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Air-Conditioning, Heating, and Refrigeration Institute

April 19, 2012

California Energy Commission (CEC)

Re: March 12, 2012 45-day Language Hearing for Nonresidential Buildings - 2013 Building Energy Efficiency Standards (AHRI Comments on §140.4(e)4; Docket # 12-BSTD-1)

Dear CEC Staff:

The Air-Conditioning, Heating and Refrigeration Institute (AHRI) is the trade association representing manufacturers of heating, cooling, water heating, and commercial refrigeration equipment. Over 300 members strong, AHRI is an internationally recognized advocate for the industry, and develops standards for and certifies the performance of many of the products manufactured by our members. In North America, the annual output of the HVACR industry is worth more than $20 billion. In the United States alone, our members employ approximately 130,000 people, and support some 800,000 dealers, contractors, and technicians.

We have some comments on the code language that was proposed at the hearing on March 12, 2012. We feel that the tolerances proposed in §140.4(e)4G – *Sensor Accuracy*, should be reconsidered. Attached is a recent study which proves that the stringent tolerances proposed in §140.4(e)4G have very little impact on energy savings and cannot be economically justified. The study shows that higher tolerances with respect to temperatures also save energy and can be justified. The study is attached and we recommend the following based on the study's findings:

- The drybulb tolerance in §140.4(e)4Gi should be changed from a ±1 ^{o}F to ±2 ^{o}F with a temperature range of 60 – 80 ^{o}F.
- The wetbulb temperature tolerance should be eliminated as it is not used in the requirements.
- The enthalpy accuracy in §140.4(e)4Gii should be changed from 1 Btu/lb to ±3 Btu/lb over a range of 25 – 35 Btu/lb.
- The relative humidity tolerance in §140.4(e)4Giii should be eliminated as it is not used in the requirements.
- A ± 3 ^{o}F differential drybulb tolerance should be added to the differential drybulb sensor requirements with a temperature range of 0 – 15 ^{o}F.

In the case of §140.4(e)4H – *Sensor Calibration Data*, it is unclear as to what is required. Issues are likely to occur if the intent is to use field instrumentation. Such instrumentation is likely to go out of calibration over a period of time and is not appropriate for calibrating factory calibrated sensors. Proper calibration can occur only through laboratory grade

instruments that are routinely calibrated to known standards. We recommend that factory certified calibration be allowed in the code language.

We appreciate this opportunity to submit comments and urge that CEC reconsider the proposed code language in §140.4(e)4G and §140.4(e)4H based on the issues that have been raised in this letter. If you have any questions or wish to discuss this further, please do not hesitate to call me at (703) 600-0383.

Sincerely,

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Title 24 Economizer Change Background

- In the proposed 45 day language for the Title 24 Standard several changes are being made to the economizer requirements
  - Addition of accuracy requirements for high limit changeover devices
    - Dry bulb and wet bulb temperatures accurate to +/-1 F (at what temperature?)
    - Enthalpy accurate to with 1 Btu/lbm (? +/-)
    - Relative humidity accurate to within 5% (5% of what)
  - Revision to the high limit shutoff control requirements defined in table 140.4-B with both elimination of some options and changes in set points
    - Eliminated Fixed Enthalpy, Electronic Enthalpy, and Differential Enthalpy
    - Change is dry bulb set points and addition of offset to differential drybulb
- Lowered the threshold for economizers to 54,000 Btu/hr
- Revision in the economizer elimination table to be similar to ASHRAE 90.1
- Addition of 2 speed and fan staging requirements for >65K has been added
- In parallel to this ASHRAE 90.1 has also been looking at the same type of changes

Title 24 Economizer High Limit

TABLE 140.4-B AIR ECONOMIZER HIGH LIMIT SHUT OFF CONTROL REQUIREMENTS

Device Type[a]	Climate Zones	Required High Limit (Economizer Off When):	
		Equation[b]	Description
Fixed Dry Bulb	1, 3, 5, 11-16	$T_{OA} > 75°F$	Outdoor air temperature exceeds 75°F
	2, 4, 10	$T_{OA} > 73°F$	Outdoor air temperature exceeds 73°F
	6, 8, 9	$T_{OA} > 71°F$	Outdoor air temperature exceeds 71°F
	7	$T_{OA} > 69°F$	Outdoor air temperature exceeds 69°F
Differential Dry Bulb	1, 3, 5, 11-16	$T_{OA} > T_{RA}$	Outdoor air temperature exceeds return air temperature
	2, 4, 10	$T_{OA} > T_{RA}-2°F$	Outdoor air temperature exceeds return air temperature minus 2°F
	6, 8, 9	$T_{OA} > T_{RA}-4°F$	Outdoor air temperature exceeds return air temperature minus 4°F
	7	$T_{OA} > T_{RA}-6°F$	Outdoor air temperature exceeds return air temperature minus 6°F
Fixed Enthalpy[c] + Fixed Drybulb	All	$h_{OA} > 28$ Btu/lb[c] or $T_{OA} > 75°F$	Outdoor air enthalpy exceeds 28 Btu/lb of dry air[c] or Outdoor air temperature exceeds 75°F
~~Fixed Enthalpy[c]~~	~~4, 6, 7, 8, 9, 10 & 12~~	~~$h_{OA} > 28$ Btu/lb[b]~~	~~Outdoor air enthalpy exceeds 28 Btu/lb of dry air[b]~~
~~Electronic Enthalpy~~	~~All~~	~~$(T_{OA}, RH_{OA}) > A$~~	~~Outdoor air temperature/RH exceeds the "A" set point curve[c]~~
~~Differential Enthalpy~~	~~All~~	~~$h_{OA} > h_{RA}$~~	~~Outdoor air enthalpy exceeds return air enthalpy~~

[a] Only the high limit control devices listed are allowed to be used and at the setpoints listed. Others such as Dew Point, Fixed Enthalpy, Electronic Enthalpy, and Differential Enthalpy Controls are prohibited in all climate zones. ~~Fixed Enthalpy Controls are prohibited in climate zones 1, 2, 3, 5, 11, 13, 14, 15 & 16.~~

[b] Devices with selectable (rather than adjustable) setpoints shall be capable of being set to within 2°F and 2 Btu/lb of the setpoint listed.

~~[b, c]~~ At altitudes substantially different than sea level, the Fixed Enthalpy limit value shall be set to the enthalpy value at 75°F and 50% relative humidity. As an example, at approximately 6000 foot elevation the fixed enthalpy limit is approximately 30.7 Btu/lb.

~~[c] Set point "A" corresponds to a curve on the psychometric chart that goes through a point at approximately 75°F and 40% relative humidity and is nearly parallel to dry bulb lines at low humidity levels and nearly parallel to enthalpy lines at high humidity levels.~~

Title 24 Sensor Accuracy Requirements

G. **Sensor accuracy.** Outdoor air, return air and supply air sensors shall be calibrated within the following accuracies.

   i. Drybulb and wetbulb temperatures accurate to ±1°F

   ii. Enthalpy accurate to within 1 Btu/lb

   iii. Relative humidity accurate to within 5%

H. **Sensor calibration data.** Sensor calibration data of sensors used for control of economizer shall be plotted on sensor performance curve.

I. **Sensor high limit control.** Sensors used for the high limit control shall be located to prevent false readings, e.g. properly shielded from direct sunlight.

J. **Relief air system.** Relief air system shall be designed to provide up to 100% outside air without over-pressurizing the building

ASHRAE 90.1 Study

- In the following pages you will find the result of the work that has been performed to analyze the high limit set points and set point accuracy.
- The basic study which is very detailed is being done for ASHRAE 90.1 change evaluations, but has been adapted to the 16 Title 24 climate zones.
- The ASHRAE 90.1 standard model for a 5,000 ft^2 office building was used to model a 7 ton rooftop equipped with the 2 speed fan and staging requirements defined by ASHRAE 90.1 and Title 24 proposed changes including the ASHRAE requirement for 2 speed economizers.
- Subsequently, the model was run for each of the 17 climate zones starting at a high limit of 55 ^oF and ramped it up to 80 ^oF.
- We also mapped the ASHRAE climate zones to the Title 24 16 climate zones so that we can use the data for analysis of title 24.
- We used an energy cost of $.1032/kWh which is the ASHRAE standard work number. California will likely be more like $.16/kWh but we were not sure if there is a defined number for analysis so we used the ASHRAE US average.

Study Scope

We looked at the following items.

- Drybulb change over setpoints and drybulb sensor accuracy
- Differential drybulb setpoint and accuracy
- Enthalpy changeover setpoints and accuracy

General Comments on Tolerances

- As noted earlier the Title 24 change proposal includes requirements on accuracy.
  - Drybulb and wetbulb temperatures accurate to ±1°F
  - Enthalpy accurate to within 1 Btu/lb
  - Relative humidity accurate to within 5%

- Neither the wetbulb or humidity are used in the requirements for economizer high limits and should be removed. Yes they may be used to determine enthalpy, but there already is a tolerance on enthalpy.
- The bulb temperature has an accuracy of ±1°F which is too tight and not cost justified as will be shown in the following study.
- Typically when an accuracy is specified for temperature it is over a given range of temperatures. As the proposal only requires switching at a range of 69 – 75 °F the accuracy should also include a range of 60 – 80 °F.
- The enthalpy is not properly specified. We are assuming it is required to be ±1 Btu/lbm which is also too tight and not economically justified as will be shown in the following study.
- The enthalpy should also include an accuracy range of around 25 – 35 Btu/lbm.
- Not sure why there is a requirement on setpoint capability which is larger than the accuracy requirements. Does not make sense.

Inconsistent Tolerances

- Although the wetbulb tolerance is not need you can compare the ±1 °F wetbulb and drybulb temperature impact on enthalpy
  - For example take 65 °F drybulb/65 °F wetbulb with 63 °F drybulb/63 °F wetbulb and the change in enthalpy is 30.06 Btu/lbm to 28.572 Btu/lbm for a change of 1.488 Btu/lbm.
  - The enthalpy tolerance is +/- 1 Btu/lb which would require 50% tighter tolerances on the drybulb and wetbulb temperatures.

- You can do the same analysis for the relative humidity tolerance of 5%. Starting with 65 °F drybulb and 100% RH and then looking at 63 °F (-2 °F = ±1 °F) and 90% RH (-10% = ±5%) the enthalpy change is 30.06 Btu/lbm to 27.203 Btu/lbm for a change of 2.857 Btu/lbm is 2.8 times the tolerance for the enthalpy.

- Conclusion is that the specific tolerances do not agree with the end result tolerance for Btu/lbm.

Drybulb Setpoint and Tolerance Analysis

- Using the model of the 5,000 ft^2 building we ran the model for the 7 ton units in all 17 ASHRAE climate zones from 55 °F changeover temperature to an 80 °F changeover temperature.

- The units for the building was a 7 ton rooftop with the new staging requirements defined for ASHRAE 90.1 and Title 24 including the 2 speed fan and 2 stage economizer.

- The unit was run with an external static of 1 inch.

- We calculated the change in cooling energy cost as a function of the change in drybulb high limit.

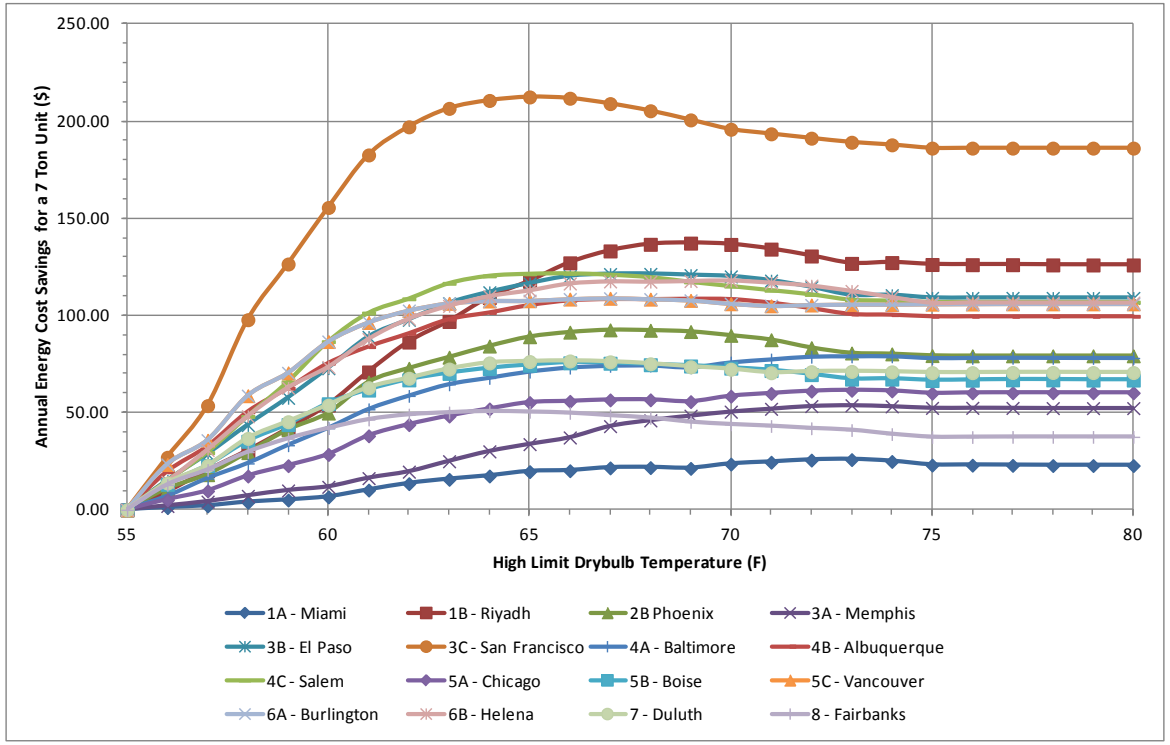
Drybulb Changeover Results

- The following table shows the energy cost savings for each climate zone as a function of the drybulb changeover setpoint.
- The values are annualized energy cost savings relative to 55 °F changeover for the 7 ton system based on an energy cost of 0.1032 $/kwh.

ASHRAE Climate Zone	ASHRAE Benchmark City	Title 24 Climate Zone	Drybulb Changeover temperature (F)																										
			55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
			Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F	Savings vs 55 F
			$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$
1A	1A - Miami		0.00	1.12	2.01	3.88	5.02	6.63	10.15	13.46	15.66	17.39	19.63	20.11	21.56	21.71	21.32	23.52	24.48	25.57	25.82	24.88	23.00	22.94	22.86	22.77	22.77	22.76
1B	1B - Riyadh		0.00	9.11	20.12	30.37	41.62	53.93	70.90	86.31	96.90	109.23	117.53	127.06	133.19	136.60	137.21	136.53	134.12	130.58	126.78	127.20	126.20	126.11	126.11	126.00	125.97	125.97
2A	2A - Houston		0.00	5.01	9.41	18.58	24.43	29.53	34.48	41.23	46.50	49.43	52.25	53.20	54.18	54.19	53.53	56.00	57.50	58.61	58.87	58.19	56.71	56.69	56.69	56.69	56.69	56.69
2B	2B Phoenix		0.00	10.77	18.08	29.43	41.13	49.78	65.74	72.81	78.52	84.25	89.05	91.40	92.58	92.38	91.73	89.78	87.52	83.44	80.68	80.22	79.36	79.24	79.24	79.24	79.24	79.24
3A	3A - Memphis		0.00	1.97	4.18	7.18	9.93	11.83	16.29	19.62	25.00	30.08	33.78	37.21	43.04	46.03	48.38	50.47	51.96	53.37	53.77	53.25	52.44	52.47	52.41	52.33	52.31	52.31
3B	3B - El Paso	6,8,9,10,11,12, 13,14,15	0.00	15.01	28.61	43.60	57.61	72.83	88.97	97.76	106.31	111.92	116.45	120.20	121.29	121.36	120.76	120.08	117.93	114.51	110.43	110.41	109.03	109.00	109.03	109.00	109.00	109.00
3C	3C - San Francisco	3	0.00	27.01	53.60	97.81	126.45	155.55	182.57	197.03	206.54	210.60	212.40	211.75	208.98	205.30	200.60	195.79	193.43	191.20	189.10	187.77	186.09	186.09	186.09	186.09	186.09	186.09
4A	4A - Baltimore		0.00	6.93	16.08	23.86	33.22	42.01	51.72	58.62	64.55	67.85	71.05	73.13	74.04	74.19	73.25	75.77	77.32	78.74	78.92	78.95	78.03	78.13	78.19	78.15	78.11	78.09
4B	4B - Albuquerque		0.00	19.54	32.62	50.41	62.55	75.44	83.95	90.76	98.08	101.53	105.35	107.80	108.49	108.41	108.62	108.42	106.61	103.77	100.77	100.41	99.58	99.57	99.55	99.57	99.57	99.57
4C	4C - Salem	4	0.00	14.71	29.44	48.03	65.82	86.52	101.23	108.56	116.53	120.35	121.39	121.61	120.92	119.65	117.24	115.06	112.94	110.80	108.02	107.51	106.87	106.89	106.89	106.88	106.87	106.87
5A	5A - Chicago		0.00	5.15	9.72	17.36	22.69	28.46	38.06	43.81	48.23	51.88	55.17	55.81	56.55	56.58	55.65	58.46	59.87	61.05	61.49	61.16	59.96	60.17	60.22	60.21	60.19	60.19
5B	5B - Boise		0.00	13.13	22.77	35.26	43.83	54.56	61.60	66.85	70.18	72.68	74.38	75.62	75.41	74.65	73.99	72.89	71.66	69.56	67.25	67.26	66.52	66.70	66.87	66.86	66.76	66.76
5C	5C - Vancouver	5	0.00	23.32	35.79	58.71	70.47	86.59	96.40	102.51	106.23	107.44	107.56	108.42	108.84	108.39	107.76	106.02	104.96	105.37	105.63	105.66	105.80	105.89	105.97	105.97	105.97	105.97
6A	6A - Burlington		0.00	7.40	14.84	26.63	33.47	41.38	49.68	54.04	58.34	61.98	64.64	65.45	65.86	65.46	63.82	61.68	59.82	60.97	61.18	61.00	60.29	60.28	60.28	60.28	60.28	60.28
6B	6B - Helena	2	0.00	14.43	30.82	48.14	62.80	73.47	87.84	98.25	104.91	109.89	112.89	116.44	117.50	117.36	117.70	117.97	116.85	115.31	112.59	109.43	106.49	106.65	106.59	106.57	106.57	106.57
7	7 - Duluth	1,7	0.00	13.77	22.76	36.74	45.31	53.84	62.81	67.68	72.42	75.57	76.26	76.58	76.13	75.12	73.58	72.33	70.52	71.07	71.20	70.97	70.56	70.56	70.64	70.65	70.60	70.60
8	8 - Fairbanks		0.00	12.80	20.50	29.69	36.61	41.96	46.48	48.98	50.06	50.71	50.40	49.85	48.54	47.28	45.21	43.98	43.12	41.96	41.03	38.96	37.43	37.43	37.51	37.53	37.53	37.53

Drybulb Changeover Results

- This is the same data but plotted to show where the peak energy savings occurs and that the curve in the range of the setpoints is very flat.
- From this you can see that many of the Title 24 changes are higher than the peak energy savings changeover setpoint and could lowered.
- This has an advantage of protecting the space from humidity problems on days with high relative humidity.
- Also it shows that you can change the setpoints with very little impact on operating cost which indicates the tolerance is not as critical as assumed when a ± 1 °F tolerance was specified.



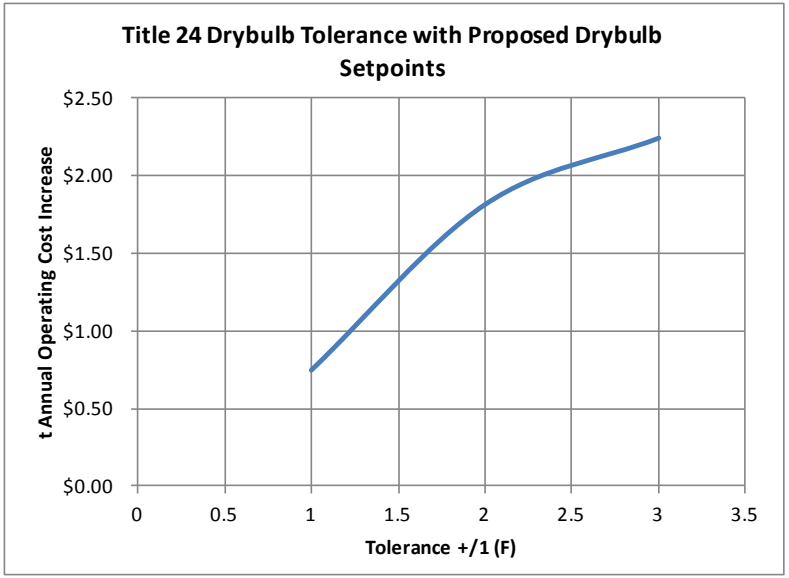
Drybulb Tolerance

- Using the analysis I think looked at ± tolerances of 1, 2, and 3 °F and the impact on operating cost.
- I used the Title 24 setpoints which results in some cases the savings actually increasing with the increased tolerances.

California Climate Zone	City	HDD	CDD	ASHRAE Climate Zone	Title 24 Drybulb Setting	Optimum Setting	Energy Cost Savings vs Nominal Setpoint Title 24 Setpoint					
							+/- 1 F		+/- 2 F		+/- 3 F	
							-1 F	+1 F	-2 F	+2 F	-3 F	+3 F
1	Arcata	5297	5	7	75	66	$0.41	$0.00	$0.64	$0.08	$0.51	$0.09
2	Sata Rosa	4001	712	6B	73	67	($2.72)	($3.15)	$4.26	($6.10)	$5.39	($5.94)
3	Oakland	3383	276	3C	75	65	$1.68	$0.00	$3.01	$0.00	$5.11	$0.00
4	Sunnyvale	2676	558	4C	73	66	$2.78	($0.51)	$4.92	($1.15)	$7.04	($1.13)
5	Santa Maria	3541	323	5C	75	67	($0.14)	$0.09	($0.17)	$0.17	($0.43)	$0.17
6	Los Angeles	1699	963	3B	71	69	$2.15	($3.42)	$2.83	($7.50)	$3.43	($7.52)
7	San Diego	1220	617	3B	69	66	$0.60	($0.68)	$0.53	($2.83)	($0.55)	($6.24)
8	El Toro	1512	879	3B	71	69	$2.15	($3.42)	$2.83	($7.50)	$3.43	($7.52)
9	Burbank	1699	963	3B	71	69	$0.60	($0.68)	$0.53	($2.83)	($0.55)	($6.24)
10	Riverside	3165	1711	3B	73	69	$4.09	($0.02)	$7.50	($1.40)	$9.65	($1.43)
11	Red Bulff	3104	1974	3B	75	69	$1.38	($0.03)	$1.40	($0.00)	$5.49	($0.03)
12	Sacramento	3285	1345	3B	75	69	$1.38	($0.03)	$1.40	($0.00)	$5.49	($0.03)
13	Fresno	2682	2258	3B	75	69	$1.38	($0.03)	$1.40	($0.00)	$5.49	($0.03)
14	China Lake	3135	2816	3B	75	69	$1.38	($0.03)	$1.40	($0.00)	$5.49	($0.03)
15	El Centro	1392	4476	3B	75	69	$1.38	($0.03)	$1.40	($0.00)	$5.49	($0.03)
16	Mt Shasta	6455	699	7	75	69	$1.38	($0.03)	$1.40	($0.00)	$5.49	($0.03)
						average	$1.24	($0.75)	$2.20	($1.82)	$4.12	($2.25)
					highest negative cost		($0.75)		($1.82)		($2.25)	

Drybulb Tolerances

- Taking the prior chart you can then plot the operating cost increase as a function of the 1, 2, and 3 °F tolerance.



- As you can see if we doubled the tolerance to ±2 °F the operating cost on average only increased $1.75 per year for the 7 ton system
- Assuming a base cost for the sensor of $20 and that the ±1 °F tolerance would double the cost it would have a payback of 11.4 years using the ASHRAE 90.1 power cost. This is well beyond a reasonable payback.
- **We recommend to tolerance be increased to +/-2 °F for a temperature range of 60 to 80 F ambient temperatures**

Enthalpy Setpoint and Tolerance

- The title 24 proposal only allows enthalpy and temperature combined high limit setpoint which is a good approach.
- The use of enthalpy control is beneficial for constant volume systems that do not control the leaving air temperature like VAV systems to prevent indoor humidity and moisture problems during high humidity days which can occur on raining days or early in the morning when economizers are often used.
- The use of the 28 Btu/lbm setpoint is a accepted limit based on years of use to prevent moisture issues in the space, so we would not recommend it be change even though the study sometimes show so changes could be made.
- In the following page you will find the results of the study where we just varied the enthalpy from 20 to 36 Btu/lbm.

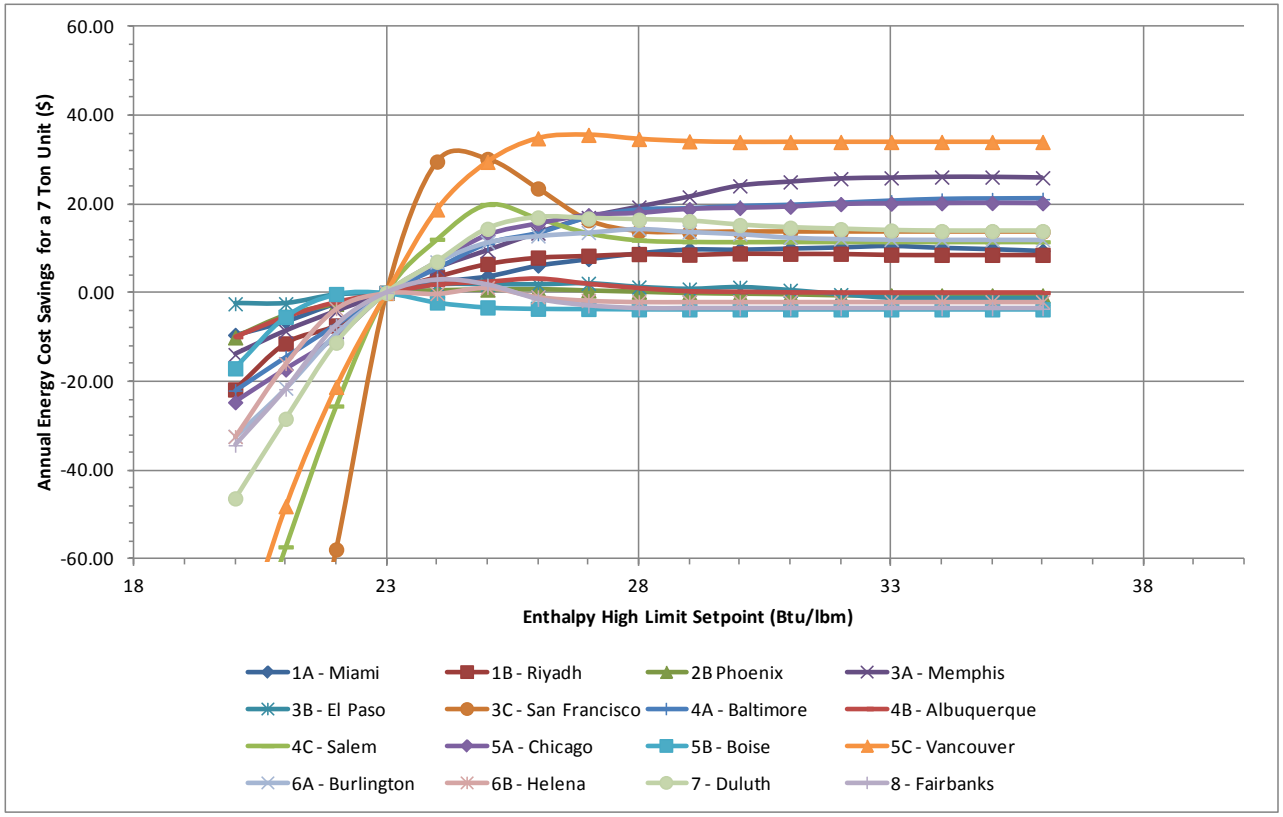
Enthalpy Changeover Energy Savings Results

- The following is a summary for each climate zone showing the annualized energy savings for the 7 ton unit with fixed enthalpy control relative to a 23 Btu/lbm setpoint.
- The red values are the peak savings point, ignoring any issues with space humidity.

ASHRAE Climate Zone	ASHRAE Benchmark City	Title 24 Climate Zone	Fixed Enthalpy Changeover Value (Btu/lbm)																
			20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
			Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm	Savings vs 23 Btu/lbm
			$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$
1A	1A - Miami		-9.48	-6.39	-2.40	0.00	2.44	3.73	6.15	7.61	8.95	9.80	9.77	10.03	10.29	**10.62**	10.20	9.90	9.48
1B	1B - Riyadh		-21.78	-11.41	-7.36	0.00	3.60	6.52	7.94	8.36	8.74	8.61	8.87	**8.81**	8.81	8.59	8.57	8.57	8.57
2A	2A - Houston		-18.13	-10.50	-5.39	0.00	3.69	8.03	10.54	13.58	16.76	18.61	19.41	19.61	19.81	**20.10**	19.90	19.71	19.50
2B	2B Phoenix		-10.03	-5.07	-2.49	0.00	0.58	0.74	**0.85**	0.54	0.26	-0.04	-0.19	-0.32	-0.57	-0.57	-0.57	-0.57	-0.57
3A	3A - Memphis		-13.92	-8.68	-4.23	0.00	5.51	9.49	13.46	16.97	19.33	21.60	24.10	25.00	25.73	25.90	**26.09**	26.08	25.93
3B	3B - El Paso	6,8,9,10,11,12, 13,14,15	-2.46	-2.45	-0.46	0.00	1.85	1.92	1.90	**2.13**	1.31	0.84	1.25	0.56	-0.41	-1.25	-1.31	-1.31	-1.31
3C	3C - San Francisco	3	-153.87	-108.52	-57.83	0.00	29.57	30.16	23.51	16.37	**13.87**	13.69	13.77	13.77	13.77	13.77	13.77	13.77	13.77
4A	4A - Baltimore		-22.03	-14.53	-7.27	0.00	5.39	10.96	13.31	16.81	18.57	18.85	19.37	19.62	20.09	20.56	20.95	21.05	**21.11**
4B	4B - Albuquerque		-9.90	-5.43	-2.11	0.00	1.87	2.48	**3.20**	2.04	1.07	0.34	0.23	0.09	0.06	0.06	0.06	0.06	0.06
4C	4C - Salem	4	-90.32	-57.24	-25.51	0.00	12.07	**19.91**	16.82	13.47	11.87	11.53	11.48	11.50	11.50	11.50	11.50	11.50	11.50
5A	5A - Chicago		-24.65	-17.28	-10.11	0.00	6.89	13.00	15.56	17.50	**17.96**	18.87	19.13	19.40	19.99	20.10	20.19	20.23	20.19
5B	5B - Boise		-17.01	-5.41	-0.28	**0.00**	-2.16	-3.28	-3.58	-3.63	-3.70	-3.71	-3.71	-3.71	-3.71	-3.71	-3.71	-3.71	-3.71
5C	5C - Vancouver	5	-83.37	-48.08	-21.19	0.00	18.80	29.52	34.83	**35.60**	34.68	34.15	33.99	34.00	34.00	34.00	34.00	34.00	34.00
6A	6A - Burlington		-32.34	-21.47	-9.12	0.00	6.96	11.38	12.83	13.61	**14.43**	13.77	13.28	12.49	12.18	12.04	12.00	12.00	11.97
6B	6B - Helena	2	-32.37	-15.95	-3.57	0.00	-0.16	**1.18**	-0.88	-1.71	-2.01	-2.01	-2.01	-2.01	-2.01	-2.01	-2.01	-2.01	-2.01
7	7 - Duluth	1,7	-46.32	-28.39	-11.23	0.00	7.01	14.42	**16.98**	16.75	16.47	16.16	15.27	14.67	14.35	14.03	13.90	13.90	13.90
8	8 - Fairbanks		-34.35	-21.72	-7.37	0.00	**2.85**	1.74	-1.50	-2.96	-3.58	-3.58	-3.58	-3.58	-3.58	-3.58	-3.58	-3.58	-3.58

Peak Enthalpy Changeover Setpoint

- The following is a plot of the energy savings.
- Again it shows that in the range of a 28 Btu/lbm setpoint that the curves are flat and changes or tolerances will not have a big impact.



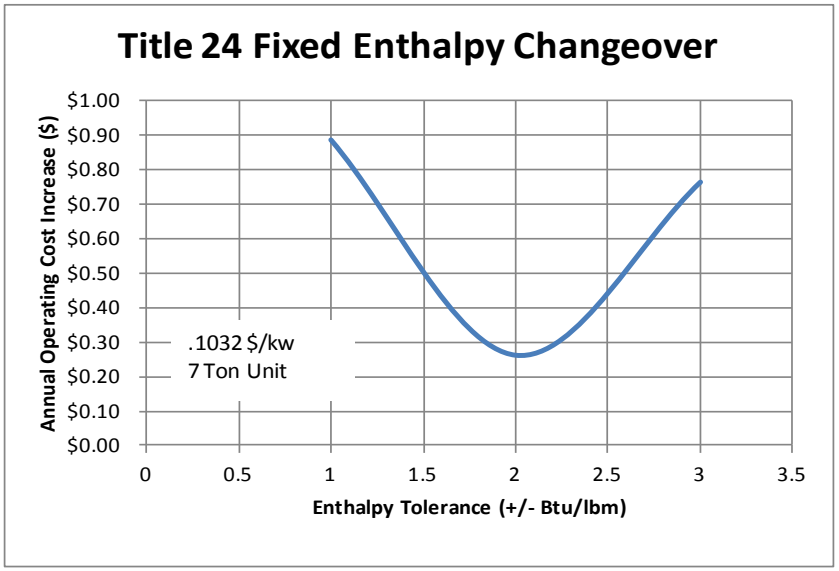
Enthalpy Setpoint Tolerance Study

- Using the model I looked at the energy cost impact for ± 1, 2, and 3 Btu/lbm tolerances relative to a 28 Btu/lbm setpoint.

City	HDD	CDD	ASHRAE Climate Zone	Title 24 Enthalpy Setting	Optimum Setting	Energy Cost Savings vs 28 Btu/lbm Setpoint					
						+/-1 Btu/lbm		+/-2 Btu/lbm		+/-3 Btu/lbm	
				Btu/lbm	Btu/lbm	-1	+1	-1	+1	-1	+1
Arcata	5297	5	7	28	26	($0.28)	$0.31	$0.51	($1.20)	($2.05)	($1.80)
Sata Rosa	4001	712	6B	28	25	($0.30)	$0.00	$1.13	$0.00	$3.19	$0.00
Oakland	3383	276	3C	28	28	($2.51)	$0.17	$9.65	($0.09)	$16.30	($0.09)
Sunnyvale	2676	558	4C	28	25	($1.60)	$0.34	$4.95	($0.39)	$8.04	($0.37)
Santa Maria	3541	323	5C	28	27	($0.92)	$0.52	$0.15	($0.69)	($5.16)	($0.68)
Los Angeles	1699	963	3B	28	27	($0.82)	$0.47	$0.59	($0.06)	$0.61	($0.74)
San Diego	1220	617	3B	28	27	($0.82)	$0.47	$0.59	($0.06)	$0.61	($0.74)
El Toro	1512	879	3B	28	27	($0.82)	$0.47	$0.59	($0.06)	$0.61	($0.74)
Burbank	1699	963	3B	28	27	($0.82)	$0.47	$0.59	($0.06)	$0.61	($0.74)
Riverside	3165	1711	3B	28	27	($0.82)	$0.47	$0.59	($0.06)	$0.61	($0.74)
Red Bulff	3104	1974	3B	28	27	($0.82)	$0.47	$0.59	($0.06)	$0.61	($0.74)
Sacramento	3285	1345	3B	28	27	($0.82)	$0.47	$0.59	($0.06)	$0.61	($0.74)
Fresno	2682	2258	3B	28	27	($0.82)	$0.47	$0.59	($0.06)	$0.61	($0.74)
China Lake	3135	2816	3B	28	27	($0.82)	$0.47	$0.59	($0.06)	$0.61	($0.74)
El Centro	1392	4476	3B	28	27	($0.82)	$0.47	$0.59	($0.06)	$0.61	($0.74)
Mt Shasta	6455	699	7	28	26	($0.28)	$0.31	$0.51	($1.20)	($2.05)	($1.80)
					average	($0.88)	$0.39	$1.43	($0.26)	$1.52	($0.76)
					maximum cost increase	($0.88)		($0.26)		($0.76)	

Enthalpy Tolerances

- Taking the prior chart you can then plot the operating cost increase as a function of the 1, 2, and 3 Btu/lbm tolerance.



- As you can see if we triple the tolerance to +/- 3 Btu/lbm that the operating cost increase vs. zero tolerance is only $.76 per year.
- Vs the 1 Btu/lbm tolerance the 3 Btu/lbm tolerance is actual lower in energy cost impact as the 28 Btu/lbm is not the optimum.
- **We recommend to tolerance be increased to ± 3 Btu/lbm for a range of enthalpy of temperature range of 25 to 35 Btu/lbm enthalpies.**

Differential Drybulb Setpoint and Tolerances

- It is well known that a differential drybulb control with accurate sensors can provide the greatest savings in a dry climate like California.
- New to the proposal for Title 24 is to offset this by 0 to 6 °F lower return air temperatures.
- Again, we used the 5 ton model to analysis the setpoints and tolerances for differential drybulb changeover.
- We ran the analysis from with a return air offset of -3 °F to 15 °F using the following high limit
  - High Limit – OAT>RAT-Offset

Differential Drybulb Offset Analysis

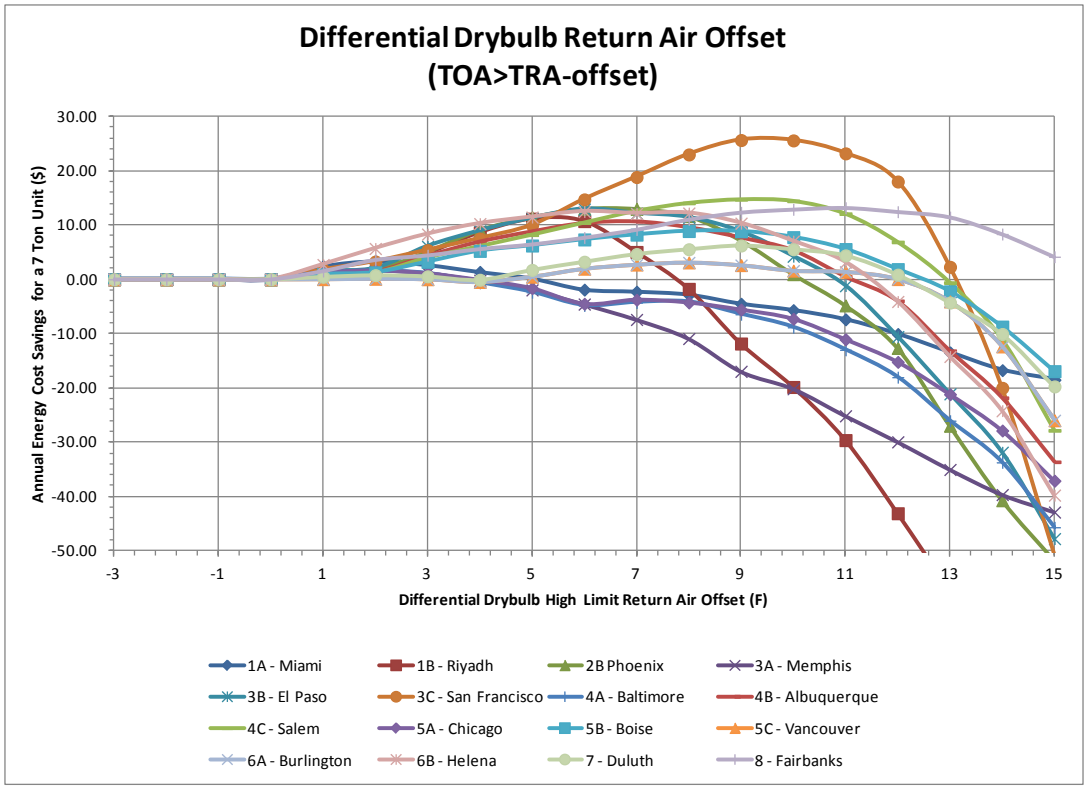
- The following shows the results of the offset analysis for the differential drybulb changeover cost savings relative to 0 °F offset.

ASHRAE Climate Zone	ASHRAE Benchmark City	Title 24 Climate Zone	Drybulb Changeover temperature (F)																	
			-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
			Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $	Savings vs 0 F $
1A	1A - Miami		0.00	0.00	0.00	0.00	2.41	**3.33**	2.65	1.37	0.16	-1.90	-2.28	-2.82	-4.50	-5.67	-7.38	-10.07	-13.46	-16.73	-18.49
1B	1B - Riyadh		0.00	0.00	0.00	0.00	1.38	1.31	4.78	8.65	**11.16**	10.71	5.03	-1.76	-11.83	-19.83	-29.61	-43.07	-57.63	-74.73	-92.22
2A	2A - Houston		0.00	0.00	0.00	0.00	1.87	**2.42**	1.91	0.07	-1.61	-3.13	-3.14	-4.44	-6.70	-10.04	-13.95	-21.04	-26.49	-31.52	-37.64
2B	2B Phoenix		0.00	0.00	0.00	0.00	1.11	1.79	5.08	9.08	11.44	**12.98**	12.98	11.63	7.17	0.94	-4.81	-12.64	-26.97	-40.68	-51.77
3A	3A - Memphis		0.00	0.00	0.00	0.00	1.22	**1.71**	1.18	-0.18	-1.95	-4.56	-7.40	-10.91	-16.95	-20.13	-25.13	-29.93	-35.02	-39.64	-42.85
3B	3B - El Paso	6,8,9,10,11,12, 13,14,15	0.00	0.00	0.00	0.00	1.47	2.04	6.05	8.90	11.23	**12.92**	12.14	11.38	8.76	4.25	-1.17	-10.55	-21.08	-31.85	-47.75
3C	3C - San Francisco	3	0.00	0.00	0.00	0.00	1.77	3.27	5.37	7.52	9.96	14.71	18.82	22.98	**25.63**	25.57	23.18	18.00	2.29	-19.99	-50.60
4A	4A - Baltimore		0.00	0.00	0.00	0.00	1.16	**1.47**	1.04	-0.66	-2.39	-4.83	-4.28	-4.20	-6.44	-8.84	-12.98	-18.02	-26.03	-33.71	-45.65
4B	4B - Albuquerque		0.00	0.00	0.00	0.00	1.08	1.46	4.35	6.97	8.86	10.42	**10.71**	9.65	7.75	5.40	0.55	-3.96	-13.14	-21.80	-33.60
4C	4C - Salem	4	0.00	0.00	0.00	0.00	0.74	1.21	3.98	6.09	8.20	10.42	12.58	14.05	**14.72**	14.43	12.08	6.87	-0.60	-11.06	-27.82
5A	5A - Chicago		0.00	0.00	0.00	0.00	1.23	**1.61**	1.10	-0.12	-1.64	-4.51	-3.77	-4.27	-5.58	-7.28	-11.05	-15.21	-21.17	-27.84	-37.08
5B	5B - Boise		0.00	0.00	0.00	0.00	0.94	1.28	3.22	5.23	6.22	7.34	8.22	**8.89**	8.84	7.76	5.56	1.87	-2.22	-8.71	-16.91
5C	5C - Vancouver	5	0.00	0.00	0.00	0.00	0.03	0.10	0.01	-0.49	0.48	1.95	2.71	**3.10**	2.61	1.59	1.39	0.04	-4.08	-12.36	-25.96
6A	6A - Burlington		0.00	0.00	0.00	0.00	0.71	1.03	0.74	-0.32	1.50	3.64	4.71	**5.12**	4.29	2.40	-0.61	-4.49	-11.04	-16.77	-25.06
6B	6B - Helena	2	0.00	0.00	0.00	0.00	2.72	5.67	8.31	10.25	11.45	**12.48**	12.12	12.18	10.32	7.02	3.16	-4.09	-14.21	-24.18	-39.74
7	7 - Duluth	1,7	0.00	0.00	0.00	0.00	0.46	0.76	0.55	-0.09	1.73	3.23	4.65	5.53	**6.22**	5.53	4.40	0.85	-4.29	-10.07	-19.72
8	8 - Fairbanks		0.00	0.00	0.00	0.00	1.53	3.58	4.43	5.59	6.45	7.68	9.15	11.01	12.32	12.88	**13.18**	12.45	11.45	8.33	4.15

- The red bold test is the peak energy savings and the red box is the title 24 recommend offset.
- In general greater offsets can be used than proposed in the title 24 table.

Peak Differential Drybulb Offset Setpoint

- The following is a plot of the energy savings for the differential drybulb changeover relative to the return air offset of 0 °F .



- This has more of a peak than pure drybulb, but there is a flat spot for each climate zone of 4 – 5 °F.

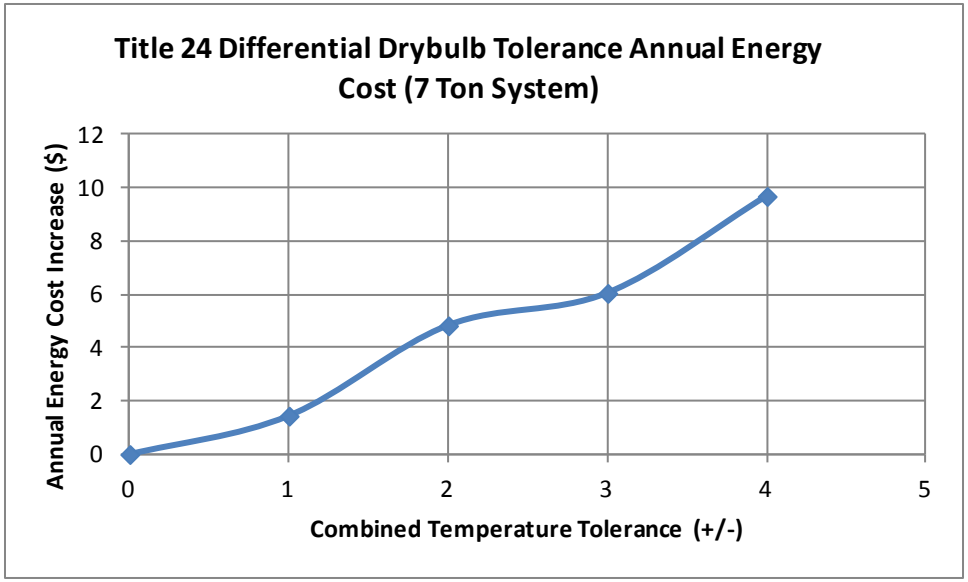
Differential Drybulb Tolerance Study

- The following is the results of the tolerance study with 1, 2, 3, and 4 tolerance ± tolerance relative to the peak offset temperature.

California Climate Zone	City	HDD	CDD	ASHRAE Climate Zone	Title 24 Drybulb Setting	Optimum Setting	Energy Cost Savings vs Nominal Setpoint							
							+/- 1 F		+/- 2 F		+/- 3 F		+/- 4 F	
							-1 F	+1 F	-2 F	+2 F	-3 F	+3 F	-4 F	+4 F
1	Arcata	5297	5	7	0	9	($0.69)	($0.69)	($1.57)	($1.82)	($2.99)	($5.37)	($4.49)	($10.51)
2	Sata Rosa	4001	712	6B	2	6	($1.03)	($0.36)	($0.46)	($0.30)	($4.17)	($2.16)	($6.81)	($5.46)
3	Oakland	3383	276	3C	0	9	($2.65)	($0.06)	($6.81)	($2.45)	($10.93)	($7.63)	($15.67)	($23.34)
4	Sunnyvale	2676	558	4C	2	9	($0.67)	($0.29)	($2.14)	($2.63)	($4.29)	($7.84)	($6.52)	($15.32)
5	Santa Maria	3541	323	5C	0	8	($0.39)	($0.49)	($1.15)	($1.51)	($2.63)	($1.71)	($3.59)	($3.06)
6	Los Angeles	1699	963	3B	4	6	($1.69)	($0.78)	($6.35)	($1.54)	($6.88)	($4.16)	($10.88)	($8.67)
7	San Diego	1220	617	3B	6	6	($1.69)	($0.78)	($6.35)	($1.54)	($6.88)	($4.16)	($10.88)	($8.67)
8	El Toro	1512	879	3B	4	6	($1.69)	($0.78)	($6.35)	($1.54)	($6.88)	($4.16)	($10.88)	($8.67)
9	Burbank	1699	963	3B	4	6	($1.69)	($0.78)	($6.35)	($1.54)	($6.88)	($4.16)	($10.88)	($8.67)
10	Riverside	3165	1711	3B	2	6	($1.69)	($0.78)	($6.35)	($1.54)	($6.88)	($4.16)	($10.88)	($8.67)
11	Red Bulff	3104	1974	3B	0	6	($1.69)	($0.78)	($6.35)	($1.54)	($6.88)	($4.16)	($10.88)	($8.67)
12	Sacramento	3285	1345	3B	0	6	($1.69)	($0.78)	($6.35)	($1.54)	($6.88)	($4.16)	($10.88)	($8.67)
13	Fresno	2682	2258	3B	0	6	($1.69)	($0.78)	($6.35)	($1.54)	($6.88)	($4.16)	($10.88)	($8.67)
14	China Lake	3135	2816	3B	0	6	($1.69)	($0.78)	($6.35)	($1.54)	($6.88)	($4.16)	($10.88)	($8.67)
15	El Centro	1392	4476	3B	0	6	($1.69)	($0.78)	($6.35)	($1.54)	($6.88)	($4.16)	($10.88)	($8.67)
16	Mt Shasta	6455	699	7	0	9	($0.69)	($0.69)	($1.57)	($1.82)	($2.99)	($5.37)	($4.49)	($10.51)
						average	($1.44)	($0.65)	($4.83)	($1.62)	($6.05)	($4.48)	($9.40)	($9.68)
						variation	($1.44)		($4.83)		($6.05)		($9.68)	

Differential Drybulb Tolerance Study

- The following is a plot of the prior chart on differential tolerances.



- We feel that a combined tolerance for the differential of ±3 °F would be appropriate. This is slightly tighter than combined error of two sensors with a ±2 °F but it would encourage the development of differential sensors.
- We are checking with suppliers of sensors to get their feedback, but even a ±4 °F would not be much of a cost penalty.

Overall Recommendations

- Consider some decrease in the fixed drybulb setpoints as most appear to be higher than the peak value.
- Consider some increase to the offset for the differential drybulb.
- Remove the requirement for wetbulb and humidity sensors accuracy as they are not used in the requirements.
- Increase the drybulb tolerance to ±2 °F for fixed drybulb and add a range requirement of 60 – 80 °F.
- Add a requirement for differential drybulb tolerance of ±3 °F tolerance with a range of 0 – 15 °F.
- Increase the enthalpy tolerance to ± 3 Btu/lbm with a range of 25 to 35 Btu/lbm.