DOCKETED

Docket Number:	15-MISC-03
Project Title:	Proposed Compliance Option for Data Centers Using a Refrigerant Economizer
TN #:	206401
Document Title:	Proposal to Include Refrigerant Economizers in The California Energy Commission 2103 Building Energy Efficiency Standards
Description:	Emerson's calculation method in response to Taylor Engineering's comment for more clarity. The purpose of this document is to demonstrate the source of the energy calculation presented in the proposal to the CEC to gain approval to include the "refrigerant" based economization system.
Filer:	Mark Alatorre
Organization:	Emerson Network Power
Submitter Role:	Public
Submission Date:	10/19/2015 3:13:46 PM
Docketed Date:	10/19/2015

Proposal to Include Refrigerant Economizers in The California Energy Commission 2103 Building Energy Efficiency Standards For Residential and Non Residential Buildings Title 24, Part 6

Liebert Modeling Process

Prepared by:

Emerson Network Power

August 28, 2015

Presented by:

Steven Madara

VP Global Thermal Sales

Purpose

The purpose of this document is to demonstrate the source of the energy calculation presented in the proposal to the CEC to gain approval to include the "refrigerant" based economization system as used in the Liebert DSE product line in the same category as the prescriptive water economization requirement as defined in Section 140.9(a) of CEC Title 24 Energy Code for Computer Rooms (Energy Code). The Exceptional Design Compliance method of modeling was used to show that the "refrigerant" economizer solution of the Liebert DSE meets or exceeds the full intent of the Energy Code.

Executive Summary

The Energy Code requires all Data Centers to meet the efficiency requirement of either one of two prescriptive economization methods (outside air economization or water economization) or to demonstrate through the Exceptional Design Compliance method the proposed solution meets or exceeds the energy efficiency of the prescriptive methods. At the time the Energy Code was written, the refrigerant economization method developed by Emerson Network Power and deployed in the Liebert DSE product line was just being released into the market place to meet the high efficiency needs of data center thermal management. Since 2012, over 1500 of the Liebert DSE systems have been installed throughout North America, South America, Europe and Australia, of which 52 systems are installed in California data centers.

The Liebert DSE data center cooling system with pumped refrigerant economization system solves many building design issues for thermal management needs, and meets or exceeds the efficiency of most water economization methods. Specifically, it meets the requirement of full economization at 40 deg F outdoor temperatures and in many cases full economization is achieved in most data centers at outdoor temperatures of 65 deg F or more. Additionally, the system design reduces or eliminates several of the power components associated with water economizers and further eliminates the need for any water in the heat rejection process. A cooling system with a water economizer uses an average of 4.2 million gallons of water per year for a data center with an IT load of 1.2 MW. Approximately, 50 MW of new data center capacity is added in California per year and over half of these sites can effectively use this technology. Other advantages of not utilizing water include, significant reduction in maintenance, chemical treatment, and the risk of bacteria exposure such as Legionella.

The Liebert DSE data center cooling system is described in more detail in the Report Detail section, but consists of an indoor evaporator (CRAC style unit), air cooled condenser and a refrigerant pump package. The system operates like a standard air cooled Direct Expansion (DX) system, but when the criteria for economization is met, the compressors turn off and a refrigerant pump is turned on to move the refrigerant through the system to reject the heat of the data center. The refrigerant pump power is

typically less than 5% of the energy of the compressor but yields the same capacity. Additionally, the control used in the Liebert DSE will allow the unit to go into economization mode automatically when conditions meet the criteria to support the load with economization. This allows 100% of the available temperature hours in the year to be utilized. Lastly, the economization mode is not based on a fixed outdoor temperature or chilled water temperature and operates in economizer mode at much higher outdoor temperatures when the load varies (lower) or the return air conditions increases.

Modeling was completed comparing a water economizer system to the Liebert DSE pumped refrigerant economizer system for all sixteen (16) climate zones in California. The modeling was completed using the Performance Compliance Approach, as specified in Section 140.1 of the Energy Code, calculation methodology by a third party engineering firm with PE licensure and LEED –AP qualification. The steps to generate the modeling comparison begin with the original product development as follows:

1. Product development and applications testing
2. System Testing - Psychrometric Room performance testing
3. Performance rating program development and confirmation (LRS – Liebert Rating System)
4. Data from the LRS was passed into a n Excel spread sheet where it was prepared for a regression analysis for following:
    a. Total Cooling Capacity as a function of Condenser Entering Air Dry Bulb temperature and Evaporator Entering Air Wet Bulb Temperature.
    b. Total Cooling capacity as a function of Supply Air Flow.
    c. EER as a function of Condenser Entering Air Dry Bulb temperature and Evaporator Entering Air Wet Bulb Temperature.
    d. EER as a function of Supply Air Flow.
    e. Part Load fraction as a function of Part Load Ratio.
5. Modeling process
    a. Regression analysis on the data in 4 to develop custom performance curve coefficients for input in the Energy Plus energy modeling program.
    b. Baseline and proposed models were generated with the CEC's CBECC-Com compliance modeling software.
    c. Modified the proposed model with the custom performance curves and added TDV multiples and ran the simulation with EnergyPlus.
    d. Extracted results for comparative analysis.

Emerson Network Power is requesting that the CEC grant an immediate formal exception to include the use of a pumped refrigerant economization system under the category of the prescriptive water economization requirement with the same stipulations imposed with the water economization method based on this modeling process

Report Details

Pumped Refrigerant Economizer Technology:

Pumped Refrigerant Economizer technology was developed to provide economization modes of operation similar to water economizers in a DX (compressorized) cooling system for applications where a chilled water thermal system is not practical. For example, in small to middle size data centers up to 2MW-3MW of IT load, the capital cost, operational costs and physical size are not suited for traditional chilled water equipment. The major growth in the data center space is lead by Co-Location companies that are building very efficient data centers. Most of these new data centers are being built in a modular approach in 500kW to 1,600kW building blocks providing reliable redundancy for the customer at the module level. A typical site could grow over time to 5MW to 10MW in total size.

The Liebert DSE cooling system with pumped refrigerant economization consists of an indoor evaporator (CRAC style unit), air cooled condenser and a refrigerant pump package. The system operates like a standard air cooled DX system, but when the criteria for economization is met, the compressors turn off and a refrigerant pump is turned on to move the refrigerant through the system to reject the heat of the data center.

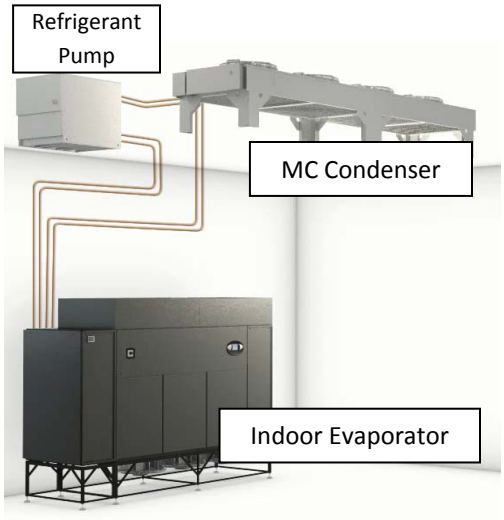


Fig 1 - System Component Layout

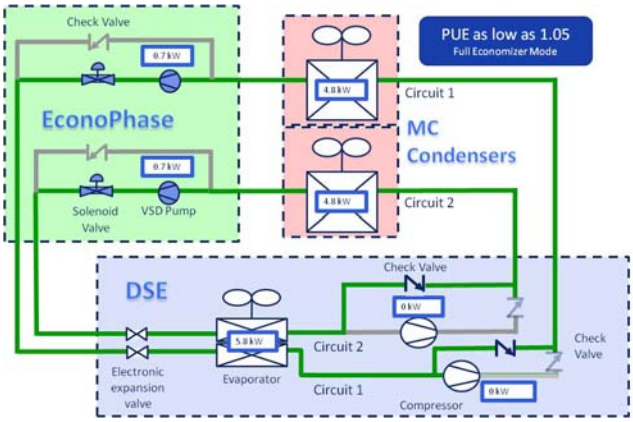


Fig 2 - System Flow Diagram

The efficiency of the system is achieved by using the most efficient system components on the market today and implementing an economizer system that circulates the refrigerant in the system to absorb the heat and then reject the heat outdoors. This unique feature of the design uses the same evaporator and condenser coil and circuit for both the DX and Economization modes requiring less overall fan power as a result of the lower system airside pressure drop. Then when the system goes into economization mode, the refrigerant pump power is typically less than 5% of the energy of the compressor but yields the same capacity. In the pump mode, refrigerant is pumped through the system where it is condensed in the condenser and then the refrigerant "boils off " in the evaporator and goes through a phase change. In Appendix A is a Pressure-Enthalphy diagram showing the

operation in pump mode and the comparison of the heat remove COP compare to water (approximately 3x greater).

In most systems, there are two refrigerant circuits, providing an opportunity for both full and partial economization modes of operation through a staged operation. The partial economization mode occurs when refrigerant circuit 1 (leading circuit in the air stream) will switch from compressor mode to pump mode. The chart below show the stages of operation – Full compressor mode (both circuits), partial economization (economization mode with circuit 1) and them full economization mode with both circuits.

Econo Mode	OD Temp		System 1		System 2		Cond Fan	Evap Fan	Total Power	Mech PUE
	° F	° C	Compr	Pump	Compr	Pump				
Full DX	95	35.0	8.9	0.0	8.9	0.0	4.1	3.5	25.4	1.24
Partial	60	15.6	0.0	0.4	8.9	0.0	2.4	3.5	15.2	1.15
Full	50	10.0	0.0	0.5	0.0	0.5	4.8	3.6	9.4	1.09
Full	40	4.4	0.0	0.6	0.0	0.6	0.5	3.6	5.3	1.05

Fig 3 – Operating Components by Ambient (example DA125 at 80% load/95°F RAT)

Additionally, when compared to a system with a water economizer, there is no intermediate heat exchanger and one less fluid pump (Water system uses a cooling tower pump and a chilled water circulating pump, Refrigerant system uses one refrigerant pump) to consume less power.

The fully integrated control used in the Liebert DSE will allow the unit to go into economization mode automatically when conditions meet the criteria to support the load with economization. This allows 100% of the available temperature hours in the year to be utilized without manual intervention or dead bands of operation. Lastly, the economization mode is not based on a fixed outdoor temperature or chilled water temperature as is typically the case with water economizers (in chilled water systems the economization mode is governed by the leaving chilled water set point regardless of the load). If the load varies (lower) or the return air conditions increase, the system will go into economizer mode at much higher outdoor temperatures. This is shown graphically in Appendix B.

The Liebert DSE pumped refrigerant economization system several benefits over a chilled water economizer and the results will show in most climates the annual performance is better. The key benefits are:

1. The system control will adjust the point of partial and full economization based on the IT load and the return air temperatures. The means economization may occur at high ambient conditions providing greater economization. Where as a chiller plant typically has a fixed chilled water temperature and that dictates the ambient temperature where economization occurs.

2. There is a full and partial economization mode providing steps of economization
3. There is no intermediate heat exchanger
4. There is no water consumption or water treatment required

All Liebert DSE performance is tested and certified to the new AHRI 1360 standard for Computer Room cooling equipment. The first listings for the new AHRI section will be published in September 2015.

Process for Developing the Compliance Exception Modeling:

The data for the Compliance Modeling originates from the product development process for all Liebert Thermal products. The key steps are:

1. Product development and applications testing
2. System Testing - Psychrometric Room performance testing
3. Performance rating program development and confirmation (LRS – Liebert Rating System)
4. Data from the LRS was passed into a n Excel spread sheet where it was prepared for a regression analysis for following:
    a. Total Cooling Capacity as a function of Condenser Entering Air Dry Bulb temperature and Evaporator Entering Air Wet Bulb Temperature.
    b. Total Cooling capacity as a function of Supply Air Flow.
    c. EER as a function of Condenser Entering Air Dry Bulb temperature and Evaporator Entering Air Wet Bulb Temperature.
    d. EER as a function of Supply Air Flow.
    e. Part Load fraction as a function of Part Load Ratio.
5. Modeling process
    a. Regression analysis on the data in 4 to develop custom performance curve coefficients for input in the Energy Plus energy modeling program.
    b. Baseline and proposed models were generated with the CEC's CBECC-Com compliance modeling software.
    c. Modified the proposed model with the custom performance curves and added TDV multiples and ran the simulation with EnergyPlus.
    d. Extracted results for comparative analysis.

The Product Development process follow ISO9001 standard and in Appendix C is shown the steps and processes for the development and testing.

The System testing is performed in a Pyschrometric Room and tested to ASHRAE standards. Appendix D outlines testing method, procedures and the facilities. The System is tested at multiple operating points (indoor return air and loads) and ambients to determine the operating performance throughout the full range operations.

The next step (3) is to correlate the actual tested performance to a performance calculation system. In this case the Liebert Rating System is a mathematical modeling tool that uses industry proven

calculations (example – heat transfer, compressor curves) to determine the performance of the system at any possible condition with in the operating envelope of the system. A brief overview of the LRS – Liebert Rating System is covered in Appendix E. Part of the correlation of the actual tested values and the predicted values out of the LRS system requires that statistically the predicted values are within 5% of the actual test values throughout the range of the unit operation. This LRS tool is used to provide accurate predictions of a cooling system performance and various operating points.

For the purposes of modeling the performance of the Liebert DSE system, data was generated out of the LRS system to be used as the input to the modeling process.

The CEC's CBECC-Com compliance software was used to generate baseline and proposed models to demonstrate a comparative energy analysis for the Exceptional Calculation Procedure for all 16 climate zones in California. The proposed model was modified with custom performance curves based on regression analysis from detailed data developed by Emerson for their DSE Computer Room Air Conditioning units with the Econphase economizer from their LRS system. Due to limitations with the CBECC-com software the proposed model was run with the EnergyPlus simulation program. Results from the baseline and proposed models were extracted to a spreadsheet to show compliance for all 16 climate zones.

California Building Codes:

The California 2013 Building Energy Efficiency Standards (Title 24), effective July 1, 2014, for Non Residential buildings (Subchapter 5) in Section 140.0(c) require either the performance compliance approach (energy budgets) in Section 140.1 or the prescriptive compliance approach in Section 140.2 for the Climate Zone in which the building will be located. The prescriptive requirement for Computer Rooms is further defined in Section 140.9 where either integrated air economizers or integrated water economizers are capable of provide 100 percent of the expected system cooling load. For water economizers, this must be met with outside air temperatures of 40°F dry-bulb/35°F wet-bulb conditions and below.

Additionally, containment is required for rooms with design loads exceeding 175 kW per room. For the data center, this typically means you can drive return air temperatures to the cooling system higher than most office environments. It is not uncommon today to see this value exceed 95°F.

Compliance Modeling Method:

Compliance Modeling requirement in section 140.1 is based on the 2013 Time Dependent Valuation (TDV) and was conducted by AlaJor Engineering, Inc (Appendix G).

Exceptional Design Compliance - End Use Summary Comparison – The table shown below is a comparison of the results from the preliminary baseline and proposed models simulated for a project in San Francisco for a 1,190kW (14,000sqft @ 85 w/sqft) Data Center using standard redundancy assumptions (N+2) and conservative return air temperatures (80°F) with containment. The baseline

water economizer model was created utilizing the CEC's CBECC-Com (Build 717) and extracting the baseline IDF model that was created. The extracted baseline IDF model was modified and removed the air economizer and added the water economizer. The model was simulated with EnergyPlus and the results extracted to the *Exceptional Design Compliance - End Use Summary Comparison* spreadsheet. The proposed Liebert DSE model was created utilizing the CEC's CBECC-Com (Build 717) and extracting the proposed IDF model that was created. The extracted proposed IDF model was modified and added custom curves for the Liebert DSE equipment that were developed from a regression analysis from data provided for the operation for the Liebert pumped refrigerant system (same source for AHRI ratings). The model was simulated and the results extracted to the *Exceptional Design Compliance - End Use Summary Comparison* spreadsheet. EnergyPlus models for the above are available if required.

	End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
		GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Climate Zone 3	Space Cooling	3,830.2	1,064.0	14,911.2	1,313.5	-	5,954.5	1,654.1	24,059.0	2,119.3	(805.8)
	Fans	3,197.0	888.1	12,610.2	1,110.8	-	618.9	171.9	2,439.4	214.9	895.9
	Lighting	154.1	42.8	720.9	63.5	-	154.1	42.8	720.9	63.5	-
	Pumps	709.7	197.1	2,717.1	239.3	-	-	-	-	-	239.3
	Heat Rejection	148.5	41.3	665.3	58.6	-	-	-	-	-	58.6
	Compliance Total	8,039.4	2,233.3	31,624.7	2,785.7	-	6,727.4	1,868.9	27,219.3	2,397.7	388.1
	Interior Equipment	28,527.8	7,925.0	109,114.8	9,611.6	-	28,527.8	7,925.0	109,114.8	9,611.6	-
	Total	36,567.2	10,158.4	140,739.6	12,397.4	4,063,160	35,255.1	9,793.9	136,334.1	12,009.3	388.1
											PASS

The results for this site provide a reduction of the TDV value by 388.1 and an overall reduction of MWh consumed in a year by 364.5. However, the most significant reduction is the elimination of all water consumption equal to 4,063,160 gallons per year.

Compliance Modeling Results:

The modeling for a similar Data Center was conducted for all 16 Climate Zones . The results are summarized below with the details provided in Appendix H. The Industry weight average value is based on the Co-Location data center population distribution across the state of California. Most of the Co-Location data centers are located in 9 of the 16 Climate Zones and all have favorable reductions in the TDV value by 10% and eliminate on average over 4,274,000 gallons of water per 1.2 MW of data center IT load. It is estimated there will be approximately 50MW of new data load added per year.

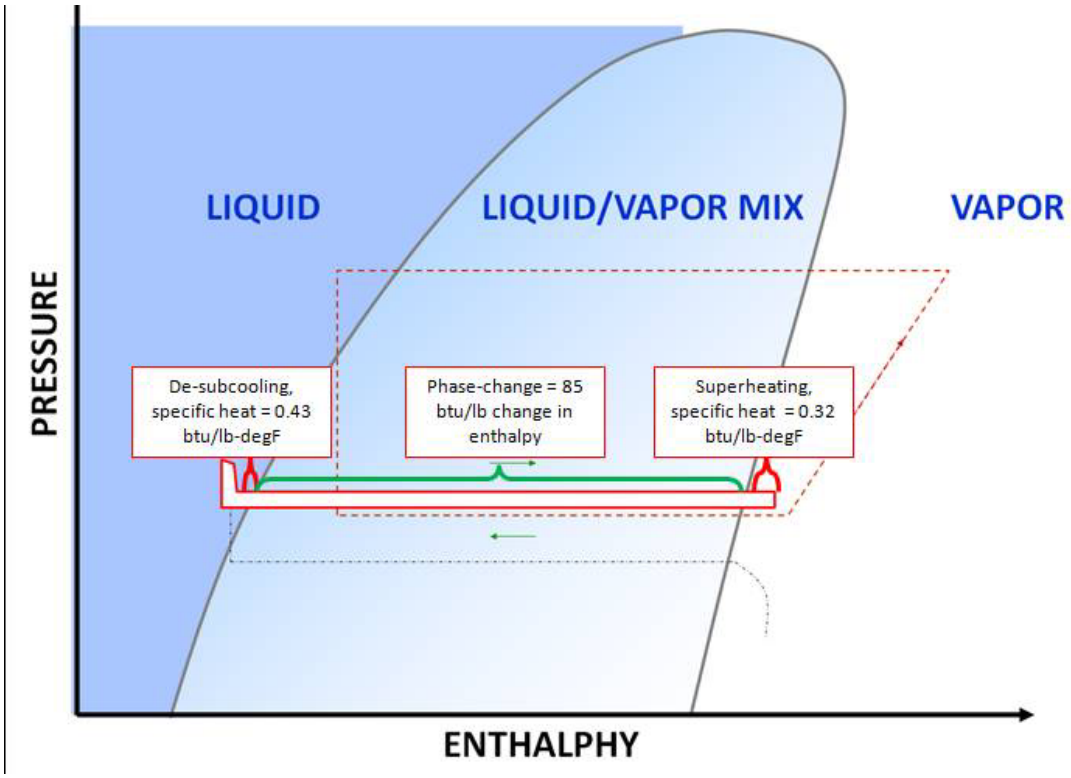
Climate Zone	MWh reduction	% MWh reduction	TDV kBtuh/ft^2 reduction	% TDV reduction	Water Reduction (1000gal/year)
Climate Zone 1 - Arcata	-686.8	30.0%	-803.8	28.1%	3,875
Climate Zone 2 - Santa Rosa	-338.1	14.8%	-285.9	9.9%	4,260
Climate Zone 3 - Oakland	-364.5	16.3%	-388.1	13.9%	4,063
Climate Zone 4 - Sunnyvale	-336.5	14.4%	-294.0	10.1%	4,378
Climate Zone 5 - Santa Maria	-426.1	18.4%	-457.0	15.9%	4,003
Climate Zone 6 - Los Angeles	-236.9	10.3%	-234.0	8.3%	4,258
Climate Zone 7 - San Diego	-225.1	9.8%	-235.0	8.1%	4,280
Climate Zone 8 - El Toro	-239.1	10.3%	-198.3	6.9%	4,312
Climate Zone 9 - Pasadena	-217.2	9.4%	-186.7	6.5%	4,414
Climate Zone 10 - Riverside	-101.9	4.5%	1.8	-0.1%	3,664
Climate Zone 11 - Red Bluff	-396.4	15.6%	-259.3	8.1%	4,755
Climate Zone 12 - Sacramento	-296.3	12.7%	-219.2	7.3%	4,541
Climate Zone 13 - Fresno	-190.9	8.1%	-60.4	2.0%	4,822
Climate Zone 14 - China Lake	-204.4	8.4%	-37.6	1.2%	5,061
Climate Zone 15 - El Centro	94.0	-4.0%	291.9	-9.9%	5,551
Climate Zone 16 - Mount Shasta	-632.1	25.9%	-610.1	19.8%	4,154
Average	-299.9	12.8%	-248.5	8.5%	4,399
Industry Weighted Average (per 1.2MW)	-293.0	12.1%	-278.0	10.2%	4,274

Actions Requested of the CEC:

The use of a “refrigerant” economizer provides significant benefits to the State of California for use in Data Centers. There is on average a 8% reduction (weighted average of 10%) in the TDV energy value but more significantly it eliminates the water requirement for these data centers. The inclusion of a “refrigerant” economizer in the prescriptive compliance method will make the adaption and implementation of this technology on par with water economization evaluations and bypass the burdensome and time consuming process of preparing the Energy Budget for each project.

Appendix A - R410a Pumped Refrigerant Cycle

- Unlike compressor operation, the evaporator is the higher pressure side of the system, so the "top" line on the p-h diagram refers to the evaporator
- The real change in energy occurs through phase-change in the evaporator and then again in the condenser. This change of state represents the 85 btu/lb difference in enthalpy. Note that this is not in btu/lb-degF, because it is happening at constant temperature.
- There is a very small effect enthalpy change associate with the superheating and subcooling effect



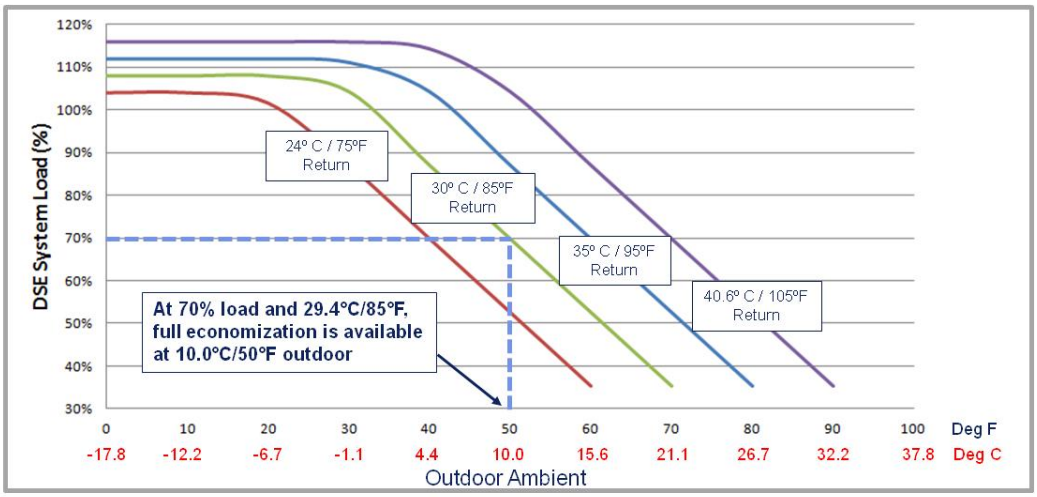
R-410A has ~3x the heat capacity as water for the same volume.

	Air		Water		Pumped Refrigerant	
Heat Density of Fluid	0.456	btu/ft^3	624	btu/ft^3	5739	btu/ft^3
Heat Removal COP	**30**	**kW/kW**	**364**	**kW/kW**	**1.115**	**kW/kW**

Appendix A – (con't)

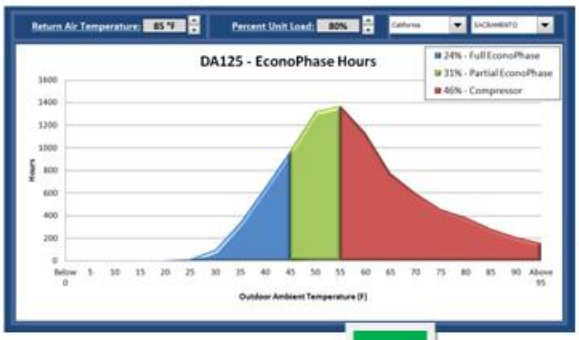
	Water		R-410A	
Density	62.4	lb/ft^3	67.52	lb/ft^3
Heat Capacity	1	btu/lb-F	85	btu/lb
Volumetric Heat Capacity	62.4	btu/ft3-F	-	-
Typical Heat Rise	10	F	-	
Volumetric Heat Transfer Content	624	btu/ft^3	5739.2	btu/ft^3
Time Period	60	min	60	min
Flow Rate	1	ft^3/min	1	ft^3/min
Heat Transfer per Unit Time	37440	btu/hr	344352	btu/hr
Heat Transfer per Unit Time	10.9698213	kW	100.894228	kW
Typical HVAC Pressure Drop	10	lb/in^2	30	lb/in^2
Typical HVAC Pressure Drop in lb/ft^2	1440	lb/ft^2	4320	lb/ft^2
Input HP per 1 CFM Flow Rate	0.04044444	hp	0.12133333	hp
Input kW per 1 CFM Flow Rate	0.03015942	kW	0.09047825	kW
Heat Transfer/HP	925,714	btu/hp-hr	2,838,066	btu/hp-hr
COP (kW removed / kW input)	**363.7**	-	**1115.1**	-
Heat Transfer Efficiency	**Base**	%	**307**	%

Appendix B – Liebert DSE Adjustable Economization Criteria for More Economization Hours

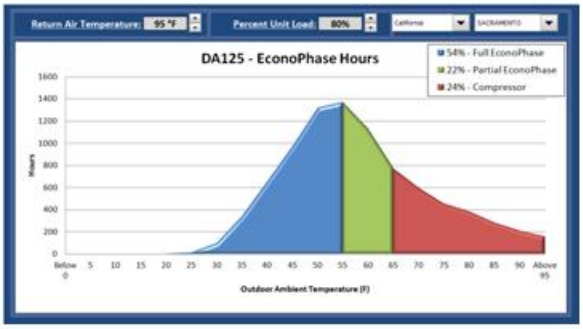


Annual free-cooling hours increase at higher return air conditions and lower unit loads:

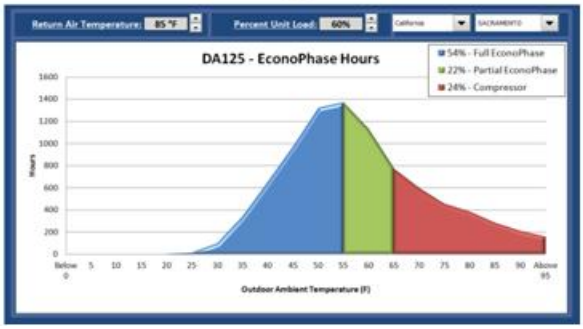
Base Line



Higher Return Air Temperatures

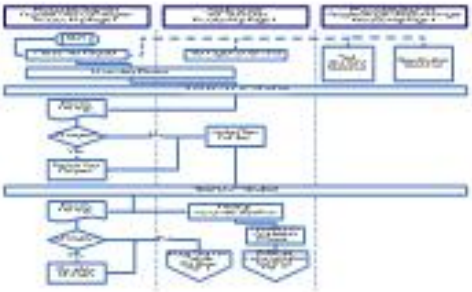


Lower IT Load



Processes (Emerson-Liebert ISO 9001 documents)

- Prototype
  - ENCL-8207-002 PROTOTYPE REQUEST CHECKLIST.
- Test Request
  - ENFM-8207-018 TST REQ CSA C22.2 #236 UL1995.
  - ENFM-8207-039 TST REQ DOC PREC CLG LAB.
  - ENFM-8207-040 TST REQ XLS PREC CLG LAB.
- Testing
  - ENPR-8207-002 TST PROC PRECISION COOLING LAB.
  - ENPR-8207-001 TST PROC CSA C22.2#236 UL 1995.
  - PSYCHROMETRIC ROOM TEST PROCESS
- Calibration
  - ENWI-8207-001 UL/CSA TEMP CAL WORK INST
  - ENWI-8207-002 UL/CSA PRSR CAL WORK INST



EMERSON Network Power

7

Appendix D – Psychrometric Room Performance Testing

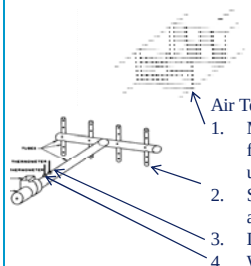
Psychrometric Capabilities

- Capacity
  - 120 ton Chilled Water, 60 ton Direct Expansion Refrigerant
- Uncertainty
  - Air flow rate ±0.7%
  - Capacity
    - Air ±3.2%
    - Refrigerant ±0.5%
    - Water ±2.6%
  - Power ±1.0%
- Throughput
  - Capacity Tests per shift: 4-8 depending magnitude of condition change
  - LabVIEW feature for un-manned programmed tests 2nd, 3rd shifts and weekends
- Compliance
  - ASHRAE 37-2009
  - ASHRAE Standard 127-2007 and 2012
  - CSA C22.2 No. 236-05 Fourth Edition

EMERSON Network Power

8

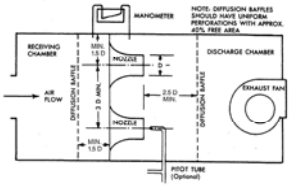
Measurement Techniques ASHRAE 37-2009



Air Temperature and Humidity

1. Mix air – room supply grilles for unit inlet, turning vanes in unit outlet sample box
2. Sample tree for further averaging
3. Dry bulb temperature
4. Wet bulb temperature

Static Pressure duct and piezometer ring



Air volume flow rate nozzle chamber

MAGFLO meter for water / glycol flow rate

Coriolis mass flow meter for refrigerant flow rate

EMERSON Network Power

9

Appendix D – con't

Instrumentation Accuracy

Measurement	ASHRAE Specification	Precision Cooling Laboratory
Air Dry Bulb Temperature	±0.2°F	±0.2°F
Air Wet Bulb Temperature	±0.2°F	±0.2°F
Water or Non-volatile Refrigerant	±0.2°F	±0.2°F
Volatile refrigerant	±1.0°F	±0.4°F
Pressure; Refrigerant, Liquid, Barometric	±2.5% of the reading	±0.25% Range (typically <±1% of the reading)
Pressure; Air Static & Differential	±0.01 inch H_2O	±0.25% Range (typically ±0.008 inch H_2O)
Nozzle diameter	±0.20%	±0.20%
Power	±2.0% of the reading for motors ±1.0% of the reading for heaters	±0.5% full scale
Voltage	±1.0% of the reading	±0.25% full scale
Volatile Refrigerant Flow	±1.0% of the reading	±0.1% of the reading
Water / Glycol Flow	±1.0% of the reading	±0.5% of the reading

EMERSON Network Power

10

Appendix E – Liebert LRS System (Liebert Rating System)

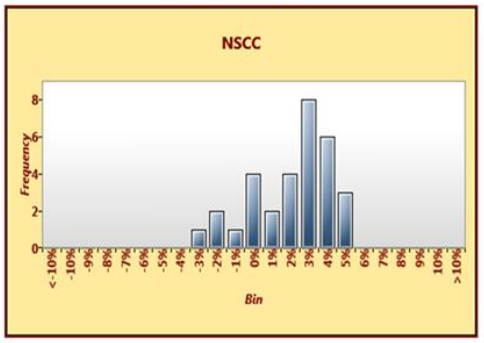
- A capacity and energy rating program for Liebert cooling product
  - A sophisticated thermal engine based on the latest published technology
  - A huge database to include all details of cooling product
    - Compressor curves
    - Heat transfer
    - Refrigerant flow / control
    - Air properties
    - Fan performances
- Used by engineering on new product development
- ASHRAE/AHRI requires to be +-5% accurate on performance prediction
- Technical references

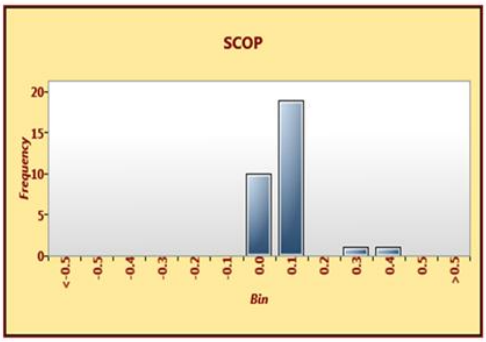
1. A. Cavallini, D. Del Col , L. Doretti, G.A. Longo, and L. Rossetto. Refrigerant vaporization inside enhanced tubes: a heat transfer model. Heat Technology., 1999. 17(2). 29–36
2. A. Cavallini, G. Censi, D. Del Col, L. Doretti, G. A. Longo, L. Rosetto, In-Tube Condensation of Halogenated Refrigerants, ASHRAE Transactions, 2002, 108 (1), Paper 4507
3. A.E. Dabiri, C.K. Rice, A compressor simulation model with corrections for the level of suction gas superheat, ASHRAE Transactions, 1981, Vo. 87, Pt. 2.
4. A.L. Souza, M.M. Pimenta, Prediction of pressure drop during horizontal two-phase flow of pure and mixed refrigerants, Cavitation and Multiphase Flow, ASME (1995), FED-Vol 210
5. Coil-Designer, Center for Environmental Energy Engineering, University of Maryland
6. D. Chisholm, An equation for velocity ratio in Two-Phase flow, NEL report 535
7. D. D. Col, A. Cavallini, J.R. Thome, Condensation of zeotropic mixtures in horizontal tubes: New simplified heat transfer model based on flow regimes, Journal of heat transfer, 2005, 127, 221-230
8. D. Steiner, VDI-Wärmeatlas (VDI Heat Atlas). Verein Deutscher Ingenieure, VDI-Gesellschaft, Verfahrenstechnik und Chemieingenieurwesen (GCV), Duesseldorf, Chapter Hbb, 1993
9. DS Jung, M McLinden, R Radermacher, D Didion, A study of flow boiling heat transfer with refrigerant mixtures, International Journal of Heat and Mass Transfer, 1989, 32, 9, 1751-1764
10. E.W. Lemmon, M.L. Huber, M.O. McLinden, NIST Standard Reference Database 23: Reference Fluid Thermodynamic and Transport Properties-REFPROP, Version 7.0, National Institute of Standards and Technology, Standard Reference Data Program, Gaithersburg, 2002
11. Frank P. Incropera, David P. Dewitt, Fundamentals of Heat and Mass Transfer, 5th edition, John Wiley and Sons,
12. H. Muller-Steinhagen and K. Heck, A Simple Friction Pressure Drop Correlation for Two-Phase Flow in Pipes, Chemical Engineering Process, 20 (1986) 297-308
13. Handbook of Hydraulic Resistance, I.E. Idlechik, Erwin Fried, Washington, Hemisphere Pub. Corp, ©1986. 2nd Ed.
14. L Friedel, Improved friction pressure drop correlations for horizontal and vertical two-phase pipe flow, In Proceedings of the European Two-phase Flow Group Meeting, Ispra, Italy, 1979, paper E2.
15. Ito, H., Pressure losses in smooth pipe bends, Journal of Basic Engineering: Transactions of ASME, March 1960, P.135.
16. J. R. Thome, Engineering Data Book III, Wolverine Tube, Inc
17. J.E. Hajal, J.R. Thome, A. Cavallini, Condensation in horizontal tubes, Part1: two-phase flow pattern map, International of Heat and Mass Transfer, 2003, 46, 3349-3383
18. J.E. Hajal, J.R. Thome, A. Cavallini, Condensation in horizontal tubes, Part2: heat transfer model based on flow regimes, International of Heat and Mass Transfer, 2003, 46, 3365-3387
19. J.M. Quiben, J.R. Thome, Flow pattern based two-phase frictional pressure drop model for horizontal tubes, Part I: Diabatic and adiabatic experimental study, International Journal of Heat and Fluid Flow 28 (2007) 1049–1059
20. J.M. Quiben, John R. Thome, Flow pattern based two-phase frictional pressure drop model for horizontal tubes, Part II: New phenomenological model, International Journal of Heat and Fluid Flow 28 (2007) 1060–1072
21. J.P. Wattlet, J.C. Chato, A.L. Souza, B.R. Christoffersen, Evaporative characteristics of R-12, R-134a, and MP39 at low mass fluxes, ASHRAE Transactions, Volume 100, Part1, Paper No. 94-2-1, 603-615
22. Julio Cesar Passos A. Vinicius Fernando Kuser A. Phillipe Haberschill B. Monique Lallemand, Convective boiling of R-407c inside horizontal microfin and plain tubes, Experimental Thermal and Fluid Science 27 (2003) 705–713
23. Jun-Young Choi, Mark A. Kedzierski, Piotr A. Domanski, Generalized pressure drop correlation for evaporation and condensation in smooth and micro-fin tubes, National Institute of Standards and Technology, NISTIR 6333
24. K.J. Bell and M.A. Ghaly, An approximate generalized design-method for multicomponent/partial condensers, AIChE Symp. Ser. 69 (1973), pp. 72–79
25. L.M Chamra, P.J Mago , M-O Tan, and C-C Kung, Modelling of evaporation and condensation pressure drop in microfin tubes, J. Mechanical Engineering Science, Proc. IMechE Vol. 219 Part C
26. L.M. Chamra and P.J. Mago, Modeling of evaporation heat transfer of pure refrigerants and refrigerant mixtures in microfin tubes, International Journal of Heat and Mass Transfer, Volume 48, Issue 7, March 2005, Pages 1293-1302
27. L.M. Schlager, M.B. Pate, A.E. Bergles, Evaporation and condensation heat transfer and pressure drop in horizontal, 12.7-mm microfin tubes with Refrigerant R22
28. L.M. Schlager, M.B. Pate, A.E. Bergles, Heat transfer and pressure drop during vaporation and condensation of R22 in horizontal micro-fin tubes, Int. J. Refrigeration 12 (1989) 6–14
29. Leszek Wojtan, Thierry Ursenbacher, John R. Thome, Investigation of flow boiling in horizontal tubes: Part I—A new diabatic two-phase flow pattern map, International Journal of Heat and Mass Transfer 48 (2005) 2955–2969
30. Leszek Wojtan, Thierry Ursenbacher, John R. Thome, Investigation of flow boiling in horizontal tubes: Part II—Development of a new heat transfer model for stratified-wavy, dryout and mist flow regimes, International Journal of Heat and Mass Transfer 48 (2005) 2970–2985
31. M. K. Dobson, J. C. Chato, Condensation in Smooth Horizontal Tubes, Journal of Heat Transfer, 1998, 120, 193-213
32. M. Lallemand, C.N. Branescu, P. Haberschill, Coefficients d__echange locaux au cours de l__ebullition du R22 et du R407C dans des tubes horizontaux, lisse ou micro-ailet_e, International Journal of Refrigeration 24 (2001) 57–72.
33. M.B. Ould Didi, N. Kattan, J.R. Thome, Prediction of two-phase pressure gradients of refrigerants in horizontal tubes, International Journal of Refrigeration 25 (2002) 935–947
34. M.M. Shah, A general correlation for heat transfer during film condensation inside pipes, International Journal of Heat and Mass Transfer, 1979, 22, 547-556
35. M.M. Shah, Chart correlations for saturated boiling heat transfer: Equations and further study, ASHRAE Transactions, 88(1): 185-196
36. Man-Hoe Kim, Joeng-Seob Shin, Evaporating heat transfer of R22 and R410A in horizontal smooth and microfin tubes, International Journal of Refrigeration, Volume 28, Issue 6, September 2005, Pages 940-948
37. N. Inoue, M. Goto, S.G. Kandlikar, Flow boiling heat transfer with binary and ternary mixtures in microfin tubes, Advances in Enhanced heat transfer, ASME 2000, HTD Vol. 365/PID Vol. 4
38. P.A. Domanski, C.J.L. Hermes, An improved two-phase pressure drop correlation for 180° return bends, 3rd Asian Conference on Refrigeration and Air-Conditioning, Gyeongju, Korea, May 21-23, 2006
39. R. Gronnerud, Investigation of liquid hold-up, flow-resistance and heat transfer in circulation type evaporators, part IV: two-phase flow resistance in boiling refrigerants, Annexe 1972-1, Bull. de l'Inst. du Froid, 1979
40. Rin Yun, Yongchan Kim, Kookjeong Seo, Ho Young Kim, A generalized correlation for evaporation heat transfer of refrigerants in micro-fin tubes, International Journal of Heat and Mass Transfer 45 (2002) 2003–2010
41. S.M. Zivi, Estimation of Steady-State Steam void fraction by means of the principal of minimum entropy generation, Journal of Heat Transfer, Vol. 86, pp. 247-252
42. S.W. Churchill, Friction-factor Equation Spans All Fluid Flow Regimes., Chemical Engineering, 1977, 7, 91-92.
43. V. Gnielinski, New equations for heat and mass transfer in turbulent pipe and channel flow, Int. J. Chem. Eng. 16 (1976) 359–367
44. X. Boissieux, M.R. Heikal, R.A. Johns, Two-phase heat transfer coefficients of three HFC refrigerants inside a horizontal smooth tube, part II: condensation, International Journal of Refrigeration, 2000, 23, 345-352
45. Z. Rouhani, E. Axelsson, Calculation of volume-void fraction in the subcooled and quality region, International Journal of Heat and Mass Transfer, Vol. 13, pp. 383-393

Appendix E – (con't) - LRS

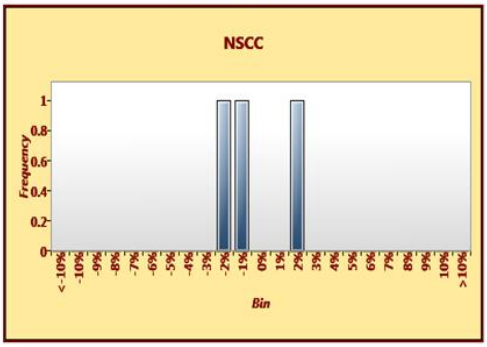
- Correlation process of LRS and test data (example)

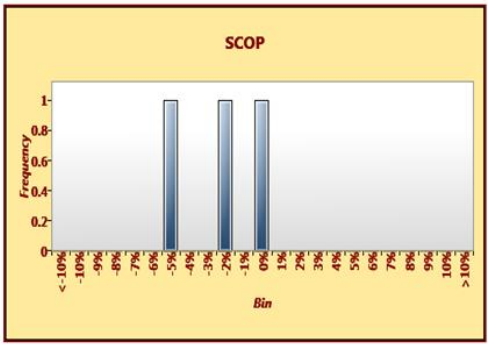
DA125



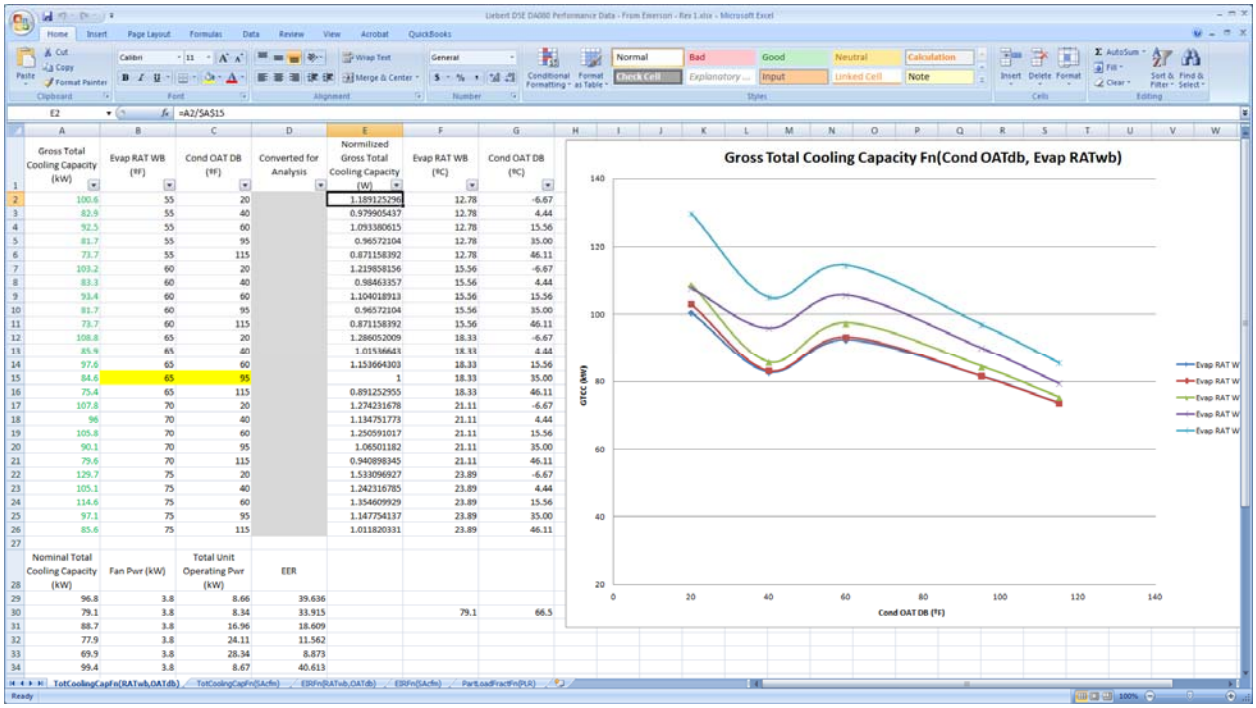


DA165

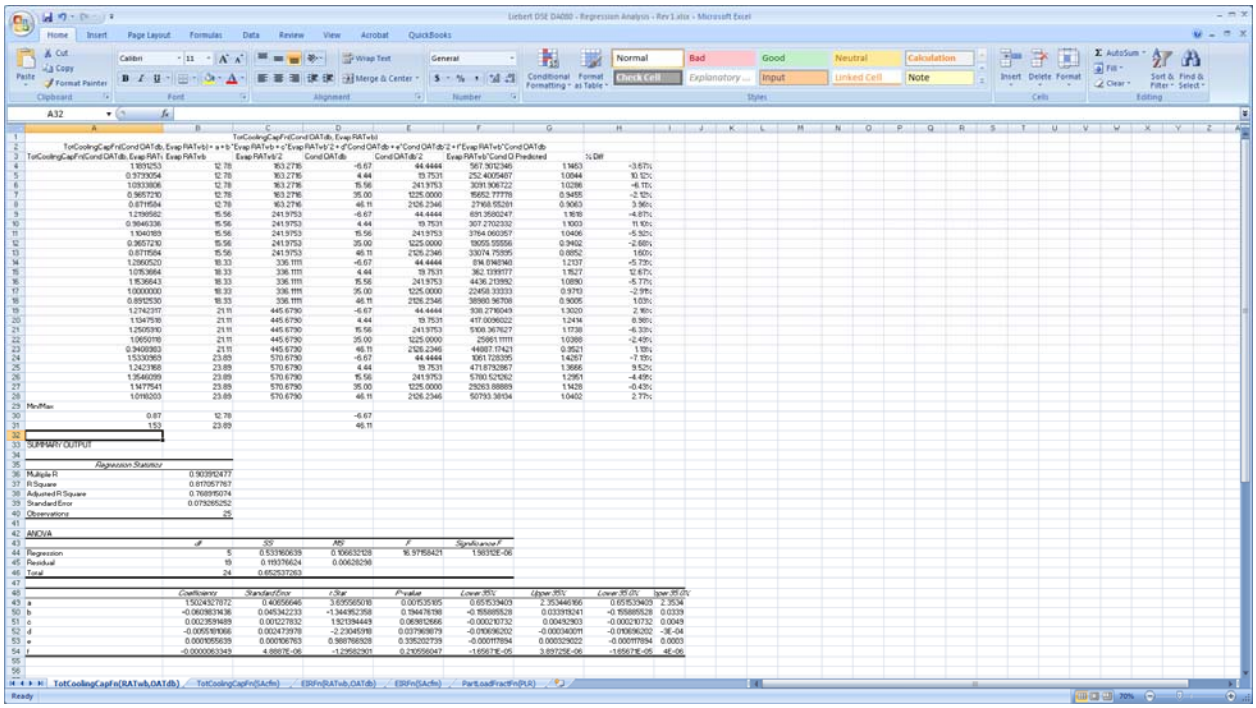




Appendix F – Examples of Data generations and curves



Total cooling Capacity data from LRS program and adjust for regression analysis



Total cooling Capacity regression analysis from data shown above

Appendix F – con't

Liebert DSE Model DA080~MCM160E2 w/Econophase - Modeling Input

Unit Selection Criteria

Outdoor Ambient:	95.0°F
Indoor Drybulb:	80.0°F
Indoor Wetbulb:	67.0°F

Air System Data

Type:	SZVAVAC
SubType:	CRAC
Night Cycle Control:	CycleOnCallAnyZone
Fan Position:	DrawThrough
Supply Temp Control:	NoSATControl

Cooling Coil Data

Type:	Direct Expansion
Condenser Type:	Air
Fuel Source:	Electric
EER:	12.1
Num. Cooling Stages:	1
Rated Net Capacity:	292,400 Btu/h

Fan Data

Control Method:	VariableSpeedDirve
Classification:	Centrifugal
Centrifugal Type:	AirFoil

Capacity and Power

Flow Capacity:	9,600 cfm
Flow Minimum:	5,280 cfm
Modeling Method:	BreakHorsePower
Motor Break HP:	4.59 hp

Motor Information

Name plate HP:	8.3hp
Type:	Open
Pole Count:	4
Motor Efficiency:	0.9

Performance Curves - See Liebert DSE DA080 Performance Data - From Emerson.xlsx & Liebert DSE DA080 Regression Analysis.xlsx for calculation of performance curve coefficients.

Cubic	
Curve	PartLoadFractFn(PLR)
Name	CoilClgDXEIRRatio_fQFrac
a	-0.1513043815
b	1.3397546998
c	-0.7307484759
d	0.4805083397
Min Value of x	0.31
Max Value of x	1.00
Min Curve Output	0.20
Max Curve Output	1.00

Quadratic		
Curve	TotCoolingCapFn(SAcfm)	EIRFn(SAcfm)
Name	CoilClgDXSnglQRatio_fCFMRatio	CoilClgDXSnglEIRRatio_fCFMRatio
a	0.7137760585	1.166932147
b	0.0875633837	-0.143939959
c	-0.0054104697	0.023656445
Min Value of x	2.49	2.49
Max Value of x	4.53	4.53
Min Curve Output	0.90	0.95
Max Curve Output	1.00	1.00

Biquadratic		
Curve	TotCoolingCapFn(Cond OATdb, Evap RATwb)	EIRFn(RATwb,OATdb)
Name	CoilClgDXQRatio_fTwbToadbSI	CoilClgDXEIRRatio_fTwbToadbSI
a	1.5024927872	-0.0586292893
b x	-0.0609831436	0.0401911484
c	0.0023591489	-0.0013337464
d	-0.0055181066	0.0132378330
e	0.0001055639	0.0003493083
f	-0.0000063349	-0.0000054297
Min Value of x	12.78	12.78
Max Value of x	23.89	23.89
Min Value of y	-6.67	-6.67
Max Value of y	46.11	46.11
Min Curve Output	0.87	0.10
Max Curve Output	1.53	1.46

Modeling input data

Appendix G– AlaJor Engineering, Inc.

Christian Hurd, PE, LEED-AP

AlaJor Engineering, Inc., President

Credentials

Professional Engineer, State of California, State of Virginia, State of Washington, State of Colorado, State of Texas, State of Florida, State of Ohio, State of Indiana, State of Illinois, State of Michigan, State of Oregon, State of Indiana
LEED-AP

Experience

Mr. Hurd has over 23 years of experience in engineering, design and construction projects. Mr. Hurd is responsible for mechanical and plumbing engineering and design and is a specialist in computational fluid dynamics, fluid flow analysis, energy modeling and building information modeling. Projects include mechanical and plumbing design of mission critical data center, telecommunication, industrial, and large commercial facilities

Appendix H – Exceptional Design Compliance Calculations for all 16 Climate Zones

Exceptional Design Compliance - End Use Summary

Climate Zone 1

End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Space Cooling	3,864.2	1,073.5	15,134.5	1,333.2	-	4,600.9	1,278.1	18,654.5	1,643.2	(310.1)
Fans	3,417.8	949.5	13,466.8	1,186.3	-	1,025.8	285.0	4,070.7	358.6	827.7
Lighting	153.6	42.7	644.3	56.8	-	153.6	42.7	644.3	56.8	-
Pumps	710.8	197.5	2,756.8	242.8	-	-	-	-	-	242.8
Heat Rejection	105.9	29.4	492.6	43.4	-	-	-	-	-	43.4
Compliance Total	8,252.5	2,292.5	32,495.0	2,862.4	-	5,780.3	1,605.8	23,369.5	2,058.6	803.8
Interior Equipment	28,527.8	7,925.0	111,278.5	9,802.2	-	28,527.8	7,925.0	111,278.5	9,802.2	-
Total	36,780.2	10,217.6	143,773.5	12,664.6	3,875,000	34,308.1	9,530.8	134,648.0	11,860.8	803.8
										PASS

Climate Zone 2

End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Space Cooling	3,980.9	1,105.9	16,067.3	1,415.3	-	5,287.2	1,468.8	22,778.5	2,006.5	(591.2)
Fans	3,208.0	891.2	12,647.8	1,114.1	-	1,540.3	427.9	6,122.4	539.3	574.8
Lighting	153.6	42.7	638.2	56.2	-	153.6	42.7	638.2	56.2	-
Pumps	682.3	189.5	2,610.8	230.0	-	-	-	-	-	230.0
Heat Rejection	173.3	48.1	820.4	72.3	-	-	-	-	-	72.3
Compliance Total	8,198.1	2,277.4	32,784.5	2,887.9	-	6,981.1	1,939.4	29,539.1	2,602.0	285.9
Interior Equipment	28,527.8	7,925.0	110,541.0	9,737.3	-	28,527.8	7,925.0	110,541.0	9,737.3	-
Total	36,725.9	10,202.4	143,325.5	12,625.2	4,260,000	35,508.9	9,864.4	140,080.1	12,339.3	285.9
										PASS

Climate Zone 3

End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Space Cooling	3,830.2	1,064.0	14,911.2	1,313.5	-	5,954.5	1,654.1	24,059.0	2,119.3	(805.8)
Fans	3,197.0	888.1	12,610.2	1,110.8	-	618.9	171.9	2,439.4	214.9	895.9
Lighting	154.1	42.8	720.9	63.5	-	154.1	42.8	720.9	63.5	-
Pumps	709.7	197.1	2,717.1	239.3	-	-	-	-	-	239.3
Heat Rejection	148.5	41.3	665.3	58.6	-	-	-	-	-	58.6
Compliance Total	8,039.4	2,233.3	31,624.7	2,785.7	-	6,727.4	1,868.9	27,219.3	2,397.7	388.1
Interior Equipment	28,527.8	7,925.0	109,114.8	9,611.6	-	28,527.8	7,925.0	109,114.8	9,611.6	-
Total	36,567.2	10,158.4	140,739.6	12,397.4	4,063,160	35,255.1	9,793.9	136,334.1	12,009.3	388.1
										PASS

Climate Zone 4

End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Space Cooling	4,018.1	1,116.2	15,785.7	1,390.5	-	5,486.1	1,524.0	22,866.6	2,014.3	(623.7)
Fans	3,344.6	929.1	13,114.5	1,155.2	-	1,543.4	428.8	6,155.6	542.2	613.0
Lighting	153.6	42.7	631.2	55.6	-	153.6	42.7	631.2	55.6	-
Pumps	687.0	190.8	2,599.2	229.0	-	-	-	-	-	229.0
Heat Rejection	191.2	53.1	860.9	75.8	-	-	-	-	-	75.8
Compliance Total	8,394.5	2,332.0	32,991.5	2,906.1	-	7,183.2	1,995.5	29,653.4	2,612.1	294.0
Interior Equipment	28,527.8	7,925.0	108,901.1	9,592.8	-	28,527.8	7,925.0	108,901.1	9,592.8	-
Total	36,922.2	10,257.0	141,892.6	12,498.9	4,378,000	35,710.9	9,920.5	138,554.5	12,204.9	294.0
										PASS

Climate Zone 5

End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Space Cooling	3,925.0	1,090.4	15,272.3	1,345.3	-	5,101.1	1,417.1	20,742.7	1,827.2	(481.9)
Fans	3,439.2	955.4	13,586.3	1,196.8	-	1,551.0	430.9	6,158.7	542.5	654.3
Lighting	153.6	42.7	637.5	56.2	-	153.6	42.7	637.5	56.2	-
Pumps	684.7	190.2	2,606.5	229.6	-	-	-	-	-	229.6
Heat Rejection	136.9	38.0	624.3	55.0	-	-	-	-	-	55.0
Compliance Total	8,339.5	2,316.7	32,726.8	2,882.8	-	6,805.7	1,890.6	27,538.9	2,425.8	457.0
Interior Equipment	28,527.8	7,925.0	109,418.5	9,638.4	-	28,527.8	7,925.0	109,418.5	9,638.4	-
Total	36,867.2	10,241.7	142,145.3	12,521.2	4,003,000	35,333.5	9,815.6	136,957.3	12,064.2	457.0
										PASS

Appendix H (con't) – Exceptional Design Compliance Calculations for all 16 Climate Zones

Exceptional Design Compliance - End Use Summary

Climate Zone 6

End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Space Cooling	4,008.6	1,113.6	15,547.4	1,369.5	-	5,704.3	1,584.6	22,660.4	1,996.1	(626.6)
Fans	3,135.0	870.9	12,220.7	1,076.5	-	1,542.1	428.4	6,148.6	541.6	534.9
Lighting	153.6	42.7	647.9	57.1	-	153.6	42.7	647.9	57.1	-
Pumps	711.0	197.5	2,685.8	236.6	-	-	-	-	-	236.6
Heat Rejection	244.8	68.0	1,011.3	89.1	-	-	-	-	-	89.1
Compliance Total	8,253.0	2,292.7	32,113.1	2,828.8	-	7,400.0	2,055.7	29,456.9	2,594.8	234.0
Interior Equipment	28,527.8	7,925.0	108,592.0	9,565.6	-	28,527.8	7,925.0	108,592.4	9,565.6	(0.0)
Total	36,780.7	10,217.7	140,705.1	12,394.3	4,258,000	35,927.8	9,980.7	138,049.3	12,160.4	233.9
										PASS

Climate Zone 7

End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Space Cooling	4,009.1	1,113.7	15,997.5	1,409.2	-	5,785.8	1,607.3	23,429.2	2,063.8	(654.6)
Fans	3,184.8	884.7	12,632.5	1,112.8	-	1,536.8	426.9	6,235.7	549.3	563.5
Lighting	153.6	42.7	652.1	57.4	-	153.6	42.7	652.1	57.4	-
Pumps	704.3	195.7	2,708.4	238.6	-	-	-	-	-	238.6
Heat Rejection	234.7	65.2	994.4	87.6	-	-	-	-	-	87.6
Compliance Total	8,286.5	2,302.0	32,985.0	2,905.6	-	7,476.2	2,076.9	30,316.9	2,670.5	235.0
Interior Equipment	28,527.8	7,925.0	110,989.4	9,776.8	-	28,527.8	7,925.0	110,989.0	9,776.7	0.0
Total	36,814.3	10,227.0	143,974.4	12,682.3	4,280,000	36,004.0	10,001.9	141,305.9	12,447.3	235.1
										PASS

Climate Zone 8

End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Space Cooling	4,061.1	1,128.2	15,992.9	1,408.8	-	5,794.5	1,609.7	23,609.0	2,079.7	(670.9)
Fans	3,215.2	893.2	12,397.5	1,092.1	-	1,535.5	426.6	6,101.8	537.5	554.6
Lighting	153.6	42.7	648.6	57.1	-	153.6	42.7	648.6	57.1	-
Pumps	683.7	189.9	2,593.4	228.4	-	-	-	-	-	228.4
Heat Rejection	230.8	64.1	978.0	86.1	-	-	-	-	-	86.1
Compliance Total	8,344.5	2,318.1	32,610.3	2,872.6	-	7,483.7	2,079.0	30,359.3	2,674.3	198.3
Interior Equipment	28,527.8	7,925.0	109,613.1	9,655.5	-	28,527.8	7,925.0	109,613.1	9,655.5	-
Total	36,872.3	10,243.1	142,223.4	12,528.1	4,312,000	36,011.4	10,004.0	139,972.4	12,329.8	198.3
										PASS

Climate Zone 9

End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Space Cooling	4,100.9	1,139.2	16,022.2	1,411.4	-	5,864.5	1,629.2	23,552.3	2,074.7	(663.3)
Fans	3,149.9	875.1	12,120.8	1,067.7	-	1,547.3	429.8	6,159.4	542.6	525.1
Lighting	153.6	42.7	639.3	56.3	-	153.6	42.7	639.3	56.3	-
Pumps	687.8	191.1	2,610.7	230.0	-	-	-	-	-	230.0
Heat Rejection	255.1	70.9	1,077.1	94.9	-	-	-	-	-	94.9
Compliance Total	8,347.5	2,318.9	32,470.2	2,860.2	-	7,565.5	2,101.7	30,351.0	2,673.5	186.7
Interior Equipment	28,527.8	7,925.0	108,035.8	9,516.6	-	28,527.8	7,925.0	108,035.8	9,516.6	-
Total	36,875.2	10,243.9	140,506.0	12,376.8	4,414,000	36,093.2	10,026.7	138,386.8	12,190.1	186.7
										PASS

Climate Zone 10

End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Space Cooling	3,811.9	1,059.0	15,430.2	1,359.2	-	6,010.1	1,669.6	25,335.5	2,231.7	(872.5)
Fans	3,378.8	938.6	13,149.0	1,158.3	-	1,562.6	434.1	6,205.0	546.6	611.7
Lighting	153.6	42.7	631.7	55.6	-	153.6	42.7	631.7	55.6	-
Pumps	595.0	165.3	2,222.6	195.8	-	-	-	-	-	195.8
Heat Rejection	154.0	42.8	717.9	63.2	-	-	-	-	-	63.2
Compliance Total	8,093.3	2,248.3	32,151.5	2,832.1	-	7,726.3	2,146.4	32,172.3	2,834.0	(1.8)
Interior Equipment	28,527.8	7,925.0	108,966.3	9,598.6	-	28,527.8	7,925.0	108,966.3	9,598.6	-
Total	36,621.0	10,173.3	141,117.8	12,430.7	3,664,000	36,254.1	10,071.4	141,138.5	12,432.5	(1.8)
										FAIL

Appendix H (con't) – Exceptional Design Compliance Calculations for all 16 Climate Zones

Exceptional Design Compliance - End Use Summary

	End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
		GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Climate Zone 11	Space Cooling	4,251.2	1,181.0	17,331.2	1,526.7	-	5,997.4	1,666.1	26,480.9	2,332.6	(806.0)
	Fans	3,873.8	1,076.1	14,856.5	1,308.7	-	1,545.4	429.3	6,144.9	541.3	767.4
	Lighting	153.6	42.7	641.5	56.5	-	153.6	42.7	641.5	56.5	-
	Pumps	649.3	180.4	2,482.5	218.7	-	-	-	-	-	218.7
	Heat Rejection	195.6	54.3	899.1	79.2	-	-	-	-	-	79.2
	Compliance Total	9,123.5	2,534.5	36,210.9	3,189.7	-	7,696.5	2,138.1	33,267.3	2,930.4	259.3
	Interior Equipment	28,527.8	7,925.0	112,214.7	9,884.7	-	28,527.8	7,925.0	112,214.7	9,884.7	-
	Total	37,651.3	10,459.5	148,425.6	13,074.4	4,755,000	36,224.2	10,063.1	145,482.0	12,815.1	259.3
											PASS

	End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
		GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Climate Zone 12	Space Cooling	4,055.9	1,126.7	16,515.0	1,454.8	-	5,677.0	1,577.1	24,638.2	2,170.3	(715.6)
	Fans	3,339.8	927.8	13,210.9	1,163.7	-	1,533.4	426.0	6,105.6	537.8	625.9
	Lighting	153.6	42.7	638.3	56.2	-	153.6	42.7	638.3	56.2	-
	Pumps	687.9	191.1	2,612.3	230.1	-	-	-	-	-	230.1
	Heat Rejection	193.4	53.7	893.8	78.7	-	-	-	-	-	78.7
	Compliance Total	8,430.6	2,342.0	33,870.2	2,983.5	-	7,364.1	2,045.7	31,382.1	2,764.4	219.2
	Interior Equipment	28,527.8	7,925.0	111,090.2	9,785.6	-	28,527.8	7,925.0	111,090.2	9,785.6	-
	Total	36,958.4	10,267.0	144,960.4	12,769.2	4,541,000	35,891.8	9,970.7	142,472.2	12,550.0	219.2
											PASS

	End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
		GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Climate Zone 13	Space Cooling	4,124.0	1,145.7	16,630.5	1,464.9	-	6,062.8	1,684.2	26,109.6	2,299.9	(835.0)
	Fans	3,281.7	911.6	12,738.0	1,122.1	-	1,544.3	429.0	6,128.2	539.8	582.2
	Lighting	153.6	42.7	639.1	56.3	-	153.6	42.7	639.1	56.3	-
	Pumps	681.5	189.3	2,605.0	229.5	-	-	-	-	-	229.5
	Heat Rejection	207.1	57.5	950.4	83.7	-	-	-	-	-	83.7
	Compliance Total	8,447.9	2,346.8	33,563.0	2,956.5	-	7,760.7	2,155.9	32,876.9	2,896.0	60.4
	Interior Equipment	28,527.8	7,925.0	111,041.5	9,781.4	-	28,527.8	7,925.0	111,041.5	9,781.4	-
	Total	36,975.6	10,271.8	144,604.5	12,737.8	4,822,000	36,288.5	10,080.9	143,918.4	12,677.4	60.4
											PASS

	End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
		GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Climate Zone 14	Space Cooling	4,116.9	1,143.7	16,544.2	1,457.3	-	6,219.7	1,727.8	27,294.9	2,404.3	(947.0)
	Fans	3,675.4	1,021.0	14,411.4	1,269.5	-	1,620.7	450.2	6,390.1	562.9	706.6
	Lighting	153.6	42.7	633.4	55.8	-	153.6	42.7	633.4	55.8	-
	Pumps	656.4	182.4	2,504.9	220.7	-	-	-	-	-	220.7
	Heat Rejection	127.6	35.4	651.0	57.3	-	-	-	-	-	57.3
	Compliance Total	8,729.9	2,425.2	34,744.8	3,060.6	-	7,994.0	2,220.7	34,318.4	3,023.0	37.6
	Interior Equipment	28,527.8	7,925.0	110,968.5	9,774.9	-	28,527.8	7,925.0	110,968.5	9,774.9	-
	Total	37,257.7	10,350.2	145,713.4	12,835.5	5,061,000	36,521.8	10,145.7	145,287.0	12,797.9	37.6
											PASS

	End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
		GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Climate Zone 15	Space Cooling	4,420.2	1,227.9	17,886.0	1,575.5	-	7,187.9	1,996.8	30,329.6	2,671.7	(1,096.1)
	Fans	3,003.1	834.3	11,396.6	1,003.9	-	1,515.9	421.1	5,984.1	527.1	476.8
	Lighting	153.6	42.7	633.5	55.8	-	153.6	42.7	633.5	55.8	-
	Pumps	658.2	182.9	2,492.1	219.5	-	-	-	-	-	219.5
	Heat Rejection	283.9	78.9	1,225.3	107.9	-	-	-	-	-	107.9
	Compliance Total	8,519.1	2,366.6	33,633.5	2,962.7	-	8,857.4	2,460.6	36,947.3	3,254.6	(291.9)
	Interior Equipment	28,527.8	7,925.0	110,144.3	9,702.3	-	28,527.8	7,925.0	111,278.5	9,802.2	(99.9)
	Total	37,046.8	10,291.6	143,777.7	12,665.0	5,551,000	37,385.2	10,385.6	148,225.8	13,056.8	(391.8)
											FAIL

Appendix H (con't) – Exceptional Design Compliance Calculations for all 16 Climate Zones

	Exceptional Design Compliance - End Use Summary										
	End Use	Baseline Waterside Economizer				Estimated Water	DSE Proposed Design - Custom Curves				
		GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	Gal / Year	GJ	MWh	TDV MJ/m^2	TDV kBtuh/ft^2	TDV Margin
Climate Zone 16	Space Cooling	4,026.8	1,118.6	16,328.6	1,438.3	-	4,668.7	1,297.0	20,711.5	1,824.4	(386.1)
	Fans	3,843.5	1,067.7	14,887.0	1,311.4	-	1,701.7	472.7	6,709.9	591.1	720.3
	Lighting	153.6	42.7	638.8	56.3	-	153.6	42.7	638.8	56.3	-
	Pumps	668.7	185.8	2,536.1	223.4	-	-	-	-	-	223.4
	Heat Rejection	106.8	29.7	595.8	52.5	-	-	-	-	-	52.5
	Compliance Total	8,799.5	2,444.5	34,986.3	3,081.9	-	6,524.1	1,812.4	28,060.1	2,471.7	610.1
	Interior Equipment	28,527.8	7,925.0	110,676.3	9,749.2	-	28,527.8	7,925.0	110,676.9	9,749.2	(0.0)
	Total	37,327.3	10,369.5	145,662.6	12,831.0	4,154,000	35,051.8	9,737.4	138,737.0	12,221.0	610.1
											PASS

References:

CEC – 2013 Building Energy Efficiency Standards Title 24, Part 6

CEC – Time Dependent Valuation for Energy for Developing Building Efficiency Standards (2103)

About Liebert:
Liebert Corporation, a division of the *Emerson Network Power, a* business unit of Emerson, is a global manufacturer of power, precision cooling and infrastructure management systems for data centers computer rooms and critical process systems. A trusted industry leader in smart infrastructure technologies, the Liebert brand provides innovative data center infrastructure solutions that bridge the gap between IT and facility management to deliver uncompromised availability and efficiency. Headquartered in Columbus, Ohio, the business employs more than 1,800 people across 12 manufacturing facilities worldwide.

About Emerson Network Power:
Emerson Network Power, a business unit of *Emerson* – a global technology company that specializes in the development and manufacture of software, hardware and services that maximize availability, capacity and efficiency for data centers, healthcare and industrial facilities. Our solutions are supported globally by local Emerson Network Power application experts and service technicians. Emerson Network Power has headquarters in Columbus, Ohio. Learn more about Emerson Network Power products and services at www.EmersonNetworkPower.com.

About Emerson:
Emerson Electric Co. (NYSE: EMR), based in St. Louis, Missouri (USA), an American multinational corporation and global leader in bringing technology and engineering together to provide innovative solutions for customers in industrial, commercial, and consumer markets around the world. The company is comprised of five business segments: Process Management, Industrial Automation, Network Power, Climate Technologies, and Commercial & Residential Solutions. Sales in fiscal 2014 were $24.5 billion. Emerson has approximately 115,000 employees and 220 manufacturing locations worldwide. For more information, visit Emerson.com.

Not to be confused with Emerson Radio.