CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Draft Measure Information Template – Chiller Minimum Efficiency

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team, April 2011

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CONTENTS

1. Overview

1.1 Measure Title

Chiller Minimum Efficiency

1.2 Description

This measure proposes to update Title 24-2013 to adopt and build on the changes to the chiller efficiency measures new in ASHRAE 90.1-2010. In particular this includes the new chiller efficiencies in 90.1-2007 Addendum M and the increase in coverage of centrifugal chillers in 90.1-2007 Addenda BL and BT (K-factor adjustment). Addendum M introduced two paths to compliance Path A for fixed speed chillers and Path B for variable speed chillers. This measure proposes to go beyond 90.1 2010 in that it seeks to choose only one path per chiller category based on life-cycle cost.

This report also proposes changes to the existing limitations for air cooled chillers 144(i) (new constructions) and 149(c) (plant expansions). These provisions have been gamed in the field and we are proposing changes to close loopholes.

1.3 Type of Change

This proposes changes to the mandatory requirements, prescriptive requirements and the performance requirements.

1.4 Energy Benefits

This measure proposes to increase the minimum energy efficiency requirements of both air-cooled and water-cooled chillers in California. Increased energy efficiency reduces the amount of cooling energy required to maintain the same cooling output.

A summary of the energy savings results are given below in

	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings	TDV Gas Savings
Per ton of cooling capacity	328.6	0.1646	0	$761.83	0
Per Prototype Building	58,053	29.079	0	$134,590	0
Savings per square foot	0.5805	0.0003	0	$1.35	0

Table 1 for the prototype building in Climate Zone 3 with medium-sized, water-cooled centrifugal, Path B chillers. The prototype building is a 100,000 square foot office building with 0.32 window to wall ratio. See Section 2 for details of the assumptions and Section 3.1 for detailed results.

	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (therms/yr)	TDV Electricity Savings	TDV Gas Savings
Per ton of cooling capacity	328.6	0.1646	0	$761.83	0
Per Prototype Building	58,053	29.079	0	$134,590	0
Savings per square foot	0.5805	0.0003	0	$1.35	0

Table 1. Summary of energy savings from proposed measure, Climate Zone 3

1.5 Non-Energy Benefits

This measure has no non-energy benefits.

1.6 Environmental Impact

There are no significant potential adverse environmental impacts of this measure.

1.7 Technology Measures

This measure as written provides a preference for variable speed chillers.

1.8 Performance Verification of the Proposed Measure

This measure requires the performance verification and commissioning that already exists for chillers. There are no new proposed acceptance requirements.

1.9 Cost Effectiveness

The details of the cost-effectiveness calculations are given in Section 3.3. The results are summarized in

a	b	c		d		e		f	g	
Measure Name	Measure Life (Years)	Additional Costs[1]– Current Measure Costs (Relative to Basecase) ($)		Additional Cost[2]– Post-Adoption Measure Costs (Relative to Basecase) ($)		PV of Additional[3] Maintenance Costs (Savings) (Relative to Basecase) (PV$)		PV of[4] Energy Cost Savings – Per Proto Building (PV$)	LCC Per Prototype Building ($)	
		Per ton of	Per Proto	Per ton of	Per Proto	Per ton of	Per Proto		(c+e)-f	(d+e)-f

		cooling capacity	Building	cooling capacity	Building	cooling capacity	Building		Based on Current Costs	Based on Post-Adoption Costs
WC PD, <75 tons	15	$52.98	$9,361	$52.98	$9,361	$0	$0	$70,087	-$60,727	-$60,727
WC PD, >75 and <150	15	$39.23	$6,931	$39.23	$6,931	$0	$0	$58,309	-$51,378	-$51,378
WC PD, >150 and <300	15	$36.31	$6,415	$36.31	$6,415	$0	$0	$52,647	-$46,231	-$46,231
WC PD, >300 tons	15	$26.07	$4,605	$26.07	$4,605	$0	$0	$47,284	-$42,678	-$42,678
WC Cent, <150 tons	15	$47.60	$8,409	$47.60	$8,409	$0	$0	$185,982	-$177,572	-$177,572
WC Cent, >150 and <300	15	$57.28	$10,119	$57.28	$10,119	$0	$0	$124,472	-$114,353	-$114,353
WC Cent, >300 and <600	15	$52.80	$9,328	$52.80	$9,328	$0	$0	$104,193	-$94,865	-$94,865
WC Cent, >600 tons	15	$44.83	$7,920	$44.83	$7,920	$0	$0	$111,353	-$103,433	-$103,433

Table 2 for Path B chillers in Climate Zone 3.

a	b	c		d		e		f	g	
Measure Name	Measure Life (Years)	Additional Costs[1]– Current Measure Costs (Relative to Basecase) ($)		Additional Cost[2]– Post-Adoption Measure Costs (Relative to Basecase) ($)		PV of Additional[3] Maintenance Costs (Savings) (Relative to Basecase) (PV$)		PV of[4] Energy Cost Savings – Per Proto Building (PV$)	LCC Per Prototype Building ($)	
		Per ton of cooling capacity	Per Proto Building	Per ton of cooling capacity	Per Proto Building	Per ton of cooling capacity	Per Proto Building		(c+e)-f Based on Current Costs	(d+e)-f Based on Post-Adoption Costs
WC PD, <75 tons	15	$52.98	$9,361	$52.98	$9,361	$0	$0	$70,087	-$60,727	-$60,727
WC PD, >75 and <150	15	$39.23	$6,931	$39.23	$6,931	$0	$0	$58,309	-$51,378	-$51,378
WC PD, >150 and <300	15	$36.31	$6,415	$36.31	$6,415	$0	$0	$52,647	-$46,231	-$46,231
WC PD, >300 tons	15	$26.07	$4,605	$26.07	$4,605	$0	$0	$47,284	-$42,678	-$42,678
WC Cent, <150 tons	15	$47.60	$8,409	$47.60	$8,409	$0	$0	$185,982	-$177,572	-$177,572

WC Cent, >150 and <300	15	$57.28	$10,119	$57.28	$10,119	$0	$0	$124,472	-$114,353	-$114,353
WC Cent, >300 and <600	15	$52.80	$9,328	$52.80	$9,328	$0	$0	$104,193	-$94,865	-$94,865
WC Cent, >600 tons	15	$44.83	$7,920	$44.83	$7,920	$0	$0	$111,353	-$103,433	-$103,433

Table 2. Life-cycle cost results for Path B chillers in Climate Zone 3

1.10 Analysis Tools

Currently available simulation programs such as eQuest are capable of modeling the requirements of this measure.

1.11 Relationship to Other Measures

This measure has no relation to other measures.

2 Methodology

Chiller minimum efficiency is not federally pre-empted and therefore California is free to set minimum efficiency requirements as it sees fit. In the past, however, the chiller efficiencies in Title 24 have been identical to ASHRAE 90.1. For example, the Title 24-2001 chiller efficiencies were updated to be consistent with ASHRAE 90.1-1999 and the Title 24-2005 chiller efficiencies were updated to be consistent with ASHRAE 90.1-2001. Chiller efficiency levels did not change in 90.1-2004 or 90.1-2007, i.e ASHRAE chiller efficiencies have not changed since 2001. There are a number of reasons why Title 24 has historically followed ASHRAE's lead on chiller efficiencies. One reason is that chiller manufacturers have generally not been willing to provide efficiency versus cost data, which makes it difficult to perform lifecycle cost analyses to determine the efficiency level at which lifecycle cost is minimized. In 2005 Title 24 went beyond 90.1 by adding a prescriptive restriction to air-cooled chillers in 144(h) and 149(c).

As mentioned in the overview, ASHRAE has recently completed three chiller addenda to 90.1-2007 which were adopted in 90.1-2010 (see Section 7.1).

- Addendum M increased both full load efficiency (COP) and integrated part load efficiency (IPLV) for all chillers and added two alternative paths of compliance: Path A for fixed speed machines and Path B for variable speed machines. Path A has a lower COP but higher IPLV than Path B. Addendum M also reorganized all chillers into positive displacement and centrifugal. Finally Addendum M eliminated the ratings for chillers without a condenser.
- Addenda BL and BT greatly increased the range of non-standard operating conditions over which the chiller efficiency requirements apply for centrifugal chilers.

The values in Addendum M were negotiated between chiller manufacturers, and manufacturers provided a limited amount of cost data which allowed ASHRAE to compute a scalar for Addendum M. ASHRAE also projected a total annual energy savings attributed to adoption of Addendum M of 457 GWh/yr.

Under Addenda BL and BT, AHRI calculated that 52% more centrifugal chillers will now be covered by 90.1-2010 compared to 90.1-2007. In other words there are now minimum efficiency requirements for many chillers which previously had no requirements at all. Addenda BL and BT are estimated to save over 24 GWh annually worldwide, with estimated savings of 12 GWh per year in the U.S.

The energy savings for both Path A and Path B presented in the 90.1 addenda were estimated using energy models. A generic large office building was modeled with a chiller plant. Chillers that comply with the existing standard were modeled, as well as chillers that comply with the proposed measure. The details of the model are given below.

2.1 Envelope

The building has 10 floors, totaling 100,000 ft^2. Each floor has four perimeter zones (each 1,275 ft^2) and one interior zone (4,900 ft^2). The floor to floor height is 12 feet, and the plenum height is 3 feet. Each floor has a continuous strip of 4.8-ft tall glazing on all exterior walls.

2.2 Internal loads

The undiversified internal loads for each of the zones are given in the table below. The schedules of the internal loading are given in Figure 1 through Figure 3 below. All zones have the same schedules.

	Lighting (W/sqft)	Equipment (W/sqft)	Occupancy (sqft/person)
1st floor perimeter zones	1.00	0.52	100
1st floor interior zone	0.76	0.34	215
2nd - 8th floor perimeter zones	1.31	1.48	85
2nd - 8th floor interior zones	1.05	0.98	80

Table 3. Undiversified internal loads

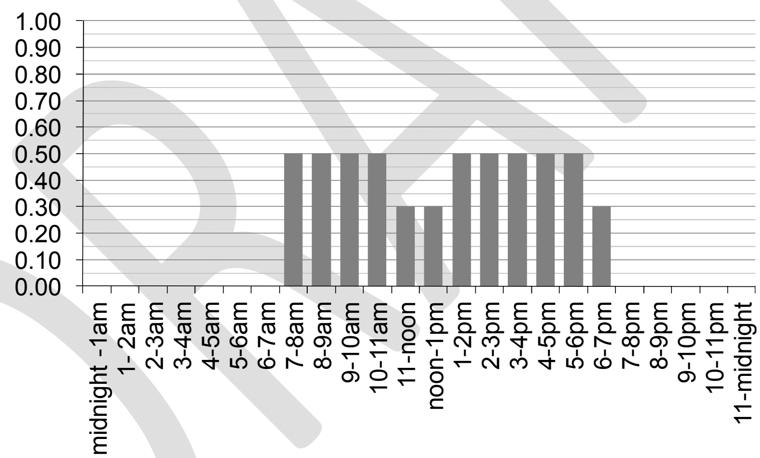

Figure 1. Occupancy schedule

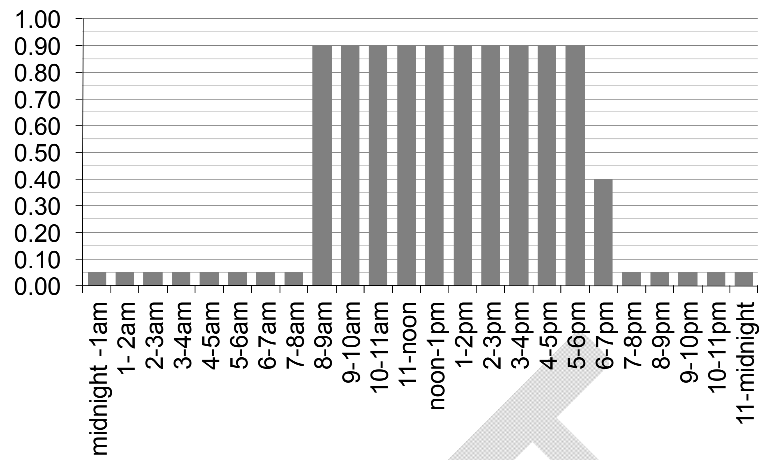

Figure 2. Lighting schedule

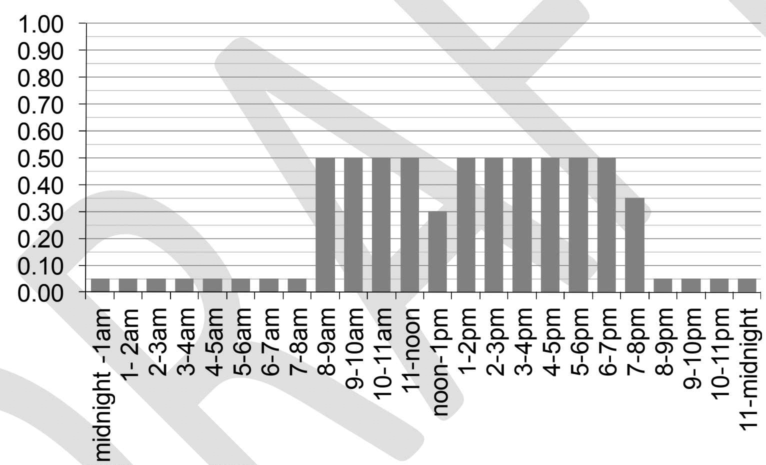

Figure 3. Equipment schedule

2.3 Mechanical system

The mechanical system consists of a large VAV air handler with chilled water and hot water coils. Local reheating is done at the zone terminal VAV boxes. Hot water is provided by a single atmospheric boiler. Water-cooled and air-cooled chillers are both modeled, the details of which are given below. The system fans run from 5am to 8pm, Monday through Friday, and 5am to 3pm on Saturdays. The fans do not run on Sundays and holidays. The thermostat setpoints in all zones are 74°F for cooling and 70°F for heating.

2.3.1 Air handler

There is one large variable air volume air handler serving the building. The air handler has plenum return and outdoor air economizers. The cooling coils in the air handler were sized for each climate zone based on the peak building load, as calculated with eQuest. The cooling supply air temperature is 55°F and is allowed to reset. The heating supply air temperature is 95°F, and has a 35°F delta T.

2.3.2 Circulation loops

The details on the circulation loops are given in Table 4 below. The circulation loops are identical in all models except for the air-cooled chiller models, which do not have condenser water loops.

	Hot water loop	Chilled water loop	Condenser water loop
Loop subtype	Primary	Primary	Primary
Sizing option	Secondary	Secondary	Secondary
Design temp	180^{0}F	44^{0}F	Varies by climate zone. See Table 7.
Loop design delta T	30^{0}F	10^{0}F	18^{0}F
Pipe head	21.6 ft	21.6 ft	21.6 ft
Loop min flow	0.05 ratio	0.10 ratio	0.05 ratio
Loop size ratio	1.0 ratio	1.0 ratio	1.0 ratio
Head setpoint control	Fixed	Fixed	Fixed
Head sensor location	Entering loop	Entering loop	Entering loop
Head setpoint	(blank)	(blank)	(blank)
Head setpoint range	2.0 ft	2.0 ft	2.0 ft
Head setpoint ratio	1.0 ratio	1.0 ratio	1.0 ratio
Loop operation	Demand	Demand	Demand
Loop flow reset	n/a	0.700	N/A
Loop setpoint range	2.0^{0}F	0.05^{0}F	0.05°F
Setpoint control	Fixed	Loads reset	Fixed
Setpoint temperature	180^{0}F	44^{0}F	Varies by climate zone. See Table 7.
Max reset temperature	N/A	47^{0}F	N/A
Min reset temperature	N/A	44^{0}F	N/A

Table 4. Details on circulation loops

2.4 Chilled water plant

The chilled water plant consists of two equally-sized chillers. The chillers were sized based on the load calculation done by eQuest. The table below shows the building peak cooling load and the total chiller capacity for each climate zone.

Climate zone	City	Building peak cooling load (kbtu/h)	Total chiller capacity (tons)
3	Oakland	1,696	177
6	Torrance	2,645	276
7	San Diego	2,698	281
8	Fullerton	2,424	252
9	Burbank	2,931	305

10	Riverside	2,749	286
12	Sacramento	2,688	280
13	Fresno	3,063	319

Table 5. Peak cooling coil load and chiller capacity

The chilled water setpoint was set to 44°F and allowed to reset up to 47°F. If one chiller is sufficient to meet the load, then only one chiller runs. When the load increases beyond the capacity of one chiller, the second chiller turns on and the two chillers share the load equally. The chillers stage down similarly. Figure 4 shows the number of run hours that each chiller operates at each part-load ratio in Climate Zone 3. As expected, the chiller spends the majority of the hours at very low loads. The second chiller only turns on when the load gets to be more than one chiller can handle.

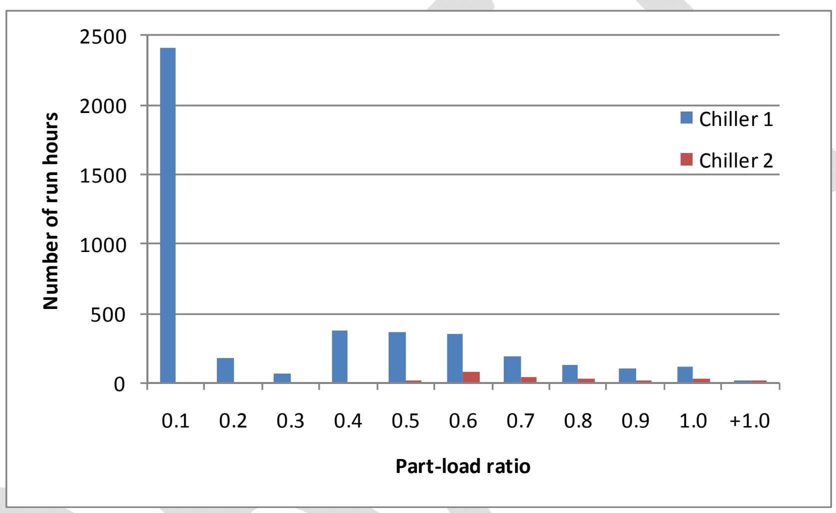

Figure 4. Number of run hours at each part-load ratio in Climate Zone 3

The chillers were modeled in eQuest by specifying curves for how the chiller performs under different operating conditions. A nominal electric-input ratio (EIR) for each chiller is set. One performance curve corrects the nominal EIR as a function of the leaving chilled water temperature and the entering condenser water temperature. One performance curve corrects the EIR for part load ratio and the temperature difference between leaving chilled water and entering condenser water. The third performance curve corrects the chiller capacity as a function of leaving chilled water temperature and entering condenser water temperature. In eQuest each of these performance curves is a bi-quadratic, meaning that it is independent in two variables and takes the form: $f(r1,r2) = c1 + c2*r1 + c3*r1^2 + c4*r2 + c5*r2^2 + c6*r1*r2$, where c1, c2, c3, c4, c5, and c6 are coefficients and r1 and r2 are dimensionless variables.

The chillers were modeled to meet the performance criteria of the basecase and proposed chillers (Path A and Path B). Coefficients for the above mentioned performance curves were based on chiller bids received from manufacturers for real jobs. These coefficients are given in Section 7.2. The nominal EIR for each chiller is given in Table 6.

		Basecase	Path A	Path B
Air Cooled	<150 tons	0.357	0.357	-
	>150 tons	0.357	0.357	-
Water Cooled Positive Displacement	<75 tons	0.238	0.222	0.228
	>75 and <150	0.225	0.220	0.225
	>150 and <300	0.204	0.193	0.204
	>300 tons	0.182	0.176	0.182
Water Cooled Centrifugal	<150 tons	0.200	0.180	0.182
	>150 and <300	0.180	0.180	0.182
	>300 and <600	0.164	0.164	0.171
	>600 tons	0.164	0.162	0.168

Table 6. Nominal EIR for chillers

Sample of plots of the chiller curves are given in **Error! Reference source not found.**.

All of the centrifugal chillers were modeled as hermetic centrifugal chillers in eQuest. All of the positive displacement chillers were modeled as hermetic screw chillers in eQuest, and all of the air-cooled chillers were modeled as hermetic screw chillers in eQuest.

The cooling tower is a one two-cell tower that operates the maximum number of cells for a given load. The tower fan has an EIR of 0.0100, and is variable speed. The design approach is 10°F. The condenser water loop temperature setpoint is 5 degrees higher than the design wetbulb temperature for each zone. The design wetbulb temperature of the tower and the condenser water temperature setpoint are given in

Climate zone	City	Cooling tower design wetbulb (ºF)	Condenser water setpoint temperature (ºF)
3	Oakland	65	70
6	Torrance	68	73
7	San Diego	69	74
8	Fullerton	69	74
9	Burbank	69	74
10	Riverside	69	74
12	Sacramento	71	76
13	Fresno	71	76

Table 7.

Climate zone	City	Cooling tower design wetbulb (ºF)	Condenser water setpoint temperature (ºF)
3	Oakland	65	70
6	Torrance	68	73
7	San Diego	69	74
8	Fullerton	69	74
9	Burbank	69	74
10	Riverside	69	74
12	Sacramento	71	76
13	Fresno	71	76

Table 7. Cooling tower design wetbulb by climate zone.

3 Analysis and Results

3.1 Energy savings

The energy savings were calculated using the methodology described above in Section 2, and are tabulated below in

Climate Zone	City	Chiller Type	Chiller Size	Path A		Path B	
				Annual kWh savings/ton	TDV savings/ton	Annual kWh savings/ton	TDV savings/ton
3	Oakland	Water-cooled positive displacement	<75 tons	32	$121	177	$450
			>75 and <150	10	$38	155	$369
			>150 and <300	23	$85	140	$334
			>300 tons	12	$46	124	$294
		Water-cooled centrifugal	<150 tons	108	$316	446	$1,100
			>150 and <300	-	-	329	$762
			>300 and <600	-	-	282	$643
			>600 tons	25	$59	292	$675
6	Torrance	Water-cooled positive displacement	<75 tons	64	$174	260	$567
			>75 and <150	20	$54	217	$452
			>150 and <300	45	$122	195	$406
			>300 tons	24	$66	173	$358
		Water-cooled centrifugal	<150 tons	168	$403	571	$1,229
			>150 and <300	-	-	393	$800
			>300 and <600	-	-	331	$659
			>600 tons	31	$67	348	$704
7	San Diego	Water-cooled positive displacement	<75 tons	64	$174	294	$622
			>75 and <150	20	$54	250	$507
			>150 and <300	45	$122	225	$455
			>300 tons	24	$66	200	$402
		Water-cooled centrifugal	<150 tons	187	$420	629	$1,280
			>150 and <300	-	-	432	$838

			>300 and <600	-	-	366	$695
			>600 tons	37	$73	385	$740
8	Fullerton	Water-cooled positive displacement	<75 tons	66	$186	255	$585
			>75 and <150	21	$58	211	$463
			>150 and <300	46	$131	190	$415
			>300 tons	25	$71	168	$366
		Water-cooled centrifugal	<150 tons	167	$423	522	$1,166
			>150 and <300	-	-	345	$716
			>300 and <600	-	-	287	$569
			>600 tons	30	$68	305	$620
9	Burbank	Water-cooled positive displacement	<75 tons	59	$180	224	$476
			>75 and <150	18	$56	185	$359
			>150 and <300	41	$126	166	$321
			>300 tons	22	$69	147	$283
		Water-cooled centrifugal	<150 tons	150	$396	475	$1,074
			>150 and <300	-	-	316	$651
			>300 and <600	-	-	261	$482
			>600 tons	27	$64	277	$536
10	Riverside	Water-cooled positive displacement	<75 tons	59	$181	221	$501
			>75 and <150	18	$56	182	$383
			>150 and <300	41	$127	163	$343
			>300 tons	22	$69	145	$301
		Water-cooled centrifugal	<150 tons	146	$396	458	$1,065
			>150 and <300	-	-	303	$645
			>300 and <600	-	-	250	$503
			>600 tons	26	$62	266	$555
12	Sacramento	Water-cooled positive displacement	<75 tons	44	$147	177	$448
			>75 and <150	14	$47	147	$352
			>150 and <300	31	$102	132	$315

			>300 tons	16	$55	118	$278
		Water-cooled centrifugal	<150 tons	114	$324	327	$800
			>150 and <300	-	-	209	$462
			>300 and <600	-	-	172	$356
			>600 tons	21	$56	185	$399
13	Fresno	Water-cooled positive displacement	<75 tons	20	$159	185	$448
			>75 and <150	16	$51	151	$344
			>150 and <300	35	$111	136	$308
			>300 tons	19	$60	121	$271
		Water-cooled centrifugal	<150 tons	124	$348	344	$844
			>150 and <300	-	-	216	$479
			>300 and <600	-	-	176	$366
			>600 tons	21	$52	190	$410

Table 8 for both Path A and Path B compared to the basecase (Title 24 2008). The analysis was done in the top 8 climate zones, which represent 85% of new construction.

Climate Zone	City	Chiller Type	Chiller Size	Path A		Path B	
				Annual kWh savings/ton	TDV savings/ton	Annual kWh savings/ton	TDV savings/ton
3	Oakland	Water-cooled positive displacement	<75 tons	32	$121	177	$450
			>75 and <150	10	$38	155	$369
			>150 and <300	23	$85	140	$334
			>300 tons	12	$46	124	$294
		Water-cooled centrifugal	<150 tons	108	$316	446	$1,100
			>150 and <300	-	-	329	$762
			>300 and <600	-	-	282	$643
			>600 tons	25	$59	292	$675
6	Torrance	Water-cooled positive displacement	<75 tons	64	$174	260	$567
			>75 and <150	20	$54	217	$452
			>150 and <300	45	$122	195	$406
			>300 tons	24	$66	173	$358

		Water-cooled centrifugal	<150 tons	168	$403	571	$1,229
			>150 and <300	-	-	393	$800
			>300 and <600	-	-	331	$659
			>600 tons	31	$67	348	$704
7	San Diego	Water-cooled positive displacement	<75 tons	64	$174	294	$622
			>75 and <150	20	$54	250	$507
			>150 and <300	45	$122	225	$455
			>300 tons	24	$66	200	$402
		Water-cooled centrifugal	<150 tons	187	$420	629	$1,280
			>150 and <300	-	-	432	$838
			>300 and <600	-	-	366	$695
			>600 tons	37	$73	385	$740
8	Fullerton	Water-cooled positive displacement	<75 tons	66	$186	255	$585
			>75 and <150	21	$58	211	$463
			>150 and <300	46	$131	190	$415
			>300 tons	25	$71	168	$366
		Water-cooled centrifugal	<150 tons	167	$423	522	$1,166
			>150 and <300	-	-	345	$716
			>300 and <600	-	-	287	$569
			>600 tons	30	$68	305	$620
9	Burbank	Water-cooled positive displacement	<75 tons	59	$180	224	$476
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		Water-cooled centrifugal	<150 tons	150	$396	475	$1,074
			>150 and <300	-	-	316	$651
			>300 and <600	-	-	261	$482
			>600 tons	27	$64	277	$536
10	Riverside	Water-cooled positive	<75 tons	59	$181	221	$501
			>75 and	18	$56	182	$383

		displacement	<150				
			>150 and <300	41	$127	163	$343
			>300 tons	22	$69	145	$301
		Water-cooled centrifugal	<150 tons	146	$396	458	$1,065
			>150 and <300	-	-	303	$645
			>300 and <600	-	-	250	$503
			>600 tons	26	$62	266	$555
12	Sacramento	Water-cooled positive displacement	<75 tons	44	$147	177	$448
			>75 and <150	14	$47	147	$352
			>150 and <300	31	$102	132	$315
			>300 tons	16	$55	118	$278
		Water-cooled centrifugal	<150 tons	114	$324	327	$800
			>150 and <300	-	-	209	$462
			>300 and <600	-	-	172	$356
			>600 tons	21	$56	185	$399
13	Fresno	Water-cooled positive displacement	<75 tons	20	$159	185	$448
			>75 and <150	16	$51	151	$344
			>150 and <300	35	$111	136	$308
			>300 tons	19	$60	121	$271
		Water-cooled centrifugal	<150 tons	124	$348	344	$844
			>150 and <300	-	-	216	$479
			>300 and <600	-	-	176	$366
			>600 tons	21	$52	190	$410

Table 8. Energy savings in all climate zones

Path B chillers save between 65% and 1400% more energy than Path A chillers over the basecase across all chiller types and sizes and across the top 8 climate zones. Path B chillers are more efficient than Path A chillers at part load, but are less efficient than Path A chillers at full load. Both Path A and Path B have both higher part load and full load efficiencies compared to the basecase in all proposed cases. Because in most buildings chillers are loaded below their full-load for the majority of the time, it is not surprising that Path B chillers save more energy than Path B.

3.2 Costs

Incremental cost data of each chiller over the basecase chillers is given in Table 9. These costs were received from AHRI. This is the costs that they used in the 90.1 analysis.

Type	Size	Path A $/ton	Path B $/ton
Air Cooled	<150 tons	$33.01	-
	>150 tons	$17.18	-
Water Cooled Positive Displacement	<75 tons	$47.34	$52.98
	>75 and <150	$35.45	$39.23
	>150 and <300	$30.74	$36.31
	>300 tons	$13.38	$26.07
Water Cooled Centrifugal	<150 tons	$31.56	$47.60
	>150 and <300	-	$57.28
	>300 and <600	-	$52.80
	>600 tons	$5.77	$44.83

Table 9. Incremental costs for Path A and Path B chillers

These costs do not include maintenance because it is unlikely that these chillers will require any additional maintenance over basecase chillers. However, one concern brought up by a stakeholder (see Section **Error! Reference source not found.**) is that because Path B chillers have VFDs, the VFDs will require replacement sooner than the chiller. To factor in the potential additional cost of these VFD replacements, a very conservative estimate was made about the cost of VFD replacement in the life-cycle cost calculations.

3.3 Life-cycle cost calculations

The annual energy use of the Basecase, Path A, and Path B chillers were calculated from the eQuest model described above. The 15-year energy costs were calculated using the results of the energy model and the given TDV rates. The incremental measure costs are pre-adaption costs. The total 15-year life-cycle cost of the Basecase, Path A, and Path B chillers were calculated for each chiller-type and size category for each climate zone. See

Climate Zone	City	Chiller Type	Chiller Size	Path A	Path B
3	Oakland	Water-cooled positive displacement	<75 tons	-$73	-$397
			>75 and <150	-$2	-$330
			>150 and <300	-$54	-$298
			>300 tons	-$33	-$268

		Water-cooled centrifugal	<150 tons	-$284	-$1,053
			>150 and <300	-	-$705
			>300 and <600	-	-$590
			>600 tons	-$53	-$630
6	Torrance	Water-cooled positive displacement	<75 tons	-$126	-$514
			>75 and <150	-$19	-$413
			>150 and <300	-$91	-$370
			>300 tons	-$53	-$332
		Water-cooled centrifugal	<150 tons	-$372	-$1,181
			>150 and <300	-	-$743
			>300 and <600	-	-$606
			>600 tons	-$61	-$659
7	San Diego	Water-cooled positive displacement	<75 tons	-$127	-$569
			>75 and <150	-$19	-$467
			>150 and <300	-$92	-$419
			>300 tons	-$53	-$376
		Water-cooled centrifugal	<150 tons	-$389	-$1,233
			>150 and <300	-	-$780
			>300 and <600	-	-$642
			>600 tons	-$67	-$695
8	Fullerton	Water-cooled positive displacement	<75 tons	-$139	-$532
			>75 and <150	-$23	-$424
			>150 and <300	-$100	-$379
			>300 tons	-$58	-$340
		Water-cooled centrifugal	<150 tons	-$392	-$1,119
			>150 and <300	-	-$659
			>300 and <600	-	-$516
			>600 tons	-$62	-$575
9	Burbank	Water-cooled positive displacement	<75 tons	-$132	-$423
			>75 and <150	-$21	-$320

			>150 and <300	-$96	-$285
			>300 tons	-$55	-$257
		Water-cooled centrifugal	<150 tons	-$364	-$1,027
			>150 and <300	-	-$594
			>300 and <600	-	-$430
			>600 tons	-$58	-$491
10	Riverside	Water-cooled positive displacement	<75 tons	-$133	-$448
			>75 and <150	-$21	-$343
			>150 and <300	-$96	-$306
			>300 tons	-$56	-$275
		Water-cooled centrifugal	<150 tons	-$364	-$1,017
			>150 and <300	-	-$588
			>300 and <600	-	-$450
			>600 tons	-$57	-$510
12	Sacramento	Water-cooled positive displacement	<75 tons	-$99	-$395
			>75 and <150	-$11	-$312
			>150 and <300	-$72	-$279
			>300 tons	-$42	-$252
		Water-cooled centrifugal	<150 tons	-$293	-$752
			>150 and <300	-	-$405
			>300 and <600	-	-$303
			>600 tons	-$51	-$355
13	Fresno	Water-cooled positive displacement	<75 tons	-$112	-$395
			>75 and <150	-$15	-$305
			>150 and <300	-$81	-$272
			>300 tons	-$46	-$245
		Water-cooled centrifugal	<150 tons	-$317	-$796
			>150 and <300	-	-$422
			>300 and <600	-	-$313

			>600 tons	-$46	-$365

Table 10 below for the results.

Climate Zone	City	Chiller Type	Chiller Size	Path A	Path B
3	Oakland	Water-cooled positive displacement	<75 tons	-$73	-$397
			>75 and <150	-$2	-$330
			>150 and <300	-$54	-$298
			>300 tons	-$33	-$268
		Water-cooled centrifugal	<150 tons	-$284	-$1,053
			>150 and <300	-	-$705
			>300 and <600	-	-$590
			>600 tons	-$53	-$630
6	Torrance	Water-cooled positive displacement	<75 tons	-$126	-$514
			>75 and <150	-$19	-$413
			>150 and <300	-$91	-$370
			>300 tons	-$53	-$332
		Water-cooled centrifugal	<150 tons	-$372	-$1,181
			>150 and <300	-	-$743
			>300 and <600	-	-$606
			>600 tons	-$61	-$659
7	San Diego	Water-cooled positive displacement	<75 tons	-$127	-$569
			>75 and <150	-$19	-$467
			>150 and <300	-$92	-$419
			>300 tons	-$53	-$376
		Water-cooled centrifugal	<150 tons	-$389	-$1,233
			>150 and <300	-	-$780
			>300 and <600	-	-$642
			>600 tons	-$67	-$695
8	Fullerton	Water-cooled positive displacement	<75 tons	-$139	-$532
			>75 and <150	-$23	-$424

			>150 and <300	-$100	-$379
			>300 tons	-$58	-$340
		Water-cooled centrifugal	<150 tons	-$392	-$1,119
			>150 and <300	-	-$659
			>300 and <600	-	-$516
			>600 tons	-$62	-$575
9	Burbank	Water-cooled positive displacement	<75 tons	-$132	-$423
			>75 and <150	-$21	-$320
			>150 and <300	-$96	-$285
			>300 tons	-$55	-$257
		Water-cooled centrifugal	<150 tons	-$364	-$1,027
			>150 and <300	-	-$594
			>300 and <600	-	-$430
			>600 tons	-$58	-$491
10	Riverside	Water-cooled positive displacement	<75 tons	-$133	-$448
			>75 and <150	-$21	-$343
			>150 and <300	-$96	-$306
			>300 tons	-$56	-$275
		Water-cooled centrifugal	<150 tons	-$364	-$1,017
			>150 and <300	-	-$588
			>300 and <600	-	-$450
			>600 tons	-$57	-$510
12	Sacramento	Water-cooled positive displacement	<75 tons	-$99	-$395
			>75 and <150	-$11	-$312
			>150 and <300	-$72	-$279
			>300 tons	-$42	-$252
		Water-cooled centrifugal	<150 tons	-$293	-$752
			>150 and <300	-	-$405
			>300 and <600	-	-$303

			>600 tons	-$51	-$355
13	Fresno	Water-cooled positive displacement	<75 tons	-$112	-$395
			>75 and <150	-$15	-$305
			>150 and <300	-$81	-$272
			>300 tons	-$46	-$245
		Water-cooled centrifugal	<150 tons	-$317	-$796
			>150 and <300	-	-$422
			>300 and <600	-	-$313
			>600 tons	-$46	-$365

Table 10. Life-cycle cost, $/ton cooling capacity

From the results above, it was determined that over a 15-year life, the proposed Path B chillers had the lowest life-cycle cost and used the least amount of energy compared to both the basecase and Path A chillers. Though Path B chillers are more expensive than Path A chillers, they save significantly more energy and pay back quickly, making them cost effective even when considering a very short life.

Therefore the proposed code measure is to require that all chillers meet the Path B requirements.

4 Stakeholder Input

In December of 2010 we received a letter from the Trane Company that raised a number of issues with our proposal to only adopt either the Path A or Path B requirements for the mandatory tables. See Section 7.3 for the full content of the letter. In particular they listed a number of items of concern:

- Chillers with voltages over 600V where the incremental costs of variable speed drives is much larger than the cost curves presented by AHRI.
- Chillers that use heat recovery. High lift, fixed speed machines can used efficiently if the recover heat for reheat or other uses.
- Chillers serving thermal energy storage (TES) systems. Again this often requires a chiller designed for high lift.

As a response to these concerns we changed our proposal to repeat the ASHRAE Addendum M tables in the mandatory section of the standard and provide a prescriptive requirement for the lowest LCC requirement for each chiller type and size (Path A or B). In addition we are proposing exceptions for each of the items listed above.

5 Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

5.1 Standard

5.1.1 Definitions

ARI 550/590 is the Air-conditioning and Refrigeration Institute document entitled "Standard for Water Chilling Packages Using the Vapor Compression Cycle," ~~1998~~ 2003 (ARI 550/590 – ~~98~~ 03).

5.1.2 New Table 112D

Equipment Type	Size Category	Units	Before 1/1/2010		~~As of 1/1/2010~~[b]				Test Procedure[c]
			Full Load	IPLV	Path A		Path B		
					Full Load	IPLV	Full Load	IPLV	
Air-cooled chillers	<150 tons	EER	≥9.562	≥10.416	≥9.562	≥12.500	NA[d]	NA[d]	ARI 550/590
	≥150 tons	EER			≥9.562	≥12.750	NA[d]	NA[d]	
Air-cooled without condenser, electrical operated	All capacities	EER	≥10.586	≥11.782	Air-cooled chillers without condensers must be rated with matching condensers and comply with the air-cooled chiller efficiency requirements.				
Water-cooled, electrically operated, reciprocating	All capacities	kW/ton	≤0.837	≤0.696	Reciprocating units must comply with water-cooled positive displacement efficiency requirements				
Water-cooled, electrically operated, positive displacement	<75 tons	kW/ton	≤0.790	≤0.676	≤0.780	≤0.630	≤0.800	≤0.600	
	≥75 tons and <150 tons	kW/ton	≤0.790	≤0.676	≤0.775	≤0.615	≤0.790	≤0.586	
	≥150 tons and <300 tons	kW/ton	≤0.717	≤0.627	≤0.680	≤0.580	≤0.718	≤0.540	
	≥300 tons	kW/ton	≤0.639	≤0.571	≤0.620	≤0.540	≤0.639	≤0.490	

Equipment Type	Size Category	Units	Before 1/1/2010 Full Load	Before 1/1/2010 IPLV	~~As of 1/1/2010~~[b] Path A Full Load	Path A IPLV	Path B Full Load	Path B IPLV	Test Procedure[c]
Water-cooled, electrically operated, centrifugal	<150 tons	kW/ton	≤0.703	≤0.669	≤0.634	≤0.596	≤0.639	≤0.450	
	≥150 tons and <300 tons	kW/ton	≤0.634	≤0.596	≤0.634	≤0.596	≤0.639	≤0.450	
	≥300 tons and <600 tons	kW/ton	≤0.576	≤0.549	≤0.576	≤0.549	≤0.600	≤0.400	
	≥600 tons	kW/ton	≤0.576	≤0.549	≤0.570	≤0.539	≤0.590	≤0.400	
Air-cooled absorption, single effect	All capacities	COP	≥0.600	NR[e]	≥0.600	NR[e]	NA[d]	NA[d]	ARI 560
Water-cooled absorption, single effect	All capacities	COP	≥0.700	NR[e]	≥0.700	NR[e]	NA[d]	NA[d]	
Absorption double-effect, indirect-fired	All capacities	COP	≥1.000	≥1.050	≥1.000	≥1.050	NA[d]	NA[d]	
Absorption double-effect, direct-fired	All capacities	COP	≥1.000	≥1.000	≥1.000	≥1.000	NA[d]	NA[d]	

Table Footnotes:

a. No requirements for:
   - Centrifugal chillers with Tchws_des<36F
   - Positive displacement chillers with Tchws_des<32F
   - Absorption chillers with Tchws_des<40F

b. Must meet both COP and IPLV of either Path A or B

c. See Section 101 Definitions

d. NA means not applicable

e. NR means no minimum requirement in this field

5.1.3 Kadj, Exception to 112(a)

EXCEPTION to Section 112(a): ~~Water-cooled centrifugal water-chilling packages that are not designed for~~

~~operation at ARI Standard 550 test conditions of 44°F leaving chilled water temperature and 85°F entering condenser water temperature shall have a minimum full load COP rating as shown in TABLE 112-H, TABLE 112-I, and TABLE 112-J, and a minimum NPLV rating as shown in TABLE 112-K, TABLE 112-L, and TABLE 112-M The table values are only applicable over the following full load design ranges:~~

~~Leaving Chiller Water Temp. 40 to 48°F~~

~~Entering Condenser Water Temp. 75 to 85°F~~

~~Condensing Water Temp. Rise 5 to 15°F~~

Water-cooled centrifugal chillers not designed for operation at ARI Standard 550/590 test conditions of 44°F leaving chilled-water temperature and 85°F entering condenser water temperature with 3 gpm/ton condenser water flow shall have maximum full-load kW/ton and *NPLV* ratings adjusted using the following equation:

Adjusted maximum full-load kW/ton rating = (full-load kW/ton from Table 112D)/*Kadj*

Adjusted maximum NPLV rating = (IPLV from Table 112D)/*Kadj*

where

Kadj = A * B

A = 0.00000014592 * (LIFT)4 – 0.0000346496 * (LIFT)3 + 0.00314196 * (LIFT)2 – 0.147199 * (LIFT) + 3.9302

LIFT = LvgCond – LvgEvap (°F)

LvgCond = Full-load leaving condenser fluid temperature (°F)

LvgEvap = Full-load leaving evaporator fluid temperature (°F)

B = 0.0015 * LvgEvap + 0.934

The adjusted full-load and NPLV values are only applicable for centrifugal chillers meeting all of the following full-load design ranges:

• Minimum Leaving Evaporator Fluid Temperature: 36°F

• Maximum Leaving Condenser Fluid Temperature: 115°F

• LIFT ≥ 20°F and ≤ 80°F

Centrifugal chillers designed to operate outside of these ranges are not covered by this standard.

EXCEPTION to Section 112(a): Positive displacement (air- and water-cooled) chillers with a leaving evaporator fluid temperature higher than 32°F, shall show compliance with Table 112D when tested or certified with water at standard rating conditions, per the referenced test procedure.

5.1.4 New Prescriptive Requirement for Chiller Efficiency

144(tbd) Minimum Chiller Efficiencies

Where it is provided, chillers shall meet or exceed Path B from Table 112D

EXCEPTION 1 to Section 144(tbd): Chillers with electrical service >600V

EXCEPTION 2 to Section 144(tbd): Chillers attached to a heat recovery system with a design heat recovery capacity of >40% of the design chiller cooling capacity

EXCEPTION 3 to Section 144(tbd): Chillers used to charge thermal energy storage systems where the charging temperature is <40F

EXCEPTION 4 to Section 144(tbd): Chillers installed in plants with more than 3 chillers

5.1.5 Modify Prescriptive Requirement 144(i) for Air-Cooled Chillers

144(i) Limitation of Air-Cooled Chillers

Chilled water plants ~~with more than 300 tons total capacity~~ shall not have more than ~~100~~ 300 tons provided by air-cooled chillers.

EXCEPTION 1 to Section 144(i): Where the designer demonstrates that the water quality at the building site fails to meet manufacturer's specifications for the use of water-cooled equipment.

EXCEPTION 2 to Section 144(i): ~~Plants that employ a~~ Chillers that are used to charge cooling thermal energy storage systems with a design temperature <40F.

EXCEPTION 3 to Section 144(i): Air cooled chillers with minimum efficiencies approved by the Commission pursuant to Section 10-109(d).

5.1.6 Modify Alterations, Prescriptive Approach 149(b)1C for Air-Cooled Chillers

149(B)1C New space-conditioning systems or components other than new or replacement space conditioning ducts shall meet the requirements of Section 144 applicable to the systems or components being altered; and

~~EXCEPTION 1 to Section 149(b)1C: For expansions of existing chilled water plants, Section 144(i) applies only to expansions of more than 300 tons.~~

EXCEPTION ~~2~~ 1 to Section 149(b)1C: For replacements of equivalent or lower capacity electric resistance space heaters for high rise residential apartment units.

EXCEPTION ~~3~~ 2 to Section 149(b)1C: For replacement of electric reheat of equivalent or lower capacity electric resistance space heaters, when natural gas is not available.

5.2 ACM

Chillers in the budget design shall use the efficiencies from 144(tbd).

5.3 Reference appendices

None.

6 Bibliography and Other Research

7 Appendices

7.1 Addendum M+BL+BT to 90.1-2007

6.4.1.2 Minimum Equipment Efficiencies—Listed Equipment—Nonstandard Conditions.

6.4.1.2.1 Water-cooled centrifugal chilling packages. Equipment not designed for operation at ARI Standard 550/590 test conditions of 44°F leaving chilled-water temperature and 85°F entering condenser water temperature with 3 gpm/ton condenser water flow *(and thus cannot be tested to meet the requirements of Table 6.8.1C)* shall have maximum full-load kW/ton and *NPLV* ratings adjusted using the following equation:

Adjusted maximum full-load kW/ton rating
= (full-load kW/ton from Table 6.8.1C)/*Kadj*

Adjusted maximum NPLV rating
= (IPLV from Table 6.8.1C)/*Kadj*

where
Kadj = A * B
where
$A = 0.00000014592 * (LIFT)^4 – 0.0000346496 * (LIFT)^3 + 0.00314196 * (LIFT)^2 – 0.147199 * (LIFT) + 3.9302$
LIFT = LvgCond – LvgEvap (°F)
LvgCond = Full-load leaving condenser fluid temperature (°F)
LvgEvap = Full-load leaving evaporator fluid temperature (°F)
B = 0.0015 * LvgEvap + 0.934

The adjusted full-load and *NPLV* values are only applicable for centrifugal chillers meeting all of the following full-load design ranges:

• Minimum Leaving Evaporator Fluid Temperature: 36°F
• Maximum Leaving Condenser Fluid Temperature: 115°F
• LIFT ≥ 20°F and ≤ 80°F

Manufacturers shall calculate the adjusted maximum kW/ton and NPLV before determining whether to label the chiller per 6.4.1.5. Compliance with 90.1-2007 or -2010 or both shall be labeled on chillers within the scope of the Standard.

Centrifugal chillers designed to operate outside of these ranges are not covered by this standard.

Example: Path A 600 ton centrifugal chiller Table 6.8.1C efficiencies as of 1/1/2010
Full Load = 0.570 kW/ton
IPLV = 0.539 kW/ton
LvgCond = 91.16°F
LvgEvap = 42°F
LIFT = 91.16 – 42 = 49.16°F
Kadj = A x B

A = 0.00000014592 x $(49.16)^4$ – 0.0000346496 x $(49.16)^3$ + 0.00314196 x $(49.16)^2$ – 0.147199 x (49.16) + 3.930 = 1.023
B = 0.0015 x 42 + 0.934 = 0.997
Adjusted full load = 0.570/(1.023 x 0.997) = 0.559 kW/ton
NPLV = 0.539/(1.023 x 0.997) = 0.528 kW/ton

6.4.1.2.2 Positive displacement (air- and water-cooled) chilling packages. Equipment with a leaving evaporator fluid temperature higher than 32°F, shall show compliance with Table 6.8.1C when tested or certified with water at standard rating conditions, per the referenced test procedure.

Reference update to chapter 12
ASHRAE-IESNA 90.1 2007 American Society of Heating Refrigerating and Air-conditioning Engineers

Replace the following table 6.8.1C with below table.
Delete Table 6.8.1H in its entirety.
Delete Table 6.8.1I in its entirety.
Delete Table 6.8.1J in its entirety.

Table 6.8.1C Water Chilling Packages – Efficiency Requirements[a]

Equipment Type	Size Category	Path A	Path B	Test Procedure[b]
Air-Cooled Chillers	<150 tons	≥9.562 EER ≥12.500 IPLV	NA[d]	
	≥150 tons	≥9.562 EER ≥12.750 IPLV	NA[d]	
Air-Cooled without Condenser, Electrical Operated	All Capacities	Air-cooled chillers without condensers must be rated with matching condensers and comply with the air-cooled chiller efficiency requirements		
Water cooled, Electrically Operated, Reciprocating	All Capacities	Reciprocating units must comply with water cooled positive displacement efficiency requirements		
Water Cooled Electrically Operated, Positive Displacement	<75 tons	≤0.780 kW/ton ≤0.630 IPLV	≤0.800 kW/ton ≤0.600 IPLV	
	≥75 tons and < 150 tons	≤0.775 kW/ton ≤0.615 IPLV	≤0.790 kW/ton ≤0.586 IPLV	ARI 550/590
	≥150 tons and < 300 tons	≤0.680 kW/ton ≤0.580 IPLV	≤0.718 kW/ton ≤0.540 IPLV	
	≥300 tons	≤0.620 kW/ton ≤0.540 IPLV	≤0.639 kW/ton ≤0.490 IPLV	
Water Cooled Electrically Operated, Centrifugal	<150 tons	≤0.634 kW/ton ≤0.596 IPLV	≤0.639 kW/ton ≤0.450 IPLV	
	≥150 tons and < 300 tons			
	≥300 tons and < 600 tons	≤0.576 kW/ton ≤0.549 IPLV	≤0.600 kW/ton ≤0.400 IPLV	
	≥600 tons	≤0.570 kW/ton ≤0.539 IPLV	≤0.590 kW/ton ≤0.400 IPLV	
Air Cooled Absorption Single Effect	All Capacities	≥0.600 COP	NA[d]	
Water-Cooled Absorption Single Effect	All Capacities	≥0.700 COP	NA[d]	ARI 560
Absorption Double Effect, Indirect-Fired	All Capacities	≥1.000 COP ≥1.050 IPLV	NA[d]	
Absorption Double Effect, Direct Fired	All Capacities	≥1.000 COP ≥1.000 IPLV	NA[d]	

a. The centrifugal chiller equipment requirements after adjustment per 6.4.1.2 do not apply to chillers where the design leaving fluid temperature is < 36°F. The requirements do not apply to positive displacement chillers with design leaving fluid temperatures ≤ 32°F. The requirements do not apply to absorption chillers with design leaving fluid temperatures < 40°F.

b. Section 12 contains a complete specification of the referenced test procedure, including the referenced year version of the test procedure.

c. Compliance with this standard can be obtained by meeting the minimum requirements of Path A or Path B. However, both the full load and IPLV must be met to fulfill the requirements of Path A or Path B.

d. NA means that this requirement is not applicable and cannot be used for compliance.

7.2 Performance curve coefficients

Chiller type	CAPFT_a	CAPFT_b	CAPFT_c	CAPFT_d	CAPFT_e	CAPFT_f
Baseline						
Positive Displacement, <75 tons,	0.446797	0.014742	0.000134	0.000440	-0.000015	-0.000085
Positive Displacement, >75 and <150 tons	0.446797	0.014742	0.000134	0.000440	-0.000015	-0.000085
Positive Displacement, >150 and <300 tons	0.446797	0.014742	0.000134	0.000440	-0.000015	-0.000085
Positive Displacement, >300 tons	0.446797	0.014742	0.000134	0.000440	-0.000015	-0.000085
Centrifugal, <150 tons	-0.497373	-0.009561	-0.000596	0.043521	-0.000584	0.000960
Centrifugal, >150 and <300 tons	-0.497373	-0.009561	-0.000596	0.043521	-0.000584	0.000960
Centrifugal, >300 and <600 tons	-0.497373	-0.009561	-0.000596	0.043521	-0.000584	0.000960
Centrifugal, >600 tons	-0.497373	-0.009561	-0.000596	0.043521	-0.000584	0.000960
Path A						
Positive Displacement, <75 tons,	0.446797	0.014742	0.000134	0.000440	-0.000015	-0.000085
Positive Displacement, >75 and <150 tons	0.446797	0.014742	0.000134	0.000440	-0.000015	-0.000085
Positive Displacement, >150 and <300 tons	0.446797	0.014742	0.000134	0.000440	-0.000015	-0.000085
Positive Displacement, >300 tons	0.446797	0.014742	0.000134	0.000440	-0.000015	-0.000085
Centrifugal, <150 tons	-0.497373	-0.009561	-0.000596	0.043521	-0.000584	0.000960
Centrifugal, >150 and <300 tons	-0.497373	-0.009561	-0.000596	0.043521	-0.000584	0.000960
Centrifugal, >300 and <600 tons	-0.497373	-0.009561	-0.000596	0.043521	-0.000584	0.000960
Centrifugal, >600 tons	-0.497373	-0.009561	-0.000596	0.043521	-0.000584	0.000960
Path B						
Positive Displacement, <75 tons,	0.334128	0.021015	-0.000102	-0.001407	-0.000029	0.000071
Positive Displacement, >75 and <150 tons	0.334128	0.021015	-0.000102	-0.001407	-0.000029	0.000071
Positive Displacement, >150 and <300 tons	0.334128	0.021015	-0.000102	-0.001407	-0.000029	0.000071
Positive Displacement, >300	0.334128	0.021015	-0.000102	-0.001407	-0.000029	0.000071

tons						
Centrifugal, <150 tons	0.180980	0.031844	-0.000154	0.009566	-0.000135	-0.000053
Centrifugal, >150 and <300 tons	0.180980	0.031844	-0.000154	0.009566	-0.000135	-0.000053
Centrifugal, >300 and <600 tons	0.363958	0.045022	-0.000274	-0.002028	-0.000088	-0.000012
Centrifugal, >600 tons	-0.455204	0.031347	-0.000057	0.020383	-0.000153	-0.000127

7.3 Letter from Trane

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TRANE

December 10, 2010

To: Mr. Jeff Stein
Cc: Mr. Steve Taylor

Taylor Engineering, LLC
1080 Marina Village Parkway, Suite 501
Alameda, CA 94501-1142

Dear Mr. Stein:

This letter is in response to the ASHRAE – Chiller Efficiency Stakeholder Meeting 2 for California Statewide Utility Codes and Standards Program presented by Taylor Engineering, LLC, on November 10, 2010. In this meeting, it was proposed that ANSI/ASHRAE Standard 90.1–2010[1] Centrifugal Path A minimum efficiency requirements be removed from California's energy code. We strongly disagree with this proposal and believe that both Path A and Path B should be included in the code.

ANSI/ASHRAE 90.1 introduced the dual-path compliance in the 2010 version of the standard after completing energy studies to verify these efficiency values. Both Path A and Path B push HVAC manufacturers to provide chillers that are efficient and that will provide energy savings to building owners and a reduction in electric demand for utility companies. The intent of ANSI/ASHRAE Standard 90.1 is to specify minimum equipment efficiencies—not technology. Path B part-load performance requirements effectively requires the application of variable frequency drives (VFD); therefore, the Title 24 energy code would be essentially mandating the use of VFDs and eliminating other energy-efficient options.

We disagree with this approach. ASHRAE 90.1 – 2010 created two chiller efficiency paths to allow building owners to make a choice. This agreement transcended the entire industry, as proponents of the CEC proposal certainly understand. If system energy efficiency is the ultimate desire, why are limitations being placed on the methods by which theses savings are achieved, specifically, focusing on equipment?

Furthermore, we do not believe that the decision to remove Path A should be based on the proposal given at the meeting. The chiller energy study cited in the presentation:

- *Incorrectly uses Integrated Part Load Value (IPLV) as the metric to measure chiller efficiency*
- *Is limited in scope*
- *Fails to factor in the high cost of VFDs, installation and replacement*
- *Fails to factor in the increased demand on electric utilities*

Each concern is addressed in more detail below.

Ingersoll Rand

Incorrect Use of IPLV

The proposal advocates the use of Integrated Part Load Value (IPLV) as the metric building owners should use to measure chiller efficiency. It has been well documented in the industry that IPLV should *not* be used in this manner. In fact, the Scope of Appendix D (Derivation of Integrated Part Load Value) of *AHRI 550/590 Standard for Performance Rating Of Water-Chilling Packages Using the Vapor Compression* states:

> "The equation was derived to provide a representation of the average part-load efficiency for a single chiller only. However, it is best to use a comprehensive analysis that reflects the actual weather data, building load characteristics, operational hours, economizer capabilities and energy drawn by auxiliaries such as pumps and cooling towers, when calculating the chiller and system efficiency. This becomes increasingly important with multiple chiller systems because individual chillers operating within multiple chiller systems are more heavily loaded than single chillers within single chiller systems." [2]

In other words, IPLV was never intended to be used for multiple chiller plants. Studies show that 80 to 90 percent of all chiller plants consist of multiple chillers. As highlighted in the *Synopsis* newsletter from Carrier Corporation, "Basing chiller selection on single-machine performance is a mistake that often leads to misapplication, which can be costly in both short and the long term." [3] In the article "A Closer Look at Chiller Ratings" published in the December 2009 edition of the *ASHRAE Journal*, the author uses energy analysis to prove that IPLV/NPLV is flawed for single and multiple chiller plants and IPLV/NPLV does not properly reflect energy savings. [4] Roy S. Hubbard Jr. of Johnson Controls Inc. stated in the March 2010 edition of the *ASHRAE Journal* that "[IPLV/NPLV] was never to calculate energy-cost savings, but rather as a comparison tool to compare one chiller with another." [5]

Instead of using IPLV to determine energy-cost savings, an energy analysis would provide a more complete picture of what the actual energy cost savings would be for Path A or Path B, allowing building owners to make an informed decision based on accurate data.

Limited Scope

The life-cycle cost analysis presented in the proposal used Oakland as the weather location and 460/480-volt chillers using variable frequency drives. While Oakland's climate could significantly benefit from the use of low-voltage VFDs, this is simply not the case for all 16 climate zones as defined by the California Energy Commission. Analysis of a single location, with a temperate climate, is inadequate for a code.

High Cost of VFDs

Medium-voltage VFDs did not appear to be considered in the study. Compliance with Path B would force building owners utilizing chillers with medium voltage (601 to 13,800 volts) motors to purchase VFDs. Based upon current available technology, this direction will financially burden building owners as the cost of a 4,160-volt VFD could more than double the cost of the chiller package (as compared to a chiller with mechanical starter) without potential economic returns or guarantees of energy savings.

This increase in cost may be prohibitive for some building owners who may not be able to afford to upgrade older chiller plants to new, more efficient chiller plants. Owners of new buildings may prefer the cost savings of unitary (direct expansion) systems, which are less efficient and would ultimately increase utility demand. More extensive research needs to be completed before mandating VFDs.

Instead of investing in VFDs, many building owners have realized energy savings by increasing the size of the heat exchangers. In fact, this can provide the building owner with chiller efficiency that substantially exceeds Path A requirements.

Cost of VFD Replacement

Additionally, the cost of VFD replacement was not included in the life-cycle analysis. A VFD on the chiller will require either replacement or extensive rebuild approximately once a decade. One VFD manufacturer[6] advertises a 10-year mean time between failures for their VFDs. The ASHRAE life of a centrifugal water-cooled chiller is 23 years[7]. The chiller energy study scenarios did not account for two replacement VFDs and installation cost.

If a Path A efficiency requirement was provided, no additional cost would be incurred by the owner, since the copper will last the lifespan of the chiller if maintained properly.

Increased Utility Demand

The table provided by Taylor Engineering in the PowerPoint[8] dated May 10, 2010, shows that Path B allows for lower full-load efficiency chillers to be used. In fact, the full-load efficiency for Path B is up to 4 percent less efficient than what was previously allowed by ANSI/ASHRAE 90.1 Standards. Chillers with worse full-load efficiency will increase the demand (kW) on the electric utility grid.

More specifically, on design days, chillers selected purely on Path B (as compared to Path A chillers) will require up to an additional 4 percent demand (kW) from the electric utilities at a time when surplus energy is not available. The cost to the electric utilities to cover this 4 percent increase has not been included in the cost analysis.

Summary

The direction set forth by the cited chiller energy study would limit the production of chillers manufactured in the United States to equipment that may be less energy efficient, more expensive, and is not financially justifiable for the building owners.

The analysis to use a single path efficiency requirement is flawed because IPLV/NPLV was inappropriately applied. Basing chiller selections off of a single standardized set of conditions (IPLV/NPLV) may result in building owners over-spending for unnecessary technology while consuming more energy.

Both Path A and Path B of ANSI/ASHRAE 90.1-2010 are critical to the success of reducing energy consumption and to building owners financial interests. The intent of Title 24 energy code is to specify minimum efficiency and *not* a specific technology.

At first glance, it may appear that removing Path A may simplify California's energy code, but the ramifications of this decision are multifaceted and detrimental to California's ongoing energy crisis.

If you would like to discuss this matter any further please do not hesitate to contact me.

Sincerely,

Randal Newton
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References

1. ANSI/ASHRAE/IENSA Standard 90.1-2010, Section 6.2.1 Mechanical Equipment Efficiency.
2. AHRI 550/590, 2003 *Standard for Performance Rating Of Water-Chilling Packages Using The Vapor Compression*, Appendix D, D2.1.
3. Carrier. "Optimizing Chiller Plant Efficiency: Factors to Consider." *Synopsis* 3:1: 1.
4. Geister, W. Ryan and Mike Thompson. "A Closer Look at Chiller Ratings." *ASHRAE Journal* (December 2010): 22-32.
5. Hubbard, Roy S. Jr. "Letters, Re: Chiller Ratings." *ASHRAE Journal* (March 2010): 16-18.
6. Toshiba Medium Voltage Drive Brochure http://www.toshiba.com/ind/data/tag_files/T300MV_Medium_Voltage_Drive_Brochure_130.pdf
7. 2007 ASHRAE Handbook HVAC Applications. "Chapter 36: Owning and Operating Costs." Table 4, p. 3.
8. Taylor Engineering. "Chiller Efficiency CASE Stakeholder Meeting #1." PowerPoint May 2010.