5. ASSESSMENT RECOMMENDATIONS

AR No. 1

Reduce Discharge Pressure

Recommended Action

Reduce the minimum condensing temperatures on your warehouse refrigeration systems from 110°F to 60°F. In order to reduce condensing temperature, we recommend installing a Liquid Refrigerant Pump (LRP) downstream from the high-pressure receivers to ensure proper system operation.

Assessment Recommendation Summary			
Energy (10^6Btu)	Cost Savings	Implementation Cost	Payback (years)
2,082	$20,500	$66,000	3.2

Background

Refrigerant condensing temperature is determined by compressor discharge pressure, which is generally controlled by the condenser fans. Compressors require less power and energy to operate against lower discharge pressure. Also, compressors use significantly more energy than condenser fans. Therefore, compressor savings significantly exceed the increased fan energy required to reduce discharge pressure, and therefore condensing temperature. Reduce compressor discharge pressure to save approximately 1% of compressor energy consumption for each degree Fahrenheit that condensing temperature is reduced. This can be accomplished in one of three ways depending on your refrigeration system:

(1) **Disable discharge pressure control.** This will allow discharge pressure to float approximately 23°F above the ambient air temperature. This approach might cause problems at low ambient temperatures, such as flash gas before the expansion control and low refrigerant flow rates. This method is not recommended if you already have any of these problems at current operating pressures.

(2) **Install a Liquid Refrigerant Pump (LRP).** This system disables the discharge pressure control and reduces or eliminates the above problems by adding a liquid pump after the condenser. This pump adds 5 to 12 pounds of pressure to the liquid line to reduce or avoid the potential problems of flash gas and refrigerant flow at low condensing temperatures.

(3) **Install a variable discharge pressure control.** This control replaces the existing fixed discharge pressure control with an adjustable control. Condensing pressure is allowed to float above the control setpoint. At lower temperatures, the control will bypass hot gas to maintain a minimum pressure.

The minimum pressure for your system will depend on its design and actual operating conditions. A detailed analysis by a refrigeration engineer or equipment supplier is recommended.

In addition, the pressure switches on the condenser fans may need adjustment to allow the pressure to drop as low as the minimum recommended condensing pressure.

Minimum discharge pressure is limited by your system's design and operating conditions. Potential problems due to reduced pressure are flash gas and inadequate refrigeration circulation. These problems may or may not appear in your system depending on system design and operation. If any problems arise, additional pipe insulation, larger piping, larger orifices in control valves, or additional circulation pumps may be necessary in order to operate at lower pressures. However, these are relatively minor expenses compared to potential compressor savings.

Reducing pressure switch settings will cause the condenser fans to run more. Some of the savings from reducing compressor power will be offset by increased energy consumption from the fans.

Equipment

Our analysis focuses on 12 refrigerated warehouses that use R22 refrigerant. Eight of these systems operate throughout the year, while the other four are only used from August through February. Six of the year round systems have air-cooled condenser units, while the others all have evaporative condensers. All the systems use one or two 60 hp Carrier compressors except for one, which uses two 20 hp compressors.

Anticipated Savings

We recommend a minimum condensing temperature of 60°F, corresponding to a discharge pressure of 102 psig. The energy and cost savings are calculated in the following Refrigeration Energy Savings worksheets, and are explained in the accompanying Refrigeration Worksheet Definitions in Appendix D.

Condensing temperature is directly related to pressure and is usually controlled by maintaining discharge pressure. Currently the pressure switches that control the condenser fans in your system are set to maintain an existing minimum condensing temperature (Tme) at 110°F (226 psig). We recommend resetting the controls to reduce the minimum condensing temperature to 60°F (102 psig). To ensure proper system operation after reducing condensing pressure, install a Liquid Refrigeration Pump (LRP) downstream of the liquid receivers. The LRP will add 5 to 12 pounds of pressure to the liquid line. This additional pressure will subcool the liquid refrigerant so that only liquid (no flash gas) flows through the expansion valve at lower pressures.

The following Refrigeration Energy Savings worksheets use annual temperatures for your area. Temperatures are grouped into "bins" with ranges of 5 °F with hours of occurrence for each temperature bin. The existing condensing temperatures in warehouses with air-cooled systems (Tce) float 23°F above the dry bulb temperature (Tdb), while those in warehouses with evaporative cooling float 23°F above wet bulb temperature (Twb). Both types of systems maintain an existing minimum condensing temperature of 110°F. Disabling the pressure control switches will allow the proposed condensing temperature (Tcp) to drop, but still float 23°F above the ambient temperature. For our calculations, we propose a minimum condensing temperature of 60°F (Tmp) to take advantage of cooler outdoor temperatures when they occur.

The Annual Compressor Energy Use table below shows the annual operation hours, horsepower, and power for each compressor. This table is summarized from the Annual Compressor Operation Hours table in Appendix D. The annual compressor energy use for each compressor is also shown and summed to give total annual compressor energy use (EC_E) for all compressors being analyzed.

Annual Compressor Energy Use					
	Warehouse	**Compressor Hp**	**Compressor Hours**	**Compressor Power (kW)**	**Compressor Energy (kWh)**
Air-Cooled Units	1	60	4,052	37.3	151,000
	3	40	4,052	24.9	101,000
	6	60	4,052	37.3	151,000
	7	60	4,052	37.3	151,000
	8	60	4,417	37.3	165,000
	9	60	2,811	37.3	105,000
	Subtotal	340		211.4	824,000
Evaporative-Cooled Units	11	120	4,198	74.6	313,000
	12	120	4,125	74.6	308,000
	Subtotal	240		149.2	621,000
Seasonal Units (AUG-FEB)	13	120	3,066	74.6	229,000
	14	60	3,066	37.3	114,000
	19	60	2,008	37.3	75,000
	20	60	2,008	37.3	75,000
	Subtotal	300		186.5	493,000
				Total	1,938,000
Compressor Motor Efficiency:		90%			
Compressor Load Factor:		75%			

The power (P) in kilowatts (kW) for each compressor motor is found from:

$$P = LF \times (0.746\ kW/Hp) \times Hp / \eta_0$$

Where:

LF = Load Factor
Hp = Horsepower
η_0 = Motor Efficiency

The energy use in kilowatt-hours (kWh) for each compressor is calculated by multiplying power by annual operating hours. The total energy use for all compressors being analyzed is the sum of their individual energy uses.

EC_E = 1,938,000 kWh/yr

The Annual Condenser Fan Power table below shows the number of condenser fans in each warehouse, their horsepower, and their combined power. The power from the condensers is found by the same calculation used to find compressor power.

Annual Condenser Fan Power				
	Warehouse	**Number of Fans**	**Fan Hp**	**Fan Demand (kW)**
Air-Cooled Units	1	5	1	3.1
	3	3	1	1.9
	6	5	1	3.1
	7	5	1	3.1
	8	5	1	3.1
	9	5	1	3.1
	Subtotal	28	28	17.4
Evaporative-Cooled Units	11	2	3	3.7
	12	2	3	3.7
	Subtotal	4	12	7.5
Seasonal Units (AUG-FEB)	13	2	3	3.7
	14	1	3	1.9
	19	1	3	1.9
	20	1	3	1.9
	Subtotal	5	15	9.3
			Total	34.2
Condenser Fan Motor Efficiency:		90%		
Condenser Fan Load Factor:		75%		

The Refrigeration Energy Savings worksheet uses the fan power for each set of condensers to determine existing and proposed condenser energy use. The existing energy use is then subtracted from the proposed use to yield the condenser fan energy increase (FEI).

The Refrigeration Savings Summary below shows the total compressor energy savings (CES) found by summing the compressor savings for all bin temperatures from all three worksheets. Also shown is the fan energy increase, which, when subtracted from compressor energy savings, yields total energy savings (ES). Total cost savings (CS) is the product of total energy savings and the electricity charge ($0.03367/kWh) from your current rate schedule.

Refrigeration Savings Summary				
	Compressor Energy (kWh)	Fan Energy Increase (kWh)	Total Savings (kWh)	Savings $
Air-Cooled Units	285,800	76,700	209,100	$ 7,000
Evaporative Units	258,000	37,000	221,000	$ 7,400
Seasonal Units	205,000	25,000	180,000	$ 6,100
Total	748,800	138,700	610,100	$ 20,500

Implementation cost

We assume that a Liquid Refrigeration Pump (LRP) will be necessary to allow lower condensing pressures. The pump is installed in the high-pressure refrigerant liquid line between the condenser and expansion valves to prevent flash gas before the expansion valves and to ensure adequate refrigerant flow rates. The LRP system is discussed in Appendix D.1.

The equipment and installation costs that follow are shown in the Available LR Pump Capacities, Application Data, and Approximate Costs table in Appendix D.1. This table shows LRP specifications ranging from freezer to air conditioner applications. The table specifies suction temperatures for freezers and air conditioners to be -24°F and 50°F, respectively. Because most of your systems operate at a suction temperature of 15°F, and most have a required tonnage of 35 tons, we assumed installation prices for LRP's would fall between those for freezers and air conditioners with similar tonnages. We use capacity (tonnage) as a frame of reference for size recommendation of the LRPs for the simplicity of comparison with the table, figure 1.4, of Appendix D.1. Installation for a LRP on each of your most common systems will cost approximately $5,000. The three refrigeration systems that use two 60 Hp compressors will require LRP's with higher capacities that are slightly more expensive. The installation costs for each of these will be approximately $7,000 each. The Implementation Cost table below shows the cost of installing LRP's in all of the refrigeration systems.

Implementation Cost of Liquid Refrigeration Pumps			
Refrigeration Systems (LRP)	**$5,000**	**$7,000**	**Cost**
Air-Cooled Units	6		$30,000
Seasonal Units	3		$15,000
Evaporative-cooled Units		2	$14,000
Seasonal Units		1	$7,000
Total			**$66,000**

Savings will pay for the implementation cost in 3.2 years.

REFRIGERATION ENERGY SAVINGS

Report:	411		
Application:	Air-Cooled Units	**Refrigerant:**	R22
Buildings:	1,3,6,7,8 & 9	**Energy Cost (E$):**	$0.03367 /kWh
Bin Data:		**Annual Hours:**	8,760

Operating Conditions	Existing	Proposed	Savings	Units
Minimum Condensing Temperature (Tm):	110	60	50	°F
Temperature Difference (DT):	23	23	0	°F
Compressor Energy (EC):	856,000	559,100	296,900	kWh/yr
Condenser Fan Horsepower (Hp):	28	28	0.0	hp
Fan Power (FP):	17.4	17.4	0.0	kW
Average Fan Use Factor (UFe):	43%	93%	-50%	
Fan Energy (FE):	65,600	142,300	-76,700	kWh
Total Energy Usage:	921,600	701,400	220,200	kWh
Total Energy Cost:	$31,030	$23,620	$7,400	

Bin Calculation

Dry Bulb (Twb)	Hours (H)	Exist Cond Temp (Tce)	Prop Cond Temp (Tcp)	Deg-hr Savings (DHS)	Savings % (E%)	Compress Savings kWh (CES)	Fan Increase kWh (FEI)	Total Savings kWh (ES)
102	7	125	125	0	0.0%	0	0	0
97	41	120	120	0	0.0%	0	1	(1)
92	99	115	115	0	0.0%	0	0	0
87	177	110	110	0	0.0%	0	1	(1)
82	259	110	105	1,295	0.1%	1,266	807	459
77	352	110	100	3,520	0.4%	3,440	1,859	1,581
72	468	110	95	7,020	0.8%	6,861	3,218	3,643
67	583	110	90	11,660	1.3%	11,395	4,722	6,673
62	714	110	85	17,850	2.0%	17,444	6,476	10,968
57	779	110	80	23,370	2.7%	22,839	7,678	15,161
52	821	110	75	28,735	3.3%	28,082	8,627	19,455
47	843	110	70	33,720	3.8%	32,954	9,319	23,635
42	827	110	65	37,215	4.2%	36,369	9,529	26,840
37	826	110	60	41,300	4.7%	40,362	9,851	30,511
32	841	110	60	42,050	4.8%	41,095	7,711	33,384
27	532	110	60	26,600	3.0%	25,996	3,890	22,106
22	276	110	60	13,800	1.6%	13,486	1,653	11,833
17	140	110	60	7,000	0.8%	6,841	701	6,140
12	81	110	60	4,050	0.5%	3,958	345	3,613
7	43	110	60	2,150	0.2%	2,101	158	1,943
2	26	110	60	1,300	0.1%	1,270	83	1,187
-3	13	110	60	650	0.1%	635	37	598
-8	7	110	60	350	0.0%	342	17	325
-13	4	110	60	200	0.0%	195	9	186
Totals	8,759			304,000	34.7%	296,900	76,700	220,200

Energy and Cost Savings

Compressor Energy Savings (CES):	296,900	kWh/yr
Fan Energy Increase (FEI):	76,700	kWh/yr
Total Energy Savings (ES):	220,200	kWh/yr
Total Cost Savings (CS):	$7,400	/yr
Implementation Cost (IC):	$30,000	
Simple Payback:	4.1	years

REFRIGERATION ENERGY SAVINGS

Report:	411		
Application:	Evaporative-Cooled Units	Refrigerant:	R22
Building:	11 & 12	Energy Cost (E$):	$0.03367 /kWh
Bin Data:		Annual Hours:	8,760

Operating Conditions	Existing	Proposed	Savings	Units
Minimum Condensing Temperature (Tm):	110	60	50	°F
Temperature Difference (DT):	23	23	0	°F
Compressor Energy (EC):	523,000	305,000	218,000	kWh/yr
Condenser Fan Horsepower (Hp):	12	12	0.0	hp
Fan Power (FP):	7.5	7.5	0.0	kW
Average Fan Use Factor (UFe):	35%	92%	-56%	
Fan Energy (FE):	23,100	60,100	-37,000	kWh
Total Energy Usage:	546,100	365,100	181,000	kWh
Total Energy Cost:	$18,390	$12,290	$6,100	

Bin Calculation

Wet Bulb (Twb)	Hours (H)	Exist Cond Temp (Tce)	Prop Cond Temp (Tcp)	Deg-hr Savings (DHS)	Savings % (E%)	Compress Savings kWh (CES)	Fan Increase kWh (FEI)	Total Savings kWh (ES)
68	7	110	91	133	0.0%	79	24	55
66	41	110	89	861	0.1%	514	147	367
65	99	110	88	2,178	0.2%	1,300	363	937
63	177	110	86	4,248	0.5%	2,536	678	1,858
61	259	110	84	6,734	0.8%	4,021	1,031	2,990
59	352	110	82	9,856	1.1%	5,885	1,449	4,436
57	468	110	80	14,040	1.6%	8,383	1,987	6,396
54	583	110	77	19,239	2.2%	11,488	2,577	8,911
52	714	110	75	24,990	2.9%	14,922	3,232	11,690
49	779	110	72	29,602	3.4%	17,675	3,640	14,035
45	821	110	68	34,482	3.9%	20,589	3,979	16,610
42	843	110	65	37,935	4.3%	22,651	4,184	18,467
38	827	110	61	40,523	4.6%	24,196	4,221	19,975
34	826	110	60	41,300	4.7%	24,660	3,606	21,054
30	841	110	60	42,050	4.8%	25,108	3,022	22,086
26	532	110	60	26,600	3.0%	15,883	1,606	14,277
21	276	110	60	13,800	1.6%	8,240	686	7,554
16	140	110	60	7,000	0.8%	4,180	292	3,888
11	81	110	60	4,050	0.5%	2,418	144	2,274
6	43	110	60	2,150	0.2%	1,284	66	1,218
2	26	110	60	1,300	0.1%	776	35	741
-3	13	110	60	650	0.1%	388	16	372
-8	7	110	60	350	0.0%	209	8	201
-13	4	110	60	200	0.0%	119	3	116
Totals	8,759			364,000	41.6%	218,000	37,000	181,000

Energy and Cost Savings

Compressor Energy Savings (CES):	218,000	kWh/yr
Fan Energy Increase (FEI):	37,000	kWh/yr
Total Energy Savings (ES):	181,000	kWh/yr
Total Cost Savings (CS):	$6,100	/yr
Implementation Cost (IC):	$14,000	
Simple Payback:	2.3	years

REFRIGERATION ENERGY SAVINGS

Report:	411		
Application:	Seasonal Units	**Refrigerant:**	R22
Building:	13,14,19 & 20	**Energy Cost (E$):**	$0.03367 /kWh
Bin Data:		**Annual Hours:**	4,760

Operating Conditions	Existing	Proposed	Savings	Units
Minimum Condensing Temperature (Tm):	110	60	50	°F
Temperature Difference (DT):	23	23	0	°F
Compressor Energy (EC):	481,000	281,000	200,000	kWh/yr
Condenser Fan Horsepower (Hp):	15	15	0.0	hp
Fan Power (FP):	9.3	9.3	0.0	kW
Average Fan Use Factor (UFe):	19%	50%	-31%	
Fan Energy (FE):	16,000	41,000	-25,000	kWh
Total Energy Usage:	497,000	322,000	175,000	kWh
Total Energy Cost:	$16,730	$10,840	$5,900	

Bin Calculation

Wet Bulb (Twb)	Hours (H)	Exist Cond Temp (Tce)	Prop Cond Temp (Tcp)	Deg-hr Savings (DHS)	Savings % (E%)	Compress Savings kWh (CES)	Fan Increase kWh (FEI)	Total Savings kWh (ES)
68	7	110	91	133	0.0%	73	16	57
66	41	110	89	861	0.1%	473	99	374
65	99	110	88	2,178	0.2%	1,196	245	951
63	177	110	86	4,248	0.5%	2,333	457	1,876
61	259	110	84	6,734	0.8%	3,698	695	3,003
59	352	110	82	9,856	1.1%	5,412	977	4,436
57	468	110	80	14,040	1.6%	7,710	1,339	6,371
54	583	110	77	19,239	2.2%	10,565	1,736	8,829
52	714	110	75	24,990	2.9%	13,723	2,178	11,546
49	779	110	72	29,602	3.4%	16,256	2,453	13,803
45	821	110	68	34,482	3.9%	18,936	2,681	16,255
42	843	110	65	37,935	4.3%	20,832	2,819	18,013
38	827	110	61	40,523	4.6%	22,253	2,844	19,409
34	826	110	60	41,300	4.7%	22,680	2,430	20,250
30	841	110	60	42,050	4.8%	23,092	2,037	21,055
26	532	110	60	26,600	3.0%	14,607	1,083	13,525
21	276	110	60	13,800	1.6%	7,578	462	7,116
16	140	110	60	7,000	0.8%	3,844	197	3,647
11	81	110	60	4,050	0.5%	2,224	97	2,127
6	43	110	60	2,150	0.2%	1,181	45	1,136
2	26	110	60	1,300	0.1%	714	24	690
-3	13	110	60	650	0.1%	357	11	346
-8	7	110	60	350	0.0%	192	5	187
-13	4	110	60	200	0.0%	110	3	107
Totals	8,759			364,000	41.6%	200,000	25,000	175,000

Energy and Cost Savings

Compressor Energy Savings (CES):	200,000	kWh/yr
Fan Energy Increase (FEI):	25,000	kWh/yr
Total Energy Savings (ES):	175,000	kWh/yr
Total Cost Savings (CS):	$5,900	/yr
Implementation Cost (IC):	$22,000	
Simple Payback:	3.7	years