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Comment on Integrated Pump Refrigerant Economizer Energy Efficiency Review

Additional submitted attachment is included below.

Comment on Integrated Pump Refrigerant Economizer Energy Efficiency Review

CALIFORNIA STATEWIDE UTILITY CODES AND STANDARDS TEAM

June 16, 2021

1. Introduction

The California Statewide Utility Codes and Standards Enhancement Team (Statewide CASE Team) appreciates the opportunity to participate in the review of the May 6, 2021 Express Terms 2022 Energy Code, Title 24 Parts 1 and 6 (45-Day Express Terms)[1].

The Statewide CASE Team actively supports code-setting bodies in developing and revising building energy codes and standards. The program's objective is to achieve significant energy savings and assist in meeting other energy-related state policy goals through the development of reasonable, responsible, and cost-effective code changes. Three California Investor Owned Utilities – Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison – and two Publicly Owned Utilities – Los Angeles Department of Water and Power and Sacramento Municipal Utility District (herein referred to as the Statewide CASE Team when including the CASE Author) – sponsored this effort. The Statewide CASE Team is actively supporting the California Energy Commission (Energy Commission) in updating the California Energy Code (Title 24, Part 6) for the 2022 code update cycle. Through CASE Reports, the Statewide CASE Team has provided the Energy Commission with the technical and cost-effectiveness information required to make informed judgments on proposed standards for promising energy efficiency design practices and technologies.

The Statewide CASE Team encourages the Energy Commission to consider the recommendations presented in this document.

2. Summary of Recommended Revisions

This memo provides energy analysis to support improvements to the proposed 45-Day Language for Title 24, Part 6, Section 140.9(a)1C for pumped refrigerant economizers.

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[1]CEC Docket #21-BSTD-01, Document #237717
https://efiling.energy.ca.gov/GetDocument.aspx?tn=237717&DocumentContentId=70942

As proposed in the 45-Day Language, Section 140.9(a)1C only includes a 50°F outdoor dry-bulb temperature threshold requirement for full economizing for pumped refrigerant economizers.

The *Integrated Pumped Refrigerant Economizer for Computer Rooms Building Energy Efficiency Measure Proposal*[2] that supported this code change was based on an analysis showing computer room air conditioning (CRAC) units with refrigerant economizers as having an equivalent time dependent valuation (TDV) energy use to a code minimally-compliant water-cooled chilled water plant with water economizing using evaporative cooling towers (as permitted under 140.9(a)1B).

This analysis did not fully isolate the effect of the refrigerant economizer on a minimally compliant CRAC unit relative to the code minimum system of a water cooled chiller with an evaporatively cooled water economizer in regards to fan energy or cooling COP. Differences in the baseline and proposed model supply fan energy inputs in the *Integrated Pumped Refrigerant Economizer for Computer Rooms Building Energy Efficiency Measure Proposal* resulted in the proposed refrigerant economizer model showing significant supply fan energy savings. Since the code change proposal is for pumped refrigerant economizers and does not include impacts to code requirements for supply fan power, no energy savings from supply fan energy should be included in order to demonstrate pumped refrigerant economizers are energy equivalent to a code baseline water economizer system. The analysis presented in this letter adjusted baseline and proposed system supply fan power inputs to remove fan energy savings impacts in the analysis. Refer to the Appendix for details.

The CRAC cooling efficiency used in the code change proposal analysis was above (better than) code minimum. In reviewing this application the Statewide CASE team adjusted the cooling COP so that TDV energy was equivalent to a minimally compliant water economizer system. To achieve TDV energy neutrality, Section 140.9(a)1C should include a minimum efficiency threshold that varies by climate zone between 2.3 and 5.5 CRAC net sensible COP rated in accordance with AHRI 1360 to ensure that all pumped refrigerant economizer systems permitted are at least energy equivalent to other economizer systems for computer rooms[3]. The equivalent cooling COPs and their corresponding net sensible COPs (accounting for fan energy) are shown in Table 2.

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[2] Source: *Vertiv Comments -Vertiv -Updated Integrated Pumped Refrigerant Economizer.* November 2020, https://efiling.energy.ca.gov/GetDocument.aspx?tn=237790&DocumentContentId=71031

[3] Alternatively, a minimally compliant CRAC, with a refrigerant economizer could be installed with an air economizer system to comply with 140.9(a)1 as is commonly done for most air-cooled equipment. This would provide an alternative compliance path for CRACs with refrigerant economizers and therefore avoid federal preemption.

An alternate approach for achieving refrigerant economizer equivalence to a water side economizer is presented in Section 6.1 which combines net sensible COP with elevated full economizing temperatures. This approach allows lower COPs if they are paired with a higher capacity heat rejection system such that the refrigerant economizer can achieve full economizing at higher outdoor temperatures.

3. Background Information

3.1 CRAC Federal Efficiency Coefficient of Performance (COP) Rating

Pumped refrigerant economizers available in today's California market are part of CRAC units. CRACs are a federally regulated product, and CRAC efficiency is rated and tested in accordance with The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Standard 1360: *Standard for Performance Rating of Computer and Data Processing Room Air Conditioners*. AHRI Standard 1360 provides efficiency ratings of CRACs in units of Net Sensible Coefficient of Performance (NSenCOP), which is defined as the ratio of net sensible cooling capacity (kW) divided by total CRAC power input (kW). According to AHRI Standard 1360, the total CRAC power input includes all indoor unit power (e.g., supply fans, compressors) and condenser/condensing unit power, but does not include reheaters and humidifiers. For water, glycol, and chilled water units, AHRI Standard 1360 includes a defined power allowance for pumps and heat rejection, which are included in NSenCOP.

3.2 Energy Analysis Methodology

3.2.1 Model COP

While CRACs have efficiency COP ratings that include supply fans, EnergyPlus (the software engine CBECC-Com uses) models supply fan energy separate from cooling energy. To model CRAC energy in EnergyPlus, an input for *cooling COP*, which includes compressor, condenser fan, and refrigerant economizer pump energy for air-cooled integrated pumped refrigerant economizer CRACs, is required. Separate inputs are used in the model to simulate supply fan energy.

Title 24, Part 6, Section 140.9(a)2 specifies a maximum supply fan power requirement at design conditions of 27 W/kBtuh. This converts to a fan COP of 10.9 for supply fan power. As a side note, the fan power requirement in Section 140.9(a)2 was compared to ASHRAE 90.1-2016, Section 11.5.2(c) fan power component in system COP and was found to be very similar in magnitude.

A CRAC NSenCOP rating can be converted to a cooling COP by removing the fan power component. This inherently results in the cooling COP being slightly higher than the NSenCOP because fan energy is added to NSenCOP which increases the denominator (energy), but the numerator (cooling capacity) remains the same. The equations below describe the conversion between NSenCOP and cooling COP.

$$NSenCOP = \frac{Capacity\ (kW)}{Total\ Input\ Power\ (kW)}$$

Equation 1. NSenCOP

$$\frac{1}{NSenCOP} = \frac{Total\ Input\ Power\ (kW)}{Capacity\ (kW)} = \frac{Fan\ Power\ (kW)}{Capacity\ (kW)} + \frac{Compressor\ Power\ (kW)}{Capacity\ (kW)}$$

Equation 2. NSenCOP Component Breakdown

$$\frac{1}{NSenCOP} = \frac{1}{Fan\ COP} + \frac{1}{Cooling\ COP}$$

Equation 3. NSenCOP Conversion Between Fan and Cooling COPs

3.2.2 Analysis Methodology

By varying the CRAC cooling COP for each climate zone, we systematically calculated the minimum CRAC cooling COP required for a pumped refrigerant economizer to have equivalent annual TDV energy consumption as a baseline water-cooled chiller with evaporative cooling tower system. Results for both 2019 code baseline and 2022 45-day language baseline were calculated.

After the equivalent cooling COP tables were developed, the cooling COP was converted to NSenCOP based on Equation 1 through Equation 3 so that results were translated into the same units as AHRI Standard 1360 for CRACs and match the value that would appear on permit documents. These results are also presented in sections 4 and 5.

3.2.2.1 2019 Title 24 vs. 2022 Title 24: Section 140.9(a)1

Title 24, Part 6, Section 140.9(a)1 is anticipated to have increased outdoor temperatures where full economizing is required, thus making a minimally code compliant baseline water economizer more energy efficient in 2022 compared to 2019. Therefore, it was important to show refrigerant economizer equivalent COP tables compared to 2022 baseline in addition to 2019 baseline.

Key changes to Section 140.9(a)1 economizer requirements between 2019 and 2022 45-day language are shown as follows:

- For air economizers: outdoor dry-bulb temperature for full economizing increased from 55°F to 65°F.
- For evaporatively-cooled water economizers: outdoor wet-bulb temperature for full economizing increased from 35°F to 45°F.
- For refrigerant economizers: not included to outdoor dry-bulb temperature for full economizing of 50°F.

3.3 Recommendation to Update Proposed Section 140.9(a)1C Language

Based on our review of the energy models presented in the *Integrated Pumped Refrigerant Economizer for Computer Rooms Building Energy Efficiency Measure Proposal*, it appears that a full-load cooling COP of 3.92 was used in the energy analysis to demonstrate equivalent energy performance of a pumped refrigerant economizer CRAC to a water-cooled chiller plant with water economizing using evaporative cooling towers, with a baseline chiller COP of 5.17. The model includes 10 CRACs operating in parallel for a total cooling capacity of 4,560,479 Btu/hr (or about 456,000 Btu/hr per CRAC). The ASHRAE 90.1-2019 minimum efficiency for this size CRAC is 2.36 COP (including supply fans)[4], which is expected to be adopted by the U.S. Department of Energy later this year. After subtracting out a 140.9(a)2 correlation for fan energy using Equation 3, this equates to a cooling COP of 3.01, which is significantly lower than the value of 3.92 used in the *Integrated Pumped Refrigerant Economizer for Computer Rooms Building Energy Efficiency Measure Proposal*.

As written, the 45-Day Language adds an allowance for refrigerant economizers to Section 140.9(a)1 but does not include a minimum COP requirement. Because a pumped refrigerant economizer requires a COP better than code minimum to be energy equivalent to 2019 Title 24, Part 6 Section 140.9(a)1 equipment, the Statewide CASE Team urges the Energy Commission to include language in Section 140.9(a)1C that establishes a minimum equipment efficiency requirement for pumped refrigerant economizers.

There were also differences in the baseline and proposed model supply fan energy inputs in the *Integrated Pumped Refrigerant Economizer for Computer Rooms Building Energy Efficiency Measure Proposal* which resulted in the proposed refrigerant economizer model showing significant supply fan energy savings. The analysis presented in this letter adjusted baseline and proposed system supply fan power inputs

[4] Minimum Net Sensible COP for air cooled CRAC with fluid economizer, downflow, ≥ 295,000 Btu/hr, per 2019 ASHRAE 90.1, Table 6.8.1-10.

to remove fan energy savings impacts in the analysis. The Appendix includes details on model input adjustments for supply fan power.

The following sections show energy analysis results for the Energy Commission's consideration in adding a minimum pumped refrigerant economizer efficiency requirement to the code language.

4. Pumped Refrigerant Economizer Energy Comparison to 2019 Title 24, Part 6 Section 140.9(a)1 Requirements

A minimum full-load cooling COP was calculated for each climate zone in order for the proposed pumped refrigerant economizer cooling energy to be equal to the energy use for a code-baseline water-cooled chiller plant with water economizing using evaporative cooling towers (chiller cooling + pumps + cooling tower energy). To compare energy, chiller cooling, pumps, and heat rejection fans in the baseline case are compared to CRAC compressor, pump, and heat rejection fan energy in the refrigerant economizer case. As shown in Table 1, *a pumped refrigerant economizer with a minimum cooling COP of 4.0 and with full economizing at 50°F outdoor dry-bulb* provides equivalent energy use to a water-cooled chiller and water economizer system under 2019 Title 24, Part 6 economizer thresholds for all climate zones, when comparing annual TDV kBtu energy use. A cooling COP of 4.0 equates to a total CRAC net sensible COP of 2.9 when including 140.9(a)2 minimally compliant supply fan energy, as shown in Table 1. Alternatively, code language could use climate zone specific COPs per Table 1.

Table 1. Minimum Pumped Refrigerant Economizer Cooling COP (top row) and Net Sensible COP (bottom row) for Equivalent Energy Use to 2019 Baseline Water-Cooled Chiller Plant with Water Economizer

	CZ01	CZ02	CZ03	CZ04	CZ05	CZ06	CZ07	CZ08	CZ09	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
Minimum Pumped Refrigerant Economizer Cooling COP	4.0	3.8	3.3	3.4	3.5	2.6	2.0	2.6	3.0	3.2	3.7	3.7	3.7	3.5	3.6	2.8
Minimum Pumped Refrigerant Economizer Net Sensible COP	2.9	2.8	2.5	2.6	2.6	2.1	1.7	2.1	2.3	2.5	2.8	2.7	2.7	2.7	2.7	2.3

5. Pumped Refrigerant Economizer Energy Comparison to 2022 Title 24, Part 6 45-Day Language Section 140.9(a)1 Requirements

The 45-Day Language for 2022 Title 24, Part 6 shows that outdoor temperature thresholds for air and water economizers are anticipated to increase, thereby reducing energy use of these systems and establishing more efficient code-baseline systems for computer rooms. If the COPs listed in Table 1 were to be adopted as a minimum requirement in 2022 Title 24, Part 6 Section 140.9(a)1C, that code-baseline refrigerant economizer system would no longer use equivalent energy use to a minimally code-compliant water-cooled chiller plant with water economizing. Instead, the pumped refrigerant economizer system would use significantly more than the other computer room economizer systems minimally-compliant with 2022 Title 24, Part 6 Section 140.9(a)1. Figure 1 shows the incremental annual TDV kBtu energy use per square foot for each climate zone for a pumped refrigerant economizer system in this case.

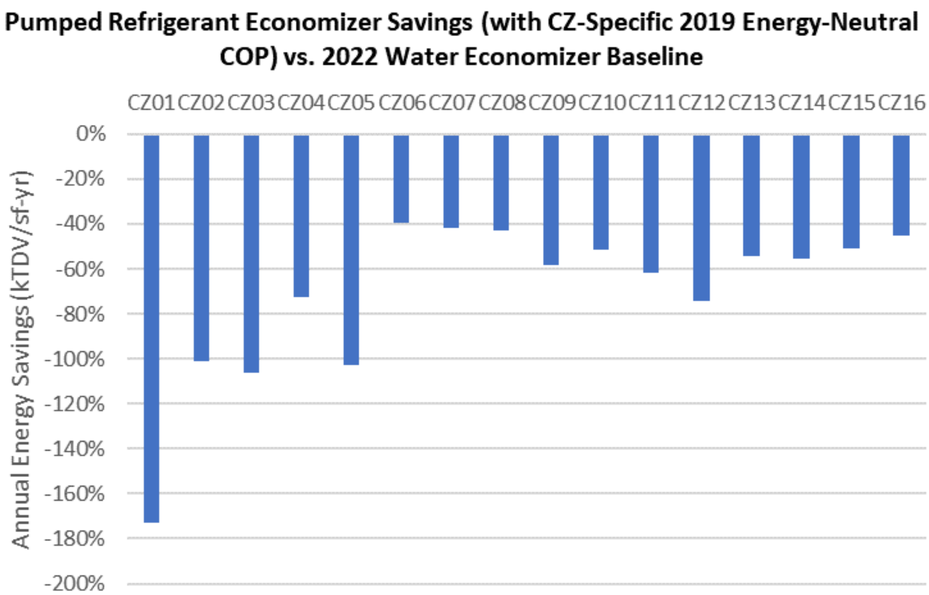

Figure 1. Pumped Refrigerant Economizer Savings (if Climate Zone-Specific COPs for Energy Equivalent Performance Compared to 2019 Water Economizer Baseline were Adopted) vs. 2022 45-Day Language Water Economizer Baseline

Therefore, it is important to understand under what conditions a pumped refrigerant economizer system would operate with equivalent energy use to this updated baseline energy use. The analysis above in section 4 was repeated to determine the minimum cooling COP necessary for a pumped refrigerant economizer to perform equivalently to this new baseline.

A minimum full-load COP was calculated for each climate zone in order for the proposed pumped refrigerant economizer cooling energy to be equal to the 2022 45-Day Language energy use for a code-baseline water-cooled chiller plant with water economizing using evaporative cooling towers (chiller cooling + pumps + cooling tower energy). As shown in Table 2, a *pumped refrigerant economizer with a minimum cooling COP of 11.0 and with full economizing at 50°F outdoor dry-bulb* provides equivalent energy use to a water-cooled chiller and water economizer system under 2022 Title 24, Part 6 economizer thresholds for all climate zones, when comparing annual TDV kBtu energy use. A cooling COP of 11.0 equates to a total CRAC net sensible COP of 5.5

when including 140.9(a)2 minimally compliant supply fan energy, as shown in Table 2. Alternatively, code language could use climate zone specific COPs per Table 2.

Table 2. Minimum Pumped Refrigerant Economizer Cooling COP (top row) and Net Sensible COP (bottom row) for Equivalent Energy Use to 2022 45-Day Language Baseline Water-Cooled Chiller Plant with Water Economizer

	CZ01	CZ02	CZ03	CZ04	CZ05	CZ06	CZ07	CZ08	CZ09	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
Minimum Pumped Refrigerant Economizer Cooling COP	11.0	7.6	6.8	6.0	7.0	3.7	2.8	3.8	4.7	4.9	6.0	6.4	5.7	5.5	5.4	4.1
Minimum Pumped Refrigerant Economizer Net Sensible COP	5.5	4.5	4.2	3.8	4.3	2.7	2.3	2.8	3.3	3.4	3.9	4.0	3.7	3.7	3.6	3.0

5.1 Example Proposed 2022 Code Language

Recommended revisions to the 45-Day Language are included in this document in red. The Statewide CASE Team's recommended language insertions are underlined and recommended language deletions are ~~struck~~. Below is example code language that could be included in Section 140.9(a)1.

140.9(a)1C. An integrated pumped refrigerant economizer with a net sensible COP meeting or exceeding the values in Table 140.9-X and capable of providing 100 percent of the expected system cooling load at 65°F to 80.6°F supply air temperature at outside air temperatures of 50°F dry-bulb and below.

Table 140.9-X: Minimum Pumped Refrigerant Economizer CRAC Net Sensible COP by Climate Zone

	CZ01	CZ02	CZ03	CZ04	CZ05	CZ06	CZ07	CZ08	CZ09	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
Minimum Pumped Refrigerant Economizer Net Sensible COP	5.5	4.5	4.2	3.8	4.3	2.7	2.3	2.8	3.3	3.4	3.9	4.0	3.7	3.7	3.6	3.0

Since Net Sensible Coefficient of Performance Rating is defined in AHRI Standard 1360 *Standard for Performance Rating of Computer and Data Processing Room Air Conditioners*, it may be helpful to add these definitions to Title 24, Part 6, Section 100.1(b):

Net Sensible Coefficient of Performance (COP) is defined by AHRI 1360 and includes all indoor unit power and air-cooled condenser/condensing unit power for air-cooled units and includes all indoor unit power and the power allowance for pump and heat rejection as described in the Heat Rejection/Cooling Fluid Standard Rating Conditions table of AHRI 1360 for water, glycol, and chilled water units.

AHRI 1360 is the Air-Conditioning, Heating,& Refrigeration Institute document titled, "Standard for Performance Rating of Computer and Data Processing Room Air Conditioners," 2017 (AHRI 1360-2017).

6. Equipment Capacity Factor Impact on Pumped Refrigerant Economizer Performance

An alternative to the energy code requiring a minimum COP to ensure equivalent energy use for pumped refrigerant economizers could be to increase the minimum outdoor dry-bulb temperature for when full economizing is required, or requiring a combination of increased minimum COP and increased outdoor dry-bulb full economizing temperature. Achieving full refrigerant economizer conditions at higher outdoor temperatures can be achieved by increasing the equipment sizing capacity at design conditions. Increasing the available heat rejection capacity allows pumped refrigerant economizers to operate in full economizing mode at higher outdoor dry-bulb temperatures, thereby reducing energy use. The manufacturer data shown in Figure 2 shows that cooling capacity of the refrigerant economizer drops off as ambient temperatures increase but that the cooling capacity of a refrigerant economizer increases if the return air temperature is higher (as in the case of hot aisle containment already required by Title 24).

The 2022 Title 24, Part 6 Standard allows computer room supply air temperatures up to 80°F when sizing an economizer, so a 95°F return air temperature is achievable. For the sample system in Figure 2, at a 85°F return air temperature and a 50°F outdoor dry-bulb temperature, the refrigerant economizer capacity is about 70% of the capacity that it can produce at 35°F outdoor dry-bulb temperature. The chart also shows that one can scale the economizer size up to 1/0.7 = 1.43 of capacity to provide full economizing at 50°F outdoor dry-bulb temperature. If the same system can be operated at 95°F return air temperature, its capacity is 90% at 50°F outdoor dry-bulb temperature, and one can scale the economizer size up to 1/0.9 = 1.11 of capacity to provide full economizing at 50°F outdoor dry-bulb temperature. A similar calculation can be done to show that at 1.6 of capacity a system with a 95°F return temperature can provide full refrigerant economizing at 65°F outdoor dry-bulb temperature or at 1.8 of capacity a system with a 90°F return temperature can provide full refrigerant economizing at 65°F outdoor dry-bulb temperature.

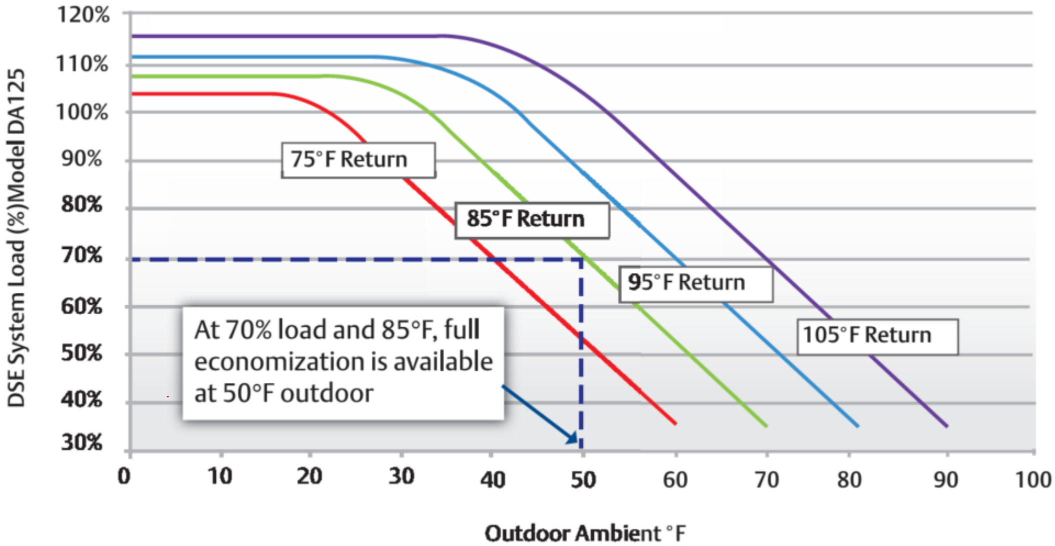

Figure 2. Manufacturer Data on Capacity Load Factor and Return Air Temperature's Impacts on Pumped Refrigerant Economizer CRAC

Source: https://www.vertiv.com/492526/globalassets/shared/liebert-dse-with-econophasehighest-efficiency-dx-cooling-with-pumped-refrigerant-economizer.pdf

6.1 Minimum CRAC COPs for Pumped Refrigerant Economizer with Elevated Full Economizing Temperatures

Additional analysis was performed to determine the minimum CRAC cooling COP and NSensCOP required for a pumped refrigerant economizer with different full economizing outdoor temperatures to have equivalent annual TDV energy consumption as a 2022 baseline water-cooled chiller with evaporative cooling tower system. We started at 50°F to match 2022 45-day language (presented in section 5) and ran iterations at 5°F increments to show the different impact on minimum COPs required for equivalent energy use. The results are shown in Table 3 through Table 5 below.

Table 3. Minimum Pumped Refrigerant Economizer Cooling COP (top row) and Net Sensible COP (bottom row) with 55°F Full Outdoor Dry-Bulb Economizing Temperature for Equivalent TDV Energy Use to 2022 45-Day Language Baseline Water-Cooled Chiller Plant with Water Economizer

	CZ01	CZ02	CZ03	CZ04	CZ05	CZ06	CZ07	CZ08	CZ09	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
Minimum Pumped Refrigerant Economizer Cooling COP	11.0	7.2	6.6	5.5	6.8	3.3	2.6	3.4	4.3	4.5	5.6	6.0	5.3	5.1	5.0	3.8
Minimum Pumped Refrigerant Economizer Net Sensible COP	5.5	4.3	4.1	3.7	4.2	2.5	2.1	2.6	3.1	3.2	3.7	3.9	3.5	3.5	3.4	2.8

Table 4. Minimum Pumped Refrigerant Economizer Cooling COP (top row) and Net Sensible COP (bottom row) with 60°F Full Outdoor Dry-Bulb Economizing Temperature for Equivalent TDV Energy Use to 2022 45-Day Language Baseline Water-Cooled Chiller Plant with Water Economizer

	CZ01	CZ02	CZ03	CZ04	CZ05	CZ06	CZ07	CZ08	CZ09	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
Minimum Pumped Refrigerant Economizer Cooling COP	11.0	6.9	6.5	5.2	6.7	3.1	2.6	3.2	4.0	4.2	5.2	5.7	4.9	4.7	4.5	3.6
Minimum Pumped Refrigerant Economizer Net Sensible COP	5.5	4.2	4.1	3.5	4.1	2.4	2.1	2.5	2.9	3.0	3.5	3.7	3.4	3.3	3.2	2.7

Table 5. Minimum Pumped Refrigerant Economizer Cooling COP (top row) and Net Sensible COP (bottom row) with 65°F Full Outdoor Dry-Bulb Economizing Temperature for Equivalent TDV Energy Use to 2022 45-Day Language Baseline Water-Cooled Chiller Plant with Water Economizer

	CZ01	CZ02	CZ03	CZ04	CZ05	CZ06	CZ07	CZ08	CZ09	CZ10	CZ11	CZ12	CZ13	CZ14	CZ15	CZ16
Minimum Pumped Refrigerant Economizer Cooling COP	11.0	6.6	6.5	5.0	6.7	3.1	2.6	3.0	3.7	3.9	4.9	5.4	4.5	4.4	4.0	3.5
Minimum Pumped Refrigerant Economizer Net Sensible COP	5.5	4.1	4.1	3.4	4.1	2.4	2.1	2.4	2.8	2.9	3.4	3.6	3.2	3.1	2.9	2.7

Appendix: Energy Modeling Inputs

Table 6 shows a summary of the key energy model inputs. We found a few errors in the baseline CRAH fan model that contributed to fan energy use being higher than code minimum. These resulted in the baseline CRAH fans operating mainly at constant air volume at 100% airflow and CRAH fans operating at a higher-than-baseline efficiency (W/cfm). Additionally, the *Integrated Pumped Refrigerant Economizer for Computer Rooms Building Energy Efficiency Measure Proposal* baseline and proposed models used different air delta-Ts. The Corrected Inputs columns show changes to inputs for the additional energy model simulations we ran.

Table 6. Comparison of Base Energy Model Inputs (green cells indicate corrections made to *Integrated Pumped Refrigerant Economizer for Computer Rooms Building Energy Efficiency Measure Proposal* models in order to follow the ACM)

Parameter	Refrigerant Economizer Building Energy Efficiency Measure Proposal Model Inputs		Corrected Inputs	
	Proposed Design	Baseline	Proposed Design- Rev. 1	Baseline- Rev. 1
Operating Return Air Temperature (°F)	80	80	80 [4]	80 [4]
Operating Supply Air Temperature (°F)	55 [1]	Allowed to go up to 104 [2]	60 [4]	60 [4]
Minimum Operating Airflow (°F)	50%	Almost 100%	50%	50%
Operating Delta-T (°F)	25	Variable (< 20)	20	20
Fan Efficiency (W/cfm)	0.48	1.1 [3]	0.58 [3]	0.58 [3]
Fan Efficiency	60%	60%	60%	60%
Fan Motor Efficiency	94%	94%	94%	94%
Fan Pressure (Pa)	569	1312 [3]	690	690
Cooling COP	3.92	5.17	3.92	5.17

[1] The original design model used a 55F supply air temperature, resulting in a larger delta-T than the baseline system. However, delta-T is a result of room air containment and should not be impacted by whether the system is a CRAC or CRAH. The baseline and proposed delta-Ts were updated to 60°F to match the ACM.

[2] Because the baseline supply air temperature was allowed to go up to 40°C (104°F), the model varied supply air temperature instead of varying airflow with load. As a result, the baseline airflow was almost always at maximum (100%), whereas the proposed design airflow varied between 50-100% as expected.

[3] The baseline CRAHs used a very high pressure drop which may have been a legacy input from when the baseline was simulated as an air economizer. This resulted in a fan efficiency of 1.1 W/cfm, which is worse than the ACM fan efficiency of 0.81 W/cfm. To achieve the ACM W/cfm value, fan pressure was adjusted. As described in the *Nonresidential Computer Room Efficiency CASE Report*[5], the ACM fan efficiency value of 0.81 W/cfm is worse than the 2019 Title 24 Part 6, 140.9(a)4 requirement when the system operates at baseline conditions of 20F delta-T. To achieve the calculated 0.58 W/cfm value from 140.9(a)4, fan pressure was adjusted.

[4] These values were adjusted to 70°F supply air temperature and 90°F return air temperature when comparing to the 2022 baseline, in order to match the assumptions in *the Nonresidential Computer Room Efficiency CASE Report* that were used to support the 2022 Title 24, Part 6 changes to the water economizer baseline.

[5] Source: *Nonresidential Computer Room Efficiency*. March 2021, NR-Computer-Room-Efficiency-Final-CASE-Report_Statewide-CASE-Team_updated.pdf (title24stakeholders.com)