Performance Assessment of Low-GWP Refrigerated Reach-In Display Cases

Ramin Faramarzi (NREL)
Alex Bulk (NREL)
Steven LaBarge (ComEd)

Photo by Dennis Schroeder, NREL 55200

Objective

Evaluate daily energy savings of medium-temperature, reach-in refrigerated display cases featured with:

- Energy-efficient heat exchangers, fan motors, and lighting
- Environmentally friendly refrigerants R290, R513a

Photo from Alex Bulk, NREL

Background

- Widespread use in convenience stores/restaurants/ small supermarkets
- Little research has investigated energy use of medium-temperature, self-contained, reach-in cases with focus on low global warming potential (GWP) refrigerants
- U.S. Environmental Protection Agency phase-down of units using hydrofluorocarbon (HFC) refrigerants starting in 2020
- Need to promote high-efficiency fixtures that use environmentally friendly refrigerants

Photos from https://www.nrel.gov/docs/fy22osti/80634.pdf

Properties of Refrigerants

Refrigerant	Saturated Liquid Density (ρ) at 25°C (kg/m^3)	Global Warming Potential	Liquid Specific Heat Capacity @ Const. Pressure (c_p) at 25°C (kJ/kg K)	Vapor Specific Heat Capacity @ Const. Pressure (c_p) at 25°C (kJ/kg K)	Enthalpy of Vaporization (kJ/kg)
R134a	1207	1301	1.425	0.851	234.7
R290	492	3	2.483	1.684	440.1
R513a	1134	573	1.412	0.881	194.8

R290: Higher refrigeration effect with nearly double enthalpy of vaporization, R290 can provide more effective cooling with reduced compressor run-time due to both lower density and higher heat transfer coefficient

R513A: Similar thermodynamic properties to R134a but with less than half GWP

Case Specifications

Photo from Alex Bulk, NREL

R290 Unit:

EE Case A

- High-density polyurethane foam insulation
- Thermal-insulated glass doors
- Efficient fan motors
- Efficient lighting/controller
- No defrost (off-cycle)

Photo from Alex Bulk, NREL

R134a Unit:

Baseline

(R513a unit is same model)

EE Case B

- Higher UA evaporator,
- Efficient fan motors
- Efficient lighting/controller

Case Operational Parameters

Selection based on most compatible cases in size, refrigeration ratings, and electrical specifications

Case	Refrigerant	Defrost Cycle Frequency	Rated Cooling Output (Btu/h)*
Baseline	R134a	24 hours	7,680
EE Case A	R290	none	6,725
EE Case B	R513a	12 hours	7,727
Case	**Merchandising Capacity (ft^3)****	**Evaporator Fan Operation**	
Baseline	48.29	Continuous	
EE Case A	49.15	1 min every 6 min when compressor is off Continuous when compressor is on	
EE Case B	48.29	With compressor cycling	

*All specs taken from product spec sheets

**Compressor spec sheet (cooling capacity using ARI (Air Conditioning and Refrigeration Institute standard) @ 45°F evap temp)

Experimental Methodology

Evaluation Protocols

Two areas of evaluation:

1. Energy consumption: total and components over 24 hours
2. Performance: product temperatures, air temperatures

Standards

- ANSI/ASHRAE 72-2018 (overall setup, procedure)
- ANSI/NSF 7-2016 (uses ASHRAE 72)
- ANSI/AHRI 1200-2013 (capacity/energy calculation, **lower** temperature limit)
- FDA food code (**upper** temperature limit)

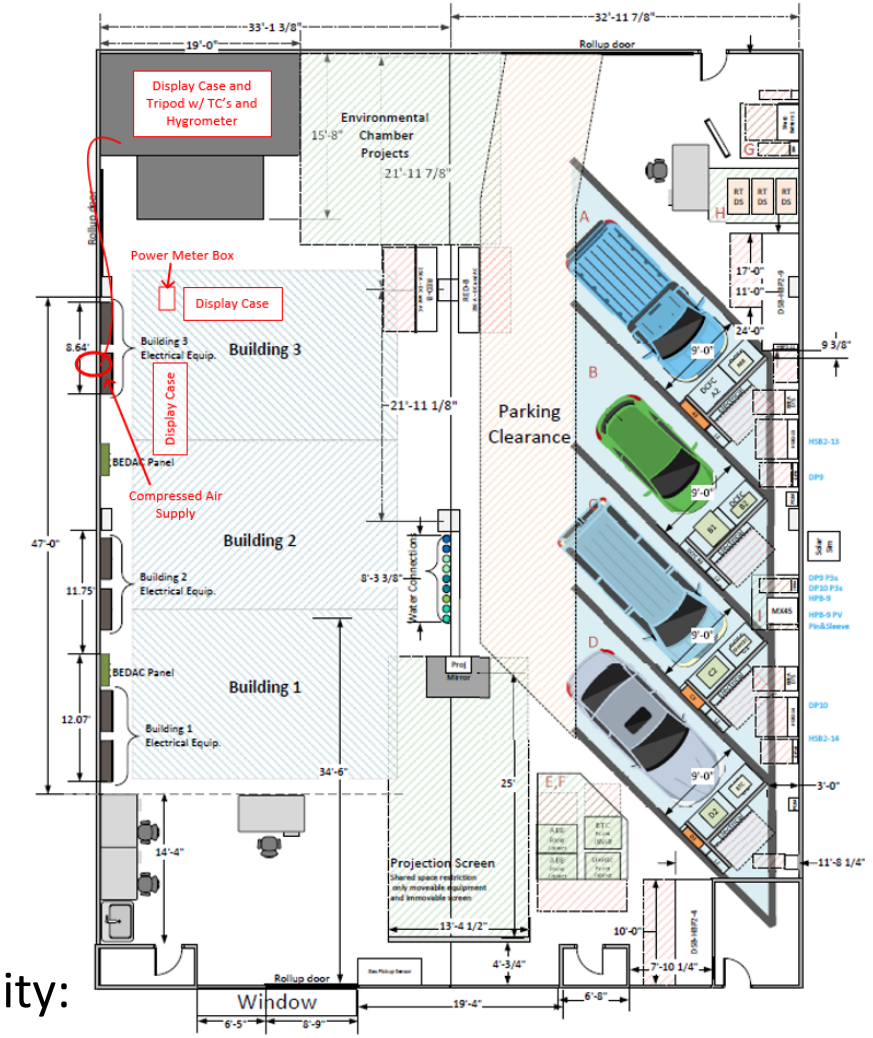
Laboratory and Environmentally Controlled Evaluation Chamber

Photos from NREL.gov

Below: Environmental chamber

Photos from Alex Bulk, NREL

Right: Map of experimentation facility:



Power and Energy Measurements and Configuration

Display Case Power

Current transformers instrumented to:

1. Total refrigeration system
2. Total lighting/ controls
3. Compressor
4. Condenser fan motor
5. Evaporator fan motor(s)

Total Power

Component Power

Photos from Alex Bulk, NREL

Wattnode Power Meter Box

Data Acquisition / Analytics

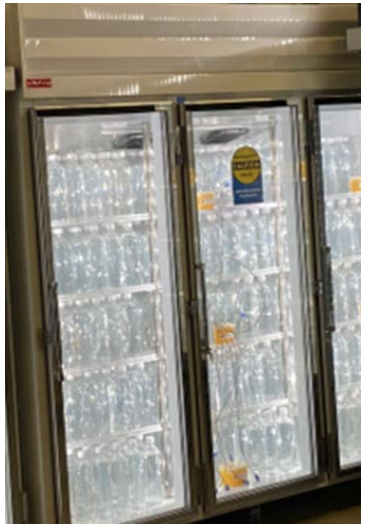
Shopper Traffic Emulation

- Door actuators were installed on each door
- Doors were opened every 10 minutes at ~90° angle for 6 seconds
- Doors opened sequentially from left to right
- Door openings for only 8-hour period of 24-hour test

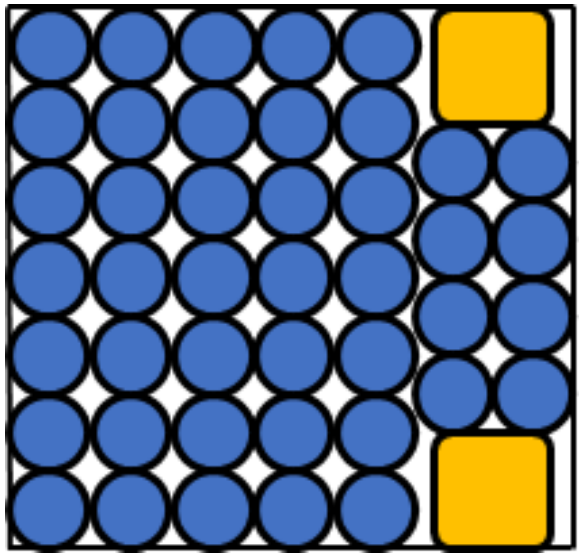
Photos from Alex Bulk, NREL

Replicating Thermal Mass of Food Product (Filler Material)

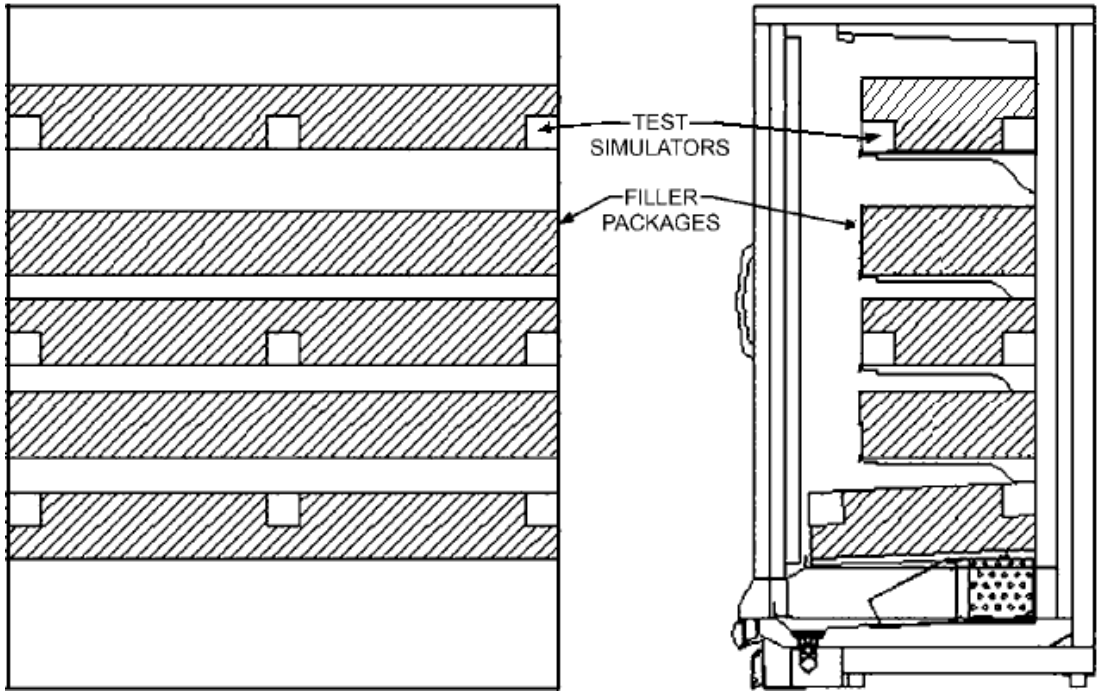
Filler material water bottles:



Orientation of bottles and simulators on shelf:



Photos from Alex Bulk, NREL



Deviations From ASHRAE 72/AHRI 1200 Standard

Deviation	Purpose
Filler material: H_2O bottles used instead of wood and propylene glycol (PG)	PG safety issues, rectangular wood blocked off airflow
Filler material: bottles only fill max ~50% internal volume, not 70–90%	Bottles are cylindrical with space in between to allow airflow
Measured condensate mass	Evaluate latent load inside case
No refrigerant pressure taps, surface thermocouples	Avoid tampering with refrigerant lines to assess case in purchased condition
Additional air temperature locations	More accurate averages

Experimentation Prep/Setup

Prior to Data Collection:

- Run cases until reach steady state:
  - Adjust set point temp until product simulators complied with FDA and AHRI
- Maintain cases at steady state for 12-hour test:
  - Ensure conditions maintained, doors open on schedule, etc.

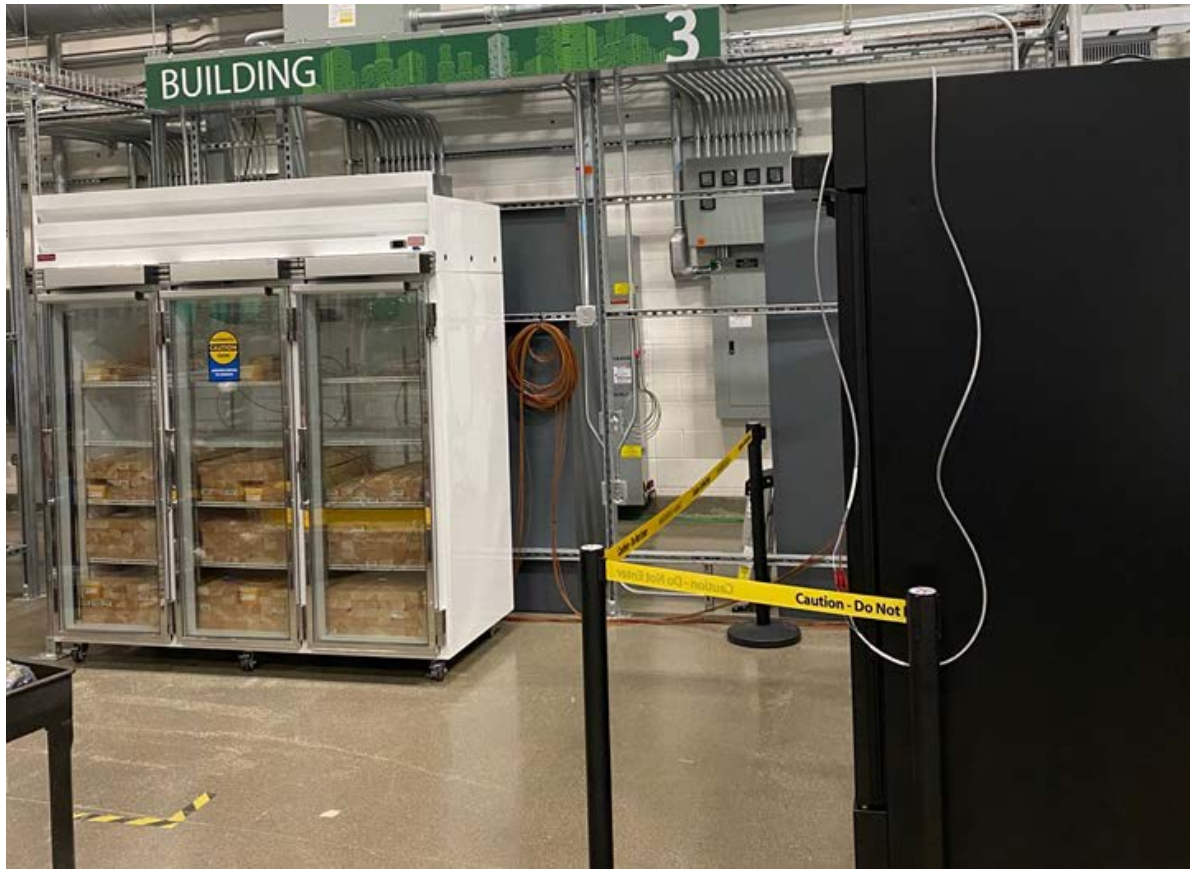


Photo from Alex Bulk, NREL

Methodology

Photos from Alex Bulk, NREL

- Start test and evaluate case parameters over 24-hour period
- 1-second data collection
- Screen raw data
- Post-process validated data
- Perform repeatability test for convergence

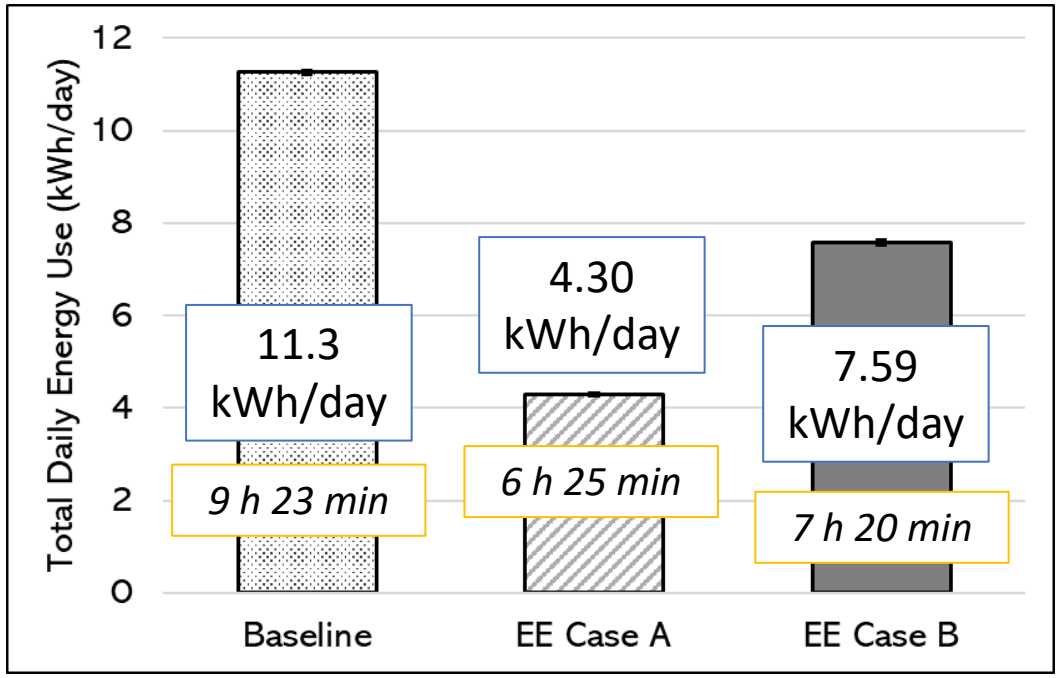
Results

Total Daily Energy and Mean Power

Energy/ Power

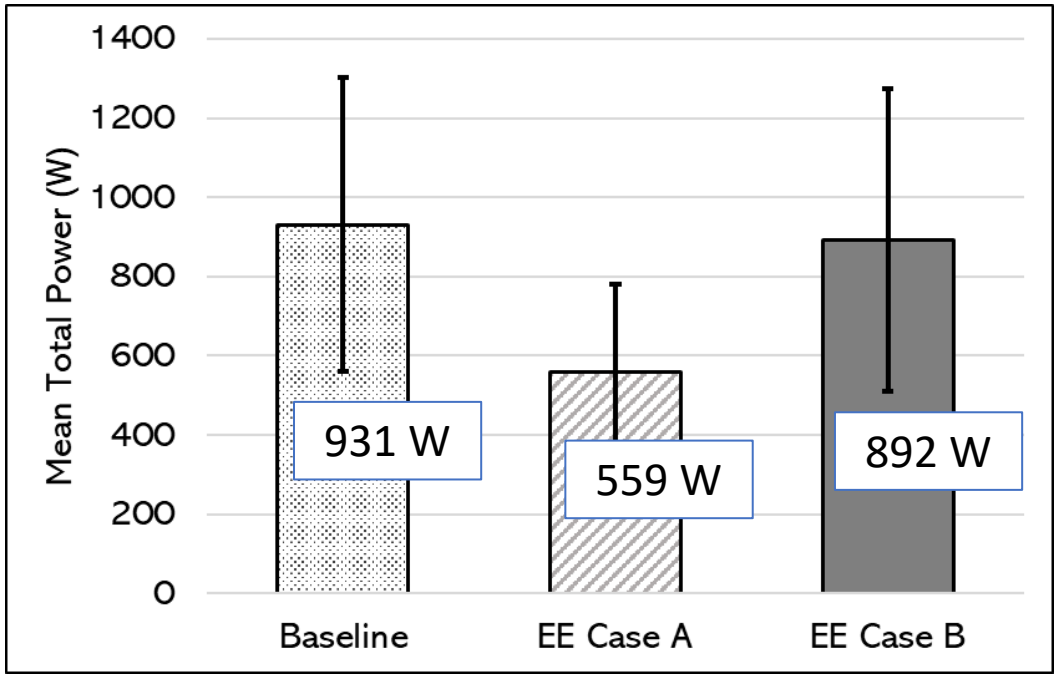
Compressor-on time

Total Mean Daily Energy



61.8% Savings **32.6% Savings**

Mean On-Cycle Power Draw

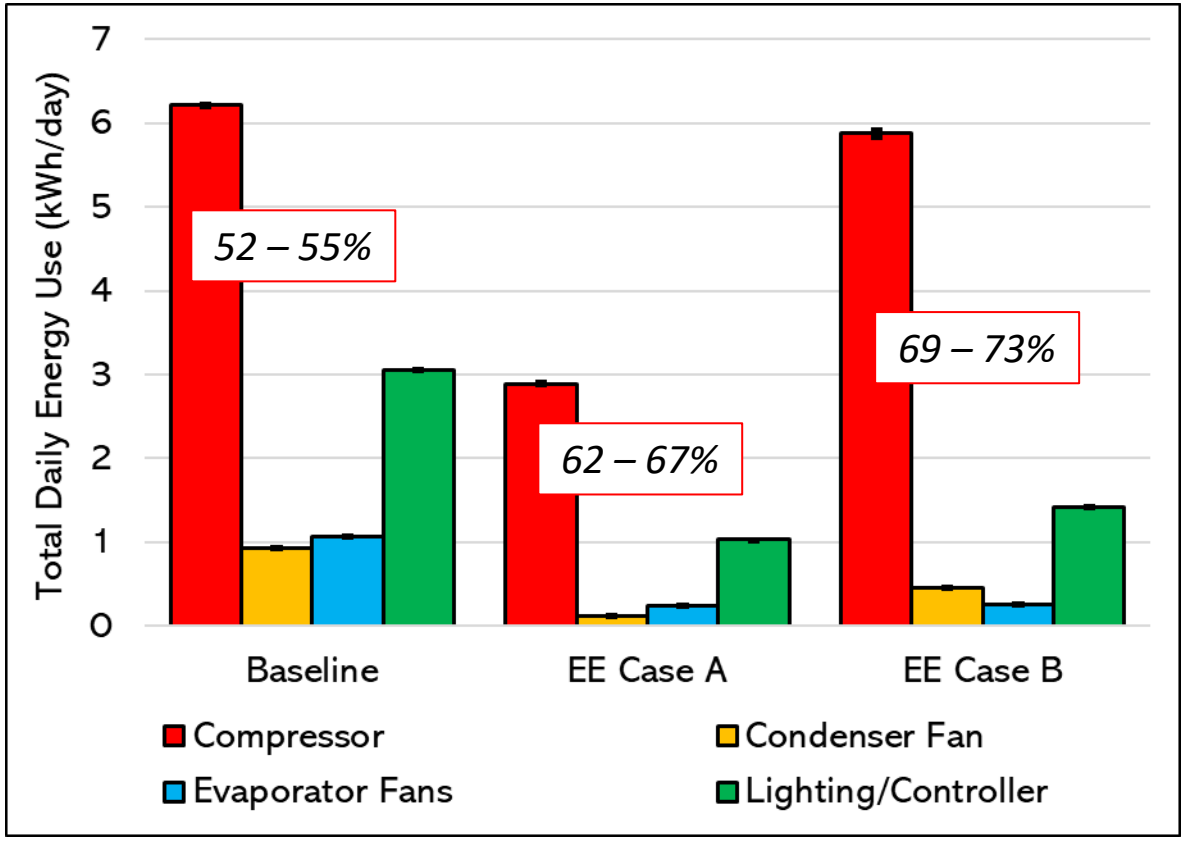


38.0% Reduction **4.12% Reduction**

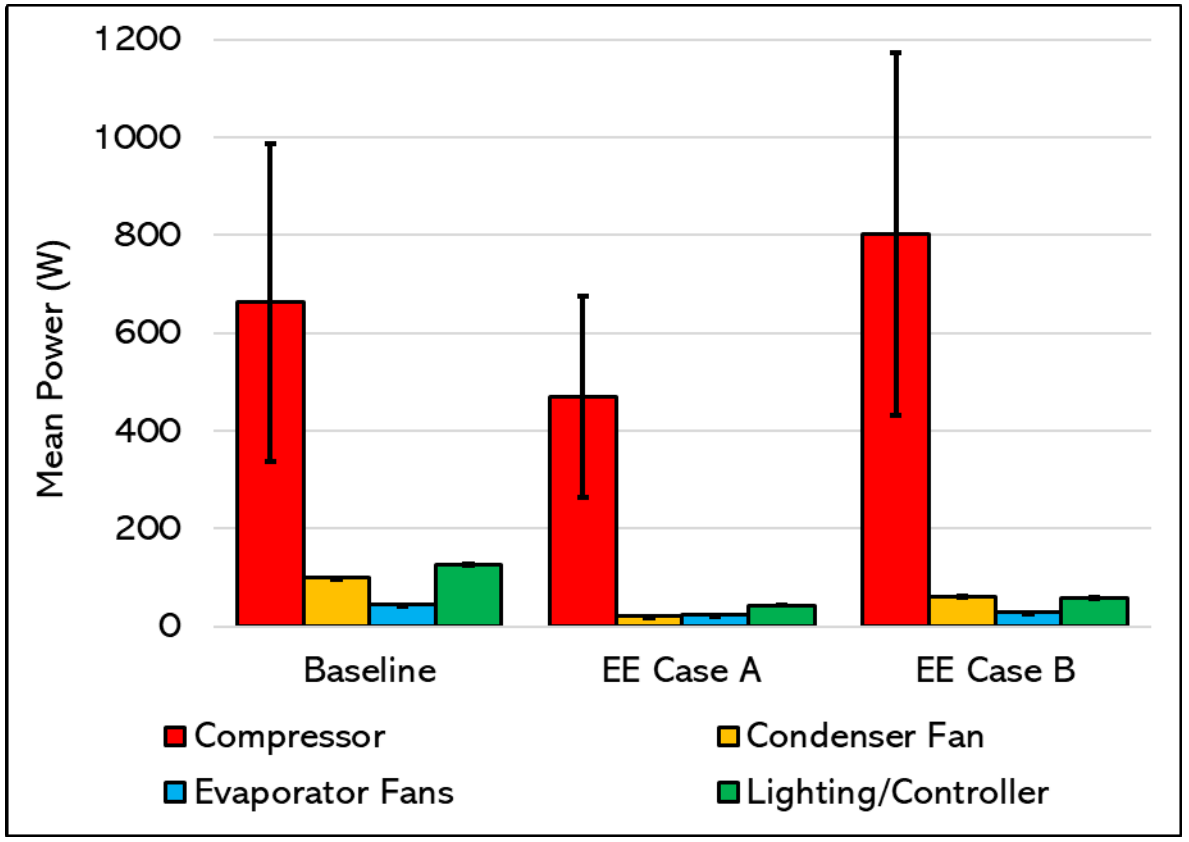
Component Energy and Mean Power Results at ASHRAE Environmental Conditions

% of Total Energy by Compressor

Component Mean Daily Energy



Component On-Cycle Power Draw



Mean, Max, Min Product Temperatures Over 24 Hours

Mean Temperatures:

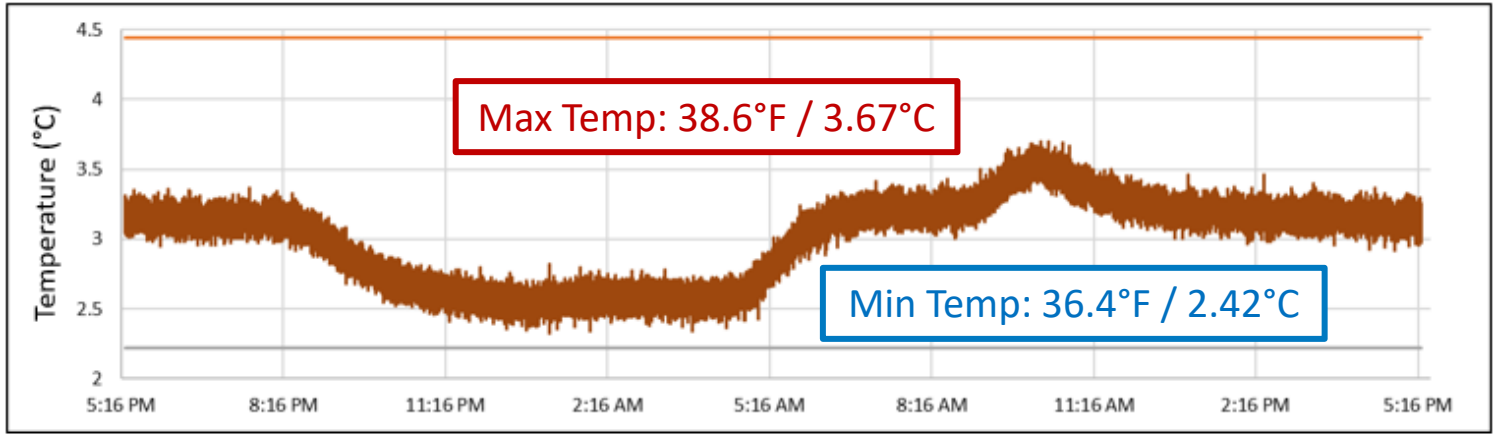
Baseline: 37.4°F / 3.00°C

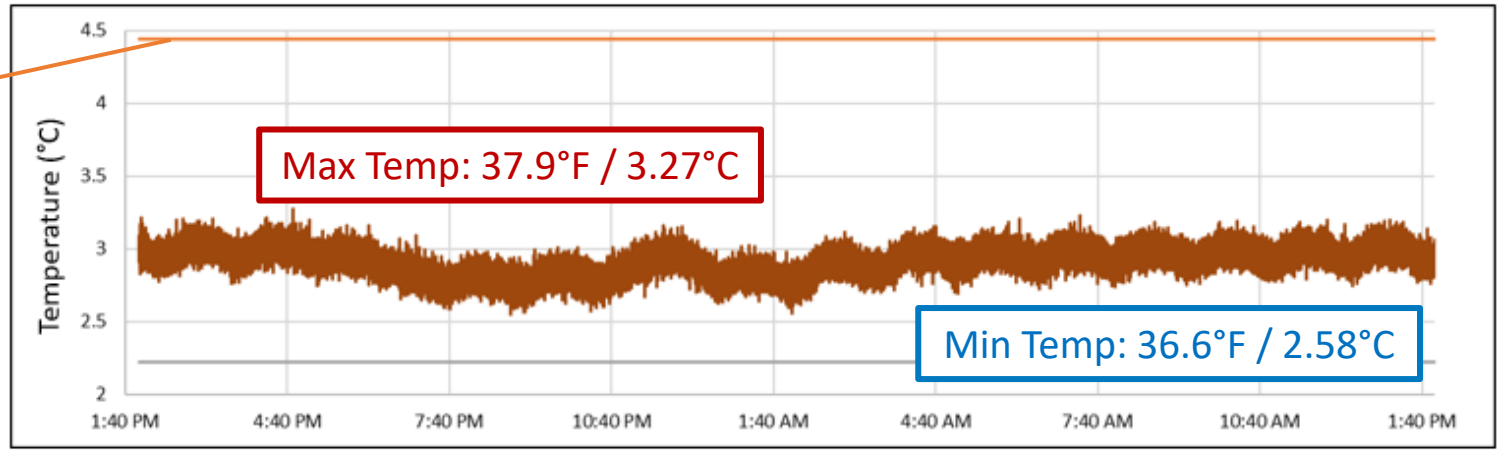
FDA/AHRI Upper Limit

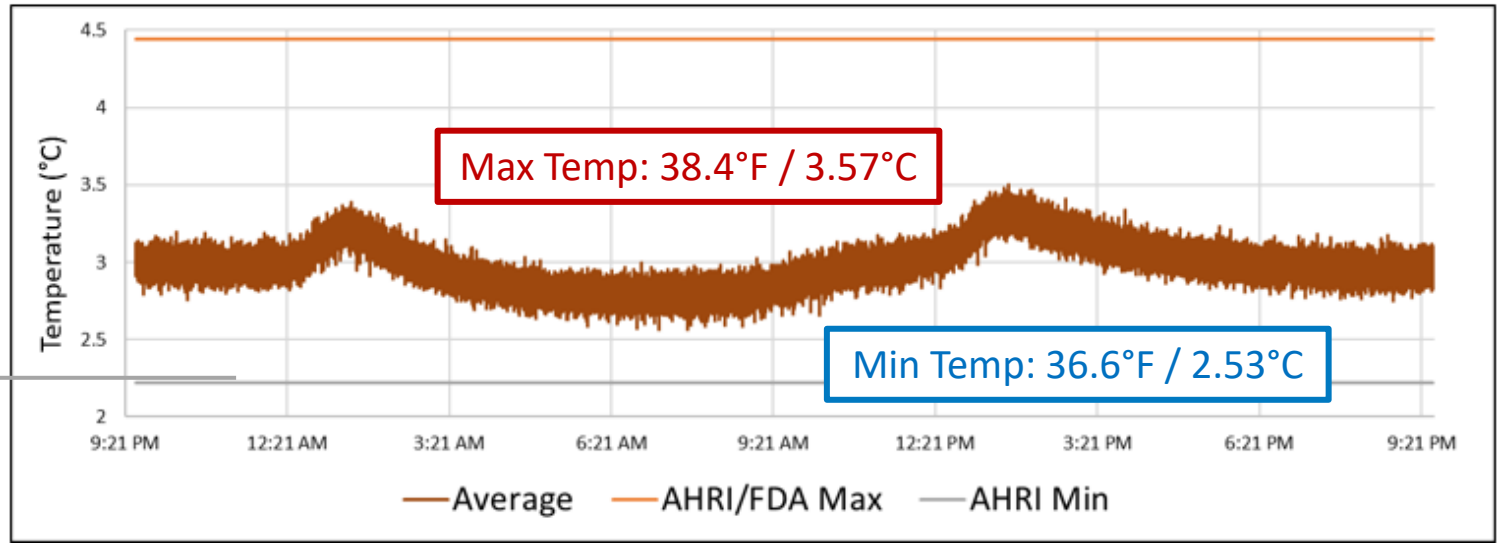
EE Case A: 37.2°F / 2.90°C

EE Case B: 37.4°F / 3.02°C

AHRI Lower Limit

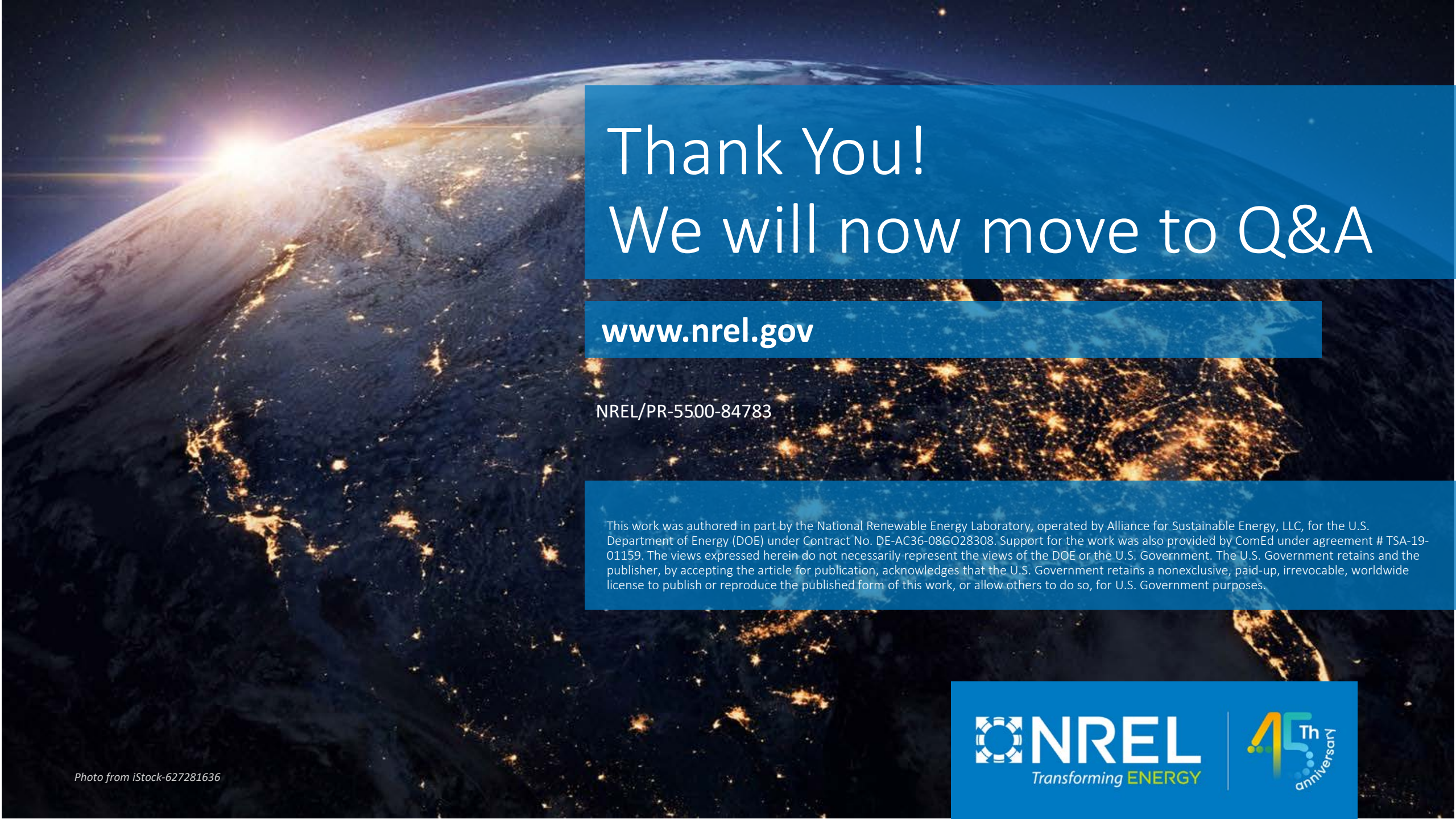






Conclusions

- EE Case A (R290) consumed 61.8% less daily energy than the baseline (4.30 vs. 11.3 kWh/day)
  - Savings attributed to a combination of energy efficiency components and thermodynamic properties of R290
- EE Case B (R513a) consumed 32.6% less daily energy than the baseline (5.79 vs. 11.3 kWh/day)
  - Savings mainly attributed to energy efficiency components since generally, thermodynamic properties of R134a and R513a are very similar



Thank You!
We will now move to Q&A

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NREL/PR-5500-84783

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Case Selection Criteria

R134a (Left), R513a (Center): Howard McCray (HMC) Model GR75

R290 (Right): True Manufacturing Model GDM-72-HC~TSL01

1. Number of shelves/doors: 4 shelves/3 doors
2. Similar discharge temp range: around 38°F (medium temp.), adjustable for altitude
3. Similar length within ±3 in.: True (78.6 in.), HMC (78.5 in.)
4. Similar internal volumetric capacity within ±5 ft^3: True (65.7 ft^3), HMC (62.1 ft^3)
5. Door type (swing)
6. Number of condensing units: 1
7. Same refrigeration system: fin & tube cond/evap, 1-speed comp, capillary tube
8. Same V/Hz/phase: 115 V/60 Hz/1-phase
9. Compressor size/type: ½ HP reciprocating
10. Condensing unit and lighting/controls all on one circuit/plug
11. DOE CCMS (Compliance Certification Management System)-database rated

Temperature Measurement Specifications

Location	Type	Model #	Distributor	Accuracy
Product Simulator, Internal Air, and Chamber Dry-Bulb Temperature Measurements	TC Type-T 1/16” probe	TMQSS-062U-6	Omega Engineering	±0.5°C (±0.9°F)
Chamber Dew Point Temperature	Chilled Mirror Dew Point Hygrometer	DewTrak II DPS3	EdgeTech	±0.22°C (±0.4°F)
Refrigerant Surface Temperatures	TC Type-T Surface Thermocouple	SA1-T-SRTC	Omega Engineering	±0.5°C (±0.9°F)

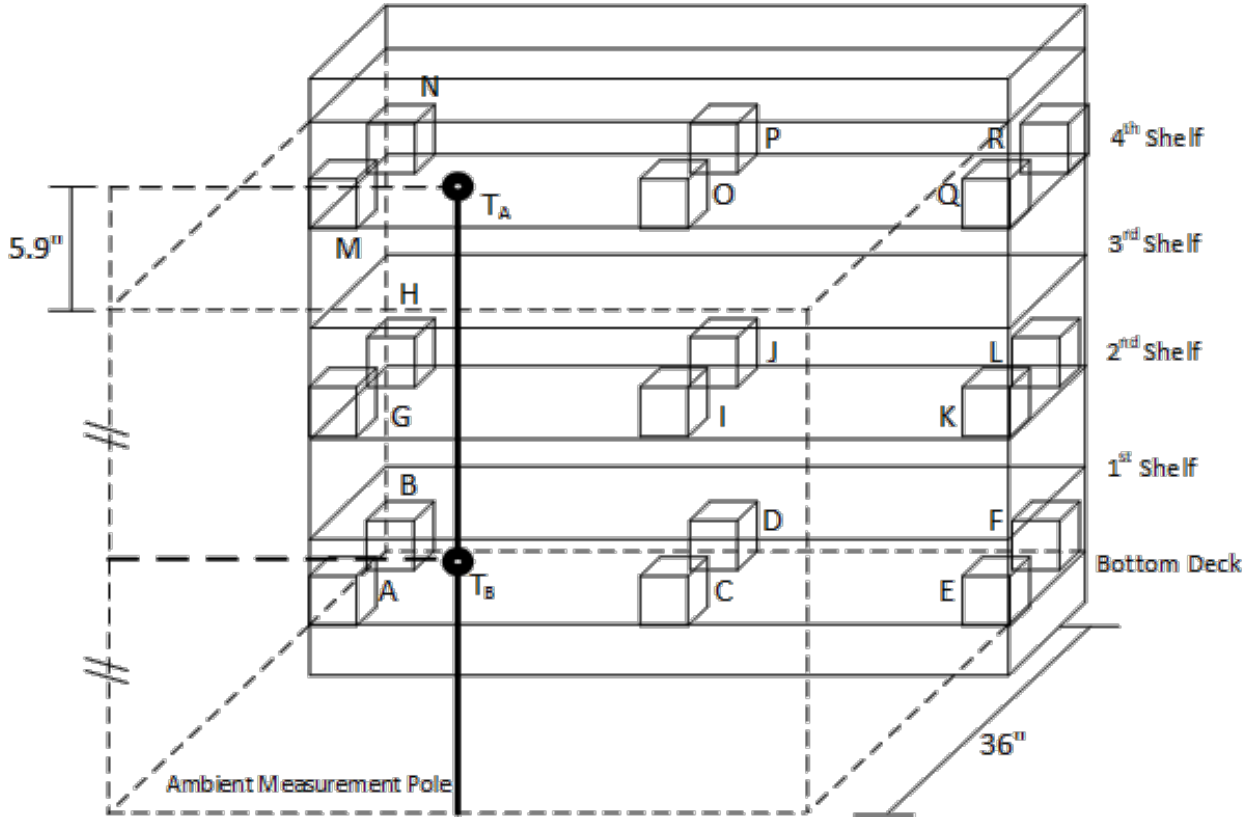
Power and Energy Measurements and Configuration

Location	Brand/Model #	Type	Accuracy
Case Total Plug and Compressor Power/Voltage/Current/Power Factor	Continental Control Systems/WMC-3Y-208-MB, Accu-CT ACTL-0750	Wattnode power meter, 20-A current transformer	±0.5%
Condenser Fan, Evaporator Fan(s), Lighting, and Controller Power/Voltage/Current/Power Factor		Wattnode power meter, 5-A current transformer	

Stabilized Chamber Conditions

Upper and lower limits for chamber dry bulb temperatures and dew point temperatures (DBT and DPT ranges based on range for ASHRAE DBT and WBT)

Sensor	Set Point	Upper Limit	Lower Limit
T_A DBT	24°C / 75.2°F	25°C / 77°F	23°C / 73.4°F
T_B DBT	Same as above	26.67°C / 80°F	21.33°C / 70.4°F
T_A DPT	15.42°C / 59.76°F	17.42°C / 30.94°F	13.23°C / 55.81°F



Set Point Correction

Adjusted compressor cut-in/cut-out temperatures and mean simulator temps (AHRI requires between 36°F/2.22°C and 40°F/4.44°C):

(Due to lowered air density at altitude)

CASE	Cut-In Temperature (°F/°C)	Cut-Out Temperature (°F/°C)	Steady-State Mean Product Simulator Temperature (°F/°C)
Baseline	38/3.33	30/−1.11	37.40 ± 0.04/3.00 ± 0.02
EE Case A	35/1.67	30/−1.11	37.22 ± 0.05/2.90 ± 0.03
EE Case B	39/3.89	31/−0.56	37.44 ± 0.05/3.02 ± 0.03

Results Summary of Component Energy at ASHRAE Conditions

Component Mean Daily Energy

Component	Baseline (kWh/day)	% Total	EE Case A (kWh/day)	% Total	EE Case B (kWh/day)	% Total
Compressor	6.21 ± 0.02	55.08%	2.89 ± 0.01	67.41%	5.87 ± 0.04	73.30%
Condenser Fan	0.94 ± 0.00	8.31%	0.13 ± 0.00	2.95%	0.45 ± 0.00	5.67%
Evaporator Fans	1.07 ± 0.00	9.47%	0.24 ± 0.01	5.56%	0.26 ± 0.01	3.25%
Lighting/ Controller	3.06 ± 0.00	27.14%	1.03 ± 0.00	24.08%	1.42 ± 0.00	17.77%

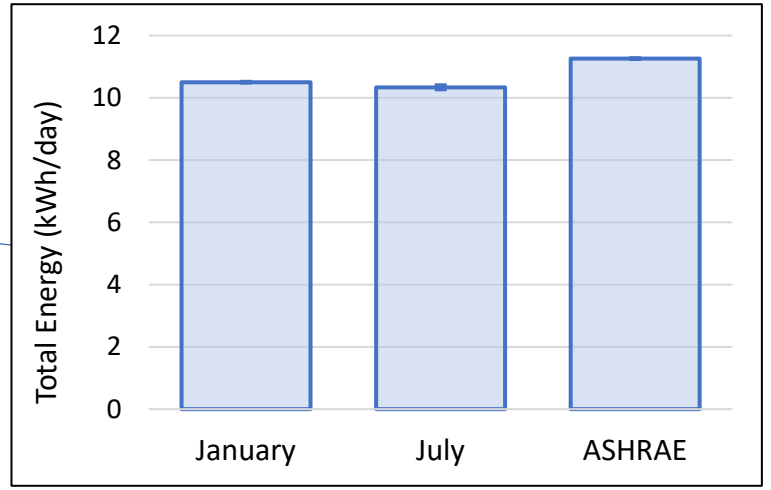
Component Mean On-Cycle Power Draw

Component	Baseline (W)	% Total	EE Case A (W)	% Total	EE Case B (W)	% Total
Compressor	662 ± 325	70.92%	469 ± 205	84.22%	802 ± 370	84.27%
Condenser Fan	100 ± 49	10.66%	21 ± 9	3.73%	62 ± 29	6.51%
Evaporator Fans	44 ± 1	4.76%	24 ± 12	4.34%	28 ± 14	2.98%
Lighting/ Controller	127 ± 1	13.65%	43 ± 0.1	7.72%	59 ± 0.2	6.23%

Baseline Results – Energy and Condensate at All Environmental Conditions

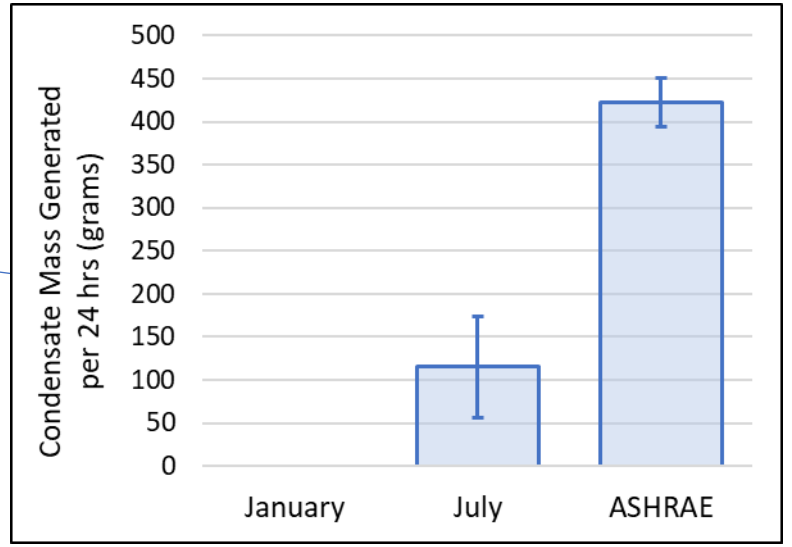
Baseline Case
Total Energy Consumption

- Higher than expected for this case



Baseline Case
Condensate Mass Produced

- Not required by ASHRAE but done in case customer uses condensate pump



Report does not compare individual cases and only compares across environmental conditions to avoid manufacturer concerns

Mean, Max, Min Product Temperatures Over 24 Hours

Baseline

Warmest Simulator

FDA/AHRI Upper Limit

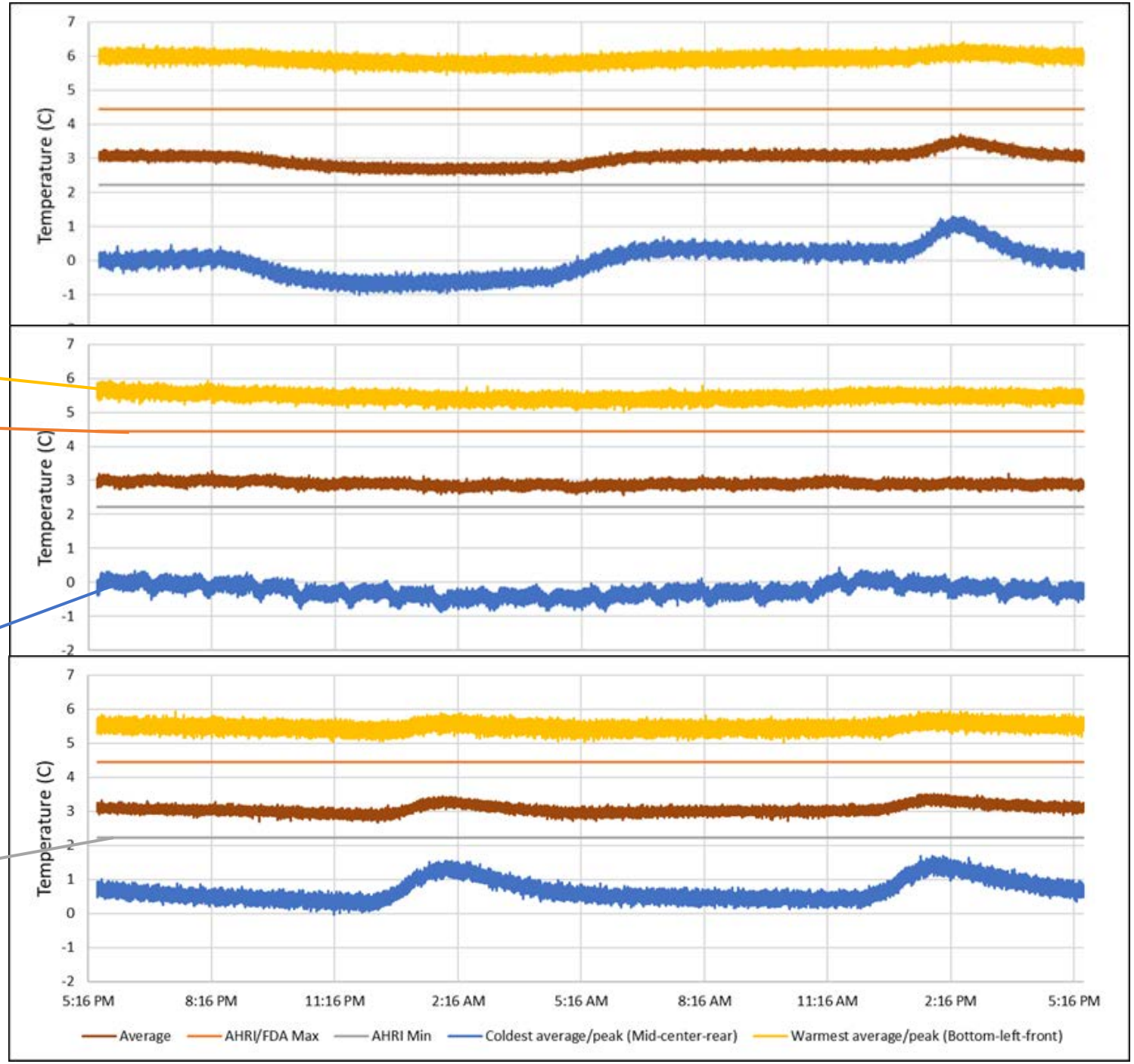
EE Case A

Average Simulator

Coldest Simulator

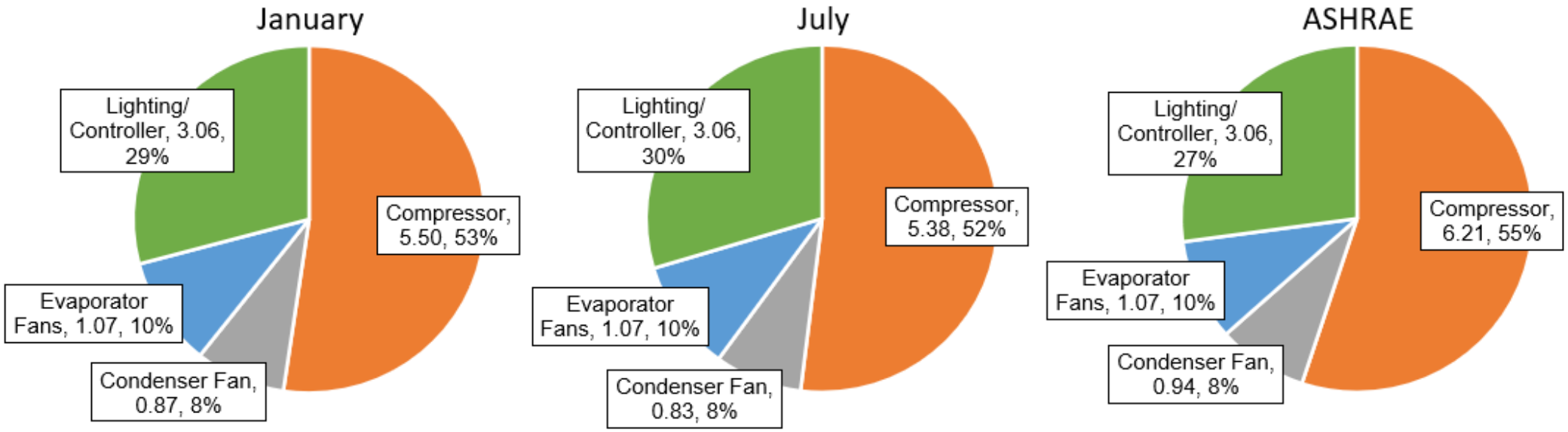
AHRI Lower Limit

EE Case B



Baseline Results – Component Energy Consumption at All Environmental Conditions

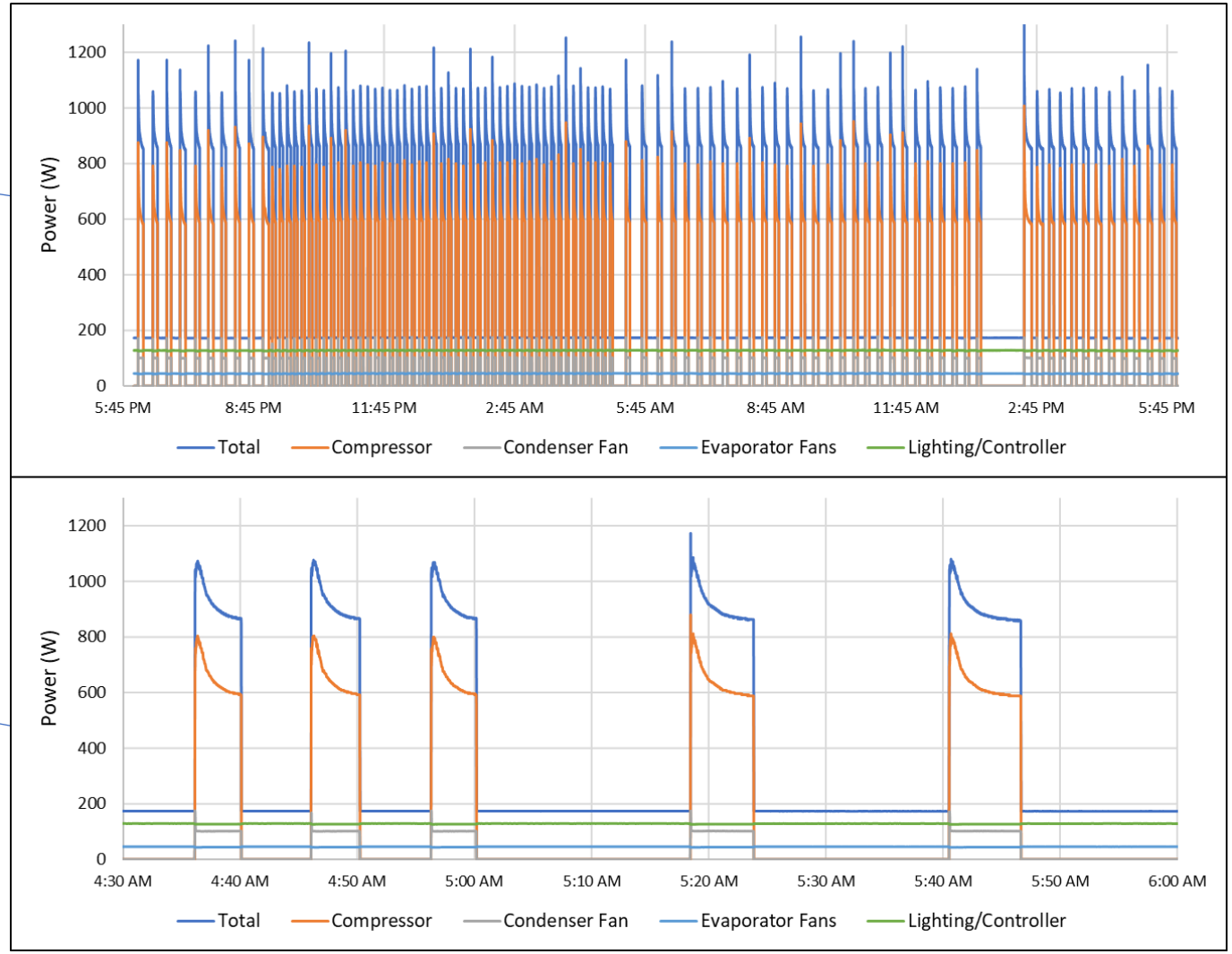
Baseline Case
Component Energy Consumption (kWh/day)



Baseline Results – Transient Energy Consumption at ASHRAE Environmental Conditions

Baseline Case Total and Component Power Consumption Over 24 Hours

- Zoomed in over 1.5 hours (around end of door opening period)



Baseline Results – Normalized Energy Consumption at All Environmental Conditions

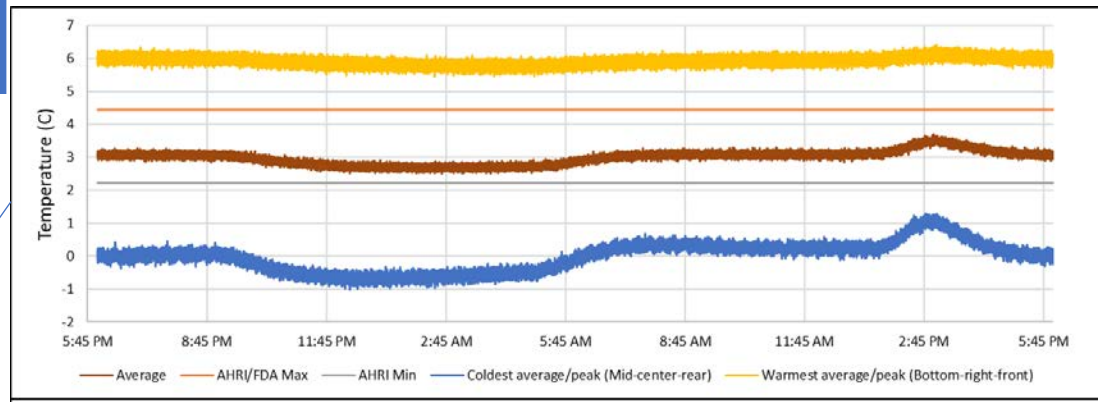
Energy consumption normalized to internal volumetric capacity and time between defrost (for ComEd to compare cases):

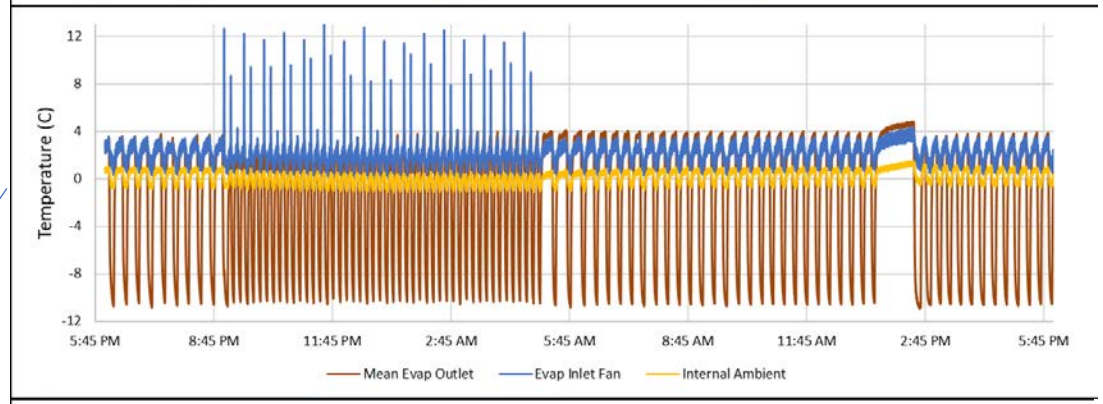
CONDITION	Total Energy Consumption (kWh/day)	Total Energy Consumption Corrected to Time-Between-Defrost (kWh/day)	Total Energy Consumption Normalized to Internal Volume (kWh/m^3 day)	Total Energy Consumption Corrected to Time-Between-Defrost and Normalized to Internal Volume (kWh/m^3 day)
January	10.50 ± 0.01	10.99 ± 0.03	7.68 ± 0.01	8.04 ± 0.02
July	10.34 ± 0.06	10.87 ± 0.03	7.56 ± 0.05	7.95 ± 0.02
ASHRAE	11.26 ± 0.01	11.82 ± 0.08	8.23 ± 0.01	8.64 ± 0.06

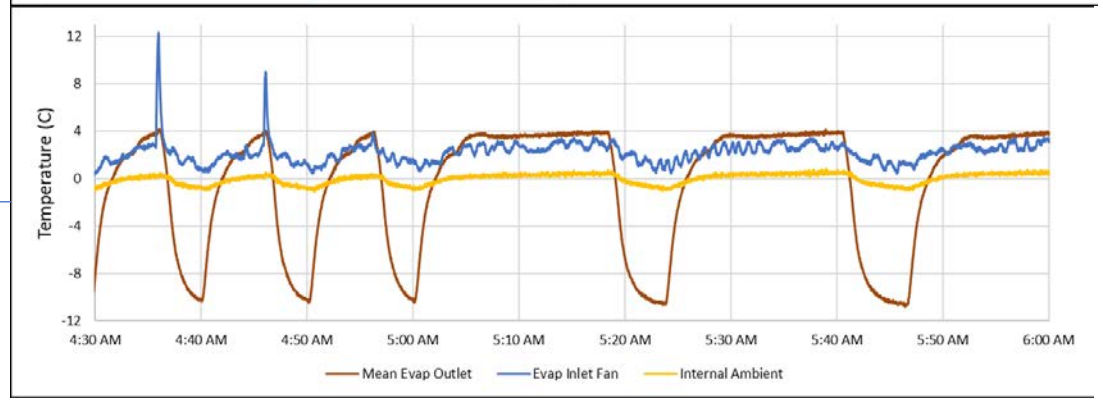
Baseline Results – Transient Temp Performance at ASHRAE Conditions

Baseline Case Product and Internal Air Temps Over 24 Hours

- Average product simulator temperature, coldest average, warmest average, coldest peak, and warmest peak product simulator temperature (and AHRI limits)
- Average of evaporator discharge grill temps, internal ambient (case geometric center), and evaporator fan inlet
- Air temps, but zoomed in over 1.5 hours







Baseline Results – Product Simulator Temps at ASHRAE Conditions

Baseline Case
Average Product Simulator Temperatures

- Shown for all environmental conditions in report

(Standard only specifies the average of all simulators to be within the required range, not individual)

Top Shelf

Rear:	2.98°C	-0.31°C	4.11°C
Front:	4.97°C	2.37°C	5.98°C

Middle Shelf

Rear:	1.56°C	-0.38°C	2.40°C
Front:	2.97°C	1.12°C	4.07°C

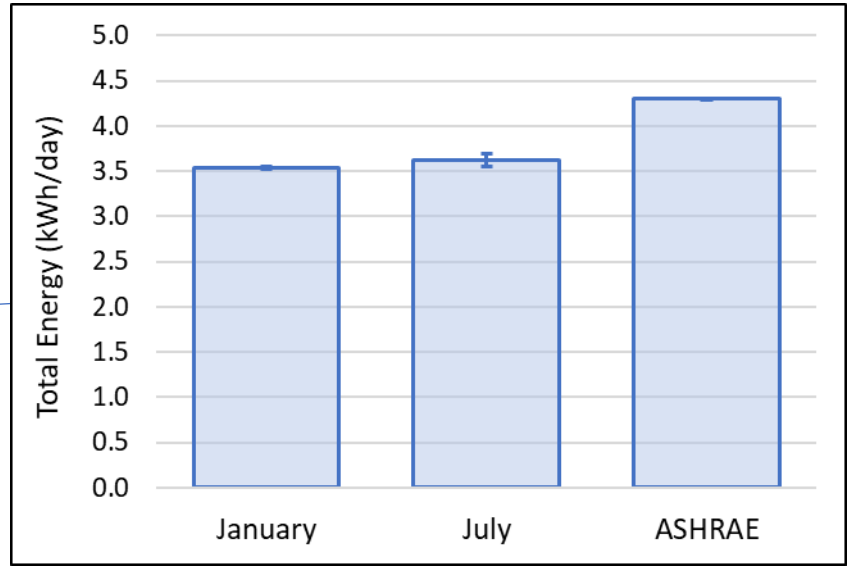
Bottom Shelf

Rear:	2.33°C	1.53°C	3.66°C
Front:	5.02°C	3.52°C	6.23°C

EE Case A Results – Energy and Condensate at All Environmental Conditions

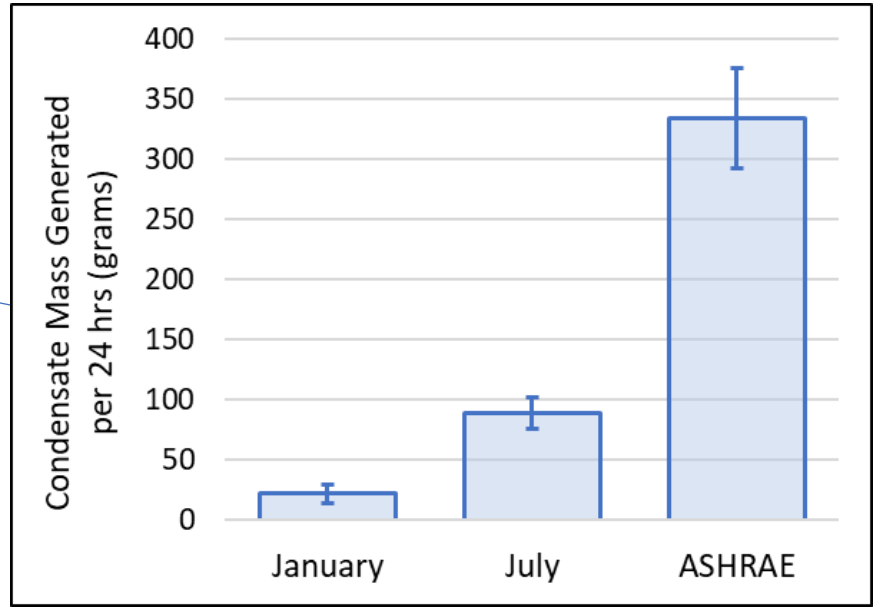
EE Case A
Total Energy Consumption

- Lower than expected for this case based on CCMS Data



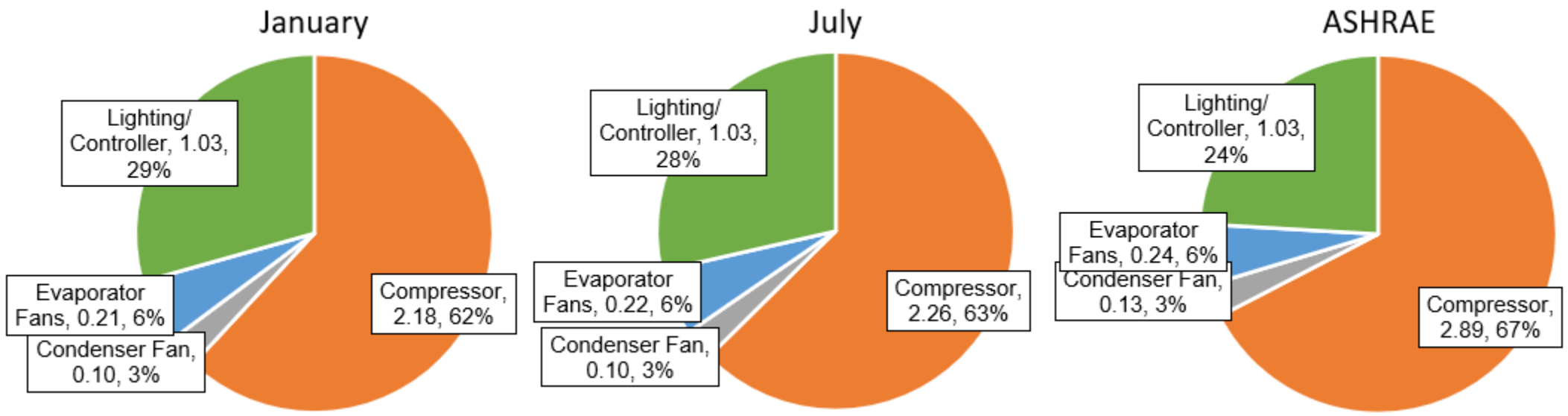
EE Case A
Condensate Mass Produced

- Not required by ASHRAE but done in case customer uses condensate pump



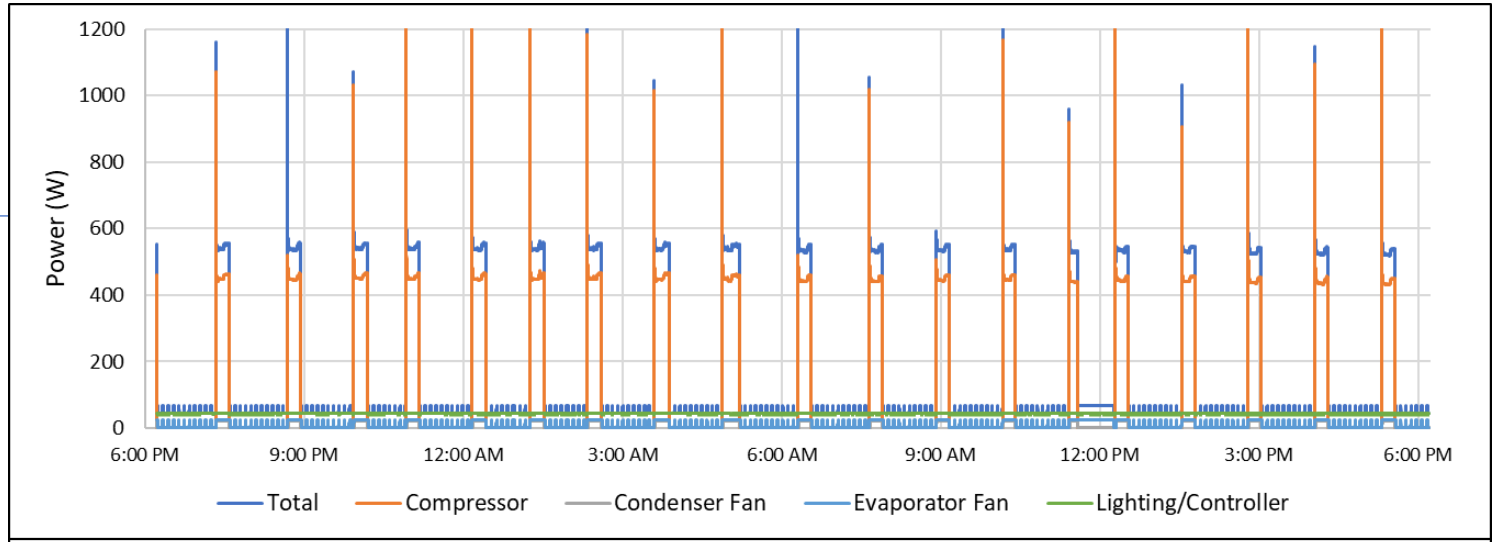
EE Case A Results – Component Energy Consumption at All Environmental Conditions

EE Case A
Component Energy Consumption (kWh/day)

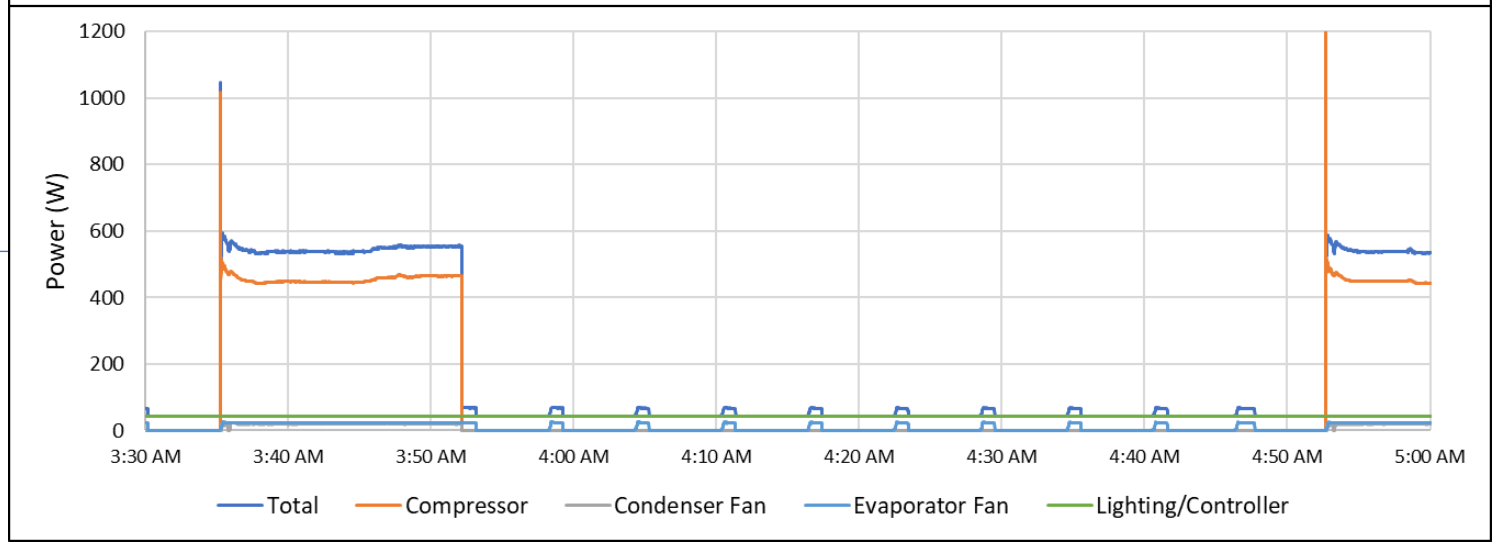


EE Case A Results – Transient Energy Consumption at ASHRAE Environmental Conditions

EE Case A Total and Component Power Consumption Over 24 Hours



- Zoomed in over 1.5 hours (around end of door opening period)



EE Case A Results – Normalized Energy Consumption at All Environmental Conditions

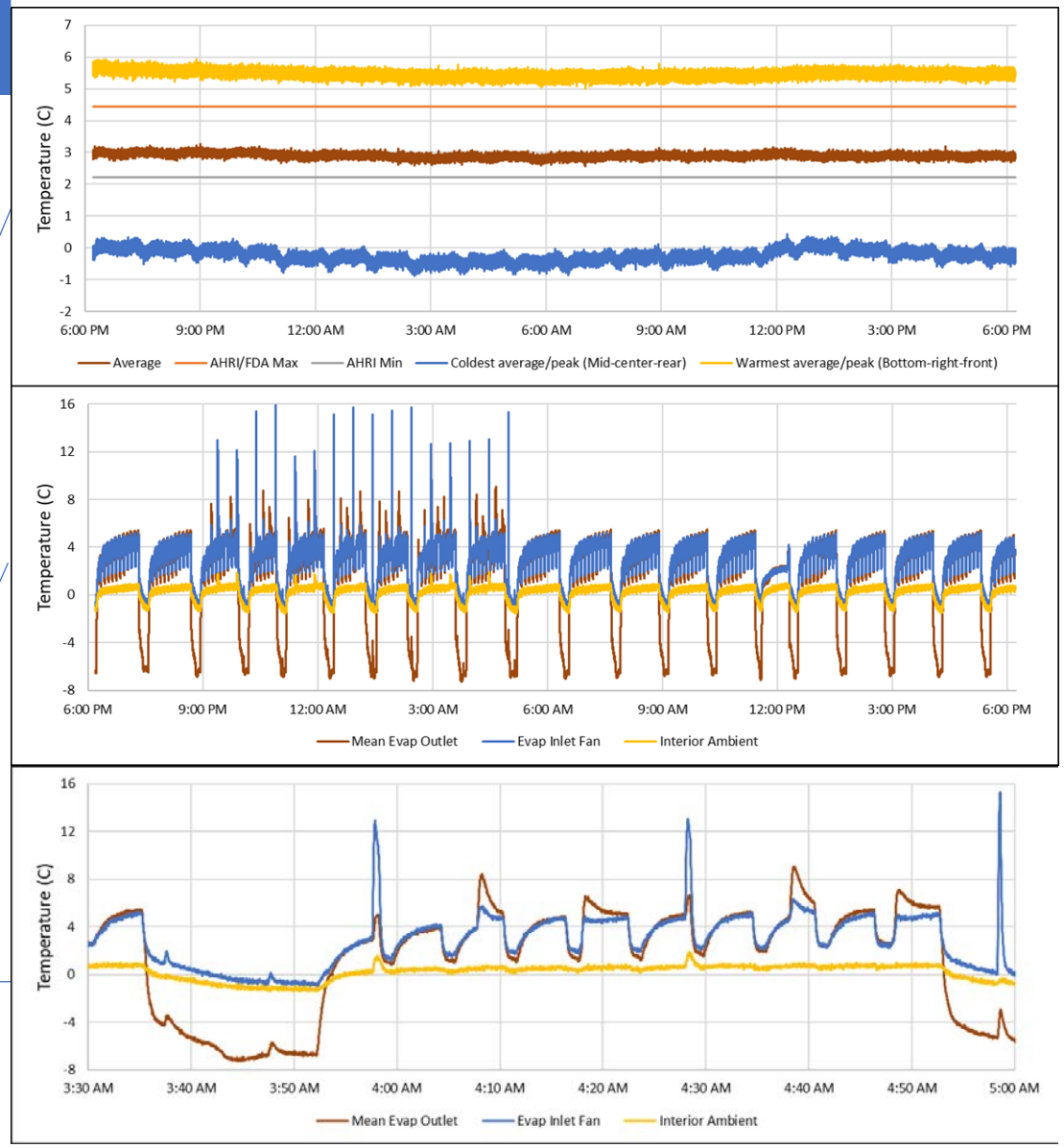
Energy consumption normalized to internal volumetric capacity and time between defrost (for ComEd to compare cases)

CONDITION	Total Energy Consumption (kWh/day)	Total Energy Consumption Corrected to Time-Between-Defrost (kWh/day)	Total Energy Consumption Normalized to Internal Volume (kWh/m^3 day)	Total Energy Consumption Corrected to Time-Between-Defrost and Normalized to Internal Volume (kWh/m^3 day)
January	3.53 ± 0.02	3.53 ± 0.02	2.54 ± 0.01	2.54 ± 0.01
July	3.63 ± 0.07	3.63 ± 0.07	2.61 ± 0.05	2.61 ± 0.05
ASHRAE	4.30 ± 0.00	4.30 ± 0.00	3.09 ± 0.00	3.09 ± 0.00

EE Case A Results – Transient Temp Performance at ASHRAE Environmental Conditions

EE Case A (R290 case) Product and Internal Air Temps Over 24 Hours

- Average product simulator temperature, coldest average, warmest average, coldest peak, and warmest peak product simulator temperature (and AHRI limits)
- Average of evaporator discharge grill temps, internal ambient (case geometric center), and evaporator fan inlet
- Air temps, but zoomed in over 1.5 hours



EE Case A Results – Product Simulator Temps at ASHRAE Environmental Conditions

EE Case A
Average Product Simulator Temperatures

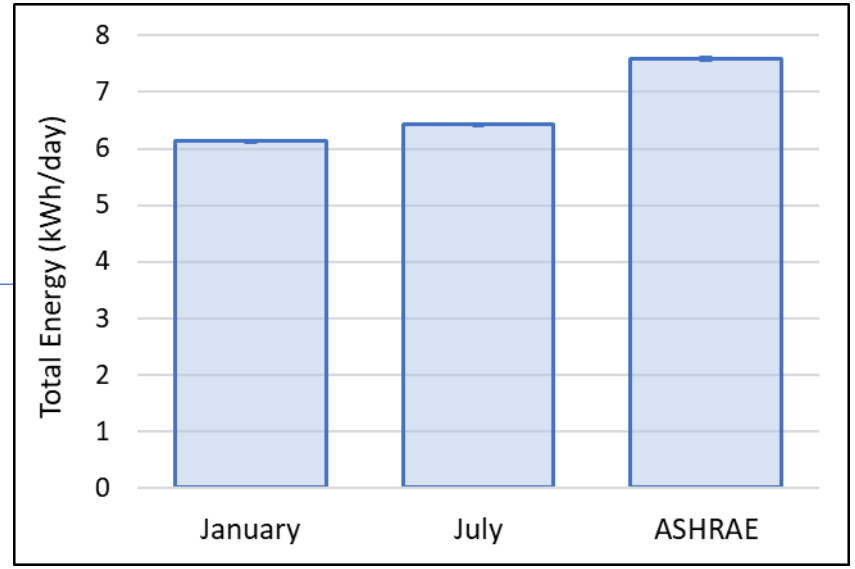
- Shown for all environmental conditions in the report

	Top Shelf		
Rear:	2.07°C	-0.29°C	1.86°C
Front:	4.27°C	1.74°C	5.02°C
	Middle Shelf		
Rear:	1.54°C	-0.50°C	2.49°C
Front:	3.46°C	0.96°C	4.20°C
	Bottom Shelf		
Rear:	3.96°C	1.77°C	5.13°C
Front:	5.13°C	3.93°C	5.75°C

EE Case B Results – Energy and Condensate at All Environmental Conditions

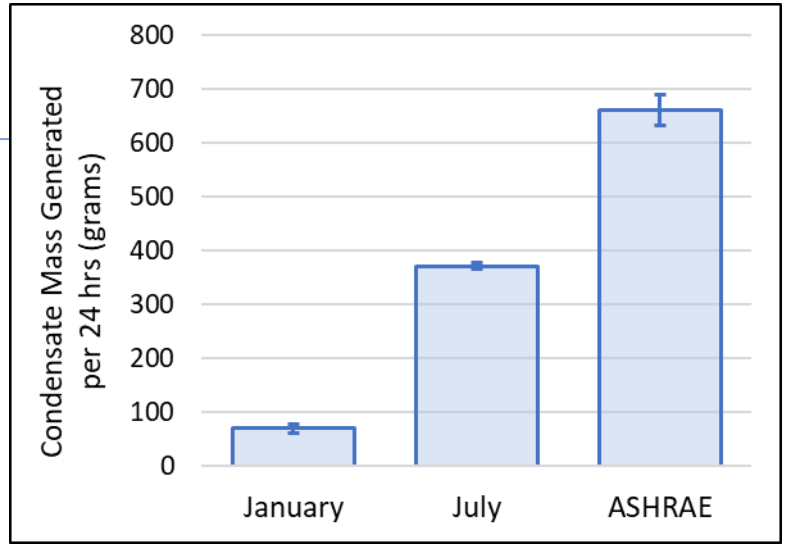
EE Case B
Total Energy Consumption

- Case has not been rated, so we had no expectations of energy consumption



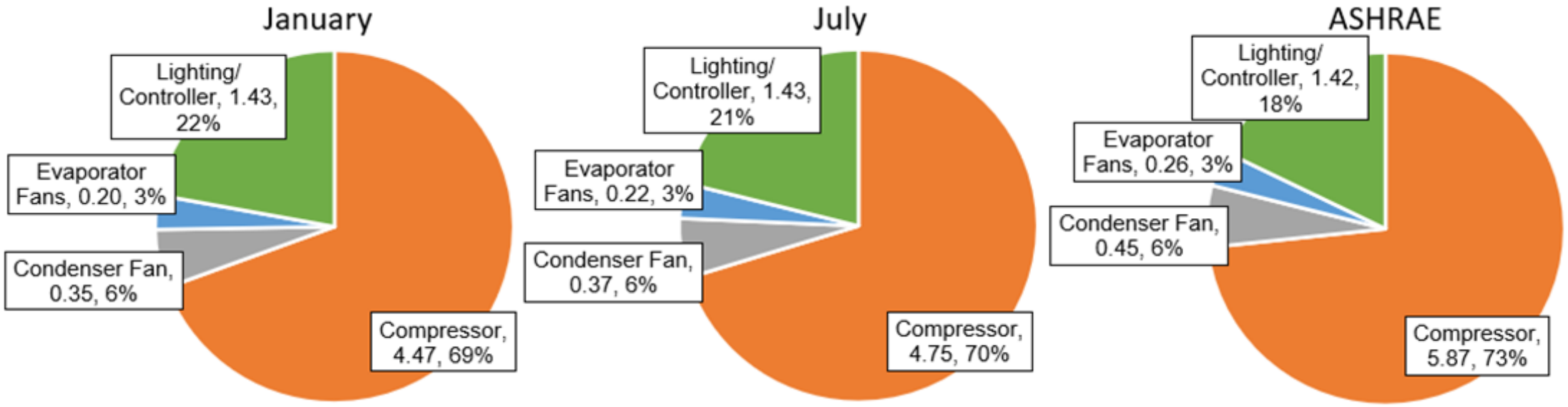
EE Case B
Condensate Mass Produced

- Not required by ASHRAE but done in case customer uses condensate pump



EE Case B Results – Component Energy Consumption at All Environmental Conditions

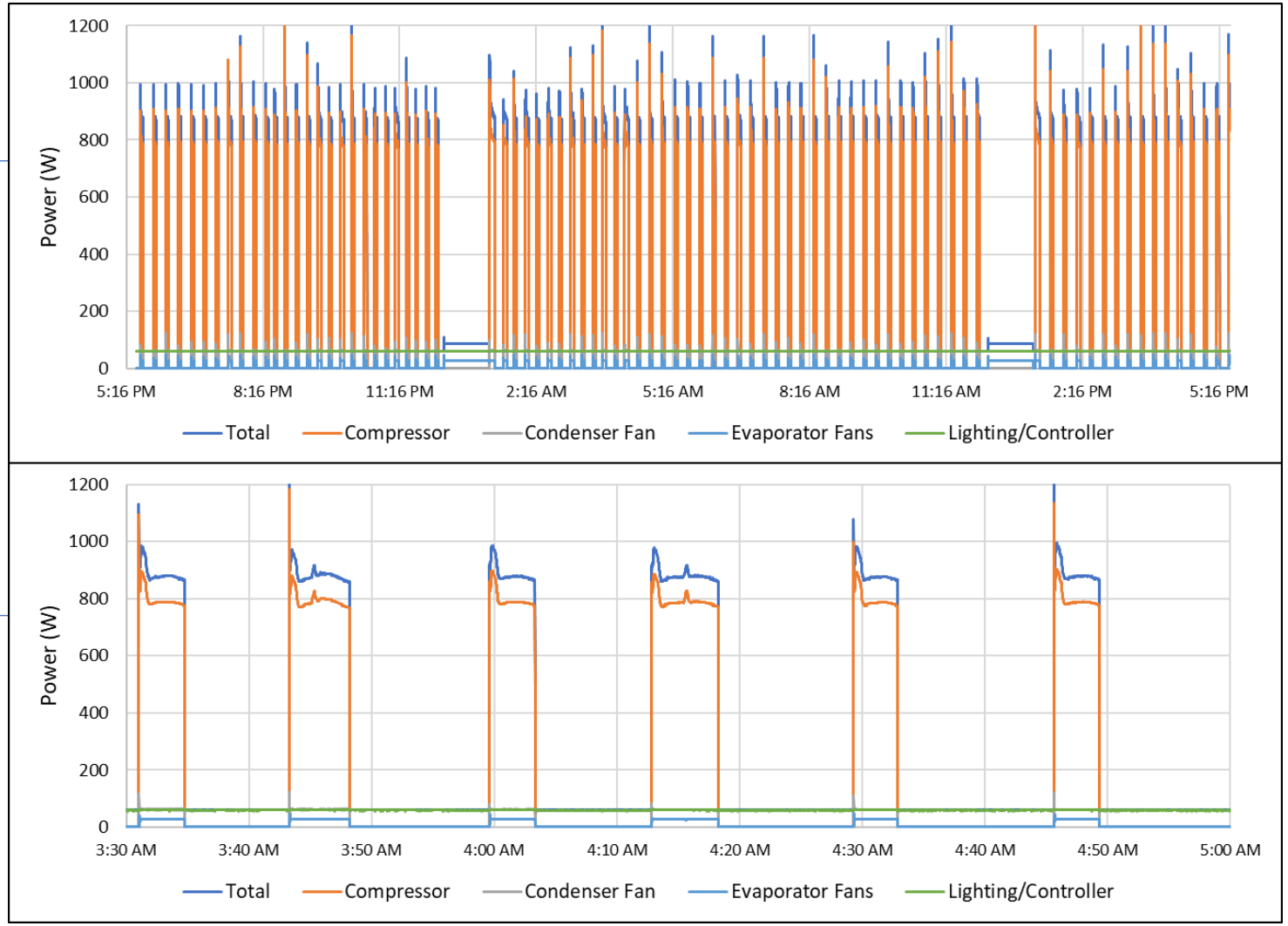
EE Case B
Component Energy Consumption (kWh/day)



EE Case B Results – Transient Energy Consumption at ASHRAE Environmental Conditions

EE Case B Total and Component Power Consumption Over 24 Hours

- Zoomed in over 1.5 hours (around end of door opening period)



EE Case B Results – Normalized Energy Consumption at ASHRAE Environmental Conditions

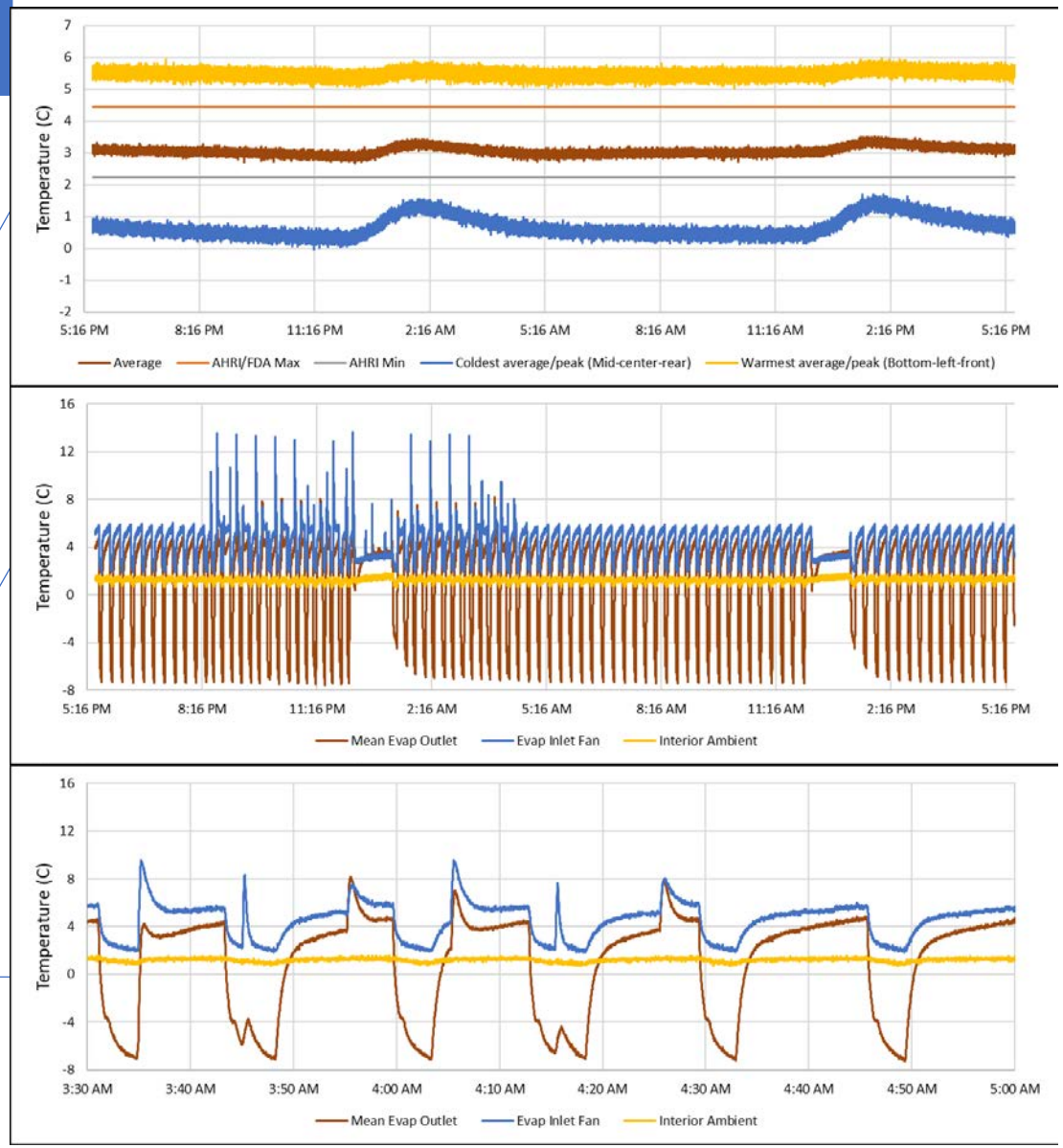
Energy consumption normalized to internal volumetric capacity and time between defrost (for ComEd to compare cases)

CONDITION	Total Energy Consumption (kWh/day)	Total Energy Consumption Corrected to Time-Between-Defrost (kWh/day)	Total Energy Consumption Normalized to Internal Volume (kWh/m^3 day)	Total Energy Consumption Corrected to Time-Between-Defrost and Normalized to Internal Volume (kWh/m^3 day)
January	6.13 ± 0.02	6.78 ± 0.00	4.48 ± 0.01	4.96 ± 0.00
July	6.42 ± 0.02	7.07 ± 0.02	4.70 ± 0.01	5.17 ± 0.02
ASHRAE	7.59 ± 0.03	8.32 ± 0.03	5.55 ± 0.02	6.09 ± 0.02

EE Case B Results – Transient Temp Performance at ASHRAE Environmental Conditions

EE Case B (R513a case) Product and Internal Air Temps Over 24 Hours

- Average product simulator temperature, coldest average, warmest average, coldest peak, and warmest peak product simulator temperature (and AHRI limits)
- Average of evaporator discharge grill temps, internal ambient (case geometric center), and evaporator fan inlet
- Air temps, but zoomed in over 1.5 hours



EE Case B Results – Product Simulator Temps at ASHRAE Environmental Conditions

EE Case B
Average Product Simulator Temperatures

- Previous graphs and this table shown for all environmental conditions (except zoomed-in air temps)

	Top Shelf		
Rear:	2.10°C	0.70°C	1.02°C
Front:	5.18°C	3.45°C	3.98°C
	Middle Shelf		
Rear:	2.36°C	0.67°C	1.08°C
Front:	4.59°C	2.67°C	3.32°C
	Bottom Shelf		
Rear:	3.40°C	2.68°C	3.06°C
Front:	5.49°C	4.01°C	5.38°C

ComEd – CLEAResult Self-Contained Medium-Temperature Refrigerator Display Case Assessment

- Chamber DBTs and DPTs and measurement limits
- Refrigerant piping surface temperatures
- Piping surface temperatures zoomed in 1.5 hours around end of door-opening period