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2008 California Energy Commission Title 24 Building Energy Efficiency Standards
February 13, 2007

February 27th, 2007 Workshop Report
DDC to the Zone Level

Measure 1: VAV Zone Minimums
Measure 2: Demand Shed Controls
Measure 3: Hydronic Pressure Reset
Measure 4: Demand Control Ventilation (DCV) for Multiple Zone Systems
Measure 5: Supply Air Temperature Reset

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February 27th, 2007 Workshop Report DDC to the Zone Level Measure 1: VAV Zone Minimums

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Overview

Description

Overview

This CASE report addresses one of five separate measures that extend the control requirements of the standard. All five of these requirements are possible at a very small cost if the installed control system is direct-digital control (DDC) to the zone level. This initiative does not seek to require installation of DDC to the zone level, rather it extends the current philosophy of the prescriptive requirements such as supply static pressure reset (Section 144(c)2D) that state a functional requirement of the control system if it is designed for DDC to the zone level.

The five measures covered by this proposal are as follows:

1. Modification of the existing prescriptive measure 144(d) (Space-Conditioning Zone Controls) to allow for "dual maximum" control of VAV boxes

2. A new mandatory measure for global demand shed controls that can automatically reset the temperature set-points of all non-critical zones by 1 to 4°F from a single central command in the building energy management and control system (EMCS).

3. Modification of the existing prescriptive measure 144(j)6 (Hydronic System Measures: Variable Speed Drives) to require demand based reset of the pressure setpoint for pumps serving variable flow systems based on valve demand. This measure is the hydronic analog of the existing prescriptive measure for supply air pressure reset in (Section 144(c)2D).

4. Modification of the existing mandatory demand controlled ventilation (DCV) requirements 121(c)3 (Required Demand Control Ventilation) to include high occupant density zones served by multiple zone systems.

5. Modification of the existing prescriptive measure 144(f) (Supply Air Temperature Reset Controls) for demand based supply air temperature reset for variable air volume (VAV) systems that operate when the system is on 100% free cooling from the air-side economizer.

As each of these measures is simply a matter of programming, the cost for implementing them is quite low. However, as described below each of these measures has a significant potential for energy and demand savings.

VAV Zone Minimums

This specific report covers the VAV Zone Minimums. Currently the standard allows reheat systems to have minimum flow rates of 30% of peak supply. This proposed change would require reheat systems to have a minimum flow rate of no greater than 20% but allow these systems to reheat up to 50% of peak supply in heating mode for systems with DDC to the zone level. This would apply to any VAV reheat system (e.g. offices and universities). The proposed change would save considerable energy at almost no cost (e.g. DDC systems can easily be programmed with dual cooling/heating maximum flow rates) and improve comfort and indoor air quality by allowing better mixing in heating mode.

Energy Benefits

The results of our simulations of a 10,000 sf building in the 16 California climate zones are shown in Table 1 below. These simulations are described in detail in Appendix A of this document. The estimated weighted average energy savings (on a per unit area basis) are as follows:

- Peak demand reduction of 0.0003 kW/ sf
- Annual electrical energy savings of 0.25 kWh/sf/yr
- Annual gas savings of 0.023 therms/sf/yr
- TDV savings of $0.69/sf

The weighting factors used in the weighted average come from the F. W. Dodge projection of new construction areas by climate and occupancy (presented in Table 2 below).

Table 1- Projected Annual Energy and TDV Cost Savings for This Measure

Climate Zone	Electrical Energy Savings [kWh/yr]	Electrical Peak Demand Reduction [kW]	TDV Electrical Cost Savings [$]	Natural Gas Energy Savings [Therms/yr]	TDV Gas Cost Savings [$]	TDV Total Cost Savings [$]	TDV Total Sa Norm
CZ01	3,000	3.6	$5,800	280	$3,700	$9,500	
CZ02	2,500	2.6	$3,800	250	$3,400	$7,200	
CZ03	2,900	2.7	$5,100	260	$3,500	$8,600	
CZ04	2,900	3.6	$4,200	230	$3,200	$7,400	
CZ05	3,600	3.0	$5,900	300	$3,900	$9,900	
CZ06	3,100	3.4	$5,000	250	$3,400	$8,500	
CZ07	3,200	3.3	$4,900	250	$3,300	$8,200	
CZ08	2,900	3.8	$4,200	230	$3,100	$7,300	
CZ09	2,800	3.1	$4,100	240	$3,200	$7,300	
CZ10	2,700	3.4	$3,700	240	$3,200	$6,900	
CZ11	2,200	2.8	$3,000	230	$3,200	$6,100	
CZ12	2,500	2.8	$3,500	270	$3,600	$7,100	
CZ13	2,300	3.1	$3,100	250	$3,400	$6,500	
CZ14	1,700	2.6	$2,300	190	$2,500	$4,800	
CZ15	2,100	3.1	$3,000	180	$2,500	$5,500	
CZ16	800	2.3	$1,200	10	$0	$1,200	
Minimum	800	2.3	$1,200	10	$0	$1,200	
Maximum	3,600	3.8	$5,900	300	$3,900	$9,900	
Wtd Avg	2,500	3.1	$3,800	230	$3,100	$6,900	

Non-energy Benefits

Non-energy benefits include improved comfort and indoor air quality due to better air mixing in heating mode. Improved comfort and indoor air quality can of course lead to improvements in occupant health, productivity, and increased property valuation.

Statewide Energy Impacts

Using the F. W. Dodge Nonresidential New Construction data (averaged from 2000 to 2003), the projected statewide construction in thousands of sf by climate zone are shown in Table 2. The projected statewide energy impacts of this measure are calculated and listed in Table 3 (based on the assumption that 30% of the commercial new construction is served by VAV systems). CBECs and CEUS data have shown that although ~ 80% of the systems installed are packaged single zone units, multiple zone systems account for approximately 50% of the conditioned floor area.

The detailed analysis found that the first year's implementation of the proposed requirements would reduce electricity energy consumption by 12.1 Gigawatt/hr per year, reduce electrical demand coincident with utility system peak by 15.0 Megawatts, and decrease natural gas consumption by 1,000,000 therms/yr. The TDV energy cost savings is estimated at $32 Million accrued over the life of these building systems (15 years).

Table 2 Average Annual Nonresidential New Construction Area by California Climate Zone from F. W. Dodge (2000 to 2003)

CTZ	AMUSEMENT	ASSEMBLY	EDUCATION	GOVT	HOTEL	MEDICAL	OFFICE	RETAIL	SCHOOL	SERVICE	STORAGE	OTHER	TOTAL
1	20	0	10	10	30	20	80	40	50	10	30	20	[illegible]
2	90	20	20	80	180	120	420	240	240	50	260	200	1,
3	850	100	150	180	1,000	330	5,000	1,870	1,110	3,080	1,030	450	15,
4	360	80	280	50	380	450	3,370	1,070	1,160	2,660	500	500	10,
5	140	30	0	20	150	80	360	240	250	240	430	170	2,
6	400	160	70	150	570	600	1,700	1,820	910	1,750	2,400	350	10,
7	160	50	70	30	530	170	1,110	740	520	940	640	80	5,
8	580	250	110	220	810	960	2,500	2,710	1,440	3,010	3,760	460	16,
9	310	110	110	160	250	780	1,440	1,780	920	1,830	2,490	430	10,
10	590	190	100	280	650	350	1,820	2,910	1,960	1,200	8,640	500	19,
11	220	150	0	50	140	220	870	1,140	380	210	450	300	4,
12	580	360	40	200	800	560	4,130	3,810	2,500	2,440	4,170	1,210	20,
13	470	130	50	330	70	570	440	1,160	660	330	1,660	450	6,
14	540	190	170	420	620	910	2,300	2,910	1,900	2,830	7,100	640	20,
15	270	100	80	110	630	250	1,420	1,370	950	1,120	2,820	300	9,
16	180	70	20	230	110	170	440	590	370	270	1,120	170	3,
Totals	**5,800**	**2,000**	**1,300**	**2,500**	**6,900**	**6,500**	**27,400**	**24,400**	**15,300**	**22,000**	**37,500**	**6,200**	**158,**

Table 3 Statewide TDV cost savings and emission reductions

Climate Zone	Electrical Energy Savings [kWh/yr]	Electrical Peak Demand Reduction (kW)	Natural Gas Savings [Therms/yr]	TDV Cost Savings [$]	Nox [lbs/yr]	CO2 [lbs/yr]	CO [lbs/yr]	PM10 [lbs/yr]
CZ01	30,000	30	3,000	**$100,000**	**40**	**100,000**	**10**	**-**
CZ02	150,000	150	15,000	**$400,000**	**190**	**300,000**	**80**	**20**
CZ03	1,340,000	1,220	120,000	**$3,900,000**	**1,640**	**3,000,000**	**670**	**200**
CZ04	930,000	1,170	76,000	**$2,400,000**	**1,070**	**2,000,000**	**440**	**130**
CZ05	230,000	190	19,000	**$600,000**	**260**	**500,000**	**110**	**30**
CZ06	1,020,000	1,120	83,000	**$2,800,000**	**1,170**	**2,200,000**	**480**	**140**
CZ07	490,000	500	37,000	**$1,200,000**	**540**	**1,000,000**	**220**	**70**
CZ08	1,460,000	1,930	115,000	**$3,700,000**	**1,640**	**3,100,000**	**680**	**200**
CZ09	900,000	980	76,000	**$2,300,000**	**1,060**	**2,000,000**	**430**	**130**
CZ10	1,550,000	1,940	136,000	**$4,000,000**	**1,870**	**3,400,000**	**760**	**230**
CZ11	270,000	350	29,000	**$800,000**	**380**	**700,000**	**150**	**50**
CZ12	1,570,000	1,770	166,000	**$4,400,000**	**2,160**	**3,800,000**	**860**	**260**
CZ13	440,000	590	47,000	**$1,200,000**	**610**	**1,100,000**	**240**	**70**
CZ14	1,040,000	1,570	115,000	**$3,000,000**	**1,480**	**2,600,000**	**580**	**180**
CZ15	580,000	880	50,000	**$1,500,000**	**690**	**1,300,000**	**280**	**80**
CZ16	90,000	260	1,000	**$100,000**	**40**	**100,000**	**20**	**10**
Total	12,100,000	15,000	1,090,000	$32,000,000	14,800	27,000,000	6,000	1,800

Environmental Impact

As shown in Table 3 above, this measure is estimated to annually reduce emissions by approximately 15 thousand pounds of NOx, 27 million pounds of CO2, 6 thousands pounds of CO and 1.8 thousand pounds of PM10.

Table 4 presents the emission factors for calculating reduced emissions based on reduction in energy usage.

Table 4 Emmision factors for Calculating Reduced Emmisions from Energy Savings (CEC 2003)

Emissions Factors for Calculating Reduced Emissions from Energy Savings				
Emissions factors	**NOx**	**CO**	**CO2**	**PM10**
Natural Gas, California (lbs/MMBtu)	0.094	0.03	115	0.01
Electricity, Western States (lbs/MWh)	0.383	0.23	1200	0.06

Type of Change

The proposed change would modify an existing prescriptive requirement. The ACM modeling rules would have to be altered slightly.

This proposed change increases the stringency of the standard and makes a new distinction between zones with direct digital controls (DDC) and all other zone controls (principally pneumatic and analog controls).

Minor changes would be required for the compliance forms that would require the applicant to indicate the type of zone controls and to list the heating maximum airflow as well as the cooling maximum and minimum flow rates.

The complete proposed changes with underlines and strikeouts are in the section Proposed Standard Language below.

Technology Measures

Measure Availability and Cost

This measure essentially requires the use of dual maximum control sequences for non-pneumatic systems. Dual maximum control logic that would satisfy this proposed requirement is available from all major control system manufacturers.

Useful Life, Persistence and Maintenance

It is not anticipated that this measure would have any impact on the useful life or maintenance of VAV boxes. Savings are expected to persist for the life of the control system. Achieving the anticipated savings does depend on proper commissioning. The incremental cost of commissioning is included in the lifecycle cost analysis.

Performance Verification

Designers will have to document the heating maximum airflow as well as the cooling maximum and the minimum. In addition designers should also be required to document the zone control sequences. They could either provide a schematic and/or narrative or choose from a list of possible options. This documentation could be part of the compliance forms or it could be something the designer must include on the plans.

Cost Effectiveness

Lifecycle cost analysis has shown the measure to be highly cost effective with significant energy savings and minimal incremental first cost. The first cost consists of some additional test and balance and commissioning costs and the possible addition of a discharge air temperature sensor. However, most reheat systems today are already specified with VAV box discharge air temperature sensors.

Analysis Tools

This measure can be easily modeled with eQuest, EnergyPro and EnergyPlus. DOE2 has an option for "REVERSE-ACTING" thermostats that can be used to simulate the required control.

Relationship to Other Measures

No anticipated impacts on other measures.

Methodology

The zone minimum requirements in the current version of the standard are based on the single maximum control sequence used by most pneumatic VAV reheat systems (see Figure *1*). As cooling load decreases the airflow is reduced from the maximum airflow (on the far right side of the figure) down to the minimum flow. Then as heating is required the reheat valve is modulated to maintain the space temperature at setpoint.

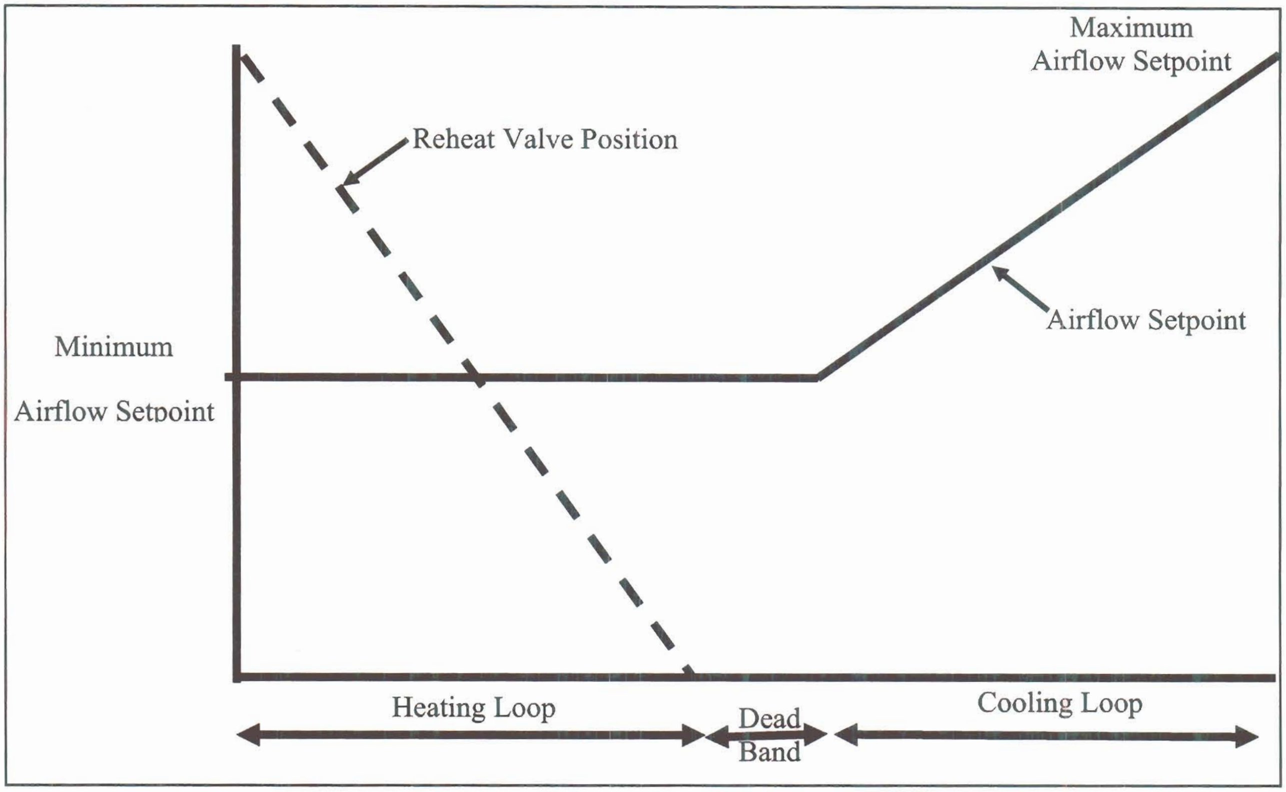
With this sequence the minimum flow rate in deadband (between heating and cooling) is also the flow rate in heating mode. The air flow in heating should be high enough that at design heating conditions the supply air is not too hot. If the supply air is too hot (e.g. greater than 90ºF) then the hot supply air may short-circuit and go back into the return air system without fully mixing in the space. Short-circuiting has several negative consequences including:

- Poor indoor air quality – According to ASHRAE Standard 62.1 (Ventilation for Acceptable Indoor Air Quality), Air Change Effectiveness is always 1.0 (good mixing) when the ceiling supply of warm air is less than 15°F above the space temperature. When the supply air is greater than 15°F above the space temperature then Air Change Effectiveness decreases, meaning that the supply air short-circuits to the return and does not remove pollutants from the space as well as systems with good mixing.

- Poor comfort – According to ASHRAE Standard 55 (Thermal Environmental Conditions for Human Occupancy), acceptable comfort conditions cannot be achieved if space vertical temperature stratification exceeds 5°F. If short-circuiting occurs then the floor of a space will remain cold while the ceiling gets hot and stratification will exceed 5°F.

- Poor temperature control – If short-circuiting occurs it may not be possible to achieve heating setpoint at the thermostat location.

Figure 1. Single Maximum Zone Control Sequence



Faced with the risks of short-circuiting, many designers routinely disregard the 30% minimum requirement. It is very common for designed to list 30% minimums on code compliance documents and then to change the minimums to 40% or 50% before the controls are set up. Surveys of commercial buildings that were performed under the NBI PIER project documented this in the five buildings surveyed (Hydeman et al 2003). The authors have seen VAV box minimums well in excess of the code requirement in a number of other buildings in California in the process of energy conserving retrofits.

With a high minimum flow setpoint, zones are often overcooled in deadband mode. This forces the zone into heating mode and results in wasted reheat energy. It is not uncommon for a building to have boilers running all summer long to provide reheat to zones with such high minimum flow rates.

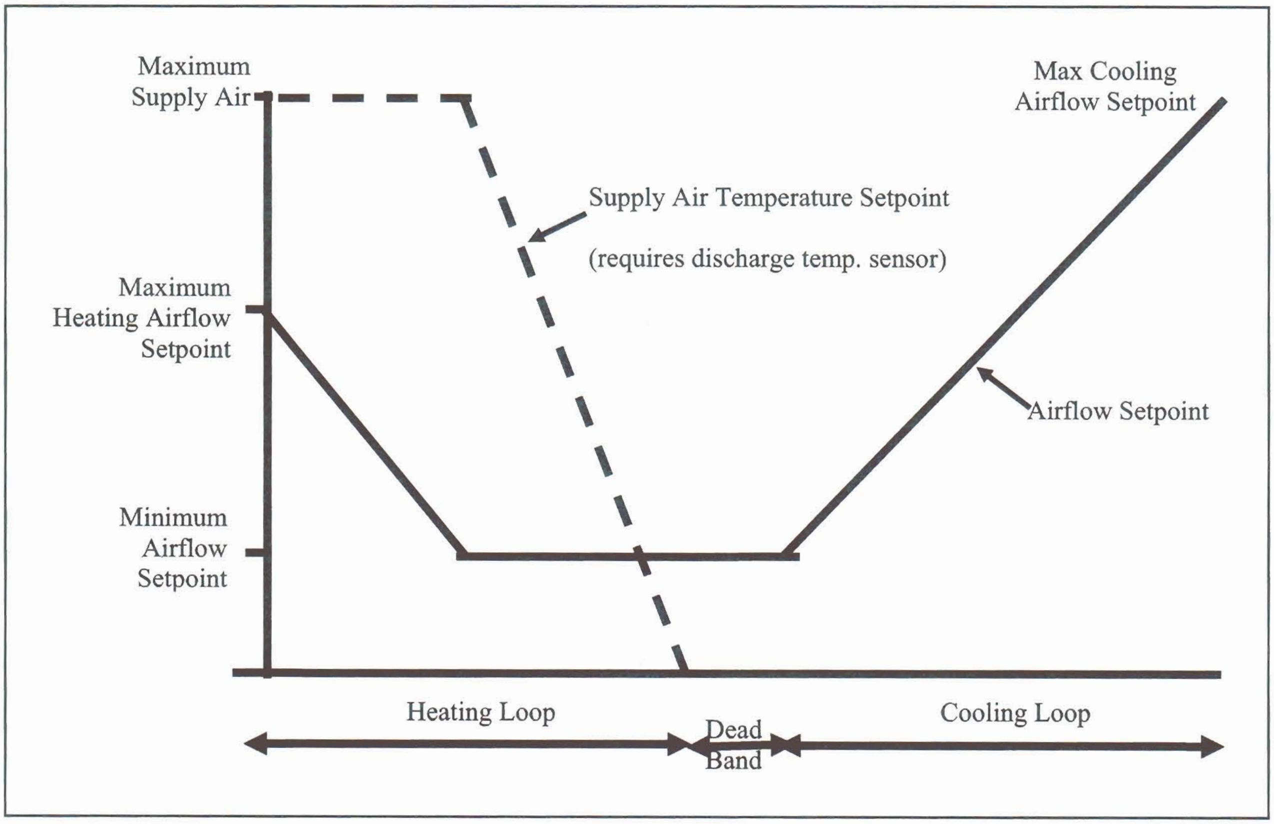
Figure 2 illustrates a dual maximum zone control sequence. Airflow is reduced from cooling maximum airflow to minimum airflow as cooling load goes down. As the zone goes into heating mode the discharge air temperature setpoint is reset from minimum temperature (e.g. 55°F) to maximum temperature (e.g. 85°F). If more heating is required then the airflow is reset from the minimum up to the heating maximum. With a dual maximum zone control sequence, the airflow in deadband is lower than the airflow at full heating. The minimum flow needs to only be high enough to satisfy the ventilation requirements, which are typically 10% or less for most perimeter zones.

The minimum flow setpoint should also be high enough to prevent "dumping". Dumping is when the supply air does not have sufficient velocity to mix with room air and a jet of cold air can "dump" on occupants. Research by Fisk (Fisk, 1997) and Bauman (Bauman, 1995) found that acceptable comfort and mixing can be maintained even with the most inexpensive diffusers at 25% flow. They did not test below 25% but their research implies that acceptable comfort and mixing can be maintained below 25% as well. It should also be noted that much of the time when a zone is in deadband it is because the zone is unoccupied. Comfort is obviously not an issue in unoccupied zones.

The minimum flow setpoint should also be high enough that the VAV box can stably and accurately maintain the flow setpoint without excessive repositioning of the damper. Recent research by Dickerhoff and Stein (2006), has shown that stability and accuracy can be maintained down to approximately 10% of design flow.

With low minimums, zones are not overcooled nearly as often as with a single maximum scheme, which results in tremendous reheat energy savings. With dual maximum control sequences it is usually possible to shut off the boiler system for the entire summer season.

Figure 2. Dual Maximum Zone Control Sequence.



Survey of the EMCS Vendors

The authors conducted an email survey of the major EMCS vendors (Siemens, Invensys, Johnson, Honeywell, Alerton, Automated Logic Corporation and Trane) in June of 2006. Of these seven companies, only three responded (Siemens, Alerton and Automated Logic Corporation). The authors subsequently sent the five draft proposals from the CEC July 13th workshop to the list server for ASHRAE Technical Committee 1.4 "Control Theory and Application." This list server includes all members, corresponding members and interested parties to TC 1.4. In addition Mark Hydeman addressed the ASHRAE TC 1.4 committee on these proposals at their meeting in Dallas on January 30th, 2007 and requested feedback for the upcoming February 2007 CEC workshop To date not a single negative comment on any of these proposals has been received.

The survey is presented in Appendix A of this report. A summary of the survey results follow:

Question 1, EMCS market place: All three respondents indicated that DDC to the zone level was between 90% to 95% of the new construction market.

Question 2, Top Factors for DDC Purchases:

- Facility Management - 3 Votes
- Improved Comfort and Controls – 3 Votes
- Tenant After Hours Management – 2 Votes
- Alarming – 2 Votes
- Energy Savings – 2 Votes
- First Cost – 2 Votes
- Web Based Access – 1 Vote

Question 3, Relative First Cost of DDC and Pneumatic Controls: The consensus of the respondents is that pneumatic controls generally have a slightly smaller first cost. This cost depends on the number of points in the system as the pneumatic control system incurs a large first cost penalty for the compressor and associated equipment (like air dryers and filters). For small control systems DDC is actually less expensive. For medium and large control systems DDC is likely to be a slight cost premium.

Question 4, Relative Maintenance Cost of DDC and Pneumatic Controls: The consensus of the respondents is that pneumatic controls have a significantly higher maintenance cost (on the order of 20%-40%).

Question 5, Support for the Proposed Requirements: All respondents support the proposed requirements.

Results

Recent research at the PG&E energy center has shown that standard DDC control and VAV boxes can stably control to the airflows (VAV box neck velocities) required in the deadband. The PG&E research compared four manufacturers controls on two different boxes. ASHRAE is currently conducting research to extend this to more controllers and VAV boxes. All combinations tested have been able to control down to 0.005" w.c. which corresponds to between 5% and 15% of design flow for typical box selections.

Energy and Cost Savings

The energy savings of this measure were estimated with a simulation model of a typical office building in all 16 California zones. The TDV cost savings are listed above in Table 1. According to the model, switching from a 30% minimum to a 20% minimum resulted in average total TDV energy cost savings of $0.69/sf. This savings is conservative as many boxes in the field have been found to be well above the code minimum of 30% as previously discussed.

Cost-effectiveness

Dual maximum control sequences are available from most DDC control system vendors at no additional cost relative to single maximum control sequences. Although a discharge air temperature sensor is recommended, no discharge air temperature sensor is required by the proposed language, the air valve and hot water reheat valves can be simultaneously controlled for heating. This requirement will add to the cost of balancing and startup as three airflows must now be measured instead of the traditional two for reheat boxes. The addition of a third measurement would conservatively be considered to add $100 to $200 to the cost of a zone. Using the higher number, the cost premium would be at most $0.50/sf for a typical 400 sf zone. This is well below the TDV savings of $0.69/sf.

Recommendations

Modify existing prescriptive requirement 144(d) to allow the dual maximum VAV box controls and to remove some of the existing exceptions that no longer are required. The rationale for the new "dual maximum" alternative to 144(d) is fully explained in the sections above. The rationale for the removal of the 0.4 CFM/sf exception and the 300 CFM exceptions is described below:

The 0.4 cfm/sf exception is deleted because it implies that a minimum air speed in the occupied space is required for comfort. ASHRAE Standard 55, however, indicates that no minimum air speed is required for comfort. Furthermore, 0.4 cfm/sf does not guarantee any particular air speed because 0.4 cfm/sf can be a small fraction (e.g. 10%) or a large fraction (e.g. 50%) of the design flow rate and thus can result in a low or high air speed.

The 300 cfm exception is deleted because the situation that it was intended to address has been largely eliminated by the new 50% exception described above. This criterion was intended to address the following applications: the occasional small zone in a VAV reheat system for which 30% is insufficient to handle heating loads, such as spaces with large north facing glass areas.

Proposed Standards Language

Section 144 (d)
Space-conditioning Zone Controls. Each space-conditioning zone shall have controls that prevent:
1. Reheating; and
2. Recooling; and
3. Simultaneous provisions of heating and cooling to the same zone, such as mixing or simultaneous supply of air that has been previously mechanically heated and air that has been previously cooled, either by cooling equipment or by economizer systems.

~~**EXCEPTION 1 to Section 144 (d):** Zones served by a variable air-volume system that is designed and controlled to reduce, to a minimum, the volume of reheated, recooled, or mixed air supply For each zone, this minimum volume shall be no greater than the largest of the following:~~

~~A. 30 percent of the peak supply volume; or~~
~~B. The minimum required to meet the ventilation requirements of Section 121; or~~
~~C. 0.4 cubic feet per minute (cfm) per square foot of conditioned floor area of the zone; or~~
~~D. 300 cfm.~~
EXCEPTION ~~2~~1 to Section 144 (d): Zones with special pressurization relationships or cross-contamination control needs.
EXCEPTION ~~3~~2 to Section 144 (d): Zones served by space-conditioning systems in which at least 75 percent of the energy for reheating, or providing warm air in mixing systems, is provided from a site-recovered or site-solar energy source.
EXCEPTION ~~4~~3 to Section 144 (d): Zones in which specific humidity levels are required to satisfy process needs.
EXCEPTION ~~5~~4 to Section 144 (d): Zones with a peak supply-air quantity of 300 cfm or less.

ALTERNATIVE to Section 144 (d): Zones served by variable air-volume systems that are designed and controlled to reduce, to a minimum, the volume of reheated, re-cooled, or mixed air supply are allowed only if the controls meet the following requirements:

A. For each zone with direct digital controls (DDC), the volumetric airflow at peak heating shall be no greater than the larger of:

1. Fifty percent of the peak supply airflow, or
2. The minimum required to meet the ventilation requirements of Section 121

B. For each zone with DDC, the minimum primary air airflow in the deadband shall be no greater than the larger of:

1. 20 percent of the peak supply airflow; or

2. The minimum required to meet the ventilation requirements of Section 121

C. For each zone without DDC, this minimum airflow shall be no greater than the larger of the following:

1. Thirty percent of the peak supply airflow; or

2. The minimum required to meet the ventilation requirements of Section 121

D. Airflow between deadband and full heating or full cooling must be modulated.

Alternate Calculation Manual

None

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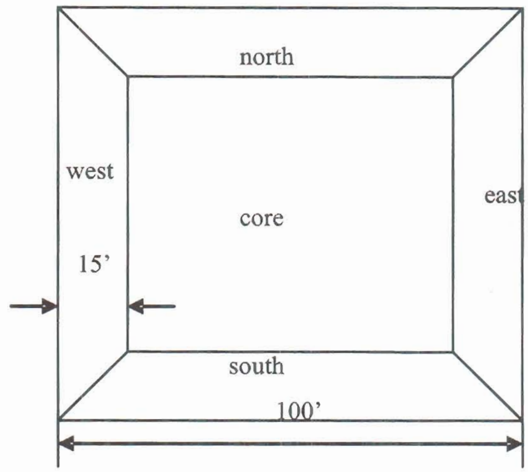
This analysis and report was produced by Jeff Stein, PE, Mark Hydeman, PE, FASHRAE and Anna Zhou of Taylor Engineering, LLC in Alameda California under contract to the Heschong Mahone Group.

Appendices

Appendix A. Modeling Assumptions and Results

A 10,000 sf five zone office building was modeled in eQuest to evaluate annual energy performance of the proposed control sequences. Figure 3 shows the layout and dimension of the zones in the eQuest model.

Figure 3 Zone Layout for eQuest Model

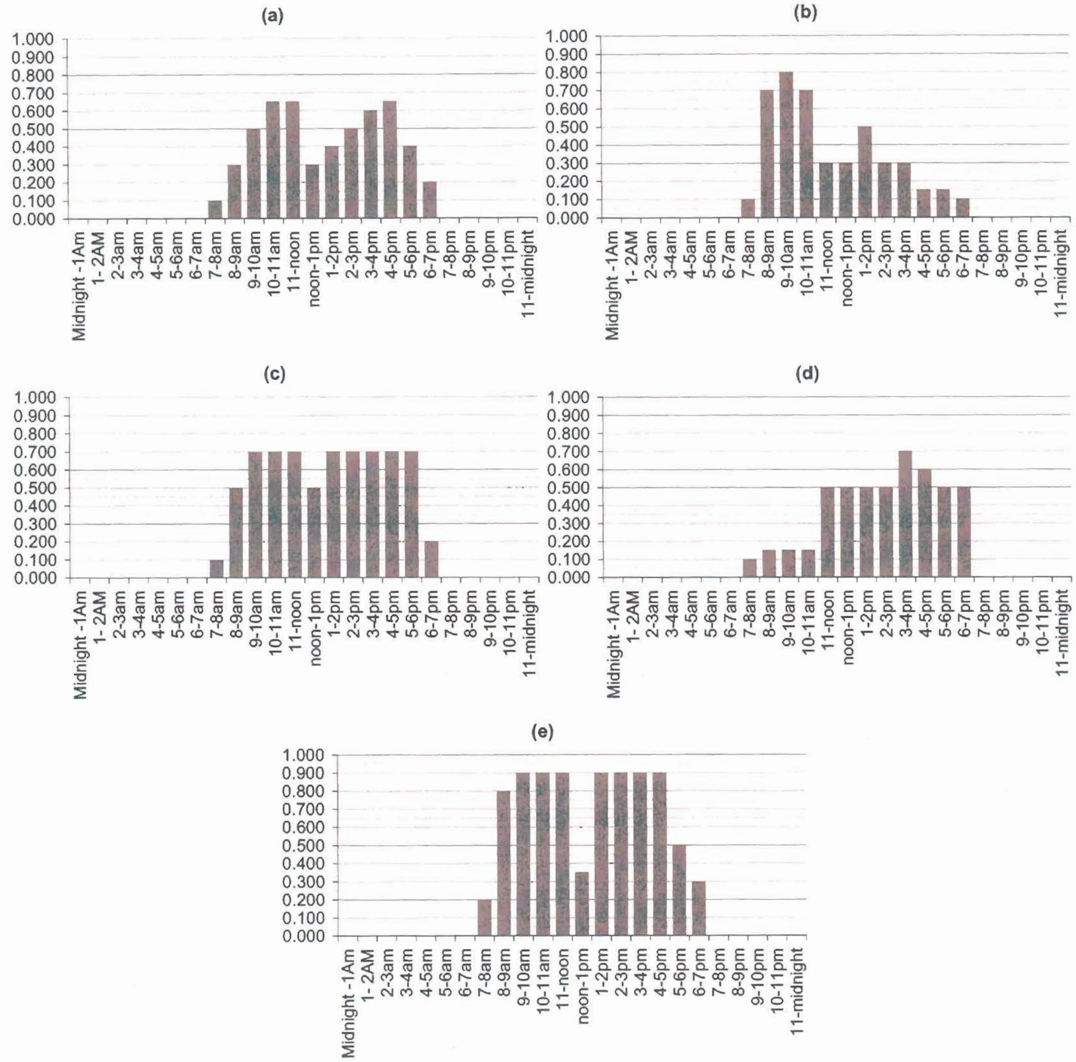


The building envelope consisted of R-19 metal frame roof and R-13 metal frame wall with 40% window wall ratio. All windows use double pane glazing. The U value of the glass is 0.47 and the SHGC value of the glass is 0.31 for non-north facing windows and 0.47 for north facing windows.

The building was modeled to be occupied from 7:00 am to 7:00 pm Monday through Friday and was closed on Saturday, Sunday and holidays. Building internal loads consist of an average 100 sf per person occupancy density, 1.3 w/sf lighting power densities and 1.5 w/sf equipment power density.

In order to simulate "real-life" building operation, five occupancy day schedules were modeled as shown in Figure 4. The simulation models were set up such that on any weekday, each of the five zones uses one of the schedules shown in Figure 4 and no two zones use the same schedule on the same day. From Monday to Friday, each zone uses a different day schedule on a different day. Lighting and equipment schedule are the same as the occupancy schedule.

Figure 4 Occupancy Schedules Used in eQuest Model



The building is conditioned by a packaged VAV system with hot water reheats at VAV boxes. Room temperature setpoint are 75/82 for cooling and 70/64 for heating during occupied/unoccupied hours. The HVAC system runs from one hour before occupancy to one hour after occupancy. System supply air temperature is fixed at 55°F in the basecase. A DOE-2 fan curve that represents static pressure reset was used for all runs.

The model was run using the weather data representing Sacramento, CA (climate zone 12) which is a relatively hot climate in California.

The detailed modeling assumptions for the basecase and the proposed control are shown in Table 5 and Figure 5 below.

Table 5 Basecase modeling assumptions

	Case #	Basecase	Dual max. with VAV heating
HVAC System	System Type	PVAVS	ditto
	Sizing Ratio	1	ditto
	Fan Control	VSD	ditto
	Air Flow	min Fan ratio = 0.1, max Fan ratio = 1.1	ditto
	Fan Eff	SA Fan 53%, RA Fan 53%	ditto
	Fan Performance Curve	Perfect fan curve	ditto
	Fan static pressure	3.5"	ditto
	OA ratio	Default (calc. from zone OA CFM)	ditto
	Economizer	differential drybulb, max temperature limit = 59	ditto
	Cooling EIR	0.36 (9.5 EER)	ditto
	Min SAT	55. °F	ditto
	Max Cooling SAT Reset Temp	59. °F	ditto
	Cooling SAT temp control	Constant	ditto
	Heating SAT temp control	Constant	ditto
	Heating Coil	No coil at packaged unit, only hot water reheating coil at each zone	ditto
	RH Coil Vavle	3-way valve	ditto
	Min Heating Reset Temp	75. °F	ditto
Zone (each)	Thermostat	Proportional	ReverseAction
	Throttling Range	.1 °F	ditto
	Cooling Min Flow Ratio	30%	20%
	Cooling Max Flow Ratio	100%	100%
	Heating Min Flow Ratio	30%	20%
	Heating Max Flow Ratio	30%	100%
	Cooling setpoint	75. °F	ditto
	Heating setpoint	70. °F	ditto
	Cooling setpoint unoccuppied	82. °F	ditto
	Heating setpoint unoccuppied	64. °F	ditto
Boiler Plant	Boiler HIR	1.25	ditto
	Design HWST	180 °F	ditto
	Design HW loop dT	40 °F	ditto
	HW loop pump control	one speed pump	ditto
Building Envelope	Exterior wall U value	R-13 (code)	ditto
	Roof U value	R-19 (code)	ditto
	WWR	40%	ditto
	Glass Type	U = 0.47, SHGC = 0.31 (nonnorth), 0.47 (north)	ditto
	Area	100 ft by 100 ft, 15 ft perimeter zone depth	ditto
Building Internal Load	Occpancy	100 sf/person	ditto
	Lighting	1.3 w/sf	ditto
	Equipment	1.5 w/sf	ditto
	Schedule	Occupied 7:00 ~19:00 M-F, Unoccupied other days	ditto

Figure 5 eQuest parametric run inputs

Component	Referenc...	Keyword	Array Idx	Baseline	DualMax...
Thermal ...	EL1 Core...	THERMO...	N/A	PROPORT...	REVERSE...
Thermal ...	EL1 Core...	HMIN-FL...	N/A		0.200
Thermal ...	EL1 Core...	CMIN-FL...	N/A		0.200
Thermal ...	EL1 Core...	MIN-FLO...	N/A	0.300	0.200
Thermal ...	EL1 Core...	MIN-CFM...	N/A	0.300	0.200
Thermal ...	EL1 Core...	HMIN-CF...	N/A		0.200
Thermal ...	EL1 Core...	CMIN-CF...	N/A		0.200
HVAC Sy...	Core Sys...	REHEAT-...	N/A	100.000	40.000

Appendix B - EMCS Market Share Survey

The authors did a literature search and surveyed the major EMCS vendors to determine the market share of EMCS vendors in the HVAC controls market nationwide. The results follow:

1. Johnson 16%-25%
2. Siemens 15%-17%
3. Trane 6%-15%
4. Honeywell 7%-10%
5. Alerton 5%-10%
6. Automated Logics 7%-10%
7. Andover 7%-10%
8. Invensys 7%
9. All others 10%-20%

Graphical data from one of the market research sources is presented in Figure 6 below.

Figure 6 – EMCS Market by Company in 2001 (BCS 2002)

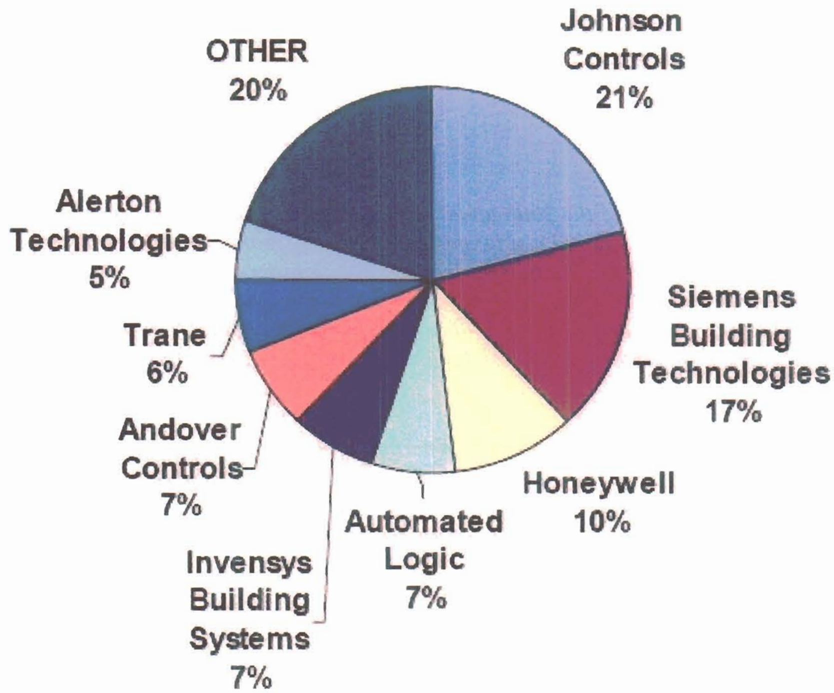
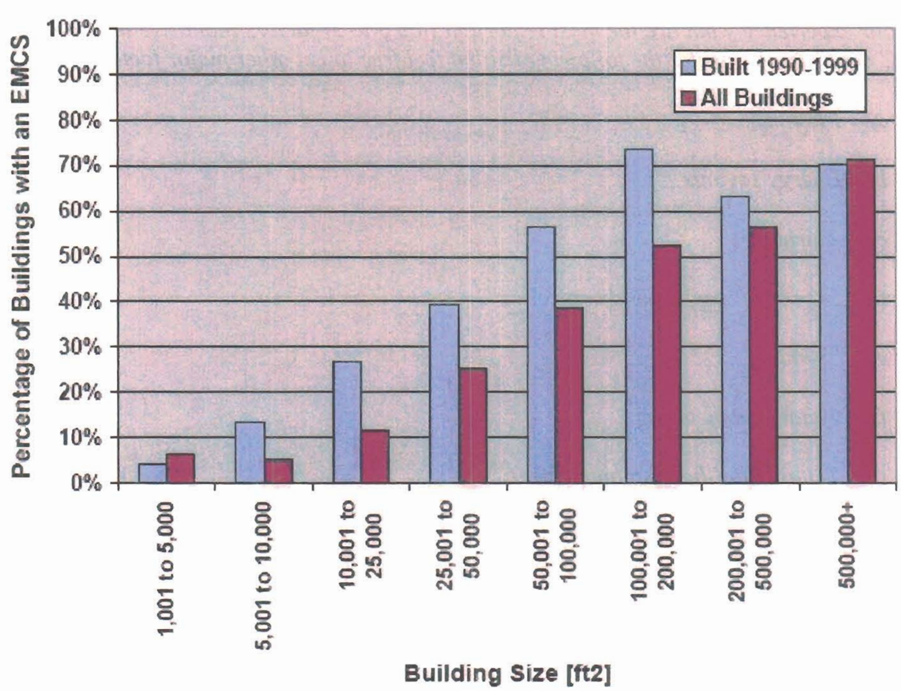


Figure 7 – Buildings with EMCS (EIA 1999)



Survey of EMCS Manufacturers on the Proposed Requirements

An email survey was sent to EMCS vendors to get their reaction to the proposed requirements. The survey was sent to Trane, Honeywell, Invensys, Alerton, Johnson, Automatic Logic Corporation and Siemens. At the time of this report, responses were received from Alerton, Automated Logic Corporation and Siemens. The survey that was sent follows:

Dear [Insert Name],

We are working on the development of the 2008 update of California's building energy code, Title 24. We are preparing for a workshop on July 13th and would appreciate your response by July 1st if possible. One of the issues we are researching relates to DDC controls. We are investigating a code change to specify control requirements on systems that have DDC to the zone level. In order to determine the feasibility of these ideas, we are surveying vendors and contractors for their opinions on the viability of these proposed measures and the make-up of the BMS market in California. To assist our deliberations, we would like you to answer the following questions:

1. *In your opinion, for new construction in commercial buildings what percentage of the controls marketplace (based on $ spent by owners) belongs to the following classes of control products:*

    a) *Fully DDC (including the zone controls)?*

    b) *Hybrid DDC and pneumatic systems?*

    c) *Fully pneumatic?*

    d) *Other (please elaborate)?*

    In considering your answer to this question exclude the single zone units that are controlled by programmable thermostats

2. *In your experience what are the most important (top 3 to 5) factors that drive a customer to purchase DDC controls? Consider the following list but feel free to list other major factors:*

    a) *First cost*

    b) *Energy savings*

    c) *Alarming*

    d) *Improved comfort and control*

    e) *Trending*

    f) *Tenant submetering*

    g) *Tenant after hours management*

    h) *Facility management*

    i) *Web based access*

    j) *Other factors (please list)*

3. *What are the relative installed costs of DDC and pneumatic systems for typical office and retail buildings?*

    a) *On a $/sf basis (or relative % cost basis) if you have the data*

    b) *Qualitatively, are they about the same or is one significantly more expensive?*

4. *Do you have any data on comparative maintenance costs for DDC and pneumatic systems?*

5. *Would you support a code change requiring DDC controls to the zone level for new control systems serving multiple zone systems and equipment?*

    a) *What are some questions or concerns you might have about such a code change?*

    b) *Are there systems or applications where this would not be appropriate?*

6. *The following are specific control requirements that we are considering. Please provide feedback (positive or negative about each). For each control requirement please address the following issues:*

    - *whether your existing systems (hardware and software) will be able to support these requirements*
    - *what exceptions should be included*
    - *the added effort to program and tune these control algorithms*

    Here are the proposed new control requirements

    a) *Hydronic pump pressure reset by demand (either directly by valve demand or through a " trim and respond " algorithm)*

    b) *Ability to globally reset cooling set points on zone thermostats on " non critical " zones by 1 to 4°F for central demand shed.*

    c) *Supply air temperature reset on VAV systems that is only enabled when the system is on 100% economizer cooling*

    d) *Demand controlled ventilation for multiple zone units serving one or more densely occupied zones. The control logic is likely to cascade with the first step controlling the zone box minimum and the second step controlling the minimum OSA damper position.*

Please contact us if you need any clarifications on the above questions. We thank you in advance for your time and we welcome your comments and feedback.

CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

2008 California Energy Commission Title 24 Building Energy Efficiency Standards
February 11, 2007

February 27th, 2007 Workshop Report DDC to the Zone Level Measure 2: Demand Shed Controls

Prepared by: Mark Hydeman, PE Principal of Taylor Engineering, LLC, Alameda CA

http://www.taylor-engineering.com

This report was prepared by Pacific Gas and Electric Company and funded by the California utility customers under the auspices of the California Public Utilities Commission.

February 11, 2007

Table of Contents

Document information

Category: Codes and Standards

Keywords: PG&E CASE, Codes and Standards Enhancements, Title 24, nonresidential, 2008, efficiency

Overview

Description

Overview

This CASE report addresses one of five separate measures that extend the control requirements of the standard. All five of these requirements are possible at a very small cost if the installed control system is direct-digital control (DDC) to the zone level. This initiative does not seek to require installation of DDC to the zone level, rather it extends the current philosophy of the prescriptive requirements such as supply static pressure reset (Section 144(c)2D) that state a functional requirement of the control system if it is designed for DDC to the zone level.

The five measures covered by this proposal are as follows:

1. Modification of the existing prescriptive measure 144(d) (Space-conditioning Zone Controls) to allow for "dual maximum" control of VAV boxes

2. A new mandatory measure for global demand shed controls that can automatically reset the temperature set-points of all non-critical zones by 1 to 4°F from a single central command in the building energy management and control system (EMCS).

3. Modification of the existing prescriptive measure 144(j)6 (Hydronic System Measures: Variable Speed Drives) to require demand based reset of the pressure setpoint for pumps serving variable flow systems based on valve demand. This measure is the hydronic analog of the existing prescriptive measure for supply air pressure reset in (Section 144(c)2D).

4. Modification of the existing mandatory demand controlled ventilation (DCV) requirements 121(c)3 (Required Demand Control Ventilation) to include high occupant density zones served by multiple zone systems.

5. Modification of the existing prescriptive measure 144(f) (Supply Air Temperature Reset Controls) for demand based supply air temperature reset for variable air volume (VAV) systems that operate when the system is on 100% free cooling from the air-side economizer.

As each of these measures is simply a matter of programming, the cost for implementing them is quite low. However, as described below each of these measures has a significant potential for energy and demand savings.

Global Demand Shed Controls

This specific report covers the global demand shed controls. This measure requires that systems with DDC controls to the zone be preprogrammed to do centralized demand shed of "non-critical" zones from a central signal (either a DDC digital contact or a gateway point.

Energy Benefits

A number of recent studies have shown that between 1 to 2.4 W/sf of peak demand can be shed by simply globally resetting setpoints of thermostats in non-critical zones in commercial buildings[i]. If implemented properly, the building's mass can float the impact of a 1°F to 4°F change in space temperature setpoint throughout the utility's on-peak period. Furthermore recent changes in ASHRAE Standard 55-2004 allow for this drift if the rate of change is controlled following rates set out in Table 5.2.5.2 (see Table 1).

Table 1 – Table 5.2.5.2 from ASHRAE Standard 55-2004					
Time Period	1/4 h	1/2 h	1 h	2 h	4 h
Maximum Operative Temperature Change Allowed	2.0°F	3.0°F	4.0°F	5.0°F	6.0°F

Non Energy Impacts

An override of setpoint can have several potential negative impacts: decrease in thermal occupant comfort and potential loss of control for process zones. The first issue, thermal comfort, is addressed in the ASHRAE Standard 55-2004 rate of change limits presented in Table 1 above. As written this measure requires that the system be programmed to maintain an adjustable rate of change on the setpoint. Having this capability in the system will allow the facility operators to adjust the rate of change to maintain occupant comfort or the current ASHRAE Standard 55 recommendations. Note this is consistent with the tradition that the Standard only mandates control capabilities and not operating setpoints (see for example the Section 122(b) requirements for thermostatic setpoint and dead band control).

The second issue, loss of control on process zones, is addressed by the exclusion of "critical zones" from the reset. A new definition for "critical zones" is part of this proposal.

Environmental Impact

This measure has no adverse environmental impacts.

Type of Change

This measure is proposed as a new mandatory requirement. It applies to new construction or retrofits of existing control systems with DDC systems to the zone level. The changes to the Title 24 documents are summarized in the following paragraphs. The complete proposed changes with underlines and strikeouts are in the section Proposed Standard Language below:

Standards

- Add a new mandatory requirement for Automatic Demand Shed Controls in Section 122(h)
- Add a new mandatory requirement for Automatic Demand Shed Control system acceptance in 125(a)
- Create a new acceptance test, NA7.5.10 Automatic Demand Shed Control Acceptance.

Technology Measures

This measure only applies to systems with DDC to the zone level. As presented in our industry survey below, this represents between 90% to 95% of the new construction market.

Measure Availability and Cost

EMCS systems with DDC to the zone level are prevalent in the current building market. Our experience and surveys of the major EMCS vendors indicate that all of the major vendors are capable of meeting these proposed requirements. At least two of the major manufacturers (Alerton and ALC) currently offer this capability as a standard feature of their systems. For all of the manufacturers once programmed this capability can easily be incorporated into their precanned programs for distribution to their licensed contractors. Data on the major market players and the surveys are presented below.

Useful Life, Persistence and Maintenance

This measure will be tested through the Title 24 acceptance testing requirements. These proposed control sequences (like all controls) will need to be reviewed as part of the routine maintenance of the EMCS.

Performance Verification

As documented below a new acceptance requirement will be added to test this proposed requirement.

Analysis Tools

This measure can easily be evaluated using either eQuest or EnergyPro through the manipulation of the standard schedules. As a mandatory requirement no modeling is required for the Performance method.

Relationship to Other Measures

This measure is related to the proposals for programmable communicating thermostats (PCT, SCE) and global temperature adjustment (GTA, LBNL). Both of these proposals are referenced in the reference section. This measure works hand in hand with the PCT proposal in that it extends the benefits to both multiple zone equipment and single zone equipment with DDC controls.

Methodology

Demand Savings

The potential demand savings from this measure have been amply documented in the existing literature (see References). No additional research has been performed in support of this measure.

Survey of the EMCS Vendors

The authors conducted an email survey of the major EMCS vendors (Siemens, Invensys, Johnson, Honeywell, Alerton, Automated Logic Corporation and Trane) in June of 2006. Of these seven companies, only three responded (Siemens, Alerton and Automated Logic Corporation). The authors subsequently sent the five draft proposals from the CEC July 13th workshop to the list server for ASHRAE Technical Committee 1.4 "Control Theory and Application." This list server includes all members, corresponding members and interested parties to TC 1.4. In addition Mark Hydeman addressed the ASHRAE TC 1.4 committee on these proposals at their meeting in Dallas on January 30th, 2007 and requested feedback for the upcoming February 2007 CEC workshop To date not a single negative comment on any of these proposals has been received from any of the control manufacturers.

The survey is presented in Appendix A of this report. A summary of the survey results follow:

Question 1, EMCS market place: All three respondents indicated that DDC to the zone level was between 90% to 95% of the new construction market.

Question 2, Top Factors for DDC Purchases:

- Facility Management - 3 Votes

- Improved Comfort and Controls – 3 Votes
- Tenant After Hours Management – 2 Votes
- Alarming – 2 Votes
- Energy Savings – 2 Votes
- First Cost – 2 Votes
- Web Based Access – 1 Vote

Question 3, Relative First Cost of DDC and Pneumatic Controls: The consensus of the respondents is that pneumatic controls generally have a slightly smaller first cost. This cost depends on the number of points in the system as the pneumatic control system incurs a large first cost penalty for the compressor and associated equipment (like air dryers and filters). For small control systems DDC is actually less expensive. For medium and large control systems DDC is likely to be a slight cost premium.

Question 4, Relative Maintenance Cost of DDC and Pneumatic Controls: The consensus of the respondents is that pneumatic controls have a significantly higher maintenance cost (on the order of 20%-40%).

Question 5, Support for the Proposed Requirements: All respondents support the proposed requirements.

Results

Cost Effectiveness

As documented in the PCT PIER report, the present value per kW of demand shed is approximately $1,900. From the PIER/LBNL studies between 1 to 2.4 W/sf of peak demand can be shed in a typical building using global temperature reset. Using the value of 1 W/sf this yields $1.9 /sf of present value savings for this measure. This far exceeds the few hours of programming time it would take to program and test a system.

Statewide Energy Savings

The statewide energy benefits are also documented in the PCT PIER report.

Recommendations

Proposed Standards Language

New Definition for Critical Zone

Critical Zones are zones serving a process where reset of the zone temperature setpoint during a demand shed event might disrupt the process. Examples include data centers, telecom/PBX rooms and laboratories.

New Mandatory Control Requirement 122(h)

(h) Automatic Demand Shed Controls. HVAC systems with DDC to the Zone level shall be programmed to allow centralized demand shed for non-critical zones as follows:

1. The controls shall remotely setup the operating cooling temperature set points by four degrees or more in all non critical zones on signal from a centralized contact or software point.

2. The controls shall remotely setdown the operating heating temperature set points by four degrees or more in all non critical zones on signal from a centralized contact or software point.

3. The controls shall have capabilities to remotely reset the temperatures in all non critical zones to original operating levels on signal from a centralized contact or software point.

4. The controls shall be programmed to provide an adjustable rate of change for the temperature setup and reset.

New Acceptance Requirement in 125(a)10

SECTION 125 – REQUIRED NONRESIDENTIAL MECHANICAL SYSTEM ACCEPTANCE

(a) Before an occupancy permit is granted the following equipment and systems shall be certified as meeting the Acceptance Requirements for Code Compliance, as specified by the Reference Nonresidential Appendix NRA7. A Certificate of Acceptance shall be submitted to the building department that certifies that the equipment and systems meet the acceptance requirements:

...

10. Automatic demand shed controls shall be tested in accordance with NA7.5.10

New NA7 Acceptance Requirement

NA7.5.10 Automatic Demand Shed Control Acceptance

NA7.5.10.1 Construction Inspection

Prior to Acceptance Testing, verify and document the following:

- That the EMCS interface provides a central demand shed interface.

NA7.5.10.2 Functional Testing

Step 1: Engage the global demand shed system. Verify and document the following:

- That the cooling setpoint in non-critical spaces increases by the proper amount.
- That the cooling setpoint in critical spaces do not change.

Step 2: Disengage the global demand shed system. Verify and document the following:

- That the cooling setpoint in non-critical spaces return to their original values.
- That the cooling setpoint in critical spaces do not change.

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The Pacific Gas and Electric Company sponsored this report as part of its CASE (Codes and Standards Enhancement) project. Steve Blanc of PG&E was the project manager for this nonresidential CASE project. Pat Eilert is the program manager for the CASE program. The Heschong Mahone Group is the prime contractor and provided coordination of the nonresidential CASE reports.

This analysis and report was produced by Mark Hydeman of Taylor Engineering, LLC, Alameda, California under contract to the Heschong Mahone Group.

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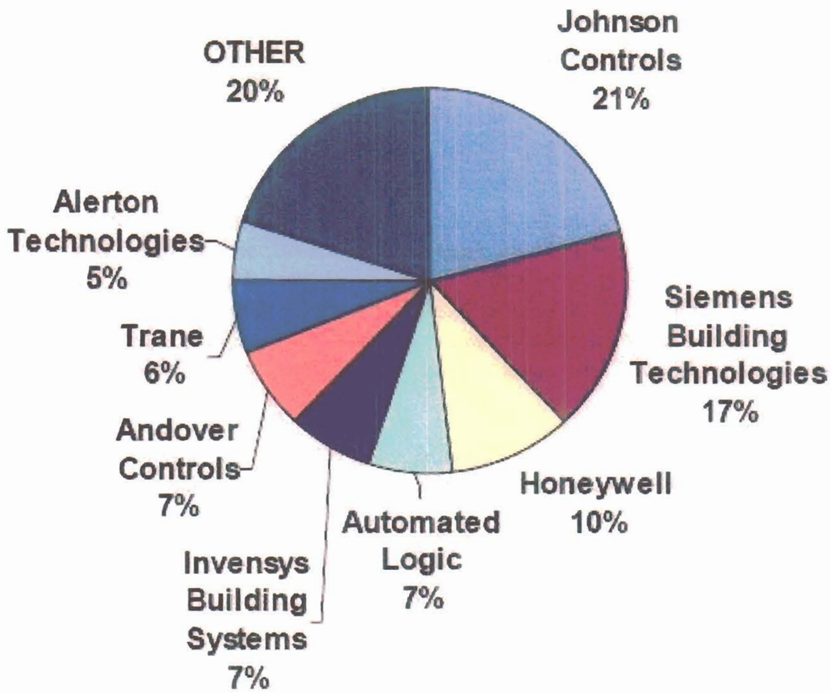
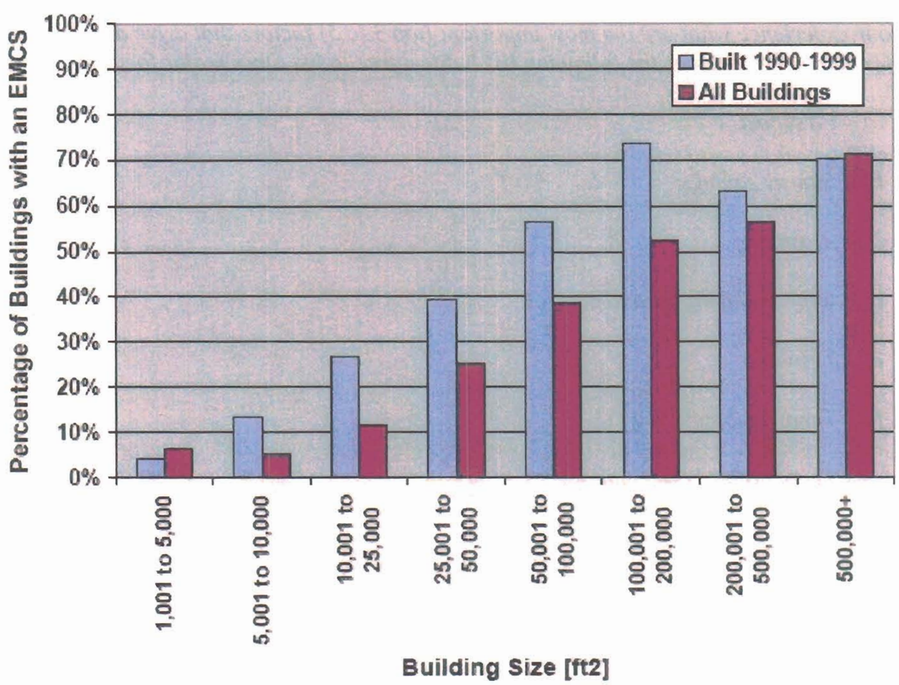


Figure 2 – Buildings with EMCS (EIA 1999)



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Dear [Insert Name],

We are working on the development of the 2008 update of California's building energy code, Title 24. We are preparing for a workshop on July 13th and would appreciate your response by July 1st if possible. One of the issues we are researching relates to DDC controls. We are investigating a code change to specify control requirements on systems that have DDC to the zone level. In order to determine the feasibility of these ideas, we are surveying vendors and contractors for their opinions on the viability of these proposed measures and the make-up of the BMS market in California. To assist our deliberations, we would like you to answer the following questions:

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    b) *Hybrid DDC and pneumatic systems?*

    c) *Fully pneumatic?*

    d) *Other (please elaborate)?*

    In considering your answer to this question exclude the single zone units that are controlled by programmable thermostats

2. *In your experience what are the most important (top 3 to 5) factors that drive a customer to purchase DDC controls? Consider the following list but feel free to list other major factors:*

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    g) *Tenant after hours management*

    h) *Facility management*

    i) *Web based access*

    j) *Other factors (please list)*

3. *What are the relative installed costs of DDC and pneumatic systems for typical office and retail buildings?*

    a) *On a $/sf basis (or relative % cost basis) if you have the data*

    b) *Qualitatively, are they about the same or is one significantly more expensive?*

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    c) *Supply air temperature reset on VAV systems that is only enabled when the system is on 100% economizer cooling*

    d) *Demand controlled ventilation for multiple zone units serving one or more densely occupied zones. The control logic is likely to cascade with the first step controlling the zone box minimum and the second step controlling the minimum OSA damper position.*

Please contact us if you need any clarifications on the above questions. We thank you in advance for your time and we welcome your comments and feedback.

---

[i] See for instance the papers posted on the website, http://drrc.lbl.gov/drrc-pubs3abs.html#58815. Also the presentation in the Feburary 2006 Title 24 2008 workshop by David Watson (see link under references).

CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

2008 California Energy Commission Title 24 Building Energy Efficiency Standards
February 12, 2007

July 13th, 2006 Workshop Report DDC to the Zone Level Measure 3: Hydronic Pressure Reset

Prepared by: Mark Hydeman, PE, FASHRAE Principal
Jeff Stein, PE, Senior Engineer
Anna Zhou, Mechanical Designer
of Taylor Engineering, LLC, Alameda CA

http://www.taylor-engineering.com

This report was prepared by Pacific Gas and Electric Company and funded by the California utility customers under the auspices of the California Public Utilities Commission.

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Overview

Description

This CASE report addresses one of five separate measures that extend the control requirements of the standard. All five of these requirements are possible at a very small cost if the installed control system is direct-digital control (DDC) to the zone level. This initiative does not seek to require installation of DDC to the zone level, rather it extends the current philosophy of the prescriptive requirements such as supply static pressure reset (Section 144(c)2D) that state a functional requirement of the control system if it is designed for DDC to the zone level.

The five measures covered by this proposal are as follows:

1. Modification of the existing prescriptive measure 144(d) (Space-conditioning Zone Controls) to allow for "dual maximum" control of VAV boxes
2. A new mandatory measure for global demand shed controls that can automatically reset the temperature set-points of all non-critical zones by 1 to 4°F from a single central command in the building energy management and control system (EMCS).
3. Modification of the existing prescriptive measure 144(j)6 (Hydronic System Measures: Variable Speed Drives) to require demand based reset of the pressure setpoint for pumps serving variable flow systems based on valve demand. This measure is the hydronic analog of the existing prescriptive measure for supply air pressure reset in (Section 144(c)2D).
4. Modification of the existing mandatory demand controlled ventilation (DCV) requirements 121(c)3 (Required Demand Control Ventilation) to include high occupant density zones served by multiple zone systems.
5. Modification of the existing prescriptive measure 144(f) (Supply Air Temperature Reset Controls) for demand based supply air temperature reset for variable air volume (VAV) systems that operate when the system is on 100% free cooling from the air-side economizer.

As each of these measures is simply a matter of programming, the cost for implementing them is quite low. However, as described below each of these measures has a significant potential for energy and demand savings.

Hydronic Pressure Reset

This specific report covers the hydronic pressure reset controls. This measure requires that variable flow hydronic systems with DDC controls to the valve level be preprogrammed to do supply pressure reset based on valve demand. It is analogous to the existing prescriptive measure for supply air pressure reset in (Section 144(c)2D).

Energy Benefits

The results of our simulations of a 100,000 sf building in the 16 California climate zones are shown in Table 1 below. These simulations are described in detail in Appendix A of this document. The estimated weighted average energy savings (on a per unit area basis) are as follows:

- Peak demand reduction of 0.0005 kW/ sf
- Annual electrical energy savings of 0.11 kWh/sf/yr
- No annual gas savings

- TDV savings of $0.24/sf

The weighting factors used in the weighted average come from the F. W. Dodge projection of new construction areas by climate and occupancy (presented in Table 2 below).

Table 1- Projected Annual Energy and TDV Cost Savings for This Measure

Climate Zone	Electrical Energy Savings [kWh/yr]	Electrical Peak Demand Reduction [kW]	TDV Electrical Cost Savings [$]	Natural Gas Energy Savings [Therms/yr]	TDV Gas Cost Savings [$]	TDV Total Cost Savings [$]	TDV Total Cost Savings Normalized [$/sf]
CZ01	9,300	4.4	$19,000	0	$0	$19,000	0.19
CZ02	10,400	4.7	$21,000	0	$0	$21,000	0.21
CZ03	10,300	4.7	$21,000	0	$0	$21,000	0.21
CZ04	10,800	4.7	$22,000	0	$0	$22,000	0.22
CZ05	10,600	4.8	$21,000	0	$0	$21,000	0.21
CZ06	11,400	5.0	$25,000	0	$0	$25,000	0.25
CZ07	11,000	4.8	$21,000	0	$0	$21,000	0.21
CZ08	11,000	4.7	$24,000	0	$0	$24,000	0.24
CZ09	12,300	5.3	$27,000	0	$0	$27,000	0.27
CZ10	11,200	4.9	$25,000	0	$0	$25,000	0.25
CZ11	11,400	5.0	$23,000	0	$0	$23,000	0.23
CZ12	11,400	4.9	$23,000	0	$0	$23,000	0.23
CZ13	12,800	5.4	$25,000	0	$0	$25,000	0.25
CZ14	11,100	4.8	$25,000	0	$0	$25,000	0.25
CZ15	12,400	5.5	$27,000	0	$0	$27,000	0.27
CZ16	9,800	4.6	$20,000	0	$0	$20,000	0.20
Minimum	9,300	4.4	$19,000	0	$0	$19,000	0.19
Maximum	12,800	5.5	$27,000	0	$0	$27,000	0.27
Wtd Avg	11,200	4.9	$24,000	0	$0	$24,000	0.24

Non-energy Benefits

In practice hydraulic demand based pressure reset has a number of non-energy benefits that include:

- Reduction of acoustical noise both at the coils and at the pump.
- Improved controllability of the coil valves as the operating pressure is reduced across them.
- Reduction of valve leakage due to over pressurization. This can improve space comfort conditions.
- Reduced maintenance and increased life for the pump motor, pump seals, valve actuators and valve seals.

Statewide Energy Impacts

Using the F. W. Dodge Nonresidential New Construction data (averaged from 2000 to 2003), the projected statewide construction in thousands of sf by climate zone are shown in Table 2. The projected statewide energy impacts of this measure are calculated and listed in Table 3 (based on the assumption that 15% of the commercial new construction is served by variable flow hydronic systems). CBECs and CEUS data have shown that although ~ 80% of the systems installed are packaged single zone units, multiple zone systems account for approximately 50% of the conditioned floor area.

The detailed analysis found that the first year's implementation of the proposed requirements would reduce electricity energy consumption by 2.7 GWh per year, reduce electrical demand coincident with utility system peak by 1.2 Megawatts, and make no change on the natural gas consumption. The TDV energy cost savings is estimated at $5.7 Million accrued over the life of these building systems (15 years).

Table 2 Average Annual Nonresidential New Construction Area by California Climate Zone from F. W. Dodge (2000 to 2003)

CTZ	AMUSEMENT	ASSEMBLY	EDUCATION	GOVT	HOTEL	MEDICAL	OFFICE	RETAIL	SCHOOL	SERVICE	STORAGE	OTHER	TOTAL
1	20	0	10	10	30	20	80	40	50	10	30	20	[illegible]
2	90	20	20	80	180	120	420	240	240	50	260	200	1,[illegible]
3	850	100	150	180	1,000	330	5,000	1,870	1,110	3,080	1,030	450	15,[illegible]
4	360	80	280	50	380	450	3,370	1,070	1,160	2,660	500	500	10,[illegible]
5	140	30	0	20	150	80	360	240	250	240	430	170	2,[illegible]
6	400	160	70	150	570	600	1,700	1,820	910	1,750	2,400	350	10,[illegible]
7	160	50	70	30	530	170	1,110	740	520	940	640	80	5,[illegible]
8	580	250	110	220	810	960	2,500	2,710	1,440	3,010	3,760	460	16,[illegible]
9	310	110	110	160	250	780	1,440	1,780	920	1,830	2,490	430	10,[illegible]
10	590	190	100	280	650	350	1,820	2,910	1,960	1,200	8,640	500	19,[illegible]
11	220	150	0	50	140	220	870	1,140	380	210	450	300	4,[illegible]
12	580	360	40	200	800	560	4,130	3,810	2,500	2,440	4,170	1,210	20,[illegible]
13	470	130	50	330	70	570	440	1,160	660	330	1,660	450	6,[illegible]
14	540	190	170	420	620	910	2,300	2,910	1,900	2,830	7,100	640	20,[illegible]
15	270	100	80	110	630	250	1,420	1,370	950	1,120	2,820	300	9,[illegible]
16	180	70	20	230	110	170	440	590	370	270	1,120	170	3,[illegible]
Totals	**5,800**	**2,000**	**1,300**	**2,500**	**6,900**	**6,500**	**27,400**	**24,400**	**15,300**	**22,000**	**37,500**	**6,200**	**158,[illegible]**

Table 3 Statewide TDV cost savings and emission reductions

Climate Zone	Electrical Energy Savings [kWh/yr]	Electrical Peak Demand Reduction (kW)	Natural Gas Savings [Therms/yr]	TDV Cost Savings [$]	Nox [lbs/yr]	CO2 [lbs/yr]	CO [lbs/yr]	PM10 [lbs/yr]
CZ01	4,000	2	-	**$9,000**	**2**	**5,000**	**1**	**0**
CZ02	30,000	14	-	**$60,000**	**12**	**40,000**	**7**	**2**
CZ03	240,000	107	-	**$480,000**	**90**	**280,000**	**54**	**14**
CZ04	180,000	76	-	**$360,000**	**67**	**210,000**	**40**	**11**
CZ05	30,000	15	-	**$70,000**	**13**	**40,000**	**8**	**2**
CZ06	190,000	82	-	**$410,000**	**71**	**220,000**	**43**	**11**
CZ07	80,000	36	-	**$160,000**	**32**	**100,000**	**19**	**5**
CZ08	280,000	118	-	**$610,000**	**106**	**330,000**	**64**	**17**
CZ09	200,000	85	-	**$430,000**	**75**	**240,000**	**45**	**12**
CZ10	320,000	140	-	**$720,000**	**123**	**390,000**	**74**	**19**
CZ11	70,000	31	-	**$140,000**	**27**	**90,000**	**16**	**4**
CZ12	350,000	153	-	**$720,000**	**136**	**420,000**	**81**	**21**
CZ13	120,000	51	-	**$240,000**	**46**	**150,000**	**28**	**7**
CZ14	340,000	148	-	**$770,000**	**131**	**410,000**	**78**	**20**
CZ15	170,000	78	-	**$380,000**	**67**	**210,000**	**40**	**10**
CZ16	60,000	26	-	**$110,000**	**21**	**70,000**	**13**	**3**
Total	2,700,000	1,163	-	$5,700,000	1,000	3,200,000	610	160

Environmental Impact

As shown in Table 3 above, this measure is estimated to annually reduce emissions by approximately 20 thousand pounds of NOx, 100 million pounds of CO2, 10 thousands pounds of CO and 3 thousand pounds of PM10.

Table 4 presents the emission factors for calculating reduced emissions based on reduction in energy usage.

Table 4 Emmision factors for Calculating Reduced Emmisions from Energy Savings (CEC 2003)

Emissions Factors for Calculating Reduced Emissions from Energy Savings				
Emissions factors	**NOx**	**CO**	**CO2**	**PM10**
Natural Gas, California (lbs/MMBtu)	0.094	0.03	115	0.01
Electricity, Western States (lbs/MWh)	0.383	0.23	1200	0.06

Type of Change

This measure is proposed as a modification of an existing prescriptive requirement. It applies to either new construction or retrofit where the coils and pump have DDC controls. The changes to the Title 24 documents are summarized in the following paragraphs. The complete proposed changes with underlines and strikeouts are in the section Proposed Standard Language below:

Standards

- Revise existing prescriptive requirement 144(j)6
- No change is required for 125 (d) Hydronic System Controls Acceptance.
- Revise the acceptance test for Hydronic System Variable Flow Controls to ensure that the setpoint is being reset.

ACM

- Modify the Standard Design Systems 4 and 5 to have pressure reset by demand

Technology Measures

This measure only applies to systems with DDC to the zone level. As presented in our industry survey below, this represents between 90% to 95% of the new construction market.

Measure Availability and Cost

EMCS systems with DDC to the zone level are prevalent in the current building market. Our experience and surveys of the major EMCS vendors indicate that all of the major vendors are capable of meeting these proposed requirements. Data on the major market players and the surveys are presented below.

Useful Life, Persistence and Maintenance

This measure will be tested through the Title 24 acceptance testing requirements. These proposed control sequences (like all controls) will need to be reviewed and the sensors recalibrated as part of the routine maintenance of the EMCS. For this requirement, the sensor calibration is part of both the base case and proposed requirements.

Performance Verification

As documented below the existing Title 24 acceptance requirements will be slightly modified to test this proposed requirement.

Analysis Tools

This measure can easily be evaluated using either eQuest or EnergyPro.

Relationship to Other Measures

This measure is an enhancement of the existing hydronic prescriptive measures in 144(j).

Methodology

Energy Model

This measure was evaluated using the eQuest program. The model was based on a simulation of a 100,000 ft2 office buildings served by a central plant. This model was run in all 16 of the California Climate zones. The TDV energy cost savings are presented in Table 1 above.

Survey of the EMCS Vendors

The authors conducted an email survey of the major EMCS vendors (Siemens, Invensys, Johnson, Honeywell, Alerton, Automated Logic Corporation and Trane) in June of 2006. Of these seven companies, only three responded (Siemens, Alerton and Automated Logic Corporation). The authors subsequently sent the five draft proposals from the CEC July 13th workshop to the list server for ASHRAE Technical Committee 1.4 "Control Theory and Application." This list server includes all members, corresponding members and interested parties to TC 1.4. In addition Mark Hydeman addressed the ASHRAE TC 1.4 committee on these proposals at their meeting in Dallas on January 30th, 2007 and requested feedback for the upcoming February 2007 CEC workshop To date not a single negative comment on any of these proposals has been received from any of the control manufacturers.

The survey is presented in Appendix B of this report. A summary of the survey results follow:

Question 1, EMCS market place: All three respondents indicated that DDC to the zone level was between 90% to 95% of the new construction market.

Question 2, Top Factors for DDC Purchases:

- Facility Management - 3 Votes
- Improved Comfort and Controls – 3 Votes
- Tenant After Hours Management – 2 Votes
- Alarming – 2 Votes
- Energy Savings – 2 Votes
- First Cost – 2 Votes

- Web Based Access – 1 Vote

Question 3, Relative First Cost of DDC and Pneumatic Controls: The consensus of the respondents is that pneumatic controls generally have a slightly smaller first cost. This cost depends on the number of points in the system as the pneumatic control system incurs a large first cost penalty for the compressor and associated equipment (like air dryers and filters). For small control systems DDC is actually less expensive. For medium and large control systems DDC is likely to be a slight cost premium.

Question 4, Relative Maintenance Cost of DDC and Pneumatic Controls: The consensus of the respondents is that pneumatic controls have a significantly higher maintenance cost (on the order of 20%-40%).

Question 5, Support for the Proposed Requirements: **All** respondents support the proposed requirements.

Results

The results of our investigations indicate that this measure is both cost effective and would be supported by the industry. The results of our simulation indicate an average TDV cost savings of $0.24/ft2. The programming of this measure is 4 to 8 hours (depending on the system size) representing an installed cost of $400 to $800. Using a conservative estimate of $800 for the installed costs this measure becomes cost effective on all buildings over 3,300 ft2. If adopted this measure would likely only be applied to buildings of 30,000 ft2 or larger (above 100 tons at a conservative 300 sf/ton).

Recommendations

Proposed Standards Language

Modification of Existing Prescriptive Requirement 144(j)6

A. 144(j)6. **Variable Speed Drives.** Individual pumps serving variable flow systems and having a motor horsepower exceeding 5 hp shall have controls and/or devices (such as variable speed control) that will result in pump motor demand of no more than 30% of design wattage at 50% of design water flow. The ~~controls or devices~~pumps shall be controlled as a function of desired flow or to maintain a minimum required differential pressure.

B. Pressure Sensor Location and Setpoint.

i. For systems without direct digital control of individual coils reporting to the central control panel, differential pressure shall be measured at or near the most remote heat exchanger or the heat exchanger requiring the greatest differential pressure.

ii. Systems with direct digital control of individual coils reporting to the central control panel, the static pressure set point shall be reset, based on the valve requiring the most pressure, to a lower static pressure until one control valve is fully open. The pressure sensor(s) may be mounted anywhere.

EXCEPTION 1 to Section 144 (j) 6: Heating hot water systems.

EXCEPTION 2 to Section 144 (j) 6: Condenser water systems serving only water-cooled chillers.

Alternate Calculation Manual

2.5.2.4 Standard Design Systems

2.5.2.4 Standard Design Systems

…

Table N2-13 System #4 Description

System Description: Chilled Water VAV With Reheat

…

Chilled Water Pumping System: Variable flow (2-way valves) with a VSD on the pump if three or more fan coils or air handlers. Constant volume flow with water temperature reset control if less than three fan coils or air handlers. Reset supply pressure by demand if proposed system has DDC controls.

…

Hot Water Pumping System: Variable flow (2-way valves) riding the pump curve if three or more fan coils or air handlers. Constant volume flow with water temperature reset control if less than three fan coils or air handlers. Reset supply pressure by demand if proposed system has DDC controls.

…

Table N2-14 System #5 Description

System Description: Four-Pipe Fan Coil With Central Plant

…

Chilled Water Pumping System: Variable flow (2-way valves) with a VSD on the pump if three or more fan coils or air handlers. Constant volume flow with water temperature reset control if less than three fan coils. Reset supply pressure by demand if proposed system has DDC controls.

…

Hot Water Pumping System: Variable flow (2-way valves) riding the pump curve if three or more fan coils or air handlers. Constant volume flow with water temperature reset control if less than three fan coils. Reset supply pressure by demand if proposed system has DDC controls.

NA 7.5.9 Hydronic System Variable Flow~~Frequency Drive~~ Controls

NA 7.5.9.1 Construction Inspection

…

- Pressure sensors are either factory or field calibrated.
- The pressure sensor location, setpoint and reset control meets the requirements of Standard Section 144(j)6B

NA7.5.9.2 Functional Testing

Step 1: Open control valves to increase water flow to a minimum of 90% design flow. Verify and document the following:

- Pump speed increases
- System pressure is either within ±5% of current operating setpoint or the pressure is below the setpoint and the pumps are operating at 100% speed.
- System operation stabilizes within 5 minutes after test procedures are initiated.

Step 2: Modulate control valves to reduce water flow to 50% of the design flow or less, but not lower than the pump minimum flow. Verify and document the following:

- Pump speed decreases.
- Current operating setpoint has decreased (for systems with DDC to the zone level).
- Current operating setpoint has not increased (for all other systems).
- System pressure is within 5% of current operating setpoint
- System operation stabilizes within 5 minutes after test procedures are initiated.

Step 3: Release all overrides, restore setpoints and restore the system to automatic control.

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Acknowledgments

The Pacific Gas and Electric Company sponsored this report as part of its CASE (Codes and Standards Enhancement) project. Steve Blanc of PG&E was the project manager for this nonresidential CASE project. Pat Eilert is the program manager for the CASE program. The Heschong Mahone Group is the prime contractor and provided coordination of the nonresidential CASE reports.

This analysis and report was produced by Mark Hydeman, PE, FASHRAE, Jeff Stein, PE and Anna Zhou of Taylor Engineering, LLC, Alameda, California under contract to the Heschong Mahone Group.

Appendices

Appendix A - Modeling Assumptions

A 100,000 ft^2 four story office building was modeled in eQuest to evaluate annual energy performance of the proposed control. The building dimension is 158 feet by 158 feet with five zones per floor. Perimeter zone depth is 15 feet.

The building envelope consists of R-19 metal frame roof and R-13 metal frame wall with 40% window wall ratio. All windows use double pane glazing. The U value of the glass is 0.47 and the SHGC value of the glass is 0.31 for non-north facing windows and 0.47 for north facing windows.

The building was modeled to be occupied from 8:00 am to 5:00 pm Monday through Friday and was closed on Saturday, Sunday and holidays. Building internal loads consist of an average 85 sf per person occupancy density, 1.3 w/sf lighting power densities and 1.5 w/sf equipment power density.

The building is conditioned by VAV reheat air handling units with hot water reheat coils at VAV boxes. Room temperature setpoint are 76/82 for cooling and 70/64 for heating during occupied/unoccupied hours. The HVAC system runs from one hour before occupancy to one hour after occupancy. System supply air temperature is fixed at 55°F. Building heating hot water is provided by a gas fired hot water boiler. Building cooling is provided by a water cooled chiller through a primary-secondary chilled water loop. Variable speed pump is used on the secondary chilled water loop.

The basecase building CHW water loop is controlled to a fixed differential pressure. The pressure setpoint is set to overcome the coil head and chilled water distribution piping pressure loss. The proposed control case chilled water loop differential pressure setpoint resets to keep at least one valve fully open. The following table shows the eQuest inputs difference in the basecase and the proposed case.

	Base Case	Proposed Case
CHW Loop Input		
HEAD-SETPT-CTRL	FIXED	VALVE-RESET
HEAD-SETPT	70.00	70.00
PIPE-HEAD	55.00	55.00
Coil Input:		
CHW-VALVE-TYPE	TWO-WAY	TWO-WAY
CHW-COIL-HEAD	15.00	15.00
CHW pump input:		
HEAD-RATIO	1.00	1.00

HEAD-PUMP	Leave blank to let DOE2 autosize based on components, e.g. coil, pipe, chiller, etc, head inputs.

Appendix B - EMCS Market Share Survey

The authors did a literature search and surveyed the major EMCS vendors to determine the market share of EMCS vendors in the HVAC controls market nationwide. The results follow:

1. Johnson 16%-25%
2. Siemens 15%-17%
3. Trane 6%-15%
4. Honeywell 7%-10%
5. Alerton 5%-10%
6. Automated Logics 7%-10%
7. Andover 7%-10%
8. Invensys 7%
9. All others 10%-20%

Graphical data from one of the market research sources is presented in Figure 1 below.

Figure 1 – EMCS Market by Company in 2001 (BCS 2002)

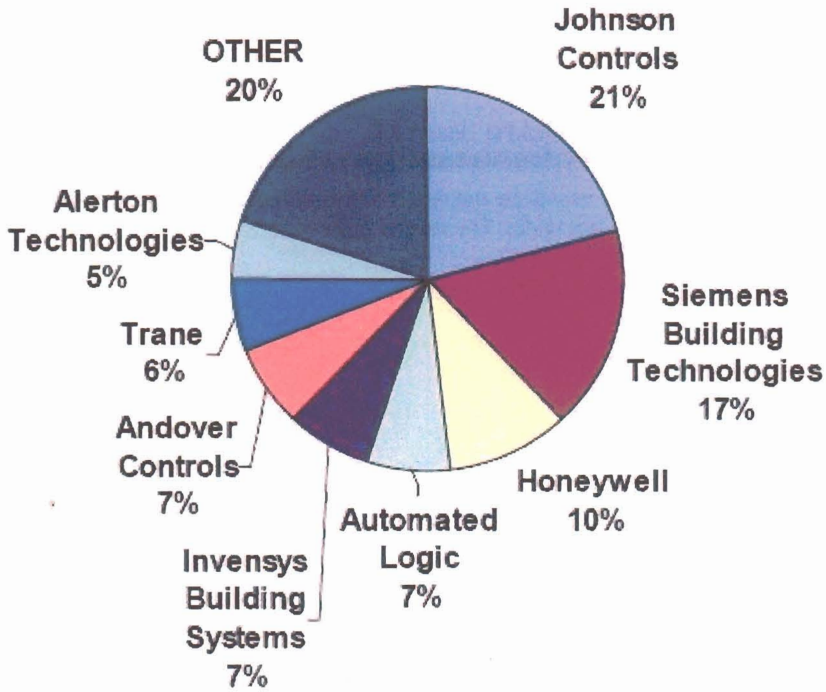
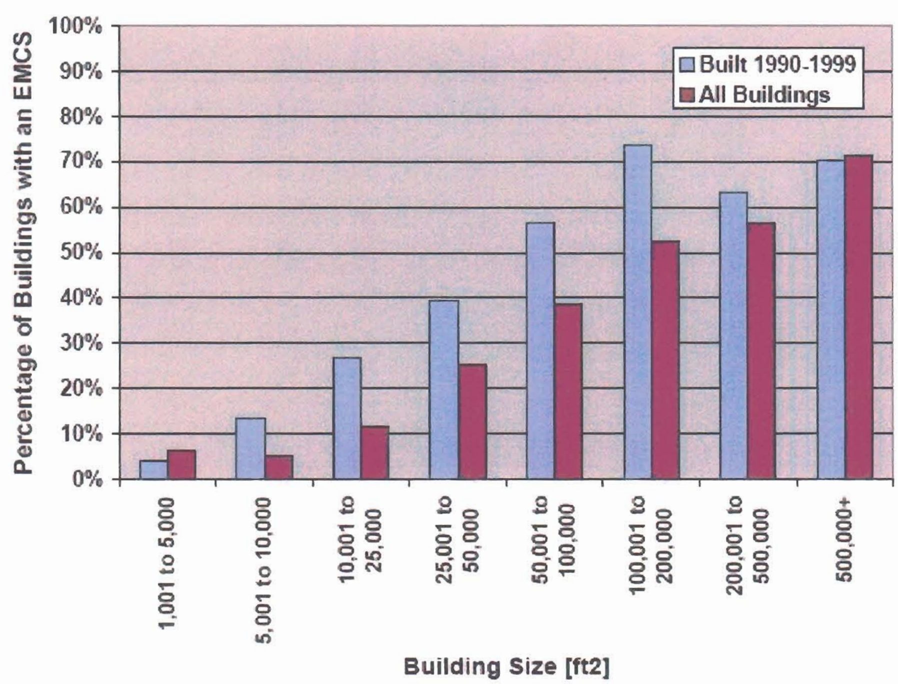


Figure 2 – Buildings with EMCS (EIA 1999)



Survey of EMCS Manufacturers on the Proposed Requirements

An email survey was sent to EMCS vendors to get their reaction to the proposed requirements. The survey was sent to Trane, Honeywell, Invensys, Alerton, Johnson, Automatic Logic Corporation and Siemens. At the time of this report, responses were received from Alerton, Automated Logic Corporation and Siemens. The survey that was sent follows:

Dear [Insert Name],

We are working on the development of the 2008 update of California's building energy code, Title 24. We are preparing for a workshop on July 13th and would appreciate your response by July 1st if possible. One of the issues we are researching relates to DDC controls. We are investigating a code change to specify control requirements on systems that have DDC to the zone level. In order to determine the feasibility of these ideas, we are surveying vendors and contractors for their opinions on the viability of these proposed measures and the make-up of the BMS market in California. To assist our deliberations, we would like you to answer the following questions:

1. *In your opinion, for new construction in commercial buildings what percentage of the controls marketplace (based on $ spent by owners) belongs to the following classes of control products:*

    a) *Fully DDC (including the zone controls)?*

    b) *Hybrid DDC and pneumatic systems?*

    c) *Fully pneumatic?*

    d) *Other (please elaborate)?*

    In considering your answer to this question exclude the single zone units that are controlled by programmable thermostats

2. *In your experience what are the most important (top 3 to 5) factors that drive a customer to purchase DDC controls? Consider the following list but feel free to list other major factors:*

    a) *First cost*

    b) *Energy savings*

    c) *Alarming*

    d) *Improved comfort and control*

    e) *Trending*

    f) *Tenant submetering*

    g) *Tenant after hours management*

    h) *Facility management*

    i) *Web based access*

    j) *Other factors (please list)*

3. *What are the relative installed costs of DDC and pneumatic systems for typical office and retail buildings?*

    a) *On a $/sf basis (or relative % cost basis) if you have the data*

    b) *Qualitatively, are they about the same or is one significantly more expensive?*

4. *Do you have any data on comparative maintenance costs for DDC and pneumatic systems?*

5. *Would you support a code change requiring DDC controls to the zone level for new control systems serving multiple zone systems and equipment?*

    a) *What are some questions or concerns you might have about such a code change?*

    b) *Are there systems or applications where this would not be appropriate?*

6. *The following are specific control requirements that we are considering. Please provide feedback (positive or negative about each). For each control requirement please address the following issues:*

    - *whether your existing systems (hardware and software) will be able to support these requirements*
    - *what exceptions should be included*
    - *the added effort to program and tune these control algorithms*

    Here are the proposed new control requirements

    a) *Hydronic pump pressure reset by demand (either directly by valve demand or through a " trim and respond " algorithm)*

    b) *Ability to globally reset cooling set points on zone thermostats on " non critical " zones by 1 to 4°F for central demand shed.*

    c) *Supply air temperature reset on VAV systems that is only enabled when the system is on 100% economizer cooling*

    d) *Demand controlled ventilation for multiple zone units serving one or more densely occupied zones. The control logic is likely to cascade with the first step controlling the zone box minimum and the second step controlling the minimum OSA damper position.*

Please contact us if you need any clarifications on the above questions. We thank you in advance for your time and we welcome your comments and feedback.

PG&E

CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

2008 California Energy Commission Title 24 Building Energy Efficiency Standards
February 13, 2007

February 27th, 2007 Workshop Report DDC to the Zone Level Measure 4: Demand Control Ventilation (DCV) for Multiple Zone Systems

Prepared by: Mark Hydeman, PE Principal
Jeff Stein, PE, Senior Engineer
Anna Zhou, Mechanical Designer
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Table of Contents

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Description

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The five measures covered by this proposal are as follows:

1. Modification of the existing prescriptive measure 144(d) (Space-conditioning Zone Controls) to allow for "dual maximum" control of VAV boxes
2. A new mandatory measure for global demand shed controls that can automatically reset the temperature set-points of all non-critical zones by 1 to 4°F from a single central command in the building energy management and control system (EMCS).
3. Modification of the existing prescriptive measure 144(j)6 (Hydronic System Measures: Variable Speed Drives) to require demand based reset of the pressure setpoint for pumps serving variable flow systems based on valve demand. This measure is the hydronic analog of the existing prescriptive measure for supply air pressure reset in (Section 144(c)2D).
4. Modification of the existing mandatory demand controlled ventilation (DCV) requirements 121(c)3 (Required Demand Control Ventilation) to include high occupant density zones served by multiple zone systems.
5. Modification of the existing prescriptive measure 144(f) (Supply Air Temperature Reset Controls) for demand based supply air temperature reset for variable air volume (VAV) systems that operate when the system is on 100% free cooling from the air-side economizer.

As each of these measures is simply a matter of programming, the cost for implementing them is quite low. However, as described below each of these measures has a significant potential for energy and demand savings.

This specific report covers the revisions to demand control ventilation (DCV).

Demand Control Ventilation (DCV) for Multiple Zone Systems

This specific report covers an expansion of the existing demand control ventilation (DCV) requirements to multiple zone systems. The current scope is for single zone systems only.

Energy Benefits

The results of our simulations of a 10,000 sf building in the 16 California climate zones are shown in **Error! Reference source not found.** below. These simulations are described in detail in Appendix A of this document. The estimated weighted average energy savings (on a per unit area basis) are as follows:

- Peak demand reduction of 0.0017 kW/ sf
- Annual electrical energy savings of 1.0 kWh/sf/yr

- Annual gas savings of 0.16 therms/sf/yr
- TDV savings of $3.9/sf

The weighting factors used in the weighted average come from the F. W. Dodge projection of new construction areas by climate and occupancy (presented in Table 2 below).

This measure saves both on-peak demand and energy by reducing fan power, reheat and OSA conditioning whenever the densely occupied zones are at less than design occupancy.

Table 1- TDV Cost Savings for Multizone Demand Control Ventilation

Climate Zone	Electrical Energy Savings [kWh/yr]	Electrical Peak Demand Reduction [kW]	TDV Electrical Cost Savings [$]	Natural Gas Energy Savings [Therms/yr]	TDV Gas Cost Savings [$]	TDV Total Cost Savings [$]	TDV Total Cost Savings Normalized [$/sf]
CZ01	7,000	11	$13,000	1920	$25,000	$38,000	3.8
CZ02	7,000	13	$14,000	1790	$24,000	$38,000	3.8
CZ03	9,000	16	$16,000	1860	$25,000	$41,000	4.1
CZ04	10,000	19	$19,000	1780	$24,000	$43,000	4.3
CZ05	10,000	18	$18,000	1850	$25,000	$42,000	4.2
CZ06	11,000	16	$19,000	1700	$23,000	$42,000	4.2
CZ07	11,000	16	$20,000	1610	$22,000	$42,000	4.2
CZ08	11,000	18	$20,000	1560	$21,000	$41,000	4.1
CZ09	11,000	18	$21,000	1560	$21,000	$42,000	4.2
CZ10	10,000	15	$18,000	1440	$19,000	$38,000	3.8
CZ11	8,000	15	$15,000	1600	$22,000	$36,000	3.6
CZ12	9,000	17	$17,000	1760	$24,000	$41,000	4.1
CZ13	9,000	19	$18,000	1490	$20,000	$38,000	3.8
CZ14	7,000	14	$13,000	1350	$18,000	$32,000	3.2
CZ15	13,000	20	$24,000	1040	$14,000	$38,000	3.8
CZ16	5,000	14	$9,000	1630	$22,000	$31,000	3.1
Minimum	5,000	11	$9,000	1040	$14,000	$31,000	3.1
Maximum	13,000	20	$24,000	1920	$25,000	$43,000	4.3
Wtd Avg	10,000	17	$18,000	1600	$21,000	$39,000	3.9

Non-energy Benefits

This measure reduces the wear and tear on both heating and cooling equipment. An additional benefit of DCV is the ability of occupants and system operators to monitor CO2 concentration in a zone and therefore receive feedback on HVAC system ventilation performance.

Statewide Energy Impacts

Using the F. W. Dodge Nonresidential New Construction data (averaged from 2000 to 2003), the projected statewide construction in thousands of sf by climate zone are shown in Table 2. The projected statewide energy impacts of this measure are calculated and listed in Table 3 (based on the assumption that 30% of the commercial new construction is served by VAV systems). CBECs and CEUS data have shown that although ~ 80% of the systems installed are packaged single zone units, multiple zone systems account for approximately 50% of the conditioned floor area.

The detailed analysis found that the first year's implementation of the proposed requirements would reduce electricity energy consumption by 46 Gigawatt/hr per year, reduce electrical demand coincident with utility system peak by 78 Megawatts, and decrease natural gas consumption by 7,500,000 therms/yr. The TDV energy cost savings is estimated at $185 Million accrued over the life of these building systems (15 years).

Table 2 Average Annual Nonresidential New Construction Area by California Climate Zone from F. W. Dodge (2000 to 2003)

CTZ	AMUSEMENT	ASSEMBLY	EDUCATION	GOVT	HOTEL	MEDICAL	OFFICE	RETAIL	SCHOOL	SERVICE	STORAGE	OTHER	TOTAL
1	20	0	10	10	30	20	80	40	50	10	30	20	[illegible]
2	90	20	20	80	180	120	420	240	240	50	260	200	1,[illegible]
3	850	100	150	180	1,000	330	5,000	1,870	1,110	3,080	1,030	450	15,[illegible]
4	360	80	280	50	380	450	3,370	1,070	1,160	2,660	500	500	10,[illegible]
5	140	30	0	20	150	80	360	240	250	240	430	170	2,[illegible]
6	400	160	70	150	570	600	1,700	1,820	910	1,750	2,400	350	10,[illegible]
7	160	50	70	30	530	170	1,110	740	520	940	640	80	5,[illegible]
8	580	250	110	220	810	960	2,500	2,710	1,440	3,010	3,760	460	16,[illegible]
9	310	110	110	160	250	780	1,440	1,780	920	1,830	2,490	430	10,[illegible]
10	590	190	100	280	650	350	1,820	2,910	1,960	1,200	8,640	500	19,[illegible]
11	220	150	0	50	140	220	870	1,140	380	210	450	300	4,[illegible]
12	580	360	40	200	800	560	4,130	3,810	2,500	2,440	4,170	1,210	20,[illegible]
13	470	130	50	330	70	570	440	1,160	660	330	1,660	450	6,[illegible]
14	540	190	170	420	620	910	2,300	2,910	1,900	2,830	7,100	640	20,[illegible]
15	270	100	80	110	630	250	1,420	1,370	950	1,120	2,820	300	9,[illegible]
16	180	70	20	230	110	170	440	590	370	270	1,120	170	3,[illegible]
Totals	5,800	2,000	1,300	2,500	6,900	6,500	27,400	24,400	15,300	22,000	37,500	6,200	158,[illegible]

Table 3 Statewide TDV cost savings and emission reductions

Climate Zone	Electrical Energy Savings [kWh/yr]	Electrical Peak Demand Reduction (kW)	Natural Gas Savings [Therms/yr]	TDV Cost Savings [$]	Nox [lbs/yr]	CO2 [lbs/yr]	CO [lbs/yr]	PM10 [lbs/yr]
CZ01	60,000	100	20,000	$400,000	200	300,000	70	20
CZ02	430,000	800	100,000	$2,200,000	1,100	1,700,000	410	130
CZ03	3,980,000	7,300	850,000	$18,700,000	9,500	14,500,000	3,460	1090
CZ04	3,260,000	6,300	580,000	$14,000,000	6,700	10,600,000	2,490	780
CZ05	630,000	1,100	120,000	$2,700,000	1,300	2,100,000	500	160
CZ06	3,460,000	5,100	550,000	$13,600,000	6,500	10,500,000	2,460	760
CZ07	1,710,000	2,400	240,000	$6,300,000	2,900	4,900,000	1,130	350
CZ08	5,750,000	8,800	790,000	$20,800,000	9,600	15,900,000	3,680	1130
CZ09	3,660,000	5,700	500,000	$13,400,000	6,100	10,100,000	2,330	720
CZ10	5,870,000	8,900	830,000	$21,700,000	10,000	16,600,000	3,840	1180
CZ11	950,000	1,900	200,000	$4,500,000	2,200	3,400,000	820	260
CZ12	5,530,000	10,600	1,090,000	$25,300,000	12,400	19,200,000	4,550	1430
CZ13	1,740,000	3,600	280,000	$7,200,000	3,300	5,300,000	1,250	390
CZ14	4,300,000	8,300	830,000	$19,500,000	9,400	14,700,000	3,480	1090
CZ15	3,700,000	5,700	290,000	$10,900,000	4,200	7,800,000	1,730	520
CZ16	550,000	1,600	180,000	$3,500,000	1,900	2,800,000	680	220
Total	45,600,000	78,000	7,500,000	$185,000,000	88,000	140,000,000	32,900	10,200

Environmental Impact

As shown in Table 3 above, this measure is estimated to annually reduce emissions by approximately 88 thousand pounds of NOx, 140 million pounds of CO2, 33 thousands pounds of CO and 10 thousand pounds of PM10.

Table 4 presents the emission factors for calculating reduced emissions based on reduction in energy usage.

Table 4 Emmision factors for Calculating Reduced Emmisions from Energy Savings (CEC 2003)

Emissions Factors for Calculating Reduced Emissions from Energy Savings				
Emissions factors	**NOx**	**CO**	**CO2**	**PM10**
Natural Gas, California (lbs/MMBtu)	0.094	0.03	115	0.01
Electricity, Western States (lbs/MWh)	0.383	0.23	1200	0.06

Beneficial environmental impacts are reduced electricity (energy and demand) and natural gas consumption. When properly tuned, DCV insures that code minimum ventilation rates are maintained at all times. It acts to reduce over-ventilation of spaces when they are not fully occupied.

DCV systems increase the concentration of bioeffluents and building-borne contaminants in the space when partially occupied. However, as documented in the Title 24 2005 DCV study (CEC April 2002), these contaminant levels are maintained at acceptable concentrations based on research, and consensus of code and standard organizations.

Type of Change

This measure is proposed as a modification of an existing mandatory requirement. It applies to either new construction or retrofit where all zones have DDC controls. The changes to the Title 24 documents are summarized in the following paragraphs. The complete proposed changes with underlines and strikeouts are in the section Proposed Standard Language below:

Standards

- Revise existing mandatory requirement 121(c)3
- No change is required for 125(a) Demand Control Ventilation Acceptance.
- Modify the existing acceptance test NA7.5.5 Demand Control Ventilation (DCV) Systems.

ACM

- Modify the language in 2.5.3.11 Zone Ventilation Air

Technology Measures

This measure only applies to multiple zone systems with DDC to the zone level. As presented in our industry survey below, this represents between 90% to 95% of the new construction market.

Measure Availability and Cost

EMCS systems with DDC to the zone level are prevalent in the current building market. Our experience and surveys of the major EMCS vendors indicate that all of the major vendors are capable of meeting these proposed requirements. Data on the major market players and the surveys are presented below.

DCV sensors are readily available from a range of manufacturers. Almost all of the large EMCS vendors manufacture or OEM CO_2 sensors. This is due in part to the Title 24 2005 requirement for DCV on single zone systems.

Useful Life, Persistence and Maintenance

This measure will be tested through the Title 24 acceptance testing requirements. These proposed control sequences (like all controls) will need to be reviewed and the sensors recalibrated as part of the routine maintenance of the EMCS. For this requirement, the sensor calibration is part of both the base case and proposed requirements.

Performance Verification

As documented below the existing Title 24 acceptance requirements will be slightly modified to test this proposed requirement.

Analysis Tools

This measure can be evaluated using either eQuest or EnergyPro. The current ACM procedures (extended to multiple zone systems) will work to capture the savings.

Relationship to Other Measures

This measure is an enhancement of the existing mandatory DCV measure in 121(c).

Methodology

Survey of the EMCS Vendors

The authors conducted an email survey of the major EMCS vendors (Siemens, Invensys, Johnson, Honeywell, Alerton, Automated Logic Corporation and Trane) in June of 2006. Of these seven companies, only three responded (Siemens, Alerton and Automated Logic Corporation). The authors subsequently sent the five draft proposals from the CEC July 13th workshop to the list server for ASHRAE Technical Committee 1.4 "Control Theory and Application." This list server includes all members, corresponding members and interested parties to TC 1.4. In addition Mark Hydeman addressed the ASHRAE TC 1.4 committee on these proposals at their meeting in Dallas on January 30th, 2007 and requested feedback for the upcoming February 2007 CEC workshop To date not a single negative comment on any of these proposals has been received.

The survey is presented in Appendix A of this report. A summary of the survey results follow:

Question 1, EMCS market place: All three respondents indicated that DDC to the zone level was between 90% to 95% of the new construction market.

Question 2, Top Factors for DDC Purchases:

- Facility Management - 3 Votes
- Improved Comfort and Controls – 3 Votes
- Tenant After Hours Management – 2 Votes
- Alarming – 2 Votes
- Energy Savings – 2 Votes
- First Cost – 2 Votes

- Web Based Access – 1 Vote

Question 3, Relative First Cost of DDC and Pneumatic Controls: The consensus of the respondents is that pneumatic controls generally have a slightly smaller first cost. This cost depends on the number of points in the system as the pneumatic control system incurs a large first cost penalty for the compressor and associated equipment

Results

The results of our investigations indicate that this measure is both cost effective and would be supported by the industry.

The results of our simulation indicate an average TDV cost savings of $1556 for a 400 ft2 zone. As established in the Title 24 2005 report for the single zone DCV measures (CEC April 2002) the installed costs per zone for DCV controls are conservatively $575 per zone. This is only 37% of the calculated TDV savings.

Statewide Energy Savings

Using the 2000~2003 average nonresidential new construction area by climate zone listed in Table 5. Table 6 listed emission factors for calculating reduced emmisions from energy savings. Assuming 30% of the new construction has VAV system, statewide energy impacts and emission reduction of this measure is calculated and listed in Table 7.

Table 5 Average of 2000~2003 nonresidential new construction area in 1000's of sf by climate zone

CTZ	AMUSEMENT	ASSEMBLY	EDUCATION	GOVT	HOTEL	MEDICAL	OFFICE	RETAIL	SCHOOL	SERVICE	STORAGE	OTHER	Total 1,000's sf
1	22	2	5	13	25	20	79	40	50	9	28	24	**318**
2	93	19	23	84	177	119	419	241	242	53	259	204	**1,934**
3	849	103	149	184	997	334	4,999	1,868	1,111	3,077	1,030	453	**15,155**
4	358	77	279	46	380	452	3,365	1,075	1,162	2,656	496	499	**10,843**
5	145	31	0	20	154	75	356	244	251	245	432	167	**2,121**
6	405	165	68	151	566	599	1,697	1,820	912	1,746	2,400	349	**10,878**
7	160	49	71	32	530	167	1,114	738	524	938	642	85	**5,049**
8	581	250	114	215	806	959	2,498	2,714	1,443	3,010	3,761	458	**16,808**
9	309	105	107	165	251	780	1,438	1,781	923	1,833	2,495	428	**10,615**
10	591	192	103	280	645	351	1,815	2,906	1,961	1,203	8,640	501	**19,188**
11	224	149	5	55	144	216	874	1,140	383	207	454	297	**4,149**
12	577	356	37	204	799	562	4,133	3,808	2,496	2,442	4,166	1,205	**20,786**
13	475	130	46	331	72	566	436	1,161	656	327	1,658	447	**6,305**
14	537	191	167	415	617	913	2,298	2,915	1,899	2,825	7,103	638	**20,518**
15	272	99	85	110	625	247	1,416	1,365	951	1,122	2,825	303	**9,419**
16	179	71	19	230	112	168	442	594	369	273	1,117	168	**3,741**
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**

Table 6 Emmision factors for Calculating Reduced Emmisions from Energy Savings

Emissions Factors for Calculating Reduced Emissions from Energy Savings				
Emissions factors	NOx	CO	CO2	PM10
Natural Gas, California (lbs/MMBtu)	0.094	0.03	115	0.01
Electricity, Western States (lbs/MWh)	0.383	0.23	1200	0.06

Table 7 Statewide TDV cost savings and emission reductions

Climate Zone	Electrical Energy Savings [10^6 Wh]	Natural Gas Savings [10^6 Btu]	Statewide TDV Cost Savings [$]	Nox [10^3lbs]	CO [10^3lbs]	CO2 [10^6lbs]	PM10 [10^3lbs]
CZ01	636,100	18,353,300	$366,100	2,000	700	2,200	200
CZ02	4,315,800	103,995,000	$2,199,900	11,400	4,100	12,500	1300
CZ03	39,806,000	846,885,900	$18,666,400	94,900	34,600	102,200	10900
CZ04	32,640,800	579,965,600	$14,032,000	67,000	24,900	70,600	7800
CZ05	6,282,500	117,701,100	$2,692,600	13,500	5,000	14,300	1600
CZ06	34,584,300	554,117,200	$13,563,000	65,300	24,600	67,900	7600
CZ07	17,099,000	243,962,900	$6,295,400	29,500	11,300	30,100	3500
CZ08	57,547,700	785,955,700	$20,805,800	95,900	36,800	97,300	11300
CZ09	36,619,400	496,030,500	$13,374,300	60,700	23,300	61,400	7200
CZ10	58,678,600	828,704,700	$21,743,700	100,400	38,400	102,300	11800
CZ11	9,459,400	199,712,400	$4,515,700	22,400	8,200	24,100	2600
CZ12	55,266,000	1,094,457,700	$25,257,300	124,000	45,500	132,500	14300
CZ13	17,369,600	282,734,400	$7,169,600	33,200	12,500	34,600	3900
CZ14	43,012,300	829,915,600	$19,544,600	94,500	34,800	100,600	10900
CZ15	36,962,500	294,358,800	$10,876,200	41,800	17,300	38,300	5200
CZ16	5,523,700	182,714,200	$3,501,000	19,300	6,800	21,700	2200
Minimum	636,100	18,353,300	$366,100	2,000	700	2,200	200
Maximum	58,678,600	1,094,457,700	$25,257,300	124,000	45,500	132,500	14,300
Average	28,487,731	466,222,813	$11,537,725	54,738	20,550	57,038	6,394

Recommendations

Proposed Standards Language

Modification of Existing Prescriptive Requirement 121(c)3 Required Demand Control Ventilation

121(c)3. **Required Demand Control Ventilation.** HVAC ~~single zone~~ systems with the following characteristics shall have demand ventilation controls complying with 121 (c) 4:

A. They have an outdoor air economizer; and

B. They serve a space with a design occupant density, or a maximum occupant load factor for egress purposes in the CBC, greater than or equal to 25 people per 1000 ft2 (40 square foot per person).; and

C. They are either:

i. Single zone systems with any controls; or

ii. Multiple zone systems with DDC controls to the zone level.

EXCEPTION 1 to Section 121 (c) 3 B: Classrooms are not required to have demand control ventilation.

EXCEPTION 2 to Section 121 (c) 3 B: Where space exhaust is greater than the design ventilation rate specified in 121 (b) 2 B minus 0.2 cfm per ft2 of conditioned area.

EXCEPTION 3 to Section 121 (c) 3 B: Spaces that have processes or operations that generate dusts, fumes, mists, vapors, or gases and are not provided with local exhaust ventilation (such as indoor operation of internal combustion engines or areas designated for unvented food service preparation).

Alternate Calculation Manual

Modifications to 2.5.3.11 Zone Ventilation Air

2.5.3.11 Zone Ventilation Air

...

Modeling Rules for Standard Design (All): The reference method determines the standard design zone ventilation rate as follows:

1. If no tailored ventilation rate has been entered, the ACM shall use values from Table N2-2 or Table N2-3for the applicable occupancy as the zone ventilation rate for the standard design.

2. If a tailored ventilation rate has been entered, the ACM shall assume the tailored value as the zone ventilation rate for the standard design.

3. If the zone is served by either a single-zone system or a multiple zone system with DDC to the zone level (in the proposed design) that has an air-side economizer and has a design occupant density greater than or equal to 25 people per 1000 ft2 (40 ft2 per person) from Table N2-2 or Table N2-3, unless space exhaust is greater than the design ventilation rate specified in 121 (b) 2 B minus 0.2 cfm per ft2 of conditioned area, the ACM shall output on compliance forms that DEMAND CONTROL VENTILATION IS REQUIRED FOR THIS ZONE PER SECTION 121 and the ACM shall use the larger of the following as the zone ventilation rate for the standard design:

a) half of the value from Table N2-2 or Table N2-3.

b) the minimum rate.

c) half of the user defined amount, if the zone ventilation rate has been entered by the user.

Modifications to NA7.5.5 Demand Control Ventilation (DCV) Systems

NA7.5.5 Demand Control Ventilation (DCV) Systems

~~Demand control ventilation is tested on package systems per Standards Section 121 (c)3.~~

~~NJ.8.1 Packaged Systems DCV Acceptance~~

NA7.5.5.1 Construction Inspection

Prior to Performance Testing, verify and document the following:

- ~~C~~All carbon dioxide (CO_2) control sensors are ~~is~~ factory calibrated (proof required) or field-calibrated per Standard Section 121(C)4~~with an accuracy of no less than 75 ppm~~.
- The sensor is located in the room between 1ft and 6 ft above the floor.
- ~~System controls are wired correctly to ensure proper control of outdoor air damper system.~~
- There is one CO_2 sensor for each densely occupied space per Standard section 121(c)4A.

NA7.5.5.2 Equipment Testing

For each zone with a CO_2 sensor verify the following:

Step 1: Disable economizer controls

Step 2~~1~~: Simulate a high CO_2 signal ~~CO2 load and enable the demand control ventilation by adjusting the demand control ventilation controller setpoint below ambient CO2 levels~~. Verify and document the following:

- For single zone units, o~~O~~utdoor air damper modulates opens ~~per Standards to maximum position~~ to satisfy the total value found in the Standards Mechanical Plan Check document MECH-3-C, Column I.~~outdoor air requirements specified in Section 121(c)~~.
- For multiple zone units, either outdoor air damper or zone damper modulate open to satisfy the zone ventilation requirements.

Step ~~2~~3: ~~Continue from Step 1 and~~ Simulate a low CO_2 signal~~disable demand control ventilation by adjusting the demand control ventilation controller setpoint above ambient CO2CO2 levels~~. Verify and document the following:

- For single zone units, o~~O~~utdoor air damper closes ~~to minimum position~~to the design minimum value
- For multiple zone units, either outdoor air damper or zone damper modulate open to satisfy the reduced zone ventilation requirements.

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This analysis and report was produced by Jeff Stein, Anna Zhou and Mark Hydeman of Taylor Engineering, LLC, Alameda, California under contract to the Heschong Mahone Group.

Appendices

Appendix A. Modeling Assumptions and Results

This measure was evaluated using eQuest. A 10,000 square foot five zone one story building was used for the analysis. The four perimeter zones are modeled as offices with 100 sf/person design load and the interior zone is modeled as a conference room with 20 sf/person design load. One package VAV unit with hot water reheat serves all five zones. In the base case model the conference room minimum ventilation is fixed at 15 CFM/person and the perimeter office minimum ventilation is fixed at 0.15 CFM/ft^2.

Figure 1 Zone Layout for eQuest Model

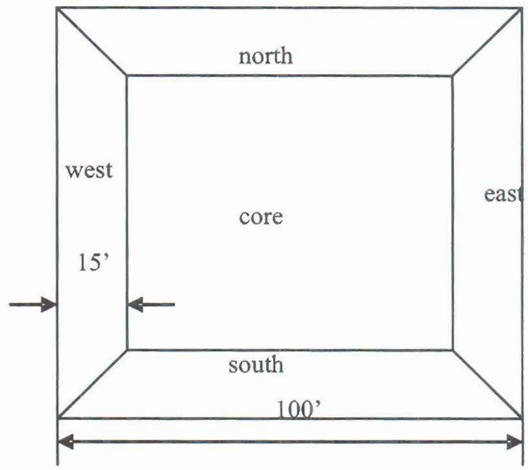


Table 8 and Figure 2 to Figure 5 summarize the major assumptions common to all three control sequences.

Table 8 Common model assumptions

	Base Case Building Model
Wall	metal frame wall with R-19 insulation
Roof	metal frame roof with R-18 insulation
Glazing	40% WWR ratio; North window: SHGC = 0.31, U = 0.47; North glazing: SHGC = 0.47, U = 0.47
Occupant Density	100 sf/person (=12.5 person) for perimeter zones; 20 sf/person(= 245 person) for core zone (conference rooms)
Perimeter Zones Area	5100 sf (51% of total area)
Interior Zone Area	4900 sf (49% of total area)
Lighting	1.32 w/sf
Equipment	1.2 w/sf
Cooling EER	9.971
Boiler Efficiency	80%
Fan Efficiency	0.44 W/cfm

Figure 2 show the occupancy schedule used for perimeter zones and core zone respectively.

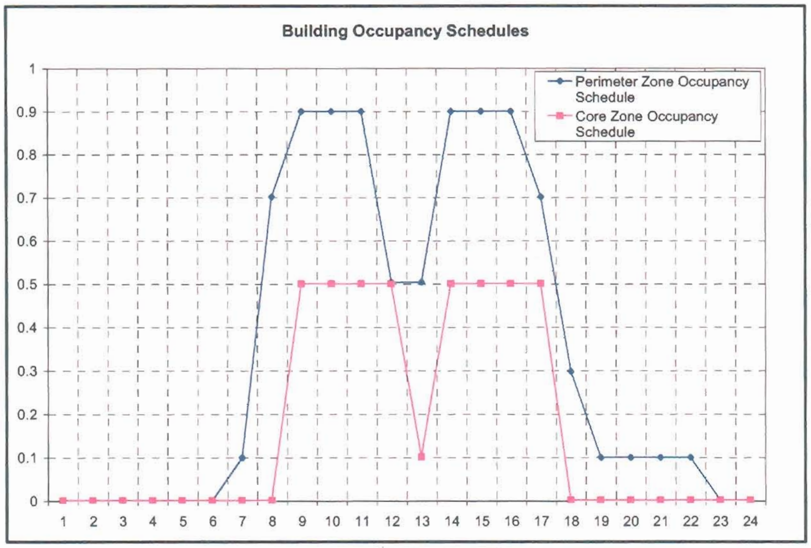


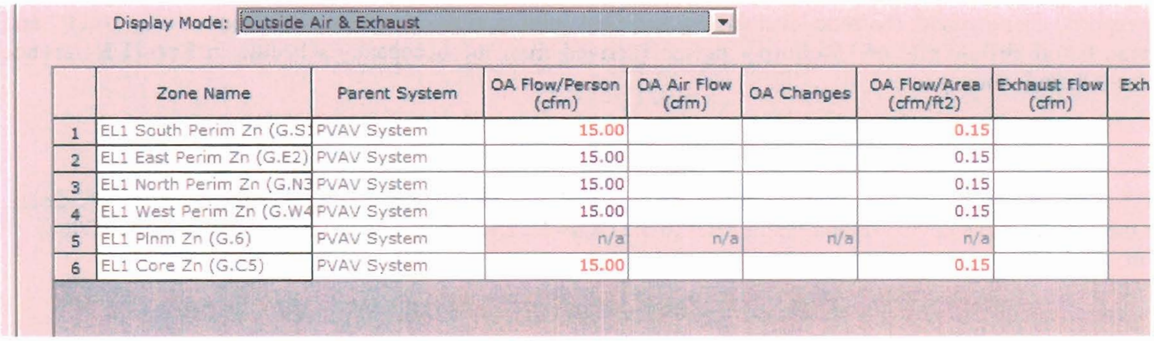
Figure 2 Occupancy schedules

Display Mode: Air Flow

Zone Name	Parent System	Flow/Area (cfm/ft2)	Assigned Flow (cfm)	Air Change	Min Flow Ratio (ratio)	Min Flow/Area	Min Flow Schedule	Min Flow Source	Min Flow Control
EL1 South Perim Zn (G.S	PVAV Syste				0.30		- undefined -	n/a	Fixed/Schedul
EL1 East Perim Zn (G.E2)	PVAV Syste				0.30		- undefined -	n/a	Fixed/Schedul
EL1 North Perim Zn (G.N3	PVAV Syste				0.30		- undefined -	n/a	Fixed/Schedul
EL1 West Perim Zn (G.W4	PVAV Syste				0.30		- undefined -	n/a	Fixed/Schedul
EL1 Plnm Zn (G.6)	PVAV Syste	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
EL1 Core Zn (G.C5)	PVAV Syste						- undefined -	n/a	Fixed/Schedul

Figure 3. Zone Air Flow Inputs

Note that Min Flow Ratio for the Core Zone (interior conference room) is left blank while it is set to 30% for the perimeter office zones. This is because the Min Flow Ratio in DOE-2 takes priority over the OA Flow/Person and the OA Flow/Area. For the perimeter zones the zone minimum flow rate is driven by the 30% minimum flow ratio but for the interior conference room zone it is driven by the 15 CFM/person ventilation requirement. The design air flow for the interior zone is approximately 0.75 CFM/ft^2 (it varies slightly by climate zone) so the design ventilation rate is approximately 100% of the design flow rate.


Display Mode: Outside Air & Exhaust

	Zone Name	Parent System	OA Flow/Person (cfm)	OA Air Flow (cfm)	OA Changes	OA Flow/Area (cfm/ft2)	Exhaust Flow (cfm)	Exh
1	EL1 South Perim Zn (G.S1	PVAV System	15.00			0.15		
2	EL1 East Perim Zn (G.E2)	PVAV System	15.00			0.15		
3	EL1 North Perim Zn (G.N3	PVAV System	15.00			0.15		
4	EL1 West Perim Zn (G.W4	PVAV System	15.00			0.15		
5	EL1 Plnm Zn (G.6)	PVAV System	n/a	n/a	n/a	n/a		
6	EL1 Core Zn (G.C5)	PVAV System	15.00			0.15		

Figure 4. Zone Outside Air Inputs

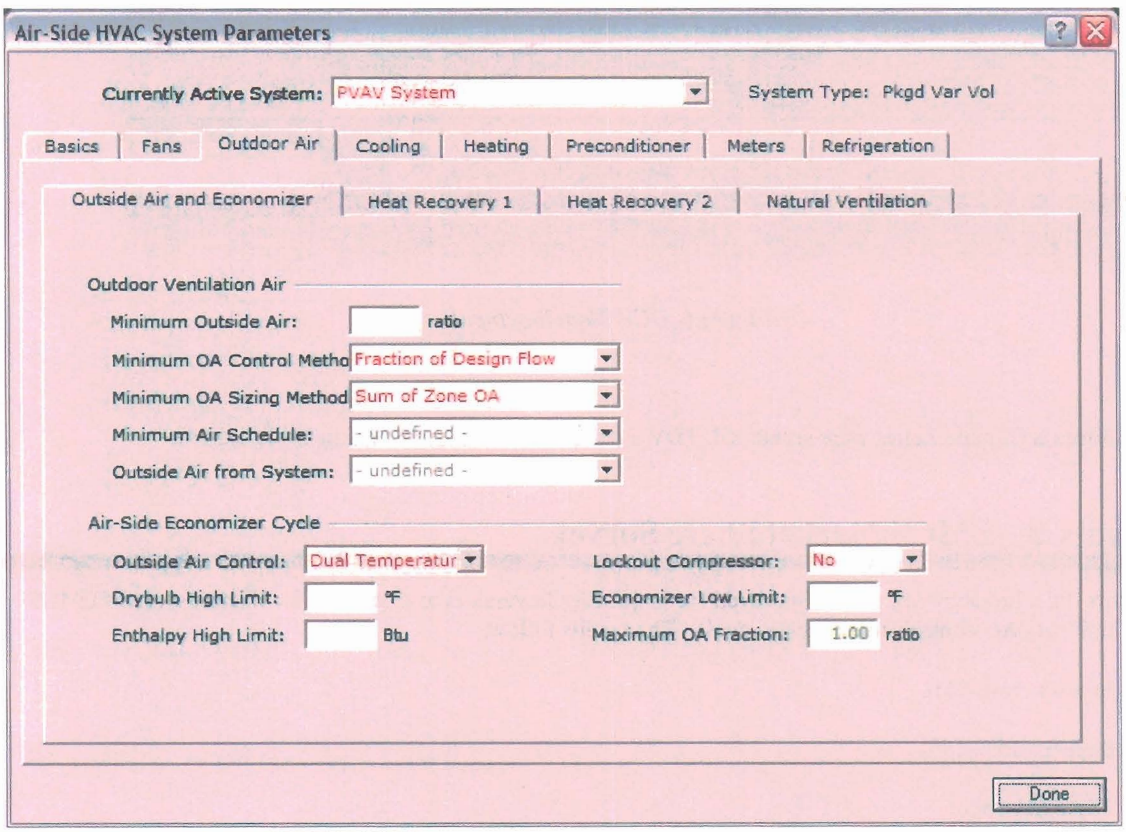


Figure 5. System Outside Air Inputs

The DCV control sequence is simulated using eQuest's "Sum of Zones" algorithm. To evaluate the energy impact of demand control ventilation, the control of the core zone VAV box and the outside air damper of the system are changed. Under demand control ventilation, each hour, the model calculates the outside air requirement based on 15cfm/person and number of people in the zone from the occupancy schedule. The VAV damper is controlled by the zone cooling/heating load indicated by the thermostat as well as the CO2 sensor, whichever gives the larger flowrate requirement. Same changes are made to perimeter zone VAV boxes. However, since the 100sf/person occupancy density at 15 cfm/per is equivalent to 0.15 cfm/sf, the DCV control doesn't change air flowrate for perimeter zones. The System ventilation is the sum of the zone requirements to maintain just enough outside air flowrate for that hour. This sequence complies with Title 24 2005 ventilation requirements. These (as verified by review of the hourly reports) changed both the zone level airflow and OSA minimum position between a floor of 0.15 cfm/ft2 and a demand based airflow rate of 15 cfm per person (derived from the occupancy schedule in **Error! Reference source not found.** above).

Figure 6 shows how the zone and system inputs were modified to model the DCV control schemes. For more detail on the meaning of these keywords and inputs refer to the DOE-2.2 Dictionary and to the Appendix on "Modeling DCV in EQUEST".

Parametric Runs Comparison Listing

Component	Reference(s)	Keyword	Array Idx	Baseline	sum of zone DCV
HVAC System	PVAV System	MIN-OA-METHOD	N/A	FRAC-OF-DESIGN-FLOW	DCV-RETURN-SENSOR
HVAC System	PVAV System	OA-SIZING-METHOD	N/A	SUM-OF-ZONE-OA	SUM-OF-ZONE-OA
Thermal Zone	EL1 Core Zn (G.C5)(1 of 2)	MIN-FLOW-CTRL	N/A	FIXED/SCHEDULED	DCV-RESET-UP/DOWN

Figure 6. DCV Modeling Inputs

All 16 California Climate Zones were simulated. TDV savings results are presented in Table 1above.

Appendix B - EMCS Market Share Survey

The authors did a literature search and surveyed the major EMCS vendors to determine the market share of EMCS vendors in the HVAC controls market nationwide. The results follow:

1. Johnson 16%-25%
2. Siemens 15%-17%
3. Trane 6%-15%
4. Honeywell 7%-10%
5. Alerton 5%-10%
6. Automated Logics 7%-10%
7. Andover 7%-10%
8. Invensys 7%
9. All others 10%-20%

Graphical data from one of the market research sources is presented in **Error! Reference source not found.** below.

Figure 7 – EMCS Market by Company in 2001 (BCS 2002)

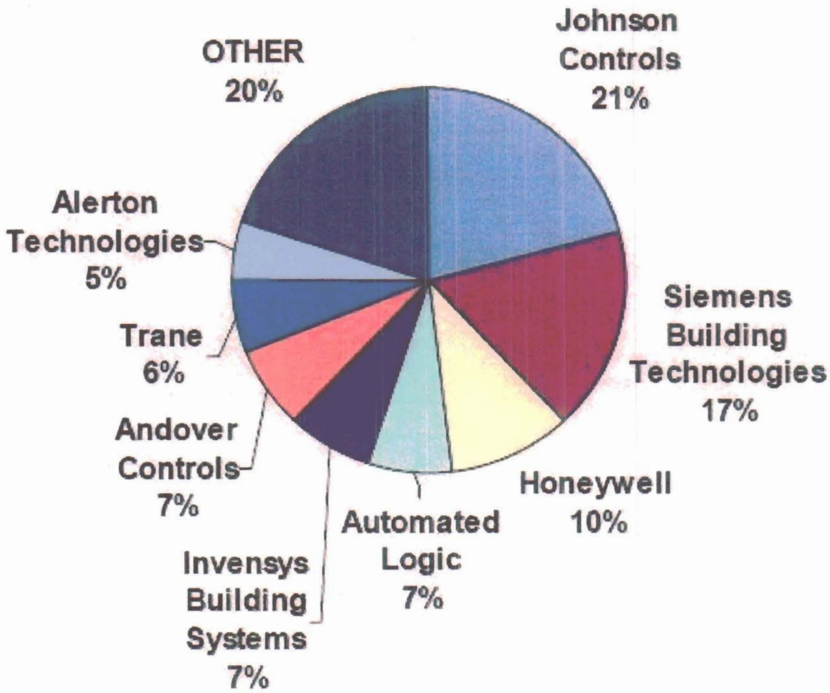
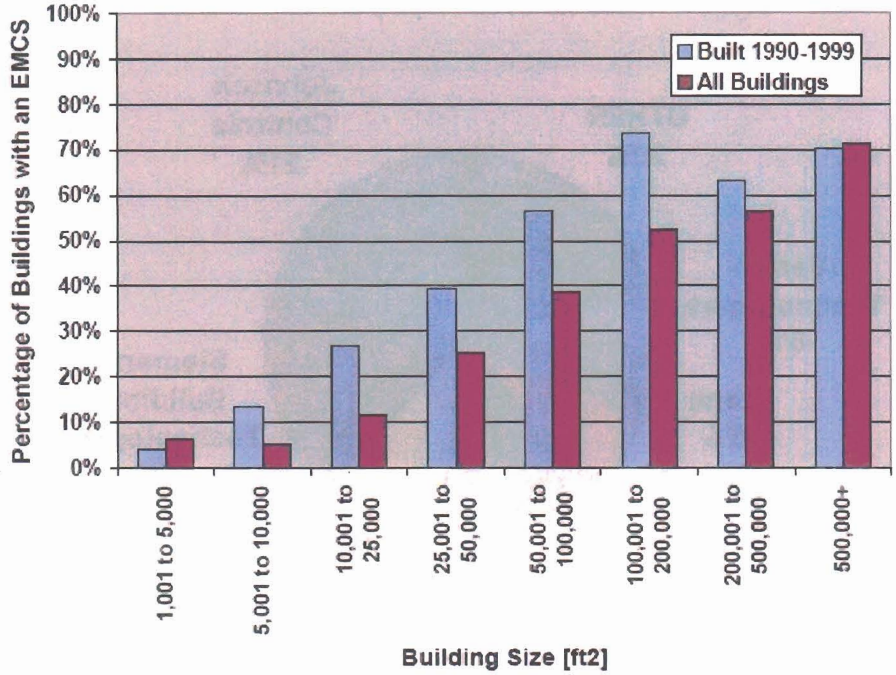


Figure 8 – Buildings with EMCS (EIA 1999)



Survey of EMCS Manufacturers on the Proposed Requirements

An email survey was sent to EMCS vendors to get their reaction to the proposed requirements. The survey was sent to Trane, Honeywell, Invensys, Alerton, Johnson, Automatic Logic Corporation and Siemens. At the time of this report, responses were received from Alerton, Automated Logic Corporation and Siemens. The survey that was sent follows:

Dear [Insert Name],

We are working on the development of the 2008 update of California's building energy code, Title 24. We are preparing for a workshop on July 13th and would appreciate your response by July 1st if possible. One of the issues we are researching relates to DDC controls. We are investigating a code change to specify control requirements on systems that have DDC to the zone level. In order to determine the feasibility of these ideas, we are surveying vendors and contractors for their opinions on the viability of these proposed measures and the make-up of the BMS market in California. To assist our deliberations, we would like you to answer the following questions:

1. *In your opinion, for new construction in commercial buildings what percentage of the controls marketplace (based on $ spent by owners) belongs to the following classes of control products:*

    a) *Fully DDC (including the zone controls)?*

    b) *Hybrid DDC and pneumatic systems?*

    c) *Fully pneumatic?*

    d) *Other (please elaborate)?*

In considering your answer to this question exclude the single zone units that are controlled by programmable thermostats

2. *In your experience what are the most important (top 3 to 5) factors that drive a customer to purchase DDC controls? Consider the following list but feel free to list other major factors:*

    a) *First cost*

    b) *Energy savings*

    c) *Alarming*

    d) *Improved comfort and control*

    e) *Trending*

    f) *Tenant submetering*

    g) *Tenant after hours management*

    h) *Facility management*

    i) *Web based access*

    j) *Other factors (please list)*

3. *What are the relative installed costs of DDC and pneumatic systems for typical office and retail buildings?*

    a) *On a $/sf basis (or relative % cost basis) if you have the data*

    b) *Qualitatively, are they about the same or is one significantly more expensive?*

4. *Do you have any data on comparative maintenance costs for DDC and pneumatic systems?*

5. *Would you support a code change requiring DDC controls to the zone level for new control systems serving multiple zone systems and equipment?*

    a) *What are some questions or concerns you might have about such a code change?*

    b) *Are there systems or applications where this would not be appropriate?*

6. *The following are specific control requirements that we are considering. Please provide feedback (positive or negative about each). For each control requirement please address the following issues:*

    - *whether your existing systems (hardware and software) will be able to support these requirements*
    - *what exceptions should be included*
    - *the added effort to program and tune these control algorithms*

    Here are the proposed new control requirements

a) *Hydronic pump pressure reset by demand (either directly by valve demand or through a " trim and respond " algorithm)*

b) *Ability to globally reset cooling set points on zone thermostats on " non critical " zones by 1 to 4°F for central demand shed.*

c) *Supply air temperature reset on VAV systems that is only enabled when the system is on 100% economizer cooling*

d) *Demand controlled ventilation for multiple zone units serving one or more densely occupied zones. The control logic is likely to cascade with the first step controlling the zone box minimum and the second step controlling the minimum OSA damper position.*

Please contact us if you need any clarifications on the above questions. We thank you in advance for your time and we welcome your comments and feedback.

PG&E

CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

2008 California Energy Commission Title 24 Building Energy Efficiency Standards
February 13, 2007

February 27th, 2007 Workshop Report DDC to the Zone Level Measure 5: Supply Air Temperature Reset

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This report was prepared by Pacific Gas and Electric Company and funded by the California utility customers under the auspices of the California Public Utilities Commission.

February 13, 2007

Table of Contents

Document information

Category: Codes and Standards

Keywords: PG&E CASE, Codes and Standards Enhancements, Title 24, nonresidential, 2008, efficiency

Overview

Description

This CASE report addresses one of five separate measures that extend the control requirements of the standard. All five of these requirements are possible at a very small cost if the installed control system is direct-digital control (DDC) to the zone level. This initiative does not seek to require installation of DDC to the zone level, rather it extends the current philosophy of the prescriptive requirements such as supply static pressure reset (Section 144(c)2D) that state a functional requirement of the control system if it is designed for DDC to the zone level.

The five measures covered by this proposal are as follows:

1. Modification of the existing prescriptive measure 144(d) (Space-conditioning Zone Controls) to allow for "dual maximum" control of VAV boxes

2. A new mandatory measure for global demand shed controls that can automatically reset the temperature set-points of all non-critical zones by 1 to 4°F from a single central command in the building energy management and control system (EMCS).

3. Modification of the existing prescriptive measure 144(j)6 (Hydronic System Measures: Variable Speed Drives) to require demand based reset of the pressure setpoint for pumps serving variable flow systems based on valve demand. This measure is the hydronic analog of the existing prescriptive measure for supply air pressure reset in (Section 144(c)2D).

4. Modification of the existing mandatory demand controlled ventilation (DCV) requirements 121(c)3 (Required Demand Control Ventilation) to include high occupant density zones served by multiple zone systems.

5. Modification of the existing prescriptive measure 144(f) (Supply Air Temperature Reset Controls) for demand based supply air temperature reset for variable air volume (VAV) systems that operate when the system is on 100% free cooling from the air-side economizer.

As each of these measures is simply a matter of programming, the cost for implementing them is quite low. However, as described below each of these measures has a significant potential for energy and demand savings.

Supply Air Temperature Reset

This specific report covers measure 5, supply air temperature reset controls. This measure drops the exception to 144(f) for systems with VAV controls based on research produced for PIER.

Energy Benefits

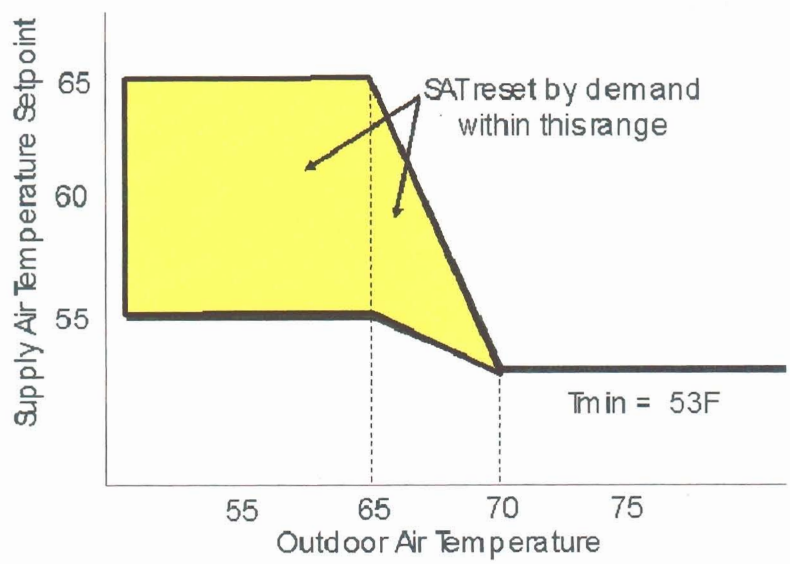
This measure was derived from the Integrated Energy Systems — Productivity and Building Science project, a Public Interest Energy Research (PIER) program administered by the California Energy Commission under contract No. 400-99-013, and managed by the New Buildings Institute. This project focused on large VAV systems and has guidance on both system selection and controls. As part of this project, the researchers simulated seven different supply air temperature control schemes in the climates of Sacramento and San Francisco (see Table 1 below). In both of these climates the same control scheme produced the lowest source energy usage. Methods 5 and 6 produced significantly lower energy usage than the other 5 methods. These schemes do supply air temperature reset by zone demand until the outside air temperature reaches a threshold. The threshold for both of these climates was between 65°F and 70°F.

Table 1 – Source Energy Savings for Supply Air Temperature Reset Controls
Table 30 from PIER VAV Guide (CEC Oct. 2003)

SAT Control Method	Cooling kWh/ft2	Fans kWh/ft2	Total kWh kWh/ft2	Heating kBtu/ft2	Total Source kBtu/ft2
San Francisco Climate					
1. Constant 55	2.43	0.38	2.81	5.23	33.9
2. Reset by zone demand	1.75	0.47	2.22	4.45	27.2
3. Switch to T-min when chiller runs	1.82	0.4	2.22	4.64	27.3
4. Switch to T-min when OAT > 60	1.88	0.4	2.28	4.58	27.9
5. Switch to T-min when OAT > 65	1.76	0.43	2.19	4.49	26.9
6. Switch to T-min when OAT > 70	1.75	0.45	2.2	4.46	27
7. Switch to T-min when OAT > 75	1.75	0.46	2.21	4.45	27.1
Sacramento Climate					
1. Constant 55	2.76	0.52	3.28	7.38	41
2. Reset by zone demand	2.3	0.63	2.93	6.55	36.5
3. Switch to T-min when chiller runs	2.33	0.52	2.85	6.8	36
4. Switch to T-min when OAT > 60	2.39	0.52	2.91	6.79	36.6
5. Switch to T-min when OAT > 65	2.3	0.54	2.84	6.6	35.7
6. Switch to T-min when OAT > 70	2.29	0.55	2.84	6.56	35.7
7. Switch to T-min when OAT > 75	2.29	0.57	2.86	6.55	35.9

The recommended control scheme in the guide is depicted in Figure 1 below. It has the controls resetting the supply air temperature between 55°F and 65°F when the outdoor air temperature is less than 70°F and fixed at the design temperature (shown as 53°F in Figure 1 below) when it is hot outside.

Figure 1 – Recommended SAT Reset Sequence from PIER VAV Design Guide (CEC Oct 2003)



The results of our simulations of a 10,000 sf building in the 16 California climate zones are shown in Table 2 below. These simulations are described in detail in Appendix A of this document. The estimated weighted average energy savings (on a per unit area basis) are as follows:

- Peak demand reduction of 0.0008 kW/ sf
- Annual electrical energy savings of 0.5 kWh/sf/yr
- Annual gas savings of 0.051 therms/sf/yr
- TDV savings of $1.40/sf

The weighting factors used in the weighted average come from the F. W. Dodge projection of new construction areas by climate and occupancy (presented in Table 3 below).

Table 2- Projected Annual Energy and TDV Cost Savings for This Measure

Climate Zone	Electrical Energy Savings [kWh/yr]	Electrical Peak Demand Reduction [kW]	TDV Electrical Cost Savings [$]	Natural Gas Energy Savings [Therms/yr]	TDV Gas Cost Savings [$]	TDV Total Cost Savings [$]	TDV Total Cost Savings Normalized [$/sf]
CZ01	8,900	7.8	$17,000	700	$9,200	$26,000	2.6
CZ02	5,100	9.7	$7,000	610	$8,300	$15,000	1.5
CZ03	7,500	8.2	$12,000	600	$8,200	$21,000	2.1
CZ04	6,500	8.4	$9,000	560	$7,700	$17,000	1.7
CZ05	8,600	8.8	$13,000	650	$8,700	$22,000	2.2
CZ06	7,400	8.1	$11,000	500	$6,800	$18,000	1.8
CZ07	7,400	9.0	$11,000	460	$6,300	$17,000	1.7
CZ08	6,100	9.5	$8,000	450	$6,200	$15,000	1.5
CZ09	5,400	9.1	$7,000	460	$6,300	$14,000	1.4
CZ10	4,900	9.1	$6,000	480	$6,500	$13,000	1.3
CZ11	3,700	7.6	$4,000	590	$8,100	$12,000	1.2
CZ12	4,900	8.6	$6,000	640	$8,800	$15,000	1.5
CZ13	3,800	8.8	$4,000	570	$7,900	$12,000	1.2
CZ14	2,100	6.1	$1,000	460	$6,300	$8,000	0.8
CZ15	1,800	8.8	$2,000	330	$4,600	$6,000	0.6
CZ16	2,200	6.4	$3,000	410	$5,400	$8,000	0.8
Minimum	1,800	6.1	$1,000	330	$4,600	$6,000	0.6
Maximum	8,900	9.7	$17,000	700	$9,200	$26,000	2.6
Wtd Avg	5,000	8.4	$7,000	510	$7,000	$14,000	1.4

Non-energy Benefits

The major non-energy benefit of SAT reset is that it reduces the number of hours of compressor cooling. It also reduces the reheat energy. On the down side it increases fan energy.

Statewide Energy Impacts

Using the F. W. Dodge Nonresidential New Construction data (averaged from 2000 to 2003), the projected statewide construction in thousands of sf by climate zone are shown in Table 3. The projected statewide energy impacts of this measure are calculated and listed in Table 4 (based on the assumption that 30% of the commercial new construction is served by VAV systems). CBECs and CEUS data have shown that although ~ 80% of the systems installed are packaged single zone units, multiple zone systems account for approximately 50% of the conditioned floor area.

The detailed analysis found that the first year's implementation of the proposed requirements would reduce electricity energy consumption by 12.1 Gigawatt/hr per year, reduce electrical demand coincident with utility system peak by 15.0 Megawatts, and decrease natural gas consumption by 1,000,000 therms/yr. The TDV energy cost savings is estimated at $32 Million accrued over the life of these building systems (15 years).

Table 3 Average Annual Nonresidential New Construction Area by California Climate Zone from F. W. Dodge (2000 to 2003)

CTZ	AMUSEMENT	ASSEMBLY	EDUCATION	GOVT	HOTEL	MEDICAL	OFFICE	RETAIL	SCHOOL	SERVICE	STORAGE	OTHER	TOTAL
1	20	0	10	10	30	20	80	40	50	10	30	20	[illegible]
2	90	20	20	80	180	120	420	240	240	50	260	200	1,[illegible]
3	850	100	150	180	1,000	330	5,000	1,870	1,110	3,080	1,030	450	15,[illegible]
4	360	80	280	50	380	450	3,370	1,070	1,160	2,660	500	500	10,[illegible]
5	140	30	0	20	150	80	360	240	250	240	430	170	2,[illegible]
6	400	160	70	150	570	600	1,700	1,820	910	1,750	2,400	350	10,[illegible]
7	160	50	70	30	530	170	1,110	740	520	940	640	80	5,[illegible]
8	580	250	110	220	810	960	2,500	2,710	1,440	3,010	3,760	460	16,[illegible]
9	310	110	110	160	250	780	1,440	1,780	920	1,830	2,490	430	10,[illegible]
10	590	190	100	280	650	350	1,820	2,910	1,960	1,200	8,640	500	19,[illegible]
11	220	150	0	50	140	220	870	1,140	380	210	450	300	4,[illegible]
12	580	360	40	200	800	560	4,130	3,810	2,500	2,440	4,170	1,210	20,[illegible]
13	470	130	50	330	70	570	440	1,160	660	330	1,660	450	6,[illegible]
14	540	190	170	420	620	910	2,300	2,910	1,900	2,830	7,100	640	20,[illegible]
15	270	100	80	110	630	250	1,420	1,370	950	1,120	2,820	300	9,[illegible]
16	180	70	20	230	110	170	440	590	370	270	1,120	170	3,[illegible]
Totals	**5,800**	**2,000**	**1,300**	**2,500**	**6,900**	**6,500**	**27,400**	**24,400**	**15,300**	**22,000**	**37,500**	**6,200**	**158,[illegible]**

Table 4 Statewide TDV cost savings and emission reductions

Climate Zone	Electrical Energy Savings [kWh/yr]	Electrical Peak Demand Reduction (kW)	Natural Gas Savings [Therms/yr]	TDV Cost Savings [$]	Nox [lbs/yr]	CO2 [lbs/yr]	CO [lbs/yr]	PM10 [lbs/yr]
CZ01	100,000	100	7,000	$200,000	100	200,000	50	0
CZ02	300,000	600	36,000	$900,000	400	800,000	200	50
CZ03	3,400,000	3,700	275,000	$9,300,000	3,900	7,300,000	1,600	500
CZ04	2,100,000	2,700	184,000	$5,400,000	2,500	4,600,000	1,050	300
CZ05	500,000	600	41,000	$1,400,000	600	1,100,000	250	50
CZ06	2,400,000	2,600	163,000	$5,800,000	2,500	4,800,000	1,050	300
CZ07	1,100,000	1,400	70,000	$2,600,000	1,100	2,200,000	450	150
CZ08	3,100,000	4,800	228,000	$7,300,000	3,300	6,300,000	1,400	400
CZ09	1,700,000	2,900	148,000	$4,400,000	2,100	3,800,000	850	250
CZ10	2,800,000	5,200	277,000	$7,200,000	3,700	6,500,000	1,450	450
CZ11	500,000	900	73,000	$1,500,000	900	1,400,000	350	100
CZ12	3,100,000	5,400	401,000	$9,500,000	4,900	8,300,000	1,900	600
CZ13	700,000	1,700	108,000	$2,300,000	1,300	2,100,000	500	150
CZ14	1,300,000	3,800	284,000	$4,600,000	3,200	4,800,000	1,150	350
CZ15	500,000	2,500	93,000	$1,800,000	1,100	1,700,000	400	100
CZ16	200,000	700	46,000	$900,000	500	800,000	200	50
Total	24,000,000	40,000	2,400,000	$65,000,000	32,000	57,000,000	12,800	3,900

Environmental Impact

As shown in Table 4 above, this measure is estimated to annually reduce emissions by approximately 32 thousand pounds of NOx, 57 million pounds of CO2, 13 thousands pounds of CO and 3.9 thousand pounds of PM10.

Table 5 presents the emission factors for calculating reduced emissions based on reduction in energy usage.

Table 5 Emmision factors for Calculating Reduced Emmisions from Energy Savings (CEC 2003)

Emissions Factors for Calculating Reduced Emissions from Energy Savings				
Emissions factors	**NOx**	**CO**	**CO2**	**PM10**
Natural Gas, California (lbs/MMBtu)	0.094	0.03	115	0.01
Electricity, Western States (lbs/MWh)	0.383	0.23	1200	0.06

Type of Change

This measure is proposed as a modification of an existing prescriptive requirement. It applies to either new construction or retrofit where the zones have DDC controls. The changes to the Title 24 documents are summarized in the following paragraphs. The complete proposed changes with underlines and strikeouts are in the section Proposed Standard Language below:

Standards

- Strike out exception 4 to the existing prescriptive requirement 144(f)

ACM

- No changes are proposed.

Technology Measures

This measure only applies to systems with DDC to the zone level. As presented in our industry survey below, this represents between 90% to 95% of the new construction market.

Measure Availability and Cost

EMCS systems with DDC to the zone level are prevalent in the current building market. Our experience and surveys of the major EMCS vendors indicate that all of the major vendors are capable of meeting these proposed requirements. Data on the major market players and the surveys are presented below.

Useful Life, Persistence and Maintenance

This measure will be tested through the Title 24 acceptance testing requirements. These proposed control sequences (like all controls) will need to be reviewed and the sensors recalibrated as part of the routine maintenance of the EMCS. For this requirement, the sensor calibration is part of both the base case and proposed requirements.

Performance Verification

None is proposed.

Analysis Tools

This measure can be evaluated using either eQuest or EnergyPro.

Relationship to Other Measures

This measure is an enhancement of the existing supply air reset control measure in 144(f).

Methodology

Energy Model

This measure was evaluated using the eQuest program. The model was based on a real project with two 200,000 ft2 office buildings that were served by a central plant. This model was run in all 16 of the California Climate zones. The TDV energy cost savings are presented in Table 2 above.

Survey of the EMCS Vendors

The authors conducted an email survey of the major EMCS vendors (Siemens, Invensys, Johnson, Honeywell, Alerton, Automated Logic Corporation and Trane) in June of 2006. Of these seven companies, only three responded (Siemens, Alerton and Automated Logic Corporation). The authors subsequently sent the five draft proposals from the CEC July 13th workshop to the list server for ASHRAE Technical Committee 1.4 "Control Theory and Application." This list server includes all members, corresponding members and interested parties to TC 1.4. In addition Mark Hydeman addressed the ASHRAE TC 1.4 committee on these proposals at their meeting in Dallas on January 30th, 2007 and requested feedback for the upcoming February 2007 CEC workshop To date not a single negative comment on any of these proposals has been received.

The survey is presented in Appendix A of this report. A summary of the survey results follow:

Question 1, EMCS market place: All three respondents indicated that DDC to the zone level was between 90% to 95% of the new construction market.

Question 2, Top Factors for DDC Purchases:

- Facility Management - 3 Votes
- Improved Comfort and Controls – 3 Votes
- Tenant After Hours Management – 2 Votes
- Alarming – 2 Votes
- Energy Savings – 2 Votes
- First Cost – 2 Votes
- Web Based Access – 1 Vote

Question 3, Relative First Cost of DDC and Pneumatic Controls: The consensus of the respondents is that pneumatic controls generally have a slightly smaller first cost. This cost depends on the number of points in the system as the pneumatic control system incurs a large first cost penalty for the compressor and associated equipment (like air dryers and filters). For small control systems DDC is actually less expensive. For medium and large control systems DDC is likely to be a slight cost premium.

Question 4, Relative Maintenance Cost of DDC and Pneumatic Controls: The consensus of the respondents is that pneumatic controls have a significantly higher maintenance cost (on the order of 20%-40%).

Question 5, Support for the Proposed Requirements: **All** respondents support the proposed requirements.

Results

The results of our investigations indicate that this measure is both cost effective and would be embraced by the industry. As shown in Table 2 above, the TDV for this measure across all climate zones is $1.4/ft2. The cost to implement this measure is $400 to $800 making this cost effective on all systems serving an area over 600 ft2 (>2 tons of cooling).

Recommendations

Proposed Standards Language

Modification of Existing Prescriptive Requirement 144(f)

(f) Supply Air Temperature Reset Controls. Mechanical space-conditioning systems supplying heated or cooled air to multiple zones shall include controls that automatically reset supply-air temperatures:

1. In response to representative building loads or to outdoor air temperature; and

2. By at least 25 percent of the difference between the design supply-air temperature and the design room air temperature.

Air distribution to zones that are likely to have constant loads, such as interior zones, shall be designed for the fully reset supply temperature.

EXCEPTION 1 to Section 144 (f): Systems that meet the requirements of Section 144 (d), without using Exception 1 or 2 to that section.

EXCEPTION 2 to Section 144 (f): Where supply-air temperature reset would increase overall building energy use.

EXCEPTION 3 to Section 144 (f): Zones in which specific humidity levels are required to satisfy process needs.

~~EXCEPTION 4 to Section 144 (f): Variable air volume space-conditioning systems with variable speed drives.~~

Alternate Calculation Manual

No proposed changes

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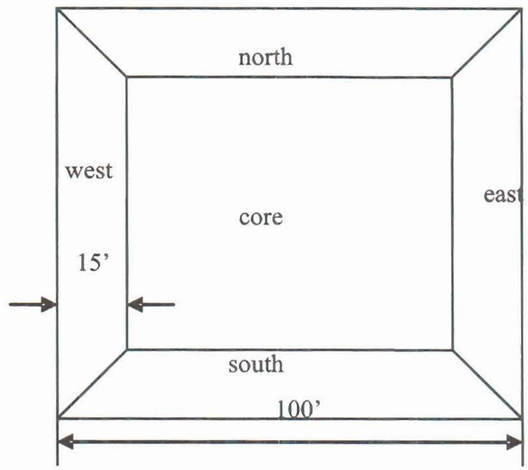
This analysis and report was produced by Jeff Stein and Mark Hydeman of Taylor Engineering, LLC, Alameda, California under contract to the Heschong Mahone Group.

Appendix A. Modeling Assumptions and Results

A 10,000 sf five zone office building was modeled in eQuest to evaluate annual energy performance of the proposed control sequences. Figure 2 shows the layout and dimension of the zones in the eQuest model.

Figure 2 Zone Layout for eQuest Model

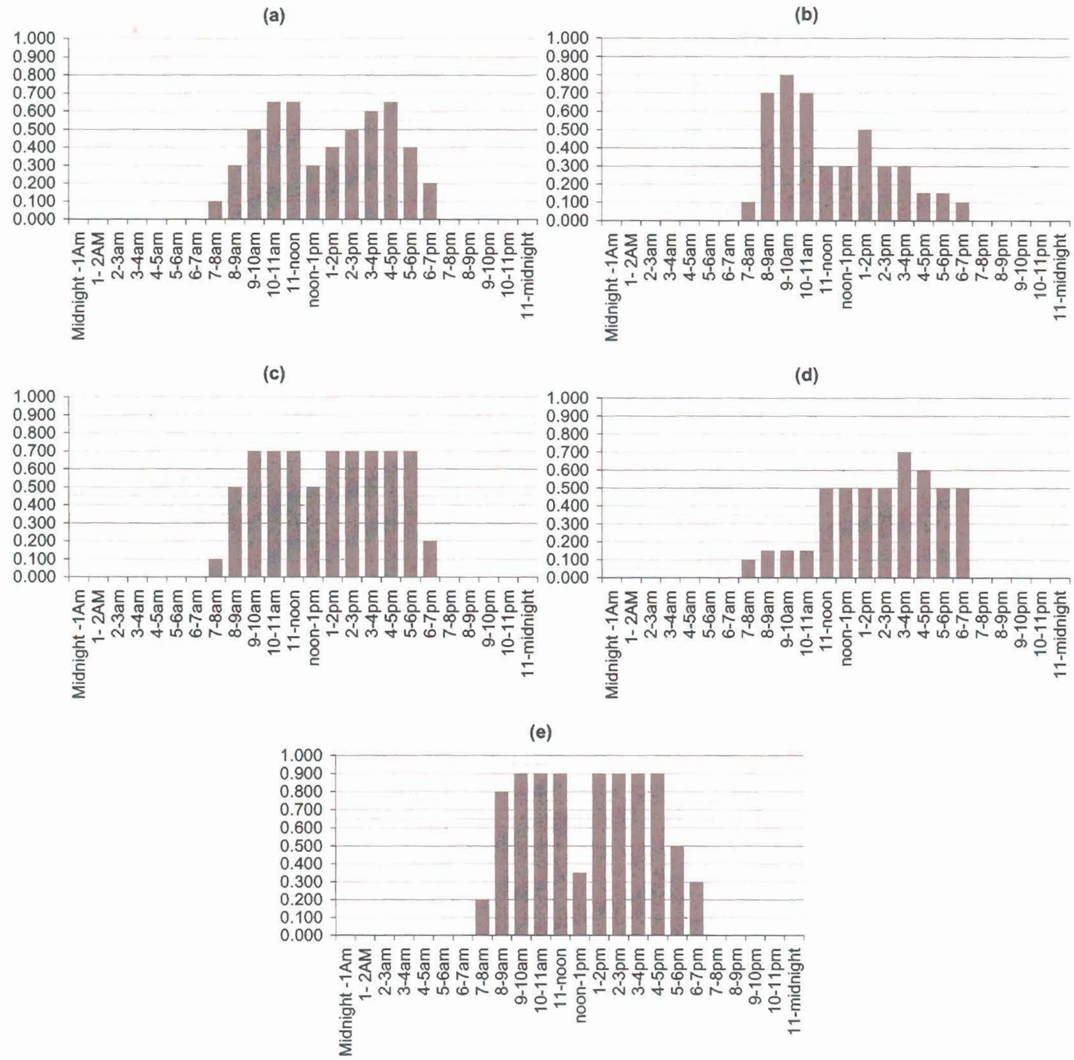


The building envelope consisted of R-19 metal frame roof and R-13 metal frame wall with 40% window wall ratio. All windows use double pane glazing. The U value of the glass is 0.47 and the SHGC value of the glass is 0.31 for non-north facing windows and 0.47 for north facing windows.

The building was modeled to be occupied from 7:00 am to 7:00 pm Monday through Friday and was closed on Saturday, Sunday and holidays. Building internal loads consist of an average 100 sf per person occupancy density, 1.3 w/sf lighting power densities and 1.5 w/sf equipment power density.

In order to simulate "real-life" building operation, five occupancy day schedules were modeled as shown in Figure 3. The simulation models were set up such that on any weekday, each of the five zones uses one of the schedules shown in Figure 3 and no two zones use the same schedule on the same day. From Monday to Friday, each zone uses a different day schedule on a different day. Lighting and equipment schedule are the same as the occupancy schedule.

Figure 3 Occupancy Schedules Used in eQuest Model



The building is conditioned by a packaged VAV system with hot water reheats at VAV boxes. Room temperature setpoint are 75/82 for cooling and 70/64 for heating during occupied/unoccupied hours. The HVAC system runs from one hour before occupancy to one hour after occupancy. System supply air temperature is fixed at 55°F in the basecase. A DOE-2 fan curve that represents static pressure reset was used for all runs.

The model was run using the weather data representing Sacramento, CA (climate zone 12) which is a relatively hot climate in California.

The detailed modeling assumptions for the basecase and the proposed control are shown in Table 6 and Figure 4 below.

Table 6 Basecase modeling assumptions

	Case #	Basecase	Dual max. with VAV heating
HVAC System	System Type	PVAVS	ditto
	Sizing Ratio	1	ditto
	Fan Control	VSD	ditto
	Air Flow	min Fan ratio = 0.1, max Fan ratio = 1.1	ditto
	Fan Eff	SA Fan 53%, RA Fan 53%	ditto
	Fan Performance Curve	Perfect fan curve	ditto
	Fan static pressure	3.5"	ditto
	OA ratio	Default (calc. from zone OA CFM)	ditto
	Economizer	differential drybulb, max temperature limit = 59	ditto
	Cooling EIR	0.36 (9.5 EER)	ditto
	Min SAT	55. °F	ditto
	Max Cooling SAT Reset Temp	59. °F	ditto
	Cooling SAT temp control	Constant	ditto
	Heating SAT temp control	Constant	ditto
	Heating Coil	No coil at packaged unit, only hot water reheating coil at each zone	ditto
	RH Coil Vavle	3-way valve	ditto
	Min Heating Reset Temp	75. °F	ditto
Zone (each)	Thermostat	Proportional	ReverseAction
	Throttling Range	.1 °F	ditto
	Cooling Min Flow Ratio	30%	20%
	Cooling Max Flow Ratio	100%	100%
	Heating Min Flow Ratio	30%	20%
	Heating Max Flow Ratio	30%	100%
	Cooling setpoint	75. °F	ditto
	Heating setpoint	70. °F	ditto
	Cooling setpoint unoccupied	82. °F	ditto
	Heating setpoint unoccupied	64. °F	ditto
Boiler Plant	Boiler HIR	1.25	ditto
	Design HWST	180 °F	ditto
	Design HW loop dT	40 °F	ditto
	HW loop pump control	one speed pump	ditto
Building Envelope	Exterior wall U value	R-13 (code)	ditto
	Roof U value	R-19 (code)	ditto
	WWR	40%	ditto
	Glass Type	U = 0.47, SHGC = 0.31 (nonnorth), 0.47 (north)	ditto
	Area	100 ft by 100 ft, 15 ft perimeter zone depth	ditto
Building Internal Load	Occpancy	100 sf/person	ditto
	Lighting	1.3 w/sf	ditto
	Equipment	1.5 w/sf	ditto
	Schedule	Occupied 7:00 ~19:00 M-F, Unoccupied other days	ditto

Figure 4 eQuest parametric run inputs

Component	Referenc...	Keyword	Array Idx	Baseline	DualMax...
Thermal ...	EL1 Core...	THERMO...	N/A	PROPORT...	REVERSE...
Thermal ...	EL1 Core...	HMIN-FL...	N/A		0.200
Thermal ...	EL1 Core...	CMIN-FL...	N/A		0.200
Thermal ...	EL1 Core...	MIN-FLO...	N/A	0.300	0.200
Thermal ...	EL1 Core...	MIN-CFM...	N/A	0.300	0.200
Thermal ...	EL1 Core...	HMIN-CF...	N/A		0.200
Thermal ...	EL1 Core...	CMIN-CF...	N/A		0.200
HVAC Sy...	Core Sys...	REHEAT-...	N/A	100.000	40.000

Appendix B - EMCS Market Share Survey

The authors did a literature search and surveyed the major EMCS vendors to determine the market share of EMCS vendors in the HVAC controls market nationwide. The results follow:

1. Johnson 16%-25%
2. Siemens 15%-17%
3. Trane 6%-15%
4. Honeywell 7%-10%
5. Alerton 5%-10%
6. Automated Logics 7%-10%
7. Andover 7%-10%
8. Invensys 7%
9. All others 10%-20%

Graphical data from one of the market research sources is presented in Figure 5 below.

Figure 5 – EMCS Market by Company in 2001 (BCS 2002)

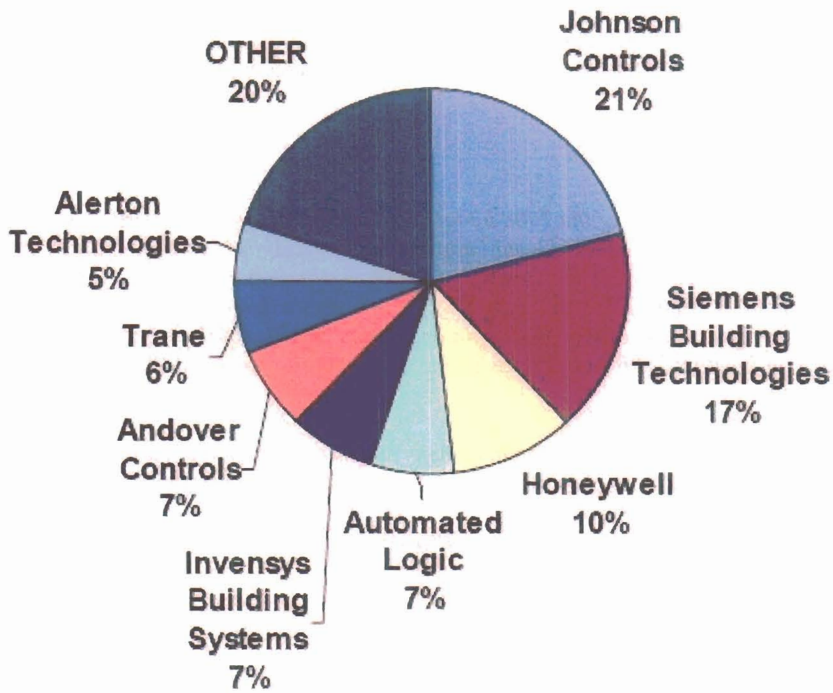
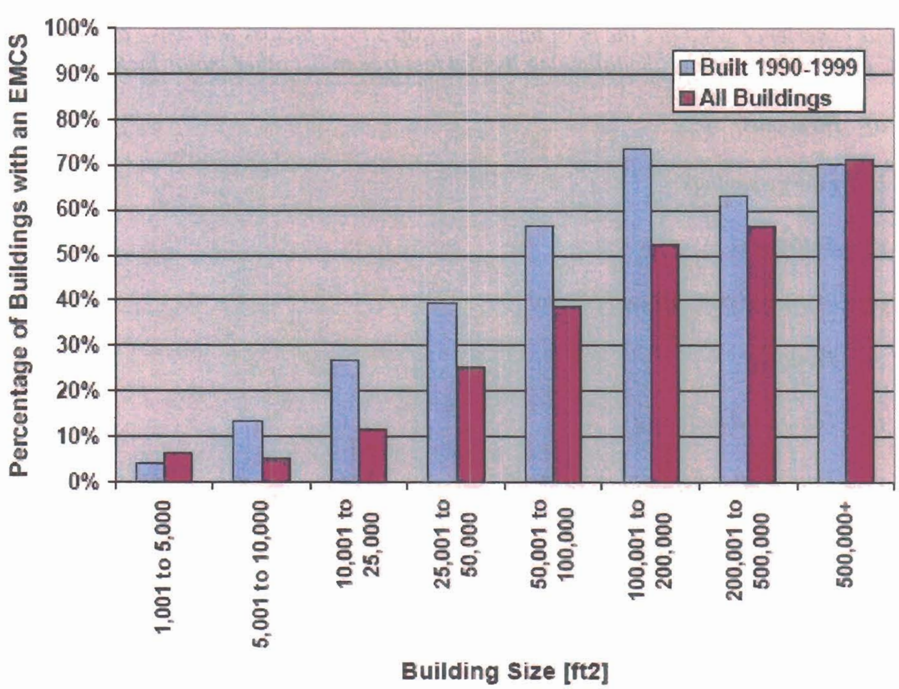


Figure 6 – Buildings with EMCS (EIA 1999)



Survey of EMCS Manufacturers on the Proposed Requirements

An email survey was sent to EMCS vendors to get their reaction to the proposed requirements. The survey was sent to Trane, Honeywell, Invensys, Alerton, Johnson, Automatic Logic Corporation and Siemens. At the time of this report, responses were received from Alerton, Automated Logic Corporation and Siemens. The survey that was sent follows:

Dear [Insert Name],

We are working on the development of the 2008 update of California's building energy code, Title 24. We are preparing for a workshop on July 13th and would appreciate your response by July 1st if possible. One of the issues we are researching relates to DDC controls. We are investigating a code change to specify control requirements on systems that have DDC to the zone level. In order to determine the feasibility of these ideas, we are surveying vendors and contractors for their opinions on the viability of these proposed measures and the make-up of the BMS market in California. To assist our deliberations, we would like you to answer the following questions:

1. *In your opinion, for new construction in commercial buildings what percentage of the controls marketplace (based on $ spent by owners) belongs to the following classes of control products:*

    a) *Fully DDC (including the zone controls)?*

    b) *Hybrid DDC and pneumatic systems?*

    c) *Fully pneumatic?*

    d) *Other (please elaborate)?*

    In considering your answer to this question exclude the single zone units that are controlled by programmable thermostats

2. *In your experience what are the most important (top 3 to 5) factors that drive a customer to purchase DDC controls? Consider the following list but feel free to list other major factors:*

    a) *First cost*

    b) *Energy savings*

    c) *Alarming*

    d) *Improved comfort and control*

    e) *Trending*

    f) *Tenant submetering*

    g) *Tenant after hours management*

    h) *Facility management*

    i) *Web based access*

    j) *Other factors (please list)*

3. *What are the relative installed costs of DDC and pneumatic systems for typical office and retail buildings?*

    a) *On a $/sf basis (or relative % cost basis) if you have the data*

    b) *Qualitatively, are they about the same or is one significantly more expensive?*

4. *Do you have any data on comparative maintenance costs for DDC and pneumatic systems?*

5. *Would you support a code change requiring DDC controls to the zone level for new control systems serving multiple zone systems and equipment?*

    a) *What are some questions or concerns you might have about such a code change?*

    b) *Are there systems or applications where this would not be appropriate?*

6. *The following are specific control requirements that we are considering. Please provide feedback (positive or negative about each). For each control requirement please address the following issues:*

    - *whether your existing systems (hardware and software) will be able to support these requirements*
    - *what exceptions should be included*
    - *the added effort to program and tune these control algorithms*

    Here are the proposed new control requirements

    a) *Hydronic pump pressure reset by demand (either directly by valve demand or through a " trim and respond " algorithm)*

    b) *Ability to globally reset cooling set points on zone thermostats on " non critical " zones by 1 to 4°F for central demand shed.*

    c) *Supply air temperature reset on VAV systems that is only enabled when the system is on 100% economizer cooling*

    d) *Demand controlled ventilation for multiple zone units serving one or more densely occupied zones. The control logic is likely to cascade with the first step controlling the zone box minimum and the second step controlling the minimum OSA damper position.*

Please contact us if you need any clarifications on the above questions. We thank you in advance for your time and we welcome your comments and feedback.