Refrigerant Comparison: R290 vs. R404a

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Version: 08.23

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1. History of Refrigeration

Beginning in the early 20th century, both household and commercial refrigeration began to be utilized. The first refrigeration systems operated with toxic gases such as ammonia, methyl chloride, and/or sulfur dioxide. In 1920, Propane (R290 Refrigerant) was discovered to be non-toxic, relatively safe, and contain excellent thermo-physical properties. However, around the same time, Chlorofluorocarbon (CFCs) refrigerants were introduced. Despite being deemed safe for use, R290 took a backseat to refrigeration development due to its flammability.

Quickly, CFCs became widely used throughout the refrigeration industry. In 1974, scientists found that the use of CFCs were having a harmful effect on the earth's atmospheric ozone layer. Depletion of the ozone layer can cause damaging effects on the worldwide ecosystem. Therefore, in 1987, the Montreal Protocol was implemented to phase out the use and production of CFCs. At that time, the refrigeration industry began the transition to Hydrofluorocarbon (HFCs) refrigerants such as R134a and R404a.

HFCs, unlike CFCs, are not harmful to the ozone layer, but rather significant contributors to global warming. Therefore, introducing a new risk to the worldwide ecosystem. R404a is 3922 times more potent as a global warming gas than the main contributor, which is Carbon Dioxide (CO2). So, once again, the refrigeration industry began looking to transition refrigerants, which brought to light the refrigerant of the 1920s: Propane (R290).

Hydrocarbon (HCs) refrigerants such as Propane (R290) and Isobutane (R600a) have seen limited use over the years because of their misunderstood flammability. Significant technological progress has been made since the 1920s on how to safely distribute, store, and use such refrigerants. R290 has been used in Europe for over 20 years now, and the safety and reliability of this refrigerant can be verified by the sheer number of appliances in use today. Over 1.5 billion refrigeration systems around the world use HC refrigerants, according to webstaurantstore.com.

The United States Environmental Protection Agency (EPA) has listed R290 Refrigerant as an acceptable and preferred alternative due to its low Global Warming Potential (GWP) and Ozone Depletion Potential (ODP).

2. Leer's History of Refrigerants

As an industry leader in temperature-controlled storage solutions, Leer is committed to staying at the forefront of ever-changing technologies and market demands. Leer strives to continuously adapt to these conditions so we can consistently offer our customers best in-industry products. Since Leer began manufacturing Ice Merchandisers in 1952, R290 is the fourth primary refrigerant offered. R12 was the go-to refrigerant for most refrigeration manufacturers from its introduction in the 1930's until the 1990's. Since then, technological improvements and environmental awareness have driven refrigerant transitions every 10-15 years.

Leer's refrigerant use history is summarized in Figure 01.

Refrigerant	Leer's Years of Use	ODP	GWP	Thermal Conductivity	Performance
R12	Thru 1994	1.0	10000+	0.0482	Good
R134a	1994 - 2007	0	1300	0.0586	Good
R404a	2007 - **2023**	0	3900	0.0497	Fair
R448a	Considered	0	1300	0.0469	Fair
R290	**2020 - TBD**	**0**	**3**	**0.0676**	**Very Good**

Figure 01 – Leer's History of Refrigerants

***Ozone Depletion Potential (ODP)** = The measure of the effectiveness in removing ozone, relative to standard compound (CFC-11/R11). A lower value is better.*

***Global Warming Potential (GWP)** = The measure of the ability of a gas to trap heat in the atmosphere, relative to carbon dioxide (CO2). A lower value is better.*

***Thermal Conductivity** = The ability of material to transfer heat, measured in Btu/hr-ft- o F. Values listed are via ASHRAE. A higher value is better.*

3. R290 Definition and Benefits

In everyday terms, R290 is referred to as refrigeration grade propane. R290 is classified as a hydrocarbon refrigerant, which is natural and non-toxic. It is currently the preferred alternative, in small cooler and freezer applications, to the harmful CFC and HFC refrigerants. R290 is referenced as the go-to refrigerant for three main reasons.

Reason 1: High Performance Refrigerant

R290 has higher thermal conductivity than other refrigerants, which results in higher refrigerant performance and potentially lower energy costs.

R290 also has lower high side compressor pressures, which results in projected longer compressor life.

Lastly, R290 has more consistent performance, which results in limited to no temperature glide and less unpredictable temperature variations – keeping your product in premium condition.

Due to R290's high performance. Leer Ice Merchandisers only require between 3 oz and 5.25 oz of refrigerant. This is comparable to the amount of flammable material used in common everyday items, such as aerosol cans and lighters.

Reason 2: Eco-Friendly

R290 classified as a hydrocarbon (HC) refrigerant, which is a natural, non-toxic refrigerant. It also contains an ultra-low Global Warming Potential and zero Ozone Depletion Potential.

Due to its eco-friendly properties, its projected to have long-term approval and acceptance as a commercial refrigerant.

Reason #3: Federal & 50 State Compliance

50 State Compliance

The California Air Resources Board (CARB) was the first state to adopt the vacated rules from EPA SNAP 20, listing a phase out date of R404a on January 1, 2020. Since then, eleven additional states, Europe, and all provinces and territories of Canada have followed a similar path phasing out R404a. Over a dozen other states are a member of the U.S Climate Alliance and/or have proposed action in regards to HFC phase down.

Federal Compliance

The American Innovation and Manufacturing (AIM) Act was enacted by Congress on December 27, 2020. The AIM Act authorizes EPA to address hydrofluorocarbon (HFC) phase down.

On December 15, 2022, the EPA published a proposed rule that will require Stand-Alone Retail Food Refrigeration units to be manufactured with refrigerant having a GWP of 150 or less. The proposed compliance date for this rule is January 1, 2025. If finalized, this ruling will delist R134a, R404a, and R448a/R449a in most refrigeration applications at the Federal level.

The EPA has confirmed that R290 Refrigerant complies with all regulations and has categorized it as an acceptable and preferred alternative.

4. R290, So How Well Does It Really Work – Testing Data

Leer has gathered qualitative and quantitative data supporting R290 performance from numerous sources including industry publications, manufacturer publications, Leer R290 Ice Merchandiser Refrigeration Testing, 'real-world' side-by-side field testing in partnership with Emerson/Copeland (and a major packaged ice manufacturer), and Leer production line performance validation.

Leer R290 Ice Merchandiser Refrigeration Testing

Leer invested in state-of-the-art production performance testing and data acquisition equipment. The new equipment enabled improved production quality checks as well as performance data collection for analysis. Every model of Leer Ice Merchandisers and Ice Vending Machines underwent detailed testing to verify R290 performance.

Unit Life Expectancy

As noted in Leer Refrigerant History table, R290 has a higher thermal conductivity than R404a. Therefore, the amount of refrigerant needed to achieve the same amount of heat transfer (Cooling Effect), is much less with R290 than R404a. Using less refrigerant results in several benefits including lower compressor discharge pressure and temperatures. Lower pressures and temperatures should result in longer compressor life expectancy.

Leer's test data for the R404a-L100UASE and the R290-L100UASP was captured across ambient operating temperatures from +60^{0}F to +120^{0}F.

The summarized data in Figure 02 highlights R290 discharge temperatures approximately 15^{o}F lower and discharge pressures approximately 30% lower than R404a.

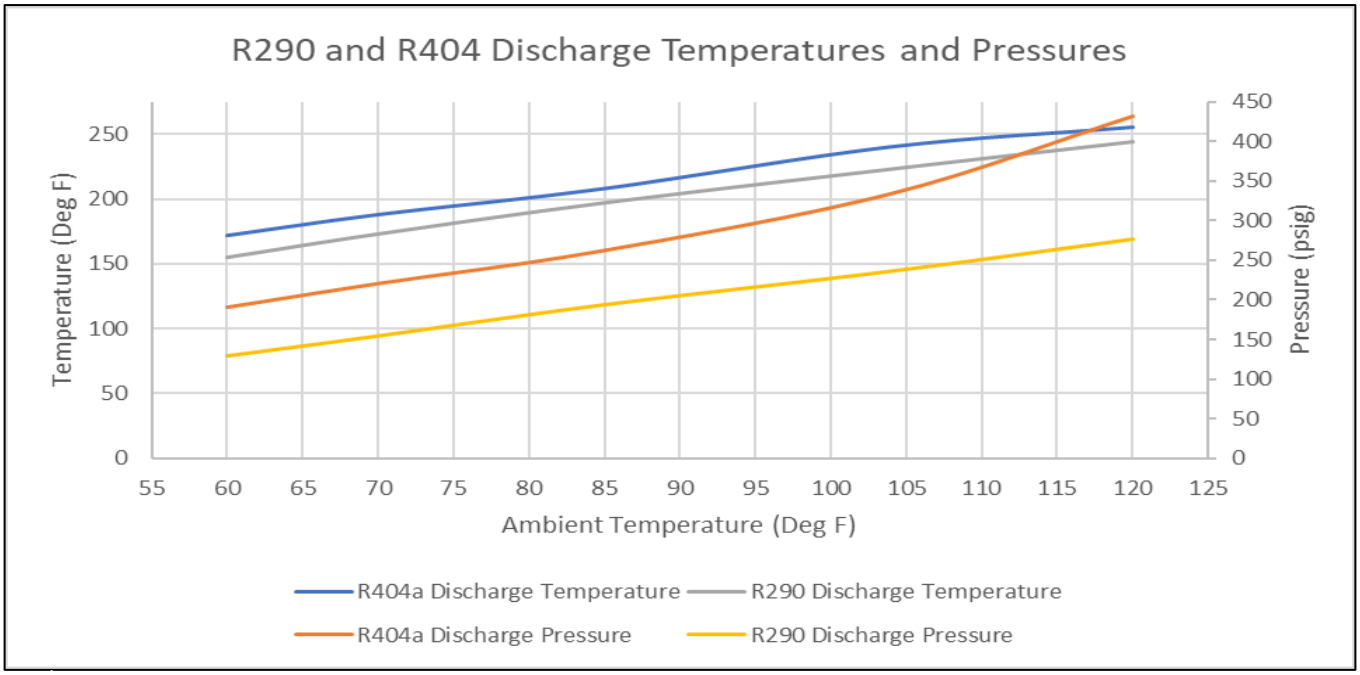


Figure 02 – Discharge Temperatures & Pressures

***Ambient Temperature** = The air temperature of any object or environment where equipment is stored.*

***Discharge Temperature** = A measure of the superheated refrigerant's vapor temperature (^{o}F). In this case, lower is better and should result in longer compressor life.*

***Discharge Pressure** = The pressure at which refrigerant is expelled from the compressor in the system (psig). In this case, lower is also better and should result in longer compressor life.*

Unit Efficiency

To evaluate the efficiency of R290, the Coefficient of Performance and overall power consumption of R404a-L100UASE and R290-L100UASP units were measured.

The Coefficient of Performance (COP) is a common calculation use to compare refrigeration systems. COP is the ration between the amount of energy (Heat) removed from the refrigerated space and the amount of energy it takes to move that heat (Power Usage). Higher is better.

$$COP = \frac{\Delta h}{W} = \frac{What\ you\ want}{What\ you\ pay\ for}$$

The COP values across the testing temperatures were calculated and normalized (Figure 03). The chart highlights the relative COP for R290 is consistently higher than that of R404a. Thus, showing the system with R290 is running more efficiently.

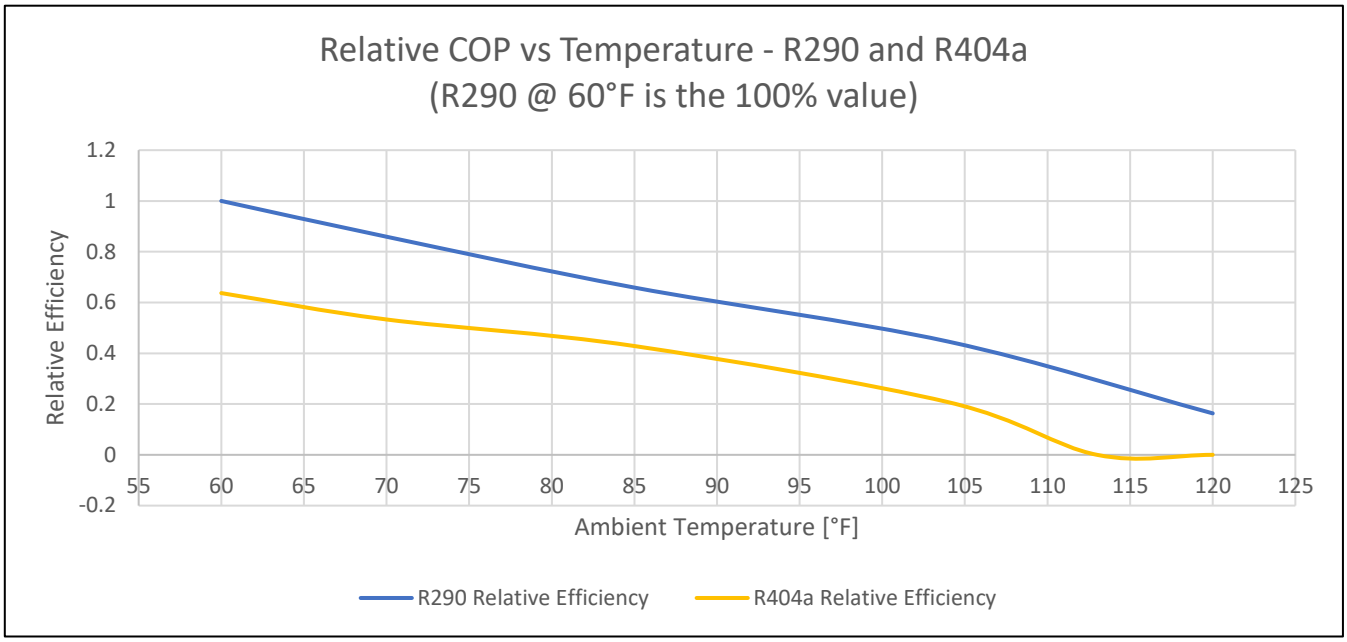


Figure 03 – Coefficient of Performance

System energy usage, while the compressor was running, was also measured and normalized (Figure 04). The chart highlights the system with R290 is consistently using less power across the full array of ambient operating temperatures that were tested. This study shows R290 to be potentially 10-15% more efficient.

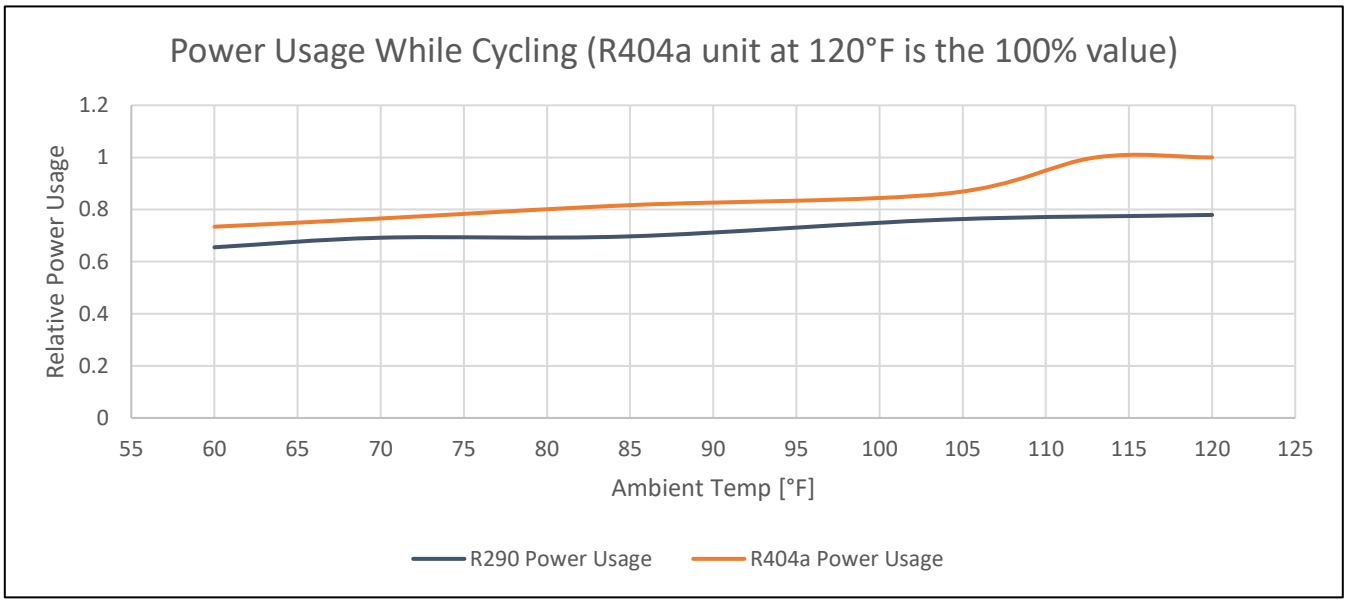


Figure 04 – Power Usage

Unit Operating Costs

Leer's new production test equipment was used to measure and review power consumption. Sixty units were randomly selected for this comparison: thirty R290-L100UASP units and thirty R404a-L100UASE units. With an ambient temperature, in the manufacturing facility of approximately 80°F, the normalized trendlines show the R290 units using less energy (Figure 05). Based on production test data, on average, the R290-L100UASP units consumed 6.3% less energy than R404a-L100UASE units.

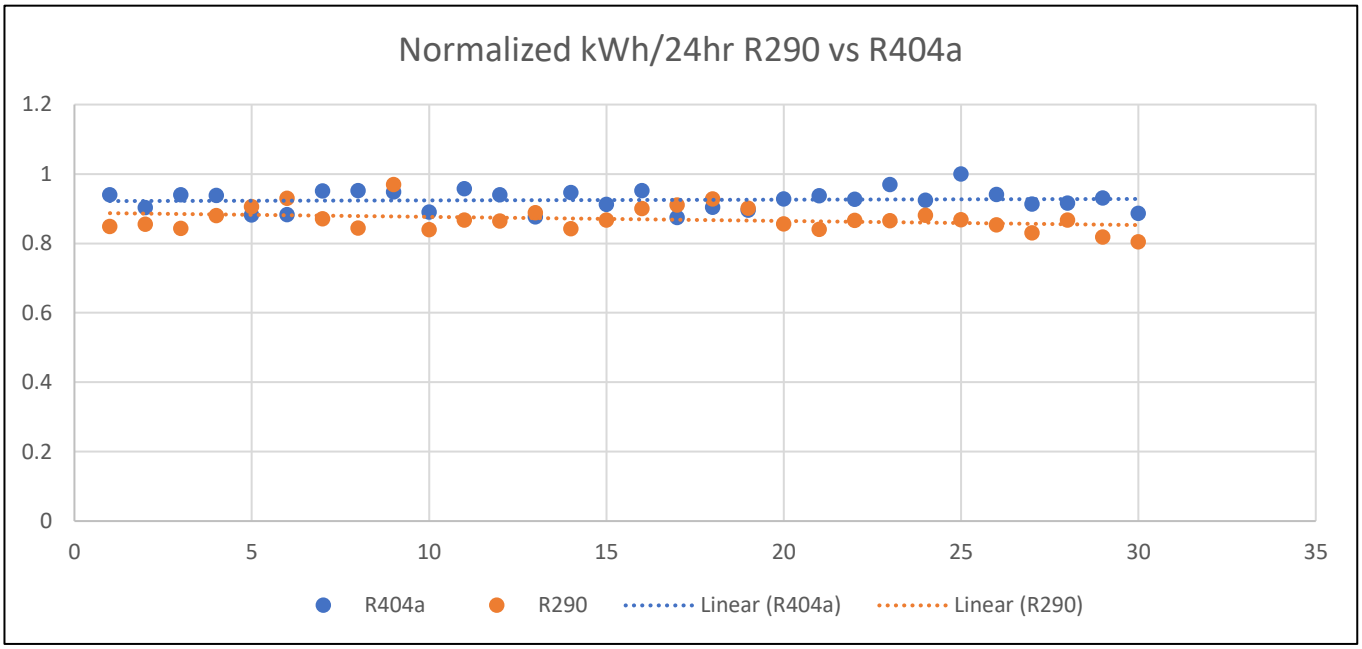


Figure 05 – kWh/24hr Usage

5. R290, So How Well Does it Really Work – Real World Data

For this study, we chose the Phoenix, AZ metro area, as it provided an opportunity to test low ambient temperatures in the winter months, moderate temperatures in the spring, as well as some of the hottest temperatures in the summer. The operation of the unit was charted to compare actual performance to the compressor's defined standard operating envelope.

- **Low Ambient Test**
  - December 15-21, 2020
  - Average Temp: Mid 50s °F
  - Low Temp: 43 °F
  - High Temp: 76 °F
- **Moderate Ambient Test**
  - April 14-21, 2021
  - Average Temp: Mid 70s °F
  - Low Temp: 59 °F
  - High Temp: 87 °F
- **High Ambient Test**
  - July 29-August 4, 2021
  - Average Temp: Upper 90s °F
  - Low Temp: 88 °F
  - High Temp: 111 °F

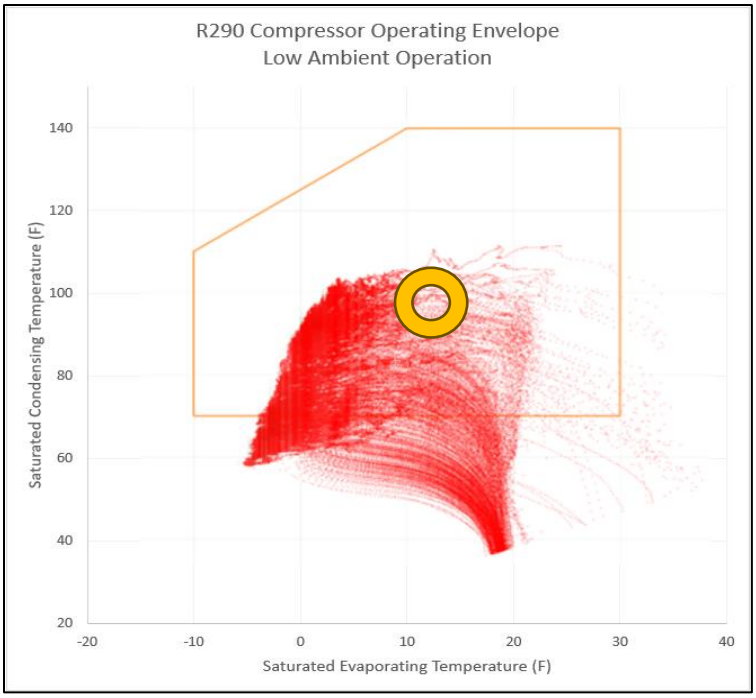
Chart Explanation:

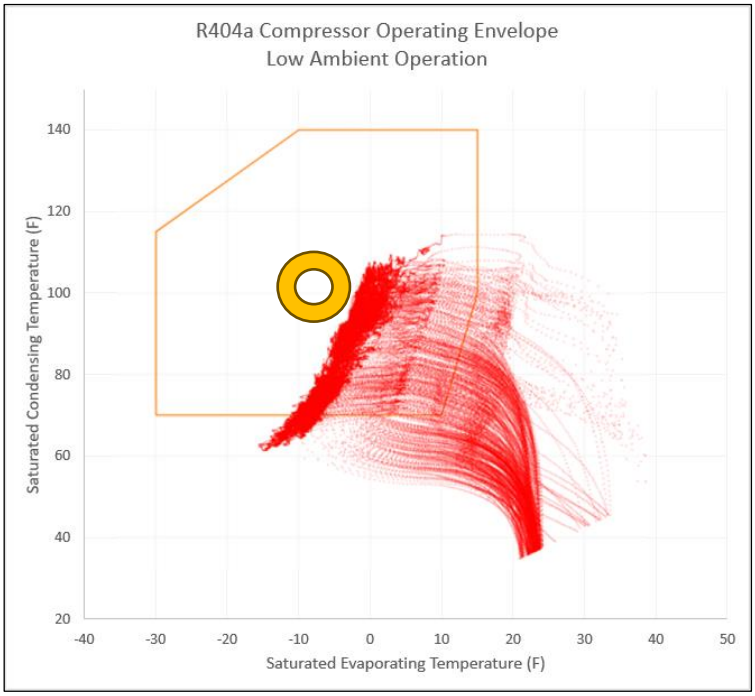
Operating Envelope *(orange box) = A specific and limited range of parameters in which set the safest and most efficient operating range of the refrigeration system. It is defined by plotting the recommended limits of the Saturated Evaporating and Saturated Condensing temperatures of the refrigeration system. Actual operation data is overlayed onto the chart (red data points) to assess refrigeration system performance and efficiency. The "bullseye" is provided as a visual identifier near the center of the operating envelope.*

Saturated Condensing Temperature *= The temperature at which refrigerant changes liquid state to vapor.*

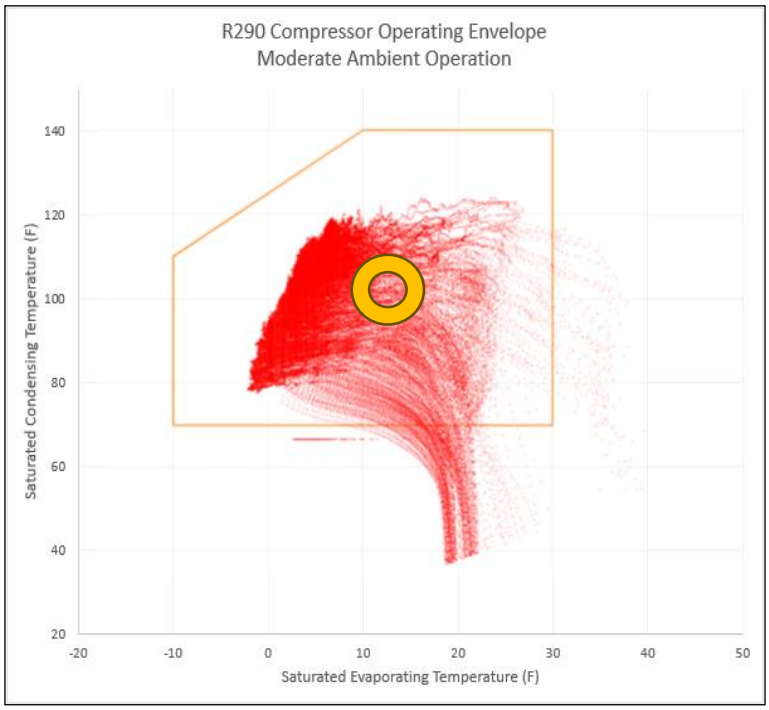
Saturated Evaporating Temperature *= The temperature at which refrigerant changes from liquid state to vapor.*

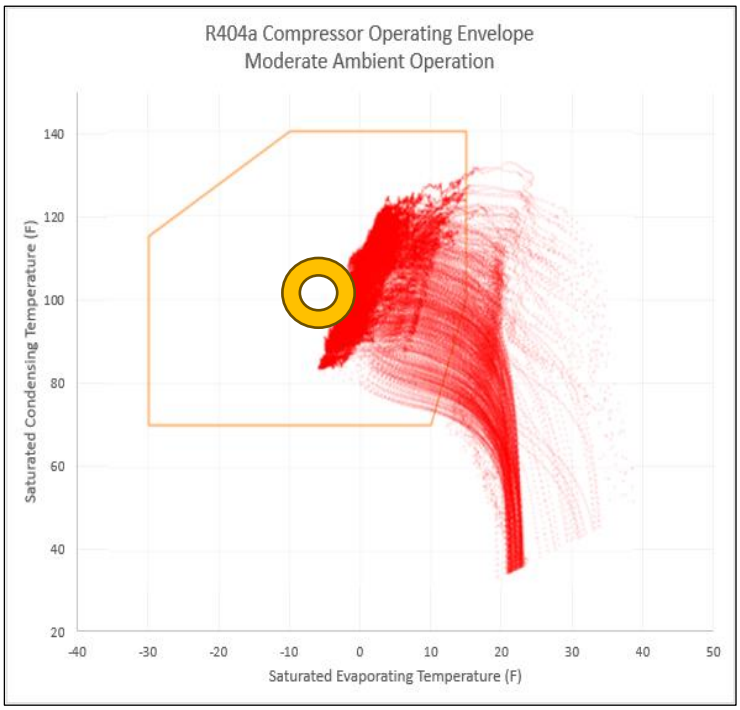
Low Ambient Test





Moderate Ambient Test

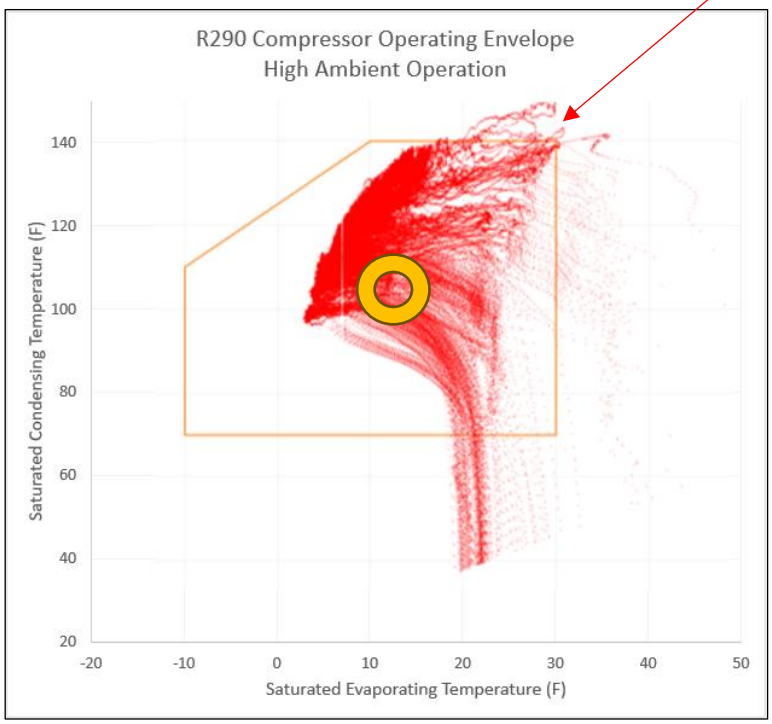


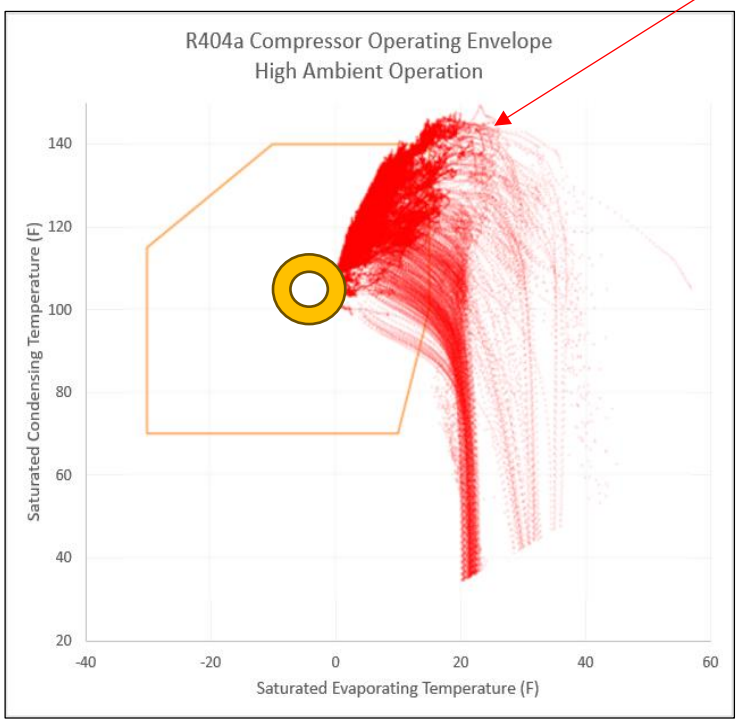


High Ambient Test

0 Thermal Overload Events

16 Thermal Overload Events
Risk of Compressor Overload





Operating Envelope Analysis

The R290 system operated effectively across tested low, moderate, and high ambient temperatures. In the high ambient temperatures, R290's higher thermal conductivity and lower operating pressure extended it's safe and reliable performance to ambient temperatures exceeding 100 ^{o}F.

6. Conclusion

The entirety of Leer, Inc.'s research and quantitative performance test data support industry claims that R290 refrigeration systems are more efficient, consume less energy, and should have longer life expectancy than like R404a systems. Similarly, Leer, Inc. and Emerson/Copeland field tests demonstrate that R290 refrigeration systems are more capable of running within compressor manufacturers suggested 'operating envelopes' across a wider ambient temperature range than R404a systems.

In conclusion, as an industry leader in temperature-controlled storage solutions, Leer is committed to staying at the forefront of ever-changing technologies and market demands. We are proud to lead the packaged ice industry in transitioning to a superior refrigerant, R290.

To all our customers, thank you for your continued support and dedication to Leer!