CALIFORNIA ENERGY CODES & STANDARDS
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Second Stakeholder Meeting for Warehouse Topics

Hybrid Condensers for Refrigerated Warehouses and Commercial Refrigeration

March 21, 2017

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Agenda

1. Background
2. Proposed Code Changes
3. Technical and Market Barriers
4. Compliance and Enforcement
5. Cost-Effectiveness and Energy Impacts
6. Next Steps

1. Background

Introduction to Refrigeration System Condensers

- Definition of hybrid condensers
  – A refrigeration system component that condenses refrigerant vapor by rejecting heat to air mechanically circulated over its heat transfer surface, causing a temperature rise in the air, with the additional capability to utilize evaporative precooling of the entering air, for operation only during high ambient temperatures, and accomplished as part of a single factory-made unit.
- Description of change:
  – Applies to refrigeration systems in refrigerated warehouses and commercial refrigeration (supermarkets)
  – Add hybrid condensers (not currently mentioned in the code) in addition to existing requirements for air cooled and evaporative condensers
  – Include CO_2 as a refrigerant with exemptions for CO_2 systems to allow for the differences of transcritical operation

Refrigeration System Condensers Current Practice

- Commercial Refrigeration
  - Both air-cooled and evaporative condensers used throughout California with some use of hybrid condensers beginning with market entry ~5 years ago
  - Increase in transcritical CO_2 system installations employing air-cooled gas coolers or hybrid gas coolers
- Refrigerated Warehouses
  - Historic use of only evaporative condensers for ammonia systems
  - Recent interest in air cooled systems to reduce water use and cost

Relevant Code History

- There are existing mandatory requirements in Title 24, Part 6 for refrigeration equipment
  - Section 120.6(a) for Refrigerated Warehouses
  - Section 120.6(b) for Commercial Refrigeration
- Existing requirements cover
  - Air-cooled condensers
  - Evaporative-cooled and fluid coolers/water-cooled condensers

  - No mention of hybrid condensers
  - No mention of CO_2 as a refrigerant

What do you think?

- Any questions about the basic technology?
- Are you clear on the code history?

2. Proposed Code Changes

Proposed Code Change

- Type of change
  - Mandatory requirement
- Types of building impacted
  - Refrigerated warehouse
  - Commercial refrigeration (supermarkets)
  - New construction only
- Building system impacted
  - Refrigeration
- Description of change
  - Add hybrid condensers (not currently mentioned in the code) in addition to current requirements for air cooled and evaporative condensers
  - Include CO_2 as a refrigerant
    - Include current condenser requirements (minimum SCT, variable speed fans, variable setpoint) during subcritical operation
    - Exemption from condenser sizing and specific efficiency requirements

Proposed Code Change (Cont'd)

Hybrid condenser proposed code changes already considered standard practice:

- Mandatory variable speed fan control
- Mandatory floating head pressure

Proposed Code Change (Cont'd)

Hybrid condenser code changes currently undergoing analysis of their cost effectiveness:

- Mandatory variable SCT set point control
  - Option A: reset SCT set point based on drybulb temperature, independent of mode of operation
  - Option B: reset SCT set point based on drybulb temperature with fixed 70F SCT during adiabatic operation
  - Option C: reset SCT set point based on pre-coil inlet air (i.e. after adiabatic pads)
- Maximum dry mode TD (sizing) requirement
- Minimum dry mode specific efficiency requirement

Proposed Code Change (Cont'd)

CO_2 code changes:

- Clarify that condenser requirements in Section 120.6 apply to CO2 systems during subcritical operation
- Exempt CO2 systems from sizing and specific efficiency requirements

Why Are We Proposing This Code Change

- Reduce code enforcement conflicts and confusion
- Reduce design confusion over condenser sizing practices
- Allow designers to fully realize their condenser options as they make future design decisions, particularly as water savings becomes increasingly important
- Establish a baseline against which high efficiency choices can be evaluated and incentives provided

What about the proposed code changes?




3. Technical and Market Barriers

Technical and Market Barriers

Variable Speed Fan Control and Floating Head Pressure:

- No major technical or market barriers
- Already minimum requirement for other condenser types
- Technology and technical knowledge well known and widely implemented

- Optimum strategy for fan speed during adiabatic mode is more complex than during dry mode – balancing saturation efficiency and performance of heat exchange surface

Technical and Market Barriers

Variable SCT Setpoint Operation:

- Low technical and market barriers
- Previously observed sites already integrate condenser into supervisory control system, making variable setpoint control easily achievable
- Some installations are already being installed with additional sensor between adiabatic pad and condenser heat transfer surface

Technical and Market Barriers

Maximum Dry Mode TD (Sizing)/Minimum Specific Efficiency:

- Performance uncertainty
- Likely differences by climate zone
- Observed tendency to undersize in dry mode vs. air-cooled, which can lead to lower annual efficiency
- Understanding the relationship between dry mode and the adiabatic mode performance
  - Manufacturers and owners may take different approaches to optimize
  - Adiabatic mode (turn on water) setpoint can be adjusted as desired

4. Compliance and Enforcement

Compliance Process

Design Phase

- Mechanical designer selects appropriate system type and equipment based on project needs and local conditions
- Complete appropriate forms:
  - – NRCC-PRC-05-E for Commercial Refrigeration
  - – NRCC-PRC-06-E for Refrigerated Warehouses

Permit Application Phase

- Plan reviewer will verify NRCC-PRC forms

Compliance Process

Construction Phase

- Contractor installs equipment based on design

Inspection Phase

- Acceptance Test Technicians (ATTs) need to become familiar with new NRCA-PRC form for adiabatic compressor requirements
- ATTs perform test when applicable

Compliance and Enforcement Barriers

- Dry mode sizing compliance
  - System SCT and condenser selection at design conditions would be with condenser in adiabatic mode
  - Designers would additionally need to consider dry mode capacity
  - Manufacturers would need to define dry mode capacity
  - Compliance form will need to calculate for the dry mode TD required to meet the design heat rejection at design SCT
    - Explanation required to avoid confusion; SCT would not be increased from the adiabatic mode SCT

What about the barriers?

5. Cost-Effectiveness and Energy Impacts

General Disclaimer

- **Results presented in this section are to be considered preliminary and for general discussion only**
- **Results will be made available after meeting for stakeholders to further review**

Definition of Baseline and Proposed Conditions: Prototypes

Prototype ID	Occupancy Type	Area (ft^2)	Refrigerant	Compressor Type
Large Supermarket (LSM)	**Supermarket**	**60,700**	**R-404A**	**Reciprocating**
Small Refrigerated Warehouse (SRWH)	Refrigerated Warehouse	26,000	R-407A	Reciprocating
Large Refrigerated Warehouse (LRWH)	Refrigerated Warehouse	92,000	R-717 (Ammonia)	Screw

Minimum Code Requirements for Air-Cooled and Evaporative-Cooled Compared to Hybrid Condenser Base Case

Requirement	Air-Cooled	Evaporative Cooled	Hybrid (Base Case)
Fan Control	Continuous Variable Speed in Unison	Continuous Variable Speed in Unison	Continuous Variable Speed in Unison
Minimum SCT	70°F	70°F	70°F
Condensing Temperature Reset	Drybulb	Wetbulb	Fixed SCT
Minimum Efficiency	• 75 Btuh/Watt (ammonia, RWH) • 65 Btuh/Watt (halocarbon, RWH) • 65 Btuh/Watt (Commercial Refrigeration)	• 350 Btuh/Watt (THR>8,000 MBH, RWH) • 160 Btuh/Watt (THR<8,000 MBH, RWH) • 160 Btuh/Watt (THR<8,000 MBH, Commercial Refrigeration)	• 30 Btuh/W (halocarbon, proposed) • TBD Btuh/W (ammonia)
Rating Condition	105°F Saturated Condensing Temperature (SCT), 95°F Outdoor Drybulb Temperature	100°F Saturated Condensing Temperature (SCT), 70°F Outdoor Wetbulb Temperature	• Same as air-cooled for dry mode

Proposed Conditions Compared to the Hybrid Condenser Base Case

Variable	Base Case	Variable SCT Setpoint	Dry Mode Sizing	Dry Mode Minimum Specific Efficiency
Condensing Temperature Reset	70F Fixed SCT	**Option A:** Drybulb (independent of operation mode) **Option B:** Drybulb (dry mode); Fixed 70F SCT (adiabatic mode) **Option C:** Condenser Inlet Air (independent of operation mode)	Same as Base Case	Same as Base Case
Rating Temperature Difference (TD)	10 TD (dry mode) 30 TD (wet mode)	Same as Base Case	Varies from 10F LT & 15F HT to 30F LT & 45F HT (dry mode) 30 TD (wet mode)	Same as Base Case
Minimum Efficiency	• 30 Btuh/W (halocarbon, proposed) • TBD Btuh/W (ammonia)	Same as Base Case	Same as Base Case	Comparing values from 25 Btuh/W to 65 Btuh/W

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Cost Effectiveness Analysis

Incremental Cost Savings (Benefits)

Energy Cost Savings/ft^2 over 15-year period of analysis

- **Variable SCT Setpoint Operation:**
  - Total Energy Cost Savings per SF = range of $0.37 to $9.95 depending on Option and climate zone
  - Energy cost savings explained in more detail in following slides.
  - Measure cost includes price for sensor, wiring and instruments, labor and programming
- **Maximum Dry Mode TD (Sizing)**
  - Total Energy Cost Savings TBD
  - First installment cost is calculated using price regression of available technology to calculate cost per unit capacity for various capacity ranges ($/MBH)
- **Minimum Specific Efficiency**
  - TBD

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Benefit-to-Cost Ratio: Variable SCT Setpoint (LSM)

Climate Zone	Option A	Option B	Option C
1	99.9	25.8	47.5
3	348.8	145	170.5
5	296.3	141	144.6
7	687.3	478.6	331.3
8	654	330	293
10	384.9	214.7	201.7
12	328.9	167.5	174.3
13	384.4	165.2	188.2
14	311.3	97.7	169.4
15	330	154.6	170.5

Cost-Effective in All Modeled Climate Zones

If Benefit-to-Cost Ratio is over 1, measure is cost-effective.

Annual Energy Savings Per SF, Variable SCT Setpoint (LSM)

Climate Zone	Option A		Option B		Option C	
	TDV Energy Savings (TDV kBtu/yr)	15 Year TDV Energy Cost Savings ($2020)	TDV Energy Savings (TDV kBtu/yr)	15 Year TDV Energy Cost Savings ($2020)	TDV Energy Savings (TDV kBtu/yr)	15 Year TDV Energy Cost Savings ($2020)
1	16.03	$1.43	4.14	$0.37	16.02	$1.47
3	55.99	$4.98	23.275	$2.07	57.59	$5.13
5	47.56	$4.23	22.64	$2.02	48.8	$4.34
7	110.33	$9.82	76.83	$6.84	111.84	$9.95
8	104.99	$9.34	53.02	$4.72	98.93	$8.8
10	61.79	$5.5	34.46	$3.07	69.1	$6.15
12	52.8	$4.7	26.89	$2.39	58.85	$5.24
13	55.94	$4.98	26.52	$2.36	63.54	$5.65
14	49.98	$4.45	15.69	$1.4	57.18	$5.09
15	52.98	$4.72	24.81	$2.2	57.55	$5.12

Annual Energy Savings Per SF, Variable SCT Setpoint (LSM)

Climate Zone	Option A		Option B		Option C	
	Annual Electricity Savings (kWh/SF/yr)	**Peak Electric Demand Reduction (kW)**	**Annual Electricity Savings (kWh/SF/yr)**	**Peak Electric Demand Reduction (kW)**	**Annual Electricity Savings (kWh/SF/yr)**	**Peak Electric Demand Reduction (kW)**
1	0.24	49.5	0.06	0	0.24	49.5
3	1.57	47.6	0.87	1.1	1.6	11.8
5	1.42	14.1	0.76	0	1.45	12.6
7	3.68	34.9	2.97	1.9	3.69	17.4
8	3.64	39.1	2.21	0	3.35	29.4
10	2.21	15.4	1.44	0	2.41	9.5
12	1.8	20.3	1.13	0	1.97	3.9
13	1.91	20.7	1.1	0	2.14	8.8
14	1.67	5.4	0.66	0	1.89	5.4
15	1.91	(0.1)	1.02	0	2.11	5.5

The annual energy savings for Large supermarket prototype is in the range of 14,500 kWh to 225,000 kWh

What about the costs and savings?

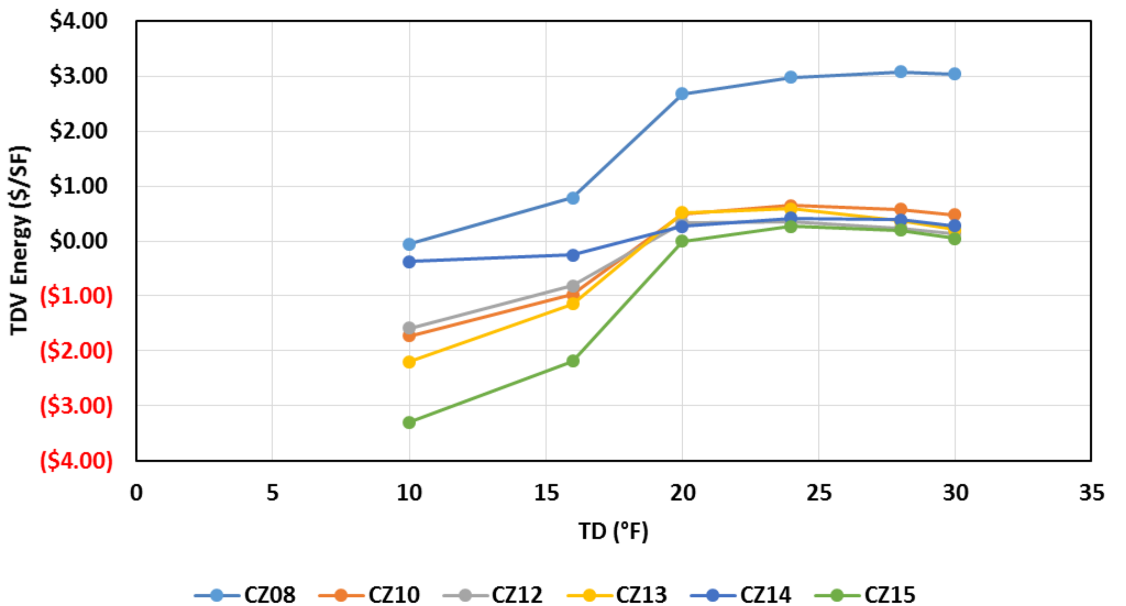
Benefit-to-Cost Ratio: Variable Dry Mode Hybrid Condenser Sizing (LSM)

Climate Zone	Benefit to Cost
1	TBD
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	

Cost Effective in All Climate Zones

If Benefit-to-Cost Ratio is over 1, measure is cost-effective.

Annual Cost Savings Per SF, Dry Mode Hybrid Condenser Sizing (LSM) - Warm Climate



*At Base Case specific efficiency of 30 Btu/h/W

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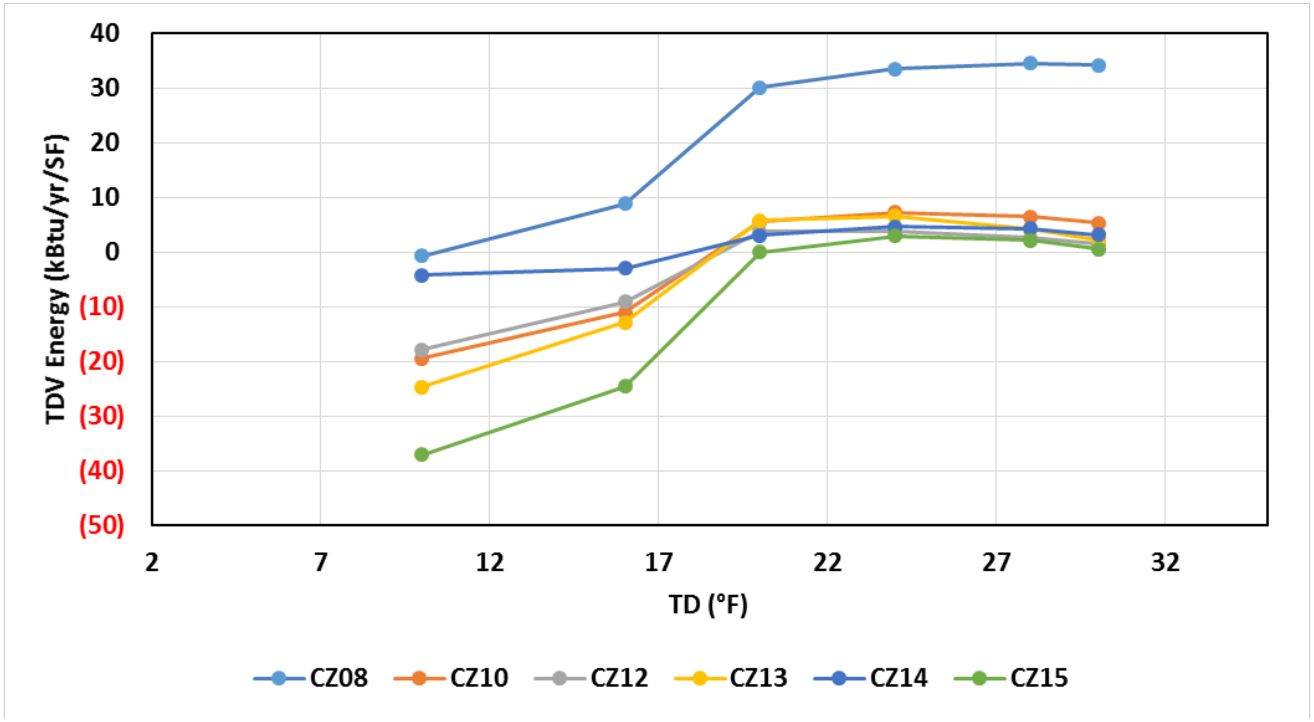
Annual Energy Savings Per SF, Dry Mode Hybrid Condenser Sizing (LSM) - Warm Climate



*At Base Case specific efficiency of 30 Btu/h/W

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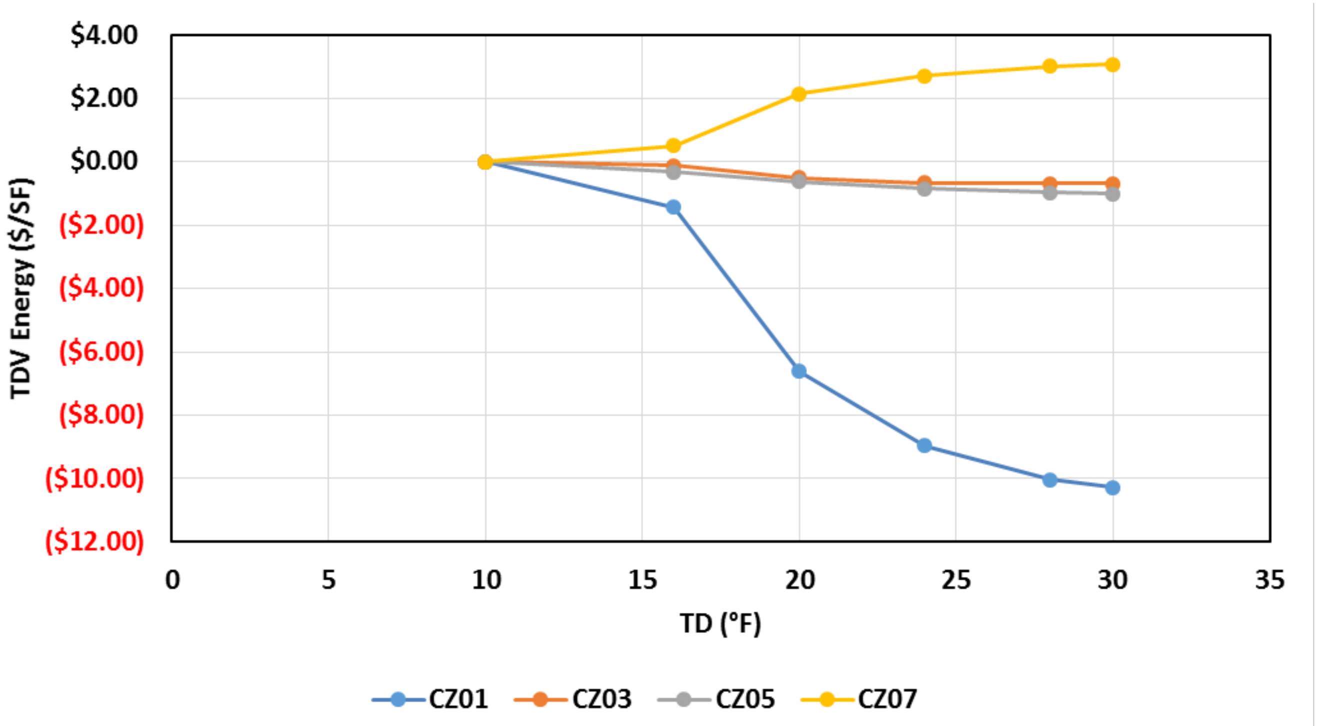
Annual Cost Savings Per SF, Dry Mode Hybrid Condenser Sizing (LSM) - Cool Climate



*At Base Case specific efficiency of 30 Btu/h/W

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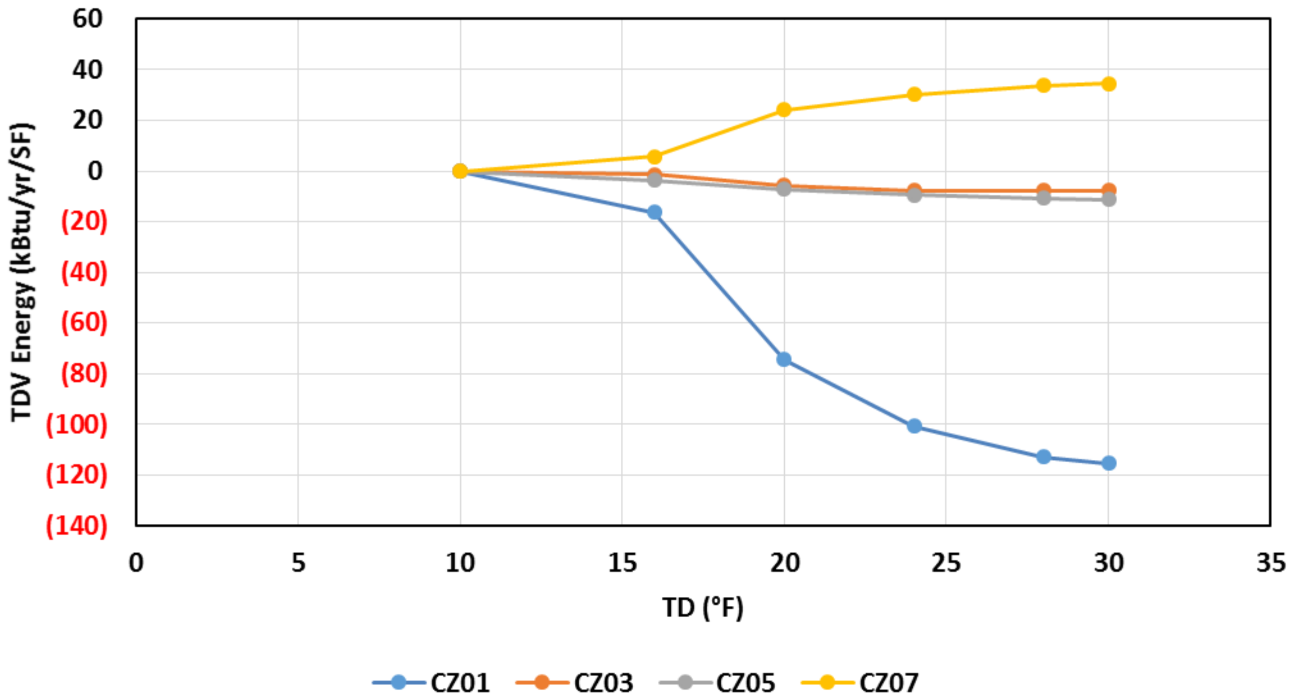
Annual Energy Savings Per SF, Dry Mode Hybrid Condenser Sizing (LSM) - Cool Climate



*At Base Case specific efficiency of 30 Btu/h/W

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Benefit-to-Cost Ratio: Hybrid Condenser Specific Efficiency (LSM)

Climate Zone	Benefit to Cost
1	TBD
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	

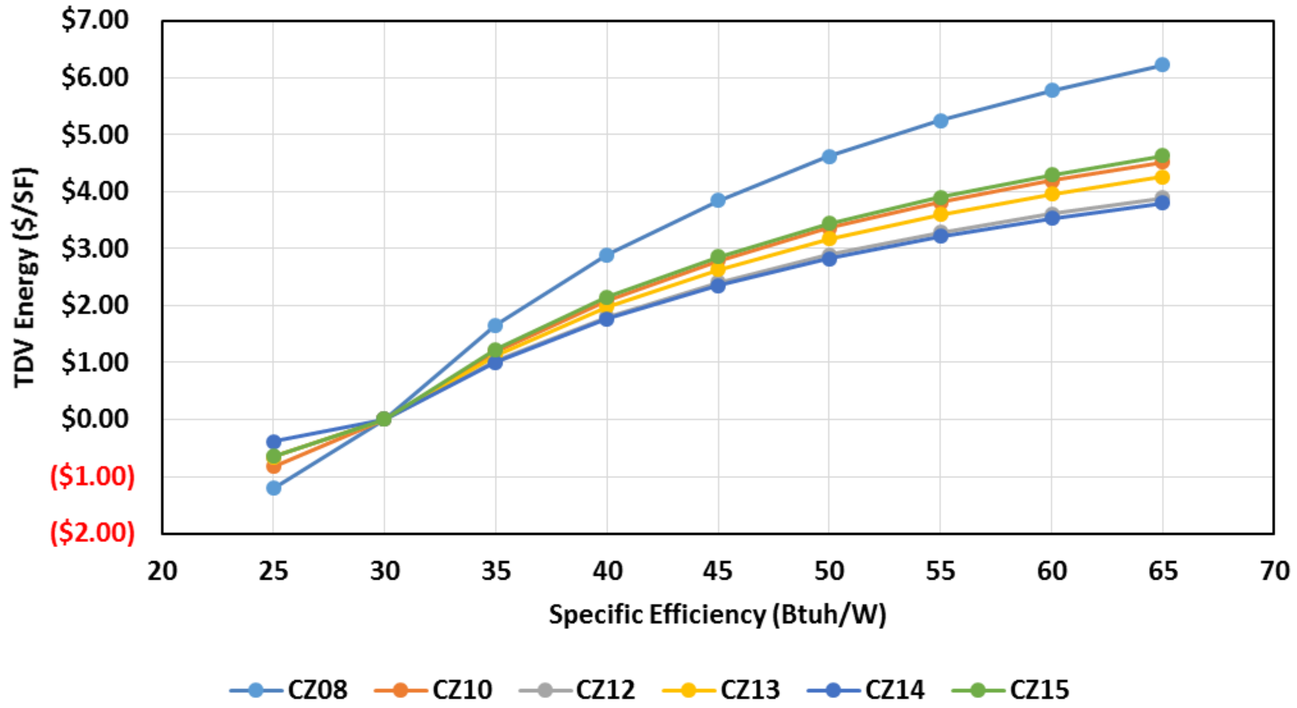
Cost Effective in All Climate Zones

If Benefit-to-Cost Ration is over 1, measure is cost effective.

Note:

- Incremental cost associated with higher efficiency options is still under development.

Annual Cost Savings Per SF, Hybrid Condenser Specific Efficiency (LSM) - Warm Climate



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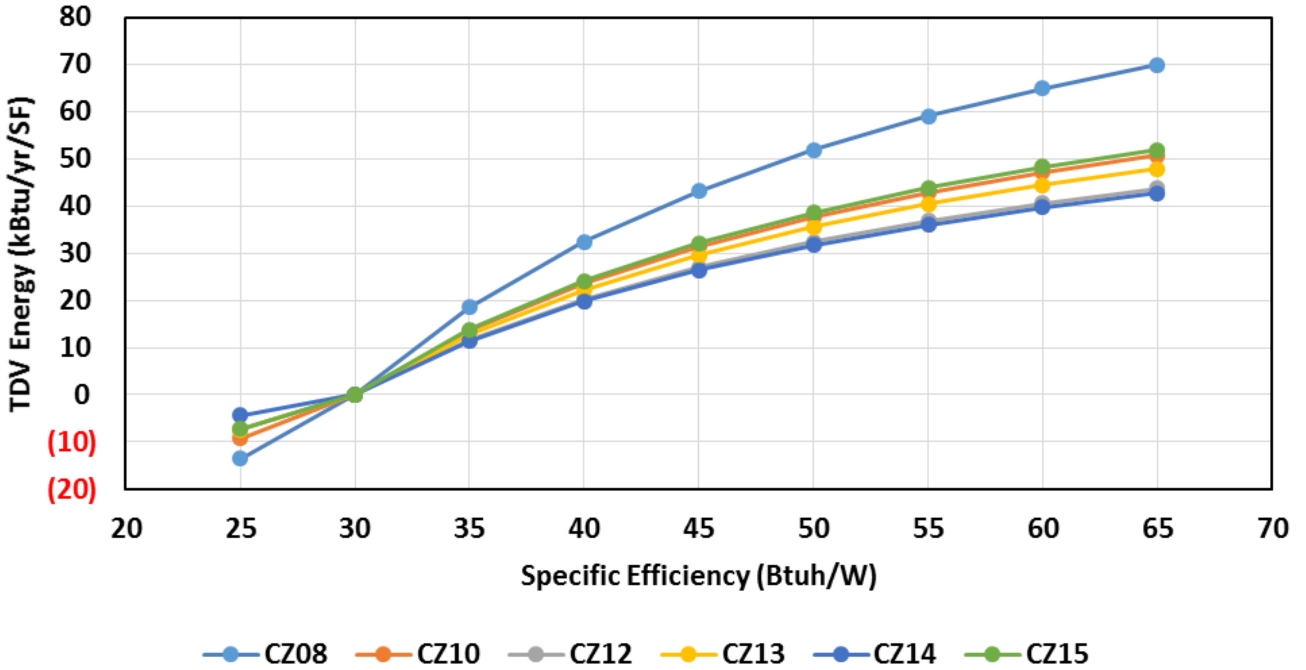
Annual Energy Savings Per SF, Hybrid Condenser Specific Efficiency (LSM) - Warm Climate



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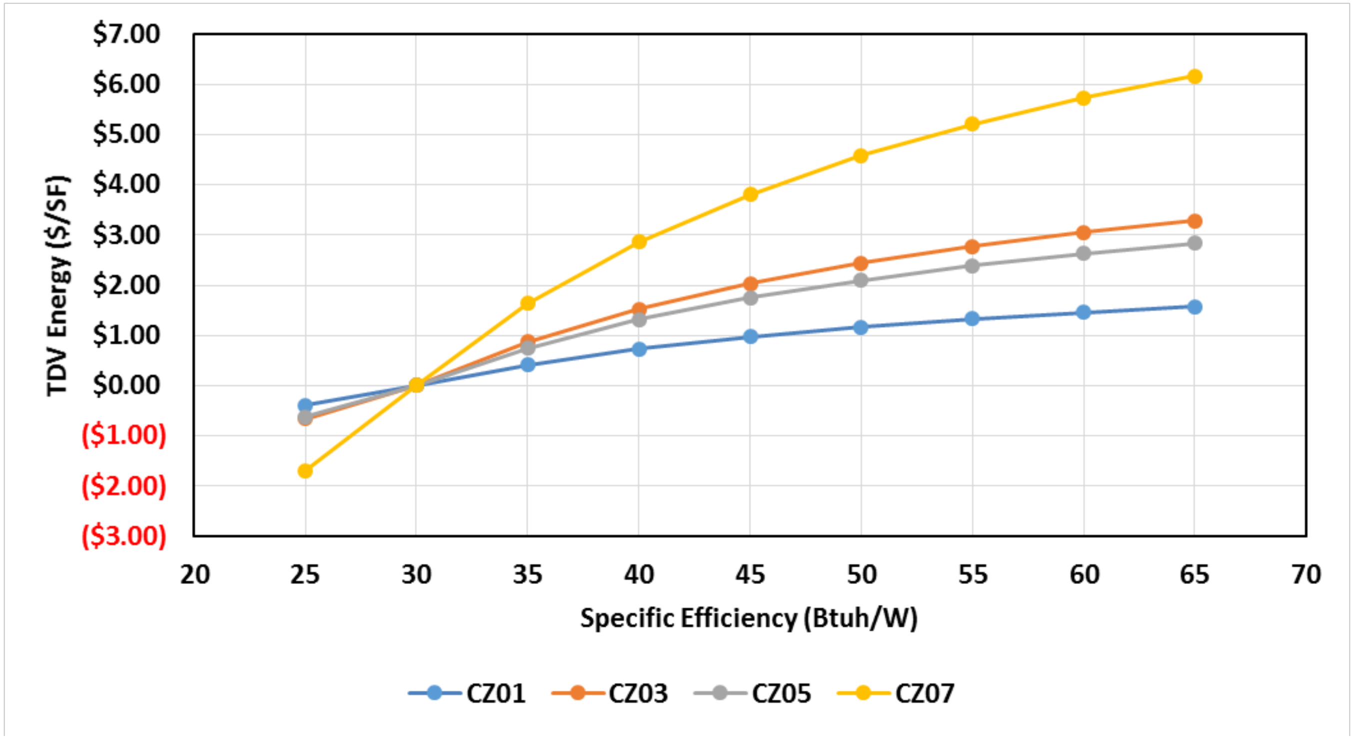
Annual Cost Savings Per SF, Hybrid Condenser Specific Efficiency (LSM) - Cool Climate



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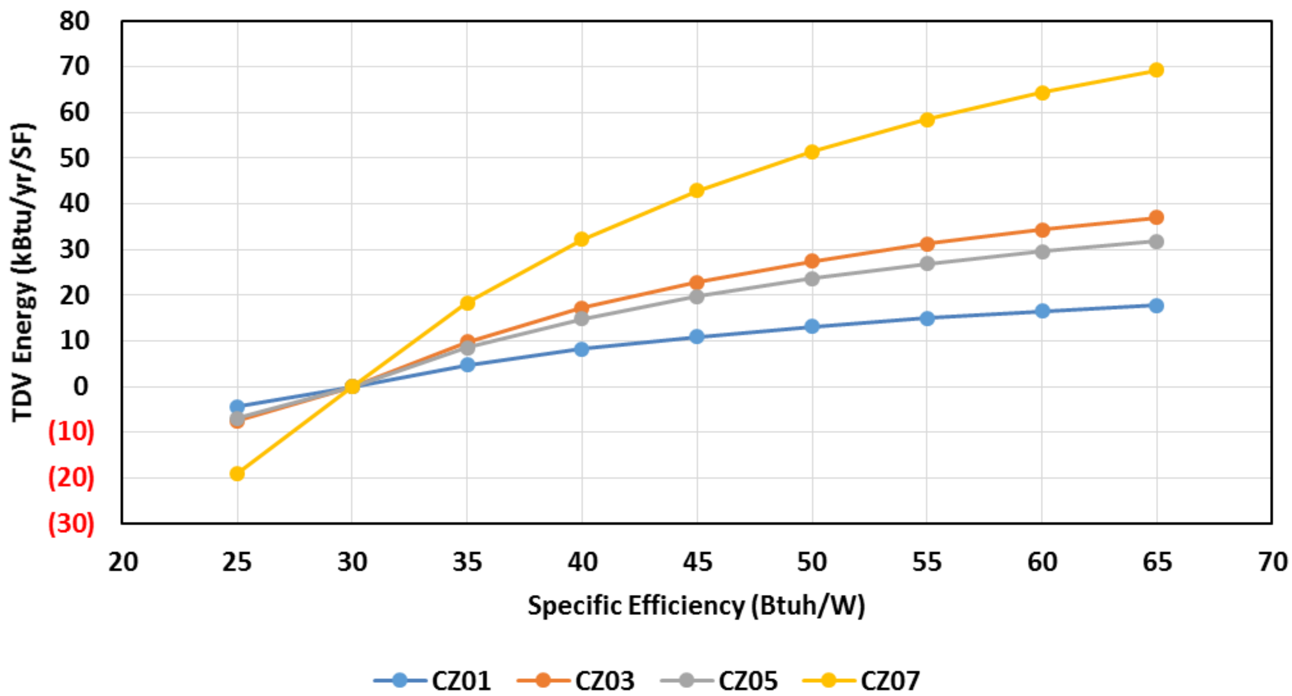
Annual Energy Savings Per SF, Hybrid Condenser Specific Efficiency (LSM) - Cool Climate



Annual Energy Savings Per SF, Hybrid Condenser Specific Efficiency (LSM)

Climate Zone	25 Btuh/W Annual Electricity Savings (kWh/SF/yr)	25 Btuh/W Peak Electric Demand Reduction (kW)	65 Btuh/W Annual Electricity Savings (kWh/SF/yr)	65 Btuh/W Peak Electric Demand Reduction (kW)
1	-0.06	0	0.26	30
3	-0.27	-11	1.06	30
5	-0.23	-9	0.96	30
7	-0.73	-11	2.29	30
8	-0.56	-10	2.33	19
10	-0.39	-1	1.73	19
12	-0.31	-4	1.43	19
13	-0.31	0	1.59	19
14	-0.18	0	1.39	19
15	-0.30	0	1.85	15

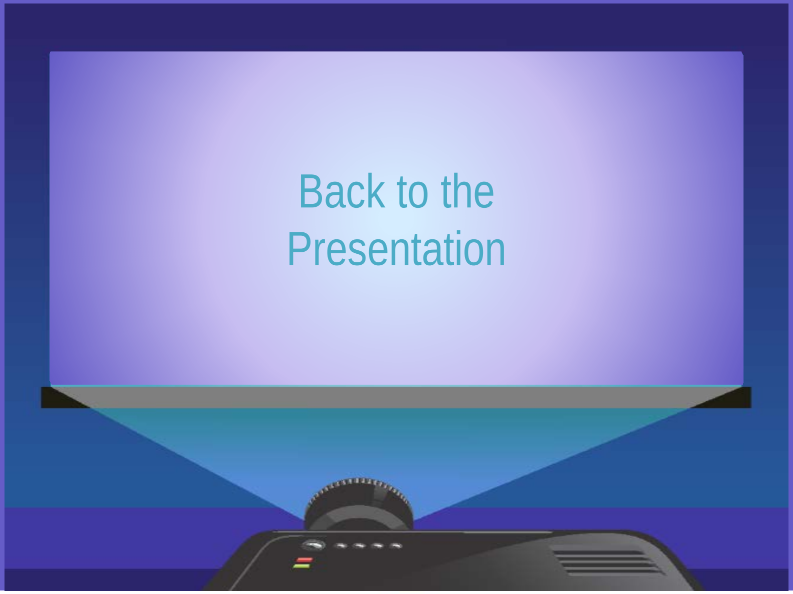
Notes:
- Values compared to a base case value of 30 Btuh/W.
- Base case specific efficiency still preliminary.
- kWh increases range from 4,000 kWh/yr to 44,000 kWh/yr on a prototype basis for 25 Btuh/W specific efficiency
- kWh savings range from 15,000 kWh/yr to 140,000 kWh/yr on a prototype basis for 65 Btuh/W specific efficiency

Sizing vs. Specific Efficiency – conclusions

- Condenser size and condenser specific efficiency are highly interactive
  - At a low specific efficiency, a larger condenser also has proportionally larger fan motors
  - The condenser fan power increase offsets the compressor power decrease resulting from lower condensing temperature
- Conclusions:
  - From the assumed Base Case starting values, increasing specific efficiency (reducing fan power) is more beneficial than increasing condenser size
  - Sizing will be rerun after establishing a minimum specific efficiency

Let’s talk about…

Next Steps



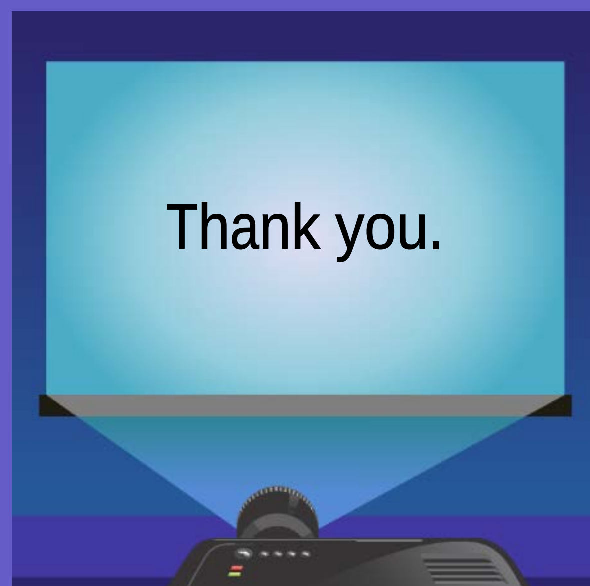
6. Next Steps

Next Steps

- Please send any additional feedback within 2 weeks to:
  - Doug Scott, VaCom
  - Catherine Chappell, TRC
  - Info@title24stakeholders.com
- Keep an eye on Title24Stakeholders.com for:
  - Presentations from today's meeting
  - Draft Code Change Language
  - Notes from today's meeting
  - Draft CASE Report (will be posted in April)

Let’s move on to…

Dock Seals



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Appendix:

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Will not include Appendix as download unless more than next slide is included (which is fine)

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References

- Title24Stakeholders.com
- EnergyCodeAce.com
  - See Reference Ace for 2016 Standards, Appendices, and Compliance Manuals
- California Energy Commission 2019 Standards Webpage