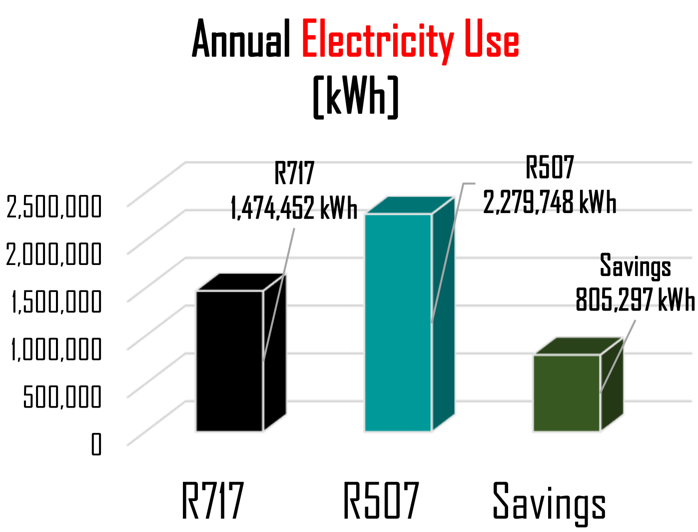
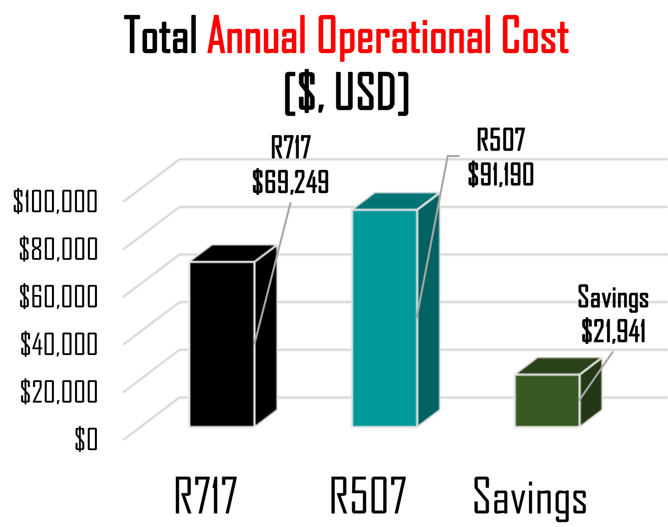
Energy Analysis for:

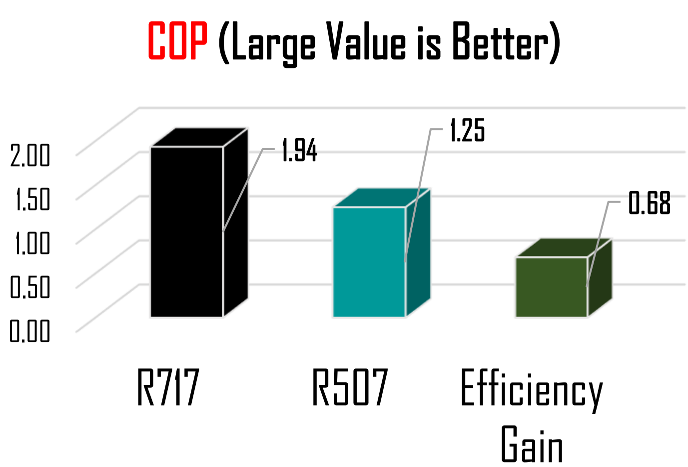
Conducted by:
PermaCold Engineering
Updated on:

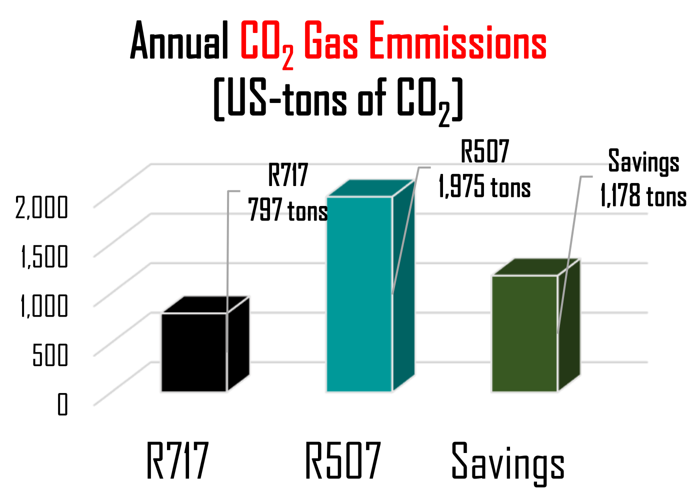
Purpose:
The purpose of this energy analysis is to provide a preliminary, budgetary, operational costs of a packaged freon system to those of a built up ammonia refrigeration system.

This analysis is conducted by assuming a saturated condensing temperature (SCT) of 85[F], and a saturated suction temperature (SST) of -20[F]. For the sake of simplicity, we also adopt an assumption of 1TR per 600sqft to approximate a typical load for an assumed 100K sqft freezer. An appropriate ammonia refrigeration system was designed and appropriate freon equipment selected. An efficiency rating was generated, and based on $0.04/kW*hr electric charge rate, $1.20 per 1000gal for supply water, and $1.44 per 1000gal for sewer water (rates which are approximated for industrial users), an approximation was made for annual savings due to an ammonia refrigeration system. These savings, combined with approximate refrigerant leakage from the freon system, were used to estimate the tonnage of CO_2 saved by using an ammonia system.









Values are subject to change. This is meant for preliminary, budgetary analysis only.

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Hypothetical Case Study of R717 & R507 in a Cold Storage

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Nomenclature:

Q	Heat	m_{dot}	Mass Flow Rate
E	Energy	T	Temperature
V	Volume	Δ	Change
m	Mass	GWP	Global Warming Potential
q	Specific heat	h	Enthalpy / Pump head
Θ	refrigeration demand	t	Time
C	Cost	V_{dot}	Volumetric Flow Rate
η	Pump/ motor Efficiency	ε	Emmission of CO_2

Key Units:

$MBH := 1000 \frac{Btu}{hr}$ $\quad 1\ kW = 3\ MBH$ $\quad 1\ hp = 3\ MBH$

$TR := 12\ MBH$ $\quad 1\ hp = 1\ kW$ $\quad 1\ ft^3 = 7\ gal$

$1\ yr = 8766\ hr$ $\quad mo := \frac{yr}{12}$ $\quad kBtu := 1000\ Btu$

Given Information:

- 100,000 sqft Cold Storage to be maintained @ 0[F]

$$A_{CS} := 100000\ ft^2$$

Goals:

- Figure an approximate design using readily available industrial refrigeration components and products
- Use the design to compare the budgetary annual utility costs of an ammonia (R717) refrigeration system to that of a Freon Refrigeration system

Assumptions:

- Design peak refrigeration load required is $1\ TR$ per $600\ ft^2$
- Load profile follows that of which is shown below
- The ammonia system will use a VFD on the compressor motor to match the load, the Freon system will switch on and off condensing units to match the load.
- The R717 system will use a proper control system which will maintain a $17\ °F$ approach to the web bulb temperature.
- The location of the refrigeration system has a design wet bulb temperature of $68\ °F$ and a design ambient dry bulb temperature of $95\ °F$
- The load profile follows as is shown in the analysis.
- The synthetic freon refrigerant selected is HFC R507 with a GWP of 3300.

$T_{WB} := 68\ °F$ $\Delta T_{Evap} := 10\ \Delta °F$ $T_{storage} := 0\ °F$ $GWP_{R507} := 3300$

$T_{SCT} := 85\ °F$ $T_{SST} := -20\ \Delta °F$ $GWP_{R717} := 0$

$T_{DB} := 95\ °F$

$\eta_{pump} := 50\%$ $\eta_{motor} := 95\%$

$$q_{peak\_load} := \frac{1\ TR}{600\ ft^2}$$

$$C_{electricity} := 0.04\ \frac{\$}{kW \cdot hr}$$

$$C_{water} := \frac{1.20}{1000}\ \frac{\$}{gal} = 0\ \frac{1}{gal}$$

$$C_{sewer} := \frac{1.44}{1000}\ \frac{\$}{gal} = 0\ \frac{1}{gal}$$

$$\varepsilon_{CO2\_US.equiv} := 1238.516\ \frac{lb}{MW \cdot hr}$$ from EPA GHG calculator

Analysis:

$$Q_{design} := q_{peak\_load} \cdot A_{CS}$$

$$Q_{design} = 167 \; TR$$

R717 System Design:

$\therefore$ Select $N_{evap} := 7 \; evap$

$$Q_{in\_evap.R717} := 25 \; TR$$

$$E_{evap.R717} := N_{evap} \cdot 12.12 \; \frac{hp}{evap}$$

$$E_{evap.R717} = 85 \; hp$$

NH3 Pump:

$$h_{v.neg20F.R717} := 604.789 \; \frac{Btu}{lb}$$

$$h_{l.neg20F.R717} := 21.253 \; \frac{Btu}{lb}$$

$$\Delta h_{vap\_neg20F\_R717} := h_{v.neg20F.R717} - h_{l.neg20F.R717}$$

$$m_{dot} := 4 \cdot \frac{Q_{design}}{\Delta h_{vap\_neg20F\_R717}}$$ assuming a 4:1 feed rate

$$m_{dot} = 228 \; \frac{lb}{min}$$

$$\rho_{l\_R717\_neg20F} := 42.23 \; \frac{lb}{ft^3}$$

$$V_{dot\_R717} := \frac{m_{dot}}{\rho_{l\_R717\_neg20F}}$$

$$V_{dot\_R717} = 40 \; gpm$$

Assuming a Head pressure of about 40psi gives a total equivelent head of approximately 140ft, and to be conservative I will assume a pump efficiency of 50% and a motor efficiency of 95%

$h_{pump.R717} := 140\ ft$ $\rho_{l\_R718} := 62.428\ \frac{lb}{ft^3}$

$$E_{pump.R717} := \frac{V_{dot\_R717} \cdot h_{pump.R717} \cdot \frac{\rho_{l\_R717\_neg20F}}{\rho_{l\_R718}}}{3960\ \frac{ft \cdot gpm}{hp} \cdot \eta_{pump} \cdot \eta_{motor}}$$

$E_{pump.R717} = 2\ hp$

Compressor Selection:

Using the GEA software RTSelect 6.3, the compressor conditions are calculated assuming thermosyphon cooling with a $10\ °F$ approach DX economizer, set to optimum intermediate temperature. The SCT is set at $85\ °F$ and the SST is set to $-20\ °F$.

$Q_{design} = 167\ TR$

Select: $N_{comp.R717} := 1$ GEA 340GLX

$Q_{in.comp.R717} := 172.4\ TR$

$E_{in.comp.R717} := 311.8\ hp$

$$E_{comp.R717} := \frac{E_{in.comp.R717}}{Q_{in.comp.R717}} \cdot Q_{design}$$

$E_{comp.R717} = 301\ hp$

Condenser Selection:

$N_{WB.corr.factor} := 1.72$

$Q_{design.cond} := N_{WB.corr.factor} \cdot \left(Q_{design} + E_{comp.R717} \cdot N_{comp.R717}\right)$

$Q_{design.cond} = 4759.189\ \mathbf{MBH}$

$Q_{cond.nom} := 4777\ \mathbf{MBH}$

$Q_{cond.nom} > Q_{design.cond} = 1$

Select Evapco ATC-325E-1g

$E_{cond.R717} := 1\ \mathbf{fan} \cdot 15\ \frac{\mathbf{hp}}{\mathbf{fan}} + 1\ \mathbf{pump} \cdot 3\ \frac{\mathbf{hp}}{\mathbf{pump}}$

$E_{cond.R717} = 18\ \mathbf{hp}$

Calculating flow rate of water in condenser, please note that this changes drastically based water quality and treatment system.

$Q_{reject.cond} := Q_{design} + E_{comp.R717} \cdot N_{comp.R717}$

$Q_{reject.cond} = 2767\ \mathbf{MBH}$

$\Delta h_{vap\_pos85F\_R718} := 1045.9\ \frac{\mathbf{Btu}}{\mathbf{lb}}$

$\rho_{l\_R718\_pos85F} := 62.164\ \frac{\mathbf{lb}}{\mathbf{ft}^3}$

$V_{dot\_evap.H20.cond.R717} := \frac{Q_{reject.cond}}{\Delta h_{vap\_pos85F\_R718} \cdot \rho_{l\_R718\_pos85F}}$

$V_{dot\_evap.H20.cond.R717} = 5\ \mathbf{gpm}$

$N_{max.cycles} := 3$

$V_{dot\_bleed.H20.cond.R717} := \frac{V_{dot\_evap.H20.cond.R717}}{N_{max.cycles} - 1}$

$V_{dot\_bleed.H20.cond.R717} = 3\ \mathbf{gpm}$

Chemical estimate based on very poor quality water and devided in two to reach a more typical value for chemical, please note that this changes drastically based on location and water quality. Please note that this number comes from an actual customer with a much larger system, then corrected based on the flow rates as shown.

$$C_{chem.reference} := 40000 \ \frac{\$}{yr} \qquad V_{dot.cond.chem.reference} := 50 \ gpm$$

$$C_{chem} := \frac{C_{chem.reference}}{V_{dot.cond.chem.reference}} \cdot \left(V_{dot\_bleed.H20.cond.R717} + V_{dot\_evap.H20.cond.R717}\right)$$

$$C_{chem} = 6367 \ \frac{\$}{yr}$$

R507 System Design:

Condensing Unit Selection:

Select Qty $N_{R507.cond.unit} := 8$

$$Q_{nom.cond.unit.R507} := 268.339\ MBH$$

$$Q_{nom.cond.unit.R507} = 22\ TR$$

$$E_{nom.cond.unit.R507} := 55.65\ kW$$

$$E_{cond.unit.R507} := Q_{design} \cdot \frac{E_{nom.cond.unit.R507}}{Q_{nom.cond.unit.R507}}$$

$$E_{cond.unit.R507} = 556\ hp$$

Evaporator Unit Selection:

Select Qty $N_{R507.evap.unit} := 2\ \frac{evap}{cond}$

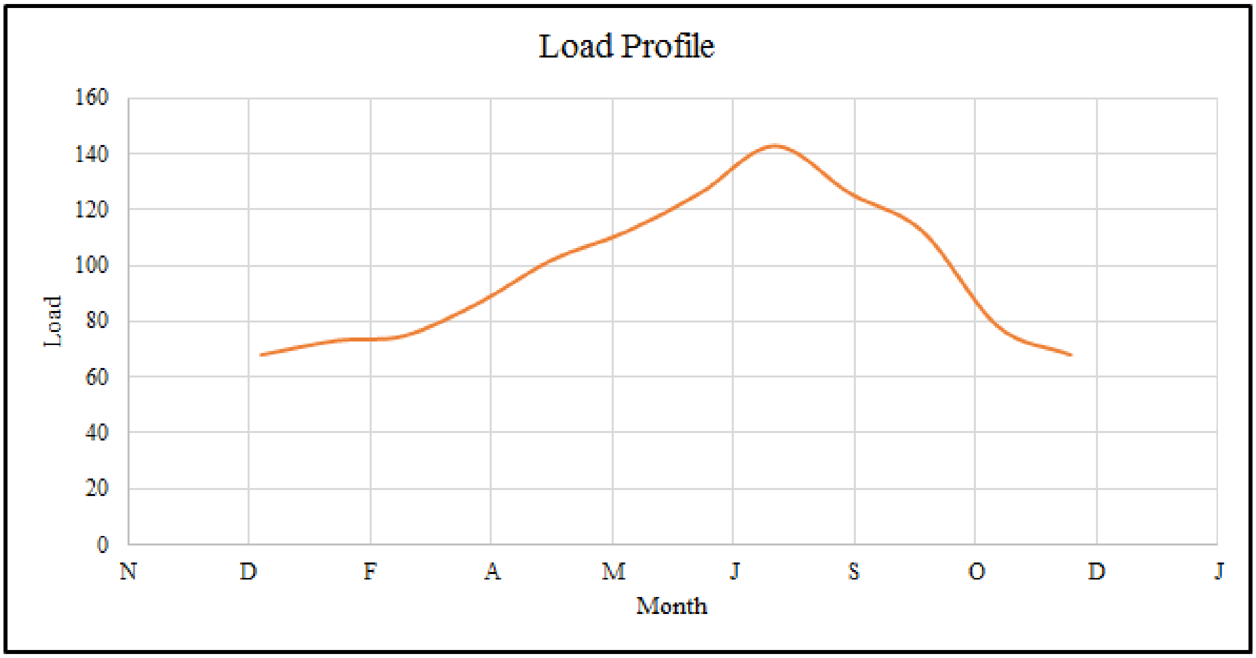
$$Q_{nom.evap.unit.R507} := 132.507\ MBH \cdot N_{R507.evap.unit}$$

$$Q_{nom.evap.unit.R507} = 22\ \frac{TR}{cond}$$

$$E_{evap.R507} := 1.5\ \frac{hp}{fan} \cdot 3\ \frac{fan}{evap} \cdot N_{R507.evap.unit} \cdot N_{R507.cond.unit}$$

$$E_{evap.R507} = 72\ hp$$

Load Profile:



The equation for the line that best fits this profile is:

$$Q(t) := \left(-0.343 \cdot t^3 + 4.7922 \cdot t^2 - 9.3009 \cdot t + 72.241\right) \frac{TR}{yr}$$

$$\Theta := \left(\int_1^{12} Q(t)\, \mathrm{d}t\right) mo$$

$$\Theta = 811072 \frac{TR \cdot hr}{yr}$$

$$t_{equiv} := \frac{\Theta}{Q_{design}} = 4866 \frac{hr}{yr}$$

Energy Analysis:

R717:

System Efficiency:

$$E_{tot\_system.R717} := E_{evap.R717} + E_{comp.R717} + E_{cond.R717} + E_{pump.R717}$$

$$E_{tot\_system.R717} = 406\ hp$$

$$Q_{design} = 167\ TR$$

$$COP_{R717} := \frac{Q_{design}}{E_{tot\_system.R717}}$$

$$\frac{E_{tot\_system.R717}}{Q_{design}} = 2\ \frac{hp}{TR}$$

$$COP_{R717} = 1.93$$

Utility Costs:

Electricity:

$$P_{use\_R717} := \frac{\Theta}{COP_{R717}}$$

$$P_{use\_R717} = 1.47\ \frac{GW \cdot hr}{yr}$$

$$C_{elec.use\_R717} := P_{use\_R717} \cdot C_{electricity}$$

$$C_{elec.use\_R717} = 58978\ \frac{\$}{yr}$$

Water/ Sewer:

$$V_{use\_evap} := t_{equiv} \cdot V_{dot\_evap.H20.cond.R717}$$

$$V_{use\_evap} = \left(1.549 \cdot 10^{6}\right) \frac{gal}{yr}$$

$$V_{use\_bleed} := t_{equiv} \cdot V_{dot\_bleed.H20.cond.R717}$$

$$V_{use\_bleed} = \left(774.618 \cdot 10^{3}\right) \frac{gal}{yr}$$

$$C_{water.use\_R717} := V_{use\_evap} \cdot C_{water} + V_{use\_bleed} \cdot \left(C_{water} + C_{sewer}\right) + C_{chem}$$

$$C_{water.use\_R717} = 10271 \frac{\$}{yr}$$

Approximate Costs of R717 system:

Electric Consumption Cost .... $58,978 ea yr

Water Use Cost .... $10,271 ea yr

R507:

System Efficiency:

$$E_{tot\_system.R507} := E_{evap.R507} + E_{cond.unit.R507}$$

$$E_{tot\_system.R507} = 628\ hp$$

$$Q_{design} = 167\ TR$$

$$COP_{R507} := \frac{Q_{design}}{E_{tot\_system.R507}} \qquad \frac{E_{tot\_system.R507}}{Q_{design}} = 4\ \frac{hp}{TR}$$

$$COP_{R507} = 1.25$$

Utility Costs:

Electricity:

$$P_{use\_R507} := \frac{\Theta}{COP_{R507}}$$

$$P_{use\_R507} = 2.28\ \frac{GW \cdot hr}{yr}$$

$$C_{elec.use\_R507} := P_{use\_R507} \cdot C_{electricity}$$

$$C_{elec.use\_R507} = 91190\ \frac{\$}{yr}$$

Approximate Costs of R507 system:

Electric Consumption Cost .... $91,190 ea yr

Savings:

$$C_{tot\_R717} := C_{water.use\_R717} + C_{elec.use\_R717}$$

$$C_{tot\_R717} = 69249 \ \frac{\$}{yr}$$

$$C_{tot\_R507} := C_{elec.use\_R507}$$

$$C_{tot\_R507} = 91190 \ \frac{\$}{yr}$$

$$\Delta C_{tot\_R717} := C_{tot\_R507} - C_{tot\_R717}$$

$$\Delta C_{tot\_R717} = 21941 \ \frac{\$}{yr}$$

$$\Delta P_{use\_R717} := P_{use\_R507} - P_{use\_R717}$$

$$\Delta P_{use\_R717} = 805297 \ \frac{kW \cdot hr}{yr}$$

Approximate Savings of an R717 system:

Consumption Savings .... $21,941 ea yr

Electricity Savings .... 805,297 kW*hr/yr

Approximate Carbon Footprint Savings:

$$\varepsilon_{CO2\_US.equiv} = 1 \frac{lb}{kW \cdot hr}$$

$$CO_{2\_electric.savings} := \varepsilon_{CO2\_US.equiv} \cdot \left(\Delta P_{use\_R717}\right)$$

$$CO_{2\_electric.savings} = 499 \frac{ton}{yr}$$

Approximate Refrigerant Charges:

R507 .... 3,000 lbs

R717 .... 2,200 lbs

$$W_{charge.R507} := 3000\ lb$$

$$W_{charge.R507\_leak} := W_{charge.R507} \cdot 15\% \frac{1}{yr}$$

$$W_{charge.R507\_leak} = 450 \frac{lb}{yr}$$

$$CO_{2\_refrigerant.savings} := GWP_{R507} \cdot W_{charge.R507\_leak}$$

$$CO_{2\_refrigerant.savings} = 742.5 \frac{ton}{yr}$$

$$CO_{2\_savings} := CO_{2\_electric.savings} + CO_{2\_refrigerant.savings}$$

$$CO_{2\_savings} = 1241 \frac{ton}{yr}$$

Potential Savings in Carbon Dioxide Emissions:

Savings of 1,241 US-tons of CO2 / yr