Cooling Tower Energy Efficiency Stakeholder Meeting 3

California Statewide Utility Codes and Standards Program

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Energy Solutions
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Overview

- Cooling tower efficiencies unchanged since T24 2001 (90.1-1999)
- Existing efficiencies were designed to cut out bottom ~5% of the products.
  - There was no analysis used to determine the efficiency levels
- Cooling towers not federally pre-empted but T24 has always followed 90.1
- VSDs required since 2001 for ≥7.5hp (144(h)2)
- Title 24 2005 added
  - Minimum flow 33% (144(h)3), and
  - Restriction on centrifugal cooling towers (144(h)4) for towers with rated capacity of > 900 gpm (~300 tons) at 95/85/75 (all cells)

Overview (contiued)

- ASHRAE Standard 90.1-2010 added requirements for close-circuit cooling towers.

Measure Scope

- Prescriptive scope for new construction only
  - Not replacement or expansion as space is likely limited and tower basins must be at the same level.
- Commercial/ Industrial/ Institutional
- Evaporative Cooling Towers

Proposed Code Change

- Mandatory:
  - Add requirements from 90.1 for closed-circuit cooling towers, leave open towers the same.
- Prescriptive:
  - Minimum cooling tower efficiency (new construction only)
    - ≥80 gpm/hp at 95/85/75
    - Note that higher efficiencies are justified but this was lowered in response to industry feedback.
  - Maximum cooling tower approach (new construction only)
    - ≤5°F approach for 24/7 plants (e.g. data centers, manufacturing facilities and labs)
    - No requirement for other facilities
  - Minimum flow turndown
    - Increase to ≤ 50%

Analysis (Office)

- Nominal 900 ton load
- 2 chiller plant (2 x 500t) with a 2-cell cooling tower
- Cooling towers designed for 50% flow turndown
- Used VBA TOPP model
  - The modified DOE 2 model for the chillers (EnergyPlus)
  - The DOE 2.2 model for cooling towers
  - Variable condenser water flow
  - Variable speed drive on towers
  - Optimal controls

TOPP Model

- Input:
  - Weather: time stamp, OADB, OAWB
  - CHW Load: time stamp, GPM, Ton, CHWST (CHWRT) --- from eQuest model results
  - Equipment schedule and performance curves:
    - Chiller: design data, performance curves, pressure drop;
    - Tower: design WB, Ta, Tr, GPM, HP, pressure drop
    - Pumps: design Heat, GPM, BHP, HP, MechEff, MotorEff, pressure drop, Pump Efficiency curve, Pump curve
    - HXs: design cold and hot: Tin, Tout, Q, type of HX, pressure drop
    - Waterloops: design flow, pressure drop
- Controls:
  - %Fan = 0%~ 100% at 10% (adj.) increment
  - %Cwflow = 10%~150% at 10% (adj.) increment
  - #chiller online: 1 or 2
  - # tower online: always run maximum number of towers that satisfy towers minimum flow req.

Simulations Run (Office)

- Climate:
  3C: Oakland
  4B: Albuquerque
  5C: Chicago
- Plant Load:
  - Peak Load = 900 ton
  - 10% oversized: Two chillers each 500 ton.
- Tower: A, B, C, D in the order of increasing design Approach
  Tower A: approach = 3 ~ 5 ^{o}F
  Tower B: approach = 5 ~ 7 ^{o}F
  Tower C: approach = 7 ~ 10 ^{o}F
  Tower D: approach = 9 ~ 12 ^{o}F
- Chillers:
  - A (Trane) multistage
  - B (York) single stage

Condenser Water System Costs

- 12 cooling towers
  - Low, medium and high efficiency (~45 to 100 gpm/hp)
  - 4 approaches (~5F to 12F)
- We got contractor’s costs FOB to jobsite from vendors and added
  - 28.75% contractors mark-up
  - 50% installation cost premium

Cooling Tower Models

Tower Name	B.A.C GPM @ 78/85/95	Tower pumping head PSI	Tower Code Name	Motor size	GPM/HP
3781C	***2342.02***	***6.69***	L01	50	46.8
3676C	***1938.02***	***4.9***	L02	40	48.5
3482C	***1377.01***	***4.9***	L03	30	45.9
3436C	***1266.01***	***4.32***	L04	30	42.2
3728C/V	***2277.02***	***6.69***	M01	40	56.9
3618C	***1773.01***	***4.9***	M02	30	59.1
3473C	***1374.01***	***4.32***	M03	25	55.0
3455C-MM	***1212.01***	***4.9***	M04	20	60.6
3872C-OM/V	***2268.02***	***7.85***	H01	30	75.6
3728C-NM	***1884.01***	***6.69***	H02	25	75.4
3552C-MM	***1392.01***	***4.9***	H03	20	69.6
3473C-LM/V	***1212.01***	***4.32***	H04	15	80.8

Preliminary Tower Efficiency Results

Climate Zone	TowerID	Ta	ChillerkWh	TowerkWh	CHWPkWh	CWPkWh	TotalKWh	TDV Energy Cost	Tower cost	Total LCC cost
			kWh/yr	kWh/yr	kWh/yr	kWh/yr	kWh/yr	15 year PV	First Cost installed	NPV
CZ03	H01	5.4	180,569	14,020	22,964	40,246	257,644	$ 1,103,350	$ 262,000	$ 1,365,350
CZ03	H02	7.0	182,346	13,521	23,000	36,827	255,532	$ 1,103,764	$ 231,613	$ 1,335,377
CZ03	H03	10.4	187,444	13,276	23,154	31,725	255,423	$ 1,116,114	$ 179,863	$ 1,295,977
CZ03	H04	12.3	189,456	12,084	23,153	30,352	254,736	$ 1,118,379	$ 156,753	$ 1,275,132
CZ03	L01	5.1	181,678	21,294	22,912	37,021	262,781	$ 1,121,414	$ 250,538	$ 1,371,951
CZ03	L02	6.7	183,925	19,130	22,922	32,167	258,006	$ 1,113,480	$ 221,825	$ 1,335,305
CZ03	L03	10.5	189,512	18,194	23,218	31,623	262,391	$ 1,145,187	$ 167,263	$ 1,312,450
CZ03	L04	11.6	191,805	19,350	23,248	30,207	264,471	$ 1,157,815	$ 152,963	$ 1,310,778
CZ03	M01	5.3	181,451	17,701	22,918	37,002	258,911	$ 1,109,230	$ 250,425	$ 1,359,655
CZ03	M02	7.6	183,871	16,056	22,971	32,065	254,788	$ 1,105,815	$ 208,375	$ 1,314,190
CZ03	M03	10.5	188,558	15,929	23,142	30,369	257,862	$ 1,127,638	$ 170,838	$ 1,298,475
CZ03	M04	12.3	191,091	14,560	23,248	31,572	260,247	$ 1,141,057	$ 156,625	$ 1,297,682
CZ06	H01	4.8	318,341	23,324	26,221	61,764	429,471	$ 1,340,801	$ 262,000	$ 1,602,801
CZ06	H02	6.4	322,553	22,260	26,305	56,133	427,009	$ 1,341,083	$ 231,613	$ 1,572,695
CZ06	H03	9.7	332,716	22,064	26,530	48,021	428,957	$ 1,356,798	$ 179,863	$ 1,536,661
CZ06	H04	11.5	336,446	20,703	26,743	45,271	428,763	$ 1,360,233	$ 156,753	$ 1,516,985
CZ06	L01	4.6	321,058	34,655	26,206	56,714	438,378	$ 1,365,013	$ 250,538	$ 1,615,551
CZ06	L02	6.1	324,504	31,704	26,207	49,211	431,397	$ 1,353,309	$ 221,825	$ 1,575,134
CZ06	L03	9.8	336,604	30,068	26,691	47,460	440,622	$ 1,392,354	$ 167,263	$ 1,559,616
CZ06	L04	10.9	340,832	31,788	26,771	45,190	444,434	$ 1,407,210	$ 152,963	$ 1,560,172
CZ06	M01	4.8	320,057	29,398	26,216	56,636	432,004	$ 1,348,871	$ 250,425	$ 1,599,296
CZ06	M02	7.0	325,705	26,250	26,267	48,956	427,006	$ 1,344,460	$ 208,375	$ 1,552,835
CZ06	M03	9.8	334,893	26,249	26,540	45,870	433,350	$ 1,371,124	$ 170,838	$ 1,541,961
CZ06	M04	11.5	340,430	23,741	26,811	47,103	437,755	$ 1,387,656	$ 156,625	$ 1,544,281

Preliminary Tower Efficiency Results

Climate Zone	TowerID	Ta	ChillerkWh	TowerkWh	CHWPkWh	CWPkWh	TotalKWh	TDV Energy Cost	Tower cost	Total LCC cost
			kWh/yr	kWh/yr	kWh/yr	kWh/yr	kWh/yr	15 year PV	First Cost installed	NPV
CZ07	H01	4.6	291,468	23,474	28,450	63,170	406,361	$ 1,261,344	$ 262,000	$ 1,523,344
CZ07	H02	6.2	295,670	22,170	28,520	57,532	403,543	$ 1,259,872	$ 231,613	$ 1,491,484
CZ07	H03	9.4	305,294	21,713	28,705	49,514	404,841	$ 1,272,814	$ 179,863	$ 1,452,676
CZ07	H04	11.3	308,944	20,304	28,843	47,044	404,704	$ 1,275,053	$ 156,753	$ 1,431,806
CZ07	L01	4.4	293,697	35,487	28,435	57,861	415,132	$ 1,284,996	$ 250,538	$ 1,535,534
CZ07	L02	5.9	297,513	31,904	28,446	50,211	407,923	$ 1,272,334	$ 221,825	$ 1,494,159
CZ07	L03	9.6	308,717	29,829	28,809	49,242	416,405	$ 1,306,531	$ 167,263	$ 1,473,793
CZ07	L04	10.7	313,264	31,284	28,855	47,012	420,284	$ 1,320,545	$ 152,963	$ 1,473,508
CZ07	M01	4.6	292,808	29,863	28,437	57,880	408,790	$ 1,269,175	$ 250,425	$ 1,519,600
CZ07	M02	6.8	298,432	26,390	28,482	50,092	403,167	$ 1,262,052	$ 208,375	$ 1,470,427
CZ07	M03	9.6	307,640	25,742	28,756	47,255	409,022	$ 1,285,993	$ 170,838	$ 1,456,831
CZ07	M04	11.3	312,483	23,666	28,947	48,902	413,623	$ 1,301,280	$ 156,625	$ 1,457,905
CZ08	H01	4.6	375,606	25,577	44,399	69,623	515,040	$ 1,643,617	$ 262,000	$ 1,905,617
CZ08	H02	6.2	380,396	25,381	44,486	63,880	513,926	$ 1,649,159	$ 231,613	$ 1,880,771
CZ08	H03	9.4	392,910	26,411	44,781	55,059	518,792	$ 1,676,482	$ 179,863	$ 1,856,345
CZ08	H04	11.3	397,140	25,599	44,950	52,388	519,693	$ 1,684,111	$ 156,753	$ 1,840,864
CZ08	L01	4.4	379,135	37,078	44,324	64,306	524,614	$ 1,670,813	$ 250,538	$ 1,921,351
CZ08	L02	5.9	383,669	34,876	44,350	55,875	518,581	$ 1,663,348	$ 221,825	$ 1,885,173
CZ08	L03	9.6	398,007	35,116	45,084	54,566	532,619	$ 1,720,686	$ 167,263	$ 1,887,949
CZ08	L04	10.7	403,637	37,345	45,174	52,048	538,111	$ 1,741,840	$ 152,963	$ 1,894,802
CZ08	M01	4.6	377,584	32,007	44,366	64,190	517,936	$ 1,653,101	$ 250,425	$ 1,903,526
CZ08	M02	6.8	384,801	29,752	44,393	55,773	514,483	$ 1,655,070	$ 208,375	$ 1,863,445
CZ08	M03	9.6	396,334	30,680	44,820	52,582	524,219	$ 1,694,642	$ 170,838	$ 1,865,480
CZ08	M04	11.3	402,195	28,882	45,059	54,600	530,438	$ 1,718,601	$ 156,625	$ 1,875,226

Cooling Tower Energy Efficiency

Preliminary Tower Efficiency Results

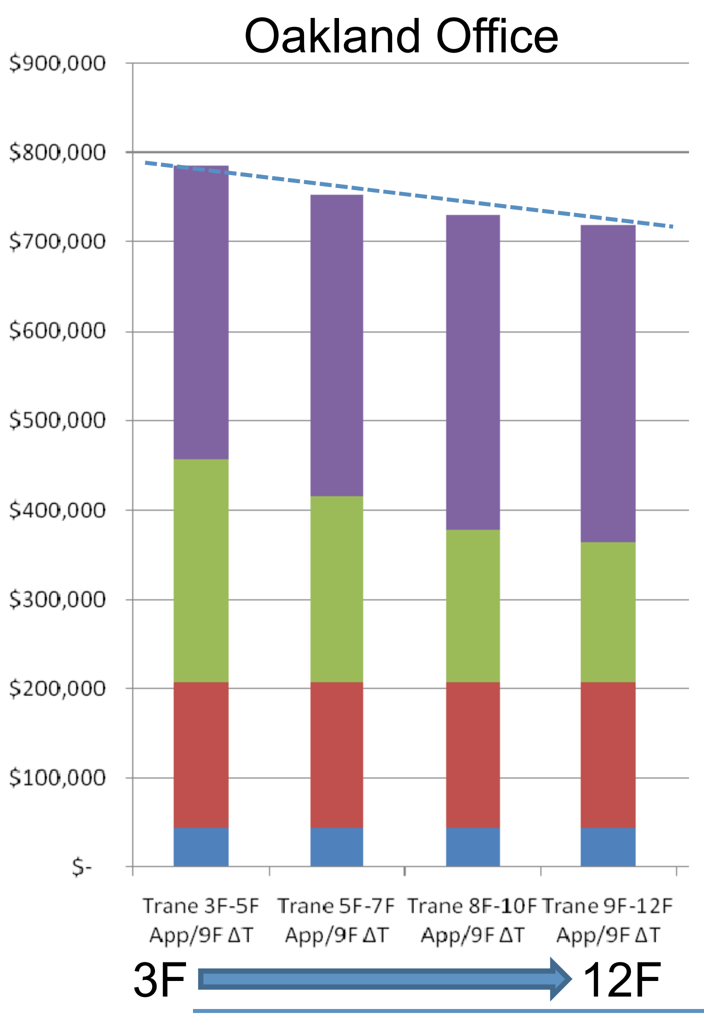
Climate Zone	TowerID	Ta	ChillerkWh	TowerkWh	CHWPkWh	CWPkWh	TotalKWh	TDV Energy Cost	Tower cost	Total LCC cost
			kWh/yr	kWh/yr	kWh/yr	kWh/yr	kWh/yr	15 year PV	First Cost installed	NPV
CZ09	H01	4.4	331,167	22,319	35,891	61,193	450,389	$ 1,623,254	$ 262,000	$ 1,885,254
CZ09	H02	6.0	335,003	22,274	36,146	55,487	448,677	$ 1,629,768	$ 231,613	$ 1,861,381
CZ09	H03	9.2	345,866	22,838	36,486	47,590	452,461	$ 1,660,487	$ 179,863	$ 1,840,350
CZ09	H04	11.0	349,197	22,105	36,728	45,085	452,799	$ 1,668,651	$ 156,753	$ 1,825,403
CZ09	L01	4.2	333,184	33,178	35,724	56,669	458,570	$ 1,649,520	$ 250,538	$ 1,900,058
CZ09	L02	5.7	337,318	30,870	35,872	48,848	452,812	$ 1,645,508	$ 221,825	$ 1,867,333
CZ09	L03	9.3	350,534	30,179	36,781	47,012	464,348	$ 1,704,094	$ 167,263	$ 1,871,357
CZ09	L04	10.4	355,859	31,659	37,009	44,600	468,976	$ 1,726,197	$ 152,963	$ 1,879,159
CZ09	M01	4.4	332,494	28,260	35,854	56,320	452,777	$ 1,633,036	$ 250,425	$ 1,883,461
CZ09	M02	6.6	338,620	25,940	35,939	48,678	448,974	$ 1,637,609	$ 208,375	$ 1,845,984
CZ09	M03	9.4	348,995	26,404	36,598	45,312	457,105	$ 1,679,428	$ 170,838	$ 1,850,266
CZ09	M04	11.0	353,741	24,937	36,907	46,825	462,129	$ 1,702,196	$ 156,625	$ 1,858,821
CZ10	H01	4.6	446,094	27,879	72,944	84,499	631,323	$ 1,930,418	$ 262,000	$ 2,192,418
CZ10	H02	6.2	453,801	27,844	72,942	78,453	632,836	$ 1,941,966	$ 231,613	$ 2,173,578
CZ10	H03	9.4	469,707	30,879	72,942	68,412	641,740	$ 1,979,060	$ 179,863	$ 2,158,923
CZ10	H04	11.3	474,636	31,115	72,942	65,334	643,786	$ 1,990,020	$ 156,753	$ 2,146,772
CZ10	L01	4.4	450,311	39,165	72,946	78,589	640,847	$ 1,958,043	$ 250,538	$ 2,208,581
CZ10	L02	5.9	458,214	36,715	72,877	68,514	636,155	$ 1,955,246	$ 221,825	$ 2,177,071
CZ10	L03	9.6	475,414	41,360	72,942	68,412	657,945	$ 2,030,096	$ 167,263	$ 2,197,358
CZ10	L04	10.7	482,036	45,187	72,942	65,334	665,391	$ 2,056,501	$ 152,963	$ 2,209,464
CZ10	M01	4.6	449,899	33,031	72,944	78,511	634,262	$ 1,940,940	$ 250,425	$ 2,191,365
CZ10	M02	6.8	460,491	31,626	72,875	68,514	633,385	$ 1,949,601	$ 208,375	$ 2,157,976
CZ10	M03	9.6	472,894	36,693	72,942	65,334	647,758	$ 2,000,203	$ 170,838	$ 2,171,040
CZ10	M04	11.3	479,907	36,139	72,942	68,412	657,128	$ 2,030,142	$ 156,625	$ 2,186,767

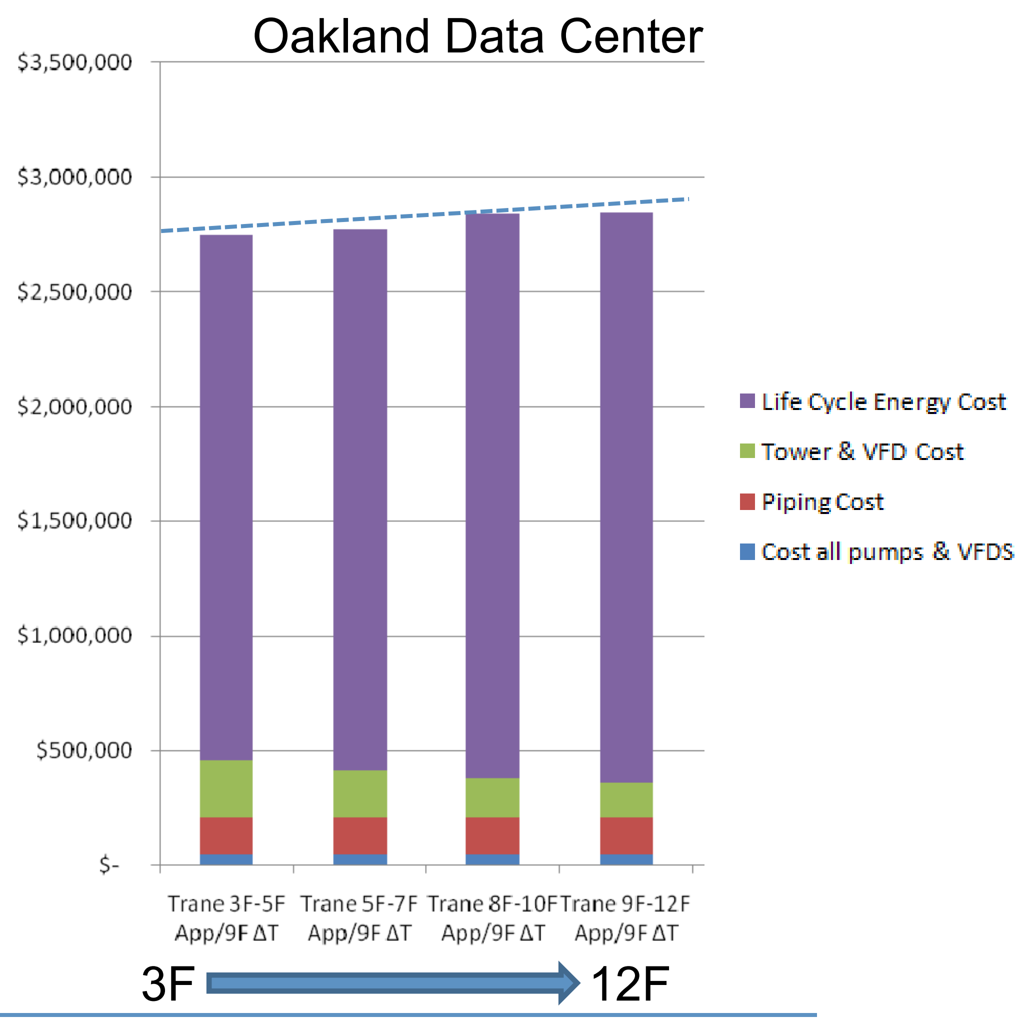
Cooling Tower Energy Efficiency

Preliminary Tower Efficiency Results

Climate Zone	TowerID	Ta	ChillerkWh	TowerkWh	CHWPkWh	CWPkWh	TotalKWh	TDV Energy Cost	Tower cost	Total LCC cost
			kWh/yr	kWh/yr	kWh/yr	kWh/yr	kWh/yr	15 year PV	First Cost installed	NPV
CZ12	H01	4.3	274,646	18,377	32,318	50,653	375,837	$ 1,417,565	$ 262,000	$ 1,679,565
CZ12	H02	5.8	278,910	17,919	32,464	46,259	375,326	$ 1,425,026	$ 231,613	$ 1,656,639
CZ12	H03	9.0	287,833	19,271	32,817	39,602	379,268	$ 1,451,953	$ 179,863	$ 1,631,815
CZ12	H04	10.8	290,455	19,390	33,119	37,402	380,160	$ 1,459,439	$ 156,753	$ 1,616,191
CZ12	L01	4.0	276,928	26,748	32,310	46,685	382,516	$ 1,440,014	$ 250,538	$ 1,690,552
CZ12	L02	5.5	280,564	25,234	32,284	40,605	378,604	$ 1,436,805	$ 221,825	$ 1,658,630
CZ12	L03	9.1	292,064	25,032	33,016	39,262	389,258	$ 1,490,150	$ 167,263	$ 1,657,412
CZ12	L04	10.2	296,584	26,517	33,172	37,321	393,449	$ 1,509,746	$ 152,963	$ 1,662,709
CZ12	M01	4.2	275,896	23,123	32,339	46,589	377,846	$ 1,425,876	$ 250,425	$ 1,676,301
CZ12	M02	6.4	281,836	21,440	32,483	40,231	375,833	$ 1,431,035	$ 208,375	$ 1,639,410
CZ12	M03	9.1	290,663	22,058	32,879	37,774	383,170	$ 1,467,874	$ 170,838	$ 1,638,712
CZ12	M04	10.8	295,402	20,814	33,298	38,837	388,155	$ 1,490,542	$ 156,625	$ 1,647,167
CZ13	H01	4.3	348,205	22,801	58,995	71,107	501,038	$ 1,606,974	$ 262,000	$ 1,868,974
CZ13	H02	5.8	354,755	22,932	58,995	66,058	502,509	$ 1,617,588	$ 231,613	$ 1,849,200
CZ13	H03	9.0	367,985	25,399	58,994	57,584	509,724	$ 1,649,429	$ 179,863	$ 1,829,292
CZ13	H04	10.8	372,211	25,654	58,994	54,994	511,668	$ 1,660,321	$ 156,753	$ 1,817,074
CZ13	L01	4.0	351,057	32,590	58,990	66,077	508,612	$ 1,629,990	$ 250,538	$ 1,880,528
CZ13	L02	5.5	357,882	30,718	58,990	57,618	505,046	$ 1,627,273	$ 221,825	$ 1,849,098
CZ13	L03	9.1	372,860	33,664	58,994	57,584	522,968	$ 1,692,756	$ 167,263	$ 1,860,019
CZ13	L04	10.2	379,015	36,287	58,994	54,994	529,187	$ 1,715,050	$ 152,963	$ 1,868,013
CZ13	M01	4.2	351,067	27,328	58,995	66,058	503,348	$ 1,615,291	$ 250,425	$ 1,865,716
CZ13	M02	6.4	359,969	26,093	58,990	57,601	502,538	$ 1,622,742	$ 208,375	$ 1,831,117
CZ13	M03	9.1	371,458	29,385	58,994	54,994	514,686	$ 1,666,883	$ 170,838	$ 1,837,720
CZ13	M04	10.8	376,365	30,074	58,994	57,584	522,704	$ 1,694,299	$ 156,625	$ 1,850,924

Preliminary Tower Approach LCCA





Estimating Cooling Tower Market

- This is covered in the cooling tower water savings presentation

Proposed Code Change Mandatory

TABLE 112-G PERFORMANCE REQUIREMENTS FOR HEAT REJECTION EQUIPMENT[d]

Equipment Type	Total System Heat Rejection Capacity at Rated Conditions	Subcategory or Rating Condition	Performance Required [a,b]	Test Procedure [c]
Propeller or Axial Fan Open Cooling Towers	All	95°F Entering Water 85°F Leaving Water 75 °F wb Outdoor Air	≥ 38.2 gpm/hp	CTI ATC-105 and CTI STD-201
Centrifugal Fan Open Cooling Towers	All	95°F Entering Water 85°F Leaving Water 75 °F wb Outdoor Air	≥ 20.0 gpm/hp	CTI ATC-105 and CTI STD-201
Propeller or axial fan closed-circuit cooling towers	All	102°F entering water 90°F leaving water 75°F *entering wb*	≥14.0 gpm/hp	CTI ATC-105S and CTI STD-201
Centrifugal closed-circuit cooling towers	All	102°F entering water 90°F leaving water 75°F *entering wb*	≥7.0 gpm/hp	CTI ATC-105S and CTI STD-201

Proposed Code Change Prescriptive 144(h)

144(h) Heat Rejection Systems.

1 General. Subsection 144(h) applies to heat rejection equipment used in comfort cooling systems such as aircooled condensers, open cooling towers, closed-circuit cooling towers, and evaporative condensers.

2 Fan Speed Control. Each fan powered by a motor of 7.5 hp (5.6 kW) or larger shall have the capability to operate that fan at 2/3 of full speed or less, and shall have controls that automatically change the fan speed to control the leaving fluid temperature or condensing temperature/pressure of the heat rejection device.

EXCEPTION 1 to Section 144(h)2: Heat rejection devices included as an integral part of the equipment listed in Table 112-A through Table 112-E.

EXCEPTION 2 to Section 144(h)2: Condenser fans serving multiple refrigerant circuits.

EXCEPTION 3 to Section 144(h)2: Condenser fans serving flooded condensers.

EXCEPTION 4 to Section 144(h)2: Up to 1/3 of the fans on a condenser or tower with multiple fans where the lead fans comply with the speed control requirement.

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Proposed Code Change Prescriptive 144(h)

144(h) Heat Rejection Systems.

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3 Tower Flow Turndown. Open cooling towers configured with multiple condenser water pumps shall be designed so that all cells can be run in parallel with the larger of:

A. The flow that's produced by the smallest pump, or

B. ~~33~~50 percent of the design flow for the cell.

4 ~~Limitation on Centrifugal Fan Cooling Towers. Open cooling towers with a combined rated capacity of 900 gpm and greater at 95°F condenser water return, 85°F condenser water supply and 75°F outdoor wet-bulb temperature shall use propeller fans and shall not use centrifugal fans.~~

~~EXCEPTION 1 to Section 144(h)4: Cooling towers that are ducted (inlet or discharge) or have an external sound trap that requires external static pressure capability.~~

~~EXCEPTION 2 to Section 144(h)4: Cooling towers that meet the energy efficiency requirement for propeller fan towers in Section 112, Table 112-G.~~ Efficiency. Open cooling towers shall have a minimum efficiency of 80 gpm/hp when rated at the test conditions and procedures in Table 112-G

Exception 1 to Section 144(h)4: New towers added to an existing condenser water system.

5 Approach. Open cooling towers serving 24/7 facilities shall be selected for a maximum approach of 5F at design conditions.

Exception 1 to Section 144(h)5: New towers added to an existing condenser water system.

Industry Comments ASHRAE TC8.6

- Negative impact on product offering
  - 100 gpm/hp only 10% of products
- May drive market to less efficient systems
- Increased customer costs

- In recognition of this we are reducing the maximum efficiency from 100 gpm/hp to 80 gpm/hp.
- We already have a prescriptive limit on air-cooled chillers
- This is accounted for in the LCCA

Industry Comments ASHRAE TC8.6

- Increased footprint
- Requires more sophisticated controls
- Water loading is a problem with turndown requirements

- This is a prescriptive requirement, projects with footprint problems can go performance
- Not in our experience
- In response we are proposing an increase on turndown to 50%

Industry Comments ASHRAE TC8.6

- Maximum approach should be provided

- This was not borne out in our analysis for office buildings. We have provided a maximum approach for 24X7 facilities.

Next Steps

- Complete analysis for the rest of the climates
- Repeat simulations (at least a few test cases) for single stage chillers

Documentation

- TOPP Model:
  - Mark Hydeman and Anna Zhou. *Optimizing Chilled Water Plant Controls.* ASHRAE Journal, June 2007.
- Modified DOE2 (chiller) model:
  - Mark Hydeman, et alia. *Development and Testing of a Reformulated Regression Based Electric Chiller Model.* ASHRAE Transaction, HI-02-18-02, 2002
- DOE 2.2 Cooling Tower Model:
  - DOE 2.2 Engineering Manual
  - Mark Hydeman and Dudley Benton. *An Improved Cooling Tower Algorithm for the CoolTools™ Simulation Model*. ASHRAE Transaction, AC-02-9-04, 2002
- Available from http://tinyurl.com/23xegku