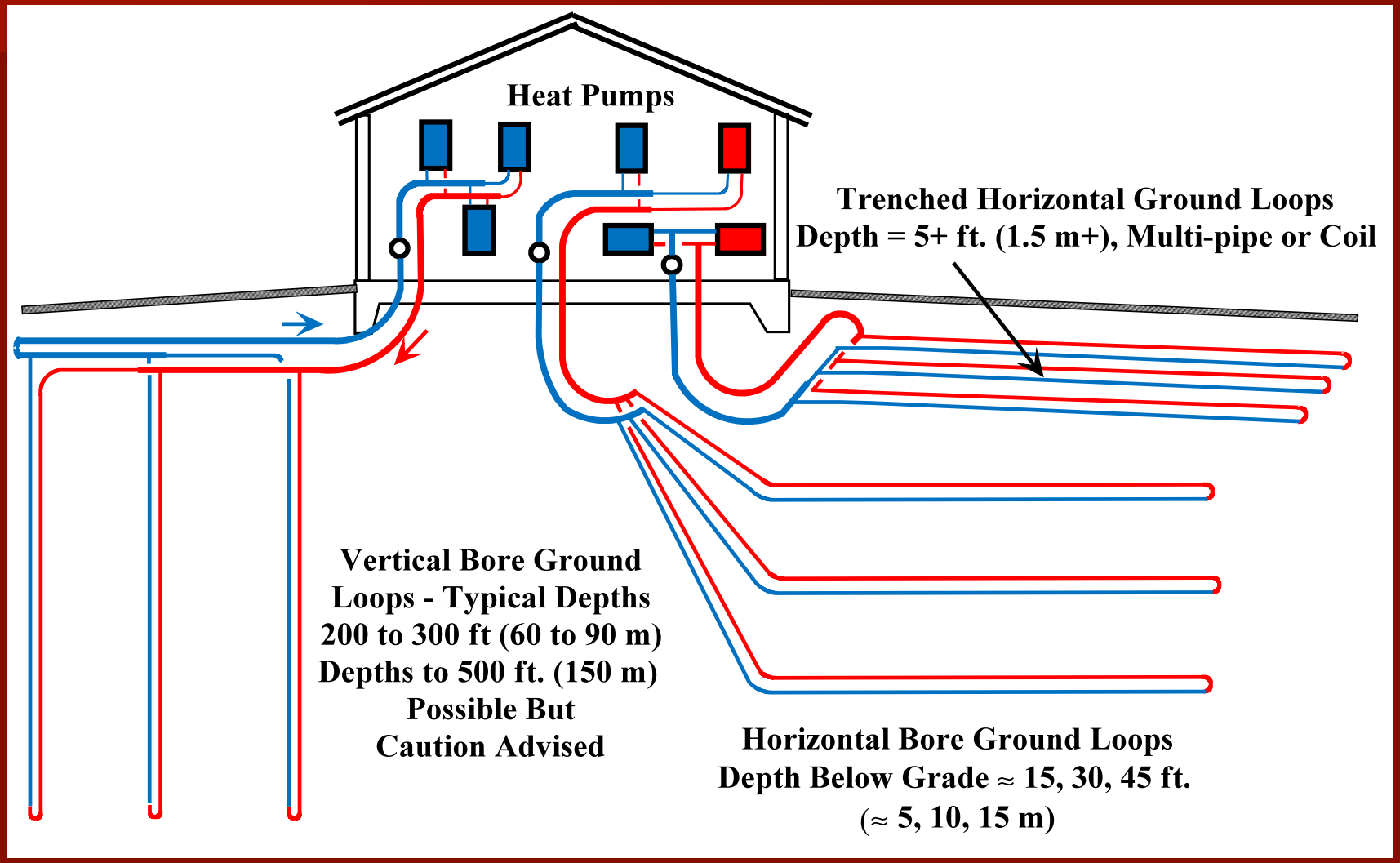
Simple Ground Source Heat Pump (GSHP) Systems: Lower Costs, Higher Performance

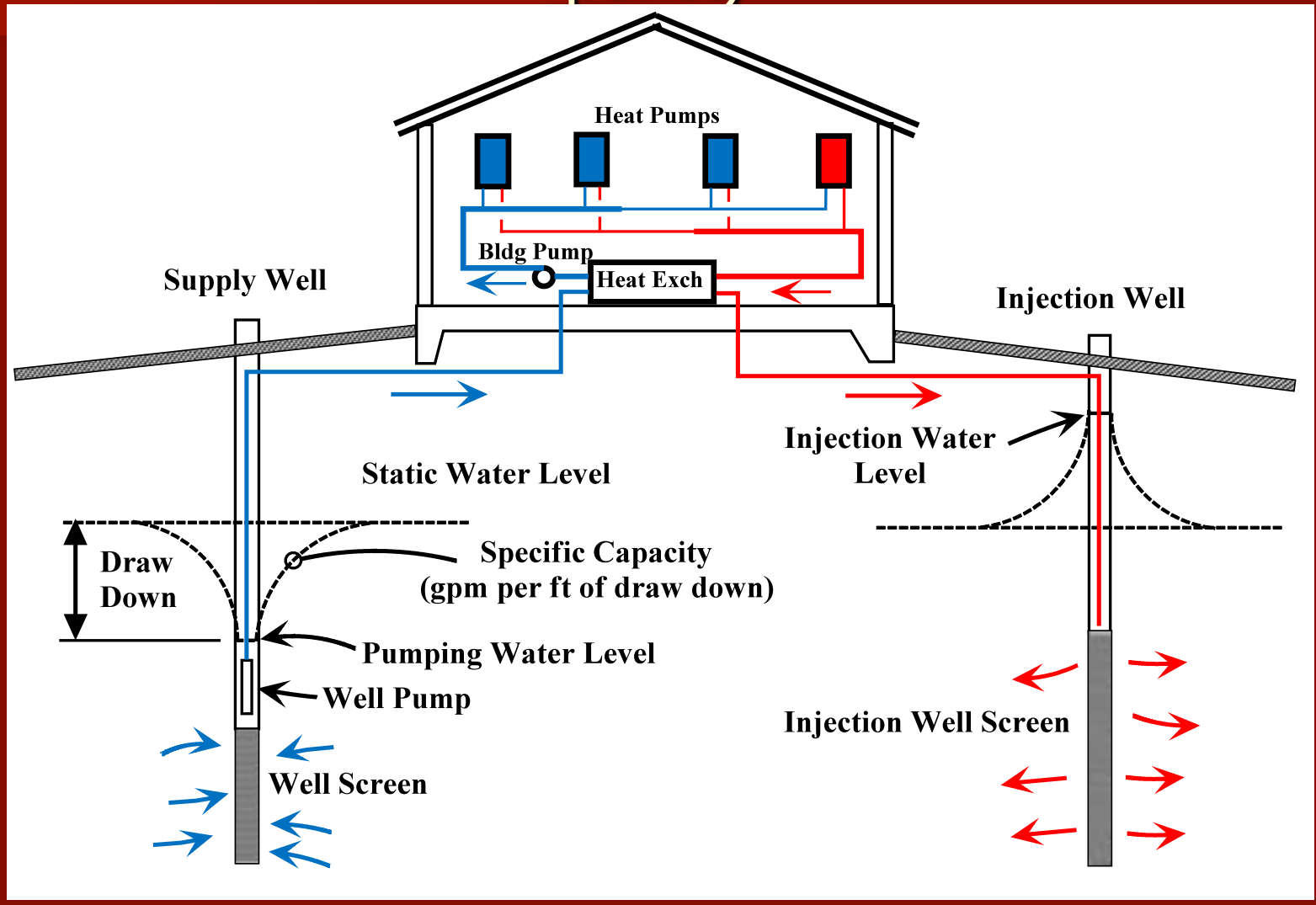
CIBSE – ASHRAE Group Webinar

Dr. Steve Kavanaugh
Professor Emeritus (retired)
University of Alabama

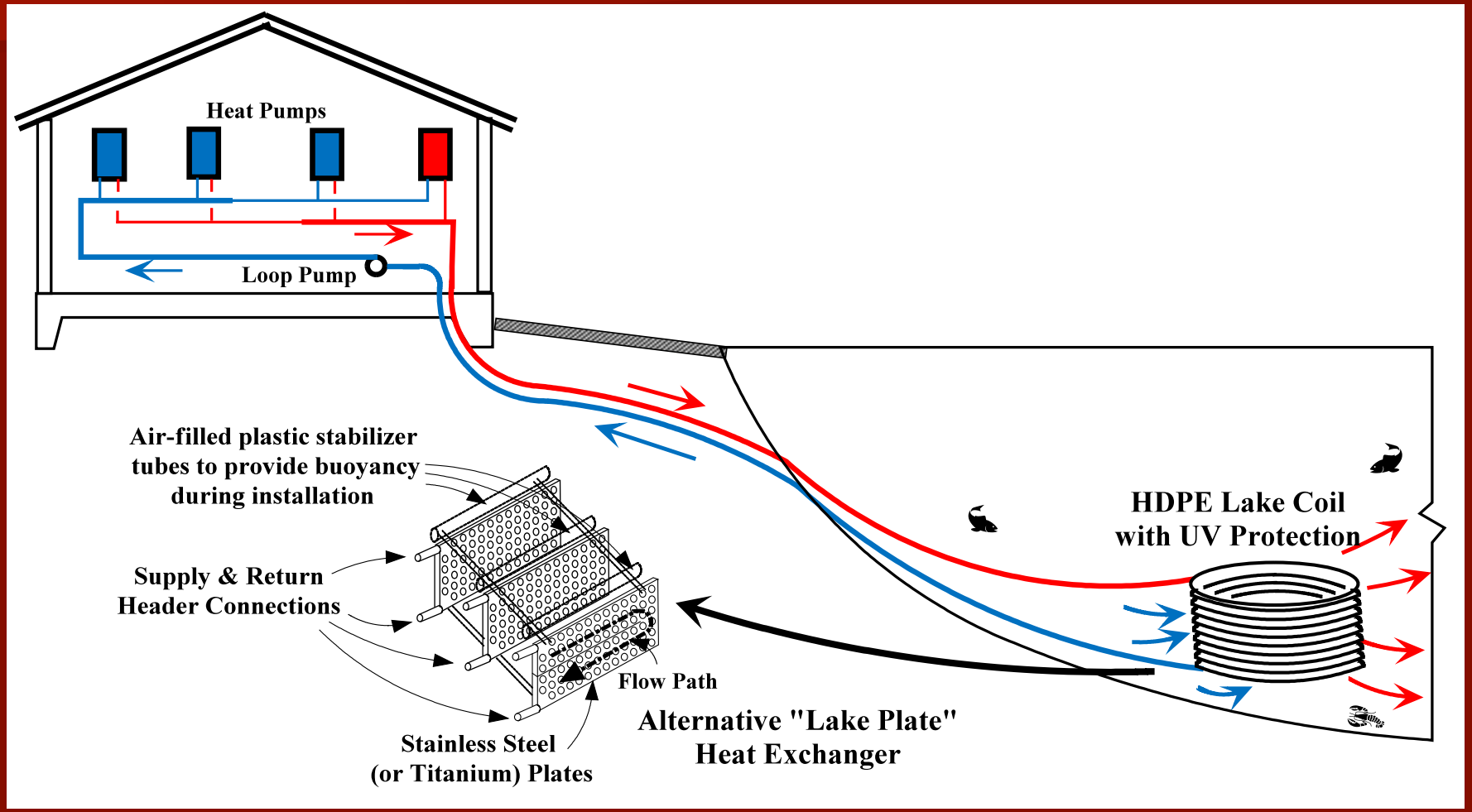
GSHP Types (geothermal heat pump, geo-exchange)
Ground-Coupled Heat Pumps (GCHPs)
a.k.a. Closed Loop Geothermal – Focus of Webinar



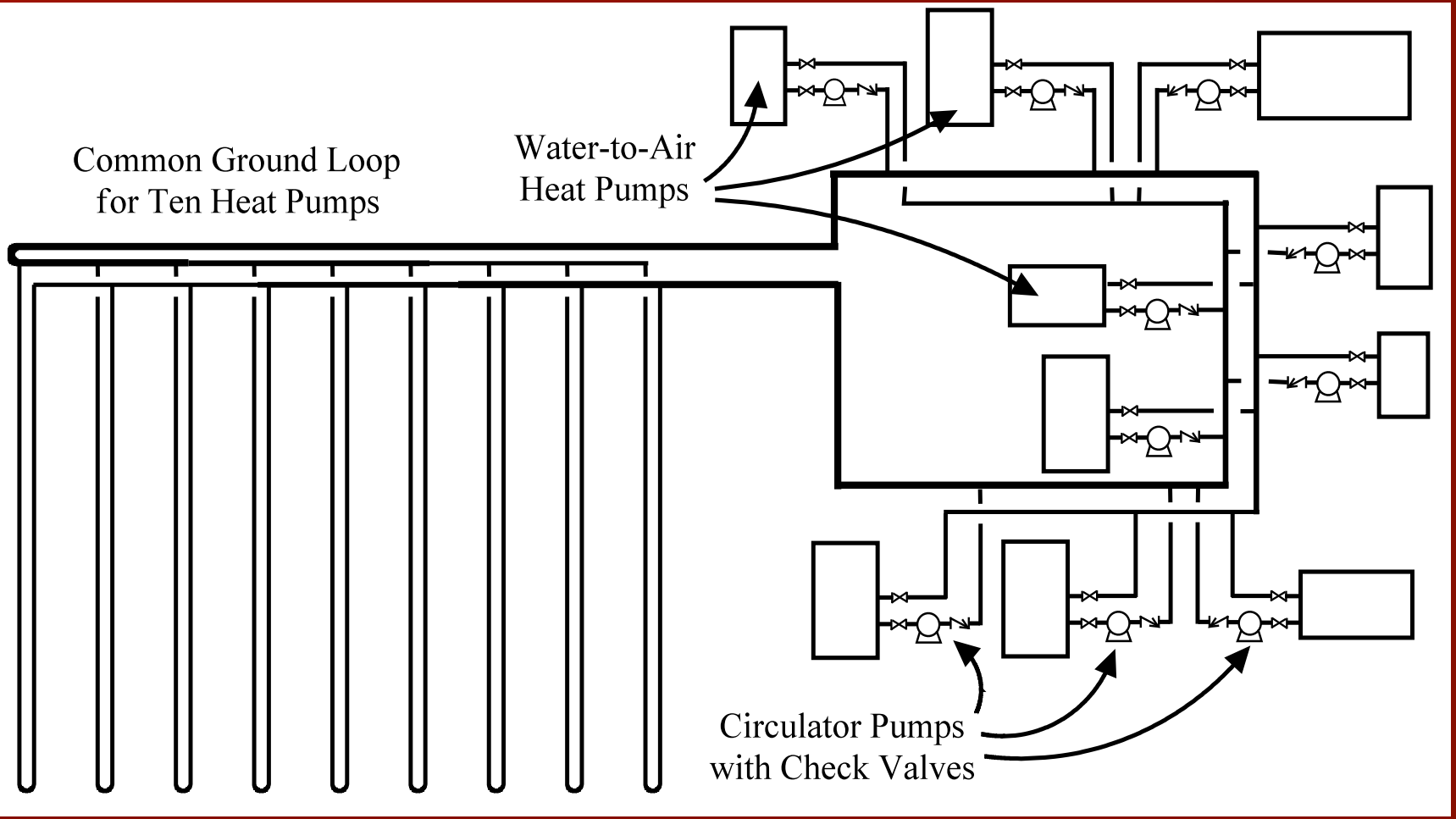
GSHP Types - Ground Water Heat Pumps (GWHPs) a.k.a open loop geothermal, "pump and dump" (derogatory term used by closed loop purist)



GSHP Types - Surface Water Heat Pumps (SWHP)s a.k.a. pond loop, lake loop, ocean loop (Open Loop Systems Not Shown)

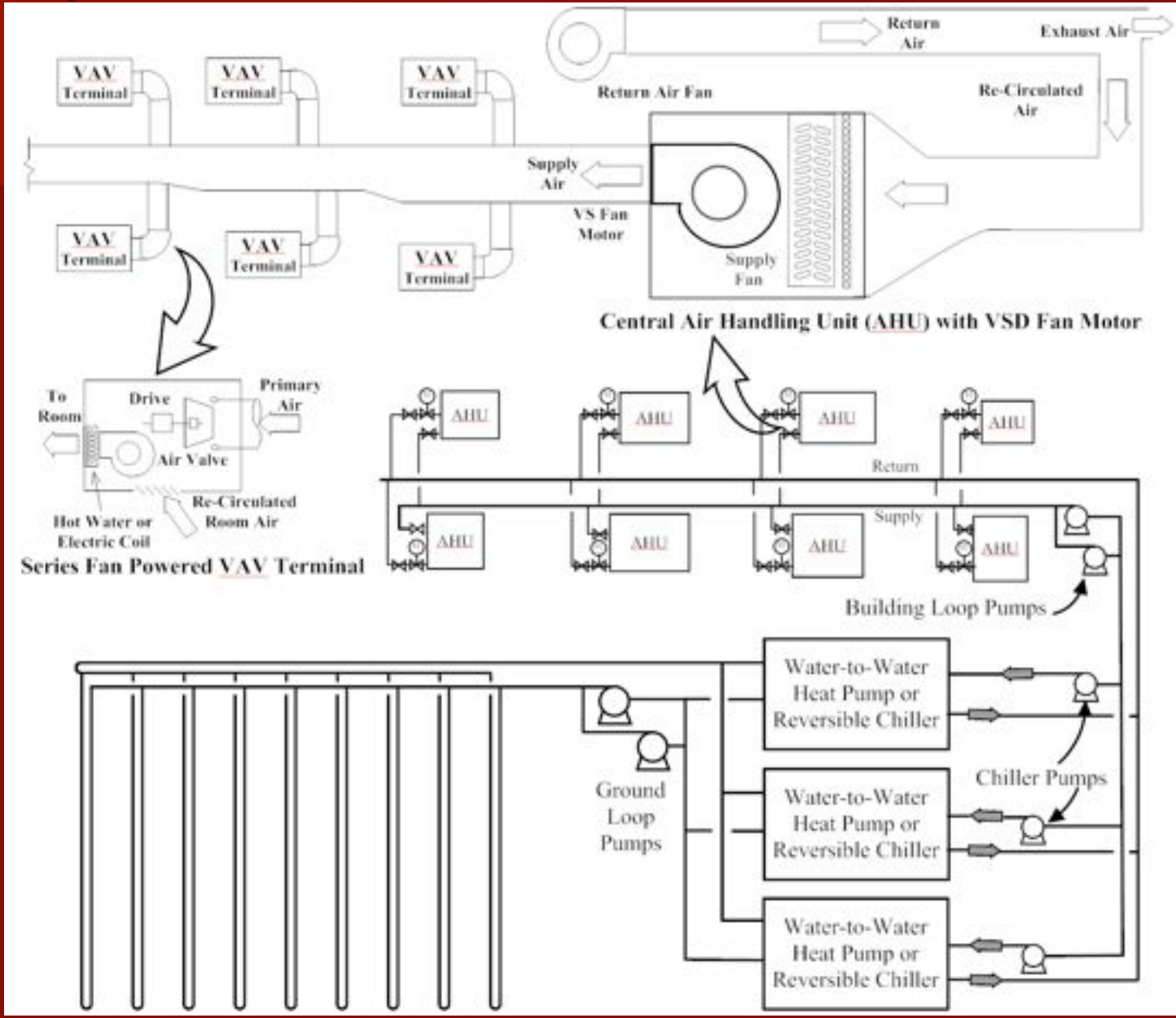


What HVAC System is Best for GCHPs Simple?



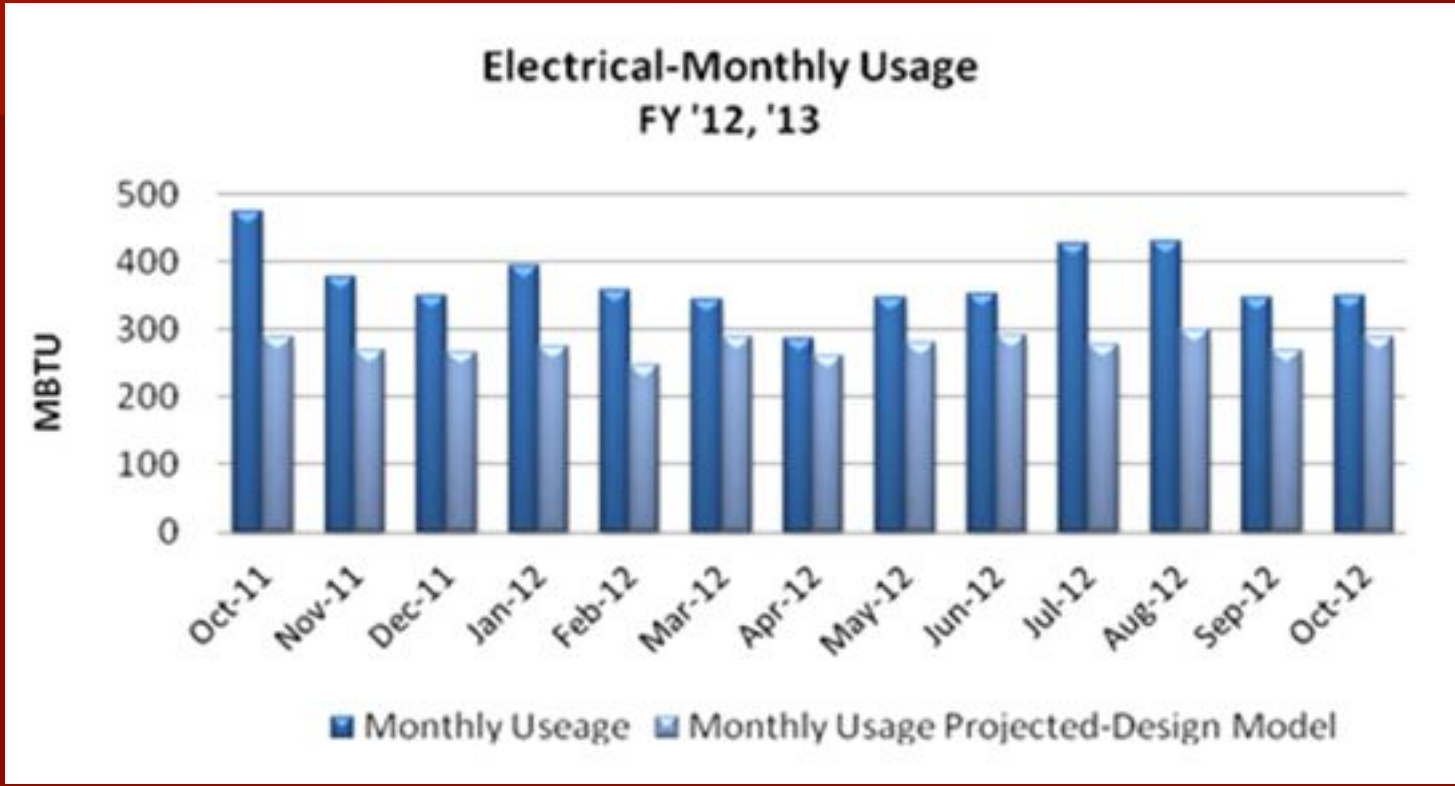
OR

Sophisticated and State-of-the Art?



Can Modeling be Used to Tell Us What's Best

Model of LEED Platinum Office Building with Off-Target Chilled Water VAV GCHP



What happens when modeling not done well?

In the US, not much (unless the owner hires lawyers).

In the EU, Building's Energy Performance is Known

Hopefully the US will soon emphasize actual performance.

Calculating GSHP System Efficiency Including All Components

Chilled Water VAV

- Screw Chiller - 118 kW input
  168 ton gross, 142 ton net
  (590 kW gross/500 kW net)
- AHU Fans - 44 kW
- VAV fans - 14 kW
- Return fans - 21 kW
- ChW pumps - 12 kW
- Grn. Pumps - 13 kW

CW-VAV total - 222 kW

System
kW/ton = 1.56
EER = 7.7
COP = 2.2

W-A Heat Pump GSHP

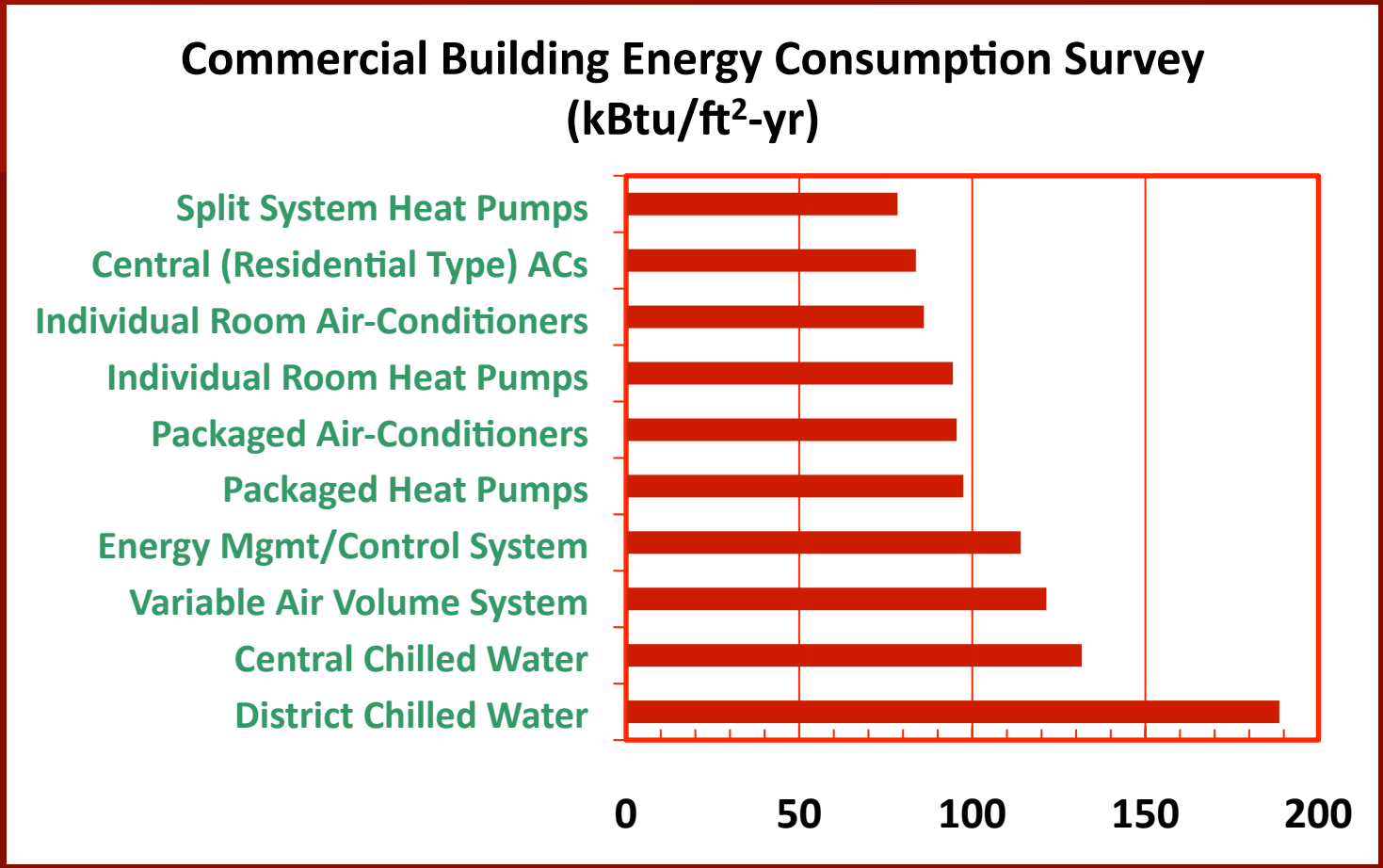
- WAHPs (56) - 118 kW input
  168 ton gross, 163 ton net
  (590 kW gross/573 kW net)
- HP Fans - 18 kW
- Grn. pumps - 10 kW

GSHP Total - 146 kW

HEAT

System
kW/ton = 0.90
EER = 13.4
COP = 3.9

Energy Consumption Survey Tends to Support Simple Systems Use Less Energy for All Equipment Types



GSHPs provide the opportunity to take advantage of the SYSTEM energy efficiency of unitary equipment in small, medium, and large buildings

Long-Term Performance of Commercial GSHPs

Project Sponsors:

Electric Power Research Institute – Ron Domitrovic

Southern Company – Chris Gray

Tennessee Valley Authority – David Dinse

EPRI, the Southern Co. and TVA permitted results to be published in the *ASHRAE Journal* in a series of articles that appeared from June 2012 through February 2013

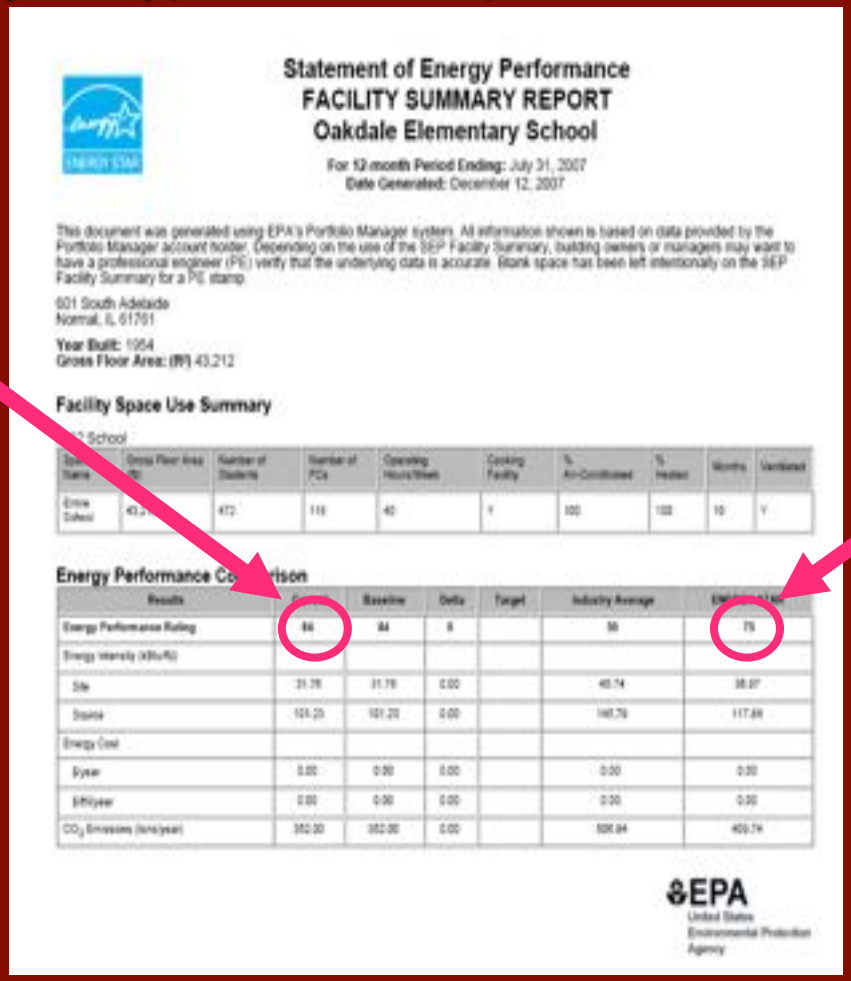
For non-ASHRAE members pdf files can be found on www.geokiss.com

An Energy Star Rating of 84 Indicates That Energy Use is Less Than 84% of Buildings of a Similar Type

(Offices are compared to other offices, schools are compared to other schools, etc. and results are normalized for climate, occupancy, schedules, and internal loads)

84

Energy Star Rating



Statement of Energy Performance
FACILITY SUMMARY REPORT
Oakdale Elementary School

For 12-month Period Ending: July 31, 2007
Date Generated: December 12, 2007

This document was generated using EPA's Portfolio Manager system. All information shown is based on data provided by the Portfolio Manager account holder. Depending on the use of the SEP Facility Summary, building owners or managers may want to have a professional engineer (PE) verify that the underlying data is accurate. Blank space has been left intentionally on the SEP Facility Summary for a PE stamp.

601 South Adelaide
Normal, IL 61761

Year Built: 1954
Gross Floor Area: (ft²) 43,212

Facility Space Use Summary

K-12 School

Space Name	Gross Floor Area (ft²)	Number of Students	Number of PCs	Operating Hours/Week	Cooking Facility	% Air-Conditioned	% Heated	Months	Ventilated
Entire School	43,212	472	118	40	Y	100	100	10	Y

Energy Performance Comparison

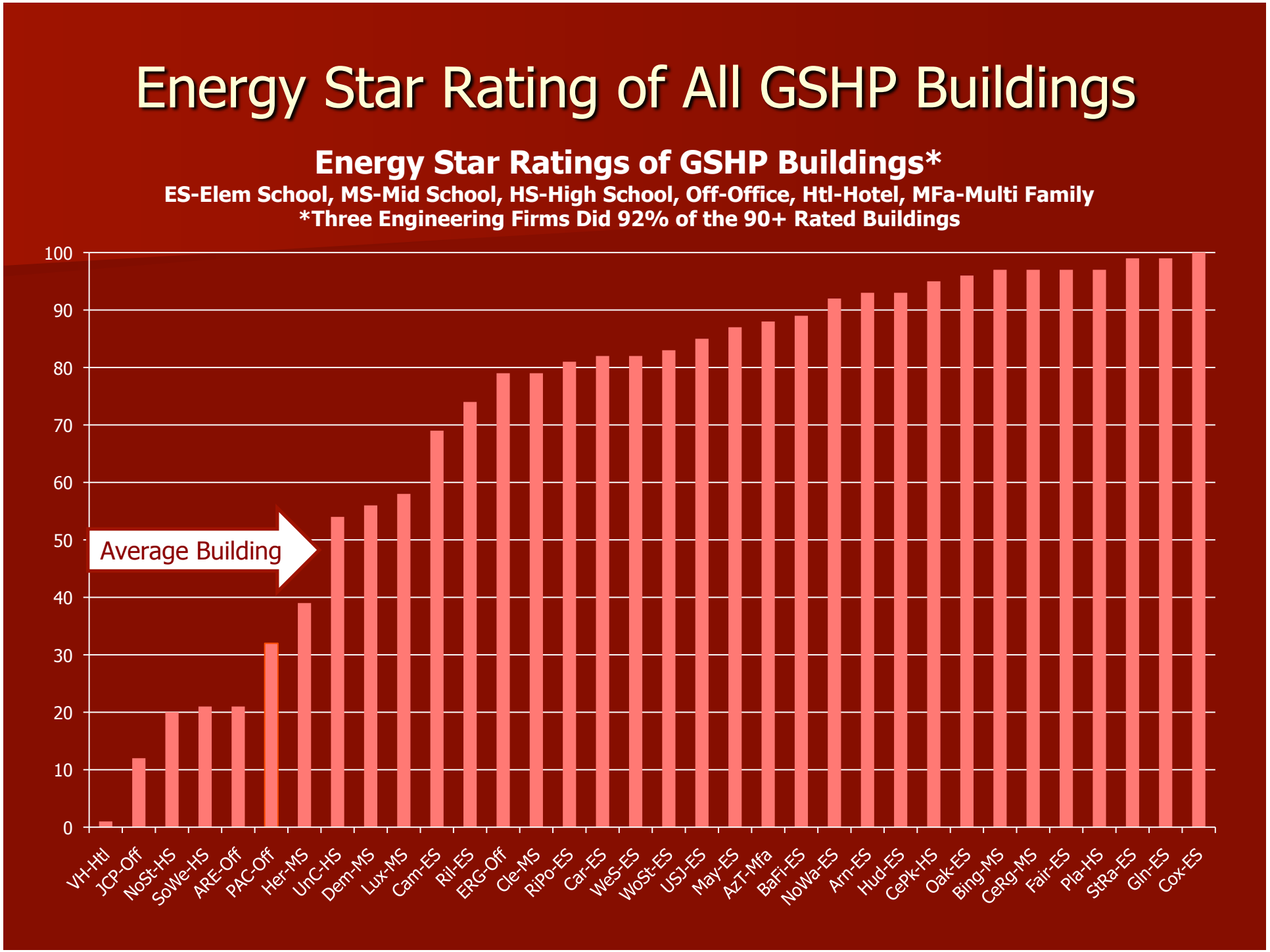
Results		Baseline	Delta	Target	Industry Average	Efficient Practice
Energy Performance Rating	84	84	0		50	75
Energy Intensity (kBtu/ft²)						
Site	31.78	31.78	0.00		48.74	38.97
Source	101.23	101.23	0.00		160.79	117.84
Energy Cost						
$/year	0.00	0.00	0.00		0.00	0.00
$/ft²/year	0.00	0.00	0.00		0.00	0.00
CO_2 Emissions (tons/year)	362.00	362.00	0.00		590.64	429.74

EPA
United States Environmental Protection Agency

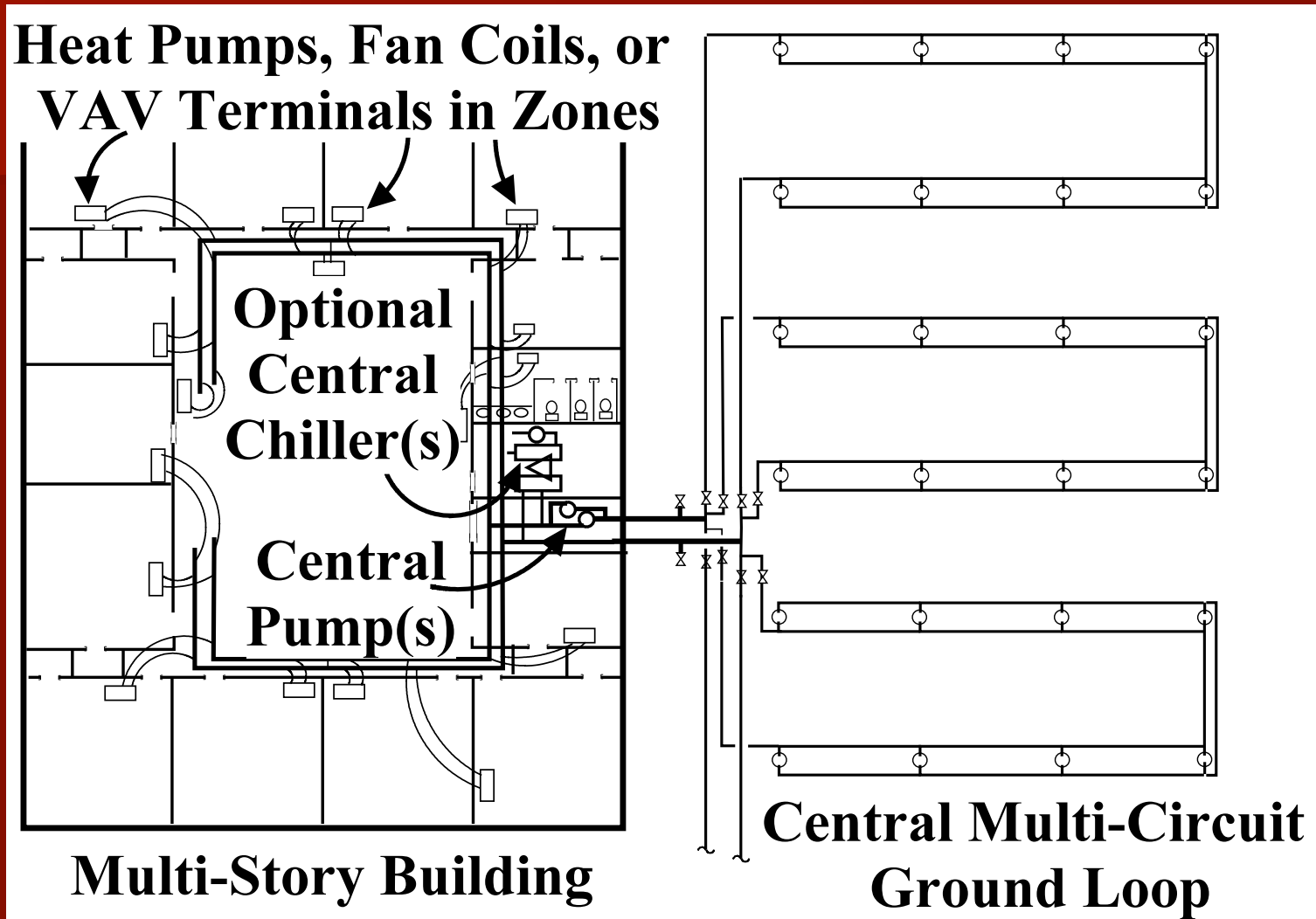
Minimum Required to Achieve Energy Star

75

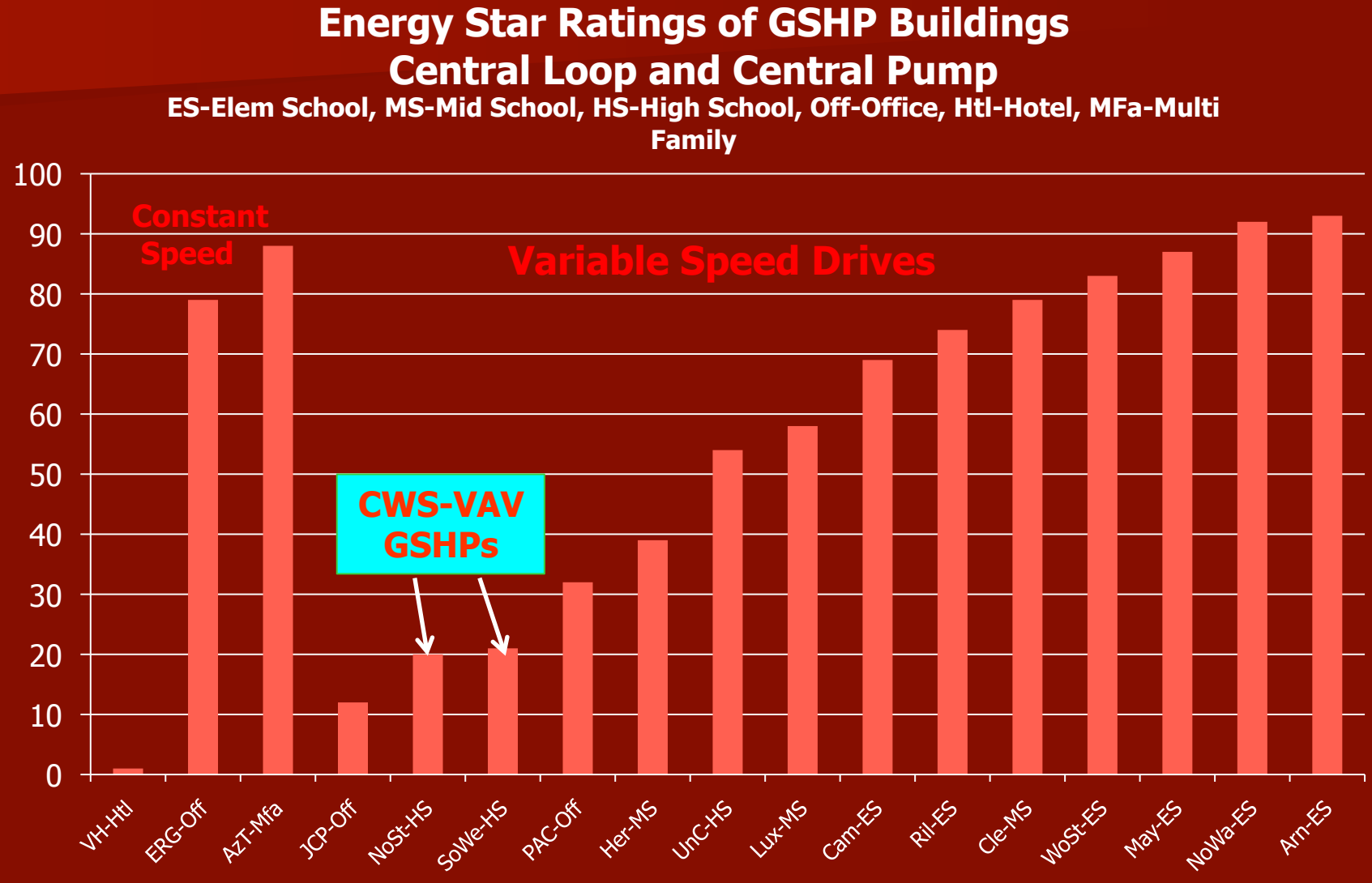
Energy Star Rating of All GSHP Buildings



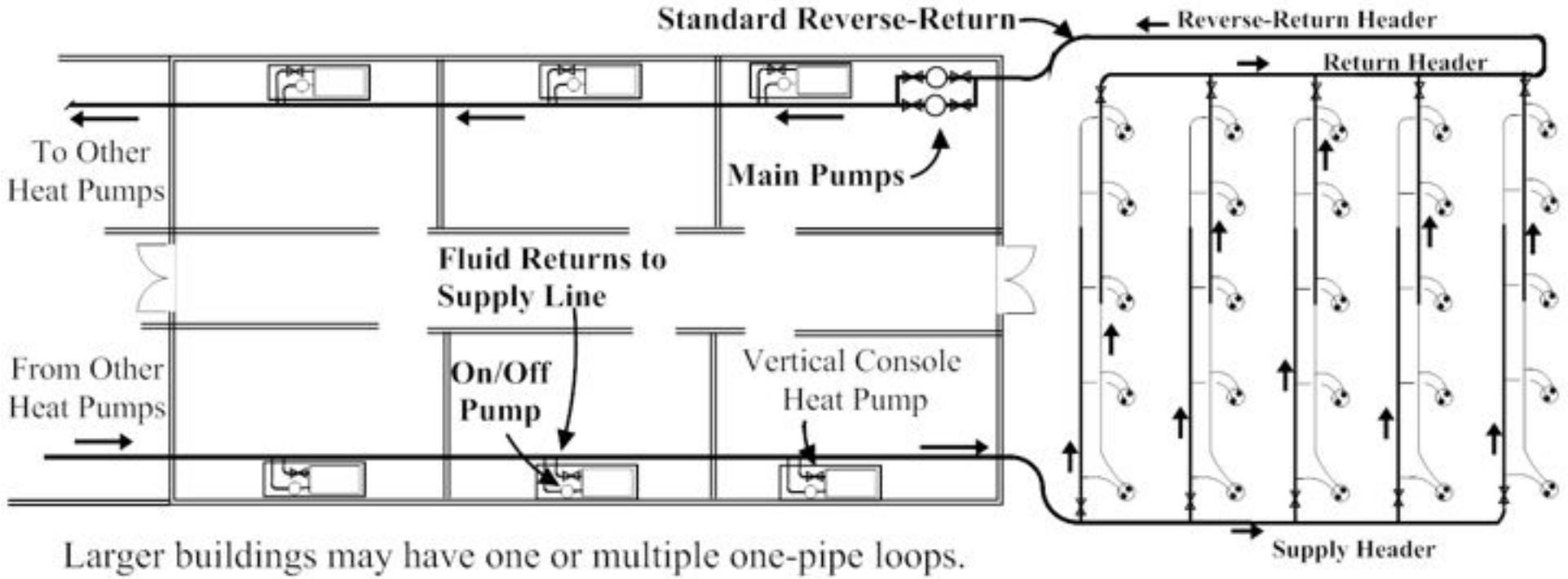
Central Ground-Coupled Heat Pump Loop



Energy Star Ratings of Central Loop GSHP Buildings with Central Pump



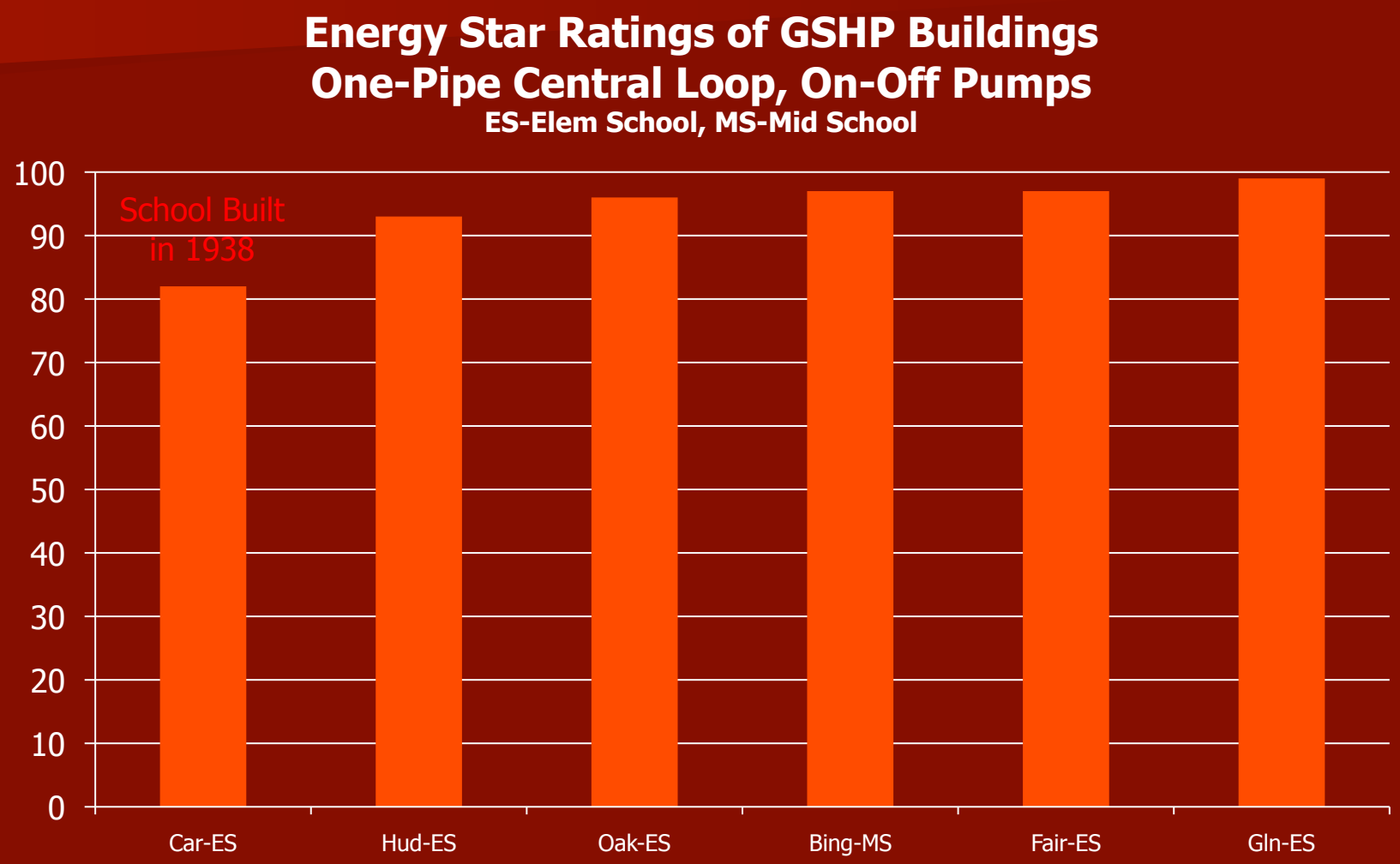
One-Pipe GSHP



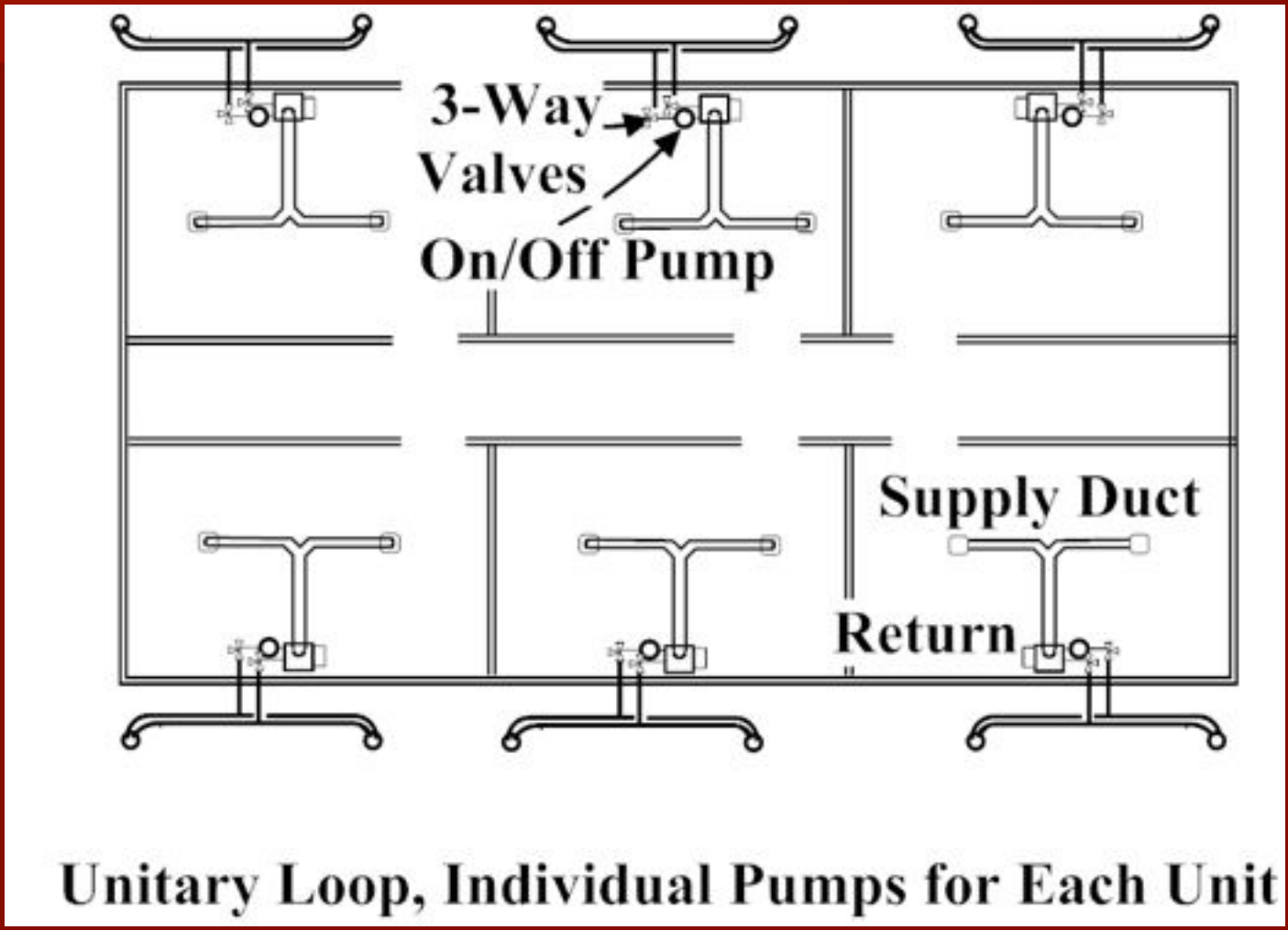
Larger buildings may have one or multiple one-pipe loops.

HVAC Cost at \$16 to \$22/ft^2 in Central Illinois School retrofits

Energy Star Ratings of One-Pipe Central Loop GSHP Buildings with On-Off Pumps

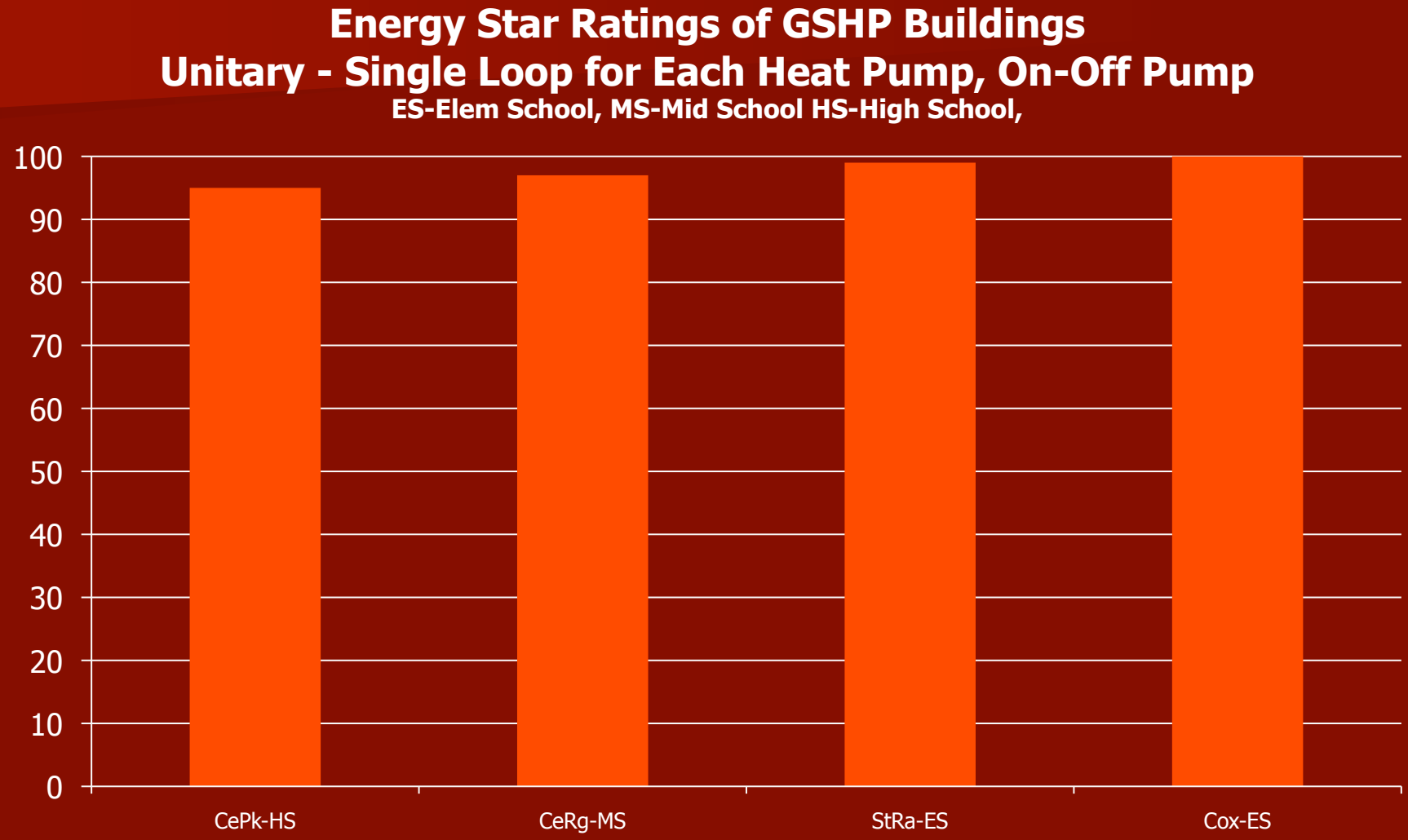


Loop Field Headers and Building Piping Unitary HDPE Loops



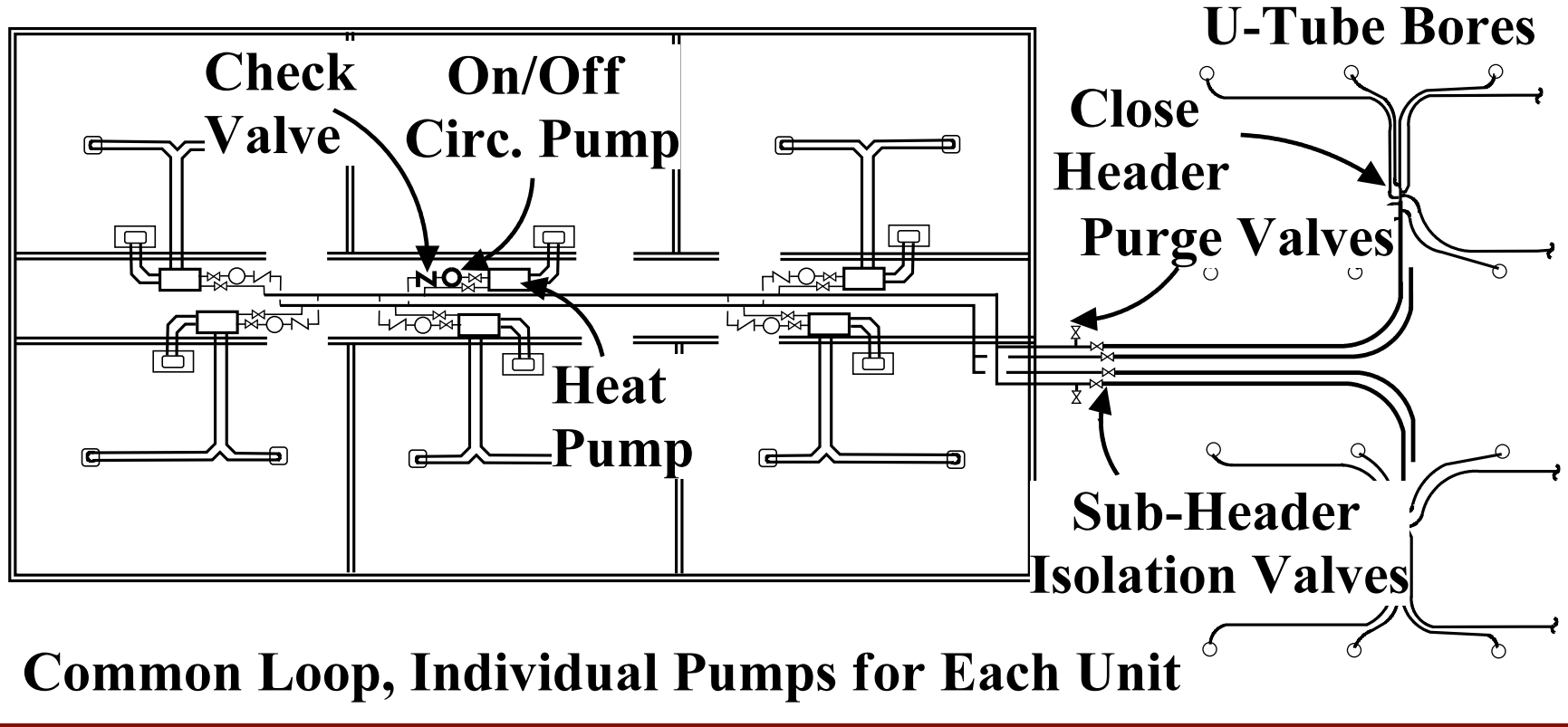
Unitary Loop, Individual Pumps for Each Unit

Energy Star Ratings of Unitary – Single Loop for Each Heat Pump, On-Off Pump

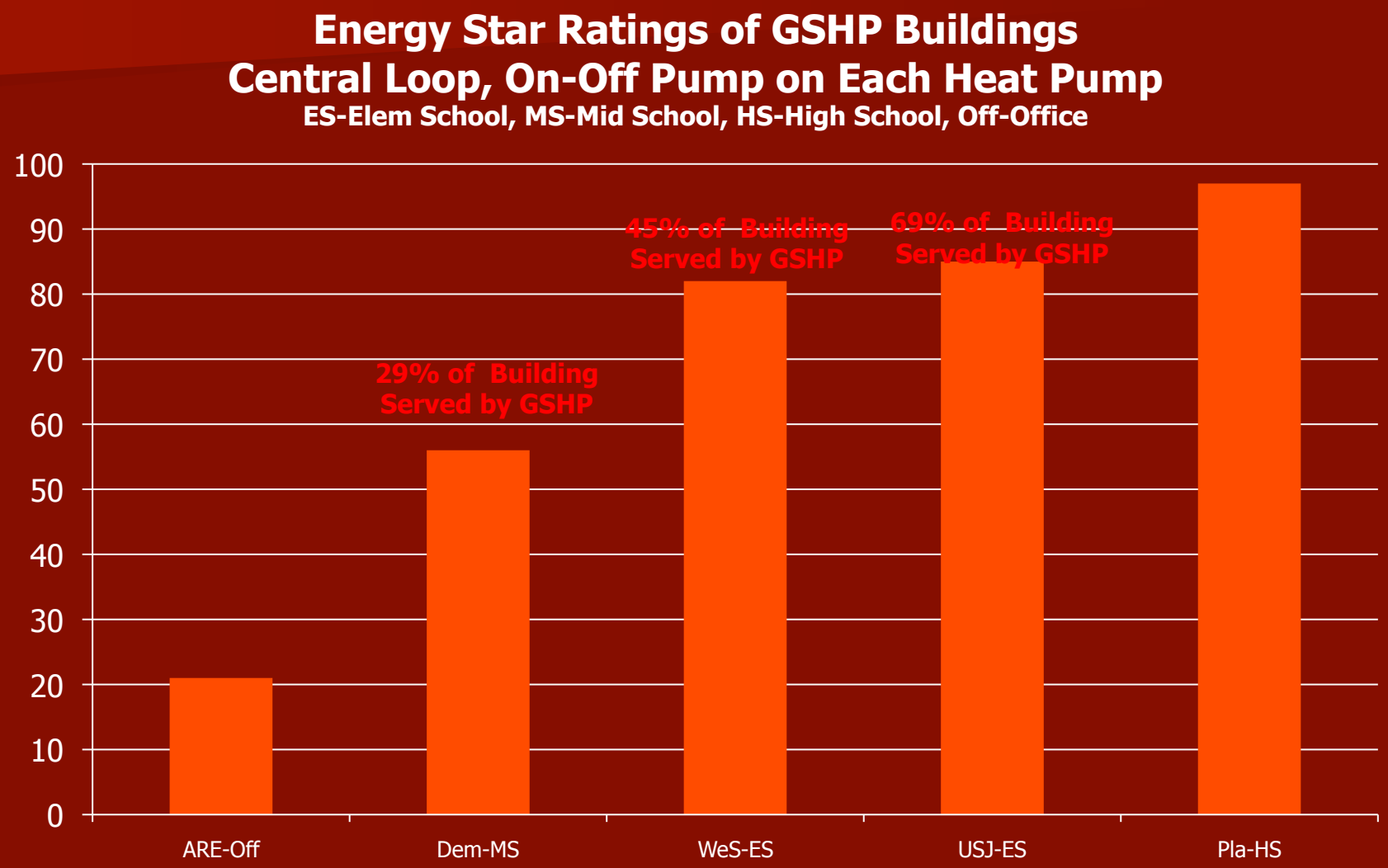


School district has 31 Energy Star rated schools, four rating 100 in 2011.

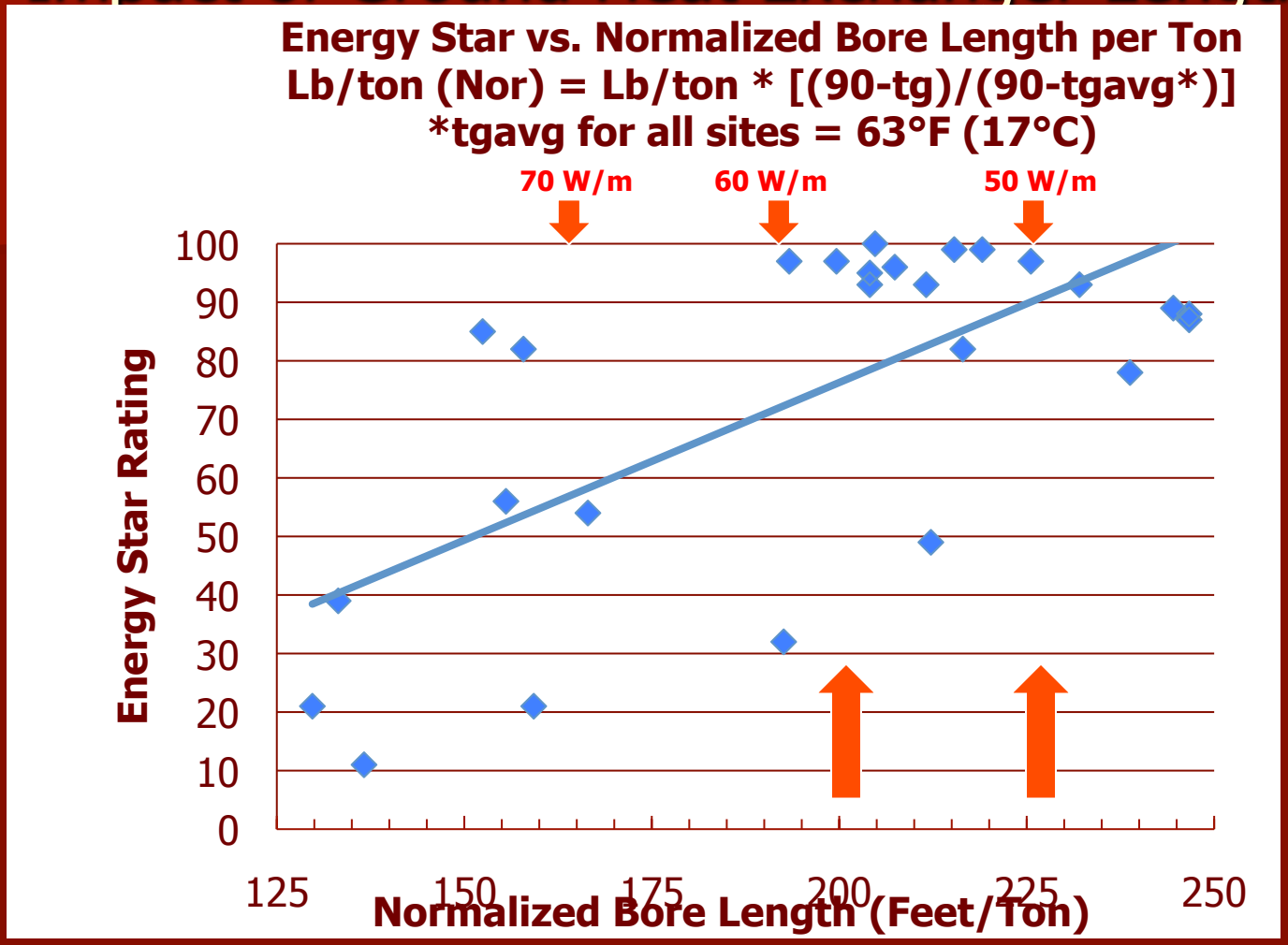
Loop Field Headers and Building Piping
Common HDPE Loops



Energy Star Ratings of One-Pipe Central Loop GSHP Buildings with On-Off Pumps



Impact of Ground Heat Exchanger Length

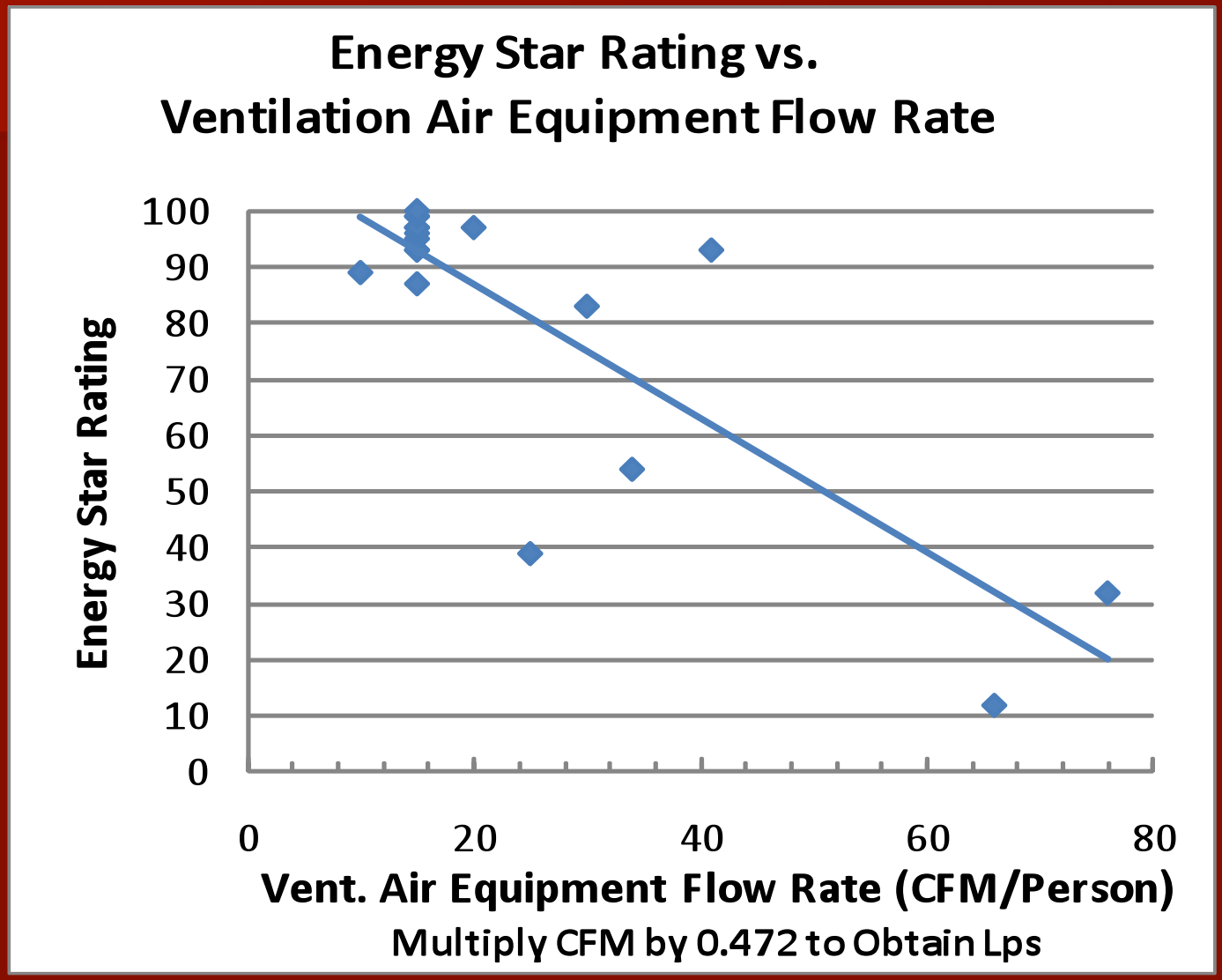


Rearrange Eqn. to find L_b/ton= L_b /ton (Nor)* (90-t_{gavg})/(90-t_g)

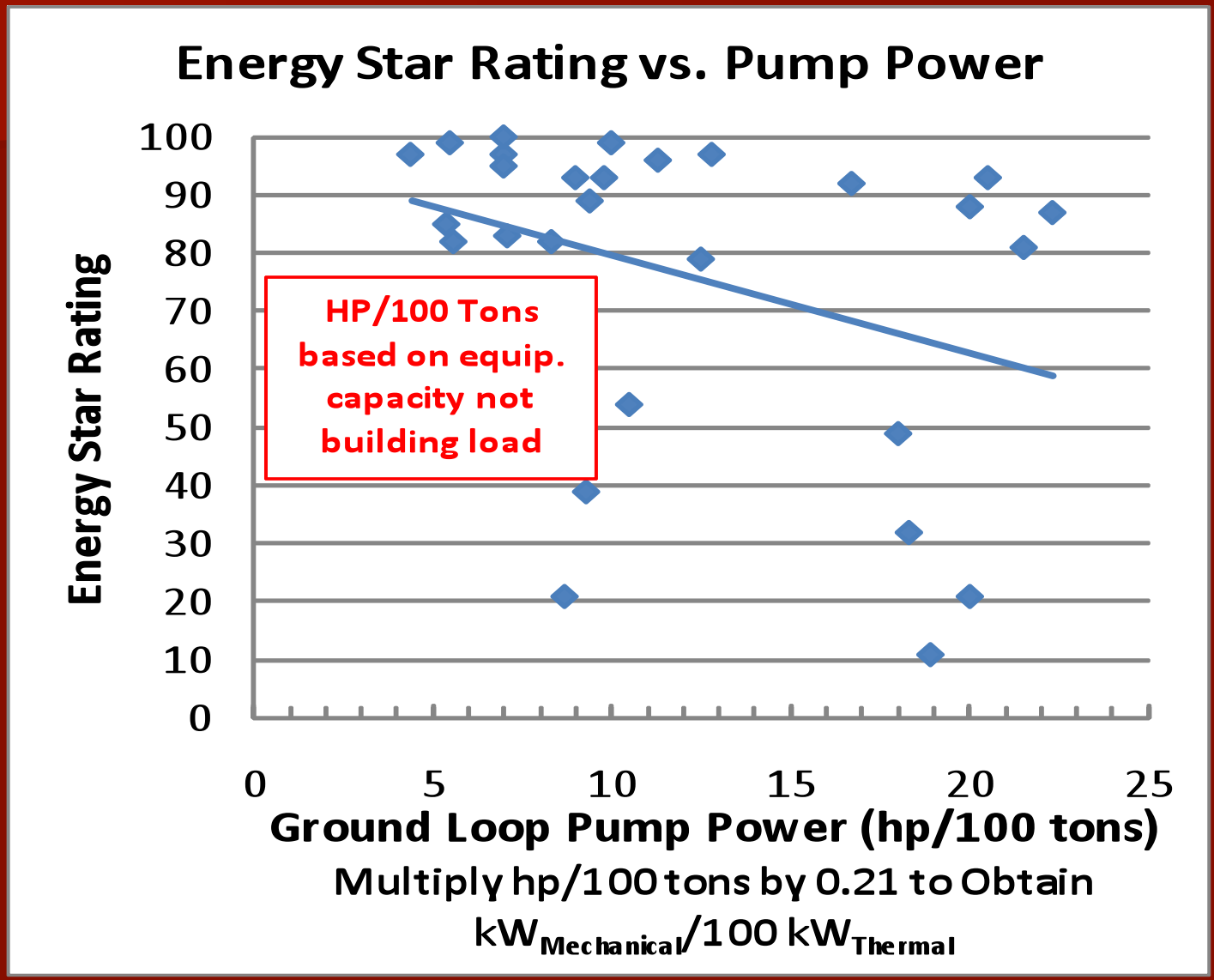
For SE TN: L_b/ton ≈ 210 ft/ton * (90-63)/(90-60) ≈ 190 ft/ton of capacity

L_b/ton ≈ 210 ft/ton to 240 ft/ton of cooling load

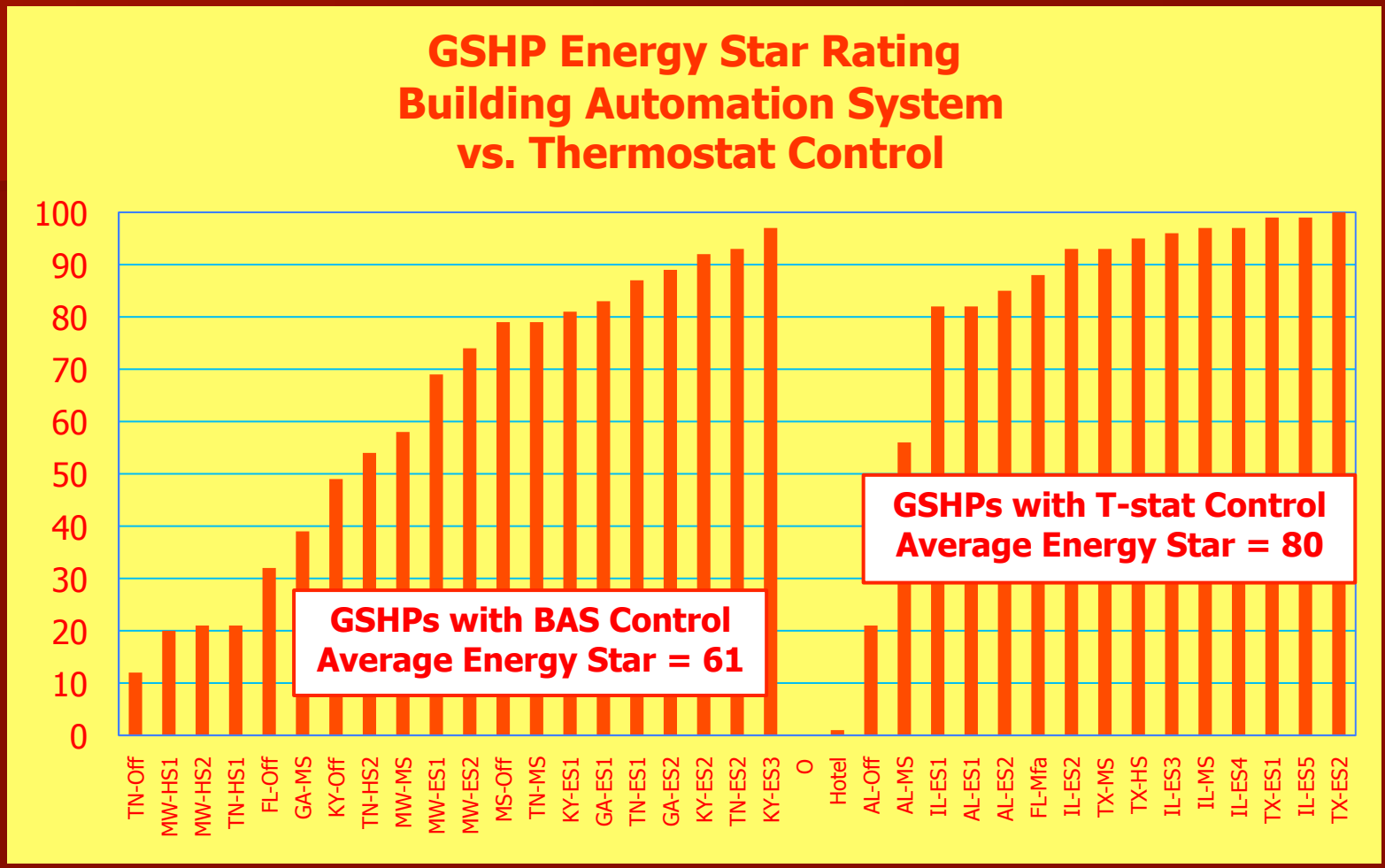
Impact of Ventilation Air Equipment Flow Rate



Impact of Ground Loop Pump Power



Impact of Control Type

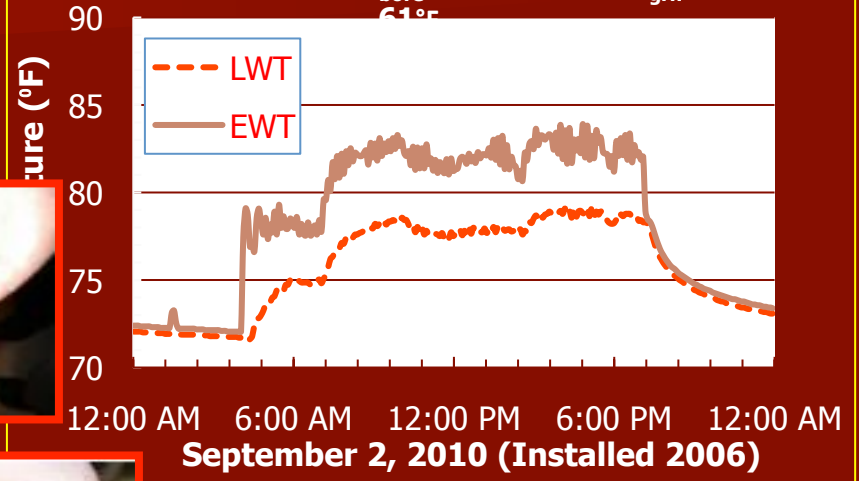


Are Systems Installed, Maintained & Operated as Intended?
Fourteen VS Pump Drives Surveyed – One Worked as Intended

Ground Loop EWT & LWT, VSD Frequency
E-Star = 83, High Air Temp = 93°F
GA Elem. School, L_{bore} = 214 ft/ton, t_{grn} = 60°F

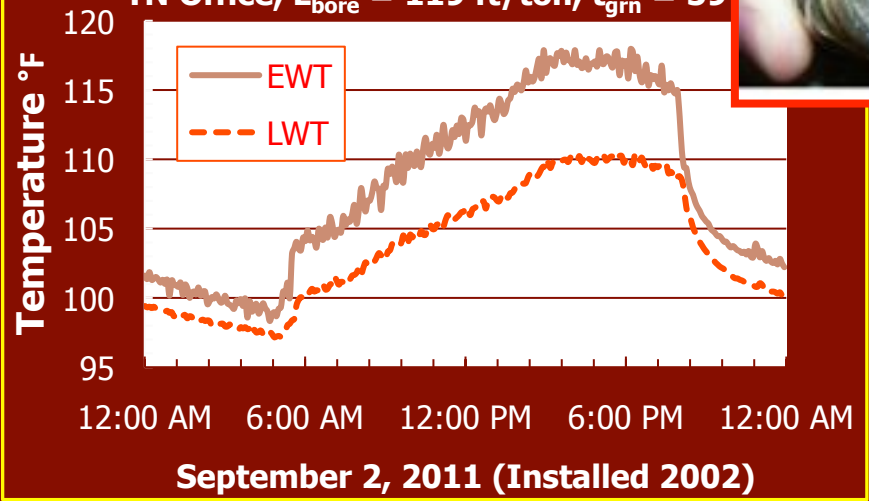
September 7, 2010 (Installed 2003)

Ground Loop EWT and LWT
E-Star = 93, High Air Temp = 97°F
TN Elem. School, L_{bore} = 197 ft/ton, t_{grn} =



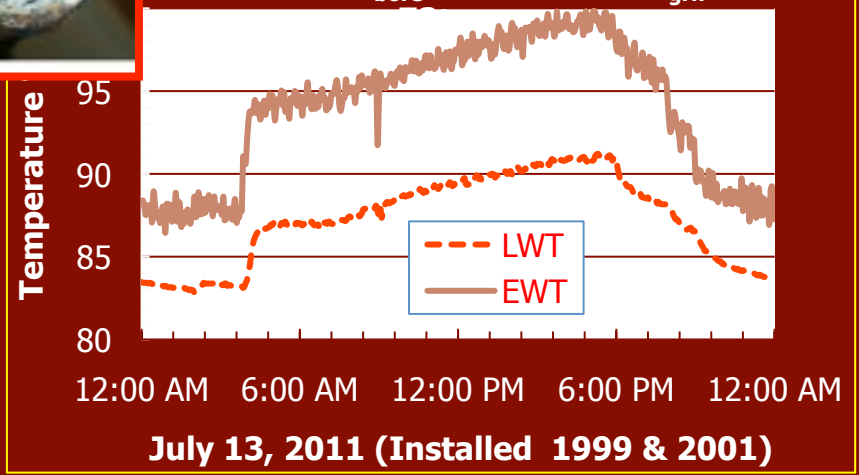
September 2, 2010 (Installed 2006)

Ground Loop EWT and LWT
E-Star = 11, High Air Temp = 95°F
TN Office, L_{bore} = 119 ft/ton, t_{grn} = 59



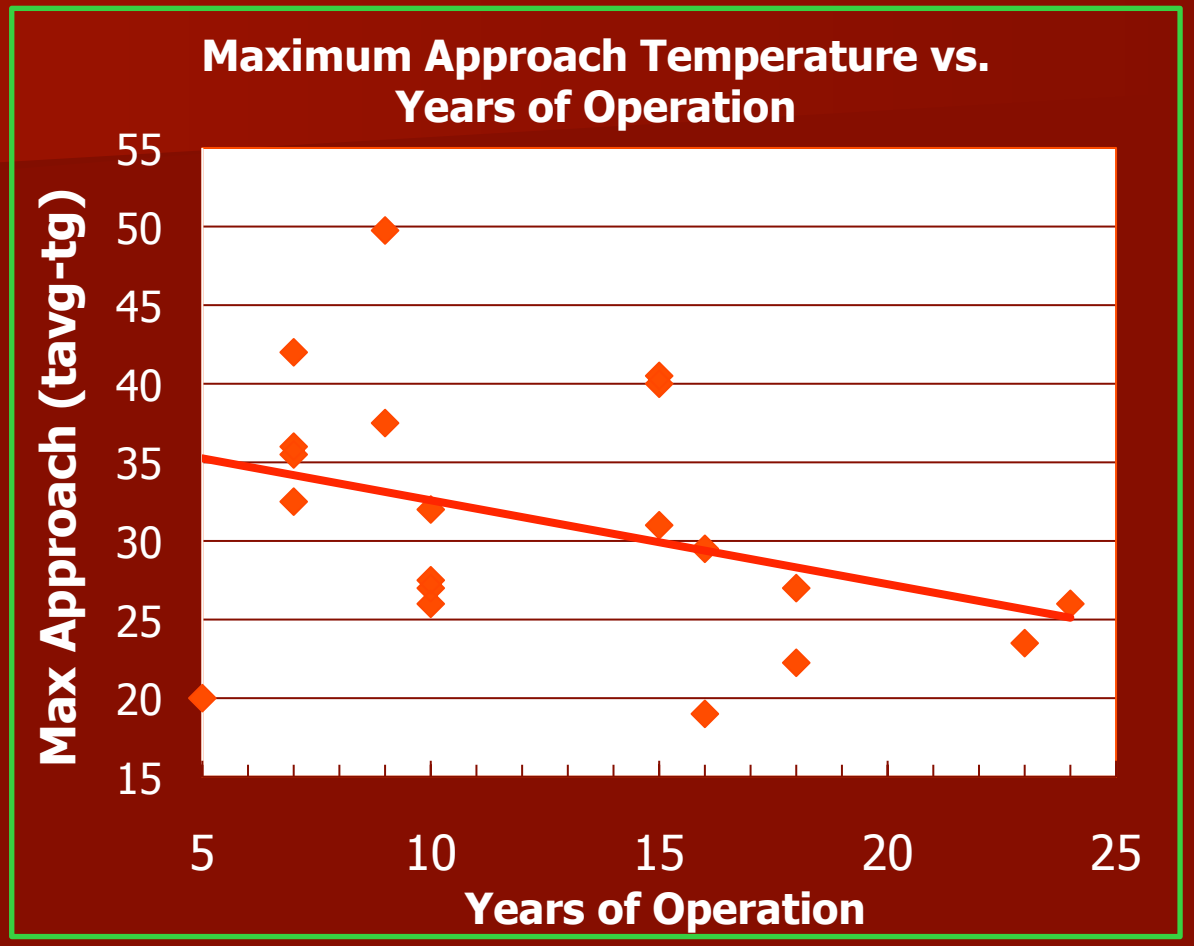
September 2, 2011 (Installed 2002)

Ground Loop EWT and LWT
E-Star = 32, High Air Temp = 96 °F
lorida Office, L_{bore} = 270 ft/ton, t_{grn} =



July 13, 2011 (Installed 1999 & 2001)

Do Ground Loops Overheat and Be Abandoned After a Number of Years?



Field data indicates otherwise when systems properly sized and installed! Problems occur if loops too short, too close together, or improperly grouted. More data needed to establish limits.

Building Occupant Comfort and Satisfaction Survey

???☺ 😐 ☹???

☑ Check the box that reflects your level of satisfaction with the **summer** indoor temperature and humidity

☐ **Very Dissatisfied** ☐ **Dissatisfied** ☐ **Acceptable** ☐ **Satisfied** ☐ **Very Satisfied**

☑ Check the box that reflects your level of satisfaction with the **winter** indoor temperature

☐ **Very Dissatisfied** ☐ **Dissatisfied** ☐ **Acceptable** ☐ **Satisfied** ☐ **Very Satisfied**

☑ Check the box that reflects your level of satisfaction with the **air quality** (odors, stuffiness, air "freshness")

☐ **Very Dissatisfied** ☐ **Dissatisfied** ☐ **Acceptable** ☐ **Satisfied** ☐ **Very Satisfied**

☑ Check the box that reflects your level of satisfaction with the **acoustics** (noise levels related to heating and cooling equipment)

☐ **Very Dissatisfied** ☐ **Dissatisfied** ☐ **Acceptable** ☐ **Satisfied** ☐ **Very Satisfied**

☑ Check the box that reflects your level of satisfaction with the **lighting** level

☐ **Very Dissatisfied** ☐ **Dissatisfied** ☐ **Acceptable** ☐ **Satisfied** ☐ **Very Satisfied**

If are Dissatisfied or very dissatisfied, was the lighting level ☐ **Too Low or** ☐ **Too High**

☑ Check the box that reflects your level of satisfaction with the **responsiveness** and **ease of reporting building maintenance problems**

☐ **Very Dissatisfied** ☐ **Dissatisfied** ☐ **Acceptable** ☐ **Satisfied** ☐ **Very Satisfied**

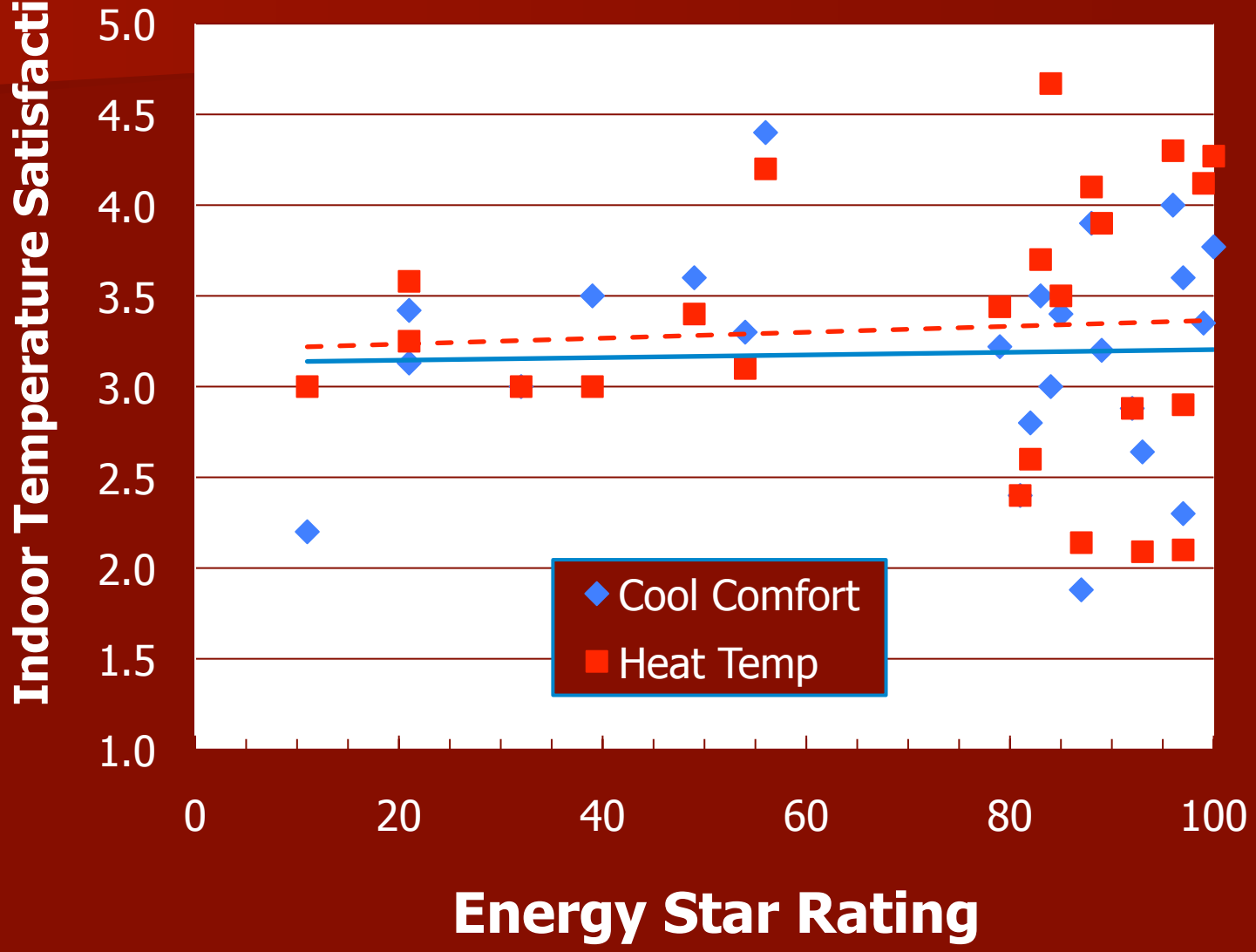
☑ Check the box that reflects your ability to adjust the **thermostat settings** in your space

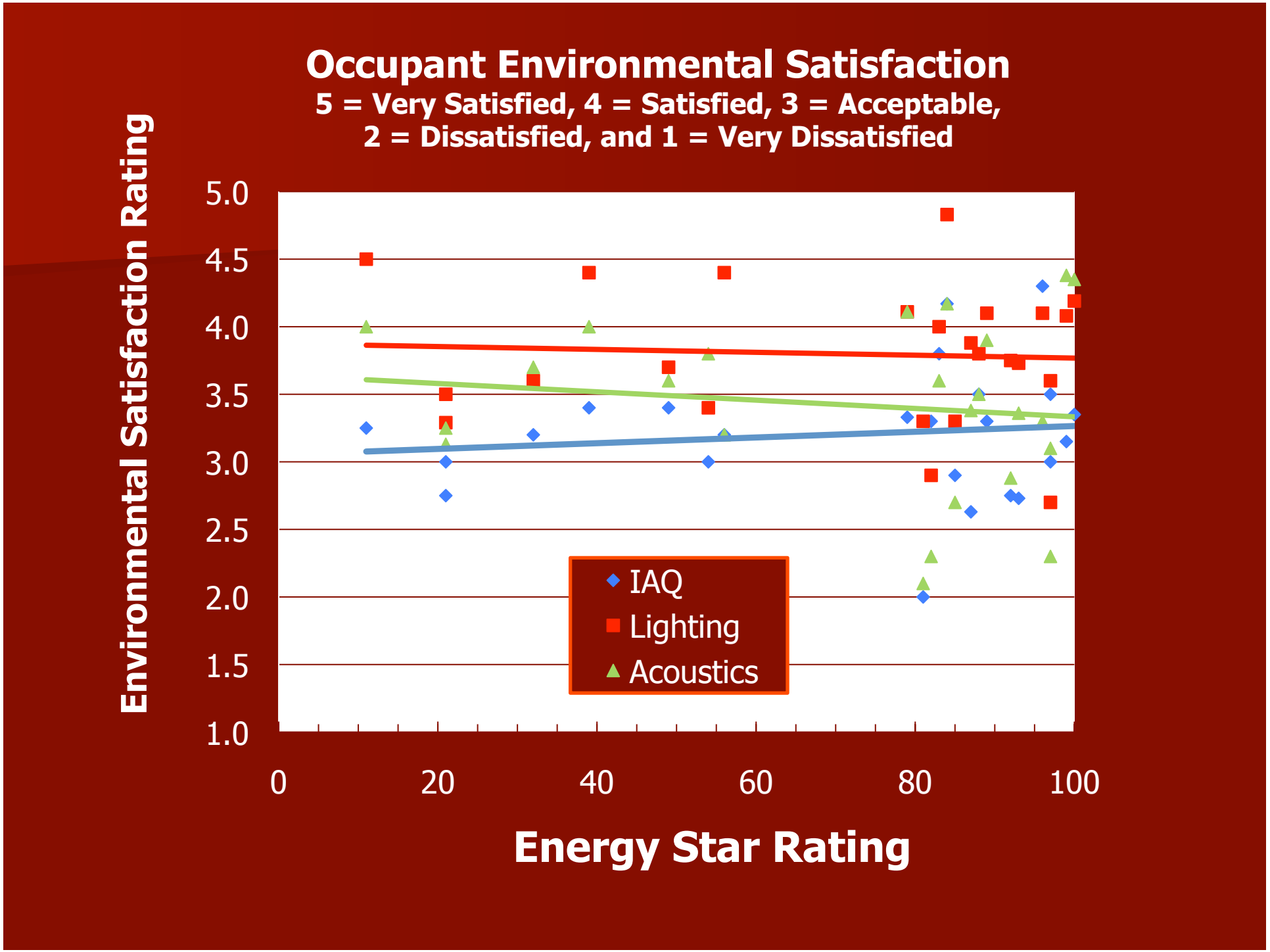
☐ **Very Dissatisfied** ☐ **Dissatisfied** ☐ **Acceptable** ☐ **Satisfied** ☐ **Very Satisfied**

Other Comments:

Occupant Temperature Satisfaction

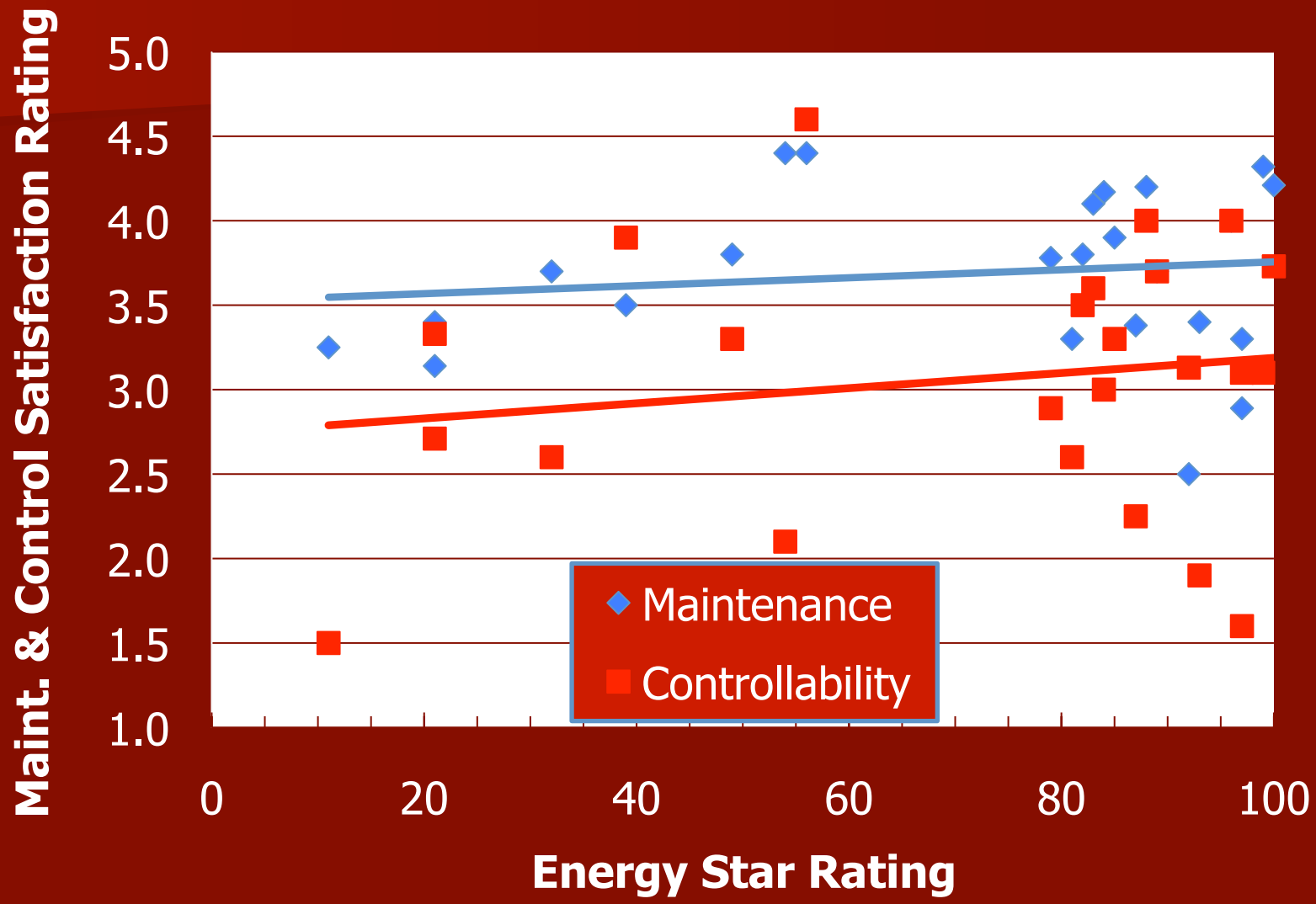
5 = Very Satisfied, 4 = Satisfied, 3 = Acceptable, 2 = Dissatisfied, and 1 = Very Dissatisfied

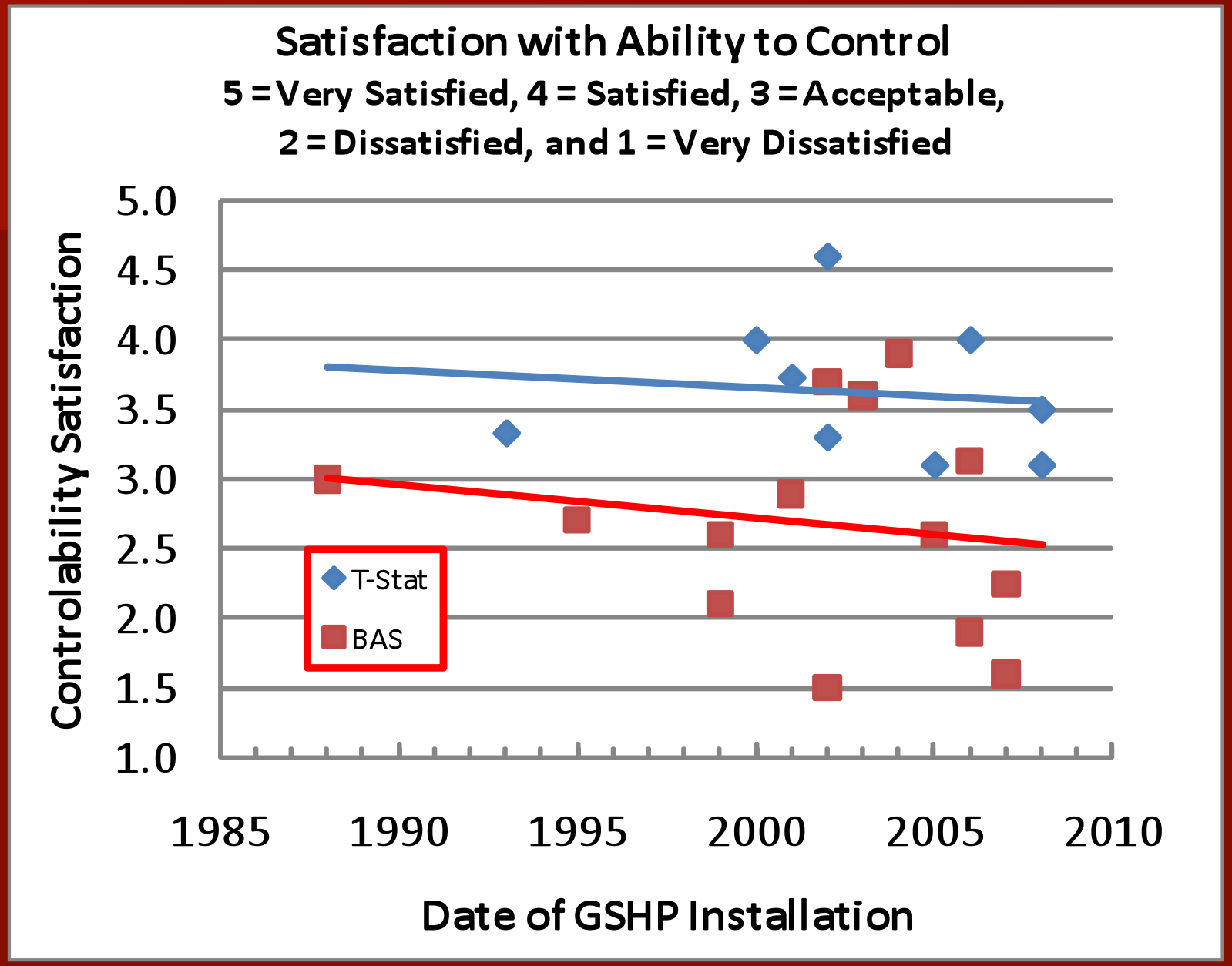



Occupant Environmental Satisfaction
5 = Very Satisfied, 4 = Satisfied, 3 = Acceptable,
2 = Dissatisfied, and 1 = Very Dissatisfied
Environmental Satisfaction Rating
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0
20
40
60
80
100
Energy Star Rating
IAQ
Lighting
Acoustics

Maintenance and Control Satisfaction

5 = Very Satisfied, 4 = Satisfied, 3 = Acceptable,
2 = Dissatisfied, and 1 = Very Dissatisfied




Satisfaction with Ability to Control
5 = Very Satisfied, 4 = Satisfied, 3 = Acceptable,
2 = Dissatisfied, and 1 = Very Dissatisfied
Controlability Satisfaction
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
T-Stat
BAS
1985
1990
1995
2000
2005
2010
Date of GSHP Installation

Service Friendly Equipment & Installations

Difficult to Service Equipment & Installations

What about Simple Single Speed Heat Pumps vs. State-of-the-Art Multi-Capacity & Variable Speed

AHRI/ISO 13256-1 Performance Ratings

Variable Speed ECM Motor

AHRI/ASHRAE/ISO 13256-1
English (IP) Units

Indoor Air = 27°C

15°C

25°C
20°C

Model	Capacity Modulation	Flow Rate Clg/Htg	Water Loop Heat Pump				Ground Water Heat Pump				Ground Loop Heat Pump			
			Cooling EWT 86°F		Heating EWT 68°F		Cooling EWT 59°F		Heating EWT 50°F		Cooling Full Load 77°F Part Load 68°F		Heating Full Load 32°F Part Load 41°F	
		cfm	Capacity Btu/h	EER Btu/h per W	Capacity Btu/h	COP	Capacity Btu/h	EER Btu/h per W	Capacity Btu/h	COP	Capacity Btu/h	EER Btu/h per W	Capacity Btu/h	COP
036	Full	1300/1500	32,000	18.0	50,000	5.3	38,000	31.5	41,000	4.6	36,000	22.0	32,000	3.5
	Part		11,000	21.0	17,000	7.5	13,000	47.2	14,000	5.9	14,000	37.0	13,000	5.3
048	Full	1500/1800	41,000	17.6	67,000	5.0	49,000	31.7	55,000	4.3	46,000	21.7	43,000	3.6
	Part		16,000	22.5	24,000	7.6	19,200	53.2	19,000	5.9	19,000	41.0	16,000	5.3
060	Full	1800/2200	50,000	16.3	78,000	4.8	60,000	28.6	65,000	4.3	56,000	19.4	51,000	3.5
	Part		20,000	21.7	29,000	7.5	23,200	45.8	23,000	6.0	23,000	36.0	20,000	5.1

Cooling capacities based upon 80.6°F DB, 66.2°F WB entering air temperature
Heating capacities based upon 68°F DB, 59°F WB entering air temperature
All ratings based upon 208V operation

6/15/12

Part-Load Air Flow same as Full-Load

COP=15.6

COP=12

What about Simple Single Speed Heat Pumps vs. State-of-the-Art Multi-Capacity & Variable Speed

Water-to-Air Heat Pump Full-Load **TC(kBtu/h), EER, HC(kBtu/h) & COP**

Cooling: 86°F EWT & 80.6/66.2°F EAT - Heating: 50°F EWT & 68°F EAT

Model/Capacity	30°C Cfm	TC	EER	Cfm	10°C HC	COP
NS-036/Single (10 kW_t)	1200	34.5	19.6	1200	30.3	5.2
NS-048/Single (14 kW_t)	1500	47.0	17.5	1500	45.1	4.8
NS-060/Single (18 kW_t)	1800	64.3	17.2	1800	55.1	4.7
Average EER			**18.1**	COP=5.3		**4.9**
ND-038/Dual	1200	39.0	17.2	1200	34.8	5.0
ND-049/Dual	1500	48.3	15.8	1500	47.2	4.7
ND-064/Dual	1800	64.5	16.2	1800	56.8	4.6
Average EER			**16.4**	COP=4.8		**4.8**
NV-036/Variable	1300	32.0	18.0	1500	41.0	4.6
NV-048/Variable	1500	41.0	17.6	1800	55.0	4.3
NV-060/Variable	1800	50.0	16.3	2200	65.0	4.3
Average EER			**17.3**	COP=5.1		**4.4**

Water-to-Air Heat Pump Corrector Included with Revision to Ground Source Heat Pumps (ASHRAE, Late 2014)

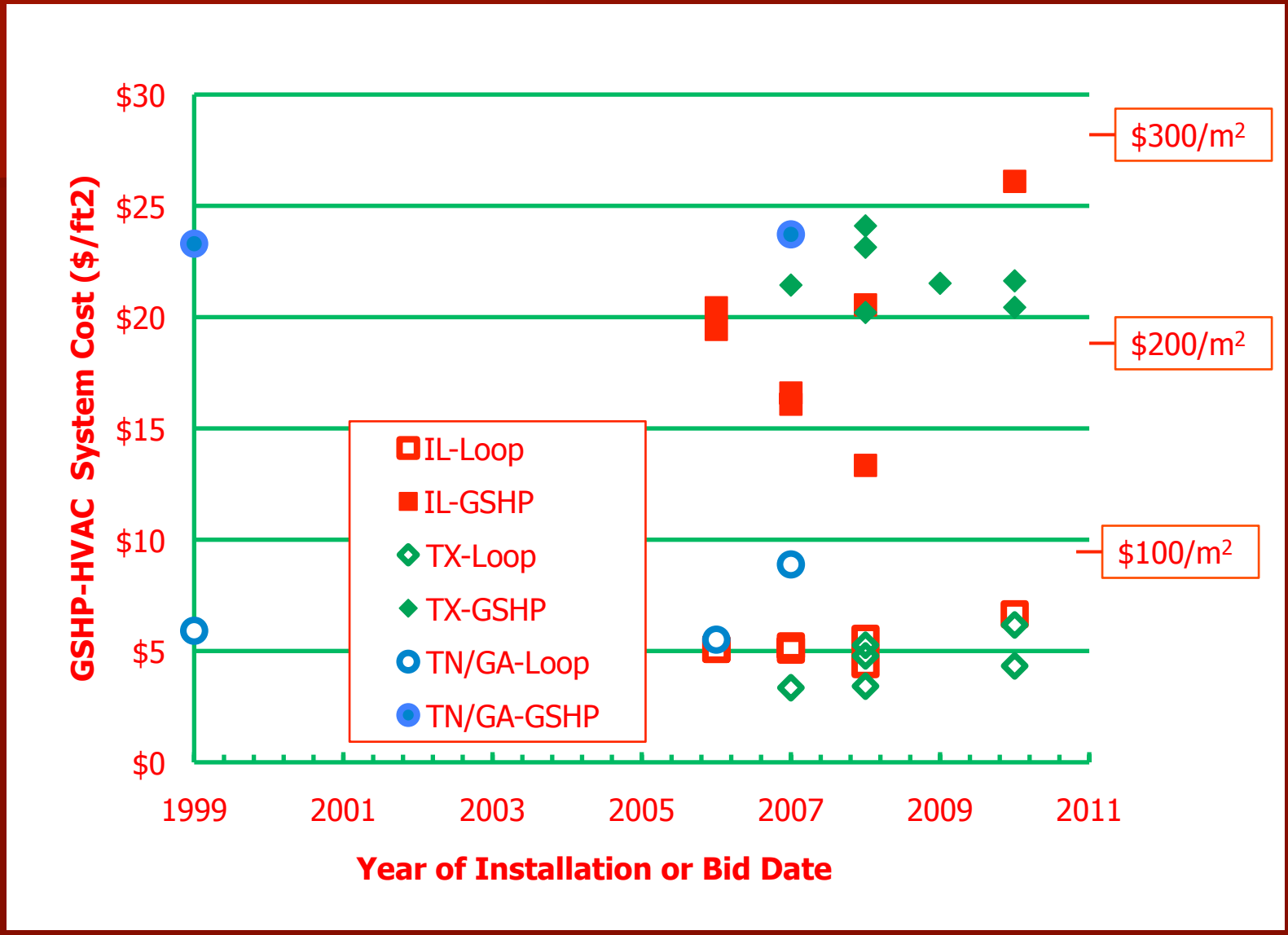
- Provide TC, EER, HC, COP at Six ISO Conditions
- Enter Operating Conditions and Pump Power
- Read Out Corrected Performance

GLHP Rated Performance			Operating Conditions			Corrected Capacity, Power, EER and COP				
Model#	ECM-60		ELTClg	80.0	°F		Pump(s) not Included		Pump(s) Included	
TC-77°F	66.8	kBtu/h	ELTHtg	43.0	°F	TC	61.6	kBtu/h	61.6	kBtu/h
SC-77°F	0	kBtu/h	EATdbClg	75.0	°F	SC_Est	41.6	kBtu/h	41.6	kBtu/h
EER-77°F	19.5	Btu/W-h	EATwbClg	63.0	°F	SHR	0.68		0.68	
HC-32°F	43.3	kBtu/h	EATHtg	70.0	°F	EERnoCF	18.7	Btu/W-h		Btu/W-h
COP-32°F	3.9	W/W	Actgpm	15.0	gpm	kWc	4.02	kW	4.40	kW
WtrFlow	15.0	gpm	Actcfm	1800	cfm	EER	15.3	Btu/W-h	14.0	Btu/W-h
AirFlow	1800	cfm	Fan Power and Heat Correction			HC	52.0	kBtu/h	52.0	kBtu/h
GpmPTonR	2.7		FanMotor	ECMwFCBlade		COPnoCf	4.39	W/W		W/W
CfmPTonR	323		ESP	0.5	in. water	kWh	3.95	kW	4.34	kW
GpmPTonA	2.7		FilterLoss	0.3	in. water	COP	3.85	W/W	3.51	W/W
			WAEff	30%						
			kWFan	0.51	kW		Optional Pump Power			
			FanHeat	1.7	kBtu/h		kWpump	0.385	kW	

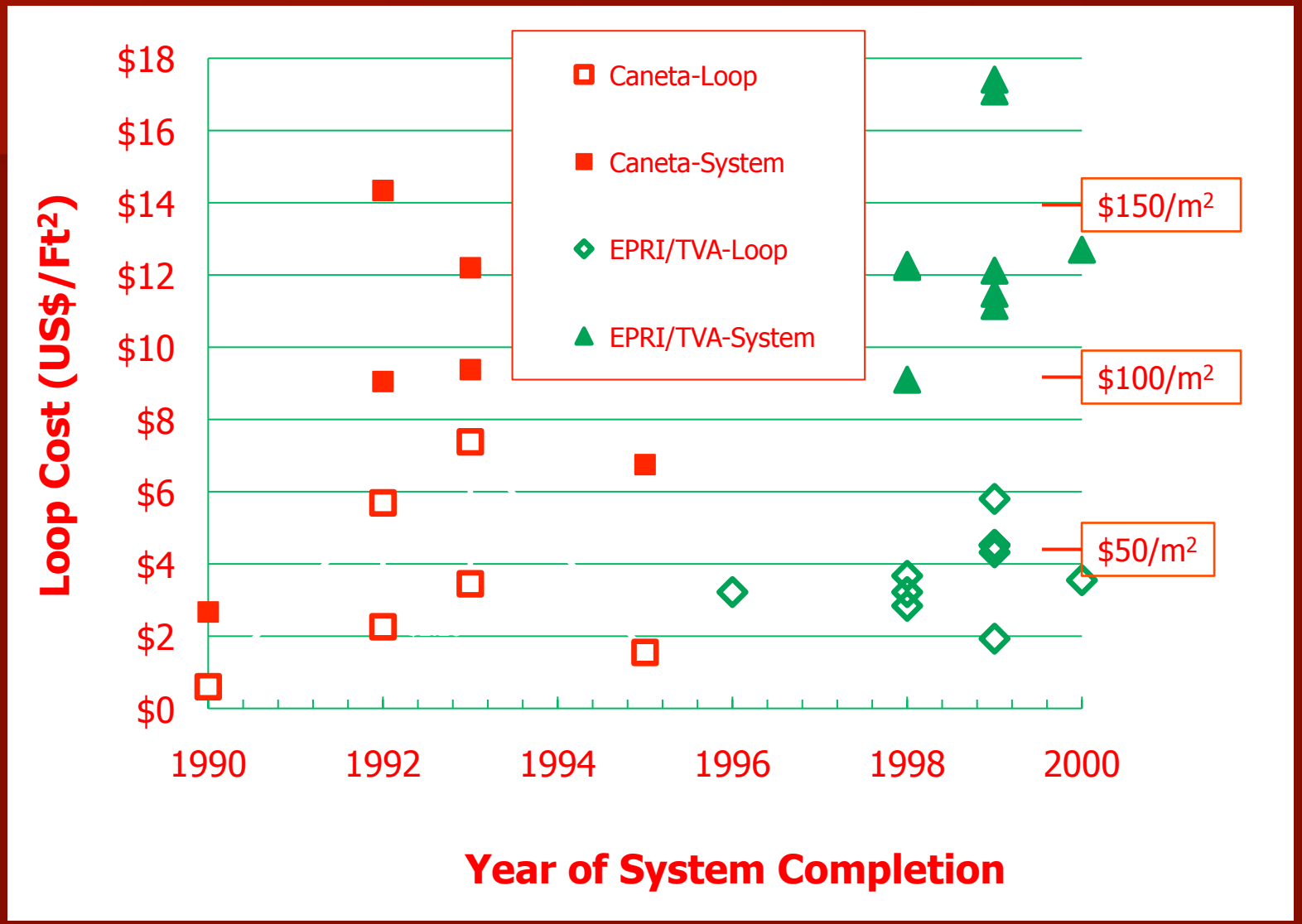
GSHP Installation Cost

- A common comment is “GSHPs cost too much”.
- But few seem to know how much they cost (or they are embarrassed to share).
- A common comment is “you have to get the loop cost down” (even though the loop costs in this survey were 26% of the total while the HVAC cost was 74%).
- Only a few engineers were willing to share information (they had the highest Energy Star ratings and also reasonable installation costs).

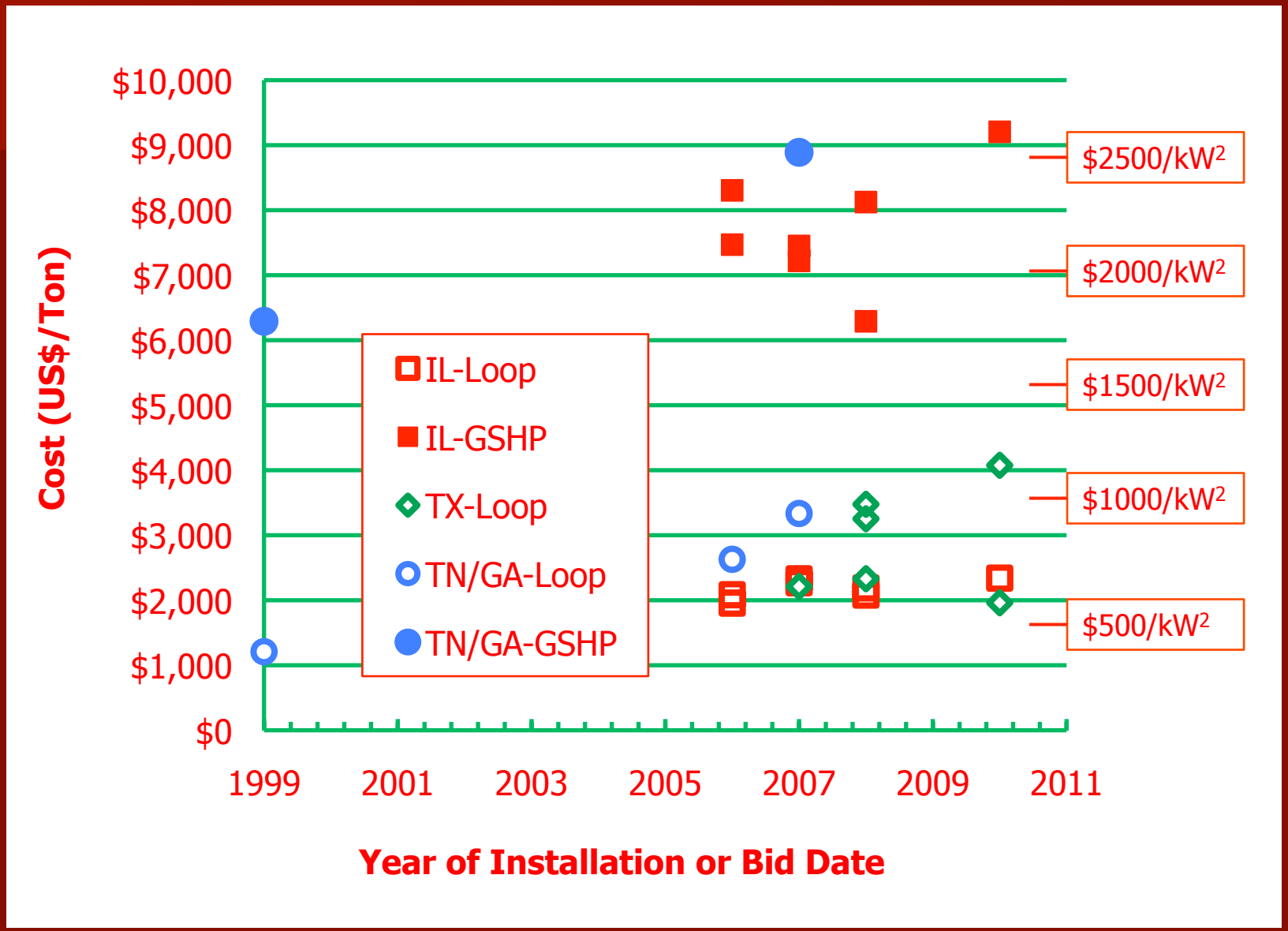
2010 GSHP Loop & System Cost $/ft^2 ($/m^2)



1995/2000 GSHP Loop & System Cost - $/ft² ($/m²)

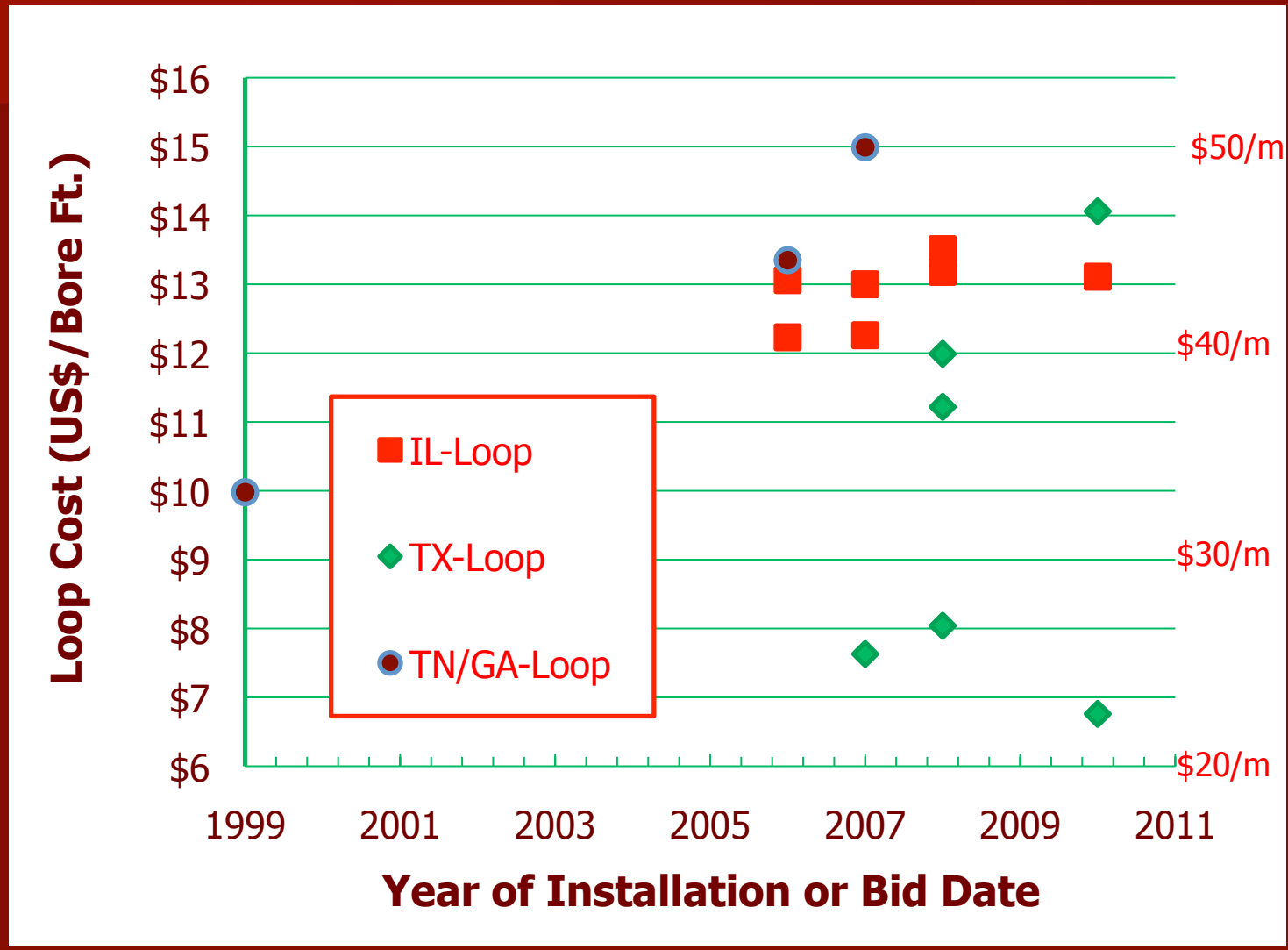


GSHP Loop and Total System Cost/Ton (kW)



GSHP Loop System Cost - $/Bore Ft. ($/m)

Costs Include Headers, TX Loops Also Include Interior Piping



Summary

- Most GSHP systems did well (33% E-Star > 90, 61% E-Star > 75)
- Unitary loop and one-pipe GSHPs performed very well (Avg E-Star = 95)
- Central loop GSHPs performed slightly above average HVAC systems
- A few GSHPs don't work very well - 19% E-Star < 50% (Short loops, dysfunctional controls, big fans & OA units)
- Systems with simple thermostat controls performed better than those with building automated systems (BAS)
- Only one of the 14 VS ground loop pump drives was working properly.
- Buildings with high ventilation air flows have higher energy consumption and poor occupant satisfaction ratings
- The average cost for the inside the building HVAC was 74% of the total GSHP system cost and has increased by 175% since 1995 survey.
- The average cost for the ground loop was 26% of the total GSHP system cost and has increased by 50% since 1995 survey.
- Measured data does not show any significant incidence of overheated loops due to long term imbalances of cooling loads compared to heating loads (no data for when heating loads much larger than cooling loads).

Characteristics of Successful GSHPs

- The ENERGY STAR rating of the building exceeds 90.
- Most extreme loop temperatures returning from the ground are below 90^{0}F (32°C) in cooling and above 45°F (7°C) in heating.
- The vertical ground loops tend to be long.
- The primary heat pump type tends to be water-to-air.
- Piping circuits are individual, small central, or common ground loops.
- Pump control tends to be on-off rather than variable speed.
- Loop pump power tends to less than 10 hp/100 tons (2 kW_m/100 kW_t.
- Piping tends to non-metalic (which require corrosion inhibitors).
- Control is provided by thermostats or simple building automation systems .
- Occupants and maintenance personnel rate indoor comfort, IAQ, acoustics, lighting, maintenance, and control as satisfactory.
- Owners and designers are satisfied with installation and operating cost and are willing to provide details with public.

ASHRAE
GSHP Book (1997)
Being Revised
(Available Late 2014)

Questions

Comments