Technical Papers

30th Annual Meeting

International Institute of Ammonia Refrigeration

March 16–19, 2008

2008 Ammonia Refrigeration Conference & Exhibition
The Broadmoor Hotel
Colorado Springs, Colorado

ACKNOWLEDGEMENT

The success of the 30th Annual Meeting of the International Institute of Ammonia Refrigeration is due to the quality of the technical papers in this volume and the labor of its authors. IIAR expresses its deep appreciation to the authors, reviewers, and editors for their contributions to the ammonia refrigeration industry.

Board of Directors, International Institute of Ammonia Refrigeration

ABOUT THIS VOLUME

IIAR Technical Papers are subjected to rigorous technical peer review.

The views expressed in the papers in this volume are those of the authors, not the International Institute of Ammonia Refrigeration. They are not official positions of the Institute and are not officially endorsed.

International Institute of Ammonia Refrigeration
1110 North Glebe Road
Suite 250
Arlington, VA 22201

+ 1-703-312-4200 (voice)
+ 1-703-312-0065 (fax)
www.iiar.org

2008 Ammonia Refrigeration Conference & Exhibition
The Broadmoor Hotel
Colorado Springs, Colorado

Technical Paper #3

Ammonia as the Sustainable Refrigerant: An Ammonia-Halocarbon Comparison

Alex Gooseff
ALTA Refrigeration
Peachtree City, Georgia

Jamie Horton
ElectroMotion Refrigeration
Fenton, Missouri

Abstract

When contemplating the question "Should our facility utilize an ammonia or halocarbon refrigeration system?" an owner should perform a detailed financial analysis of the two systems. The first cost difference of the two systems may be easily returned via the savings in operating costs and the long term benefits can be significant. For the example Case Study, the original investment of $208,000 for an ammonia system resulted in a simple pay-back of about 1.7 years and a total savings of about $4.9 million over 20 years. In general the following rules of thumb apply for a distribution facility application: Less than 50,000 sq. ft. refrigerated space, halocarbon split circuit systems are normally accepted. A 50,000 to 200,000 sq. ft. refrigerated space, both halocarbon split circuit systems and central ammonia systems are common. Over 200,000 sq. ft. refrigerated space, central ammonia refrigeration systems are most common.

2008 IIAR Ammonia Refrigeration Conference & Exhibition, Colorado Springs, Colorado

Introduction

Owners of refrigerated distribution centers and cold storage facilities frequently ask refrigeration design engineers a common question: *Should our facility utilize an ammonia or halocarbon refrigeration system?*

This question has been asked more frequently since the U.S. Occupational Safety and Health Administration (OSHA) enacted 29 CFR 1910.119 entitled *Process Safety Management of Highly Hazardous Chemicals* (PSM) in 1992. Also, the U.S. Environmental Protection Agency (EPA) issued a rule under the Clean Air Act (CAA) encompassing provisions for accidental release prevention in 1992 which required facilities to develop and implement a Risk Management Plan (RMP). Ammonia systems containing over 10,000 lbs (4536 kg) of refrigerant are required to comply with OSHA PSM and EPA RMP programs. The latest government compliance is the chemical facility anti-terrorism security (CFATS) regulation required by the Department of Homeland Security (DHS) in 2007. Companies with 10,000 lbs (4536 kg) or more of ammonia on-site in a refrigeration system were required to submit information to DHS by January 22, 2008.

Another issue which brings this question to light is the current and proposed phase out of certain CFC and HCFC refrigerants like R-22. These phase-outs have raised concern over the long term availability of refrigerants that have high Ozone Depleting Potential (ODP) and Global Warming Potential (GWP).

Most industrial refrigeration design engineers will agree that for refrigerated distribution centers, the smaller size facility under 50,000 sq. ft. (4645 m^2) are usually split circuit halocarbon systems (one or two air units traditionally connected with a close coupled air-cooled condensing compressor unit on the roof directly above). Also, refrigerated spaces over 200,000 sq. ft. (18580 m^2) are traditionally ammonia, due to ownership costs. Those facilities in between 50,000 and 200,000 sq. ft. (4645 and 18580 m^2) will require considerations and an understanding of an owner's priorities and preferences.

In order to properly answer the question of which system type is the best choice, an owner should make a comprehensive comparison of the alternatives based on a life cycle cost analysis. Additional items that should enter into this evaluation are:

- Purchase or lease facility
- New or existing facility
- Future expansion considerations
- Refrigeration system costs
  - Build cost considerations
  - Compressor room requirements
  - Power availability and cost
  - Water and sewage availability and cost
- Equipment cost considerations
  - Initial cost
  - Operating cost
  - Preventative maintenance and service costs
  - Safety equipment provisions
- Regulation compliance costs
  - PSM/RMP documentation and personnel training
  - Personnel safety equipment and training requirements
  - Liability and property damage insurance
- Facility location and the surrounding areas
  - Off-site consequential liability

Case Study Selection

The IIAR Education Committee was tasked with developing a sample Case Study for a refrigerated distribution facility. This Case Study provides an example comparison of two of the most common ammonia and halocarbon refrigeration systems for this type of facility application.

The Committee selected a 150,000 sq. ft. (13935 m^2) facility as the model to be developed for the Case Study. The system types selected for this analysis were a central ammonia system compared to multiple split halocarbon R-507 system. The distribution center was assumed to be new construction and the owner was to be the occupant of the space.

The items that are included in the ownership analysis are:

- Initial construction cost
- Energy and operating costs
- Maintenance cost
- Major component replacement costs
- Simple pay-back
- 20-year life cycle cost

The following information and analysis is the basis for the Case Study published by the IIAR Education Committee.

Refrigeration System Selection

The refrigerated cold storage loads are calculated based upon a facility located in Atlanta, GA and consist of the parameters in Table 1. Both the ammonia and split halocarbon systems are sized to handle the determined loads.

Ammonia System Model

The ammonia system selected for the Case Study is a single stage economized, two temperature central-type system with liquid over-feed, thermosyphon oil cooling and evaporative condensing, as shown in Figures 1 and 2, that includes the following:

Floor Plan and Equipment Layout

- –10°F (–23°C) Freezer: Served by four air units 35 TR (123 kW) with three 2 HP fans and long throw air adapter each. Total capacity of 140 TR (492 kW) (482 sq. ft./TR, 12.7 m^2/kW)
- Coolers: Each cooler is served by two air units ranging from 25.5 TR (90 kW) to 19 TR (67 kW) each with two 2 HP fans and long throw air adapters. Total capacity of 175 TR (616 kW) total coolers (385 sq. ft./TR, 10.2 m^2/kW)
- Cold Dock: 15,000 sq. ft. (1394 m^2) with twelve truck doors served by three 6-fan air units at 25 TR (88 kW) each. Total capacity of 75 TR (264 kW) (200 sq. ft./TR, 5.3 m^2/kW)

Block Flow Diagram

- (2) –20°F (–29°C) screw compressors 200 HP with economizer ports and thermosyphon oil cooling
- +20°F (–6.7°C) screw compressor 263 HP with dual suction valves, economizer port when operating on low temperature and thermosyphon oil cooling
- Evaporative condenser with three 10 HP fans and one 7.5 HP pump sized for 80°F (27°C) ambient wet bulb temperature
- Thermosyphon/pilot receiver, 300 psi (20.7 bar) design
- +20°F (–6.7°C) liquid recirculator with two 3 HP refrigerant pumps (100% standby), 250 psi (17.2 bar) design
- –20°F (–29°C) liquid recirculator with two 3 HP refrigerant pumps (100% standby), 250 psi (17.2 bar) design
- Foul gas purger
- Let down pressure regulator – computer controlled
- Hot gas regulator valve with condensate float drainer
- Freezer: four air units with individual valve groups
- Coolers: eight air units with individual valve groups
- Glycol underfloor heating system with hot gas, a 3 HP pump servicing the freezer and a 28°F (–2.2°C) cooler (84,375 sq. ft. (7839 m^2) total)

- Computer control system
- Compressor room exhaust fans
- Ammonia detectors in each cooler (4), freezer (2), dock (1), compressor room (2), for a total of (9)

Halocarbon System Model

The most common types of halocarbon systems considered for the Case Study were:

- Air Cooled Condensing Unit Split Circuit System: Compressors are factory packaged with condensers that are usually close-coupled with one or two air units. Condensing units are normally located on the roof directly above the air unit. Condensing units can also be located on the ground level.
- Rack Systems: Several compressors are connected together on a common suction accumulator, and several of these compressor racks are connected together to serve various suction levels. Rack systems are normally skidded and pre-packaged by an equipment manufacturer or packaging fabricators. Large air-cooled condensers are most commonly applied to a rack system, but evaporative condensers can also be utilized to reduce operating costs. Rack systems are most commonly applied in grocery stores and are not common in distribution centers due to the added equipment and piping costs when compared to air-cooled split circuit systems. In addition, system refrigerant leaks and semi-hermetic compressor burn-outs which can contaminate a common oil return system on a rack arrangement can cause problems with many air units, and can affect a large refrigerated area compared to multiple halocarbon split circuit systems.
- Central Industrial Type Halocarbon System: Similar to the central ammonia system previously described but generally with a 10% to 15% higher initial cost due to requirements of larger vessels, pipes, additional insulation for cold piping and vessels, and the substantially higher cost of refrigerant charge. The operating power for a halocarbon system is between 2% to 20% higher than an ammonia system depending on the type of halocarbon refrigerant utilized and the operating temperature.

A system consisting of multiple roof mounted air-cooled condensing unit split systems utilizing R-507 refrigerant, as shown in Figure 3, was selected for this Case Study. This system type was selected because it is one of the most prevalent choices for this type of application, driven mainly by the low first cost.

Floor Plan and Equipment Layout

- –10°F (–23°C) Freezer: Served by eight 17.5 TR (62 kW) air cooled condensing units with two 30 HP compressors each coupled with two air units with three 1 HP fans. A total of sixteen air units. Electric defrost is provided for all of the air units. Total capacity of 140 TR (492 kW) (482 sq. ft./TR, 12.7 m^2/kW).
- Coolers: Each cooler has two air cooled condensing units ranging from 25.5 TR (90 kW) to 19 TR (67 kW) each for a total of eight total condensing units. Each condensing unit is coupled with two air units with three 1 HP fans. A total of sixteen air units. Electric defrost is provided for all of the cooler spaces at 38°F (3.3°C) and below. Total capacity of 175 TR (616 kW) (385 sq. ft./TR, 10.2 m^2/kW).
- Cold Dock: 15,000 sq. ft. (1394 m^2) with twelve truck doors served by two 37.5 TR (132 kW) air cooled condensing units two 35 HP compressors per unit coupled with two air units each with four 1 HP fans. A total of four evaporators. Total capacity of 75 TR (264 kW) (200 sq. ft/TR, 5.3 m^2/kW).

It should be noted that these system types are not only different in the type of refrigerant utilized but are different in the quality and complexity of the equipment and controls.

Construction Costs

Estimated construction costs are calculated for both systems. The costs are based on non-union labor rates for Atlanta, GA, and year 2007 material and equipment costs, including a 6% sales tax.

There are several differences to be noted between the ammonia and halocarbon system types due to codes and industry standards. Some of these differences, such as the requirement of an equipment room, underfloor heating system, and refrigerant detectors, are shown in Table 2.

Ammonia System Construction Costs

Table 3 gives the cost of construction of the ammonia system. Individual construction costs such as the control system and electrical installation are estimated. The total estimated construction cost is $2,100,000, or $14 per square foot. The ammonia system construction costs include the following scope items:

- Polystyrene piping insulation with metal jacketing outdoors and PVC indoors
- Condenser mounted on roof structure on top of the engine room
- Condenser make-up water and drain piping
- Computer controlled system including control wiring
- Individual Wye-Delta combination starters for each compressor
- Ammonia detectors (9)
- Construction of an equipment room
- Equipment room ventilation system with 100% standby
- Motor control center (MCC) with starters for fans and pump
- Glycol underfloor heating system for the freezer and 28°F (–2.2°C) cooler (84,375 sq. ft. (7839 m^2) total)
- Hot gas defrost for all freezer and cooler air units
- Painting, piping labels and valve tags
- Refrigerant, oil charge and glycol charge

- Freight, crane, rigging and rentals
- Project management and engineering
- Refrigeration equipment, carbon steel piping materials and valves
- Process Safety Management program development
- Startup and training.

Halocarbon (R-507) Construction Costs

Table 4 gives the cost of construction of the halocarbon system. Comparing Tables 3 and 4 shows the difference in cost of construction for the two systems. The total estimated construction cost is $1,892,000, or $12.61 per square foot. The split halocarbon system construction costs include the following scope items:

- Rubber material piping insulation with no jacketing
- Condensing units mounted on roof structure
- Computer controlled system including control wiring
- Electric underfloor heating system for freezer and 28°F (–2.2°C) cooler (84,375 sq. ft. (7839 m^2) total)
- Electric defrost for the freezer and cooler units.
- Refrigerant R-507 and oil charge
- Freight, crane, rigging and rentals
- Project management and engineering
- Refrigeration equipment, copper piping materials and valves
- Startup and training.

Operating Costs

For purposes of the Case Study the following operating costs for each of the two system alternatives are calculated:

- Electrical Utility
- Water consumption and treatment costs

- Preventative maintenance
- Refrigerant loss

Electric Utility Cost

There are multiple methods to estimate the electrical energy consumption of a refrigeration system from very basic to more complex. One of the very simple comparison methods is to take the sum of the full load kW for the system and calculate an estimated annual electrical operation cost as follows:

- Full Load kW x Utilization Factor x Annual Hours x Cost/kWh
  = Annual Operating Cost

The total of the full load kW consumption for all components of each system is:

- Ammonia System Full Load kW = 636 kW (refer to Appendix A for details)
- Split Halocarbon System Full Load kW = 945 kW (refer to Appendix B for details)

Taking this full load kW and estimating a *utilization factor* of 75% annually and an electrical utility rate of $0.08/kWh results in a simple operating cost estimate as follows:

- Ammonia System = 636 kW x 0.75 utilization factor x 8750 hours x $0.08/kWh
  = $ 333,900
- Halocarbon System = 945 kW x 0.75 utilization factor x 8750 hours x $0.08/kWh
  = $ 496,125

This simplistic approach is a valid method to use as a quick check of the viability of the comparison, but should not be used as the final analysis of the alternatives.

A more complex analysis is performed for this Case Study. Energy consumption for the two refrigeration system alternatives is calculated based on weather BIN data for Atlanta, GA. BIN data provides the number of hours that the ambient dry bulb temperature occurred within a five degree range. This data is used to establish the load placed on the refrigeration system as well as the kW/TR consumption of the equipment.

Load Profiles

The load profiles shown in Figures 4, 5 and 6 are used for each space, based on 25% ambient related loads for the cooler and freezer, and 70% ambient related load for the loading dock. The maximum load is calculated for the weather BIN of 95 to 99°F (35 to 37°C).

Equipment Performance Data

Full load and part load kW/TR efficiencies are estimated for each system using equipment performance data for an air-cooled halocarbon system and an evaporative cooled ammonia system.

Evaporative Cooled Ammonia System Performance

Tables 5 and 6 list the performance data for the ammonia system at the maximum operating condition of 95°F (35°C) condensing temperature (80°F (27°C) wet bulb).

The kW/TR performance is then calculated for each weather BIN using:

- Constant kW/TR performance for condenser and evaporator at all conditions
- Screw compressor energy consumption based upon 1 psi (0.07 bar) suction and discharge line pressure losses, suction and discharge valve losses, 100% slide valve position for ambient temperature greater than 89°F (32°C) and 80% slide valve position for all other ambient conditions.

Table 7 shows performance data for the ammonia system at various BINs. Please note that for the Case Study the energy consumption of the equipment room continuous exhaust fan or the refrigerant pumps are not included.

Air-Cooled Halocarbon System Performance

Tables 8 and 9 list the performance data for the halocarbon system at the maximum operating condition of 105°F (41°C) ambient temperature. Actual conditions on the roof in the summer may exceed the 105°F (41°C) condition but these higher conditions were not used in this analysis. Table 10 shows performance data for the halocarbon system at various BINs.

The minimum condensing pressure for the air-cooled halocarbon system is based upon the required minimum operating pressure for a direct expansion R-507 system of 180 psig (12.4 barg), which is associated with 80°F (27°C) condensing temperature. This minimum is established for proper thermal expansion valve operation and is controlled by the condensing unit head pressure controls.

Constant kW/TR performance for the evaporator and air-cooled condenser fans is used at all load conditions to match the ammonia system calculation.

System Energy Consumption

Utilizing the equipment performance data and weather BIN data, the total annual system energy consumption is calculated as shown in Tables 11 and 12. The underfloor heat consumption is based upon an installation on 4 ft centers and is assumed to operate 35% of the time. The total estimated annual energy consumption for the ammonia refrigeration system is $296,063 which includes both the refrigeration and underfloor heat energy consumption. The underfloor electric heat consumption is based upon an installation on 8 ft centers and is assumed to operate 65% of the time. The spaces included are the –10°F (–23°C) freezer and the 28 to 34°F (–2.2 to 1.1°C) cooler.

The defrost is based upon all units in the –10°F (–23°C) freezer and the 28 to 34°F (–2.2 to 1.1°C) cooler requiring defrost twice a day. The units in the 34 to 36°F (1.2 to 2.2°C) cooler will require a defrost, but they have not been included in this analysis.

The total estimated annual energy consumption for the split halocarbon system is $443,203 which includes the refrigeration, electric defrost and underfloor heat energy consumption.

Water Consumption, Sewer and Treatment Costs

The ammonia system model utilizes an evaporative condenser. In order to properly evaluate the operating cost of the system, the cost of water consumption and treatment is required.

Water Consumption: The estimated evaporation rate for the condenser is 12 gpm (2.7 m^3/h). Using a bleed off rate of 3 gpm (0.7 m^3/h) will maintain a 4:1 concentration level for a total maximum water consumption of 15 gpm (3.4 m^3/h). Using this rate, operating 50% of the time calculates to be 324,000 gallons (1226 m^3) per month. The cost for water in Atlanta, GA is $2.80/1000 gallons ($2.80/3.79 m^3) plus a $20.00/month meter fee. The total cost for the water calculates to be $11,126 annually.

Sewer Costs: The 3 gpm (0.7 m^3/h) bleed-off rate and the 50% operating time results in a monthly water flow to the sewer of 64,800 gallons/month (245 m^3/month). Using an estimated sewer charge of $2.75/1000 gallons ($2.75/3.79 m^3), the monthly sewer charge would be around $178.00/month or $2,136 annually.

Water Treatment: The estimated cost for water treatment is $900 per month for a total of $10,800 annually.

The total cost associated with water usage of the evaporative condenser is $11,126 + $ 2,136 + $ 10,800 = $ 24,062.

Preventative Maintenance

All repairs of failed components have been excluded for this analysis. It should be noted that there are a significantly higher number of components that can fail for the split halocarbon system model.

There are multiple levels of preventative maintenance that an owner can implement. For this system comparison the following has been included.

Ammonia System: The recommended preventative maintenance for the ammonia system includes:

Screw compressors:

- Vibration and oil analysis (every 6 months)
- Change oil filters, clean suction, liquid and oil screens, check and calibrate controls (including safeties) and check electrical connections (every 12 months)
- Grease motors (every 3 months)

Evaporative condenser:

- Clean water basin and water distribution nozzles (every 12 months)
- Grease motors and check belt tension (every 3 months)

Ammonia detection:

- Testing and calibration (every 6 months)

Vessels:

- Testing of high level cut-outs (every 12 months)

Estimated annual maintenance cost = $ 9,000

Split Halocarbon System: The recommended preventative maintenance for the model halocarbon system includes:

Air-cooled condensing units:

- Cleaning of air-cooled condenser coils (every 6 months)
- Check refrigerant operating pressures, check and calibrate controls and check electrical connections (every 12 months)

Estimated annual maintenance cost = $ 8,700

All maintenance labor was estimated at a rate of $80/hour.

Refrigerant Loss

Both the ammonia and halocarbon system will experience fugitive losses of refrigerant on an annual basis. There is a separate debate on which of the selected system types would have a higher or lower refrigerant loss rate. Many feel that the ammonia system will experience a much lower leak rate as the system is constructed of welded carbon steel with a fewer number of evaporator connections. For this evaluation, it is assumed that the percentage of losses is the same.

Estimated Ammonia System Charge = 14000 lbs (6350 kg)
Annual leak rate = 5% = 700 lbs (318 kg)
Annual cost = 700 lbs. x $1.00/lb. = $700

Estimated Split Halocarbon System Charge = 4400 lbs (1996 kg)
Annual leak rate = 5% = 220 lbs (100 kg)
Annual cost = 220 lbs. x $8.00/lb. = $ 1760

Refrigerant costs are based on a purchase of 100 lbs (45 kg).

Financial Analysis

Simple Pay-Back

The simple pay-back is calculated by dividing the difference in initial construction costs by the operational cost difference as follows:

Initial cost difference = $ 2,100,000 – $ 1,892,000 = $ 208,000

Operational Cost Difference = $ 453,663 – $ 329,825 = $ 123,838

Simple Pay-Back = $ 208,000 first cost difference / $ 123,838 annual savings = 1.68 years

20 Year Life Cycle

A more detailed financial analysis method is to perform a life cycle cost analysis. For this Case Study, a term of 20 years is selected. This analysis is shown in Tables 14 and 15. All costs are escalated at a rate of 5% per year from the year 2007 baseline. Component replacement costs are included based on traditional equipment service life. Not included in the analysis is any cost associated with financing the initial capital investment.

The replacement costs include replacement of the screw compressor with a remanufactured compressor during years 11, 12 and 13 and the replacement of the evaporative condenser in year 18. No other component replacement costs are included, because all of the other major system components are expected to have a service life of 20 years or greater. Minor component replacement costs are not included in this analysis.

The Process Safety Management (PSM) costs include a mechanical integrity audit and replacement of the relief valves every five years. Yearly PSM administrative costs were not included because there are annual administrative costs associated with halocarbon refrigerants as well.

Component replacement costs include replacement of two of the compressors every other year starting at year 6 and ending at 14. During years 16 and 17 the complete replacement of 12 of the 18 air-cooled condensing units is included (6 per year). No other component replacement costs are included because all of the other major system components are expected to have a service life of 20 years or greater. Minor component replacement costs are not included in this analysis.

20 Year Life Cycle Comparison

- Initial Construction Cost Difference:
  $ 2,100,000 (Ammonia) – $ 1,892,000 (Halocarbon) = **$ 208,000**
- Total 20 Year Operational Cost Difference:
  $ 11,282,147 (Ammonia) – $ 16,161,757 (Halocarbon) = – **$ 4,880,610**

Investing an extra $208,000 in construction costs will result in a $4,880,610 savings over 20 years.

Sustainable Benefits

Not only does ammonia hold the life cycle cost advantage, but there are other sustainable benefits to utilizing ammonia as the refrigerant of choice.

- Naturally occurring *green* substance
- No potential for ozone depletion (Ozone Depletion Potential = 0)
- No potential for direct global warming impact (Global Warming Potential =0)
- Requires less primary energy to produce a given refrigeration effect than other common refrigerants (highest coefficient of performance)
- Low replacement cost
- Self-alarming odor helps to detect leaks and minimize emissions.

Conclusion

When contemplating the question *Should our facility utilize an ammonia or halocarbon refrigeration system?* an owner should perform a detailed financial analysis of the two systems. The first cost difference of the two systems may be easily returned via the savings in operating costs and the long term benefits can be significant.

For the example, this Case Study original investment of $208,000 for an ammonia system resulted in a simple pay-back of about 1.7 years, and a total savings of about $4.9 million over 20 years.

In general, the following rules of thumb apply for a distribution facility application:

- Less than 50,000 sq. ft. (4645 m^2) refrigerated space: halocarbon split circuit systems are normally accepted.
- 50,000 to 200,000 sq. ft. (4645 to 18580 m^2) refrigerated space: both halocarbon split circuit systems and a central ammonia system are common. The owner's priorities must be considered. A life cycle cost analysis should be performed, such as the one outlined in this paper.
- Over 200,000 sq. ft. (18580 m^2) refrigerated space: central ammonia refrigeration systems are most common.

NOTE: The dollar amounts listed in this paper are for a specific model, location and time period. Construction and operating costs will vary, as prices are constantly changing and should therefore be adjusted to represent other models and circumstances.

Figure 1. Central Ammonia System, 150,000 sq. ft. Refrigerated Area, Floor Plan

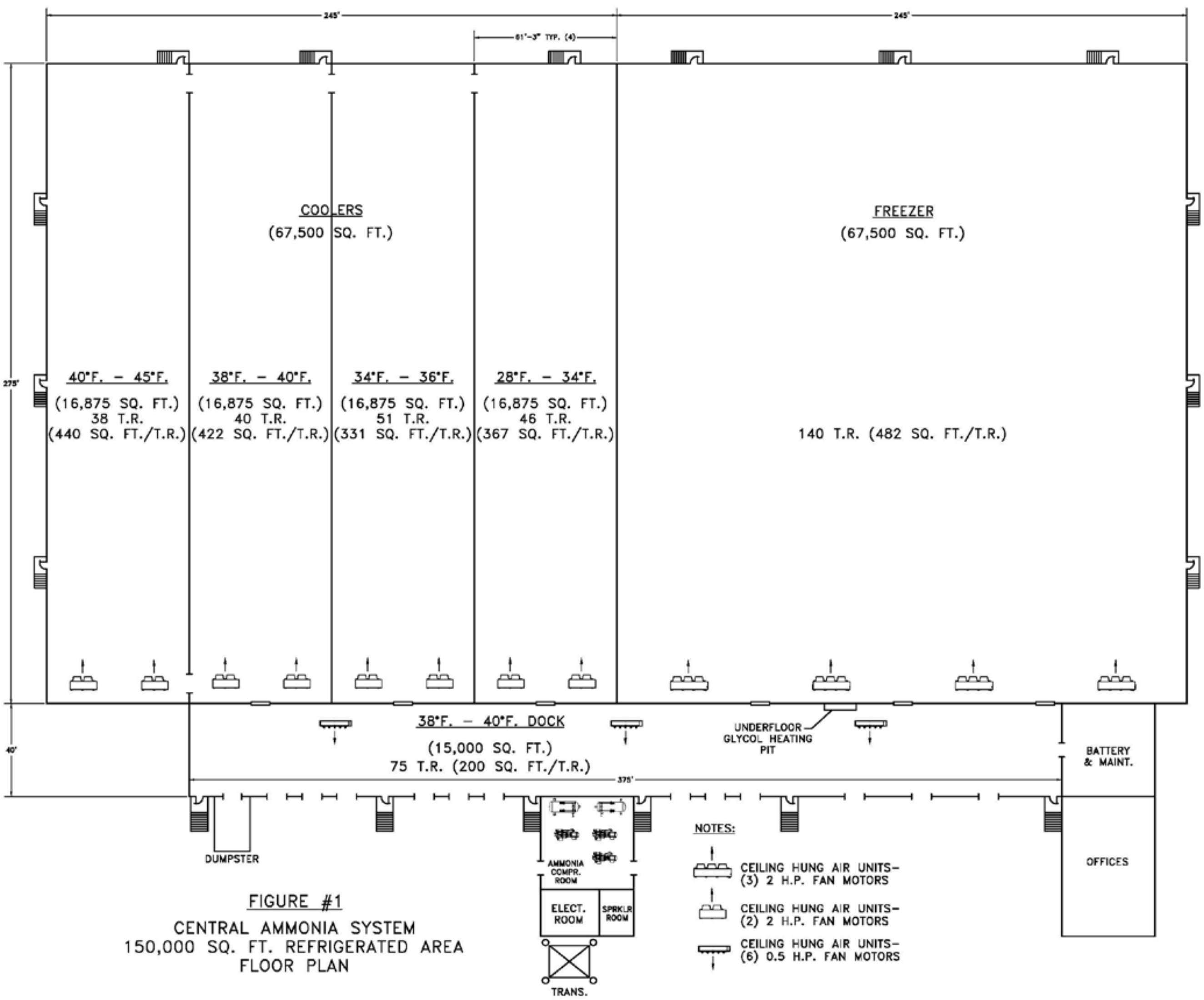


Figure 2. Central Ammonia System, 150,000 sq. ft. Refrigerated Area, Block Flow Diagram

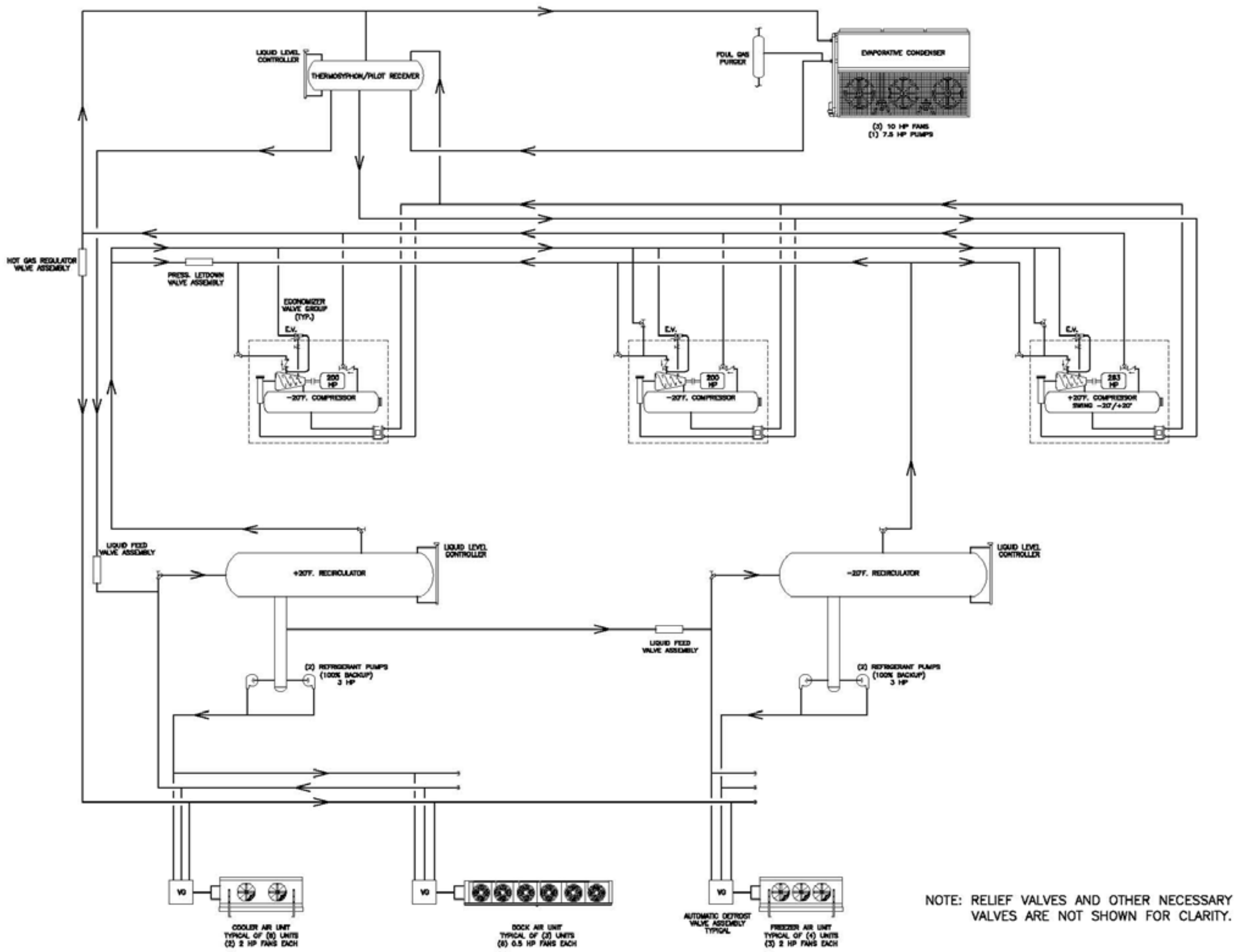
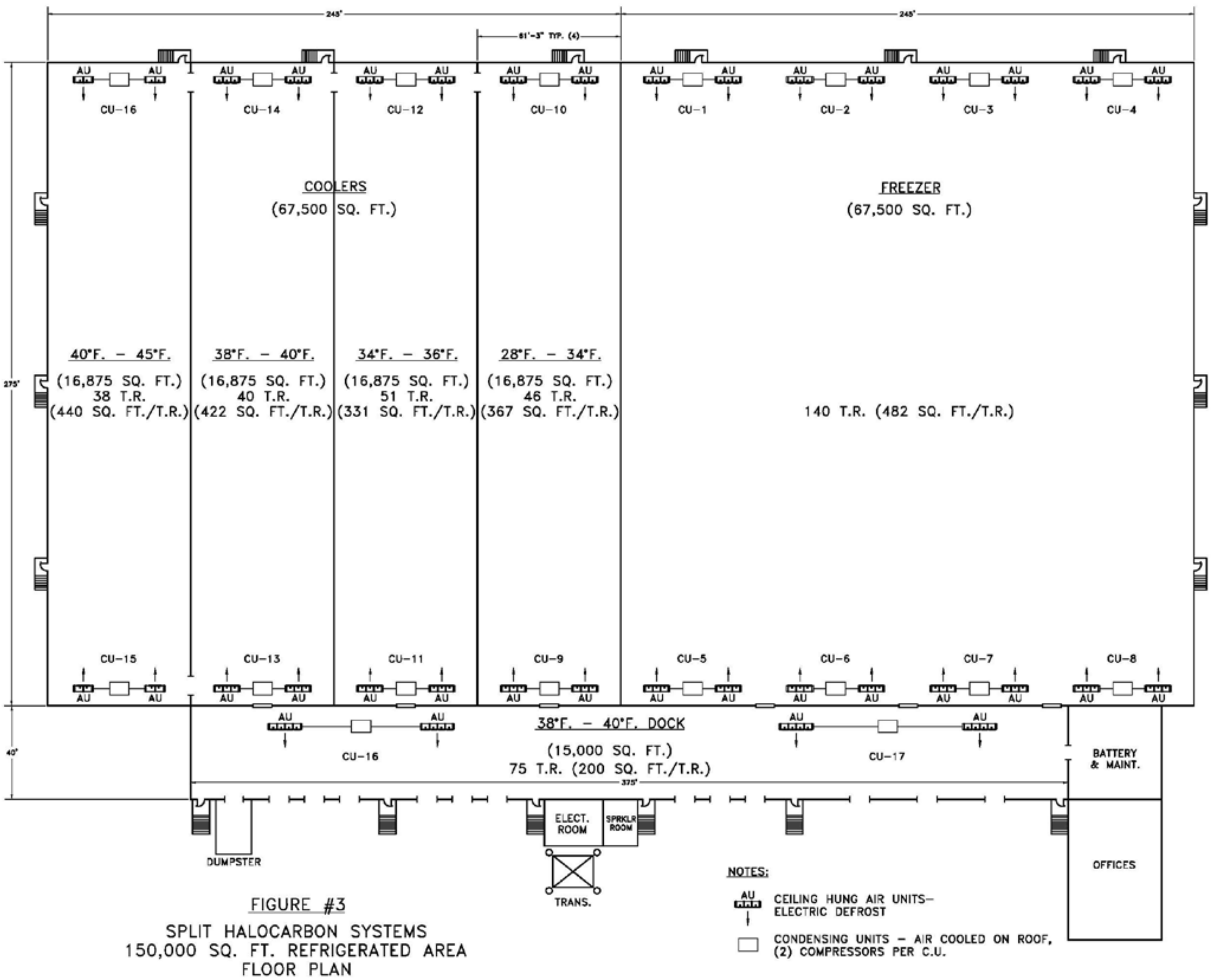


FIGURE #2
CENTRAL AMMONIA SYSTEM
150,000 SQ. FT. REFRIGERATED AREA
BLOCK FLOW DIAGRAM

Figure 3. Split Halocarbon Systems, 150,000 sq. ft. Refrigerated Area, Floor Plan



HALOCARBON EQUIPMENT SELECTIONS:

1. LOCATION: ATLANTA, GA
2. 115°F. AMBIENT EQUIPMENT SELECTION AND 105°F. AMBIENT POWER.
3. REFRIGERANT R-507

C.U. CONDENSING UNIT COMPRESSORS (NOMINAL H.P.)

A. –10°F. FREEZER (2) 30 H.P. PER C.U.
2 x 30 H.P. x 8 C.U. = 480 H.P.
TOTALS: 140 T.R. @ 442.4 KW

B. +28°F. COOLER (2) 25 H.P. PER C.U.
2 x 25 H.P. x 2 C.U. = 100 H.P.
TOTALS: 46 T.R. @ 97.2 KW

C. +34°F. COOLER (2) 25 H.P. PER C.U.
2 x 25 H.P. x 2 C.U. = 100 H.P.
TOTALS: 51 T.R. @ 101.4 KW

D. +38°F. COOLER (2) 20 H.P. PER C.U.
2 x 20 H.P. x 2 C.U. = 80 H.P.
TOTALS: 40 T.R. @ 81.3 KW

E. +40°F. COOLER (2) 12 H.P. PER C.U.
2 x 12 H.P. x 2 C.U. = 48 H.P.
TOTALS: 38 T.R. @ 72.4 KW

F. +38°F. DOCK (2) 35 H.P. PER C.U.
2 x 35 H.P. x 2 C.U. = 140 H.P.
TOTALS: 75 T.R. @ 150.2 KW

TOTAL POWER = 944.9 KW

Figure 4. R-507 Freezer Load Profile

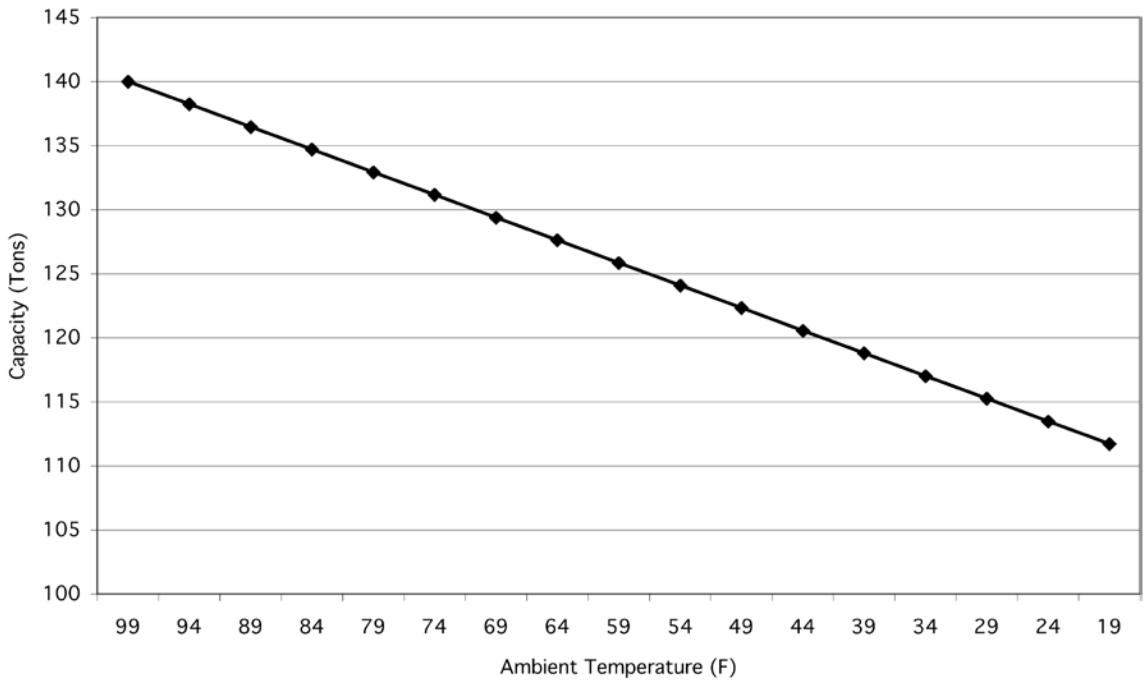


Figure 5. R-507 Cooler Load Profile

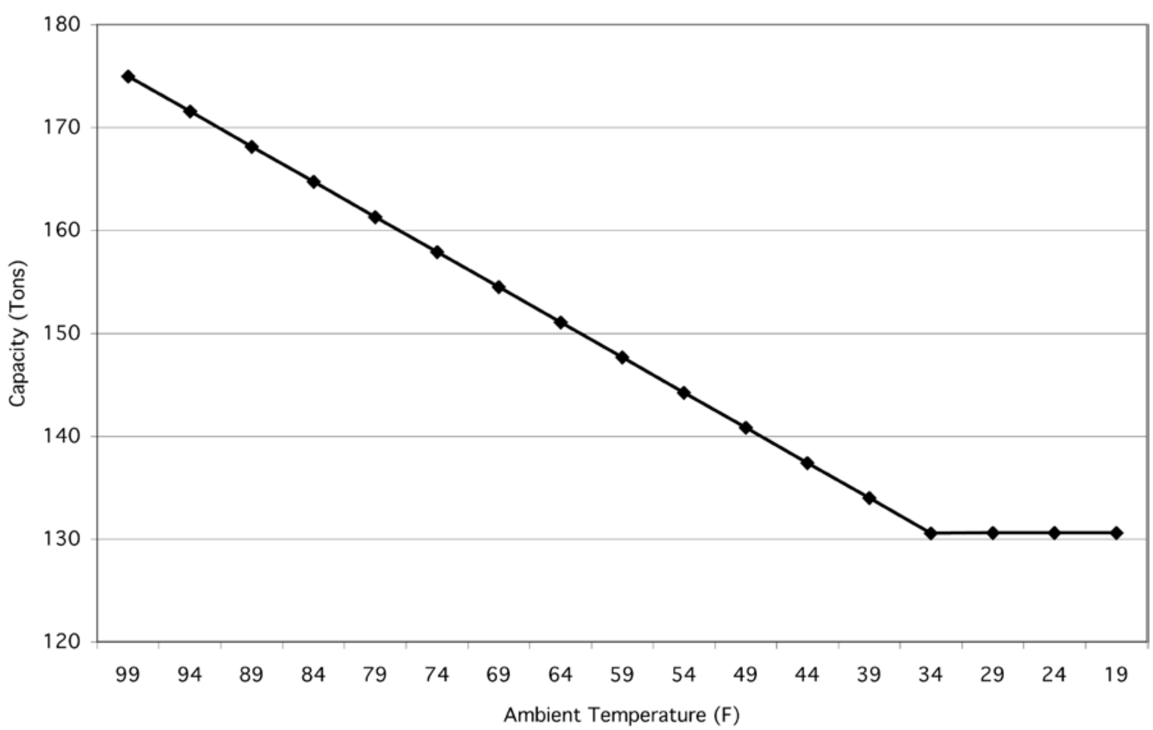


Figure 6. R-507 Dock Load Profile

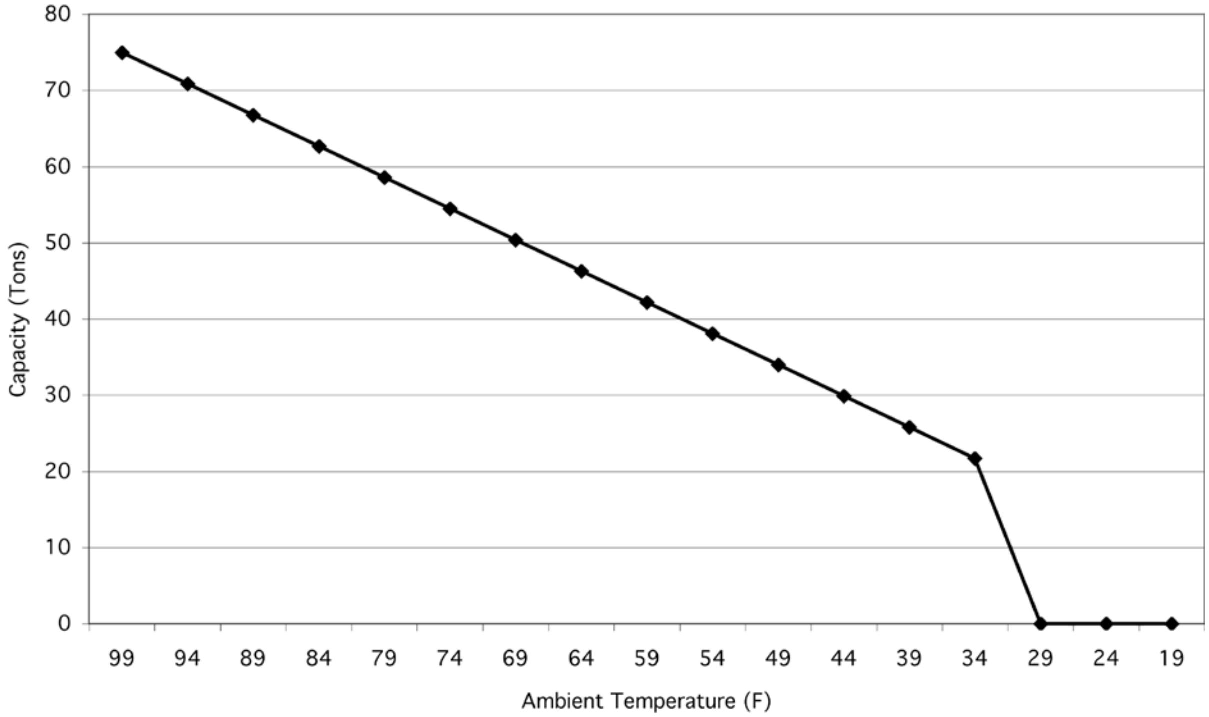


Table 1. System Parameters

Area	Size	Capacity	Sq. Ft. / TR
–10°F Freezer	67,500 ft^2	140 TR	482
Coolers*	67,500 ft^2	175 TR	385
38°F Dock	15,000 ft^2	75 TR	200
Totals	**150,000 ft^2**		

Note: TR = tons of refrigeration

* The Coolers are comprised of four 16,875 square foot independent coolers operating at 28–34°F, 36–36°F, 38–40°F and 40–45°F respectively (See Figures 1 and 3).

Table 2. Comparison of System Types

	Ammonia System	Split Halocarbon System
Control System	Computer Control	Computer Control
Refrigerant Detection	Yes	No
Compressor Room	Yes	No
Equipment Room/ Ventilation System	Yes	No
Underfloor Heating System	Glycol	Electric
Insulation	Rigid polystyrene with jacketing	Rubber material with no jacketing
Water Treatment	Yes	No

Table 3. Ammonia System Construction Costs

Construction Component	Estimated Cost
Refrigeration System Installation	$ 1,430,000
Refrigerant Charge	$ 10,000
Underfloor Heat System	$ 130,000
Equipment Room	$ 135,000
Control System	$ 125,000
Electrical Installation	$ 270,000
TOTAL:	**$ 2,100,000**
Construction Cost $ / square feet ($/ton)	$ 14.00 ($5,385)

Table 4. Halocarbon System Construction Costs

Construction Component	Estimated Cost
Refrigeration System Installation	$ 1,255,000
Refrigerant Charge	$ 35,000
Underfloor Heat System	$ 102,000
Control System	$ 100,000
Electrical Installation	$ 400,000
TOTAL:	**$ 1,892,000**
Construction Cost $ / square feet ($/ton)	$ 12.61 ($4,851)

Table 5. Ammonia Cooler and Dock Performance Data at 20°F Suction / 95°F Condensing

Equipment	kW/TR
Screw Compressor	0.84
Evaporative Condenser (Fans)	0.07
Evaporative Condenser (Pump)	0.02
Evaporator (Fans)	0.18
TOTAL	1.11

Table 6. Ammonia Freezer Performance Data at –20°F Suction / 95°F Condensing

Equipment	kW/TR
Screw Compressor	1.98
Evaporative Condenser (Fans)	0.07
Evaporative Condenser (Pump)	0.02
Evaporator (Fans)	0.17
TOTAL	2.24

Table 7. Evaporative Cooled Ammonia System Performance (kW/TR) at Various Weather BINs

Air Temperature (°F)	Condensing Temperature* (°F)	Cooler & Dock kW/TR	Freezer kW/TR
99–95	95	1.11	2.24
94–90	93	1.08	2.18
89–85	91	1.08	2.29
84–80	88	1.04	2.23
79–75	86	1.00	2.14
74–70	84	0.92	2.00
69–65	80	0.86	1.87
< 64	70	0.79	1.78

*Evaporative condenser performance is determined by ambient wet bulb conditions, but for this comparison the condensing pressure is associated with a dry bulb temperature as a representation of reductions to ambient conditions. The actual wet bulb BINs were analyzed and the total operating hours at the various conditions were similar to the dry bulb conditions used for this analysis.

Table 8. Halocarbon Cooler and Dock Performance Data at 20°F Suction / 105°F Ambient

Equipment	kW/TR
Air Cooled Condensing Unit	1.76
Evaporative (Fans)	0.25
TOTAL	2.01

Table 9. Halocarbon Freezer Performance Data at –20°F Suction / 105°F Ambient

Equipment	kW/TR
Air Cooled Condensing Unit	2.87
Evaporative (Fans)	0.29
TOTAL	3.16

Table 10. Air Cooled Halocarbon System Performance (kW/TR) at Various Weather BINs

Air Temperature (°F)	Condensing Unit Ambient (°F)	Cooler & Dock kW/TR	Freezer kW/TR
99–95	105	2.01	3.16
94–90	100	1.87	2.96
89–85	95	1.75	2.78
84–80	85	1.54	2.48
79–75	80	1.45	2.33
< 75	75	1.36	2.21

Table 11. Ammonia System Energy Calculation

Weather BIN Data		Freezer				Cooler				Loading Dock			
MAX DB (5F Range)	Hours @ DB Range	−10F Freezer Tons	−10F Freezer Ton x Hrs.	kW/TR	kWh	35F Cooler Tons	35F Freezer Ton x Hrs.	kW/TR	kWh	Loading Dock Tons	Loading Dock Ton x Hrs.	kW/TR	kWh
99	15	140	2,100.0	2.24	4,704	175	2,625.0	1.11	2,914	75	1,125.0	1.11	1,249
94	153	138.2	21,149.5	2.18	46,106	171.6	26,252.1	1.08	28,352	70.9	10,847.5	1.08	11,715
89	372	136.5	50,764.8	2.29	116,252	168.2	62,557.0	1.08	67,562	66.8	24,848.4	1.08	26,836
84	615	134.7	82,838.6	2.23	184,730	164.7	101,318.8	1.04	105,372	62.7	38,557.6	1.04	40,100
79	963	132.9	128,010.9	2.14	273,943	161.3	155,359.0	1.00	155,359	58.6	56,425.8	1.00	56,426
74	1149	131.2	150,704.7	2.00	301,409	157.9	181,438.8	0.92	166,924	54.5	62,611.5	0.92	57,603
69	996	129.4	128,876.4	1.87	240,999	154.5	153,874.2	0.86	132,332	50.4	50,189.1	0.86	43,163
64	834	127.6	106,440.3	1.78	189,464	151.1	125,995.9	0.79	99,537	46.3	38,605.1	0.79	30,498
59	810	125.9	101,945.5	1.78	181,463	147.7	119,601.6	0.79	94,485	42.2	34,171.9	0.79	26,996
54	900	124.1	111,681.8	1.78	198,794	144.2	129,814.5	0.79	102,553	38.1	34,277.3	0.79	27,079
49	612	122.3	74,861.8	1.78	133,254	140.8	86,182.0	0.79	68,084	34.0	20,798.4	0.79	16,431
44	585	120.6	70,525.0	1.78	125,535	137.4	80,380.4	0.79	63,500	29.9	17,481.4	0.79	13,810
39	420	118.8	49,890.9	1.78	88,806	134.0	56,273.4	0.79	44,456	25.8	10,828.1	0.79	8,554
34	213	117.0	24,925.3	1.78	44,367	130.6	27,810.6	0.79	21,970	21.7	4,617.8	0.79	3,648
29	108	115.3	12,447.3	1.78	22,156	130.6	14,104.8	0.79	11,143	0.0	0.0	0.79	0
24	33	113.5	3,745.0	1.78	6,666	130.6	4,309.8	0.79	3,405	0.0	0.0	0.79	0
19	6	111.7	670.3	1.78	1,193	130.6	783.6	0.79	619	0.0	0.0	0.79	0
14	0	109.9	0.0	1.78	0	130.6	0.0	0.79	0	0.0	0.0	0.79	0
9	0	108.2	0.0	1.78	0	130.6	0.0	0.79	0	0.0	0.0	0.79	0
		Tons = 25% ambient related				Tons = 25% ambient related				Tons = 70% ambient related			

REFRIGERATION ELECTRICAL CONSUMPTION

	Total kWh	$/kWh	Annual $
Freezer	2,159,840	0.08	$ 172,787
Cooler	1,168,566	0.08	$ 93,485
Loading Dock	364,107	0.08	$ 29,129
			$ 295,401

UNDERFLOOR HEAT ELECTRICAL CONSUMPTION

Pump HP	Pump kW	Hours	kWh	$/kWh	Annual $
3	2.7	3,063	8,270	$ 0 .08	$ 661.61

Weather BIN Data		Freezer				Cooler				Loading Dock			
MAX DB (5F Range)	Hours @ DB Range	−10F Freezer Tons	−10F Freezer Ton x Hrs.	kW/TR	kWh	35F Cooler Tons	35F Freezer Ton x Hrs.	kW/TR	kWh	Loading Dock Tons	Loading Dock Ton x Hrs.	kW/TR	kWh
99	15	140	2,100.0	3.16	6,636	175	2,625.0	2.01	5,276	75	1,125.0	2.01	2,261
94	153	138.2	21,149.5	2.96	62,603	171.6	26,252.1	1.87	49,091	70.9	10,847.5	1.87	20,285
89	372	136.5	50,764.8	2.78	141,126	168.2	62,557.0	1.75	109,475	66.8	24,848.4	1.75	43,485
84	615	134.7	82,838.6	2.48	205,440	164.7	101,318.8	1.54	156,031	62.7	38,557.6	1.54	59,379
79	963	132.9	128,010.9	2.33	298,265	161.3	155,359.0	1.45	225,271	58.6	56,425.8	1.45	81,817
74	1149	131.2	150,704.7	2.21	333,057	157.9	181,438.8	1.36	246,757	54.5	62,611.5	1.36	85,152
69	996	129.4	128,876.4	2.21	284,817	154.5	153,874.2	1.36	209,269	50.4	50,189.1	1.36	68,257
64	834	127.6	106,440.3	2.21	235,233	151.1	125,995.9	1.36	171,354	46.3	38,605.1	1.36	52,503
59	810	125.9	101,945.5	2.21	225,299	147.7	119,601.6	1.36	162,658	42.2	34,171.9	1.36	46,474
54	900	124.1	111,681.8	2.21	246,817	144.2	129,814.5	1.36	176,548	38.1	34,277.3	1.36	46,617
49	612	122.3	74,861.8	2.21	165,445	140.8	86,182.0	1.36	117,208	34.0	20,798.4	1.36	28,286
44	585	120.6	70,525.0	2.21	155,860	137.4	80,380.4	1.36	109,317	29.9	17,481.4	1.36	23,775
39	420	118.8	49,890.9	2.21	110,259	134.0	56,273.4	1.36	76,532	25.8	10,828.1	1.36	14,726
34	213	117.0	24,925.3	2.21	55,085	130.6	27,810.6	1.36	37,822	21.7	4,617.8	1.36	6,280
29	108	115.3	12,447.3	2.21	27,508	130.6	14,104.8	1.36	19,183	0.0	0.0	1.36	0
24	33	113.5	3,745.0	2.21	8,276	130.6	4,309.8	1.36	5,861	0.0	0.0	1.36	0
19	6	111.7	670.3	2.21	1,481	130.6	783.6	1.36	1,066	0.0	0.0	1.36	0
14	0	109.9	0.0	2.21	0	130.6	0.0	1.36	0	0.0	0.0	1.36	0
9	0	108.2	0.0	2.33	0	130.6	0.0	1.36	0	0.0	0.0	1.36	0
		Tons = 25% ambient related				Tons = 25% ambient related				Tons = 70% ambient related			

REFRIGERATION ELECTRICAL CONSUMPTION

	Total kWh	$/kWh	Annual $
Freezer	2,563,209	0.08	$ 205,057
Cooler	1,878,719	0.08	$ 150,297
Loading Dock	579,297	0.08	$ 46,344
			$ 401,698

FREEZER DEFROST ELECTRICAL CONSUMPTION

Watts / Heater	Units to Defrost	Total Watts	Hours / Day / Unit	Total kWh	$/kWh	$ / year
27,000	20	540,000	1.2	236,520	0.08	$18,922

UNDERFLOOR HEAT ELECTRICAL CONSUMPTION

Btuh/ sq. ft.	Freezer & Cooler sq. ft.	Btuh	watts	% utilization	kWh	$/kWh	$ / year
2	84,375	168,750	49,632	65	282,284,007	0.08	$22,583

Table 12. R-507A Split System Energy Calculation

Table 13. Final Comparison

	Ammonia Central System	Split Halocarbon System
Initial Construction Cost	$2,100,000	$1,892,000
Annual Estimated Operating Costs		
Electrical Utility	$296,063	$443,203
Water Consumption and Treatment	$24,062	$0
Preventative Maintenance	$9,000	$8,700
Refrigerant	$700	$1,760
Total:	**$329,825**	**$453,663**

Table 14. Ammonia System 20-Year Costs

Year	Electric Utility Cost	Water, Sewer, Treatment	Maintenance Contract Cost	Annual Refrigerant Cost	PSM Cost	Component Replacement Costs
1	$296,063	$24,062	$9,000	$700		
2	$310,866	$25,265	$9,450	$735		
3	$326,409	$26,528	$9,923	$772		
4	$342,730	$27,855	$10,419	$810		
5	$359,866	$29,248	$10,940	$851	$18,233	
6	$377,860	$30,710	$11,487	$893		
7	$396,753	$32,245	$12,061	$938		
8	$416,590	$33,858	$12,664	$985		
9	$437,420	$35,551	$13,297	$1,034		
10	$459,291	$37,328	$13,962	$1,086	$23,270	
11	$482,255	$39,194	$14,660	$1,140		$26,551
12	$506,368	$41,154	$15,393	$1,197		$27,879
13	$531,687	$43,212	$16,163	$1,257		$29,272
14	$558,271	$45,372	$16,971	$1,320		
15	$586,184	$47,641	$17,819	$1,386	$29,699	
16	$615,494	$50,023	$18,710	$1,455		
17	$646,268	$52,524	$19,646	$1,528		
18	$678,582	$55,151	$20,628	$1,604		$183,361
19	$712,511	$57,908	$21,660	$1,685		
20	$748,136	$60,803	$22,743	$1,769	$37,904	
Total:	**$9,789,606**	**$795,633**	**$297,594**	**$23,146**	**$109,106**	**$267,063**

Total 20-Year Life Cycle Cost (Ammonia System) = **$11,282,147**

Table 15. Halocarbon System 20-Year Costs

Year	Electric Utility Cost	Maintenance Contract Cost	Annual Refrigerant Cost	Component Replacement Costs
1	$443,203	$8,700	$1,760	
2	$465,363	$9,135	$1,848	
3	$488,631	$9,592	$1,940	
4	$513,063	$10,071	$2,037	
5	$538,716	$10,575	$2,139	
6	$565,652	$11,104	$2,246	$23,866
7	$593,934	$11,659	$2,359	
8	$623,631	$12,242	$2,476	$26,313
9	$654,813	$12,854	$2,600	
10	$687,553	$13,497	$2,730	$29,010
11	$721,931	$14,171	$2,867	
12	$758,028	$14,880	$3,010	$31,983
13	$795,929	$15,624	$3,161	
14	$835,725	$16,405	$3,319	$35,262
15	$877,512	$17,225	$3,485	
16	$921,387	$18,087	$3,659	$495,377
17	$967,457	$18,991	$3,842	$520,146
18	$1,015,829	$19,941	$4,034	
19	$1,066,621	$20,938	$4,236	
20	$1,119,952	$21,984	$4,447	
Total:	**$14,654,930**	**$287,674**	**$58,196**	**$1,161,957**

Total 20-Year Life Cycle Cost (Split Halocarbon System) = **$16,162,757**

							Nominal Total			Total	Projected Total	
Motor	**Qty**	**HP**	**BHP**	**FLA**	**EFF**	**PF**	**KVA**	**kW**	**KVAR**	**FLA**	**kW**	**KVAR**
–20 Compressor	1	200	176	240.0	93.0	87.0	184.4	160.4	90.9	240.0	141.2	80.0
–20 Compressor	1	200	176	240.0	93.0	87.0	184.4	160.4	90.9	240.0	141.2	80.0
–20 Compressor	1	263	258	318.0	88.7	88.7	233.6	207.2	107.9	318.0	203.2	105.8
Condenser Fans	3	10	10	14.0	87.0	85.0	10.1	25.7	15.9	42.0	25.7	15.9
Condenser Pump	1	7.5	7.5	11.0	86.0	85.0	7.7	6.5	4.0	11.0	6.5	4.0
–20 Ammonia Pump	1	3	3	4.8	82.0	75.0	3.6	2.7	2.4	4.8	2.7	2.4
–20 Ammonia Pump	1	3	3	4.8	82.0	75.0	3.6	2.7	2.4	4.8	2.7	2.4
–10 Freezer Air Units	12	2	2	4.3	74.0	60.0	3.4	24.2	32.3	51.6	24.2	32.3
–35 Cooler	16	2	2	4.3	74.0	60.0	3.4	32.3	43.0	68.8	32.3	43.0
–35 Dock	3	3	3	4.8	82.0	75.0	3.6	8.2	7.2	14.4	8.2	7.2
Underfloor Glycol Pump	1	3	3	4.8	82.0	75.0	3.6	2.7	2.4	4.8	2.7	2.4
Com Room Vent Fans	1	3	3	4.8	82.0	75.0	3.6	2.7	2.4	4.8	2.7	2.4
		1000 sq ft	circuits									
Sub Floor Heat			0									
TOTAL:								**635.7**	**401.7**	**1005.0**	**593.3**	**377.8**

Nominal kW:	635.7	Projected kW:	593.4
Nominal KVAR:	401.7	Projected KVAR:	377.9
Nominal KVA:	752.1	Projected KVA:	703.5
Nominal Power Factor:	0.8	Projected Power Factor:	0.8
Required Ampacity:	1084.5		

Note: FLA, EFF, PF and BHP based on published “average values” for motors to be supplied.

Appendix A. New Ammonia Freezer System, Atlanta, GA (150,000 sq. ft.)

Appendix B. Split Halocarbon System Estimate Basis

1. Project located in Atlanta, GA area
2. Equipment selected for 115°F ambient capacity and 105°F ambient power
3. Refrigerant R-507
4. Rubber material insulation for suction and condensate drain piping
5. First year labor warranty excluded
6. 20 ft of piping for suction and liquid on each circuit
7. Liquid line velocity < 300 fpm
8. Suction line velocity < 3000 fpm
9. Condensate drains piped to hub below evaporator
10. Thermostat control wired by others
11. No underfloor heating system
12. Power wiring by others
13. Room sizing and Temperatures:

Total	Freezer	Temp	Cooler	Temp	Dock	Temp
150,000	67,500	–10°F	16,875	28°F	15,000	38°F
			16,875	34°F		
			16,875	38°F		
			16,875	40°F		

14. Split system equipment count:

Location	Number of Condensing Units	Number of Evaporators
–10°F freezer	8	16
28°F cooler	2	4
34°F cooler	2	4
38°F cooler	2	4
40°F cooler	2	4
38°F dock	2	4

15. System kW:

Location	Number of Condensing Units	Number of Evaporators	Total kW
–10°F freezer	8	16	442.4
28°F cooler	2	4	97.2
34°F cooler	2	4	101.4
38°F cooler	2	4	81.3
40°F cooler	2	4	72.4
38°F dock	2	4	150.2
		System Total:	**944.9**

Appendix B. Split Halocarbon System Estimate Basis (continued)

16. System tonnage:

Location	Number of Condensing Units	Number of Evaporators	Total TR
−10°F freezer	8	16	140
28°F cooler	2	4	46
34°F cooler	2	4	51
38°F cooler	2	4	40
40°F cooler	2	4	38
38°F dock	2	4	75
		System Total:	**390**

17. Room load:

Location	Number of Condensing Units	Number of Evaporators	Sq ft/TR
−10°F freezer	8	16	482
28°F cooler	2	4	367
34°F cooler	2	4	331
38°F cooler	2	4	422
40°F cooler	2	4	440
38°F dock	2	4	200

Notes: