# Federal Technology Alert

A publication series designed to speed the adoption of energy-efficient and renewable technologies in the Federal sector

Prepared by the New Technology Demonstration Program

# Liquid Refrigerant Pumping

*Technology for Improving Refrigeration Performance and Capacity*

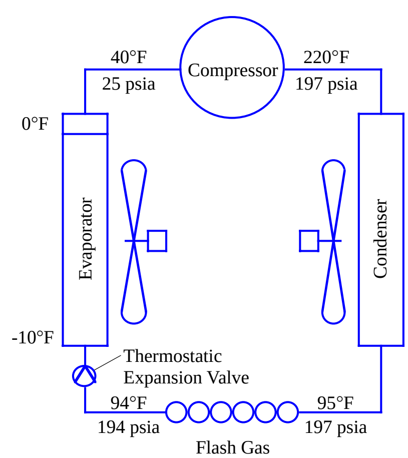
Liquid refrigerant pumping (LRP) is a simple, reliable way to improve refrigeration efficiencies. This technology modifies a conventional direct-expansion (DX) refrigeration system in such a way that average compressor load is reduced and cooling capacity is increased. The central component is an ultra-reliable, seal-less, magnetically coupled pump that is installed in the liquid refrigerant line between the receiver and the thermal expansion valve, as shown below. The technology is available through Hy-Save, Inc., Portland, Oregon.

This Federal Technology Alert (FTA), one of a series, describes the theory of operation, field experience (savings and reliability), range of application, and how to evaluate the LRP for a particular application.

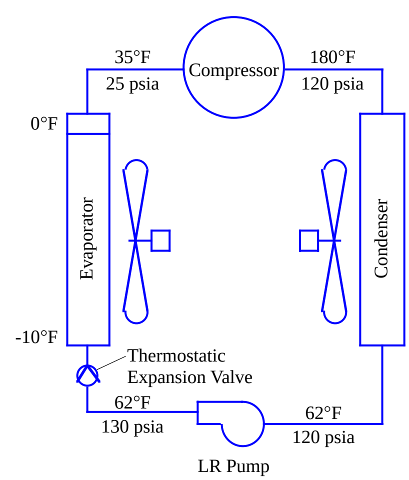
## Energy-Saving Mechanism

The LRP is a simple, reliable means of converting a refrigeration system to floating-head operation, which is the efficient operation obtained by allowing the condenser to operate at lower pressure and temperature when ambient conditions permit. In an LRP retrofit, the pump overcomes head losses in the liquid line and dryer that would otherwise cause some flashing (refrigerant boiling) ahead of the expansion valve. With the LRP suppressing flash gas, the condensing setpoint (temperature or pressure) can be changed to a lower value.

Little, if any, savings will be obtained by applying LRP to systems that already have floating-head control or that do not operate much during the low ambient temperature conditions necessary to accrue floating-head savings.




Normal System




System with LRP Added



DoD EPA DOE SERDP
Strategic Environmental Research and Development Program
Improving Mission Readiness through Environmental Research

## Technology Selection

LRP is just one of many energy technologies to emerge in the last 20 years. The FTA series targets technologies that appear to have the greatest untapped federal-sector potential. New technologies were identified through advertisements in the *Commerce Business Daily* and trade journals, and through direct correspondence. Numerous responses were obtained from manufacturers, utilities, trade associations, research institutes, federal sites, and other interested parties. Based on these responses, the technologies were evaluated in terms of potential energy, cost, and environmental benefits to the federal sector. They were also categorized as those that are just coming to market and those for which field data already exist. Technologies classified as just coming to market will be considered for field demonstration through FEMP and industry partnerships, while technologies for which field data already exist are considered as topics for Technology Alerts. The LRP technology was found to have significant potential for federal-sector savings and to have had demonstrated field experience and reliability.

## Recognition

In 1989, the National Institute of Standards & Technology's Office of Energy Related Inventions recommended the LRP technology based on theoretical analysis of refrigeration cycles. Two projects involving the technology have received recognition from DOE: 1) the Presidential Citation to Andy Dorer, USMC, Albany, GA and 2) the Environmental Protection Agency's Stratospheric Ozone Protection Award for Hannaford Brothers Supermarkets.

## Potential

Analysis of a large sample (nearly 25% by floor area) of federal facilities indicates a major, untapped energy conservation potential in the federal sector. The life-cycle cost-effective market potential for HVAC system retrofits is estimated to be $23 million installed cost, representing present value savings of $34 million, in this sample. Some 12,500 LRP systems are currently operating in the United States, but only a comparative few (200, representing an aggregate initial cost of perhaps $100 thousand) are in operation in the federal sector.

## Application

Based on the FEMP analysis and FEMP review of evaluations by others, the LRP technology is recommended for deployment at federal facilities in applications where conversion from fixed- to floating- head operation is life-cycle cost- effective.

Laboratory testing, field testing, and theoretical analyses have shown LRP technology to be technically valid and most likely to be economically attractive in applications such as the following:

- air conditioners for computer rooms
- air conditioning systems for core zones of buildings
- refrigerated display cases and storerooms.

Depending on climate, load, and electric rates, skating rinks, refrigerated warehouses, packaged air conditioners, DX chillers, process cooling, and heat pump systems may also make cost-effective retrofits.

Applications where LRP is usually not appropriate include the following:

- flooded evaporator machines
- domestic refrigerators and similar systems with indoor condensers
- systems that cannot use (or already have) floating-head control.

## Field Experience

LRP installations have been monitored in many commercial and federal sites by utility engineers, site facility managers, and at least one supplier of refrigerated systems. In these tests, the expected floating-head savings, simplicity, and reliability have been confirmed. Installation costs are between $50 and $250/ton, and the only maintenance required is to check the LRP and new condenser pressure/temperature setpoint during normal seasonal preventive maintenance and replace the impeller every 5 years.

## Case Study

As a test case, the LRP technology was installed in a retrofit at Fort Drum, New York. This was a good demonstration because installation of the LRP, and the reduction in condensing setpoint that the LRP enabled, were the only system modifications. The system was monitored before and after the retrofit. The installation of LRP on a 9-ton system increased average condenser fan power by 0.48 kW and reduced average compressor power by 2.64 kW, for a net average system power reduction of over 14%. Further analysis indicated that savings for an average year would be over 17%, yielding a simple payback of 1.2 years.

## Implementation Barriers

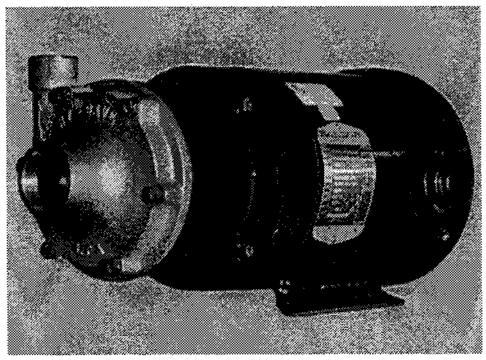
One of the main issues surrounding LRP technology is acceptance by refrigeration manufacturers. To endorse LRP is to acknowledge that one's equipment is not as efficient as it could be. As a result, approval of LRP by component manufacturers is well documented, while endorsement by package equipment manufacturers can only be traced by examining construction documents and submittals in the few cases where LRP was specified and installed in new construction. Since large package equipment manufacturers exercise considerable control over the flow of information, the user acceptance and application concerns we have encountered are not surprising.

The Federal Technology Alert attempts to close the LRP information gap. A detailed version of the Alert on LRP is available to interested individuals.

# Federal Technology Alert

# Liquid Refrigerant Pumping

*Technology for Improving Refrigeration Performance and Capacity*



## Abstract

The liquid refrigerant pump (LRP) is a simple, reliable means of increasing the capacity and efficiency of new and existing refrigeration and air conditioning systems. To benefit from the technology, the target system must employ a direct-expansion evaporator and minimum head pressure controls. Many package HVAC, small chiller, and refrigerated display case systems fit these application criteria. The LRP reduces compressor load by compensating for the pressure drop through the liquid line and filter/dryer and prevents boiling (flash gas formation) between the condenser and expansion valve. The discharge pressure set-point may then be lowered to obtain significant compressor load reductions in cool weather. Annual energy savings typically range from 10 to 30% and paybacks of under two years are often realized.

This Federal Technology Alert provides detailed information and procedures that a federal energy manager needs to evaluate most LRP applications. The New Technology Demonstration Program (NTDP) technology selection process and general benefits to the federal sector are outlined. Principles of refrigeration and LRP energy-saving mechanisms are explained. Procedures are given for preliminary sizing of equipment, estimating energy savings, and calculating life-cycle costs (LCC). Proper application, installation, and operations and maintenance (O&M) impacts are discussed. A federal-sector case study is presented to give the reader a good sense of what is really involved in implementing this technology. A list of federal sector users and a bibliography are included for prospective users who have specific or highly technical questions not fully addressed in the Alert. Details of LCC analysis, a sample Energy Conservation Investment Program (ECIP) form, a sample procurement specification, and an application checklist are also provided.

# Contents

# About the Technology

The liquid refrigerant pump technology modifies a conventional direct-expansion, vapor-compression refrigeration system by adding a simple, low-power pump in the liquid refrigerant line. This addition allows the minimum head pressure control to be adjusted to allow lower compressor discharge pressures at lower ambient temperatures.[a] This, in turn, yields reduced compressor load and increased refrigeration capacity. In 1989, the U.S. Department of Commerce, National Institute of Standards and Technology, completed its evaluation of liquid refrigerant pumping as disclosed in U.S. Patent Number 4,599,873 (July 1986) and found the technology to be "technically valid and worthy of consideration for appropriate Government support." Patent Numbers 5,150,580 (September 1992) and 5,291,744 (March 1994a) were granted to the same inventor for extensions and additional claims. A typical LRP installation is pictured in Figure 1.

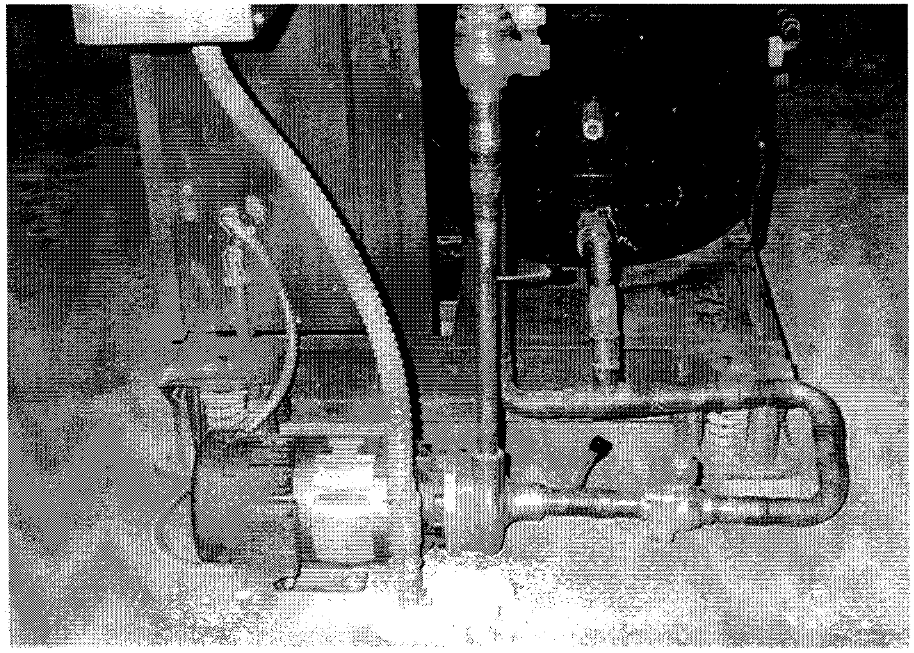


**Fig. 1. Typical LRP installation**

Numerous field tests have demonstrated typical compressor energy savings of 10 to 30% and typical paybacks of 1 to 3 years. However, an understanding of the savings mechanism and how equipment, load, and climate characteristics affect savings is essential to proper application of the technology. A thorough understanding of conventional (minimum head pressure) and floating-head control and thermostatic expansion valve (TEV)[b] operation is also critical to proper installation and ongoing operation and maintenance. These important topics are reviewed in the ensuing subsections.

### *Application Domain*

About 12,500 liquid refrigerant pumps (11,000 systems, since some applications use multiple pumps) have reportedly been installed in the private sector by the original inventor's company, Hy-Save, Inc., and its distributors. About 200 installations are reported in the federal sector. The large number of field tests that have been reported confirm energy savings of 10 to 30% and confirm the validity of a temperature-bin based calculation to predict savings in a variety of applications.

The technology is generally applicable to direct-expansion equipment in which liquid refrigerant flow is controlled by a thermostatic expansion valve, evaporator pressure regulator (EPR), or capillary tube.[c] Most existing and new

(a) The result is known in the industry as "floating-head control" or "floating-head operation" (EPRI 1985).
(b) The abbreviation TXV is used in place of TEV in some literature.
(c) The capillary tube should be replaced by a TEV at the evaporator inlet and properly sized liquid line from the condenser to the TEV. Evaporator pressure regulator control, as used in scroll-compressor-based refrigeration plants, may require adjustment. Subsequent references to TEV-controlled equipment should be understood to include capillary-tube and EPR-controlled equipment.

reciprocating-compressor-based refrigeration equipment is TEV-controlled. Thus, most any assembly described as a "packaged" or "split system" air conditioner, a refrigerated display case or storeroom, or a packaged reciprocating chiller is a candidate for LRP.

Flooded evaporator machines generally do not benefit because they use a float valve to modulate liquid refrigerant flow and maintain liquid level in the evaporator rather than a thermostatically controlled expansion valve. Virtually all centrifugal chillers are of this type. The LRP is not applicable to centrifugal chillers and other flooded evaporator equipment regardless of the type (wet or dry) of heat rejection employed. There is one exception: when the LRP is used to inject a small portion of the condensed liquid into the compressor discharge to desuperheat the vapor, there may be some energy savings at, or close to, full load.

Small machines (<5 tons) may appear to be poor candidates for retrofit because installation labor cost per pump is essentially fixed. However, some residential space cooling applications may be attractive as a factory installed condensing unit option (for example, on a multi-unit new housing project).

### *Energy-Saving Mechanism*

The typical TEV-controlled, vapor-compression refrigeration system (Figure 2) uses an evaporator in the fluid stream to be cooled, an expansion valve to meter the flow of refrigerant, a compressor to raise the pressure of the refrigerant vapor, a condenser to reject heat to the outside, and a receiver (downstream of the condenser) to store liquid refrigerant. The condenser is usually located outside the building. Conventional refrigeration systems incorporate minimum head pressure controls to ensure that refrigerant pressure between the condenser and the expansion valve is kept high enough to prevent flash gas formation. Minimum head pressure control is simple but it results in additional compressor work under most operating conditions.

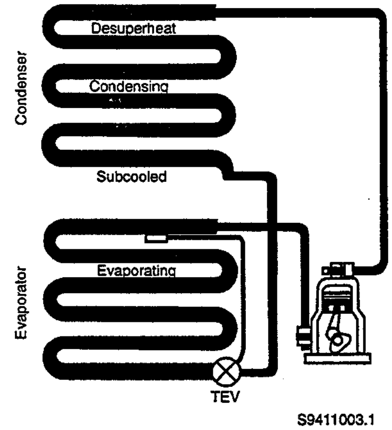



**Fig. 2. Conventional System**

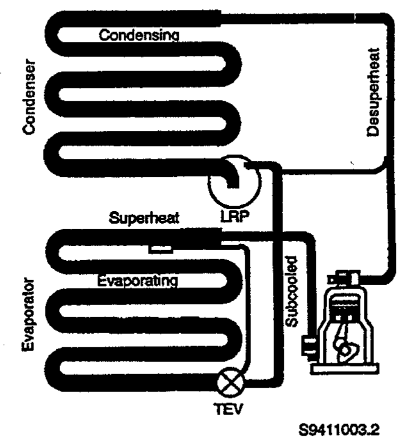



**Fig. 3. System with LRP added**

The LRP technology eliminates the need for a high minimum head pressure setpoint by inserting a pump in the liquid line between the condenser and the expansion valve, as shown in Figure 3. The pump raises the pressure of the liquid refrigerant by 5 to 12 psi to suppress flash gas formation. With the LRP installed, the minimum head pressure controls can be adjusted to allow the condenser pressure and temperature to float downward with the ambient temperature. The lower the condenser temperature, the more efficient the refrigeration cycle.

Figure 4, a pressure-enthalpy diagram, shows the refrigerant cycle, ABCDEFA, of a system with minimum head pressure control and no LRP. The refrigerant states are representative of a typical refrigeration system under ambient temperature conditions where minimum head pressure control is just becoming active. At this condition, an increase in ambient temperature will cause the condensing pressure to increase but a decrease in ambient temperature will have no effect because the condenser effectiveness is controlled (decreased) to maintain the minimum condensing pressure. Line E-F represents desuperheating,

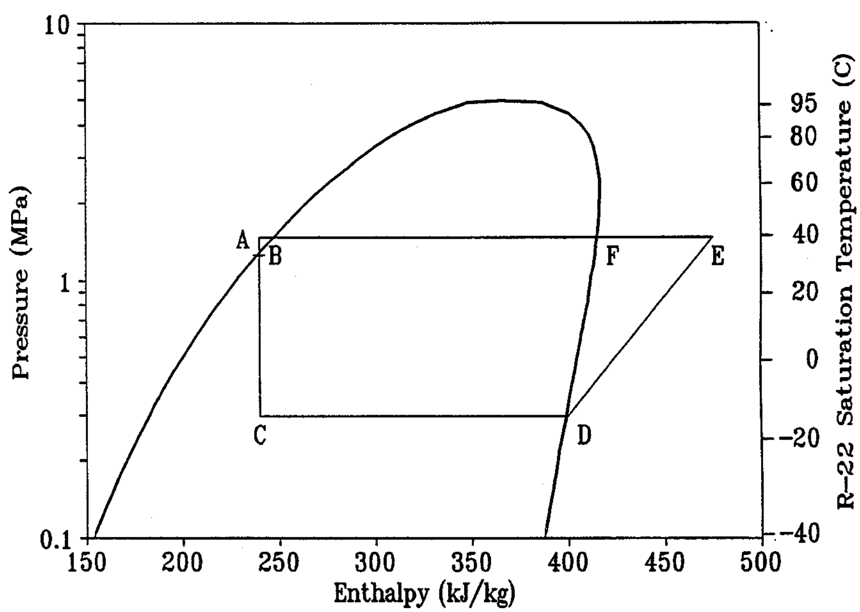



**Fig. 4. Pressure-enthalpy diagram showing conventional cycle. Flash gas may form between condenser outlet, A, and TEV inlet, B.**

F-A represents condensing and subcooling in the condenser, A-B dryer and liquid line pressure drop, B-C throttling valve pressure drop, C-D evaporation, and D-E compression. At low ambient temperatures, minimum head pressure control constrains the cycle to follow the same path, ABCDEFA, even though condensation at lower pressures could be achieved. Thus, the path ABCDEFA represents the non-LRP cycle for all ambient temperatures at or below the temperature where minimum head pressure control begins to act.

Note that the pressure drop A-B is such that the refrigerant is no longer in the subcooled (entirely liquid) region at the TEV inlet; some refrigerant gas bubbles will therefore be present in the liquid. The TEV is more prone to unstable control (alternately underfeeding and overfeeding refrigerant to the evaporator) in the presence of gas bubbles if there is insufficient--typically less than 0.7 MPa (100 psi)--pressure across the TEV. Also, when flash gas is present the maximum capacity of the TEV drops and the compressor must run longer to provide the same average cooling effect. Minimum head pressure control, therefore, has two purposes: 1) to minimize the generation of flash gas and 2) to help promote stable TEV operation.

Figure 5 shows refrigerant cycles of the otherwise identical system with floating-head control and LRP added at two conditions.

Under the conditions of Figure 4 (high ambient temperature), the cycle of the refrigerant state follows line ABCDEFGA. At this condition, the small amount of flash gas that might have been present in the pre-LRP system is eliminated. There will be a correspondingly small increase in cooling capacity because what was flash gas in the pre-LRP system now enters the TEV as liquid and this liquid contributes a latent cooling effect. The refrigerant mass flow rate will be about the same as it was without the LRP because it is controlled by evaporator superheat. Suction pressure will be a little lower because of the increased cooling capacity (lower evaporator temperature needed to drive heat transfer between the refrigerant and load sides of the evaporator). This will, in turn, result in a slightly higher volumetric flow rate through, but slightly lower pressure difference across, the compressor. The net result is a compressor load (product of volumetric flow rate and pressure difference) that is virtually unchanged from the pre-LRP condition. The efficiency improvement at high ambient temperatures is thus due entirely to the very small evaporator capacity increase.[a] The important point is that the LRP will, if anything, improve compressor efficiency and evaporator capacity under high ambient conditions.

An additional, much greater efficiency improvement is realized under low ambient temperature conditions. At the new minimum condensing temperature and pressure, determined by the new, lower minimum head pressure setpoint, the refrigerant cycle follows line abcDefga. Note that the pressure rise provided by the LRP, g-a, is such that the refrigerant is still in the subcooled (entirely liquid) region at the TEV inlet, b. The TEV can therefore operate properly down to a TEV pressure drop of typically 20-30 psi or 0.2 MPa (Schoen 1992). Savings accrue whenever ambient temperature is low enough for condensing to take place below the old minimum head pressure setpoint (F in Figure 4). Annual savings are therefore related to the portion of annual compressor run time that occurs during low ambient temperature conditions.

The conversion from fixed- to floating-head operation is especially attractive when two-speed or parallel compressor control schemes are used to obtain closer condenser and evaporator approach temperatures under part load. With floating-head control the theoretical potential for savings from closer approach temperatures can be realized.

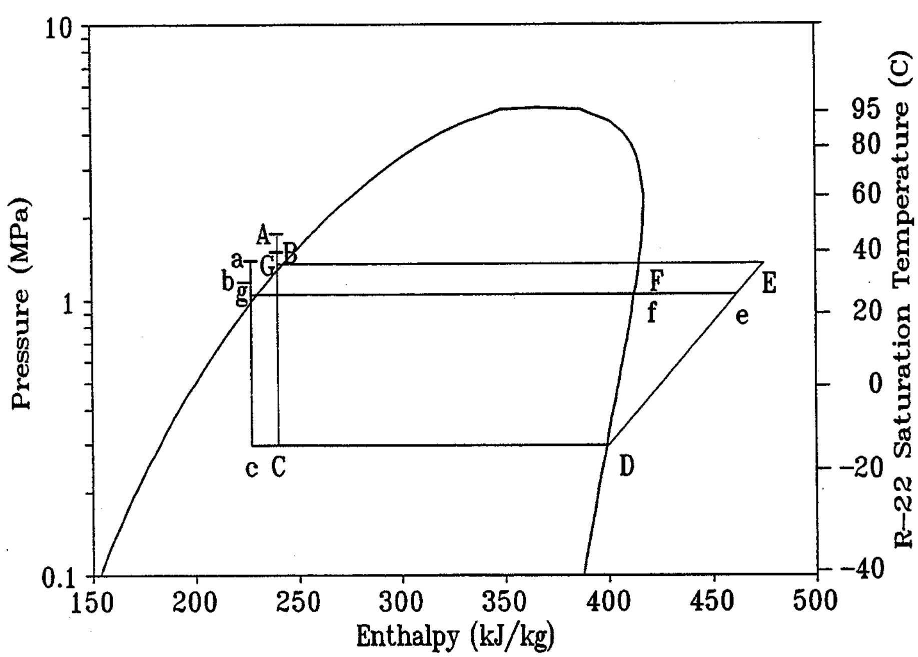



**Fig. 5. Pressure-enthalpy diagram showing LRP-augmented cycle at the original (ABCDEFG) and new (abcDefg) minimum head pressure setpoints.**

(a) The evaporator pressures, C, represented in Figures 4 and 5 are too close to distinguish; the same is true of the condenser pressures, F. Note that the distance A-B is exaggerated in both figures to make the graphs readable.

### *Other Benefits*

By lowering the minimum condenser pressure constraint, the compressor can operate with a reduced duty fraction, lower internal temperatures, and lower stress, whenever low ambient temperatures permit. Floating-head operation therefore results in less noise, vibration and wear, as well as greater capacity and efficiency.

Although difficult to quantify, it is clear that conversion to floating-head control must extend equipment life and reduce maintenance costs of compressors in systems that receive LRP retrofits.

### *Variations*

Two energy-saving features can be easily added to a refrigeration plant at the same time that the LRP is retrofit: liquid injection desuperheating and a dehumidification coil. Both depend on the pressure boost imparted to the liquid refrigerant by the LRP.

To obtain superheat suppression, the pressure boost provided by the LRP is used to inject a portion (~5%) of the liquid refrigerant at the compressor discharge where it precools the vapor to its condensing temperature. This modification makes more efficient use of the condenser to achieve closer approach temperatures and, consequently, higher cycle efficiency for certain refrigerants.

Liquid injection desuperheating is attractive with some refrigerants in space cooling applications and warm climates where a large fraction of a machine's operation occurs under near-design ambient temperatures.

In air conditioning applications with high latent-to-sensible load ratios or low supply-air dew point requirements, a supplementary coil can be added downstream of the main cooling coil to reduce sensible capacity and increase latent capacity (Hyde 1994b). In this arrangement the pumped refrigerant is further subcooled as it passes through the supplementary coil enroute to the TEV and main coil. (The pump is necessary to prevent flash vapor formation in the supplementary coil.) The resulting supply air has a lower dew point but a higher dry bulb temperature.

These two LRP variations may be the subjects of future Technology Alerts or Test Bed Field Demonstrations and will not be discussed further here.

### *Installation*

The installer should measure compressor discharge pressure and, if possible, condenser and liquid line pressure drops under full-load prior to pump installation. The installer must also determine that discharge temperature or pressure setpoints can be safely and significantly reduced. (A list of important characteristics to check before applying LRP is provided in Appendix D.) The liquid refrigerant pump is installed between the condenser and the TEV, usually just downstream of the liquid receiver. There is room in most existing equipment enclosures to accommodate the pump and wiring.

For example, a 1/8-hp pump for units up to 7.5-ton capacity has a 26 x 19.4 cm (10.5 x 7.75 in.) footprint and weighs about 7.7 kg (17 lb). A 1/2-hp pump for units up to 75-ton capacity has a 39 x 23 cm (15.6 x 9.2 in.) footprint and weighs about 13 kg (29 lb). In a retrofit application the refrigerant must be removed and the liquid line severed at the appropriate pump location. Solder connections are made with a heat sink or wet rag on the pump body using low-temperature solder. In some cases the pump must be dismantled and reassembled to ensure reliable connections without heat damage. The motor is wired in parallel with the compressor. The minimum head pressure setpoint is changed (lowered) to allow condensing pressure to float down to the minimum allowed by the TEV or compressor manufacturer, whichever is greater.

The system is then recharged, checked for leaks, and tested. Installation is usually performed by a mechanic licensed by the manufacturer. The technicians who normally service the equipment are instructed in LRP theory and O&M practice by the installer or other manufacturer's representative. Installation by an unlicensed installer (for example, facility maintenance staff) should not be undertaken without the manufacturer's approval. Installer qualifications and installation procedures must also comply with government regulations concerning CFC recycling and release.

# Federal Sector Potential

The potential cost-effective savings achievable by this technology were estimated as a part of the technology assessment process of the New Technology Demonstration Program.

### *Technology Screening Process*

New technologies were identified through advertisements in the *Commerce Business Daily* and trade journals, and through direct correspondence. Numerous responses were obtained from manufacturers, utilities, trade associations, research institutes, federal sites, and other interested parties. Based on these responses, the technologies were evaluated in terms of potential federal-sector energy savings and procurement, installation, and maintenance costs. They were also categorized as either just coming to market ("unproven" technologies) or as technologies for which field data already exist ("proven" technologies).

The energy savings and market potentials of each candidate technology were evaluated using a modified version of the Facility Energy Decision Screening (FEDS) software tool, developed for FEMP, CERL, and NFESC by Pacific Northwest Laboratory.

*Estimated Savings and Market Potentials*

The LRP technology was evaluated for space cooling applications. Existing equipment was assumed to operate with a minimum condensing temperature equal to the local ASHRAE 2.5% design temperature and with the condenser and fan sized to provide rated capacity at the local ASHRAE 2.5% design temperature. The LRP technology was assumed to increase refrigeration efficiency 2.3% per Kelvin (1.4% per °F) drop in ambient temperature.

The potential federal-sector market for 21 of the 54 new technologies submitted during the first half of FY 1994 was assessed. Thirty-three were eliminated in the qualitative prescreening process for various reasons. Either they were not ready for production, or they did not qualify as energy-saving, or they were not applicable to a sufficient fraction of existing facilities, or they were not a U.S. technology. Eighteen[a] of the remaining 21 technologies were found to be life-cycle cost-effective (at one or more federal sites) in terms of installation cost, net present value, and energy savings. The 18 technologies have an estimated aggregate first cost of $884 million, a net present value (NPV) of $1055 million, aggregate site energy saving potential of 8934 trillion Joule/yr (8468 billion Btu/yr), and a present value of energy and O&M savings of $1916 million.[b] The corresponding numbers for the LRP technology are $23 million first cost, $11 million NPV, 232 trillion Joule/yr (6447 million kWh/yr or 220 billion Btu/yr) site energy savings, and $34 million present value of energy and O&M savings. (Federally mandated life-cycle costing procedures and metrics are summarized in Appendix A.) The LRP technology's contributions to savings and cost-effectiveness threshold (breakeven electric energy price as defined in Appendix A) relative to other new technologies are shown in Figure 6. Each step in the plot represents one of the evaluated technologies. Technologies that are more cost-effective than LRP fall to the left of the arrow; technologies that are less cost-effective fall to the right.

*Laboratory Perspective*

The liquid refrigeration pumping technology has been shown through laboratory testing, field testing and theoretical analysis to be technically valid and economically attractive in many applications. The technology works by virtue of its being a simple, reliable fix to a number of refrigeration "problems" that are inherent to conventionally designed DX refrigeration system. Performance of the technology, when properly applied, has been conclusively demonstrated. The remaining barriers to rapid implementation involve user acceptance and correct application. This Technology Alert is intended to address these concerns by reporting on the collective experience of LRP users and evaluators and by providing application guidance.

# Application

This section addresses technical aspects of applying LRP. The range of applications and climates in which the technology can best be applied are discussed. The advantages, limitations, and benefits in each application are enumerated. Design and integration considerations for the LRP technology are highlighted, including costs, options, and installation details. Utility incentives are also discussed.

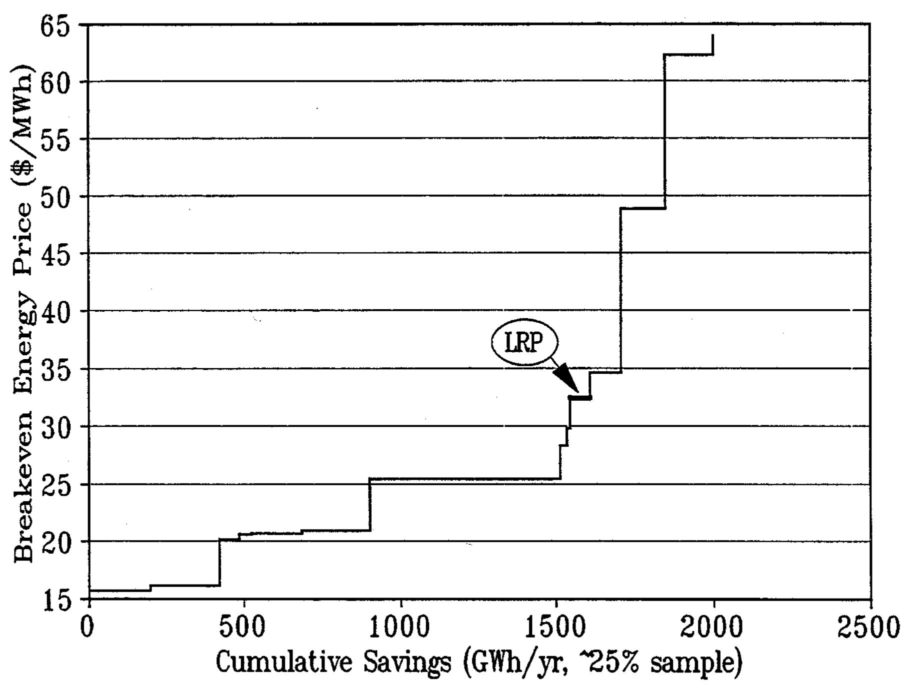


**Fig. 6. LRP's potential contribution (relative to other new technologies, LRP highlighted) to federal-sector savings**

(a) Actually, there were 19, including the LRP dehumidification enhancement technology; however, the dehumidification technology is an add-on to the LRP technology that will be treated in another Federal Technology Alert.

(b) The modified FEDS analysis gives estimates of aggregate NPV, installed cost, SIR, and annual energy savings for a *sample* of federal-sector facilities. These estimates are for the sample (Nemeth 1993) only (which represents about 25% of the federal building stock) and were not extrapolated to the entire federal sector.

## *Application Screening*

The LRP is a simple, reliable way to convert refrigeration and air conditioning equipment from minimum head pressure control to floating-head control. In floating-head control the thermodynamic efficiency of the cycle is increased by allowing heat rejection to occur closer to ambient temperature. With conventional (minimum head pressure) control, the refrigerant is not allowed to condense below a set temperature, which is usually close to design ambient temperature (30 to 40°C, 86 to 104°F).

Energy savings will be very closely tied to the annual load distribution, the annual ambient temperature distribution, and the relation between the two distributions (their joint distribution). In general, a bin method is the simplest calculational procedure that can be used to reliably estimate the savings for a given application and climate. (Bin methods rely on load and ambient wet or dry bulb temperature distributions.) However, some general guidance can be given on appropriate applications and climate/ application combinations.

The most common applications use R-22 refrigerant or other organic refrigerants that operate at pressures of the same magnitude. Routine LRP retrofits are made to systems charged with R-502 and R-12. Limited testing has been conducted with R-134a and an HFC-125/143a blend (ASHRAE 1994), which are candidate replacements for R-502 and R-22, and with AZ-20, R-13B1, R-401, R-402, R-404A, and R-507 (Hy-Save 1994).

## *Where to Apply LRP*

The refrigeration applications are listed below from the generally highest potential LRP savings applications to the lowest. Note that in all cases the savings result from lower condensing temperatures obtained by lowering the condenser head setpoint. There will be no savings if the setpoint is not, or cannot be lowered. If load and climate are such that there are few hours of operation when ambient temperatures are cool enough to realize lower condensing temperatures the savings will be small.

- Computer room air conditioners. These applications have fairly constant year-round loads. Thus, a large fraction of annual load occurs at low ambient temperature.

- Refrigerated display cases. These also have approximately constant year-round loads.

- Off-peak cold storage systems. With many hours of operation at low nocturnal ambient temperatures, the savings from a change to minimum head pressure control can be substantial.

- Direct-expansion skating rinks. Outdoor rinks operate seasonally during months with average temperatures of 5°C (40°F) or less. Indoor rinks have a fairly constant load. Condenser air-side temperature variation is large in both cases.

- Refrigerated warehouses. Frozen food (-18°C; 0°F) warehouse loads are more constant than cool storage (5°C; 40°F) loads, making frozen food warehouses the more attractive application.

- Process cooling applications. Many process loads are constant or fairly constant throughout the year. In general, however, the assumptions used for air conditioning and refrigerated case and storage applications are not valid and analyses of savings must be made on a case-by-case basis.

- Air conditioning systems. Large, multi-story buildings have core zones in which workday cooling loads are fairly constant throughout the year. Core DX equipment operating in cold or temperate climates that cannot be retrofit with air-side economizers should therefore be targeted for LRP application.

- Heat pump systems. Residential heat pump systems are potential retrofit candidates in climates where annual run time in heating or cooling mode is large. Large heat pump systems, while less common, may also be considered for retrofit. The additional controls complexity involving the reversing valve signal must be considered in all heat pump systems. For cooling mode operation, the LRP is installed in the outdoor unit, as in a conventional split-unit air-conditioning system. For heating mode the LRP must be installed at the indoor coil. In some cases it may be cost effective to install two pumps to obtain LRP savings in both modes.

Remember, climates with wide variations in ambient temperature in the periods when the refrigeration equipment must operate generally favor LRP retrofits involving conversion from minimum head pressure to floating-head control.

## *What to Avoid*

The LRP technology is usually not appropriate in the following refrigeration applications.

- Poor candidates for floating-head conversion. These include refrigeration systems 1) that already have floating-head control, 2) that have minimum head pressure controls which are difficult to modify, and 3) that offer little savings potential by conversion to floating-head control.

- Flooded evaporator machines. In most cases these machines already have floating-head controls and require no minimum head for proper throttling valve operation.

- Refrigerating systems involving indoor condensers. This class of equipment operates over a narrow range of condenser air-side temperature (near room temperature) and includes domestic refrigerators.

An application checklist is presented in Appendix D. The first-cut data may be collected and analyzed by the site energy manager. The second-cut data must be collected by a refrigeration technician.

### *Equipment Integration*

**Size and location**. In package equipment, a suitable pump location can usually be found within the enclosure. The pump and receiver are of comparable size and the receiver is often found attached to the enclosure floor at the base of the condenser coil. There is usually room here adjacent to the receiver for the pump. In refrigerated display case applications, the receiver is usually located in a mechanical room on (or adjacent to) the compressor rack and can be very large. The outdoor condenser, being some distance from the receiver, may not be a viable pump location. The pump can be set adjacent to the rack with its motor bracket secured to the rack. It is important to minimize pressure drop between the receiver and pump inlet by using a short, straight pipe run and an adequately sized isolation valve. The pump inlet should be level with or below the bottom of the receiver tank.

**Thermostatic expansion valve.** The intended function of the TEV is unchanged by the LRP installation. However, it is important to check for proper TEV operation because the amount of liquid reaching a compressor because of a TEV fault will, if anything, increase after LRP installation and hasten the compressor's demise (Schoen 1992, Vinnicombe 1991). The TEV should be adjusted per system manufacturer's specifications--usually 2 to 7 K (4 to 12°F) superheat.

**Flash gas control**. Some systems employ a flash gas sensor downstream of the receiver to control subcooling by modulating condenser flow. A condenser shunt valve is opened to reduce the pressure difference driving the flow of refrigerant through the condenser whenever flash gas is detected. To realize the full potential savings, the LRP must be installed between the receiver and the flash gas sensor. The sensor may have to be relocated in some applications. It may be possible to simply disable the bypass valve in other applications; consult the manufacturer of the target equipment.

**Condenser heat control**. There are a number of schemes for cycling or modulating condenser air or water flow to maintain minimum head pressure. Most systems use some combination of pressure setpoint and temperature setpoint controllers and interlocks. The objective of LRP retrofit is to reduce the minimum head pressure to the larger of the minimums required by the compressor or TEV manufacturer. This is best accomplished by a technician familiar with the LRP technology and the equipment to which it is being applied. In space cooling applications, where suction pressure is more variable, greater savings can be achieved by using a differential pressure control to maintain minimum pressures required across the compressor and TEV.

**Capacity control**. Capacity control can generally be left as found. The pump should be wired to run whenever any of the compressors are on. In rare cases it may be beneficial for multiple liquid refrigerant pumps to be staged in parallel with compressors.

**Equipment warranties**. The prospective user should ask the refrigeration system's supplier to accept the LRP application before it is installed. In new installations a factory LRP installation, or field installation by factory authorized technicians, may be possible. A sample specification for procuring LRP for new or existing refrigeration equipment is given in Appendix C.

### *Costs*

Liquid refrigerant pumps are listed by nominal refrigeration capacity. Application-specific parameters, such as refrigerant, static head, type and size of TEV, and compressor modulation or staging controls may necessitate selection of one size larger or smaller than the nominal size or in selecting multiple parallel pumps to obtain a given aggregate capacity. In the following table, the capacities of available pump sizes are indicated for low-temperature refrigeration (R-502) and air conditioning (R-22) (Hy-Save 1994). Pump and installation costs may vary by distributor and installer from the costs shown (Smith 1993).

### *Utility Incentives and Support*

Of the 53 utilities contacted, 25 offer demand-side management (DSM) incentives to commercial and industrial customers. Twenty-one offer custom incentives and 17 of these offer an LRP-specific incentive. Three utilities specifically stated that they do not support LRP retrofits. Most incentives fall under a custom retrofit category of DSM measures. In some cases, the utility is prepared to make an application-specific analysis of life-cycle cost, as well as an estimation of expected annual energy savings. The numbers provided by a utility analysis can often be plugged directly into the BLCC program to obtain a FEMP-acceptable life-cycle cost analysis.

# Technology Performance

About 12,500 liquid refrigerant pumps have reportedly been installed in the private sector. About 200 installations are reported in the federal sector. Observations about

**Available LR pump capacities, application data, and approximate costs**

| Typical Capacity $tons_{thermal}(kW_{thermal})$ | | Boost[a] Pressure | Electrical | | | Length | Weight | Cost[b] Elements ($) | |
|---|---|---|---|---|---|---|---|---|---|
| Freezer[c] | A/C[d] | psi(kPa) | Voltage | Ø | hp (W) | in. (cm) | lbm (kg) | LRP Unit | Installation[e] |
| 7.8(27) | 13.4(47) | 4.1(28) | 230 | 1 | 0.04(30) | 7.8(20) | 7(3) | 604 | 500 |
| 7.8(27) | 13.3(47) | 4.1(28) | 230/460 | 3 | 0.13(95) | 10.4(26) | 17(8) | 803 | 550 |
| 5.8(21) | 10.0(35) | 5.1(35) | 230/460 | 3 | 0.13(95) | 13.4(34) | 20(9) | 1045[f] | 550 |
| 10.4(37) | 17.9(63) | 8.2(56) | 230 | 1 | 0.2(150) | 11.3(28) | 19(9) | 1444 | 700 |
| 14.8(52) | 25.4(89) | 10.0(68) | 230/460 | 3 | 0.4(300) | 15.0(38) | 29(13) | 1559 | 720 |
| 51(180) | 88(310) | 19.0(129) | 230/460 | 3 | 0.5(370) | 15.6(39) | 29(23) | 3833 | 820 |
| 66(230) | 113(400) | 14.9(101) | 230/460 | 3 | 0.75(560) | 17.3(44) | 44(20) | 5649 | 920 |

(a) Capacity depends on pump's operating point; here pressure boost at midpoint of pump's preferred operating range is assumed.
(b) Representative of a particular manufacturer's products, applied to a typical basic system, at the time of this Alert's writing.
(c) Refrigeration application with saturation temperatures of -24°F suction and 86°F condensing using R-502 refrigerant.
(d) Air conditioning application with saturation temperatures of 34°F suction and 105°F condensing using R-22 refrigerant.
(e) Labor plus material (tees, valves, dryer, etc.) plus overhead and profit for typical installation.
(f) High-pressure boost model.

field performance obtained from federal and private-sector users are summarized in this section.

### *Field Experience*

The large number of field tests that have been reported confirm typical energy savings of 10 to 30% and confirm the validity of a temperature-bin-based calculation to predict savings in a variety of applications. A significant number of installations with lower savings have also been reported. It appears that in most of these cases the low savings are due to equipment and/or operating characteristics that made the target application a poor candidate for LRP retrofit in the first place.

One federal facility energy manager reports that the minimum head pressure control was restored to its pre-retrofit setpoint by a maintenance contractor. This points to the importance of adequate training. Most new technologies that integrate with existing systems are susceptible to this kind of treatment. The importance of operation and maintenance (O&M) training and thorough and accessible installation-specific documentation cannot be overemphasized.

### *Energy Savings*

The commercial installation base of 11,000 LRP systems (many with multiple pumps) involves about 350,000 MW (100,000 tons) of capacity. This corresponds to about 1 billion kWh/yr (10 trillion Btu primary energy) aggregate refrigeration end-use consumption. Assuming, conservatively, a typical savings of 10%, the existing LRP installation base is already saving at least 100 million kWh/yr in electricity, or at least 0.03% of annual U.S. electrical consumption for commercial-sector cooling and refrigeration (Spanner 1992).

### *Maintenance*

The centrifugal pump implementation of the LRP technology is a mature product. These pumps are expected to become available with five-year warranties beginning in 1995, based on wear-test results that project a time-to-failure of over 60,000 continuous operating hours in properly charged and operated refrigeration systems. This durability has been achieved by continuous refinement of pump materials, design details, and tolerances. The cost of 5-year LRP impeller renewal will be more than offset by the maintenance savings stemming from reduced compressor run time and reduced discharge pressure in most cases.

However, LRP retrofit also involves changing the minimum head pressure setpoint or other control modifications. Staff must be properly trained in the operation and maintenance of floating-head controls. LRP dealers generally provide this training at the time of installation and should be asked to provide additional training when new O&M staff are employed after installation. At sites with computer-dispatched preventive maintenance, the maintenance program should be modified to reflect the lower discharge pressure setpoint and a check of each LRP's operation at least once per year.

### *Other Impacts*

There are no special code compliance issues beyond the usual codes and regulations that must be observed when installing or servicing refrigeration equipment. The pump must meet ASME and any other applicable pressure/safety codes. Refrigerant handling regulations must be observed.

There are no significant negative environmental impacts associated with a properly installed LRP system. Moreover, the associated energy savings result in reduced power plant emissions. Typical per-MWh emissions reductions are 0.14 kg (0.3 pounds) of particulates, 1.5 kg (3.3 pounds) of sulfur oxides, 2.4 kg (5.3 pounds) of nitrogen oxides, and 780 kg (1,720 pounds) of carbon dioxide. These numbers vary with time and region, depending on the generation mix (EPA 1994; Nemeth 1993).

# Case Study

The case study described here concerns a 9-ton refrigeration system in the commissary at Fort Drum. Fort Drum is a U.S. Army facility located near Watertown, New York.

## *Facility Description*

The Fort Drum Commissary has three low-temperature and four medium-temperature refrigeration racks that provide cooling to refrigerated store rooms and display cases for frozen food, meat, and dairy products. The commissary was built in 1989. The location in the upstate New York snowbelt has 4,098 heating Celcius degree-days (7376 °F-days), 256 cooling Celcius degree-days (461°F-days), and a 2.5% cooling design temperature of 28°C (83°F). The on-peak electricity price of $58.59/MWh is applied between 10:00 a.m. and 10:00 p.m. on workdays. The off-peak price of $43.82/MWh is in effect at all other times. The monthly on-peak demand charge is $5.51/ peak kW, and there is no ratchet or off-peak demand charge.

Application of the LRP technology to rack #3, a low-temperature system, is considered here.

## *Existing Technology Description*

Rack #3 has three parallel compressors of 10, 10, and 5 hp with a combined rating of 9 tons (2 kW/ton nominal) at design conditions. The compressor rack is shown in Figure 7.

Rack #3 serves two walk-in freezers and a frozen-food display case. Case temperatures are maintained between -23 and -18°C (-10 and 0°F). The system is charged with R-502 refrigerant. Like most display case applications, it operates 24 hr/day, 365 day/yr.

Condenser capacity is 27.5 kW (93,773 Btuh) and aggregate evaporator capacity is 32.3 kW (110,300 Btuh). There are six 1-hp condenser fans controlled in pairs. The condenser is pictured in Figure 8, which also illustrates the

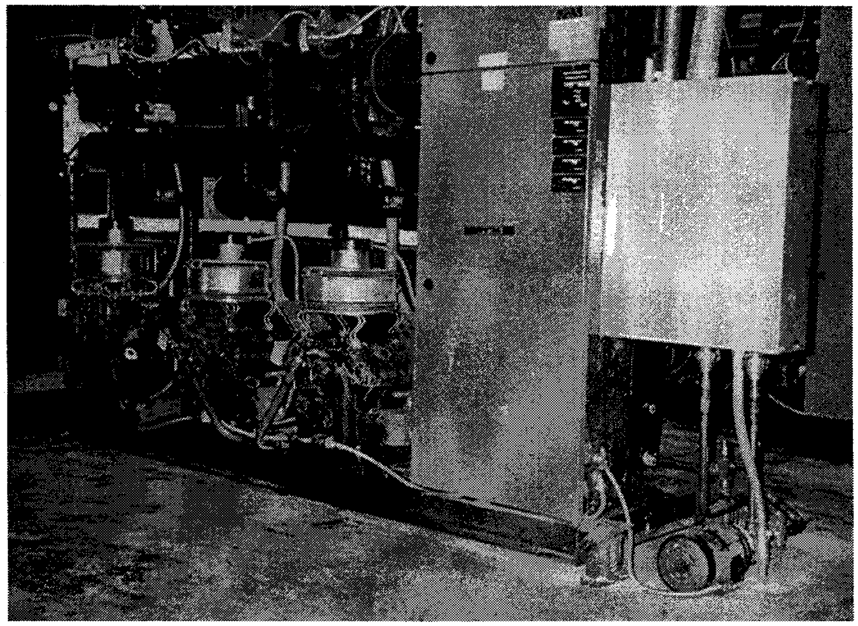


**Fig. 7. Refrigeration rack #3 at Fort Drum commissary (LRP in lower right-hand corner)**

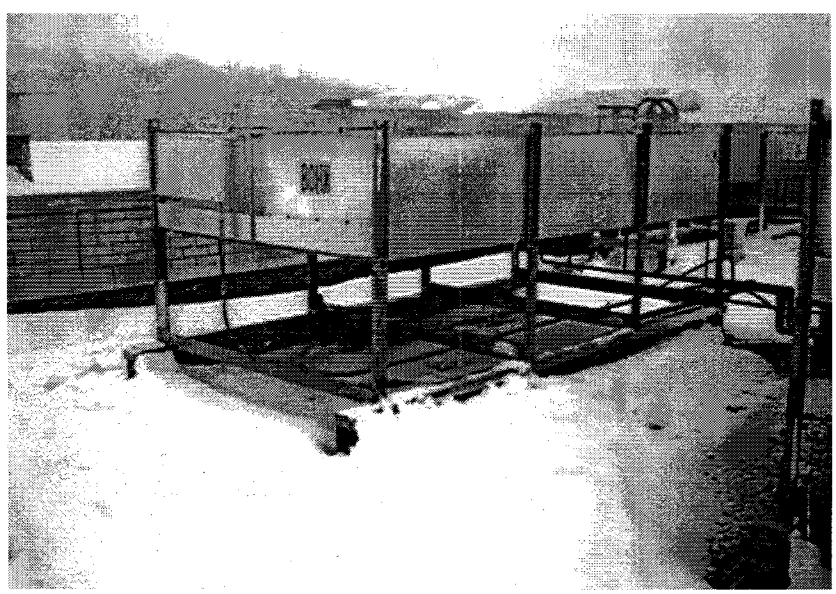


**Fig. 8. Condenser for refrigeration rack #3 at Fort Drum commissary**

typical (cold) ambient conditions in which floating-head operation is beneficial.

The electric load of rack #3 and associated condenser fans was monitored for 14 days (6-19 May 1992). During that time, outdoor temperature ranged from -1 to 27°C (30 to 80°F). Average load was 15.3 kW, or two-thirds of design load, indicating that the capacity of the existing equipment is quite adequate. On the basis of this average load, annual energy use is 131,500 kWh. Note that similar data could have been obtained using a time-clock wired in parallel with each compressor and in parallel with each pair of condenser fans. If monitoring is not possible, a load factor must be assumed (75% is reasonable, higher if the facility manager reports conditions when display case setpoint cannot be maintained).

A heat recovery desuperheater is included in the refrigerant circuit to provide free service hot water heating.

Rack #3 is located in a well-organized and spacious mechanical room located above the retail sales area. A high-bay warehouse area adjoins on one side and the condensers are located immediately outside one of the exterior walls. The equipment has at least 15 years of useful service life remaining.

## *LRP Equipment Selection*

A listing, by nominal refrigeration capacity of LRP, was presented in the Applications section. Application-specific parameters, such as refrigerant, static head, type and size of TEV, and compressor modulation or staging controls, may result in selecting one size larger or smaller than the nominal size or in selecting multiple parallel or series pumps to obtain a given aggregate capacity or pressure boost. Thus, while a nominal 7.8-ton pump might have been adequate, a nominal 10.4-ton unit was selected for rack #3 to ensure adequate flow at full capacity under all conditions.

## *Savings Potential*

The energy savings are estimated by an outdoor temperature bin method. The calculations are performed in a spreadsheet using 5°F bin data, since this is the form in which data are readily available to most federal energy managers (TM 5-785).

The analysis begins by estimating baseline energy use, as shown in the table below. Column 1 indicates the base of each temperature bin, e.g., hours with recorded temperatures of 90 to 94°F are accumulated in the "90" row. Column 2 gives the average number of hours per year in each temperature bin. Column 3 gives the average refrigerant condensing temperature, in this case the bin midpoint temperature plus 15°F. The condensing-ambient temperature

**Fort Drum LRP energy savings analysis by the bin method[a]**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|
| $T_{bin}$[b] | freq[c] | $T_{cnd}$[d] | PtLd[e] | avgPwr | Energy | $T_{cndLRP}$ | LRP Savings | | | |
| °F(C) | hr/yr | °F(C) | % | kW | kW/yr | °F(C) | %/°F(%/C)[f] | °F(C) | % | kWh/yr |
| 95(35) | 0 | 112(44) | 81 | 24.2 | 0 | 112(44) | 1.250(2.250) | 0 | 0.00 | 0 |
| 90(32) | 15 | 107(42) | 77 | 18.6 | 280 | 107(42) | 1.196(2.153) | 0 | 0.00 | 0 |
| 85(29) | 88 | 102(39) | 73 | 17.7 | 1555 | 102(39) | 1.142(2.006) | 0 | 0.00 | 0 |
| 80(27) | 206 | 97(36) | 69 | 16.7 | 3440 | 97(36) | 1.088(1.958) | 0 | 0.00 | 0 |
| 75(24) | 360 | 95(35)[g] | 65 | 15.7 | 5663 | 92(33) | 1.034(1.861) | 3 | 3.10 | 176 |
| 70(21) | 540 | 95(35) | 65 | 15.7 | 8494 | 87(31) | 0.981(1.766) | 8 | 7.84 | 666 |
| 65(18) | 690 | 95(35) | 65 | 15.7 | 10854 | 82(28) | 0.927(1.669) | 13 | 12.05 | 1308 |
| 60(16) | 704 | 95(35) | 65 | 15.7 | 11074 | 77(25) | 0.883(1.589) | 18 | 15.89 | 1759 |
| 55(13) | 680 | 95(35) | 65 | 15.7 | 10696 | 72(22) | 0.845(1.521) | 23 | 19.43 | 2078 |
| <55(13)[h] | 5477 | 95(35) | 65 | 15.7 | 86153 | 70(21)[g] | 0.830(1.494) | 25 | 20.74 | 17871 |
| Totals | 8760 | | | | 138208 | | | | 17.26 | 23859 |

(a) A site-specific, equipment-specific spreadsheet analysis is customarily provided by the LRP installer or dealer.
(b) When the original data is reported in engineering units we give the SI conversion second, i.e., engineering(SI).
(c) Frequency of occurrence based on data from the closest TM-785 site, Griffiss AFB, near Rome, NY.
(d) *Condensing temperature* ($T_{cnd}$) equals *bin temperature* ($T_{bin}$) plus *condenser approach temperature* as measured under load or reported in the manufacturer's data.
(e) Annual percent compressor run time.
(f) From ASHRAE (1993) Tables 16.9 and 16.10 or from manufacturer's compressor or system performance data.
(g) The minimum condensing temperature is the refrigerant's saturation temperature at the minimum head pressure setpoint.
(h) Add bins (spreadsheet rows) as needed to extend $T_{cndLRP}$ to correspond to minimum head pressure setpoint.

difference can be measured during typical steady operating conditions (preferred) or can be obtained from the equipment manufacturer. Column 4 gives the average load fraction in each bin based on the original design calculations. Column 5 gives the average compressor power corresponding to column 4. Column 6 is the average annual bin energy use, the product of columns 2 and 5. The sum of the column 6 entries is the total annual baseline energy.

The savings from reduced condensing temperatures result, in cool weather, from having lowered the minimum head pressure setpoint that controls condenser fan cycling. Column 7 shows the average condensing temperature that will be experienced in each bin after the LRP retrofit. Column 8 gives the power savings as a percent per degree of condensing temperature reduction. Column 9 gives the reduction in condensing temperature, the difference between the column 3 and column 7 temperatures. Column 10 is the total percent reduction, the product of columns 8 and 9. Column 11 is the annual bin energy savings, the product of columns 6 and 10. The sum of the column 11 entries is the total annual savings.

### *Life-Cycle Cost*

The total installation cost, including material, labor, overhead and profit, was $2280. Design and SIOH are each assumed to add 6% to installation cost. The reimbursement rate for the Commissary is 0.0833 $/kWh with no demand charge. The additional non-energy O&M cost for the retrofit was taken to be $300 every 5 years for impeller renewal. Feeding these numbers, and the annual energy use numbers, to the 1992 BLCC program gives the results shown in the "printout."

### *Implementation and Post-Implementation Experience*

The LRP was installed 20 April 1992. The installation took 1 day, including refrigerant transfer and recharge. The condensing setpoint was reduced from 95 to 70°F at the time of installation. A lower setpoint could have been used, based on the 30 psid minimum TEV pressure drop; however, the installer and site energy engineer decided to use a conservative setting because this was the first installation at Ft. Drum and one of the first for the Army. Flash gas was observed downstream of the receiver before the retrofit; no flash gas was observed after the retrofit.

The electric load of rack #3 was monitored for 12 days (22 April to 3 May 1992) during which time ambient temperature ranged from -1 to 27°C (30 to 80°F). Average load was 13.15 kW, or 2.16 kW less than the pre-retrofit load. On the basis of this average load, annual energy use is 115,200 kWh.

"Throughout the testing period, all existing and new equipment performed reliably... As expected, the highest energy savings occurred at the lower ambient temperatures" (Rowley 1993). The measured savings percentage was less than the estimated annual savings percentage by 3 points. "...this discrepancy can be explained. No data was taken [below] 30°F. Colder conditions are where a significant portion of the [LRP] savings would occur" (Rowley 1993).

# The Technology in Perspective

The future of the LRP technology in the federal sector looks good. There are many potential applications involving DX refrigeration equipment with minimum head pressure controls. Since building demolition, renovation, and new construction rates are low in the federal sector this existing equipment will, in most cases, stay in service until it wears out. Elaborate modification of such equipment and associated controls is not attractive because it presents an added maintenance burden. The LRP technology, on the other hand, provides a simple, low maintenance path to eliminating the inefficiencies of plants with minimum head pressure control and associated high discharge temperatures.

### *The Technology's Development*

The liquid refrigeration pumping technology has been shown through laboratory testing, field testing and theoretical analysis to be technically valid and economically attractive in many applications. Energy savings have been verified in a large number of field tests over the last decade. The remaining barriers to rapid implementation involve user acceptance and correct application. This Technology Alert is intended to address these concerns by reporting on the collective experience of LRP users and evaluators and by providing application guidance.

### *Relation to Other Technologies*

The LRP has the virtue of being a simple, reliable fix to a number of refrigeration "problems" that are inherent to conventionally designed DX refrigeration systems. There are other solutions that are well known to all manufacturers of this type of equipment. Some, such as increased evaporator, condenser, drier, and liquid line flow capacities, are simple and only add cost. Improved controls (for example, sensitive flash gas sensor and electronic TEV), on the other hand, may add to O&M costs and increase overall failure rates.

With the LRP installed, another energy-saving modification, liquid injection desuperheating, can be employed. This modification results in more effective use of the condenser heat transfer surfaces and reduced condenser refrigerant-side pressure drop (Holtzapple 1989).

In air conditioning applications with high latent-to-sensible load ratios or low supply-air dew point requirements, a supplementary coil can be added downstream of the main cooling coil to reduce sensible capacity and increase latent capacity (Hyde 1994b). In this arrangement, the pumped refrigerant is further subcooled as it passes through the supplementary coil en route to the TEV and main coil. (The pump is necessary to prevent flash vapor formation in the supplementary coil.) The resulting supply air has a lower dew point but a higher dry bulb temperature.

Analysis of the energy savings that can be achieved by adding the liquid injection desuperheating or supplementary dehumidification coil features to an LRP installation is complex—considerably more complex than the analysis of savings achieved by converting minimum head pressure controls to floating-head controls. The facility manager must therefore be cautious when adding these features to an LRP retrofit. A number of apparent misapplications of liquid injection desuperheating have been identified in federal and commercial buildings.

These technologies may be the subject of another Federal Technology Alert or Test Bed Demonstration.

NIST BLCC: COMPARATIVE ECONOMIC ANALYSIS

BASE CASE: RAK3BAS[a]
ALTERNATIVE: RAK3LRP[b]

PRINCIPAL STUDY PARAMETERS:

ANALYSIS TYPE: Federal Analysis--Energy Conservation Projects
STUDY PERIOD: 15 YEARS (1992 THROUGH 2006)
DISCOUNT RATE: 4.0% Real (exclusive of general inflation)

COMPARISON OF PRESENT-VALUE COSTS

| | BASE CASE: RAK3BAS | ALTERNATIVE: RAK3LRP | SAVINGS FROM ALT. |
|---|---|---|---|
| INITIAL INVESTMENT ITEM(S): | | | |
| CASH REQUIREMENTS AS OF OCCUPANCY | $0 | $2,280 | -$2,280 |
| SUBTOTAL | $0 | $2,280 | -$2,280 |
| FUTURE COST ITEMS: | | | |
| ENERGY EXPENDITURES | $123,724 | $102,366 | $21,359 |
| SUBTOTAL | $123,724 | $102,366 | $21,359 |
| TOTAL P.V. LIFE-CYCLE COST | $123,724 | $104,646 | $19,079 |

NET SAVINGS FROM PROJECT RAK3LRP COMPARED TO PROJECT RAK3BAS

| | | |
|---|---|---|
| Net Savings = | P.V. of non-investment savings | $21,359 |
| | - Increased total investment | $2,280 |
| | Net Savings: | $19,079 |

SAVINGS-TO-INVESTMENT RATIO (SIR)
FOR PROJECT RAK3LRP COMPARED TO PROJECT RAK3BAS

$$SIR = \frac{\text{P.V. of non-investment savings}}{\text{Increased total investment}} = 9.37$$

ADJUSTED INTERNAL RATE OF RETURN (AIRR)
FOR PROJECT RAK3LRP COMPARED TO PROJECT RAK3BAS
(Reinvestment rate = 4.00%; Study period = 15 years)

AIRR = 20.73%

Note: the NS, SIR, and AIRR computations include differential capital replacement costs and resale value (if any) as investment costs, per NIST Handbook 135 (FEMP analysis only).

(a) File name for base case.
(b) File name for LRP alternative.

*Technology Outlook*

There are some opportunities, relating to general trends in motor and controls technologies, to make the LRP technology even more attractive.

A major portion of the typical LRP retrofit costs are for plumbing, wiring, and the evacuate/recharge process. Another large portion may be attributed to the amortized development and production and distribution start-up and expansion costs. The component manufacturing and assembly costs comprise only a fraction of the total retrofit cost. Therefore, refinements in LRP motor and pump characteristics may well be justified. A variable-speed, electrically commutated permanent-magnet motor with TEV differential pressure control (TEV not fully open) and evaporator superheat control (TEV fully open) would minimize pumping energy. TEV and LRP controls could be integrated into a reliable, low-cost package in this technology scenario. Liquid injection controls could also be integrated in applications (for example, package equipment) where evaporator-condenser proximity allows. The variable-speed motor technologies may also be used to benefit overall system efficiency by modulating evaporator and condenser air-side flow rates and compressor speed/power in response to load and conditions. This will result in closer evaporator and condenser approach temperatures to further reduce compressor head load but may require TEV modifications.

# Suppliers

One manufacturer of field proven liquid refrigerant pumps responded to the New Technology solicitation of October 1993:

Hy-Save, Inc.
18448 S.E. Pine Street
Portland, Oregon 97233-4859
Russ Smith, VP Marketing
(503) 667-5091; FAX (503) 667-5865

# Who is Using the Technology

The list below includes federal sector contacts, agencies, and locations that already have the new technology installed and operating. Many of the listed federal energy managers are knowledgeable about LRP, and most already have LRP systems installed and operating. The reader is invited to ask questions and learn more about the new technology.

Air Force Academy
Colorado Springs, Colorado
Edward Siggldorf
(719) 472-4714

Marine Corps Logistics Base
Albany, Georgia
Andy Dorer
(912)846-4976

Marine Corps Aviation Station
Beaufort, South Carolina
David Brown
(803) 522-7539

U.S. Marine Logistics Base
Barstow, California
Larry Emmons
(619) 577-6739

USMC
29 Palms, California
Stewart Hammons
(619) 368-7789

Fermi National Accelerator Lab
Chicago, Illinois
Steve Krstulovich
(708) 840-3000

Fairchild AFB
Spokane, Washington
Dan Whicker
(509) 247-5468

Fort Drum
Watertown, New York
Steve Rowley
(315) 772-5433

Naval Facilities Engineering Service Center
Port Hueneme, California
Bradly Yee
(805) 982-4259

Smithsonian Institution
Washington, DC
Kenneth Fisher
(301) 763-5196

**Committed Sites**

Defense Commissary Agency (DECA)
Fort Lee, Virginia
Wade Shankle
(804) 734-8857

Naval Surface Warfare Center
Crane Naval Facility, Indiana
Larry Cullop
(812) 854-3675

**Proposed Sites**

Patrick AFB
Florida

Fort Jackson
South Carolina

GSA
Tucson, Arizona

GSA
Jacksonville, Florida

NOAA
Seattle, Washington

VA Medical Center
Oregon

Fort McPherson
Atlanta, Georgia

# For Further Information

**User and third party field and lab test reports:**


Engstrom, R. A. 1994. *LPA/Superheat Suppression Demonstration, McClellan AFB, Building 1104*. 4-page letter report, 3 May 1994.

Fiorino, D. 1988. *LPA Performance on Four Air-conditioning Systems at Texas Instruments' Miller Road Facility*. 2-page letter report, 1 August 1988.

*Rowley, S. E. 1993. *Test Report on Liquid Pressure Amplification at the Fort Drum Commissary*. 10 pages and 10 figures and tables and four additional attachments. Energy Branch, DEH, Fort Drum, NY. April 1993.

*Vinnicombe, G. A. and G. A. Ibrahim. 1991. *The Performance of Refrigeration Expansion Devices* (13 pages and 15 figures), Department of Mechanical Engineering, King's College London; Electricity Association Technology, Ltd., Contract U1420.


**Manufacturer's Application Notes:**


Hy-Save. 1986. *The Liquid Pressure System*, 3rd edition, 24 pages, Hy-Save, Inc.

Hy-Save. 1986. *The Liquid Pressure System--Supermarket Refrigeration Application Guide*. 5 pages, Hy-Save, Inc.

Hy-Save. 1991. *The Thermodynamic Principles of Liquid Pressure Amplification and Liquid Injection*. 5 pages, Hy-Save, Inc.

Hy-Save. 1992. *Liquid Injection with the LPA*. 1 page. Hy-Save, Inc.

Hy-Save. 1993a. *The Hy-Dry System*. 2 pages and 5 figures. Hy-Save, Inc.

Hy-Save. 1993b. *Energy and Performance Analysis Programs for Hy-Save Systems*. 16 pages. Hy-Save, Inc., December 1993.

*Hy-Save. 1994. *How to Size LPA*, Hy-Save, Inc., July 14, 1994.

Powers, M. 1992. *Liquid Pressure Amplification (LPA) and Liquid Injection Technology Overview*.

Delaney, P. S. 1988. *Evaluation of Fluid Pressure Amplifiers at Fairchild AFB, Spokane, WA*. NEESA 41-054, 2 pages. Executive Summary, March 1988, Port Hueneme, CA.

**Utility, Information Service, or Government Agency Tech-Transfer Literature:**

Hibberd, D. 1993. *The Liquid Pressure Amplifier*. E-Source, Inc., E-News Series TU-93-5, Boulder, CO, May 1993.

Mouzouris, Y. A. 1987. *Refrigeration Improvement by Liquid Pressure Amplification*, Bulletin 871, 1 page, U. Kansas EADC.

PGE. 1988. *LPA Pump Boosts Refrigeration Efficiency*, two-page bulletin, re:source, Portland General Electric's Energy Resource Center.

Yee, B. and D. Hardisty. 1994. *Liquid Pressure Amplification and Liquid Injection in Air Conditioning and Refrigeration Systems*. Naval Facilities Engineering Service Center, Technical Data Sheet Series, TDS-2005-ENG, Port Hueneme, CA.

**Case Studies:**

Babb, B. R. 1987. "Hauke Endorses Hy-Save System," *Oregon Independent Grocer*, June/July 1987.

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# Appendixes

Appendix A: Federal Life-Cycle Costing Procedures and the BLCC Software

Appendix B: Life-Cycle Cost Analysis Summary: Energy Conservation Investment Program (ECIP)

Appendix C: Sample Specification for Integrating LRP in New or Existing Equipment

Appendix D: Data for Evaluating a Candidate LRP Application

# Appendix A

# Federal Life-Cycle Costing Procedures and the BLCC Software

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (10 CFR Part 436). A life-cycle cost evaluation computes the total long-run costs of a number of potential actions, and selects the action that minimizes the long-run costs. When considering retrofits, sticking with the existing equipment is one potential action, often called the *baseline* condition. The life-cycle cost (LCC) of a potential investment is the present value of all of the costs associated with the investment over time.

The first step in calculating the LCC is the identification of the costs. *Installed Cost* includes cost of materials purchased and the labor required to install them (for example, the price of an energy-efficient lighting fixture, plus cost of labor to install it). *Energy Cost* includes annual expenditures on energy to operate equipment. (For example, a lighting fixture that draws 100 watts and operates 2,000 hours annually requires 200,000 watt-hours (200 kWh) annually. At an electricity price of $0.10 per kWh, this fixture has an annual energy cost of $20.) *Nonfuel Operations and Maintenance* includes annual expenditures on parts and activities required to operate equipment (for example, replacing burned out light bulbs). *Replacement Costs* include expenditures to replace equipment upon failure (for example, replacing an oil furnace when it is no longer usable).

Because LCC includes the cost of money, periodic and aperiodic maintenance (O&M) and equipment replacement costs, energy escalation rates, and salvage value, it is usually expressed as a present value, which is evaluated by

$$LCC = PV(IC) + PV(EC) + PV(OM) + PV(REP)$$

where PV(x) denotes "present value of cost stream x,"
IC is the installed cost,
EC is the annual energy cost,
OM is the annual nonenergy O&M cost, and
REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost-reducing alternative and the LCC of the existing, or baseline, equipment. If the alternative's LCC is less than the baseline's LCC, the alternative is said to have a positive NPV, i.e., it is cost-effective. NPV is thus given by

$$NPV = PV(EC_0) - PV(EC_1)) + PV(OM_0) - PV(OM_1)) + PV(REP_0) - PV(REP_1)) - PV(IC)$$

or

$$NPV = PV(ECS) + PV(OMS) + PV(REPS) - PV(IC)$$

where subscript 0 denotes the existing or baseline condition,
subscript 1 denotes the energy cost saving measure,
IC is the installation cost of the alternative (note that the IC of the baseline is assumed zero),
ECS is the annual energy cost savings,
OMS is the annual nonenergy O&M savings, and
REPS is the future replacement savings.

Levelized energy cost (LEC) is the breakeven energy price (blended) at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost-effective (NPV >= 0). Thus, a project's LEC is given by

$$PV(LEC*EUS) = PV(OMS) + PV(REPS) - PV(IC)$$

where EUS is the annual energy use savings (energy units/yr). Savings-to-investment ratio (SIR) is the total (PV) savings of a measure divided by its installation cost:

$$SIR = (PV(ECS) + PV(OMS) + PV(REPS))/PV(IC).$$

Some of the tedious effort of life-cycle cost calculations can be avoided by using the Building Life-Cycle Cost software, BLCC, developed by NIST. For copies of BLCC, call the FEMP Help Desk at (800) 566-2877.

# Appendix B

# Life-Cycle Cost Analysis Summary Energy Conservation Investment Program (ECIP)

The Fort Drum LRP project that serves as a case study for this Technology Alert might have been funded as part of an ECIP project. The life-cycle cost analysis for each element of an ECIP proposal is required in the standard format shown here. For complete instructions, see "ECIP Guidance," a memorandum from the Engineering & Housing Support Center, Ft. Belvoir, Virginia, 4 November 1992. Non-DoD agencies have similar life-cycle cost documentation requirements.

Location: Ft. Drum, NY Project No. 99999
Project Title: Case Study for New Technology Assessment Fiscal Year 1993
Discrete Portion Name: Liquid Refrigeration Pump--Commissary Refrigeration Rack#3
Analysis Date: 9-30-91 Economic Life: 20 years Preparer: Steve Rowley

1. Investment Costs:

| | | |
|---|---|---|
| A. | Construction Cost | $ 2280 |
| B. | SIOH | $ 137 |
| C. | Design Cost | $ 137 |
| D. | Total Cost (1A+1B+1C) | $ 2554 |
| E. | Salvage Value of Existing Equipment | $ 0 |
| F. | Public Utility Company Rebate | $ 0 |
| G. | Total Investment (1D-1E-1F) | $ 2554 |

2. Energy Savings (+)/Cost (-):
Date of NISTIR 85-3273-X Used for Discount Factors FY92

| Energy Source | Cost $/MBtu(1) | Saving MBtu/yr(2) | Annual $ Savings(3) | Discount Factor(4) | Discounted Savings(5) |
|---|---|---|---|---|---|
| A. ELEC | $ 24.4 | 81.4 | $ 1987 | 13.15 | $ 26130 |
| B. DIST | $ | | $ | | $ |
| C. RESID | $ | | $ | | $ |
| D. NG | $ | | $ | | $ |
| E. PPG | $ | | $ | | $ |
| F. COAL | $ | | $ | | $ |
| G. SOLAR | $ | | $ | | $ |
| H. GEOTH | $ | | $ | | $ |
| I. BIOMA | $ | | $ | | $ |
| J. REFUS | $ | | $ | | $ |
| K. WIND | $ | | $ | | $ |
| L. OTHER | $ | | $ | | $ |
| M. DEMAND SAVINGS | | | $ | | $ |
| N. TOTAL | | 81.4 | $ 1987 | | $ 26130 |

3. Non Energy Savings (+) or Cost (-):

| | | |
|---|---|---|
| A. | Annual Recurring (+/-) | $ 0 |
| | (1) Discount Factor (Table A) | 13.59 |
| | (2) Discounted Savings/Cost (3A X 3A1) | $ 0 |

B. Non Recurring Savings (+) or Cost (-)

| | Item | Savings(+) Cost(-) (1) | Year of Occur. (2) | Discount Factor (3) | Discounted Savings (+) Cost(-) (4) |
|---|---|---|---|---|---|
| a. | | $ -300 | 1998 | 0.82 | $ -246 |
| b. | | $ -300 | 2003 | 0.68 | $ -204 |
| c. | | $ -300 | 2008 | 0.56 | $ -168 |
| d. | Total | $ -900 | | | $ -618 |

C. Total Non Energy Discounted Savings (3A2+3Bd4) $ -618

| | | |
|---|---|---|
| 4. | Simple Payback 1G/(2N3+3A+(3Bd1/Economic Life)): | 1.26 years |
| 5. | Total Net Discounted Savings (2N5+3C): | $ 25512 |
| 6. | Savings to Investment Ratio (SIR) 5/1G: | 9.99 |
| 7. | Adjusted Internal Rate of Return (AIRR): | 16.68% |

# Appendix C

## Sample Specification for Integrating LRP in New or Existing Equipment

- System must be fitted with a magnetically coupled (no shaft seals), centrifugal, liquid refrigerant pump that is capable of producing the pressure boost (8 to 30 psi) appropriate for the system at the rated maximum system refrigerant flow rate.
- Pump must be of a suitable type for permanent installation in a refrigeration system.
- Pump must be listed (UL standard 207) for psi working pressure appropriate for the system discharge side and temperature rated to 250°F.
- Pump materials and gaskets must be suitable for use with the system refrigerant.
- Pump motor must not be refrigerant cooled. Pump motor windings must be external to the refrigerant containing portions of the system.
- Pump motor must be provided with internal overload protection.
- Pump must be installed by persons trained and licensed in the application of permanently installed liquid refrigerant pumps, or be under the direct and immediate supervision of persons that are trained and licensed.
- Isolation valves shall be installed to facilitate pump servicing. The free areas of the valves shall be equal to or greater than the free areas of the corresponding pump ports.
- A sight glass shall be installed at least ten diameters downstream of the pump discharge port and at least ten diameters downstream of any intervening valve, elbow, or other turbulence inducing element. A Schrader valve shall be installed between the pump and one of the isolation valves.
- A sight glass and Schrader valve shall be installed just upstream of the TEV if either is not present in the existing system.
- A Schrader valve shall be installed between the condenser and pump if none is present in the existing system
- The discharge pressure setpoint shall be reduced to the minimum value that will permit proper compressor and TEV operation and the new setpoint and documented.
- Installer shall test and certify that the TEV maintains correct superheat over the range of TEV pressure drops and the TEV shall be replaced by a balanced port TEV if necessary.
- The contractor shall provide documentation of LRP modifications and related system data including:

  - tagging of pump and minimum head pressure controls
  - submittal of control setpoints before and after retrofit in the attached format (Appendix D)
  - submittal of minimum head pressure characteristics provided by TEV and compressor (or target system) manufacturer
  - submittal of technical product descriptions for all components and controls installed
  - submittal of all maintenance schedules for site's preventive maintenance database
  - annotation of and addendum to facility manager's files regarding the foregoing submittals

- The contractor or LRP supplier shall provide LRP training to facility maintenance staff.

# Appendix D

# Data for Evaluating a Candidate LRP Application

The data indicated must be recorded to document that the target system is a good candidate for LRP retrofit. RETAIN this document with equipment service records!

**General Data for First-Cut Evaluation**

Building__________ Date______ Time______ Recorded by__________________

Application: chiller___ display case___ cold storage___ pkg A/C___

Other________________________________________________________________

Capacity of Evaporator/TEV(s) ____ ____ ____ ____ ____ Total_____kBtuh

Condenser make_____________ model__________________ capacity_____kBtuh

Refrigerant R-___ Replace with R-___ Quantity______lbm

| Compressor: | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| hp | _____ | _____ | _____ | _____ |
| ton | _____ | _____ | _____ | _____ |
| #cylinders | _____ | _____ | _____ | _____ |
| #unloaders | _____ | _____ | _____ | _____ |

Heat recovery load_______(Btuh); temperature:___________°F

| TEV # | type | model | capacity (ton) | pressure (psia) | $T_{saturation}$ (°F) | superheat (°F) |
|---|---|---|---|---|---|---|
| 1 | ________ | ______________ | ________ | ________ | ________ | ________ |
| 2 | ________ | ______________ | ________ | ________ | ________ | ________ |
| 3 | ________ | ______________ | ________ | ________ | ________ | ________ |
| 4 | ________ | ______________ | ________ | ________ | ________ | ________ |
| 5 | ________ | ______________ | ________ | ________ | ________ | ________ |

Condenser pressure control type__________; model____________________

stage 1 pressure setpoint=______psia ($T_{saturation}$=______°F); fan load=______kW

stage 2 pressure setpoint=______psia ($T_{saturation}$=______°F); fan load=______kW

stage 3 pressure setpoint=______psia ($T_{saturation}$=______°F); fan load=______kW

Estimated operating hours by time of year and time of day:

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0000-0800 | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |
| 0800-1600 | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |
| 1600-2400 | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |

**Detailed Data for Second-Cut Evaluation or Performance Verification**
(Obtain this data Before LRP procurement if first-cut evaluation leaves any doubt)

**Before** LRP installation:
Date____________ Time_____________ Technician______________________
Capacities of active TEVs: 1___ 2___ 3___ 4___ 5___ Total____(ton)
Measured refrigerant pressures & temperatures under_____% load:
suction_________psia
discharge_________psia
receiver_________psia
TEV inlet_________psia
evaporator superheat__________°F
compressor superheat__________°F
condenser subcooling__________°F
Conditions: condenser entering AIR or WATER (circle one) tmp________°F
Load: CASE or entering AIR or WATER (circle one) temperature________°F
Flash gas visible?__________(if variable, note conditions & percent of time)

__________________________________________________________________________________

Measured operating hours or kWh (circle one) & average temperature during operation:

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Compressors | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |
| Condns fans | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |
| AverageTamb | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |

**After** LRP installation:
Date____________ Time_____________ Technician______________________
Capacities of active TEVs: 1___ 2___ 3___ 4___ 5___ Total____(ton)
Measured refrigerant pressures & temperatures under_____% load:
suction_________psia
discharge_________psia
receiver_________psia
TEV inlet_________psia
evaporator superheat__________°F
compressor superheat__________°F
condenser subcooling__________°F
Conditions: condenser entering AIR or WATER (circle one) tmp________°F
Load: CASE or entering AIR or WATER (circle one) temperature________°F
Flash gas visible?__________(if variable, note conditions & percent of time)

__________________________________________________________________________________

Measured operating hours or kWh (circle one) & average temperature during operation:

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Compressors | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |
| Condns fans | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |
| AverageTamb | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |

# About the Federal Technology Alerts

The Energy Policy Act of 1992, and subsequent Executive Orders, mandate that energy consumption in the federal sector be reduced by 30% from 1985 levels by the year 2005. To achieve this goal, the U.S. Department of Energy's Federal Energy Management Program (FEMP) is sponsoring a series of programs to reduce energy consumption at federal installations nationwide. One of these programs, the New Technology Demonstration Program (NTDP), is tasked to accelerate the introduction of new energy-saving technologies into the federal sector and to improve the rate of technology transfer.

As part of this effort, FEMP, in a joint venture with the Department of Defense's Strategic Environmental Research and Development Program (SERDP), is sponsoring a series of Federal Technology Alerts that provide summary information on candidate energy-saving technologies developed and manufactured in the United States. The technologies featured in the Alerts have already entered the market and have some experience but are not in general use in the federal sector. Based on their potential for energy, cost, and environmental benefits to the federal sector, the technologies are considered to be leading candidates for immediate federal application.

The goal of the Alerts is to improve the rate of technology transfer of new energy-saving technologies within the federal sector and to provide the right people in the field with accurate, up-to-date information on the new technologies so that they can make educated judgments on whether the technologies are suitable for their federal sites.

Because the Alerts are cost-effective and timely to produce (compared with awaiting the results of field demonstrations), they meet the short-term need of disseminating information to a target audience in a timeframe that allows the rapid deployment of the technologies—and ultimately the saving of energy in the federal sector.

The information in the Alerts typically includes a description of the candidate technology; the results of its screening tests; a description of its performance, applications and field experience to date; a list of potential suppliers; and important contact information. Attached appendixes provide supplemental informationand example worksheets on the technology.

FEMP sponsors publication of the Federal Technology Alerts to facilitate information-sharing between manufacturers and government staff. While the technology featured promises significant federal-sector savings, the Alerts do not constitute FEMP's endorsement of a particular product, as FEMP has not independently verified performance data provided by manufacturers. FEMP encourages interested federal energy and facility managers to contact the manufacturers and other federal sites directly, and to use the worksheets in the Alerts to aid in their purchasing decisions.

### Federal Energy Management Program

The federal government is the largest energy consumer in the nation. Annually, in its 500,000 buildings and 8,000 locations worldwide, it uses nearly two quadrillion Btu (quads) of energy, costing over $11 billion. This represents 2.5% of all primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the federal infrastructure.

Over the years several federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; and, most recently, Executive Order 12759 in 1991, the National Energy Policy Act of 1992 (EPACT), and Executive Order 12902 in 1994.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting New Technology Demonstrations to hasten the penetration of energy-efficient technologies into the federal marketplace.

### Strategic Environmental R&D Program

The Strategic Environmental Research and Development Program, SERDP, co-sponsor of these Federal Technology Alerts, was created by the National Defense Authorization Act of 1990 (Public Law 101-510). SERDP's primary purpose is to "address environmental matters of concern to the Department of Defense and the Department of Energy through support for basic and applied research and development of technologies that can enhance the capabilities of the departments to meet their environmental obligations." In 1993, SERDP made available additional funds to augment those of FEMP, for the purpose of new technology installations and evaluations.

FEMP
FEDERAL ENERGY MANAGEMENT PROGRAM

DoD EPA DOE SERDP
Strategic Environmental Research and Development Program
Improving Mission Readiness through Environmental Research

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