PG&E

CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

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Draft Report
Refrigerated Warehouses

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Overview

The standards have never addressed refrigerated warehouses or the processes around them; previous standards have focused on buildings that are heated and/or cooled for the purpose of human comfort. Refrigerated warehouses and the processes around them such as pre-coolers and food processing are extremely energy intensive and are fertile ground for additional energy savings and demand reductions.

HVAC systems for refrigerated warehouses are specialized equipment that is very different from equipment used to condition spaces intended for human occupancy. These differences will challenge the methods and procedures that we have used in the past to develop standards. Outside air ventilation is low or non-existent, refrigeration systems in large warehouses typically use ammonia rather than more conventional refrigerants, evaporators (essentially fan coils) are suspended or otherwise mounted in the cooler or freezer, and these are coupled to multiple compressors and condensers. Systems for large warehouses are typically custom designed, while small walk-in coolers may use packaged equipment.

Facilities can range from small walk-in coolers used in restaurants and grocery stores to very large food storage warehouses (250,000 ft^2 or more). Indoor design conditions can range from freezers to moderate temperature coolers. The actual freezer or cooler is the simpler and less energy intensive part of the operation. Pre-coolers are often a part of the operation and these are designed to rapidly cool the product before the product goes into the warehouse. Many refrigerated warehouses also are coupled with various types of food processing activities. The focus of this proposal is refrigerated warehouses where the total cold and frozen storage area exceeds 3,000 sf. Thus the requirements proposed here apply only to large refrigerated storage facilities and would only apply to the very largest walk-in freezers or coolers in other applications.

Refrigerated warehouses have long been the target of energy efficiency programs run by the IOUs. These programs have generally targeted shell and refrigeration equipment specifications. Shell requirements address wall and ceiling U-values, interior wall U-values, floor U-values for frozen food warehouses, and door U-values. Refrigeration systems requirements address condenser sizing, condenser fan and pump power, condenser fan controls, compressor motor efficiency, compressor capacity control, evaporator sizing, evaporator fan control, and evaporator fan motor efficiency. Refrigerant piping and storage vessels, when located outside, have maximum U-value requirements. Lighting generally defaults to Title 24 requirements for warehouse and/or C&I work area categories.

As part of this CASE Study, we carried out secondary research on refrigerated warehouse energy efficiency, conducted interviews with contractors and designers, and conducted detailed energy modeling and economic analysis on a series of potential measures that could be addressed within Title 24. Based on the results of these activities, we propose a set of changes to the Standards.

Description

The proposed changes to Title 24 affect the building shell insulation levels, evaporator fan controls, condenser sizing and control strategies, compressor plant controls and interior lighting levels for refrigerated warehouses. The equipment-related changes deal only with the storage part of the facility; standards for pre-coolers or other clearly process related equipment were not addressed.

Energy Benefits

The recommended energy conservation measures were tested against a common practice baseline established by Savings by Design. The energy benefits calculated in terms of kWh/ft^2-yr of refrigerated warehouse floor area are on the order of 0.5 kWh/SF for shell measures, 3 kWh/SF for evaporator fan controls, 1.5 kWh/SF for oversized evaporative condensers and 0.1 kWh/SF for compressor controls. See the energy and cost savings section for more detail.

Non-energy Benefits

Non-energy benefits associated with improved refrigerated warehouse energy efficiency include increased equipment reliability and stored product security. Strategies used to improve the efficiency of the refrigeration equipment reduce the operating pressures and temperatures, reducing stress on compressors, condensers and associated equipment. Improved U-value requirements for the insulated shell allow the warehouse to "coast" longer through power and equipment outages while keeping the stored product within an acceptable temperature range.

Research conducted in the Pacific Northwest for the Northwest Energy Efficiency Alliance indicated improved product quality and reduced mass loss in fruit stored in controlled atmosphere rooms with variable speed drive (VSD) controls on evaporator fans. VSDs applied to evaporator fans in freezers provided good temperature control while reducing wind-chill effects on warehouse employees.

Statewide Energy Impacts

A detailed analysis found that the first year's implementation of the mandatory requirements for building shell, evaporator fan controls, evaporative condensers and compressor controls would reduce electricity energy consumption by 15.6 Gigawatt-hr per year, reduce electrical demand coincident with utility system peak by 1.8 Megawatts. There are no expected impacts on natural gas savings at the site. The discounted life cycle energy cost savings (3% discount rate, 15 year period) is $24.6 Million for one year's new construction. . After 10 years of this code measure the savings would be approximately tenfold or about $246 Million of energy savings that accrue over the life of these buildings.

This estimate was based upon a unit energy savings estimate of 12 kWh/SF and expanded up to the population of one year's new construction which is estimated to be 1.3 Million square feet per year for refrigerated warehouses. See the Results section of this report for a detailed description of how the statewide energy impacts were calculated.

Environmental Impact

Reductions in power plan emissions resulting from reductions in electricity consumption and demand is the principal environmental impact. There are no expected impacts on natural gas consumption, which is minimal at refrigerated warehouse sites. Leakage of glycol from underslab heating systems into groundwater is a potential environmental issue.

Type of Change

The current Title 24 reference method (DOE-2.1E) is not suitable for refrigerated warehouse analysis. The program is limited to space temperatures greater than or equal to 0°F, limiting the ability of the program to evaluate the impacts of shell improvements in freezer facilities operated at temperatures below 0°F. The current reference method is also not capable of simulating industrial refrigeration systems used in refrigerated warehouses, due primarily to limitations in the supply air temperatures, which cannot be lower that 35°F. Given that DOE-2.1E will remain the reference software for 2008, we are limited to mandatory requirements for these facilities.

Technology Measures

Measures considered by this report included:

Insulation R-values:

- Freezer Ceiling
- Freezer Exterior Wall
- Freezer to Cooler Wall

- Freezer Floor
- Cooler Ceiling
- Cooler Walls
- Dock Ceiling
- Dock to outdoor wall
- Dock Floor
- Dock Doors
- Refrigerant piping and vessels

Refrigeration System Efficiency

- Minimum efficiency standards for compressor motors.
- Condenser sizing
- Limits on condenser fan and pump power
- Evaporator coil sizing based on approach temperature at design load
- Limits on evaporator fan power

Refrigeration System Controls

- Floating head pressure
- Floating suction pressure
- Evaporator fan controls
- Compressor plant part-load controls

Measure Availability and Cost

The list of equipment manufacturers and engineering firms that design refrigerated warehouses in California is fairly small and well-known to the utilities, who have been active in this market for over 10 years. Engineering specifications from product literature were obtained and reviewed and interviews were conducted with engineering design firms and contractors to assess issues related to measure availability, costs, market capacity to supply equipment, product sources, and so on. A common-practice baseline established by the Savings by Design program for refrigerated warehouses and grocery store refrigeration systems will be used as the baseline for this project.

Useful Life, Persistence and Maintenance

Envelope measures are expected to enjoy long life and savings persistence. Maintenance practices at large refrigerated warehouse facilities assessed during the interview process did not indicate any issues with measure life or maintenance. Given the size of these facilities and the risks to the stored product in the event of equipment failure, maintenance at these facilities is assumed to be fairly good. Contractors interviewed for the project cited potential issues with equipment resonant vibration when VSDs are installed on screw compressors, requiring testing during equipment startup and elimination of certain frequencies from the VSD operation. Leakage potential in glycol under-slab heating systems for freezer spaces was cited as a potential maintenance and environmental risk.

Performance Verification

Acceptance testing of refrigeration plant control systems and factory verification of evaporative condenser performance are performance verification options applicable to this effort. Development of detailed acceptance testing procedures is beyond the scope of the current work.

Cost Effectiveness

Virtually all measures evaluated by this project were shown to be cost effective. Shell measures were evaluated using 2008 TDV values assuming a 30 year measure life, and mechanical measures were evaluated over a 15 year measure life. The cost effectiveness of the evaporator fan VSD measure and VSD controls on ammonia screw compressors was extremely good, with benefit – cost ratios exceeding 10.

Analysis Tools

The energy savings were calculated using a DOE-2.2R building energy simulation program. DOE-2.2R is a variation on DOE-2.2 designed specifically for simulating refrigeration systems. DOE-2.2R can model spaces conditioned to low temperatures and provides the capability to simulate thermal distribution loops with fluids undergoing phase change, allowing for a detailed simulation of grocery store and refrigerated warehouse refrigeration systems. DOE2.2R is currently used to estimate savings for the refrigeration component of the statewide Savings by Design nonresidential new construction energy efficiency program operated by the California investor-owned utilities (IOUs).

Relationship to Other Measures

Issues relating to sizing and specific fan and pump power for cooling towers in commercial buildings are related to refrigerated warehouse condensers. Lighting issues in refrigerated warehouses are similar to those in non-refrigerated warehouses. Minimum efficiency requirements for motors in Title 24 will also apply to motors used in refrigerated warehouse equipment, such as compressors, condensers and evaporators. Title 20 addresses efficiency of walk-in coolers, which could potentially overlap with smaller refrigerated warehouse spaces. This initiative proposes language at clarifies the applicability of Title 20 standards for walk-in cooler and these proposed changes addressing refrigerated warehouses.

Methodology

To estimate the cost effectiveness of proposed changes addressing refrigerated warehouses,, a prototype model was developed to estimate the energy savings using the DOE-2.2R program. The refrigeration version of eQUEST program was used to develop the basic DOE-2.2 input file, and manual changes were made to the text input file to complete the analysis. A description of the refrigerated warehouse prototype used in this analysis is shown in Table 1:

Table 1. Prototypical Refrigerated Warehouse Model Description

Model Parameter	**Value**
Shape	Rectangular (400 ft by 230 ft)
Floor area	Freezer: 40,000 SF Cooler: 40,000 SF Shipping Dock: 12,000 SF Total: 92,000 SF
Number of floors	1
Floor to ceiling height	30 ft

Model Parameter	Value
Exterior wall construction	Insulated metal panel
Ext wall R-Value	Cooler and loading dock – R-20 Freezer – R-26
Infiltration rate	Cooler and Freezer: 0.1 ACH Loading Dock: 0.3 ACH
Roof construction	Insulated low mass roof
Roof R-values	Cooler and loading dock – R-23 Freezer – R-46
Roof absorptivity	0.80
Lighting power density	0.6 W/SF
Equipment power density	0.7 W/SF (covers fork lifts and miscellaneous plug loads and equipment)
Operating schedule	24 / 7
No. People	184 max
Evaporator type	Constant volume, continuous fan operation
Evaporator Size (climate zone 13)	Cooler: 102 ton (392 SF/ton) Freezer: 136 ton (295 SF/ton) Dock: 55 ton (218 SF/ton)
Evaporator CFM (climate zone 13)	Cooler: 172,000 cfm (4.3 cfm/SF) Freezer: 131,400 cfm (4.79 cfm/SF) Dock: 55,300 cfm (7.9 cfm/SF)
Compressor type	Ammonia screw compressor with slide valve capacity control (Frick RWF –100 typical)
Compressor configuration	Parallel equal, 3 compressors per suction group, size ratio 0.5, 0.5, 0.5
Suction groups	Low temperature (freezer): -20°F High temperature (cooler and dock): 30°F
Room temperature	Cooler: 40°F Freezer: -10°F Dock: 40°F
Evaporator fan power	0.15 W/CFM (0.32 hp per ton)
Condenser type	Evaporative condenser
Minimum condensing temperature	85
Condenser fan and pump power	330 Btu/watt
Condenser design approach temperature	23°F (CZ 13, design wetbulb = 73°F)

An eQUEST representation of the building is shown in Figure 1:

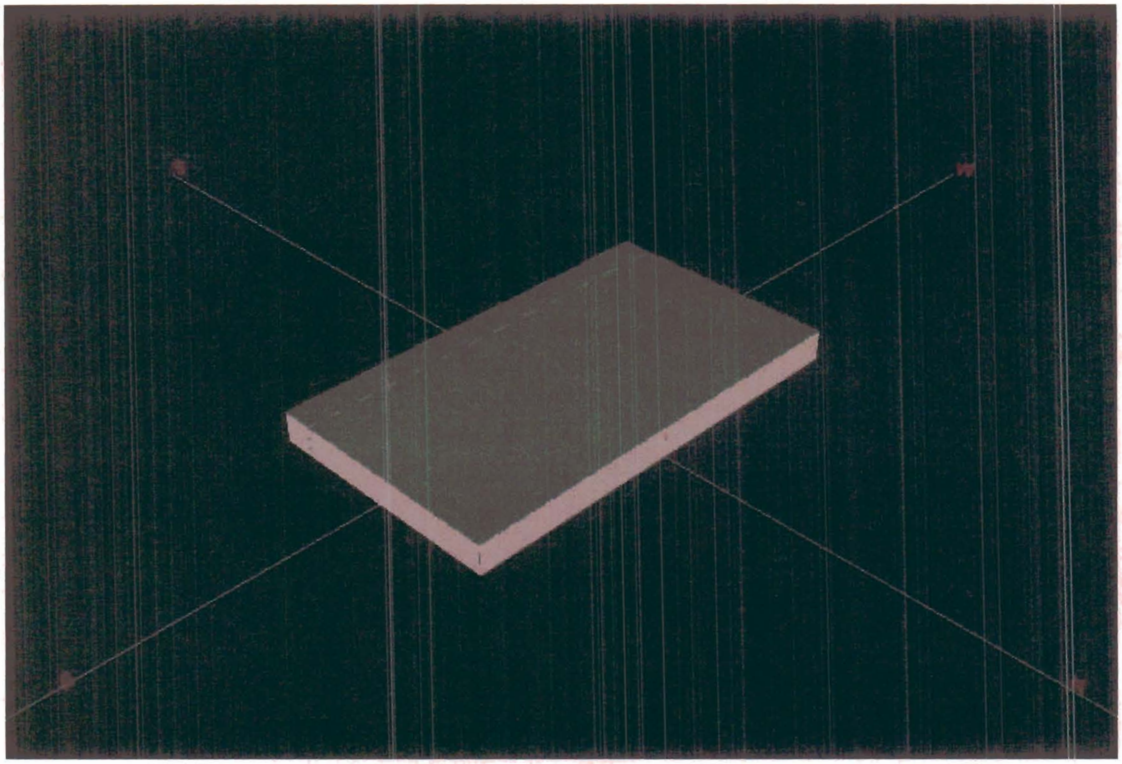

Figure 1. eQUEST representation of prototypical building model

Results

The measures evaluated in this report were generally cost effective on a TDV basis. Common practices for refrigerated warehouse design can be improved while remaining cost effective. However, given that refrigerated warehouses are not currently regulated, setting code minimum specifications that are more stringent then common practices may encounter resistance from the marketplace. Several of the contractors interviewed mentioned constructability or condensation control issues that may trump energy efficiency considerations. Several measures, such as interzone wall R-values and pipe and vessel R-values were removed from consideration based on these issues. A summary of the common practices as defined by the Savings by Design program, contractor interviews, and other sources are shown in Table 2 through Table 7.

Table 2. Refrigerated Warehouse Shell Common Practices

Attribute	Savings by Design Baseline	Common practice from interviews	ASHRAE Recommendation
Freezer Ceiling	R-46	R-50 too high	R-45 to R-50
Freezer Exterior Wall	R-26	R-32	R-35 to R-40
Freezer Floor R-value	R-30	R-30	R-27 to R-32

Attribute	Savings by Design Baseline	Common practice from interviews	ASHRAE Recommendation
Cooler Ceiling	R-23	R-24 to R-40	R-30 to R-35
Cooler Walls	R-20	R-25	R-25
Dock Ceiling	R-23	Same as rest of facility	R-30 to R-35
Dock to outdoor wall	R-20	Same as rest of facility	R-25
Underfloor heating	No electric resistance	Some concern about leakage and cost in small facilities	None

Table 3. Evaporator Common Practices

Attribute	Savings by Design Baseline	Common practice from interviews
Evaporator fan speed control	Constant volume, constant operation	Constant volume, constant operation
Evaporator design approach temperature	10°F	Variable based on humidity requirements
Evaporator fan power (W/CFM)	Not addressed	No opinion

Table 4. Evaporative Condenser Common Practices

Attribute	Savings by Design Baseline	Common practice from interviews
Condenser type	Not addressed	Evaporative condensers in ammonia facilities
Evaporative condenser fan speed control	Two speed fan	Two speed fan
Evaporative condenser design approach temperature	18°F to 25°F based on design wetbulb temperature	18°F to 20°F
Evaporative condenser fan and pump power	330 Btu/Watt-hr at 100°F SCT and 70°F WBT)	No comment

Table 5. Compressor Plant Common Practices

Attribute	Savings by Design Baseline	Common practice from interviews
Compressor capacity modulation	Not addressed	Slide valves on screw compressors
Compressor oil cooling	Not addressed	Not clear, new technology may be on the horizon

Table 6. Lighting Common Practice and Code Minimum Recommendations

Attribute	Savings by Design Baseline	Common practice from interviews
Lighting power density in warehouse spaces (W/SF)	0.6 W/SF	0.4 – 1.2 W/SF depending on application
Lighting controls	Not addressed	No control

Table 7. Refrigeration System Control Common Practice and Code Minimum Recommendations

Attribute	Savings by Design Baseline	Common practice from interviews
Suction pressure control	Not addressed	Fixed
Condensing temperature control	85°F minimum condensing temperature, fixed setpoint	Fixed
Defrost control	Not addressed	Time clock

Energy and Cost Savings

This section contains detailed energy and cost savings results that are summarized in the energy benefits section of the report. The results of the DOE-2.2R simulations of the prototypical building are presented in this section. Simulations were conducted in climate zone 3 (representing a mild coastal climate) and climate zone 13 (representing a warm, inland climate). Energy and cost savings are expressed per square foot of refrigerated warehouse floor space. TDV savings values were calculated by applying the 2005 hourly TDV multipliers by climate zone, and using updated 2008 net present value of energy costs per TDV unit. Thirty year values ($0.17592 per TDV kBtu) were used for shell measures, and 15 year values ($0.09355 per TDV kBtu) were used for the remaining measures.

Shell Measures

The energy and costs savings for shell measures are shown in Table 8. Each value is expressed relative to the common practice baseline established by Savings by Design. The energy and cost savings are spread across the entire floorspace, thus savings from freezer, cooler and dock measures should be summed to obtain energy savings from shell measures at the whole facility level.

Table 8. Energy and Cost Savings for Shell Measures

Building Component	Insulation Level	Climate Zone 3		Climate Zone 13	
		Energy Savings kWh/SF	TDV Energy cost savings (PV $/SF)	Energy Savings kWh/SF	TDV Energy cost savings (PV $/SF)
Freezer Wall (R-26 base)	R-30	0.04	0.13	0.07	0.20
	R-35	0.08	0.25	0.12	0.36
	R-40	0.11	0.33	0.12	0.38
	R-45	0.13	0.40	0.15	0.46
	R-50	0.15	0.46	0.19	0.59
Cooler Wall (R-20 base)	R-25	0.01	0.02	0.02	0.05
	R-30	0.01	0.04	0.03	0.08
	R-35	0.02	0.05	0.03	0.11
	R-40	0.02	0.06	0.02	0.09
Dock Wall (R-20 base)	R-25	0.01	0.04	0.01	0.05
	R-30	0.02	0.07	0.04	0.13
	R-35	0.03	0.09	0.07	0.20
	R-40	0.03	0.10	0.07	0.21
Freezer Ceiling (R-46 base)	R-50	0.05	0.15	0.06	0.18
	R-55	0.10	0.31	0.12	0.38
	R-60	0.14	0.45	0.17	0.55
Cooler Ceiling (R-23 base)	R-25	0.01	0.03	0.03	0.09
	R-30	0.03	0.09	0.06	0.19
	R-35	0.04	0.14	0.08	0.27
	R-40	0.05	0.17	0.10	0.36
	R-45	0.05	0.19	0.14	0.47
Dock Ceiling (R-23 base)	R-25	0.00	0.01	0.02	0.06
	R-30	0.01	0.03	0.03	0.09
	R-35	0.02	0.05	0.03	0.10
	R-40	0.02	0.06	0.04	0.12
	R-45	0.02	0.08	0.05	0.16
Freezer Floor (R-30 base)	R-35	0.13	0.38	0.13	0.40
	R-40	0.22	0.66	0.22	0.67
	R-45	0.29	0.89	0.32	0.97
	R-50	0.35	1.07	0.38	1.16

Evaporator Measures

The energy and costs savings applying variable speed drives to evaporator motors are shown in Table 9. The savings were evaluated relative to the baseline model specifications shown in Table 1, which were based on the common practice baseline established by Savings by Design. The impact of VSD fans on evaporator motors was examined over a range of oversizing conditions from ideally sized (sizing ratio =1) to twice the required capacity (sizing ratio = 2). As the sizing ratio increases, the energy and cost savings increase dramatically. The extent of oversizing in the industry is not well known, but several contractors mentioned that sizing is often done by rule-of-thumb rather than through the use of detailed design calculations.

Table 9. Energy and Cost Savings for Evaporator Fan VSD Measure

Evaporator oversizing	Climate Zone 3		Climate Zone 13	
	Energy Savings kWh/SF	TDV Energy cost savings (PV $/SF)	Energy Savings kWh/SF	TDV Energy cost savings (PV $/SF)
SIZING RATIO = 1.0	2.98	$4.58	3.67	$5.69
SIZING RATIO = 1.2	3.77	$5.91	4.48	$7.07
SIZING RATIO = 1.4	4.34	$6.86	5.26	$8.30
SIZING RATIO = 1.6	4.93	$7.79	6.06	$9.61
SIZING RATIO = 1.8	5.53	$8.76	6.80	$10.77
SIZING RATIO = 2.0	6.11	$9.68	7.60	$12.01

Condenser Measures

The energy and costs savings of a set of condenser design strategies are shown in Table 10. The savings were evaluated relative to the baseline model specifications shown in Table 1, which were based on the common practice baseline established by Savings by Design. The impact of oversized condensers was examined by reducing the design condensing temperature over a range from 4°F to 12°F. In all runs, the minimum condensing temperature was set at 70°F. Fixed and wetbulb offset control of condensing temperature was examined, along with the use of variable speed drives along with wetbulb offset control.

Table 10. Energy and Cost Savings for Condenser Sizing and Control Strategies

Condenser Sizing Strategy (reduction in wetbulb approach)	WB Approach Temperature		Condensing temp control	Fan Control	Climate Zone 3		Climate Zone 13	
	CZ 3	CZ 13			Energy Savings (kWh / SF)	TDV Energy Cost Savings (PV $ / SF)	Energy Savings kWh / SF	TDV Energy Cost Savings (PV $ / SF)
4°F	21	19	Fixed at 70°F	2 speed	1.10	$1.69	1.79	$2.69
6°F	19	17	Fixed at 70°F	2 speed	1.15	$1.78	1.85	$2.77
8°F	17	15	Fixed at 70°F	2 speed	1.18	$1.84	1.89	$2.83
10°F	15	13	Fixed at 70°F	2 speed	1.22	$1.91	1.94	$2.89
12°F	13	11	Fixed at 70°F	2 speed	1.25	$1.97	1.97	$2.92

Condenser Sizing Strategy (reduction in wetbulb approach)	WB Approach Temperature		Condensing temp control	Fan Control	Climate Zone 3		Climate Zone 13	
	CZ 3	CZ 13			Energy Savings (kWh / SF)	TDV Energy Cost Savings (PV $ / SF)	Energy Savings kWh / SF	TDV Energy Cost Savings (PV $ / SF)
4°F	21	19	9°F wetbulb offset	2 speed	1.11	$1.74	1.92	$2.98
6°F	19	17	9°F wetbulb offset	2 speed	1.16	$1.84	1.96	$3.05
8°F	17	15	9°F wetbulb offset	2 speed	1.20	$1.90	1.99	$3,08
10°F	15	13	9°F wetbulb offset	2 speed	1.23	$1.96	2.01	$3.10
12°F	13	11	9°F wetbulb offset	2 speed	1.26	$2.00	2.04	$3.15
4°F	21	19	9°F wetbulb offset	VSD	1.18	$1.85	1.96	$3.04
6°F	19	17	9°F wetbulb offset	VSD	1.22	$1.93	2.01	$3.12
8°F	17	15	9°F wetbulb offset	VSD	1.26	$1.99	2.05	$3.17
10°F	15	13	9°F wetbulb offset	VSD	1.29	$2.05	2.07	$3.22
12°F	13	11	9°F wetbulb offset	VSD	1.33	$2.12	2.13	$3.31

Compressor Control Measures

The energy and costs savings of a set of compressor capacity control are shown in Table 11. The savings were evaluated relative to the baseline model specifications shown in Table 1. The baseline model assumes a three compressor parallel-unequal compressor line for each suction group. The first run shows the energy and cost savings from applying a VSD to the smaller of the three compressors in each suction group. An additional run was done using a three compressor parallel-equal compressor line, and applying a VSD to one of the three compressors in each suction group. The energy savings resulting from applying a VSD to a parallel-equal system was much greater, due to the greater capacity of the VSD-controlled compressor and the poorer part-load performance of a parallel equal compressor line.

Table 11. Energy and Cost Savings from Compressor Capacity Control Strategies

	Climate zone 3		Climate zone 13	
	Energy Savings (kWh / SF)	TDV Energy Cost Savings (PV $ / SF)	Energy Savings (kWh / SF)	TDV Energy Cost Savings (PV $ / SF)
VSD trim compressor (parallel unequal baseline)	0.02	$0.05	0.17	$0.25
VSD trim compressor (parallel equal baseline)	2.71	$4.16	4.10	$6.29

Cost-effectiveness

The cost effectiveness of the proposed measures are calculated from the estimated incremental cost associated with the measure installation and the net present value of the TDV energy savings calculated from the DOE-2.2R simulation model. Incremental maintenance costs are assumed to be zero based on interviews with contractors.

Shell Measures

The energy cost savings and incremental measure costs for improved shell insulation is shown in Table 13. The analysis assumes that additional rigid insulation (at R-5 per inch) was applied to meet the specified insulation level. Incremental insulation costs were estimated based on the 2005 R.S. Means "CostWorks" construction cost estimating CD as shown in Table 12.

Table 12. Insulation R-value and Cost Assumptions

Insulation System	R-Value per inch	Incremental cost ($/SF-in)
Extruded Polystyrene (floor)	5.0	$0.32
Polyisocyanurate (roof)	7.1	$0.25
Polyurethane (wall)	5.0	$0.63

The TDV savings and incremental costs, expressed in terms of square foot of insulation applied are shown, along with the benefit cost ratio (BCR). Measures with a BCR > 1 are deemed cost effective on a life cycle basis. Note, the insulation parametrics were run assuming the refrigeration plant recommendations are also implemented. The cost effectiveness of the insulation requirements is very sensitive to the refrigeration plant efficiency, thus higher benefit cost ratios would result under a standard practice refrigeration plant design.

Table 13. Shell Measure Cost Effectiveness

Building Component	Insulation Level	Climate zone 3			Climate zone 13		
		TDV Savings/SF_{wall}	Incr Cost/ SF_{wall}	BCR	TDV Savings/ SFwall	Incr Cost/ SFwall	BCR
Freezer Wall (R-20 base)	R-25	$1.91	$0.63	3.0	$2.12	$0.63	3.4
	R-30	$3.19	$1.26	2.5	$4.08	$1.26	3.2
	R-35	$4.10	$1.89	2.2	$5.30	$1.89	2.8
	R-40	**$4.76**	**$2.52**	**1.9**	**$5.50**	**$2.52**	**2.2**
	R-45	$5.29	$3.15	1.7	$6.08	$3.15	1.9
	R-50	$5.72	$3.78	1.5	$7.13	$3.78	1.9
Cooler Wall (R-10 base)	R-15	$0.61	$0.63	1.0	$0.81	$0.63	1.3
	R-20	$0.91	$1.26	0.7	$1.66	$1.26	1.3
	R-25	**$1.10**	**$1.89**	**0.6**	**$2.03**	**$1.89**	**1.1**
	R-30	$1.22	$2.52	0.5	$2.29	$2.52	0.9
	R-35	$1.31	$3.15	0.4	$2.49	$3.15	0.8
	R-40	$1.37	$3.78	0.4	$2.36	$3.78	0.6

Building Component	Insulation Level	Climate zone 3			Climate zone 13		
		TDV Savings/SF_{wall}	Incr Cost/ SF_{wall}	BCR	TDV Savings/ SFwall	Incr Cost/ SFwall	BCR
Dock Wall (R-10 base)	R-15	$0.80	$0.63	1.3	$1.34	$0.63	2.1
	R-20	$1.27	$1.26	1.0	$1.93	$1.26	1.5
	R-25	**$1.53**	**$1.89**	**0.8**	**$2.23**	**$1.89**	**1.2**
	R-30	$1.72	$2.52	0.7	$2.80	$2.52	1.1
	R-35	$1.86	$3.15	0.6	$3.27	$3.15	1.0
	R-40	$1.95	$3.78	0.5	$3.34	$3.78	0.9
Freezer Ceiling (R-30 base)	R-35	$0.93	$0.18	5.2	$1.21	$0.18	6.7
	R-40	$1.65	$0.36	4.6	$1.87	$0.36	5.2
	R-45	$2.21	$0.54	4.1	$2.59	$0.54	4.8
	R-50	**$2.66**	**$0.72**	**3.7**	**$3.11**	**$0.72**	**4.3**
	R-55	$3.03	$0.90	3.4	$3.59	$0.90	4.0
	R-60	$3.34	$1.08	3.1	$3.97	$1.08	3.7
Cooler Ceiling (R-15 base)	R-20	$0.32	$0.18	1.8	$0.63	$0.18	3.5
	R-25	$0.53	$0.36	1.5	$1.02	$0.36	2.8
	R-30	$0.67	$0.54	1.2	$1.26	$0.54	2.3
	R-35	**$0.77**	**$0.72**	**1.1**	**$1.44**	**$0.72**	**2.0**
	R-40	$0.84	$0.90	0.9	$1.64	$0.90	1.8
	R-45	$0.91	$1.08	0.8	$1.90	$1.08	1.8
Dock Ceiling (R-15 base)	R-20	$0.47	$0.18	2.6	$0.26	$0.18	1.4
	R-25	$0.73	$0.36	2.0	$1.02	$0.36	2.8
	R-30	$0.91	$0.54	1.7	$1.26	$0.54	2.3
	R-35	**$1.04**	**$0.72**	**1.4**	**$1.31**	**$0.72**	**1.8**
	R-40	$1.14	$0.90	1.3	$1.47	$0.90	1.6
	R-45	$1.22	$1.08	1.1	$1.79	$1.08	1.7
Freezer Floor (R-20 base)	R-25	$1.83	$0.32	5.7	$1.91	$0.32	6.0
	R-30	**$3.06**	**$0.64**	**4.8**	**$3.19**	**$0.64**	**5.0**
	R-35	$3.92	$0.96	4.1	$4.10	$0.96	4.3
	R-40	$4.58	$1.28	3.6	$4.73	$1.28	3.7
	R-45	$5.10	$1.60	3.2	$5.42	$1.60	3.4

Evaporator Measures

The energy cost savings and incremental measure costs for VSDs applied to evaporator fan motors are shown in Table 14. Costs for VSDs applied to evaporator fan motors were obtained from the Evaporator Fan VFD Market Transformation Initiative conducted by the Northwest Energy Efficiency Alliance.[1]

[1] Evaporator Fan VFD Market Transformation Initiative Market Progress Evaluation Report No. 3. Prepared for the Northwest Energy Efficiency Alliances by Pacific Energy Associates and MetaResearch Group.

Table 14. Evaporator Fan VSD Cost Effectiveness

Evaporator oversizing	Climate Zone 3			Climate Zone 13		
	TDV Savings/ hp	Incr Cost / hp	BCR	TDV Savings/ hp	Incr Cost / hp	BCR
SIZING RATIO = 1.0	$10,775	$577	18.7	$10,972	$577	19.0
SIZING RATIO = 1.2	$11,598	$577	20.1	$11,360	$577	19.7
SIZING RATIO = 1.4	$11,526	$577	20.0	$11,436	$577	19.8
SIZING RATIO = 1.6	$11,454	$577	19.9	$11,586	$577	20.1
SIZING RATIO = 1.8	$11,447	$577	19.8	$11,540	$577	20.0
SIZING RATIO = 2.0	$11,392	$577	19.7	$11,585	$577	20.1

The data in Table 14 are based on the baseline assumption that evaporator fans are operated continuously and do not cycle with the refrigeration load. A separate series of runs was done to evaluated the savings of VSD controlled evaporator fans relative to the case where the evaporator fans cycle on and off in response to the space refrigeration load. The results of these simulations are shown in Table 15.

Table 15. Savings from VSD Controlled Evaporator Fans Relative to Cycling Fan Baseline

Sizing Ratio	Energy Savings kWh/SF	TDV Savings/ hp	Incr Cost / hp	BCR
SIZING RATIO = 1.0	3.5	$10,483	$577	18.2
SIZING RATIO = 1.2	4	$10,283	$577	17.8
SIZING RATIO = 1.4	4.3	$9,505	$577	16.5
SIZING RATIO = 1.6	4.4	$8,745	$577	15.2
SIZING RATIO = 1.8	4.4	$7,770	$577	13.5
SIZING RATIO = 2.0	4.2	$6,801	$577	11.8

The runs shown in Table 15 were done in Climate zone 13 only, but similar results are expected in other climates. The energy savings are not a dramatic as the case with continuously operating fans, but the energy savings are still substantial with a benefit cost ratio exceeding 10 in all cases studied.

Condenser Measures

The energy cost savings and incremental measure costs for oversized condensers, floating head pressure controls and VSD condenser fan controls are shown in Table 16. Costs for these measures were obtained from the 2005 DEER Measure Cost Study.[2] The DEER study evaluated oversized condensers at a 5°F reduction in the condensing temperature. The cost from the DEER study ($88.26 per ton) was scaled up and down based on the approach temperature reduction modeled. The DEER study cost of $203 per ton for a 5°F oversized condenser with VSD and wetbulb offset control was also scaled based on the approach temperature modeled. Oversized condensers with wetbulb offset controls without VSDs were credited $17.34 per ton for the VSD.

[2] 2005 DEER Measure Cost Study, conducted by Summit Blue Consulting.

Table 16. Condenser Sizing and Control Cost Effectiveness

Condenser Sizing Strategy (reduction in wetbulb approach)	WB Approach Temperature CZ 3	WB Approach Temperature CZ 13	Condensing temp control	Fan Control	Climate Zone 3 TDV Savings/ ton	Climate Zone 3 Incr Cost/ ton	Climate Zone 3 BCR	Climate Zone 13 TDV Savings/ ton	Climate Zone 13 Incr Cost/ ton	Climate Zone 13 BCR
4°F	**21**	**19**	**Fixed at 70°F**	**2 speed**	**658**	**$91**	**7.2**	**847**	**$91**	**9.3**
6°F	19	17	Fixed at 70°F	2 speed	691	$126	5.5	870	$126	6.9
8°F	17	15	Fixed at 70°F	2 speed	717	$161	4.4	892	$161	5.5
10°F	15	13	Fixed at 70°F	2 speed	743	$197	3.8	908	$197	4.6
12°F	13	11	Fixed at 70°F	2 speed	766	$232	3.3	919	$232	4.0
4°F	**21**	**19**	**9°F wetbulb offset**	**2 speed**	**675**	**$145**	**4.7**	**937**	**$145**	**6.5**
6°F	19	17	9°F wetbulb offset	2 speed	715	$226	3.2	959	$226	4.2
8°F	17	15	9°F wetbulb offset	2 speed	738	$307	2.4	970	$307	3.2
10°F	15	13	9°F wetbulb offset	2 speed	762	$389	2.0	976	$389	2.5
12°F	13	11	9°F wetbulb offset	2 speed	778	$470	1.7	991	$470	2.1
4°F	**21**	**19**	**9°F wetbulb offset**	**VSD**	**720**	**$162**	**4.4**	**956**	**$162**	**5.9**
6°F	19	17	9°F wetbulb offset	VSD	751	$244	3.1	981	$244	4.0
8°F	17	15	9°F wetbulb offset	VSD	774	$325	2.4	998	$325	3.1
10°F	15	13	9°F wetbulb offset	VSD	798	$406	2.0	1013	$406	2.5
12°F	13	11	9°F wetbulb offset	VSD	823	$487	1.7	1041	$487	2.1

Compressor Measures

The energy cost savings and incremental measure costs for compressor control measures are shown in Table 17. Incremental costs for variable speed compressors and floating suction pressure controls were obtained from the 2005 DEER Measure Cost Study.

Table 17. Compressor Control Cost Effectiveness

	Climate zone 3			Climate zone 13		
	TDV Savings/ ton	Incr Cost/ ton	BCR	TDV Savings/ ton	Incr Cost/ ton	BCR
VSD trim compressor (parallel unequal baseline)	$74	$171	0.43	286	$171	1.7
VSD trim compressor (parallel equal baseline)	$3,020	$171	17.6	$3,661	$171	21.4

Statewide Energy Savings

A series of runs was done to look at the relative contribution of each measure to the overall energy savings. The runs started with applying the most effective measures first and moving to the least effective. The runs start with VSD evaporator fans, then add VSD trim compressor control, then add condenser measures (float head pressure to

70°F, VSD condenser fan control, 20°F approach temperature limit) and finally add the shell measures. The impact of these measure groups on the overall energy consumption of the prototype building is shown in

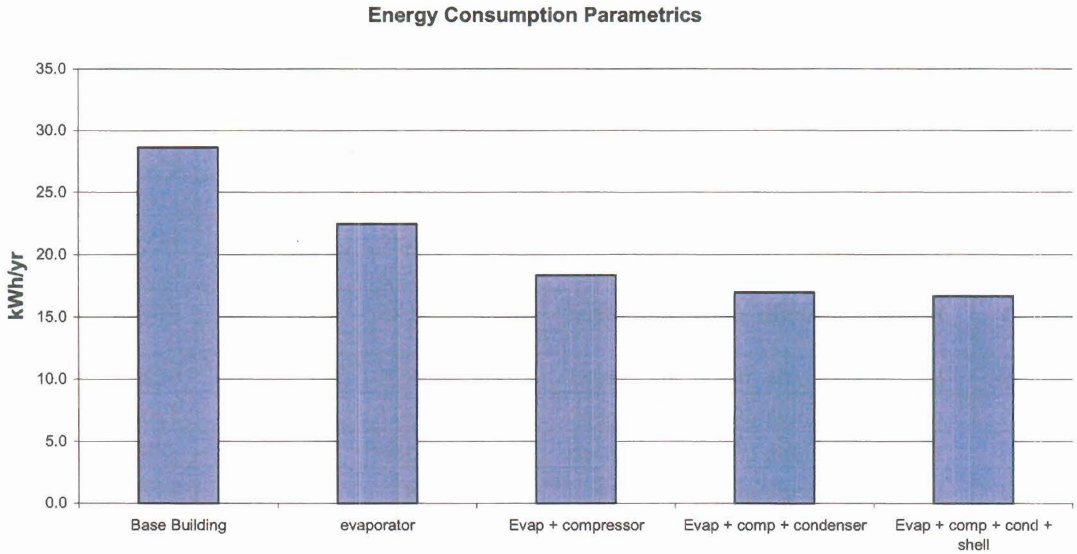

Figure 2. Energy Consumption Parametric Runs

Based in the order of implementation described above, the relative contribution of each measure group to the total energy savings is shown in Figure 3.

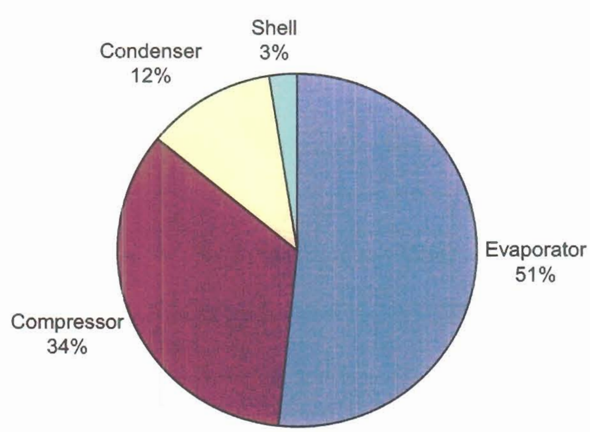

Figure 3. Relative Contribution of Each Measure to Overall Savings

The energy savings potential for the recommended measures total approximately 12 kWh/SF and 1.4 W/SF. Expanding this to the statewide estimate of refrigerated warehouse new construction estimate of 1.3 million square feet results in an overall statewide energy savings of 15.6 GWh and 1.8 MW per year.

Recommendations

Based on the interviews and analysis presented above, the following provisions for refrigerated warehouses are recommended:

- Requirements apply to only refrigerated warehouses with total of cold and frozen storage areas exceeding 3,000 sf

Minimum R-values for freezers

- R-40 Wall
- R-49 Ceiling
- R-30 Floor

Minimum R-values for coolers

- R-25 Wall
- R-35 Ceiling

Limit on electric resistance underfloor heating

- Electric underslab heating must be controlled so that the heating is off during summer on-peak periods

Evaporators

- Require VSDs on evaporator fan motors
- Limits on evaporator fan motor power of 0.15 W/cfm

Condensers

- Require evaporative condensers on all ammonia systems
- Limits on evaporative condenser wetbulb approach temperature of 20°F
- Limits on evaporative condenser fan and pump power of 400 Btu/hr-watt
- Require floating head pressure control to 70°F
- Require VSD on evaporative condenser fans controlled on wetbulb temperature or system load

Screw compressors

- Require VSD on at least one compressor per suction group
- Require compressors and accessories supplied by manufacturer to be capable of operating at 70°F condensing temperature

Lighting

- Max lighting power of 0.6 W/SF
- Require bi-level lighting controls in storage spaces

Controls

- Limit electric defrost with exception based on system size
- Require temperature termination on defrost controls

Proposed Standards Language

The Standards currently do not address refrigerated warehouses, so it is recommended that the mandatory measures be assigned to an unused section of the Standards. The refrigerated warehouse provisions would be included in a completely new Section 120 at the end of Subchapter 2: ALL OCCUPANCIES—MANDATORY REQUIREMENTS FOR THE MANUFACTURE, CONSTRUCTION AND INSTALLATION OF SYSTEMS, EQUIPMENT AND BUILDING COMPONENTS. Current sections 120 through 125 would have to be renumbered to accommodate the new section 120. The following language is recommended:

SECTION 100 – SCOPE

TABLE 100-A APPLICATION OF STANDARDS

<table>
<tr><th>Occupancies</th><th>Application</th><th>Mandatory</th><th>Prescriptive</th><th>Performance</th><th>Additions/Alterations</th></tr>
<tr><td colspan="2">General Provisions</td><td colspan="4">100, 101, 102, 110, 111</td></tr>
<tr><td rowspan="8">Nonresidential, High-Rise Residential, And Hotels/Motels</td><td>General</td><td>140</td><td>142</td><td rowspan="6">141</td><td rowspan="9">149</td></tr>
<tr><td>Envelope (conditioned)</td><td>116, 117, 118</td><td>143</td></tr>
<tr><td>Envelope (unconditioned, process spaces)</td><td></td><td>143 (c)</td></tr>
<tr><td>HVAC (conditioned)</td><td>112, 115, ~~120 125~~ 121-126</td><td>144</td></tr>
<tr><td>Water Heating (conditioned)</td><td>113, ~~123~~ 124</td><td>145</td></tr>
<tr><td>Indoor Lighting (conditioned, process spaces)</td><td>119, 130, 131</td><td>143 (c), 146</td></tr>
<tr><td>Indoor Lighting (unconditioned)</td><td>119, 130, 131</td><td>143 (c), 146</td><td rowspan="3">N.A.</td></tr>
<tr><td>Outdoor Lighting</td><td>119, 130, 132</td><td>147</td></tr>
<tr><td>Refrigerated Warehouse</td><td>Envelope and HVAC</td><td>120</td><td></td></tr>
</table>

Signs	Indoor and Outdoor	130, 132	148		
Low-Rise Residential	General	150	151 (a, f)	151 (a-e)	152
	Envelope (conditioned)	116, 117, 118, 150 (a-g, l)			
	HVAC (conditioned)	112, 115, 150 (h, i, m)			
	Water heating (conditioned)	113, 150 (j)			
	Indoor Lighting (conditioned and parking garages)	119(d), 150 (k)			
	Outdoor Lighting	119(d), 150 (k)			

SECTION 101 – DEFINITIONS AND RULES OF CONSTRUCTION

Cold storage is an area where space temperatures are maintained between 20°F and 55°F.

Frozen storage is an area where space temperatures are maintained below 20°F.

PROCESS is an activity or treatment that is not related to the space conditioning, lighting, service water heating, or ventilating of a building as it relates to human occupancy, cold storage or frozen storage.

PROCESS SPACE is a space that is thermostatically controlled to maintain a process environment temperature less than 55° F or to maintain a process environment temperature greater than 90° F for the whole space that the system serves, or that is a space with a space-conditioning system designed and controlled to be incapable of operating at temperatures above 55° F or incapable of operating at temperatures below 90° F at design conditions.

PROCESS LOAD is a load resulting from a process.

Refrigerated warehouse is a building constructed for storage of products, where mechanical refrigeration is used to maintain the space temperature at 55°F or less.

SECTION 110 – SYSTEMS AND EQUIPMENT—GENERAL

Sections 111 through ~~119~~ 120 establish requirements for the manufacture, construction, and installation of certain systems, equipment and building components that are installed in buildings regulated by Title 24, Part 6. Systems, equipment and building components listed below may be installed only if:

(a) The manufacturer has certified that the system, equipment or building component complies with the applicable manufacture provisions of Sections 111 through ~~119~~ 120; and

(b) The system, equipment or building component complies with the applicable installation provisions of Sections 111 through ~~119~~ 120.

No system, equipment or building component covered by the provisions of Sections 111 through ~~119~~ 120 that is not certified or that fails to comply with the applicable installation requirements may be installed in a building regulated by Title 24, Part 6.

The systems, equipment and building components covered are:

Appliances regulated by the Appliance Efficiency Regulations (Section 111).

Other space-conditioning equipment (Section 112).

Other service water-heating systems and equipment (Section 113).

Pool and spa heating systems and equipment (Section 114).

Gas appliances (Section 115).

Doors, windows, and fenestration products (Section 116).

Joints and other openings (Section 117).

Insulation and Cool Roofs (Section 118).

Lighting control devices (Section 119).

Refrigerated warehouses (Section 120).

All of the language is new for a new Section 120 that is at the end of SUBCHAPTER 2 ALL OCCUPANCIES—MANDATORY REQUIREMENTS FOR THE MANUFACTURE, CONSTRUCTION AND INSTALLATION OF SYSTEMS, EQUIPMENT AND BUILDING COMPONENTS. Sections 120 through 125 in the 2005 standards are renumbered to account for this new section. **Language though new is not underlined for clarity sake.**

SECTION 120 – MANDATORY REQUIREMENTS FOR REFRIGERATED WAREHOUSES

Refrigerated warehouses with the total cold storage and frozen storage area exceeding 3,000 square feet shall meet the requirements of this section.

(b) Insulation Requirements. Exterior surfaces of refrigerated warehouses shall be insulated to the levels designated in Table 120-A.

Table 120-A

Space	Surface	Minimum R-value
Frozen Storage	Roof	R-49
	Wall	R-40
	Floor	R-30
Cold Storage	Roof	R-35
	Wall	R-25

(b) Underslab heating. Electric resistance heat shall not be used for the purposes of underslab heating

EXCEPTION to Section 120 (b)

1. Facilities with freezer floor area less than or equal to 3000 square feet.

2. Underslab heating systems controlled such that the electric resistance heat is thermostatically controlled and disabled during the summer on-peak period, as defined by the local electric utility.

(c) Evaporators. Fan-powered evaporators used in coolers and freezers shall conform to the following:

1. Evaporator fans shall be variable speed and speed shall be controlled in response to space conditions
2. Evaporator fan power shall be less than or equal to 0.15 watts per cfm at design flow

(d) Condensers. Fan-powered condensers shall conform to the following:

1. Condensers shall be evaporatively cooled
2. Condensing temperatures under design conditions shall be less than or equal to the design wetbulb temperature plus 20°F.
3. The combination of the condenser heat rejection rate (Btu/hr), and condenser fan and pump power (watts) shall exceed 400 Btu/hr-watt at 100°F condensing temperature and 70°F wetbulb temperature.
4. Condenser fans shall be variable speed and controlled in response to ambient wetbulb temperature or refrigeration system load.

EXCEPTION to Section 120 (d). Systems utilizing refrigerants other than ammonia (R-717)

(e) Compressors. Compressor systems utilized in refrigerated warehouses shall conform to the following:

1. Compressors shall be designed to operate at a minimum condensing temperature of 70°F or less.
2. The compressor speed shall be controllable in response to the refrigeration load on at least one compressor per suction group.

(f) Defrost Systems

1. Electric resistance heat shall not be used for evaporator coil defrost
2. Defrost system controls shall utilize an evaporator coil temperature measurement to terminate the defrost cycle.

EXCEPTION to Section 120 (f). Facilities with refrigerated floor area less than or equal to 3000 square feet.

EXCEPTION to Section 120

1. Areas within refrigerated warehouses that are designed solely for the purpose of quick chilling or freezing of products

Alternate Calculation Manual

The proposed changes are assigned as mandatory requirement, so most of the ACM will not be affected. Language relating to the scope of Title 24 will need to be revised to include refrigerated warehouses.

Acknowledgments

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Appendix A: Summary of Contractor Interviews

Building Shell

Two of the five people interviewed did not care to offer any answers regarding the building shell and typical construction practices. No contractor offered any information on the cost of the building shell. Most stated the recent volatile oil market has caused the price of insulation to be unpredictable. It was generally perceived that the only concern with regards to availability and market capacity was price.

There did not appear to be any variability in construction or insulation performance due to climate regions.

Freezers/Coolers Ceilings, Walls and Floors

Freezer ceiling construction for larger facilities would most likely place the panels on the outside over a metal "B" deck with EPDM roofing membrane over the insulation that would also act as the vapor barrier. Layers of 5" Isocyanurate achieving R values from R-31 to R-50 is typical. This same construction is used for both ice-cream and holding freezers. A code minimum of R-50 may receive some resistance.

For smaller facilities, a 6" expanded urethane metal clad sandwich panel is typical for the ceiling.

Typical freezer wall construction consists of the same 5" or 6" expanded urethane metal clad panels with R values that range from R-32 to R-56. The metal acts as the vapor barrier. In addition to the thermal performance characteristics, the thickness of the wall also becomes a function of the wall height. A code minimum of R-26 may be too low. A code minimum of R-32 appears reasonable and may achievable.

Due to the constructability of the facility, it is common for the cooler walls and ceilings to be the same thickness as the freezer walls and ceilings for facilities that house both coolers and freezers. It is also common for loading docks adjacent to coolers to share the same wall and ceiling thickness.

The wall separating a cooler from a freezer may be built to the same thickness due to the height of the structure. The height would dictate the wall thickness. This may also be true for the wall separating the cooler and freezer from the loading dock area. These separation walls, however, may not have the same thermal characteristics.

The wall separating the cooler from the freezer and the freezer from the loading dock typically has 5" to 6" of urethane for insulation and has a metal frame structure. A code minimum may not be necessary for these types of walls due to the fact that the end user is more concerned with condensation forming on the warm side of the wall and the thermal characteristics of the wall would have to be high enough to prevent condensation from occurring. These walls are typically built to a higher R value than the suggested code minimum of R-26.

Freezer floors are typically insulated from R-18 to R-30, depending on the soil and ground characteristics. They are typically constructed with glycol tubes set in a mud slab with 4" of rigid styrene over the mud slab and 6" of reinforced concrete poured over that. The glycol tubes may also be extended two feet out under the dock. One contractor mentioned a shift away from glycol piping to electric resistance heat due to liability issues from leaking glycol pipes. The size of the facility may also influence the economic viability of installing an under-slab glycol heating system and may favor electrical resistance heating on smaller floor prints. The suggested code minimum of R-30 appears reasonable and may be achievable. The thickness of the insulating panels may be limited by the structural characteristics required and achieving R-30 appears to not pose any structural problems.

In facilities that house only cooler storage, it is typical for the ceilings to be constructed of wood frame plywood with 4" of blown-on urethane insulation on the underside with R values from R-24 to R-40. The walls could be either 4" to 5" expanded urethane metal clad panels or sandwiched concrete panels with R values from R-23 to R-40. The code minimum of R-20 appears to be too low. A code minimum of R-25 may be reasonable and achievable.

Several contractors mentioned the extensive use of pre-stressed concrete beams with poured concrete slab on the roofs and concrete tilt-up panels utilized for wall construction. This building assembly allows for stable temperature and humidity levels. The end user of these types of buildings typically store fresh fruit commodities such as grapes.

Cooler floors are typically un-insulated concrete slab on grade.

Loading dock construction is highly dependant on how the rest of the facility is constructed and will typically be built to the same characteristics as the adjacent space.

Doors

Contractors typically do not get involved with door design and the frequency of use appears seasonal. A larger issue may be the type of seals use and/or the amount of infiltration that is allowed.

Cool Roof

Most contractors interviewed did not have much experience with roofing design and wondered how much a highly reflective surface would help a building that already ahs a large amount of insulation. One contractor that has performed experiments with cool roof designs has witnessed a drop in roof surface temperatures from ~140°F to ambient on days with a 100°F dry bulb temperature.

Low-E Paint

Most contractors liked to see the insides of the facilities painted mainly for the reflective quality and the possible reduction in required electric lighting. Some questioned whether the paint could be used on facilities regulated by the USDA and one contractor did not see how the paint could have any beneficial effect.

Underfloor Heating

The issue of leaking glycol piping under the slab should be investigated further to understand the extend of this concern. The use of air to heat under the slab appears to be under utilized. The installation of under-slab glycol heating appears to be the industry norm.

Refrigeration Systems

A typical response to questions of cost was that the cost are project specific and not evaluated on a cost per ton basis. Also that no two system are similar enough to produce reliable numbers.

Questions regarding fan and/or pump power (W/cfm and/or BTU/watt) did not receive much input. This strengthens the concern brought to light by one interviewee that 90% of cold storage facilities do not have load calculations done, that equipment is selected on a square foot per ton basis or based on the last facility done.

Evaporators

Evaporator Fan Speed Control

Common design practice is single speed and perhaps fan cycling. VFDs are becoming more common but do require a certain level of control to utilize. Several contractors did not find it reasonable to require VFDs for fan speed control but only offered for comments situations that would not require any evaporator fan modulation, in other words, they viewed it unreasonable because there may be situations or products that require constant air movement. Requiring the installation of VFDs for fan speed control could only work for the storage of products that do not require constant air movement. The availability and market capacity both appear high to medium high.

Evaporator Design Temperature Difference

The common design practice for evaporator design temperature difference is 10°F to 12°F for cold storage warehouses. This delta T could be shaved down to 7°F to 8°F for a higher performance design. However, several contractors were concerned about limiting the temperature difference for situations or products that require a lower humidity. This is also a concern for evaporators serving loading docks that may be designed with a 12°F to 15°F temperature difference. This appears to be a very product dependant or application specific design parameter. For fresh fruits that require a higher level of humidity to be maintained an even lower delta T would be used. The availability and market capacity appear high for evaporators designed for lower temperature differences and the only concern is designing for commodities requiring a lower level of humidity.

Evaporator Fan Power

Very little feedback was received regarding evaporator fan power. It is common for the designer not to be concerned with evaporator fan power. The fan is selected to deliver a certain amount of air to a certain distance though a specific thickness of coil. For this reason, it is unclear what the market availability or the market capacity is for such a code minimum. For this reason, it also may be unreasonable to require a minimum watt/cfm for evaporator fan power.

Condensers

Condenser Type

The most commonly used condenser type for larger refrigerated storage facilities using ammonia refrigerant is evaporative condensing. High performance design considerations would include pre-cooling the water used (which is rarely done) or increasing the surface area. On smaller systems that utilize a halocarbon refrigerant, the evaporative condenser is considered for high performance designs only.

The limitations to utilizing an evaporative condenser on ammonia systems would be the water source and/or quality of available water. Limitations for utilizing an evaporative condenser on halocarbon refrigerant systems would also include first cost.

The availability of evaporative condensers and market capacity appears high and the only objections to requiring evaporative condensing are the cost impact to smaller systems and water availability.

Air Cooled Condenser Fan Speed Control

The common design practice for air cooled fan speed control is to cycle single speed fans. The high performance consideration is to control fan speed with a VFD. It is generally believed that because air cooled condensers are typically used on smaller systems and utilize several smaller fans which offers a wide range of modulation, the use of VFDs is often economically unattractive. However, the only comment regarding cost of adding a VFD to an air cooled condenser was an increase of 5% with no suggested increase in maintenance costs.

The code minimum specification of requiring a VFD to control fan speed on air cooled condensers appears to not be reasonable with tree responses of No, one Yes and one No comment (due to lack of experience with air cooled condensers). All contractors interviewed had more experience with evaporative condensers than with air cooled.

Air Cooled Condenser Design Approach Temperature

The responses for air cooled condenser design approach temperature varied greatly from 10°F to 30°F. When asked if having a code maximum of 10°F would be reasonable, the responses were equally varied from, it wouldn't work, the condenser would be excessively large, to, remote condensers are always 0°F for low temp. and 15°F for medium temp.

The exceptions to the 10°F code minimum were only that the capitol cost would be too much. The market availability responses were two Highs, one Low and one No comment. The market capacity responses were one High, one Medium, one Low and one No comment. The only response to first cost was a suggested increase of 10% with no added maintenance costs.

All contractors interviewed were more familiar with evaporative condenser design and selection than with air cooled condensers. If air cooled condenser manufacture's offer condensers sized for a 10°F design approach temperature, it appears reasonable for said code minimum to be achievable.

Air Cooled Condenser Fan Power

No responses were received to offer any insight into common design practices with regards to BTU per watt of condenser fan power. Fan power appears to not be part of the design selection process for air cooled condensers. Contractors interviewed had no idea what would be a reasonable number for BTU per watt or whether it would have any cost impact.

The performance of air cooled condensers would need to be analyzed to determined the most common BTU per watt and if any room for improvement exists. This would need to include an analysis of manufacture's performance data.

Evaporative Condenser Fan Speed Control

Both fan cycling and VFD fan speed control appear to be equally common. Utilization of VFDs to control fan speed on evaporative condensers has increased in recent years as the price of VFDs has come down. High performance designs would typically utilize VFD control. The availability of VFD fan speed control appears very high and the market capacity also appears high to medium. Only one contractor offered comments regarding price with a suggested 10% increase with minimal maintenance cost.

The only concerns stated for requiring a VFD to control fan speed is that it may not be necessary. However, VFDs are becoming more common due to price decreases and a growing number of contractors and facility operators that understand the control logic for optimization of head pressure control. The minimum proposed code specification of utilizing VFDs to control fan speed on evaporative condensers appears reasonable and achievable.

Evaporative Condenser Design Approach Temperature

The common design practice for evaporative condenser approach temperature ranges from 18°F to 20°F. High performance design practices range from 9°F to 15°F. The suggested code maximum design approach temperature of 20°F appears too high.

The availability and market capacity for providing an evaporative condenser with an approach temperature of 20°F appears very high. This codes minimum specification should be reviewed for opportunities to tighten this approach temperature down. A reasonable approach temperature appears to be in the range of 9°F to 15°F.

Evaporative Condenser Fan and Pump Power

Only two contractors offered comments regarding evaporative condenser fan and pump power. This code minimum specification appears similar to the fan power minimums for air cooled condensers in that it is not considered when selecting an evaporative condenser. The one response suggested that 200 BTUh/watt would be more realistic.

Some comments regarding the selection design data suggest that using 100°F saturated condensing temperature with 70°F entering wet bulb temperature may not be common. A more common selection design criteria appears to be 98°F saturated condensing temperature with a 78°F entering wet bulb temperature and 85/76 for high performance design.

The performance of evaporative condensers would need to be analyzed to determined the most common BTU per watt and if any room for improvement exists. This would need to include an analysis of manufacture's performance data.

Compressors

Compressor Capacity Modulation

The most common design practice for compressor capacity modulation is the use of slide valves on screw compressors. The high performance design practice would utilize a VFD to control the screw compressor's speed.

When asked if requiring the utilization of a VFD for compressor capacity modulation was reasonable for a code minimum specification, four of five contractors responded with No. But when asked to provide situations were an exception should be made, the responses were more mixed and those that suggested there should be exceptions could not offer specific situations other than designing a plant with more compressors to allow for more stages of modulation.

The availability of VFDs appears high and the market capacity appears medium to high. Only one contractor offered a comment on price suggesting an increase of 30% with minimal maintenance costs. It is becoming more common for compressor manufacture's to offer VFD control as a package. A code minimum specification of requiring VFD control for compressor capacity modulation may be reasonable and achievable for the trim compressor of a multiple compressor plant or for a single compressor system that will see variations in load. For systems that may require a constant load or a minimum load that could be matched to the full load of the smallest compressor, requiring a VFD for compressor modulation may encounter some resistance.

Volume Ratio

Fixed and variable volume ratios are common and appear to be available from most compressor manufactures. Variable volume ratios would be considered a higher performance design practice.

Compressor Plant Capacity Modulation

Compressor plant capacity modulation is typically a function of facility requirements. Most common design practices appear to utilize multiple compressor of either equal or unequal sizes with multiple unequal size compressors being more common. High performance design practices would utilize VFD control on the trim compressor.

Compressor Oil Cooling

Thermosyphon oil cooling is the common design practice with liquid injection as a less preferred practice. Thermosyphon oil cooling is also considered the higher performance practice. Limitations to thermosyphon oil cooling are the physical locations of the thermosyphon vessel with respect to the compressor plant. These limitations are mostly negated for new construction.

When asked if a code minimum specification of requiring thermosyphon oil cooling would be reasonable, most contractors answered No. There appears to be a growing movement from compressor manufactures toward more efficient ways to perform liquid injection oil cooling. Liquid injection may also be easier and offer a greater sense of assuredness for oil cooling.

The availability of thermosyphon oil cooling appears high and the market capacity appears medium. A code minimum specification of requiring thermosyphon oil cooling may not be necessary since most contractors already offer it at minimum (5%) additional cost and there appears to be a potential for compressor manufacture's to provide a more efficient application of liquid injection.

Compressor Plant Stages

The number of compressor plant stages appears to be specific to the facility requirements. For facilities with only coolers, single stage is common. For facilities with both coolers and freezers, two stages without an economizer and with an inter-cooler or one stage with economizer are both common. The two stage system is considered the higher performance system.

Number of Suction Groups

The number of suction groups is also very dependant on the facility requirements. If more than one evaporator suction temperature is required and the difference between the two temperatures is large enough, it appears common to design for more than one suction group.

Use of Economizers on Single Stage Systems

The general consensus for use of economizers on single stage systems is that it would be more beneficial to add another smaller compressor or design a two stage system or even add another suction group.

Use of Intercooling on Multistage systems
Both flash and shell and coil appear equally common. The use of flash intercooling is considered the higher performance design practice. Intercooling appears to be commonly utilized and the use of flash intercooling appears to be more popular.

Lighting

Two contractors interviewed did not care to comment on lighting. No contractor offered any comments on lighting costs.

Lighting power Density
Common design practices range from 0.4 to 1.2 W/SF with 0.6 W/SF. appearing to be more acceptable. High performance design considerations include the use of T-5 bulbs and the use of occupancy sensors.

The availability and market capacity appears medium to high. A code maximum specification of 0.6 W/SF appears reasonable and achievable. The only concerns offered were regarding process facilities and the safety requirements for workers.

Issues Affecting Lighting and Power Density
Ceiling height, rack height and placement and labor policies appear to be the main issues affecting lighting and power density. There is also concern on how the new high performance fixtures will perform under the extreme conditions of refrigerated storage.

Lighting Controls
Contractors admitted to not being aware of the options available but have noticed an increase in bi-level lighting controls and even occupancy sensors. It is perceived as available and reasonable to require bi-level lighting control for a code minimum specification. The concerns offered include the special requirements in process applications and labor practices.

Controls

Computerized Control Systems
It appears to be common, especially on larger systems, for a facility wide controls system to be installed. High performance design practices would include more sensors and control points. This does allow for control code minimum specifications to be easily implemented.

Suction Pressure Control
Common design practice is to utilized a fixed suction pressure control and the high performance design would utilize a floating suction pressure control. The only limitations to floating suction pressure control are specific cases that may require a constant suction pressure and the addition of a control system. As stated above, a capable control system appears to be common on larger systems.

The availability and market capacity of adding floating suction pressure control appears to be high. The only cases offered as exceptions were process systems that may require lower humidity and therefore, a constant suction pressure. Only one contractor offered a comment on price with a suggested increase of 3% and minimal maintenance cost.

Requiring floating suction pressure control as a code minimum specification for refrigerated warehouses appears reasonable and achievable.

Condensing Temperature Control

The common design practice for condensing temperature control is fixed and the high performance design would utilize floating control from the wet bulb offset. The only limitations to utilizing floating head pressure control would be specific situations requiring a minimum head pressure for defrost requirements and/or liquid injection.

Utilizing floating head pressure control appears to be more acceptable than floating suction pressure control. Wet bulb offset may not be the only algorithm for controlling head pressure and there is some concern with applying a limitation to how the floating head pressure could be controlled.

The availability and market capacity appear to be high for implementing floating head pressure control. Only one contractor offered a comment on price with a suggested increase of 2-3% and minimal maintenance cost.

Requiring floating head pressure control as a code minimum specification for refrigerated warehouses appears reasonable and achievable but may not need to be limited to wet bulb offset control.

Defrost Type and Control

The common design practices for defrost type on larger ammonia systems is air for storage above 40°F and water for storage below 40°F and hot gas defrost. Hot gas defrost is considered the higher performance design practice.

The common design practice for defrost control is to utilize a time clock for scheduling defrost times and terminating the defrost based on time or temperature. High performance defrost controls utilize an accumulative run time or on-demand defrost.

Every contractor agreed that the use of electrical resistance heat for defrost on larger system should not be allowed and that requiring a code minimum specification of on-demand controls would appear reasonable and achievable. It appears that electrical resistance defrost is only used on smaller systems.

Demand Response

All contractors interviewed are familiar with demand response practices at some facilities. The product types that might be candidates for demand response strategies would include frozen packaged products, frozen juices and frozen products that do not require a minimum temperature.

These products can typically tolerate a 5°F drift in temperature and depending on the amount of product stored, and the traffic in the storage facility, this 5°F drift may take from 4 to 6 hours.

Other factors that will affect the length of time for this 5°F drift to occur include lighting, fan requirements and insulation performance.

Products that would not tolerate this strategy include frozen vegetables and frozen meats. Fluctuations in temperature will cause moisture migration in these products.

It appears common for 10-15% spare capacity to be designed into the refrigeration systems.

Other Opportunities

Most contractors agree that refrigerated warehouse could be designed and operated more efficiently. Areas to consider include VFD control of fans and compressors, improved door design and performance, lighting improvements and lighting controls, better control packages and building simulation to be performed on all large warehouses in order to optimize building envelope and refrigeration system options.

Appendix B: Contractor Interview Survey Instrument

Refrigerated Warehouse Case Initiative
Interview Guide for Refrigeration Industry Interviews
Version 5
Architectural Energy Corporation

General Information

Contact Name	
Title	
Company	
City and State	
Phone	

Area of expertise: ❒ Large warehouses (typically >50kSF with central refrigeration plant) OR ❒ Small warehouses (typically <50kSF with packaged DX refrigeration) (if both, complete a questionnaire for both types)

Questions:

1. Building Shell

1.1 Typical construction practices.

In your experience, what are typical industry design practices for (list attribute)

Attribute	Wall Construction Type (concrete tilt up, steel frame, Prefabricated metal insulated panel,, other	Construction Details (wall/ roof thickness, support spacing and thickness, insulation location and application)	Insulation R-value or Insulation Type and Thickness	Variability by Climate region? If yes, explain
Freezer Ceiling (Ice Cream)				
Freezer Ceiling (Holding Freezer)				
Freezer Exterior Wall				
Freezer to Cooler Wall				
Freezer to Dock Wall				
Freezer Floor R-value				
Cooler Ceiling				
Cooler Walls				
Dock Ceiling				
Dock to outdoor wall				
Dock Floor				

Other Design Details

Attribute	Typical practices and materials
Under floor heating	
Roofing materials	
Interior doors (freezer to dock)	Low freq of use (< cpd): Med freq of use (100-400 cpd) Hi freq of use (> 400 cpd)
Interior doors (cooler to dock)	Low freq of use (< cpd): Med freq of use (100-400 cpd) Hi freq of use (> 400 cpd)
Exterior doors	

1.2 Measure list and specifications

We are considering including (list attribute) in the Title 24 Standards. The minimum proposed specifications for the code are (list code minimum). Does this specification seem reasonable to you? (Yes or no, list reasons)

Attribute	Code minimum specification	Reasonable (Y/N)	ASHRAE Recommendations	Comments
Freezer Ceiling (Ice Cream)	R = 50		R-50 to R-60	
Freezer Ceiling (Holding Freezer)	R = 46		R-45 to R-50	
Freezer Exterior Wall)	R = 26		R-35 to R-40	
Freezer to Cooler Wall	R = 26			
Freezer to Dock Wall	R = 26			
Freezer Floor R-value	R = 30		R-27 to R-32	
Cooler Ceiling	R = 23		R-30 to R-35	
Cooler Walls	R = 20		R-25	
Dock Ceiling	R = 23			
Dock to outdoor wall	R = 20			
Dock Doors	R = 15			
Cool Roof	Solar reflectance > 0.70, thermal emittance > 0.75		Same as commercial	
Underfloor heating	No electric resistance			

1.3 Exceptions

Can you think of any situations where an exception should be made? (Yes or no)

What are the circumstances for an exception, and what should an alternative minimum specification be under the circumstance? (list circumstances and alternative specification)

Attribute	Code minimum specification	Exceptions (Y/N)	Circumstances and alternative specification
Freezer Ceiling (Ice Cream)	R = 50		
Freezer Ceiling (Holding Freezer)	R = 46		
Freezer Exterior Wall	R = 26		
Freezer to Cooler Wall	R = 26		
Freezer to Dock Wall	R = 26		
Freezer Floor R-value	R = 30		

Attribute	Code minimum specification	Exceptions (Y/N)	Circumstances and alternative specification
Cooler Ceiling	R = 23		
Cooler Walls	R = 20		
Dock Ceiling	R = 23		
Dock to outdoor wall	R = 20		
Dock Doors	R = 15		
Cool Roof	Solar reflectance > 0.70, thermal emittance > 0.75		

1.4 Measure availability and market capacity

How would you rate the availability of the equipment and/or materials? (high – available through my normal sources; medium – available through sources that I don't normally use; low – not available anywhere to my knowledge). If Title 24 were to include (list code minimum) for (list attribute), what, in your opinion, is the capacity of the market to supply the materials and equipment necessary to meet the demand? (high- can meet demand with little to no supply disruption; medium – some early disruption in supply anticipated, low –persistent lack of equipment for the foreseeable future).

Attribute	Code minimum specification	Availability (High, Medium, Low)	Market Capacity (High, Medium, Low)
Freezer Ceiling (Ice Cream)	R = 50		
Freezer Ceiling (Holding Freezer)	R = 46		
Freezer Exterior Wall)	R = 26		
Freezer to Cooler Wall	R = 26		
Freezer to Dock Wall	R = 26		
Freezer Floor R-value	R = 30		
Cooler Ceiling	R = 23		
Cooler Walls	R = 20		
Dock Ceiling	R = 23		
Dock to outdoor wall	R = 20		
Dock Doors	R = 15		
Cool Roof	Solar reflectance > 0.70, thermal emittance > 0.75		

1.5 Costs

What are the equipment and/or material first costs (absolute costs) for (list attribute)? How much of a difference is this relative to standard practices (list standard practice and % difference). Are there any incremental maintenance costs associated with (list attribute, annual maintenance costs and units (SF, ton, etc.).

Attribute	Code minimum specification	First Cost ($/SF)	% diff from common practice	Incremental Maintenance Cost ($/SF)
Freezer Ceiling (Ice Cream)	R = 50			
Freezer Ceiling (Holding Freezer)	R = 46			
Freezer Exterior Wall)	R = 26			
Freezer to Cooler Wall	R = 26			
Freezer to Dock Wall	R = 26			
Freezer Floor R-value	R = 30			
Cooler Ceiling	R = 23			

Attribute	Code minimum specification	First Cost ($/SF)	% diff from common practice	Incremental Maintenance Cost ($/SF)
Cooler Walls	R = 20			
Dock Ceiling	R = 23			
Dock to outdoor wall	R = 20			
Dock Doors	R = 15			
Cool Roof	Solar reflectance > 0.70, thermal emittance > 0.75			

Refrigeration System
2. Evaporators

2.1 Typical design practices.

In your experience, what are typical industry design practices for (list attribute)? and what changes to common design specification if any are commonly applied for refrigerated warehouses where the client is especially motivated to minimize energy consumption? What are the limitations to applying these design practices to all refrigerated warehouses?

Attribute	Common design practice	High performance design practice	High performance practice limitations or problems
Evaporator fan speed control (single speed, two speed, variable speed, other (list))			
Evaporator design temperature difference (Room temperature – refrigerant evaporation temperature)			
Evaporator fan power (Watts of fan power per cfm of air flow rate)			
Other evaporator design options			

2.2 Measure list and specifications

We are considering including (list attribute) in the Title 24 Standards. The minimum proposed specifications for the code are (list code minimum). Does this specification seem reasonable to you? (Yes or no, list reasons)

Attribute	Code minimum specification	Reasonable (Y/N)	Comments
Evaporator fan speed control	VSD		
Evaporator design approach temperature	10°F		
Evaporator fan power (W/CFM)	0.30		

2.3 Exceptions

Can you think of any situations where an exception should be made? (Yes or no)

What are the circumstances for an exception, and what should an alternative minimum specification be under the circumstance? (list exception and alternative specification)

Attribute	Code minimum specification	Exceptions (Y/N)	Circumstances and alternative specification
Evaporator fan speed control	VSD		
Evaporator design approach temperature	10°F		
Evaporator fan power (W/CFM)	0.30		

2.4 Measure availability and market capacity

How would you rate the availability of the equipment and/or materials? (high – available through my normal sources; medium – available through sources that I don't normally use; low – not available anywhere to my knowledge). If Title 24 were to include (list code minimum) for (list attribute), what, in your opinion, is the capacity of the market to supply the materials and equipment necessary to meet the demand? (high- can meet demand with little to no supply disruption; medium – some early disruption in supply anticipated, low –persistent lack of equipment for the foreseeable future).

Attribute	Code minimum specification	Availability (High, Medium, Low)	Market Capacity (High, Medium, Low)
Evaporator fan speed control	VSD		
Evaporator design approach temperature	10°F		
Evaporator fan power (W/CFM)	0.30		

2.5 Costs

What are the equipment and/or material first costs (absolute costs) for (list attribute)? How much of a difference is this relative to standard practices (list standard practice and % difference). Are there any incremental maintenance costs associated with (list attribute, annual maintenance costs and units (SF, ton, etc.).

Attribute	Code minimum specification	First Cost ($/TR)	% diff from common practice	Incremental Maintenance Cost ($/TR)
Evaporator fan speed control	VSD			
Evaporator design approach temperature	10°F			
Evaporator fan power (W/CFM)	0.30			

3. Condensers

3.1 Typical design practices.

In your experience, what are typical industry design practices for (list attribute)

Attribute	Common design practice	High performance design practice	High performance practice limitations or problems
Condenser type (air cooled or evaporative by system size and climate region)			
Air cooled condenser fan speed control (1 speed, two speed, variable speed, other (list))			
Air cooled condenser design approach temperature (saturated condensing temperature – ambient drybulb temperature; list evaporator temp)			
Air cooled condenser fan and pump power (Btu per watt @ 10°F delta T)			
Evaporative condenser fan speed control (1 speed, two speed, variable speed, other (list))			
Evaporative condenser design approach temperature (saturated condensing temperature – ambient wetbulb temperature at design conditions; list design WBT)			
Evaporative condenser fan and pump power (Btu per watt @ 100°F SCT, 70°F EWB)			

3.2 Measure list and specifications

We are considering including (list attribute) in the Title 24 Standards. The minimum proposed specifications for the code are (list code minimum). Does this specification seem reasonable to you? (Yes or no, list reasons)

Attribute	Code minimum specification	Reasonable (Y/N)	Comments
Condenser type	Evaporative condenser required in inland applications above xx TR		
Air cooled condenser fan speed control	Variable Speed		
Air cooled condenser design approach temperature	10°F		
Air cooled condenser fan and pump power	53 BTU/Watt at 10°F TD and sea level)		

Attribute	Code minimum specification	Reasonable (Y/N)	Comments
Evaporative condenser fan speed control	Variable Speed		
Evaporative condenser design approach temperature	20°F		
Evaporative condenser fan and pump power	330 BTU/Watt at 100°F SCT and 70°F WBT)		

3.3 Exceptions

Can you think of any situations where an exception should be made? (Yes or no)

What are the circumstances for an exception, and what should an alternative minimum specification be under the circumstance? (list exception and alternative specification)

Attribute	Code minimum specification	Exceptions (Y/N)	Circumstances and alternative specification
Condenser type	Evaporative condenser required in inland applications above xx TR		
Air cooled condenser fan speed control	Variable Speed		
Air cooled condenser design approach temperature	10°F		
Air cooled condenser fan and pump power	53 BTU/Watt at 10°F TD and sea level)		
Evaporative condenser fan speed control	Variable Speed		
Evaporative condenser design approach temperature	20°F		
Evaporative condenser fan and pump power	330 BTU/Watt at 100°F SCT and 70°F WBT)		

3.4 Measure availability and market capacity

How would you rate the availability of the equipment and/or materials? (high – available through my normal sources; medium – available through sources that I don't normally use; low – not available anywhere to my knowledge). If Title 24 were to include (list code minimum) for (list attribute), what, in your opinion, is the capacity of the market to supply the materials and equipment necessary to meet the demand? (high- can meet demand with little to no supply disruption; medium – some early disruption in supply anticipated, low –persistent lack of equipment for the foreseeable future).

Attribute	Code minimum specification	Availability (High, Medium, Low)	Market Capacity (High, Medium, Low)
Condenser type	Evaporative condenser required in inland applications above xx TR		
Air cooled condenser fan speed control	Variable Speed		
Air cooled condenser design approach temperature	10°F		
Air cooled condenser fan and pump power	53 BTU/Watt at 10°F TD and sea level)		
Evaporative condenser fan speed control	Variable Speed		
Evaporative condenser design approach temperature	20°F		
Evaporative condenser fan and pump power	330 BTU/Watt at 100°F SCT and 70°F WBT)		

3.5 Costs

What are the equipment and/or material first costs (absolute costs) for (list attribute)? How much of a difference is this relative to standard practices (list standard practice and % difference). Are there any incremental maintenance costs associated with (list attribute, annual maintenance costs and units (SF, ton, etc.).

Attribute	Code minimum specification	First Cost ($/ton of refrigeration capacity)	% diff from common practice	Incremental Maintenance Cost ($/ton of refrigeration capacity)
Condenser type	Evaporative condenser required in inland applications above xx TR			
Air cooled condenser fan speed control	Variable Speed			
Air cooled condenser design approach temperature	10°F			
Air cooled condenser fan and pump power	53 BTU/Watt at 10°F TD and sea level)			
Evaporative condenser fan speed control	Variable Speed			
Evaporative condenser design approach temperature	20°F			
Evaporative condenser fan and pump power	330 BTU/Watt at 100°F SCT and 70°F WBT)			

4. Compressors

4.1 Typical design practices.

In your experience, what are typical industry design practices for (list attribute)

Attribute	Common design practice	High performance design practice	High performance practice limitations or problems
Compressor capacity modulation (slide valve, VSD, other (list))			
Volume ratio (fixed, variable, other (list))			
Compressor plant capacity modulation (multiple, equal sized compressors, multiple unequal sized compressors, VSD trim compressor, slide valve trim compressor, other (list))			
Compressor oil cooling (refrigerant injection, water cooling, thermosyphon, other (list))			
Compressor plant stages (one, two, other (list))			
Number of suction groups			
Use of economizer on single stage systems			
Use of intercooling on multistage systems Intercooler type (flash, shell and coil, other (list))			

4.2 Measure list and specifications

We are considering including (list attribute) in the Title 24 Standards. The minimum proposed specifications for the code are (list code minimum). Does this specification seem reasonable to you? (Yes or no, list reasons)

Attribute	Code minimum specification	Reasonable (Y/N)	Comments
Compressor capacity modulation	VSD on at least one compressor per suction group above xx TR, or limit over-sizing and document constant load application		
Compressor oil cooling	Thermosyphon		

4.3 Exceptions

Can you think of any situations where an exception should be made? (Yes or no)

What are the circumstances for an exception, and what should an alternative minimum specification be under the circumstance? (list exception and alternative specification)

Attribute	Code minimum specification	Exceptions (Y/N)	Circumstances and alternative specification
Compressor capacity modulation	VSD on at least one compressor per suction group above xx TR, or limit over-sizing and document constant load application		
Compressor oil cooling	Thermosyphon		

4.4 Measure availability and market capacity

How would you rate the availability of the equipment and/or materials? (high – available through my normal sources; medium – available through sources that I don't normally use; low – not available anywhere to my knowledge). If Title 24 were to include (list code minimum) for (list attribute), what, in your opinion, is the capacity of the market to supply the materials and equipment necessary to meet the demand? (high- can meet demand with little to no supply disruption; medium – some early disruption in supply anticipated, low –persistent lack of equipment for the foreseeable future).

Attribute	Code minimum specification	Availability (High, Medium, Low)	Market Capacity (High, Medium, Low)
Compressor capacity modulation	VSD on at least one compressor per suction group above xx TR, or limit over-sizing and document constant load application		
Compressor oil cooling	Thermosyphon		

4.5 Costs

What are the equipment and/or material first costs (absolute costs) for (list attribute)? How much of a difference is this relative to standard practices (list standard practice and % difference). Are there any incremental maintenance costs associated with (list attribute, annual maintenance costs and units (SF, ton, etc.).

Attribute	Code minimum specification	First Cost ($/TR)	% diff from common practice	Incremental Maintenance Cost ($/TR)
Compressor capacity modulation	VSD on at least one compressor per suction group above xx TR, or limit over-sizing and document constant load application			
Compressor oil cooling	Thermosyphon			

5. Lighting

5.1 Typical design practices.

In your experience, what are typical industry design practices for (list attribute)

Attribute	Common design practice	High performance design practice	High performance practice limitations or problems
Lighting power density in warehouse spaces (W/SF)			
Issues affecting lighting power density (lamp type, storage temperature, ceiling height, rack height, aisle width, other (list))			
Lighting controls (bi-level lighting, occupancy sensors, time clocks, other (list))			

5.2 Measure list and specifications

We are considering including (list attribute) in the Title 24 Standards. The minimum proposed specifications for the code are (list code minimum). Does this specification seem reasonable to you? (Yes or no, list reasons)

Attribute	Code minimum specification	Reasonable (Y/N)	Comments
Lighting power density in warehouse spaces (W/SF)	0.6 W/SF		
Lighting controls	Bi-level lighting		

5.3 Exceptions

Can you think of any situations where an exception should be made? (Yes or no)

What are the circumstances for an exception, and what should an alternative minimum specification be under the circumstance? (list exception and alternative specification)

Attribute	Code minimum specification	Exceptions (Y/N)	Circumstances and alternative specification
Lighting power density in warehouse spaces	0.6 W/SF		
Lighting controls	Bi-level lighting		

5.4 Measure availability and market capacity

How would you rate the availability of the equipment and/or materials? (high – available through my normal sources; medium – available through sources that I don't normally use; low – not available anywhere to my knowledge). If Title 24 were to include (list code minimum) for (list attribute), what, in your opinion, is the capacity of the market to supply the materials and equipment necessary to meet the demand? (high- can meet demand with little to no supply disruption; medium – some early disruption in supply anticipated, low –persistent lack of equipment for the foreseeable future).

Attribute	Code minimum specification	Availability (High, Medium, Low)	Market Capacity (High, Medium, Low)
Lighting power density in warehouse spaces	0.6 W/SF		
Lighting controls	Bi-level lighting		

5.5 *Costs*

What are the equipment and/or material first costs (absolute costs) for (list attribute)? How much of a difference is this relative to standard practices (list standard practice and % difference). Are there any incremental maintenance costs associated with (list attribute, annual maintenance costs and units (SF, ton, etc.).

Attribute	Code minimum specification	First Cost ($/SF)	% diff from common practice	Incremental Maintenance Cost ($/TR)
Lighting power density in warehouse spaces	0.6 W/SF			
Lighting controls	Bi-level lighting			

6. Controls

6.1 *Typical design practices.*

In your experience, what are typical industry design practices for (list attribute)

Attribute	Common design practice	High performance design practice	High performance practice limitations or problems
Computerized control systems (facility wide, component only (list), none)			
Suction pressure control (fixed, floating, other (list))			
Condensing temperature control (fixed pressure control,- control point wetbulb offset – control point other (list))			
Defrost type (air, electric resistance, hot gas, hot water, other (list))			
Defrost controls (time clock, on-demand, other (list))			

6.2 *Measure list and specifications*

We are considering including (list attribute) in the Title 24 Standards. The minimum proposed specifications for the code are (list code minimum). Does this specification seem reasonable to you? (Yes or no, list reasons)

Attribute	Code minimum specification	Reasonable (Y/N)	Comments
Suction pressure control	Floating		
Condensing temperature control	Wetbulb offset		
Defrost control	On-demand controls required for electric resistance defrost		

6.3 Exceptions

Can you think of any situations where an exception should be made? (Yes or no)

What are the circumstances for an exception, and what should an alternative minimum specification be under the circumstance? (list exception and alternative specification)

Attribute	Code minimum specification	Exceptions (Y/N)	Circumstances and alternative specification
Suction pressure control	Floating		
Condensing temperature control	Wetbulb offset		
Defrost control	On-demand controls required for electric resistance defrost		

6.4 Measure availability and market capacity

How would you rate the availability of the equipment and/or materials? (high – available through my normal sources; medium – available through sources that I don't normally use; low – not available anywhere to my knowledge). If Title 24 were to include (list code minimum) for (list attribute), what, in your opinion, is the capacity of the market to supply the materials and equipment necessary to meet the demand? (high- can meet demand with little to no supply disruption; medium – some early disruption in supply anticipated, low –persistent lack of equipment for the foreseeable future).

Attribute	Code minimum specification	Availability (High, Medium, Low)	Market Capacity (High, Medium, Low)
Suction pressure control	Floating		
Condensing temperature control	Wetbulb offset		
Defrost control	On-demand controls required for electric resistance defrost		

6.5 Costs

What are the equipment and/or material first costs (absolute costs) for (list attribute)? How much of a difference is this relative to standard practices (list standard practice and % difference). Are there any incremental maintenance costs associated with (list attribute, annual maintenance costs and units (SF, ton, etc.).

Attribute	Code minimum specification	First Cost ($/TR)	% diff from common practice	Incremental Maintenance Cost ($/TR)
Suction pressure control	Floating			
Condensing temperature control	Wetbulb offset			
Defrost control	On-demand controls required for electric resistance defrost			

7. Demand response

Demand response, using the thermal mass of the building and stored product in frozen food warehouses is an idea that Pacific Gas and Electric is interested in exploring. The overall concept is to reduce the product temperature during off-peak periods and turn the refrigeration plant off during on-peak periods, allowing the product to float up to the nominal storage temperature. This strategy could be followed on a regular basis, or only during an anticipated peak demand emergency. I would like to ask a few questions regarding this topic to assess the overall feasibility of the approach:

7.1 Are you aware of any facilities where demand response using stored product thermal mass is practiced?

7.2 What product types might be candidates for this strategy?

7.3 What level of temperature variation can be tolerated by the products listed above?

7.4 What duration (in minutes or hours per day) of refrigeration plant interruption can be tolerated?

7.5 What factors influence the maximum acceptable load interruption duration (temperature excursion, RH control, other (list))?

7.6 How much spare capacity (refrigeration plant tons / peak refrigeration load tons) is typically available in frozen food warehouses (express as a percentage):

7.7 What factors or conditions might make this approach infeasible?

8. Other measures

What other measures or energy savings strategies do you think should be considered for inclusion into Title 24?