications in the abstract is particularly difficult. Other potential reasons communication companies did not provide the requested information include competitive concerns, insufficient specification of each scenario to allow a meaningful response, or confusion regarding what information was being requested.

Because we were unable to gather robust information on the potential communication-related costs of a statewide PCT network for some of the most prominent communications technologies within the time constraints of this project, we are currently unable to provide guidance on the potential range of these costs. Information on the cost of communicating with the population of PCTs is obviously critical to the determination of cost effectiveness of a Title 24 requirement for PCTs in new construction. We therefore recommend that the CEC undertake additional research into this question.

We asked communications providers to estimate their charges under six use cases and four PCT populations. The resulting 24 scenarios were intended to bracket the range of potential communications requirements. The use cases were

1. Emergency response, 20 events per year, one-way communication only, single broadcast to all PCTs
2. Emergency response, 20 events per year, two-way communication, acknowledge receipt of signal with timestamp
3. Emergency response, 20 events per year, two-way communication, acknowledgement with information on PCT operating state, temperature, and setpoint
4. CPP response, 15 events per year, one-way communication only, single broadcast to all PCTs
5. CPP response, 15 events per year, two-way communication, acknowledge receipt of signal with timestamp
6. CPP response, 15 events per year, two-way communication, acknowledgement with information on PCT operating state, temperature, and setpoint.

The four communications providers that responded to the questionnaire did not differentiate between emergency and CPP response in their pricing, so only the first three scenarios are presented, assuming 35 events per year. Note that e-Radio proposes one-way communication only.

Table 34 Estimated costs from communications providers

		Utility investment / expense ($million)[10]				Annual data volume-related charges ($000)				Other charges[11] ($000)			
PCT Population (thousands)		50	500	2,500	5,000	50	500	2,500	5,000	50	500	2,500	5,000
Use Case	Provider												
1)	Orbcomm	0	0	0	0	300	2,700	12,000	21,000	0	0	0	0
	Mica-Tech	0	0	0	0	350	2,360	11,290	22,460	0	0	0	0
	e-Radio	<<1	<<1	<<1	<<1	131	1,313	6,563	13,125	45	450	2,250	4,500
	SkyTel	7.1	7.1	7.1	7.1	600	6,000	30,000	60,000	1,440	1,440	1,440	1,440
2)	Orbcomm	0	0	0	0	600	5,400	24,000	42,000	0	0	0	0
	Mica-Tech	0	0	0	0	350	2,360	11,290	22,460	0	0	0	0
	e-Radio	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	SkyTel	9	9	9	9	600	6,000	30,000	60,000	2,880	2,880	2,880	2,880
3)	Orbcomm	0	0	0	0	750	6,900	30,000	54,000	0	0	0	0
	Mica-Tech	0	0	0	0	350	2,360	11,290	22,460	0	0	0	0
	e-Radio	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	SkyTel	9	9	9	9	600	6,000	30,000	60,000	2,880	2,880	2,880	2,880

Proposed PCT Specification

As discussed in previous sections, we are recommending that one function listed as "Necessary" in the preliminary PCT Specification be eliminated, and that two additional functions be required by the CEC. Our proposed final PCT specification is presented in Figure 12. Our recommendation is that the CEC allow the market to dictate PCT

[10] Communication providers that have existing networks covering a portion of the state were asked to assume that 20 percent of the PCT population would be installed in regions not currently covered by their network. SkyTel assumed capital expenditures would be necessary for build-out in 50 new communities.

[11] e-Radio would charge an annual retainer to guarantee high-priority emergency access to the broadcast network. SkyTel assumed tower leases would be required in 50 new communities.

functionality beyond the minimum functions identified in the figure that are necessary to procure this resource and operate it efficiently

Because we believe that the benefits that could be obtained by requiring that all PCTs be capable of two-way communications can be provided at substantially less cost either with or without the advent of AMI networks, we recommend that the CEC not require that PCTs be capable of acknowledging receipt of emergency or price signals. Because we believe that significant additional benefit can be attained at little if any additional cost by requiring that PCTs be addressable by geographic location (indeed many existing PCTs already offer this function), we recommend that the CEC adopt this capability as a "Necessary" function. Finally, we recommend that the CEC add a requirement that PCTs be capable of compressor cycling in addition to temperature setback, as this requirement would add greater flexibility to utility demand response programs and the potential for greater confidence in the magnitude of the curtailable load, while adding little if any cost to the PCT.

Necessary Functions for Emergency Response

- Receive and respond to communication signals to control thermostat set point
- Receive and respond to communication signals to cycle the air conditioner compressor
- Respond automatically to emergency signals
- Indicate the emergency state
- Provide system operators with the ability to target specific geographic locations and select only the amount of load necessary to address individual shortage situations

Necessary Functions for Price Response

- Receive at least one type of communication signal to which the PCT can respond based upon customer's preference
- Be programmed by the customer to respond according to desired temperature changes at desired price thresholds.
- Be capable of customer override during events
- Indicate the critical peak pricing state
- Provide system operators with the ability to target specific geographic locations and select only the amount of load necessary to address individual shortage situations

Figure 12 Proposed Final PCT Specification

Necessary Functions for Emergency Response

- Receive and respond to communication signals to control thermostat set point
- Receive and respond to communication signals to cycle the air conditioner compressor
- Respond automatically to emergency signals
- Indicate the emergency state
- Provide system operators with the ability to target specific geographic locations and select only the amount of load necessary to address individual shortage situations

Necessary Functions for Price Response

- Receive at least one type of communication signal to which the PCT can respond based upon customer's preference
- Be programmed by the customer to respond according to desired temperature changes at desired price thresholds.
- Be capable of customer override during events
- Indicate the critical peak pricing state
- Provide system operators with the ability to target specific geographic locations and select only the amount of load necessary to address individual shortage situations

Appendix 3 – Statewide Estimates of Air-Conditioned Dwelling Units or Commercial Floor Space

Nonresidential New Construction Activity Estimates

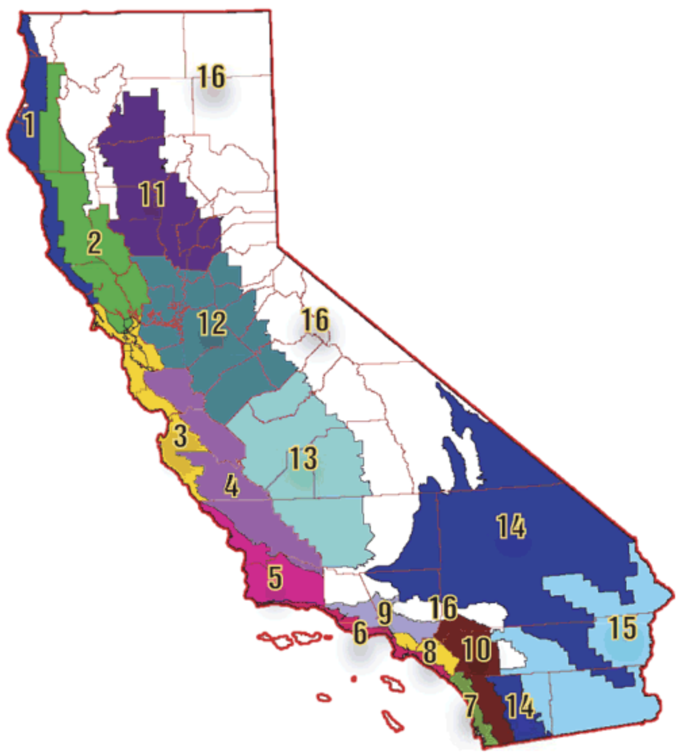

Figure 13: Title 24 California Climate Temperature Zone

The computer simulations of nonresidential building response to set-up of thermostats are performed on a Title 24 climate zone by climate zone basis. The prototypical models vary by climate zone as there are different insulation and fenestration requirements by climate zone. In addition, the climate zone specific weather files are used in conjunction with these climate specific models to generate climate specific results. To expand the energy and cost savings results up to the populations of new buildings built each year requires knowledge of the number of buildings that are built in each Title 24 climate temperature zone. As can be seen in the colored areas differentiate the extent of each climate zone, which overlap multiple counties which are drawn on this map as lines.

The McGraw-Hill Dodge database contains nonresidential construction activity by occupancy type for each of the counties in California. However, the construction activity in each Title 24 climate temperature zone was needed to expand the climate specific simulation results to the statewide level. Rob Hudler of the California Energy Commission worked with Nehemiah Stone at the Heschong Mahone Group to develop a mapping of fraction of county construction activity to each climate zone as is shown in Table 35. This mapping then allowed us to estimate the construction activity in square feet of various occupancies by climate zone. This estimate is contained in Table 36.

Since there are only two nonresidential prototypes, the results from the office simulations were allocated to the floor areas associated with Assembly, Education, Government, Hotel, Medical, Office, and Schools. The results of the small retail simulations were affiliated with Retail and Service. The results of the retail and office simulations relatively close to each other so that if the prototypes were affiliated with different occupancies, it would not change the statewide results substantially.

The scope of this report considers PCTs that are stand-alone thermostats connected to typically single zone systems. From an evaluation of the nonresidential new construction (NRNC) database, in the PIER Integrated Design of Small Commercial HVAC Systems Background Research Summary

Table 35: Mapping of Counties to Title 24 Climate Temeprature Zone

County \ CTZ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Alameda	0%	0%	70%	0%	0%	0%	0%	0%	0%	0%	0%	30%	0%	0%	0%	0%
Alpine	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
Amador	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	80%	0%	0%	0%	20%
Butte	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	90%	0%	0%	0%	0%	10%
Calaveras	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	95%	0%	0%	5%
Colusa	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
Contra Costa	0%	0%	30%	0%	0%	0%	0%	0%	0%	0%	0%	70%	0%	0%	0%	0%
Del Norte	80%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	20%
El Dorado	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	85%	0%	0%	0%	15%
Fresno	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	99%	0%	0%	1%
Glenn	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	98%	0%	0%	0%	0%	2%
Humboldt	20%	70%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%
Imperial	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	95%	0%
Inyo	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	30%	0%	70%
Kern	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	58%	40%	0%	2%
Kings	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%
Lake	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lassen	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
Los Angeles	0%	0%	0%	0%	0%	15%	0%	30%	25%	0%	0%	0%	0%	28%	0%	2%
Madera	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	70%	0%	0%	30%
Marin	0%	20%	80%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mariposa	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	70%	0%	0%	30%
Mendocino	19%	80%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
Merced	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%
Modoc	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
Mono	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
Monterey	0%	0%	60%	40%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Napa	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Nevada	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	40%	0%	0%	0%	0%	60%
Orange	0%	0%	0%	0%	0%	40%	0%	60%	0%	0%	0%	0%	0%	0%	0%	0%
Placer	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	85%	0%	0%	0%	0%	15%
Plumas	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
Riverside	0%	0%	0%	0%	0%	0%	0%	0%	0%	70%	0%	0%	0%	16%	12%	2%
Sacramento	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%
San Benito	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
San Bernardino	0%	0%	0%	0%	0%	0%	0%	0%	0%	50%	0%	0%	0%	30%	15%	5%
San Diego	0%	0%	0%	0%	0%	0%	30%	0%	0%	20%	0%	0%	0%	20%	30%	0%
San Francisco	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
San Joaquin	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%
San Luis Obispo	0%	0%	0%	40%	60%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
San Mateo	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Santa Barbara	0%	0%	0%	5%	75%	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%
Santa Clara	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Santa Cruz	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Shasta	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	80%	0%	0%	0%	0%	20%
Sierra	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
Siskiyou	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%
Solano	0%	0%	20%	0%	0%	0%	0%	0%	0%	0%	0%	80%	0%	0%	0%	0%
Sonoma	20%	80%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Stanislaus	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%
Sutter	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
Tehama	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	90%	0%	0%	0%	0%	10%
Trinity	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	98%
Tulare	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	80%	0%	0%	20%
Tuolumne	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	80%	0%	0%	0%	20%
Ventura	0%	0%	0%	0%	0%	28%	0%	0%	70%	0%	0%	0%	0%	0%	0%	2%
Yolo	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%
Yuba	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	95%	0%	0%	0%	0%	5%

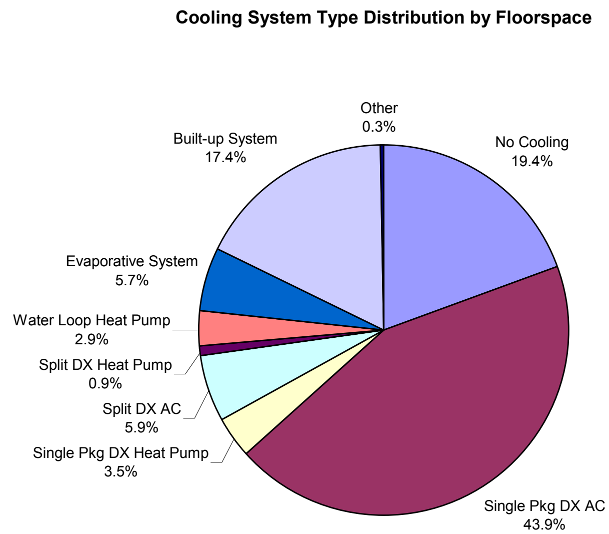

Figure 14: Floorspace Distribution of HVAC Systems in Commercial Buildings

Table 36: Average of 2000 - 2003 nonresidential new construction area in 1,000's of sf by climate zone

CTZ	AMUSEMENT	ASSEMBLY	EDUCATION	GOVT	HOTEL	MEDICAL	OFFICE	RETAIL	SCHOOL	SERVICE	STORAGE	OTHER	Total 1,000's sf	Total Office 1,000's sf	Total Retail 1,000's sf	Total Office + Retail 1,000's sf
1	22	2	5	13	25	20	79	40	50	9	28	24	**318**	195	49	**244**
2	93	19	23	84	177	119	419	241	242	53	259	204	**1,934**	1,082	295	**1,377**
3	849	103	149	184	997	334	4,999	1,868	1,111	3,077	1,030	453	**15,155**	7,877	4,945	**12,822**
4	358	77	279	46	380	452	3,365	1,075	1,162	2,656	496	499	**10,843**	5,760	3,730	**9,491**
5	145	31	0	20	154	75	356	244	251	245	432	167	**2,121**	889	489	**1,378**
6	405	165	68	151	566	599	1,697	1,820	912	1,746	2,400	349	**10,878**	4,158	3,566	**7,724**
7	160	49	71	32	530	167	1,114	738	524	938	642	85	**5,049**	2,487	1,675	**4,162**
8	581	250	114	215	806	959	2,498	2,714	1,443	3,010	3,761	458	**16,808**	6,285	5,723	**12,008**
9	309	105	107	165	251	780	1,438	1,781	923	1,833	2,495	428	**10,615**	3,769	3,615	**7,384**
10	591	192	103	280	645	351	1,815	2,906	1,961	1,203	8,640	501	**19,188**	5,347	4,108	**9,456**
11	224	149	5	55	144	216	874	1,140	383	207	454	297	**4,149**	1,826	1,348	**3,174**
12	577	356	37	204	799	562	4,133	3,808	2,496	2,442	4,166	1,205	**20,786**	8,588	6,250	**14,838**
13	475	130	46	331	72	566	436	1,161	656	327	1,658	447	**6,305**	2,237	1,488	**3,725**
14	537	191	167	415	617	913	2,298	2,915	1,899	2,825	7,103	638	**20,518**	6,500	5,740	**12,239**
15	272	99	85	110	625	247	1,416	1,365	951	1,122	2,825	303	**9,419**	3,533	2,487	**6,020**
16	179	71	19	230	112	168	442	594	369	273	1,117	168	**3,741**	1,411	866	**2,277**
Totals	**5,776**	**1,990**	**1,277**	**2,535**	**6,901**	**6,527**	**27,380**	**24,410**	**15,334**	**21,965**	**37,504**	**6,227**	**157,827**	**61,944**	**46,375**	**108,319**

Residential New Construction Estimates

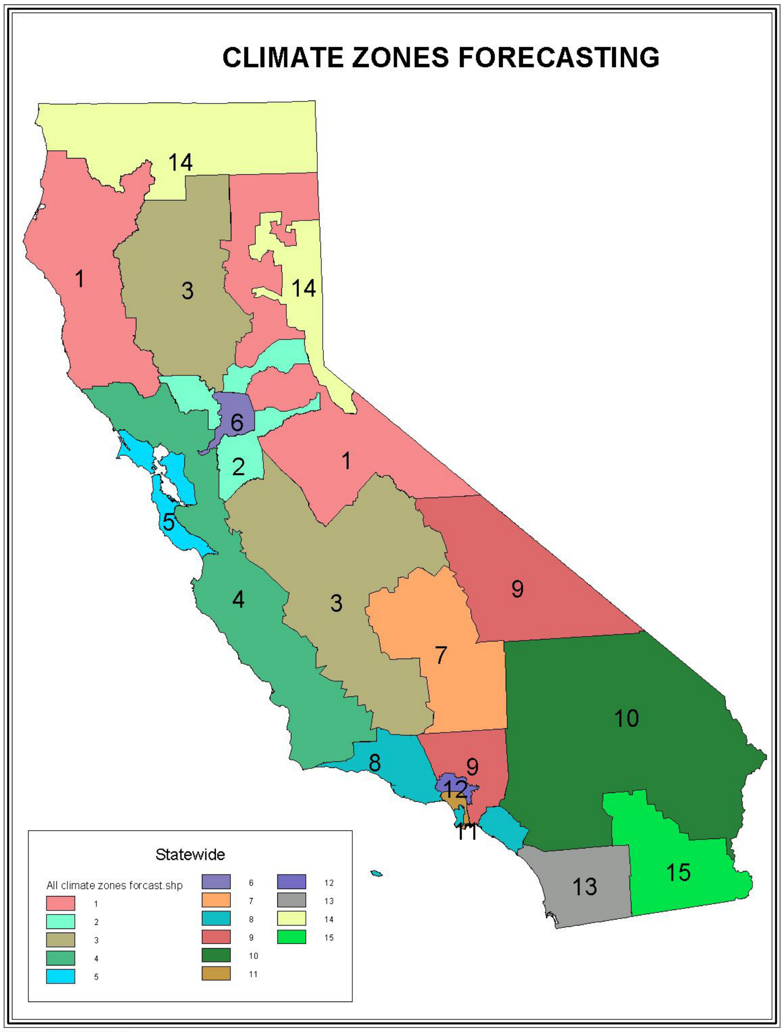

Figure 15 Map of Forecasting Climate Zones

The estimates of residential new construction and replacement air conditioners come from the "California Energy Demand 2003-2013 Forecast Staff Report" as shown in Table 37. These estimates are segmented by demand forecast climate zones which are not to be confused with the Title 24 climate temperature zones. Figure 15 Map of Forecasting Climate Zones illustrates the location of each of these forecast zones. By comparing this map with the map of the Title 24 climate temperature zones in Figure 13, one can see there is not an exact correspondence between the Title 24 zones and the forecast zones. Building on the analysis used for the 2001 DEER Update Study, we mapped the forecast climate zones to the Title 24 climate zones as shown in Table 38.

Table 37: 2008 Residential AC Installations CEC Demand Analysis Office

Mapped Title 24 California CTZ	Forecast Zone	Dwellings with AC	New Dwellings with AC	AC installed in old dwellings	Replace non-working	Total Dwellings	AC Saturation
2	1	88,290	2,251	275	3,228	285,537	31%
12	2	253,028	7,908	414	9,266	412,866	61%
13	3	637,791	18,855	461	23,360	1,067,946	60%
4	4	517,826	11,339	1,459	18,953	1,743,632	30%
3	5	46,874	968	67	1,708	1,366,545	3%
12	6	383,264	8,531	318	14,063	517,325	74%
13	7	112,589	3,121	93	4,120	197,334	57%
6	8	619,777	12,811	7,863	22,320	2,208,957	28%
9	9	434,062	14,301	1,676	15,729	851,011	51%
10	10	843,135	26,846	524	30,824	1,207,403	70%
6	11	126,147	1,869	635	4,612	851,526	15%
9	12	231,792	2,839	396	8,498	473,045	49%
7	13	357,172	7,674	3,630	12,979	1,224,771	29%
16	14	23,722	605	74	867	76,718	31%
15	15	72,158	2,298	45	2,638	103,333	70%
9	16	72,631	748	233	2,667	172,442	42%
	Totals	**4,820,258**	**122,963**	**18,163**	**175,832**	**12,760,391**	**38%**

Table 38: Mapping of Demand Forecast Climate Zones to Title-24 Climate Temperature Zone[12]s

Utility	Demand Forecast Zone	Representative City	CDD base75	HDD base68	Region	Title 24 CTZ
PG&E	1	Arcata	359	4207	North Coast	1
PG&E	1	Napa	359	3809	North Coast	**2**
PG&E	2	Sacramento	527	3351	Central Valley	**12**
PG&E	3	Fresno	980	3003	Central Valley	**13**
PG&E	4	San Jose	198	3090	North Coast	**4**
PG&E	5	San Francisco	48	3108	North Coast	**3**
SMUD	6	Sacramento	527	3351	Central Valley	**12**
SCE	7	Fresno	980	3003	Central Valley	**13**
SCE	8	Long Beach	169	1706	South Coast	**6**
SCE	9	Burbank	498	2004	South Inland	**9**
SCE	10	San Bernardino	725	2361	Desert	**10**
LADWP	11	Long Beach	169	1706	South Coast	**6**
LADWP	12	Burbank	498	2004	South Inland	**9**
SDG&E	13	San Diego	98	1735	South Coast	**7**
Other	15	Palm Springs	2399	1348	Desert	**15**
BGP	16	Burbank	498	2004	South Inland	**9**
Other	14					**16**

[12] Based upon table 5-14 "Summary Weather Definitions Used for Calibration Runs" from 2001 DEER update study http://cacx.org//deer/2001_DEER_Update_Study.PDF

Appendix 4 – Residential Estimates of Cost, Energy and Emissions Savings per Thermostat

This section provides the detailed savings estimates by each of the scenarios described in the "Assumptions Associated with Scenarios" Section in the body of this report.

Table 39: Residential Total Value per Tstat

	Residential Total Value per Tstat (PV$/Tstat)				
	Residential New Construction				
Climate Zone	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5
1	$ -	$ 17.69	$ 143.88	$ 502.33	$ 623.14
2	$ 5.21	$ 47.20	$ 290.29	$ 595.11	$ 735.58
3	$ 5.03	$ 43.23	$ 250.36	$ 559.59	$ 678.83
4	$ 7.05	$ 51.18	$ 311.01	$ 676.60	$ 827.77
5	$ 7.14	$ 36.40	$ 306.27	$ 517.93	$ 619.83
6	$ 5.03	$ 44.76	$ 239.42	$ 517.94	$ 630.94
7	$ 8.17	$ 57.79	$ 331.25	$ 590.51	$ 741.12
8	$ 6.10	$ 49.25	$ 277.04	$ 566.84	$ 699.98
9	$ 9.71	$ 73.90	$ 426.11	$ 953.06	$ 1,190.27
10	$ 7.26	$ 60.35	$ 337.63	$ 723.12	$ 895.70
11	$ 9.68	$ 67.47	$ 436.35	$ 838.22	$ 1,045.76
12	$ 8.30	$ 62.59	$ 407.59	$ 836.11	$ 1,058.81
13	$ 9.58	$ 64.18	$ 404.28	$ 830.92	$ 1,001.79
14	$ 8.61	$ 72.18	$ 449.37	$ 922.75	$ 1,134.22
15	$ 11.40	$ 92.57	$ 528.92	$ 1,064.25	$ 1,315.42
16	$ 6.78	$ 52.25	$ 317.77	$ 667.34	$ 818.92

Table 40: Residential Resource Value per Tstat

Residential Resource Value per Tstat (PV$/Tstat)					
Climate Zone	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5
1	$ -	$ 5.59	$ 109.66	$ 280.57	$ 398.54
2	$ 5.21	$ 14.15	$ 221.22	$ 334.66	$ 471.79
3	$ 5.03	$ 12.12	$ 186.97	$ 302.62	$ 418.57
4	$ 7.05	$ 15.42	$ 237.68	$ 382.62	$ 530.03
5	$ 7.14	$ 15.81	$ 241.50	$ 282.92	$ 381.81
6	$ 5.03	$ 11.90	$ 173.88	$ 269.43	$ 379.25
7	$ 8.17	$ 21.00	$ 257.78	$ 340.69	$ 488.10
8	$ 6.10	$ 14.53	$ 206.59	$ 306.79	$ 436.60
9	$ 9.71	$ 23.55	$ 324.50	$ 537.07	$ 768.95
10	$ 7.26	$ 18.08	$ 252.07	$ 391.69	$ 560.02
11	$ 9.68	$ 22.19	$ 340.95	$ 503.48	$ 706.73
12	$ 8.30	$ 19.07	$ 314.07	$ 486.10	$ 704.31
13	$ 9.58	$ 18.88	$ 306.07	$ 473.55	$ 639.84
14	$ 8.61	$ 22.03	$ 340.20	$ 515.09	$ 721.33
15	$ 11.40	$ 28.52	$ 394.45	$ 587.07	$ 832.12
16	$ 6.78	$ 16.25	$ 245.38	$ 380.92	$ 528.83

Table 41: Residential Emergency Value per Tstat

Residential Emergency Value per Tstat (PV$/Tstat)					
Climate Zone	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5
1	$ -	$ 12.10	$ 34.21	$ 221.76	$ 224.60
2	$ -	$ 33.06	$ 69.07	$ 260.45	$ 263.79
3	$ -	$ 31.11	$ 63.39	$ 256.97	$ 260.27
4	$ -	$ 35.77	$ 73.33	$ 293.98	$ 297.75
5	$ -	$ 20.60	$ 64.77	$ 235.01	$ 238.02
6	$ -	$ 32.86	$ 65.54	$ 248.51	$ 251.69
7	$ -	$ 36.79	$ 73.47	$ 249.82	$ 253.02
8	$ -	$ 34.72	$ 70.45	$ 260.05	$ 263.39
9	$ -	$ 50.36	$ 101.61	$ 415.98	$ 421.32
10	$ -	$ 42.27	$ 85.56	$ 331.43	$ 335.68
11	$ -	$ 45.28	$ 95.40	$ 334.74	$ 339.03
12	$ -	$ 43.52	$ 93.52	$ 350.02	$ 354.50
13	$ -	$ 45.30	$ 98.22	$ 357.37	$ 361.95
14	$ -	$ 50.14	$ 109.17	$ 407.66	$ 412.89
15	$ -	$ 64.05	$ 134.47	$ 477.18	$ 483.30
16	$ -	$ 36.00	$ 72.39	$ 286.41	$ 290.08

Table 42: Residential Non-Emergency Avg Demand Savings per Tstat

Residential Non-Emergency Avg Demand Savings per Tstat (kW/Tstat)					
Climate Zone	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5
1	0.00	0.04	0.17	0.44	0.46
2	0.07	0.10	0.33	0.51	0.54
3	0.08	0.10	0.31	0.50	0.53
4	0.10	0.11	0.36	0.58	0.61
5	0.07	0.06	0.31	0.46	0.49
6	0.09	0.10	0.32	0.49	0.51
7	0.10	0.11	0.36	0.49	0.52
8	0.09	0.11	0.34	0.51	0.54
9	0.13	0.16	0.49	0.82	0.86
10	0.11	0.13	0.41	0.65	0.69
11	0.12	0.14	0.46	0.66	0.69
12	0.11	0.13	0.45	0.69	0.72
13	0.08	0.14	0.48	0.70	0.74
14	0.13	0.16	0.53	0.80	0.84
15	0.16	0.20	0.65	0.94	0.99
16	0.10	0.11	0.35	0.56	0.59

Table 43: Residential Emergency Avg Demand Savings per Tstat

Residential Emergency Avg Demand Savings per Tstat (kW/Tstat)					
Climate Zone	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5
1	0.00000	0.01	0.02	0.05	0.02
2	0.00000	0.03	0.04	0.06	0.03
3	0.00000	0.02	0.03	0.06	0.03
4	0.00000	0.03	0.04	0.06	0.03
5	0.00000	0.02	0.03	0.05	0.03
6	0.00000	0.03	0.04	0.05	0.03
7	0.00000	0.03	0.04	0.05	0.03
8	0.00000	0.03	0.04	0.06	0.03
9	0.00000	0.04	0.05	0.09	0.05
10	0.00000	0.03	0.05	0.07	0.04
11	0.00000	0.04	0.05	0.07	0.04
12	0.00000	0.03	0.05	0.08	0.04
13	0.00000	0.04	0.05	0.08	0.04
14	0.00000	0.04	0.06	0.09	0.04
15	0.00000	0.05	0.07	0.10	0.05
16	0.00000	0.03	0.04	0.06	0.03

Table 44: Residential Energy Savings per Tstat

Residential Energy Savings per Tstat (kWh/Tstat)					
Climate Zone	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5
1	0.00	0.67	9.45	22.13	31.15
2	0.47	1.31	15.88	23.24	32.70
3	0.47	1.11	13.42	20.63	29.03
4	0.59	1.22	17.28	27.07	38.10
5	0.84	1.94	20.12	22.97	32.33
6	0.56	1.20	13.70	21.82	30.71
7	0.70	1.54	17.75	22.12	31.13
8	0.56	1.24	14.74	20.57	28.96
9	0.87	1.85	23.25	37.57	52.87
10	0.73	1.71	19.68	30.16	42.45
11	0.75	1.79	20.75	31.47	44.29
12	0.72	1.46	20.17	31.95	44.97
13	0.94	1.86	22.59	36.76	51.74
14	0.81	2.11	24.48	36.69	51.64
15	1.14	2.78	29.74	46.36	65.25
16	0.55	1.28	15.87	22.72	31.97

Appendix 5 – Nonresidential Estimates of Cost, Energy and Emissions Savings per Thermostat

Table 45: Nonresidential Total Value per Tstat

Nonresidential Total Value per Tstat (PV$/Tstat)										
	Office					Retail				
Climate Zone	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5
1	$ 11.47	$ 73.37	$ 442.35	$ 574.48	$ 946.86	$ 10.69	$ 62.46	$ 399.59	$ 597.48	$ 980.42
2	$ 11.75	$ 79.02	$ 475.40	$ 708.55	$1,157.17	$ 10.10	$ 59.04	$ 380.91	$ 732.64	$ 1,190.55
3	$ 9.72	$ 69.48	$ 404.12	$ 607.84	$ 991.07	$ 7.54	$ 48.64	$ 311.34	$ 603.69	$ 979.13
4	$ 12.77	$ 78.97	$ 467.23	$ 704.38	$1,141.67	$ 11.03	$ 60.88	$ 389.08	$ 721.89	$ 1,162.05
5	$ 9.90	$ 69.72	$ 408.51	$ 564.48	$ 913.22	$ 8.59	$ 53.24	$ 340.06	$ 568.80	$ 916.28
6	$ 11.06	$ 79.69	$ 439.25	$ 582.45	$ 964.62	$ 9.42	$ 60.34	$ 370.40	$ 607.52	$ 997.76
7	$ 15.01	$ 88.57	$ 496.91	$ 655.69	$1,076.15	$ 12.91	$ 55.64	$ 417.18	$ 667.59	$ 1,090.72
8	$ 10.80	$ 73.20	$ 423.33	$ 654.80	$1,078.23	$ 9.23	$ 56.14	$ 347.34	$ 640.50	$ 1,049.75
9	$ 12.52	$ 80.88	$ 470.55	$ 741.95	$1,223.20	$ 10.91	$ 62.70	$ 388.69	$ 760.37	$ 1,247.32
10	$ 12.09	$ 84.73	$ 479.27	$ 709.74	$1,176.59	$ 9.98	$ 62.84	$ 381.84	$ 740.72	$ 1,220.29
11	$ 14.47	$ 87.22	$ 553.76	$ 775.61	$1,250.48	$ 12.85	$ 66.62	$ 455.44	$ 768.91	$ 1,235.34
12	$ 13.21	$ 86.93	$ 542.28	$ 784.19	$1,292.06	$ 11.73	$ 67.63	$ 447.95	$ 817.45	$ 1,339.79
13	$ 13.26	$ 83.71	$ 505.48	$ 753.60	$1,210.95	$ 11.68	$ 65.08	$ 423.81	$ 761.66	$ 1,218.18
14	$ 12.70	$ 86.08	$ 525.32	$ 726.27	$1,185.83	$ 11.67	$ 67.33	$ 440.52	$ 729.16	$ 1,184.93
15	$ 13.44	$ 92.82	$ 542.75	$ 822.95	$1,355.85	$ 12.06	$ 71.33	$ 445.13	$ 814.41	$ 1,332.87
16	$ 11.83	$ 75.56	$ 455.66	$ 706.37	$1,139.32	$ 9.74	$ 56.94	$ 362.59	$ 726.08	$ 1,168.46

Table 46: Nonresidential Resource Value per Tstat

Nonresidential Resource Value per Tstat (PV$/Tstat)										
	Office					Retail				
Climate Zone	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5
1	$ 11.47	$ 23.26	$ 335.20	$ 317.67	$ 426.66	$ 10.69	$ 21.48	$ 304.65	$ 336.09	$ 450.94
2	$ 11.75	$ 23.40	$ 362.85	$ 403.60	$ 539.44	$ 10.10	$ 19.91	$ 292.61	$ 423.59	$ 564.52
3	$ 9.72	$ 19.76	$ 303.92	$ 335.59	$ 439.58	$ 7.54	$ 15.19	$ 235.22	$ 337.27	$ 439.45
4	$ 12.77	$ 25.98	$ 358.37	$ 402.22	$ 529.60	$ 11.03	$ 21.92	$ 299.19	$ 416.28	$ 542.98
5	$ 9.90	$ 20.04	$ 305.44	$ 306.03	$ 389.70	$ 8.59	$ 16.98	$ 255.53	$ 312.52	$ 397.14
6	$ 11.06	$ 23.50	$ 325.34	$ 310.29	$ 413.33	$ 9.42	$ 19.60	$ 276.11	$ 329.90	$ 435.40
7	$ 15.01	$ 32.60	$ 382.49	$ 373.68	$ 504.90	$ 12.91	$ 27.35	$ 320.77	$ 381.70	$ 511.62
8	$ 10.80	$ 22.56	$ 320.12	$ 363.72	$ 488.62	$ 9.23	$ 19.17	$ 264.38	$ 358.95	$ 479.42
9	$ 12.52	$ 27.08	$ 360.67	$ 423.94	$ 579.05	$ 10.91	$ 23.32	$ 299.54	$ 440.50	$ 599.37
10	$ 12.09	$ 25.72	$ 361.08	$ 391.39	$ 531.72	$ 9.98	$ 20.85	$ 289.88	$ 416.18	$ 562.90
11	$ 14.47	$ 28.41	$ 434.04	$ 458.89	$ 608.93	$ 12.85	$ 25.06	$ 360.46	$ 463.23	$ 616.16
12	$ 13.21	$ 27.91	$ 420.79	$ 457.28	$ 629.85	$ 11.73	$ 24.70	$ 350.47	$ 485.86	$ 668.09
13	$ 13.26	$ 25.34	$ 383.64	$ 422.12	$ 539.49	$ 11.68	$ 22.32	$ 325.41	$ 435.63	$ 557.77
14	$ 12.70	$ 25.67	$ 400.05	$ 407.62	$ 540.35	$ 11.67	$ 23.42	$ 339.01	$ 418.89	$ 556.42
15	$ 13.44	$ 27.81	$ 408.73	$ 455.79	$ 612.11	$ 12.06	$ 24.89	$ 338.89	$ 462.06	$ 619.13
16	$ 11.83	$ 24.27	$ 353.15	$ 412.65	$ 544.36	$ 9.74	$ 19.88	$ 282.08	$ 428.82	$ 566.33

Table 47: Nonresidential Emergency Value per Tstat

Climate Zone	Office (--) Very Pessimistic 1	Office (-) Pessimistic 2	Office (=) Base Case 3	Office (+) Optimistic 4	Office (++) Very Optimistic 5	Retail (--) Very Pessimistic 1	Retail (-) Pessimistic 2	Retail (=) Base Case 3	Retail (+) Optimistic 4	Retail (++) Very Optimistic 5
Nonresidential Emergency Value per Tstat (PV$/Tstat)										
1	$ -	$ 50.11	$ 107.15	$ 256.81	$ 520.20	$ -	$ 40.98	$ 94.95	$ 261.39	$ 529.48
2	$ -	$ 55.63	$ 112.55	$ 304.95	$ 617.73	$ -	$ 39.13	$ 88.30	$ 309.05	$ 626.03
3	$ -	$ 49.73	$ 100.21	$ 272.25	$ 551.49	$ -	$ 33.45	$ 76.11	$ 266.42	$ 539.68
4	$ -	$ 52.99	$ 108.85	$ 302.16	$ 612.07	$ -	$ 38.96	$ 89.88	$ 305.62	$ 619.07
5	$ -	$ 49.68	$ 103.07	$ 258.45	$ 523.52	$ -	$ 36.26	$ 84.53	$ 256.28	$ 519.14
6	$ -	$ 56.19	$ 113.91	$ 272.16	$ 551.30	$ -	$ 40.74	$ 94.28	$ 277.62	$ 562.36
7	$ -	$ 55.98	$ 114.42	$ 282.01	$ 571.25	$ -	$ 28.29	$ 96.41	$ 285.89	$ 579.11
8	$ -	$ 50.64	$ 103.20	$ 291.07	$ 589.61	$ -	$ 36.97	$ 82.95	$ 281.56	$ 570.33
9	$ -	$ 53.79	$ 109.88	$ 318.00	$ 644.15	$ -	$ 39.37	$ 89.15	$ 319.87	$ 647.95
10	$ -	$ 59.00	$ 118.20	$ 318.35	$ 644.87	$ -	$ 41.99	$ 91.96	$ 324.53	$ 657.39
11	$ -	$ 58.82	$ 119.72	$ 316.71	$ 641.55	$ -	$ 41.56	$ 94.99	$ 305.67	$ 619.18
12	$ -	$ 59.03	$ 121.50	$ 326.92	$ 662.21	$ -	$ 42.93	$ 97.48	$ 331.60	$ 671.69
13	$ -	$ 58.37	$ 121.84	$ 331.48	$ 671.46	$ -	$ 42.75	$ 98.40	$ 326.03	$ 660.42
14	$ -	$ 60.41	$ 125.27	$ 318.65	$ 645.47	$ -	$ 43.91	$ 101.51	$ 310.27	$ 628.50
15	$ -	$ 65.01	$ 134.03	$ 367.16	$ 743.74	$ -	$ 46.44	$ 106.25	$ 352.35	$ 713.74
16	$ -	$ 51.29	$ 102.51	$ 293.71	$ 594.96	$ -	$ 37.06	$ 80.51	$ 297.25	$ 602.12

Table 48: Nonresidential Non-Emergency Avg Demand Savings per Tstat

Climate Zone	Office (--) Very Pessimistic 1	Office (-) Pessimistic 2	Office (=) Base Case 3	Office (+) Optimistic 4	Office (++) Very Optimistic 5	Retail (--) Very Pessimistic 1	Retail (-) Pessimistic 2	Retail (=) Base Case 3	Retail (+) Optimistic 4	Retail (++) Very Optimistic 5
Nonresidential Non-Emergency Avg Demand Savings per Tstat (kW/Tstat)										
1	0.25	0.25	0.85	0.83	0.83	0.21	0.21	0.76	0.84	0.84
2	0.28	0.28	0.90	0.98	0.98	0.20	0.20	0.70	1.00	1.00
3	0.25	0.25	0.80	0.88	0.88	0.17	0.17	0.61	0.86	0.86
4	0.27	0.27	0.87	0.97	0.97	0.20	0.20	0.71	0.98	0.98
5	0.25	0.25	0.82	0.83	0.83	0.18	0.18	0.67	0.83	0.83
6	0.29	0.29	0.91	0.88	0.88	0.21	0.21	0.75	0.89	0.89
7	0.28	0.28	0.91	0.91	0.91	0.14	0.14	0.77	0.92	0.92
8	0.26	0.26	0.82	0.94	0.94	0.19	0.19	0.66	0.91	0.91
9	0.27	0.27	0.87	1.02	1.02	0.20	0.20	0.71	1.03	1.03
10	0.30	0.30	0.94	1.03	1.03	0.21	0.21	0.73	1.05	1.05
11	0.30	0.30	0.95	1.02	1.02	0.21	0.21	0.76	0.98	0.98
12	0.30	0.30	0.97	1.05	1.05	0.22	0.22	0.78	1.07	1.07
13	0.30	0.30	0.97	1.07	1.07	0.22	0.22	0.78	1.05	1.05
14	0.31	0.31	1.00	1.03	1.03	0.22	0.22	0.81	1.00	1.00
15	0.33	0.33	1.07	1.18	1.18	0.24	0.24	0.84	1.14	1.14
16	0.26	0.26	0.82	0.95	0.95	0.19	0.19	0.64	0.96	0.96

Table 49: Nonresidential Emergency Avg Demand Savings per Tstat

	Nonresidential Emergency Avg Demand Savings per Tstat (kW/Tstat)									
	Office					Retail				
Climate Zone	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5
1	0.00	0.06	0.09	0.09	0.09	0.00	0.05	0.08	0.09	0.09
2	0.00	0.07	0.10	0.11	0.11	0.00	0.05	0.08	0.11	0.11
3	0.00	0.06	0.09	0.10	0.10	0.00	0.04	0.07	0.10	0.10
4	0.00	0.07	0.10	0.11	0.11	0.00	0.05	0.08	0.11	0.11
5	0.00	0.06	0.09	0.09	0.09	0.00	0.05	0.07	0.09	0.09
6	0.00	0.07	0.10	0.10	0.10	0.00	0.05	0.08	0.10	0.10
7	0.00	0.07	0.10	0.10	0.10	0.00	0.04	0.09	0.10	0.10
8	0.00	0.06	0.09	0.10	0.10	0.00	0.05	0.07	0.10	0.10
9	0.00	0.07	0.10	0.11	0.11	0.00	0.05	0.08	0.11	0.11
10	0.00	0.07	0.10	0.11	0.11	0.00	0.05	0.08	0.12	0.12
11	0.00	0.07	0.11	0.11	0.11	0.00	0.05	0.08	0.11	0.11
12	0.00	0.07	0.11	0.12	0.12	0.00	0.05	0.09	0.12	0.12
13	0.00	0.07	0.11	0.12	0.12	0.00	0.05	0.09	0.12	0.12
14	0.00	0.08	0.11	0.11	0.11	0.00	0.06	0.09	0.11	0.11
15	0.00	0.08	0.12	0.13	0.13	0.00	0.06	0.09	0.13	0.13
16	0.00	0.07	0.09	0.11	0.11	0.00	0.05	0.07	0.11	0.11

Table 50: Nonresidential Energy Savings per Tstat

	Nonresidential Energy Savings per Tstat (kWh/Tstat)									
	Office					Retail				
Climate Zone	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5	(--) Very Pessimistic 1	(-) Pessimistic 2	(=) Base Case 3	(+) Optimistic 4	(++) Very Optimistic 5
1	1.79	3.58	40.41	36.35	48.47	1.65	3.30	37.74	41.89	55.85
2	1.70	3.40	39.65	45.56	60.75	1.49	2.98	33.56	51.07	68.09
3	1.44	2.88	34.59	38.51	51.35	1.14	2.27	27.95	40.36	53.81
4	1.75	3.50	40.19	45.10	60.13	1.53	3.06	35.09	49.62	66.16
5	1.63	3.27	37.07	36.11	48.15	1.39	2.78	31.81	38.29	51.06
6	1.93	3.86	41.96	39.31	52.41	1.61	3.23	36.64	43.94	58.58
7	2.11	4.21	44.02	40.49	53.99	1.85	3.69	39.27	45.51	60.68
8	1.64	3.28	37.68	41.88	55.83	1.43	2.86	32.87	43.66	58.21
9	1.80	3.60	41.03	48.59	64.79	1.61	3.22	36.15	54.50	72.67
10	1.92	3.84	43.28	46.81	62.42	1.58	3.16	36.84	53.94	71.92
11	1.86	3.72	42.86	44.03	58.71	1.70	3.39	38.84	47.47	63.30
12	1.94	3.88	44.95	48.74	64.98	1.74	3.49	39.77	55.84	74.45
13	2.11	4.21	45.24	49.80	66.41	1.83	3.67	41.03	54.72	72.96
14	1.93	3.86	44.28	44.29	59.05	1.77	3.54	39.67	48.19	64.26
15	2.10	4.19	47.51	54.12	72.16	1.91	3.82	41.63	59.00	78.67
16	1.52	3.05	35.85	43.29	57.72	1.28	2.56	29.97	48.23	64.30