Welcome to the

Community Heat Pump Systems Webinar

A Series of 17 Webinars on Community Heat Pump Systems

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ASHRAE®
Learning Institute

Community Heat Pump Systems: Piping, Pumping and System Controls

Presented by:
Stephen Kavanaugh, Ph.D., Fellow ASHRAE

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Learning Objectives

1. Learn of data sources of large building energy consumption
2. Learn lessons from previous district energy system performance
3. Become aware of previous low energy GSHP installation practices that may be applied to community heat pump systems
4. Understand the limitations and opportunities of community heat pumps systems to improve on existing GSHP installations
5. Understand the challenges of installing large pipe networks, assembling design teams, and available maintenance resources.

Instructors

Speaker
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Community Heat Pump Systems

New York State Energy Research Development Authority's (NYSERDA) vision is a strategic network of distribution pipes serving multiple buildings:

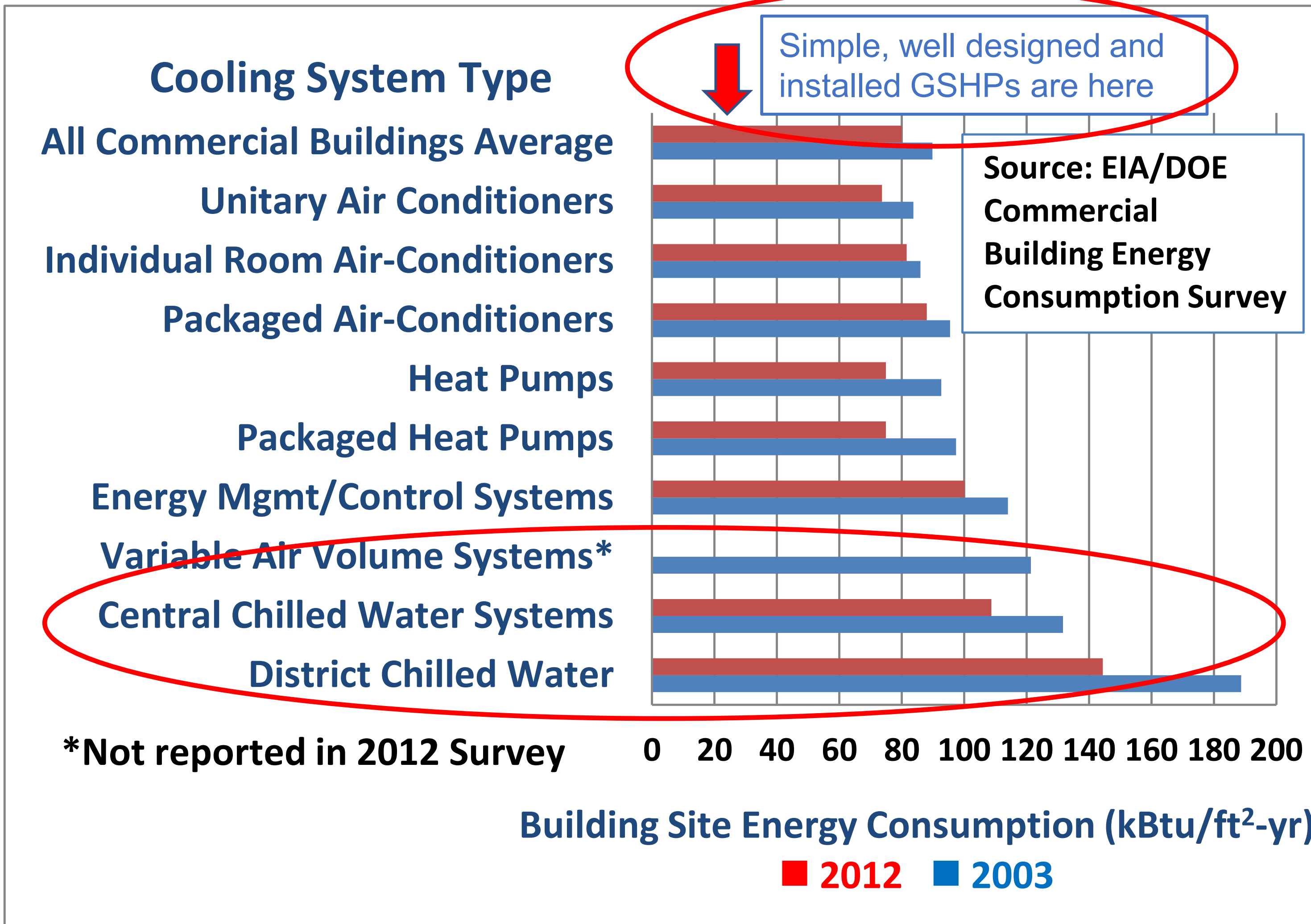
- Meet the thermal needs within a building (HVAC and DHW) using renewable electricity
- Expand clean energy options for customers who have insufficient footprint space to serve their own needs
- Leverage economy of scale
- Use this approach to address New York State's nation-leading climate goals

Outline/Agenda

1. Commercial Building Energy Consumption Survey (CBECS)
2. District GSHP Systems Lessons Learned but Not Widely Known
3. Simple GSHPs that Use 30% of CBECS Energy
4. HVAC Systems that Integrate Poorly with GSHPs
5. Does Complexity Lead to Dissatisfaction
6. Applications Where Community Heat Pumps Systems are Viable
7. Challenges – Piping Networks, Technicians, Design Teams
8. Conclusions

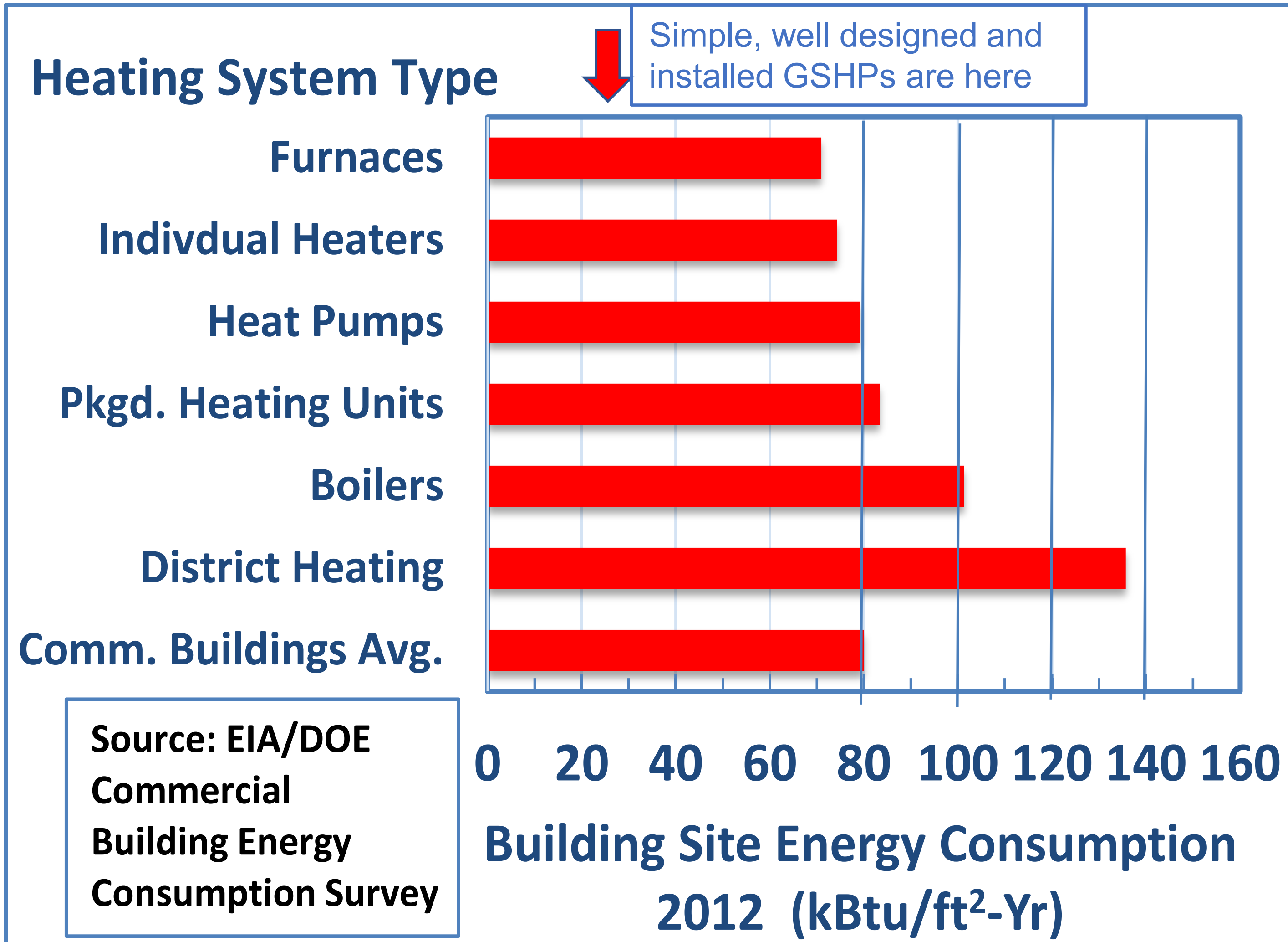
Commercial Building Energy Consumption Survey (US Energy Information Administration/DOE)

Data Indicate District Cooling Systems are Energy Intensive



Commercial Building Energy Consumption Survey (US Energy Information Administration/DOE)

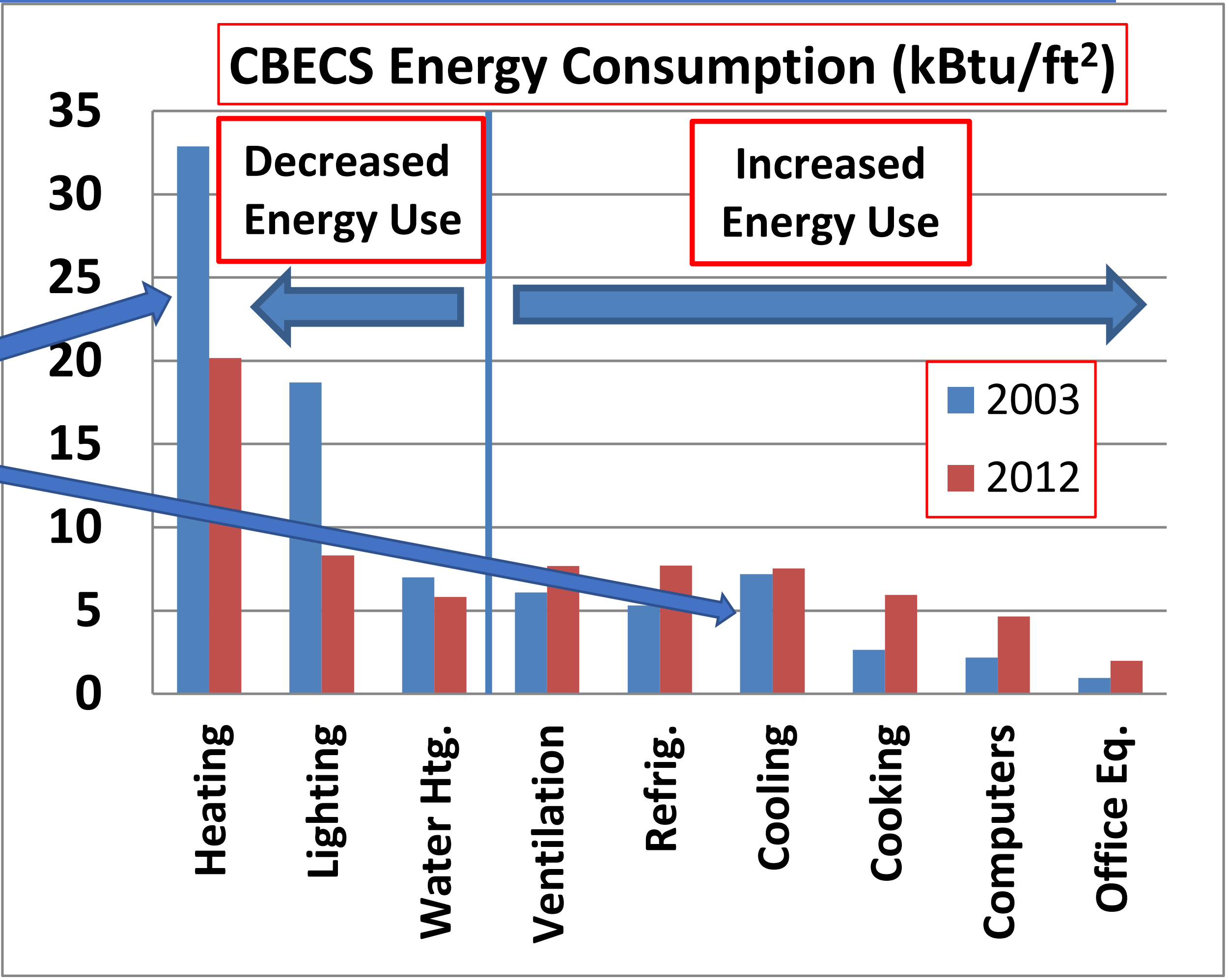
Data Indicate District Heating Systems are Energy Intensive



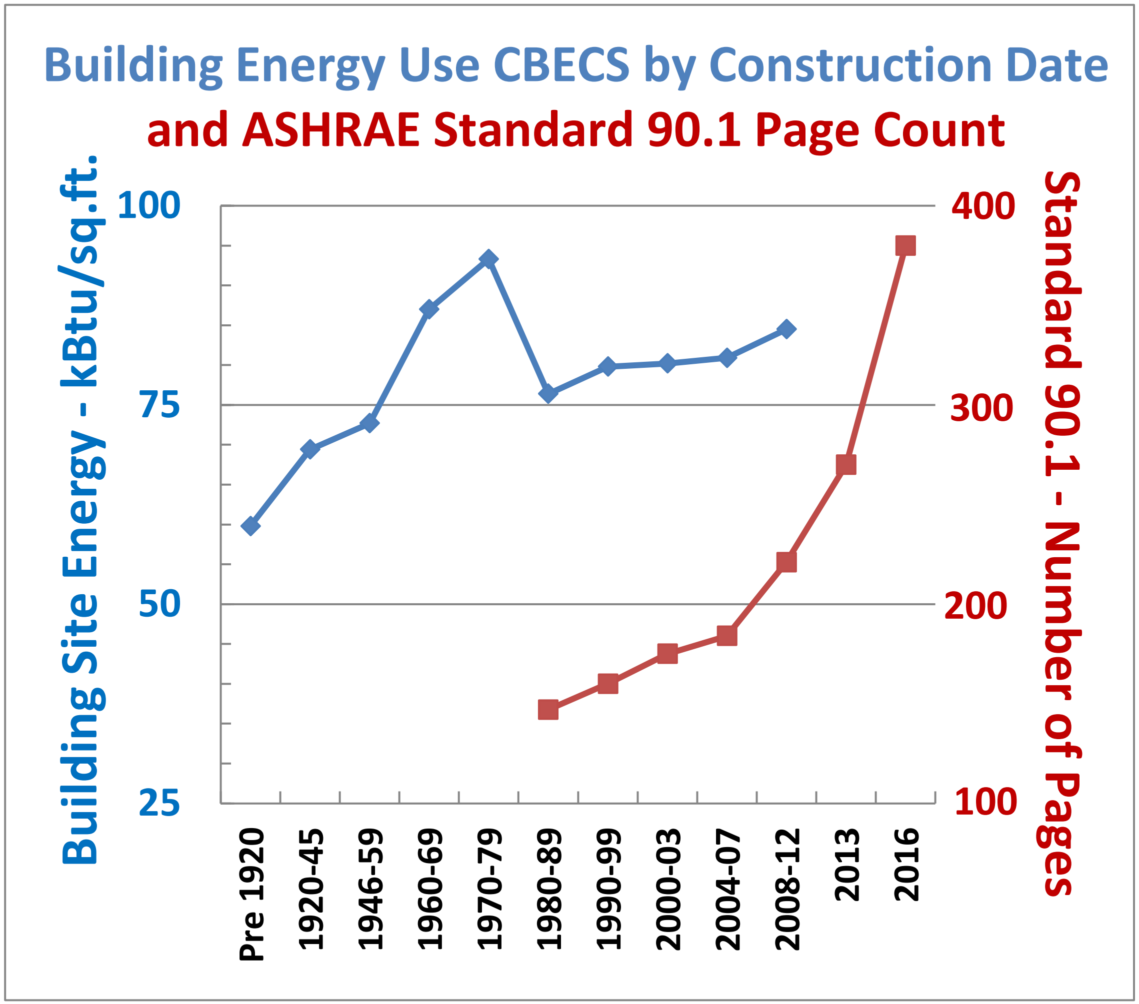
Source: EIA/DOE Commercial Building Energy Consumption Survey

Improving Design with Measured Data to Determine Changes in Building Energy Use (2003 to 2012)

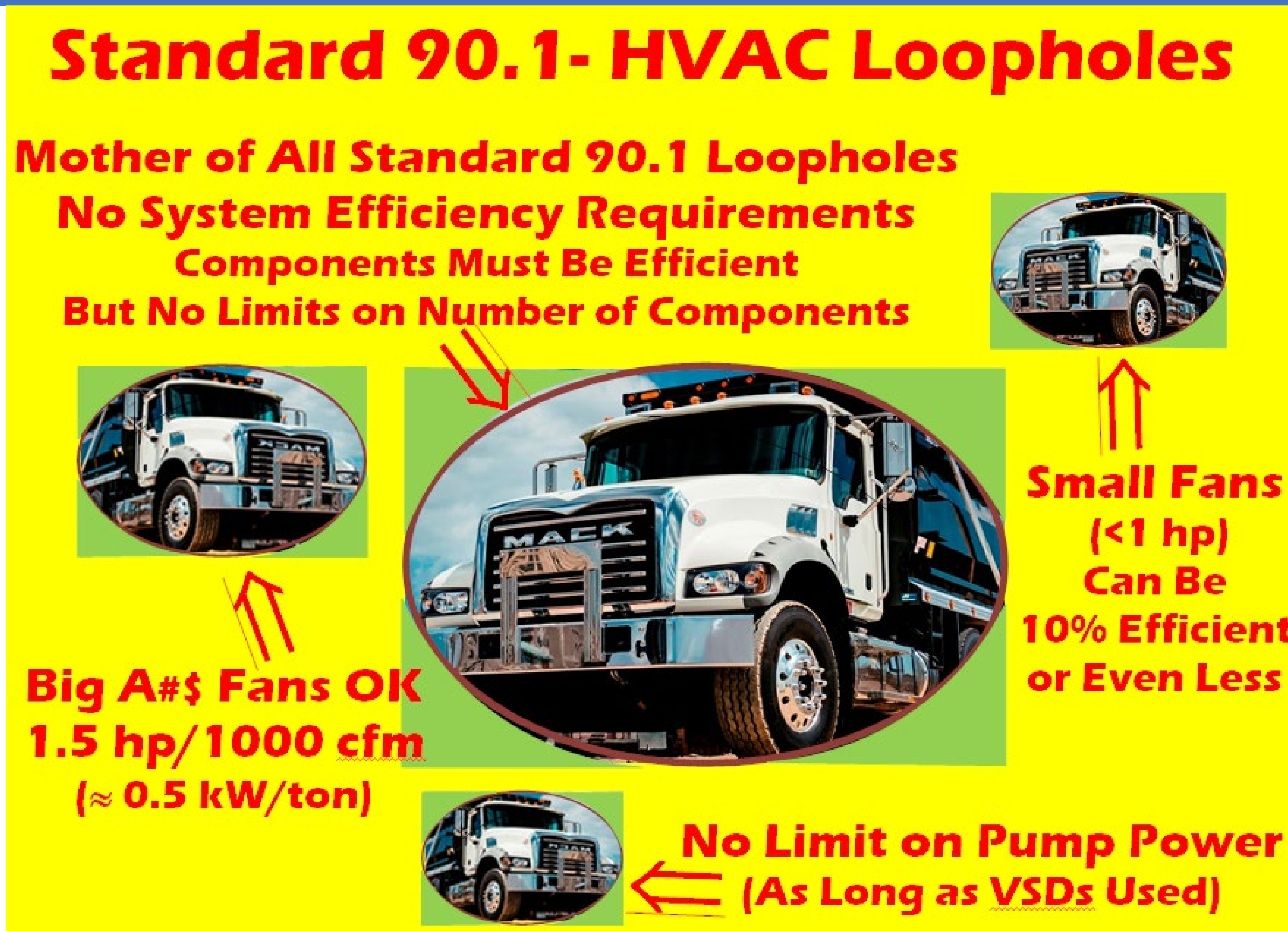
In times past, heating was the primary concern in New York type climates. Heating (and lighting) use has declined overall, while cooling has not.



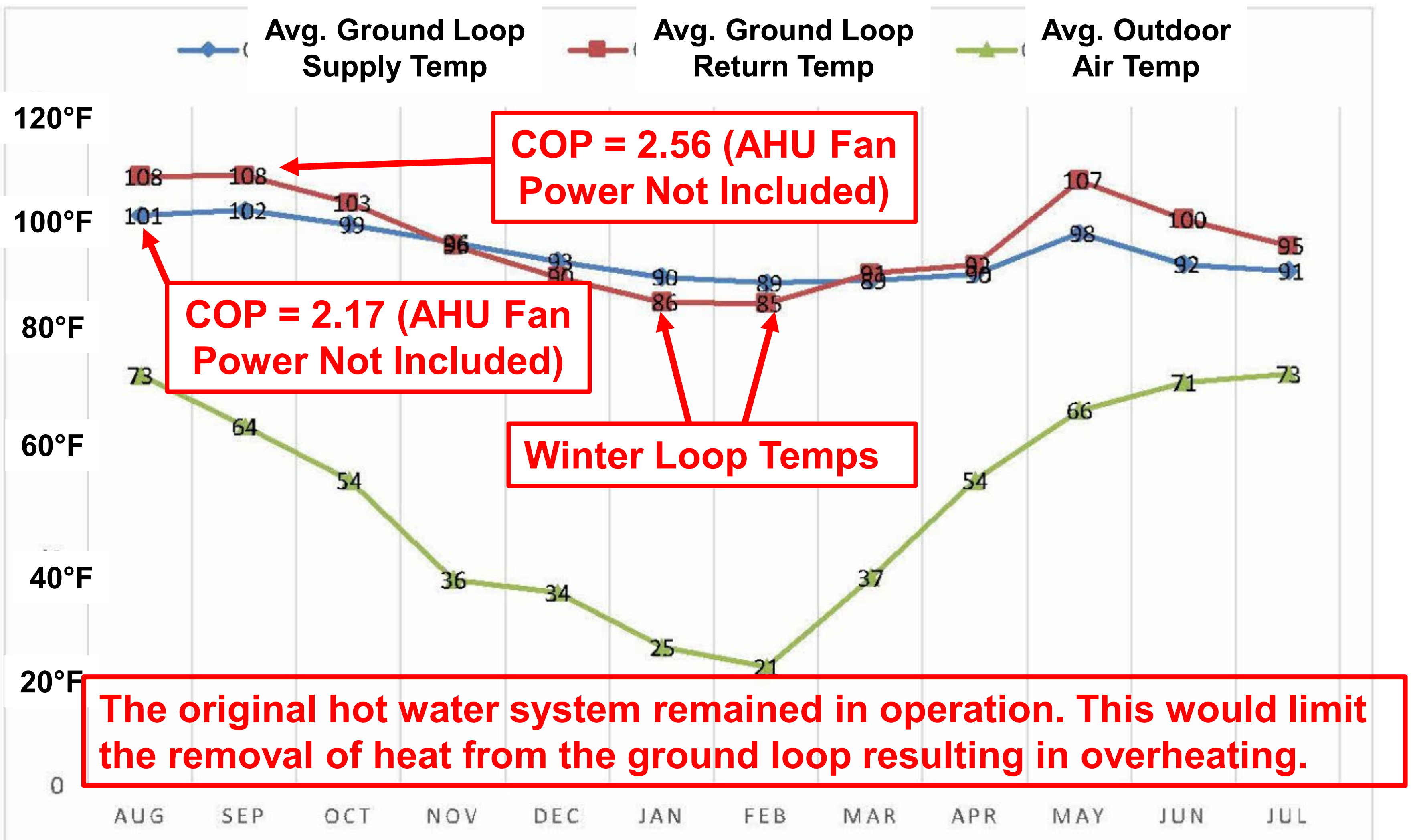
Newer Buildings Use More Energy Than Older Ones Despite Tighter Standards and Measured Reduction of Heating and Lighting Energy Use



Lessons Learned Can't Be Learned When Community GSHP Systems Issues Are Hidden Loopholes in Existing Standards



Indiana DE Campus GSHP Monthly Average Temperatures After Fluid Coolers Added - Peak Temperatures not Reported



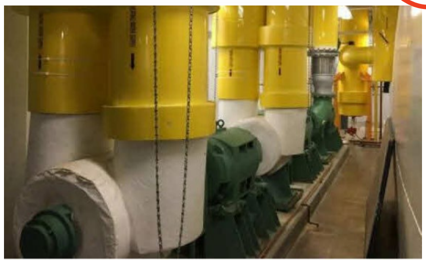
Central Loop Pumps Can Require Much Greater Head than Local Pumps (and Big Chillers)

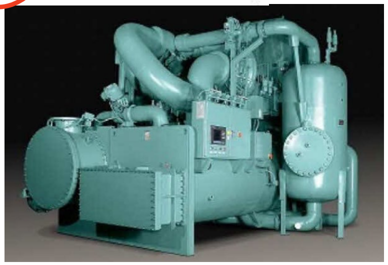
Dwg. Labels	Description	Design Flow (GPM)	Head (FT)	Motor (HP)
LFWP-1	Geothermal Loop Field Pump -1	6,000	100	250
LFWP-2	Geothermal Loop Field Pump -2	6,000	100	250
LFWP-3	Geothermal Loop Field Pump -3	6,000	100	250
PCHWP-1	Primary Chilled Water Pump - 1 (CH#1)	6,000	60	125
PCHWP-2	Primary Chilled Water Pump - 2 (CH#2)	6,000	60	125
SCHWP-1	Secondary Chilled Water Pump -1	5,800	150	350
SCHWP-2	Secondary Chilled Water Pump -2	5,800	150	350
SCHWP-3	Secondary Chilled Water Pump -3	5,800	150	350
CWP – 1	Condenser Water Pump - 1 (CH#1)	6,400	55	125
CWP – 2	Condenser Water Pump - 2 (CH#2)	6,400	55	125
HWP-1	Hot water Pump - 1	3,600	205	300
HWP-2	Hot water Pump - 2	3,600	205	300
HWP-3	Hot water Pump - 3	3,600	205	300

46 hp
100 Ton


Chilled Water Pumps


Ground Loop Pumps


Hot Water Pumps


Chiller

GSHP System Pump Power Benchmarks

Geothermal Heating and Cooling: Design of Ground Source Heat Pump Systems (ASHRAE 2014) - Table 6.2

Installed Pump Power	Power into Pump Motor	GRADE	Available Head w/70% Eff. Pump at 3 gpm/ton
< 5 hp/100 tons	< 45 W/ton	**A**	< 46 ft. of water
5 < hp/100 tons ≤ 7.5	45 < W/ton ≤ 65	**B**	46 to 69 ft. of water
7.5 < hp/100 tons ≤ 10	65 < W/ton ≤ 85	**C**	69 to 92 ft. of water
10 < hp/100 tons ≤ 15	85 < W/ton ≤ 125	**D**	92 to 138 ft. of water
> 15 hp/100 tons	> 125 W/ton	**F**	> 138 ft. of water

146 hp/100 tons	**1200 W/ton**	**FFFFFF**	**1,300 ft. of water**

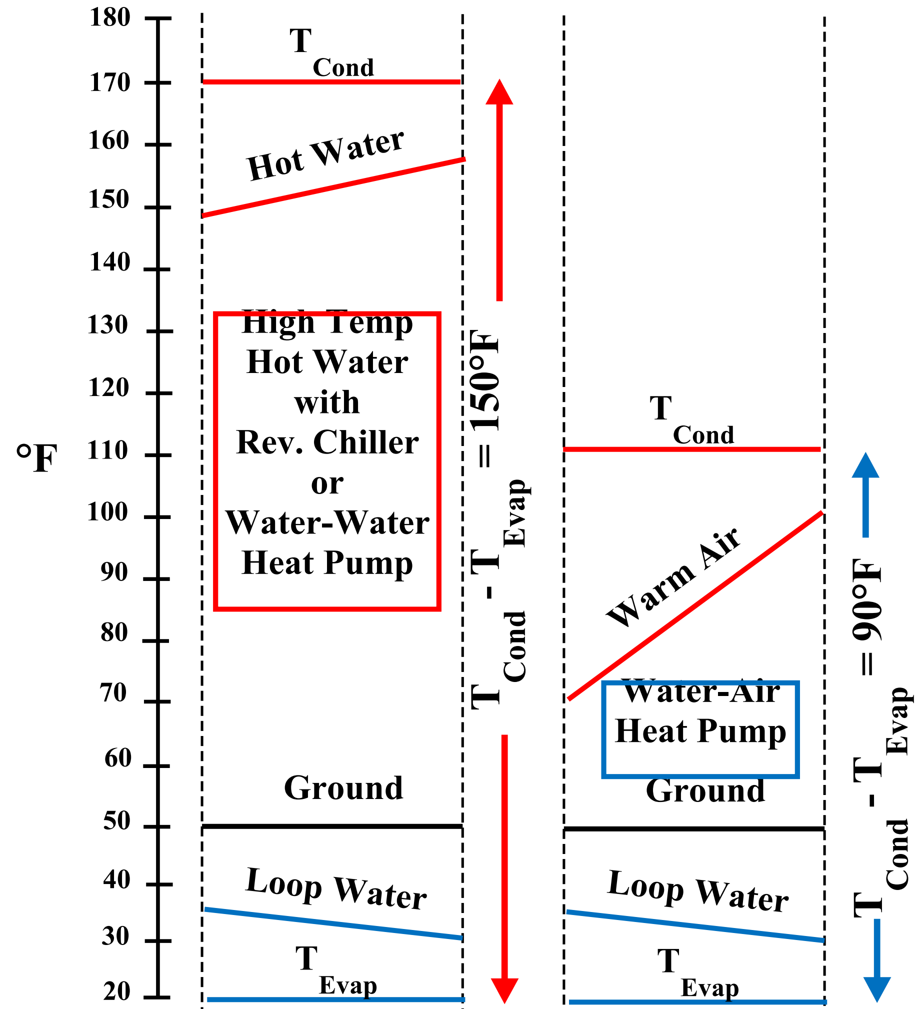
1.2 kW/ton is a lot of additional heat that ends up in the ground loop.

A Lesson Learned Long Ago That is Often Forgotten

(Why Making Really Hot Water with a Heat Pump from a Low Temperature Source is Not Efficient)

$$COP_{Htg.} = \frac{T_{Cond}\ (°R)}{T_{Cond} - T_{Evap}}$$

When these two numbers are far apart, this number is low.



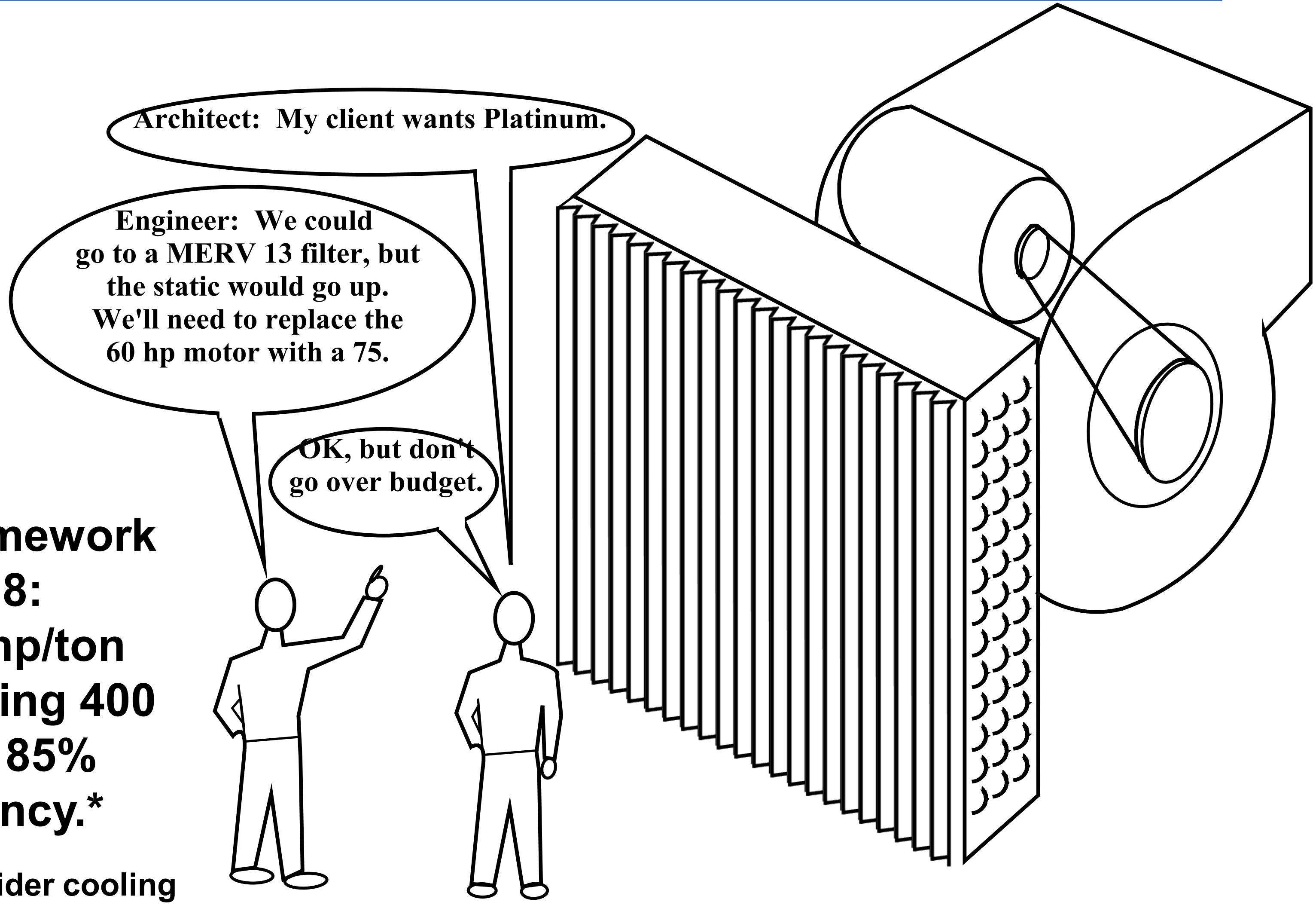
From a previous session:

- For a 120°F supply water
- The tank should be 140°F

Thus, for a 140°F supply water

- The tank should be 160°F

Fans Typically Draw More Power and Add Even More Heat to Large Buildings Than Pumps



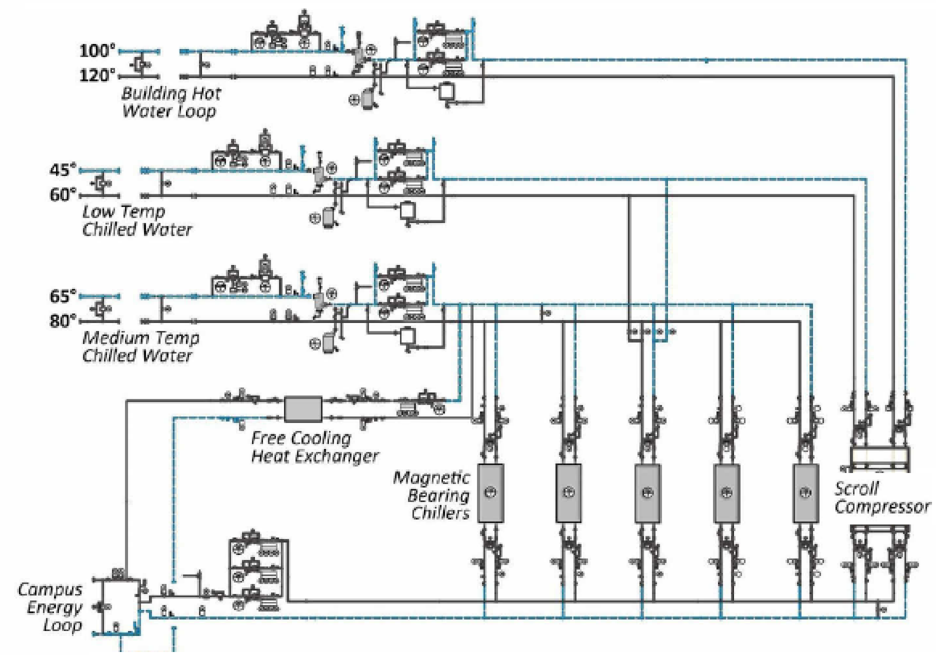
Optional Homework for Webinar 8: Convert 1.5 hp/ton to kW/ton using 400 cfm/ton with 85% motor efficiency.*

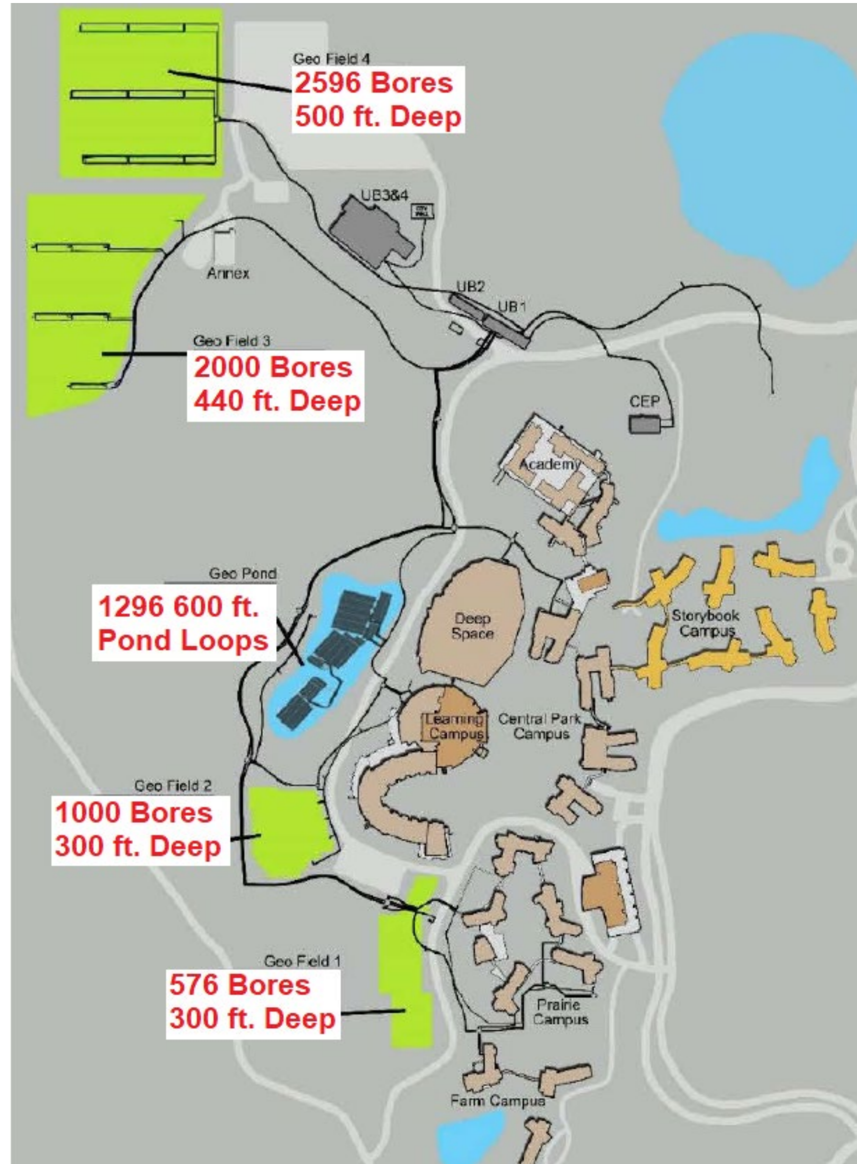
***Don't fail to consider cooling capacity loss due to fan heat.**

Corporate Campus District Geo – Verona, WI

- 7.0 Million ft^2 Occupied Space
- 1051 Acres
- 9000 Employees
- 15,000-ton Capacity

Utility Building Flow Diagram

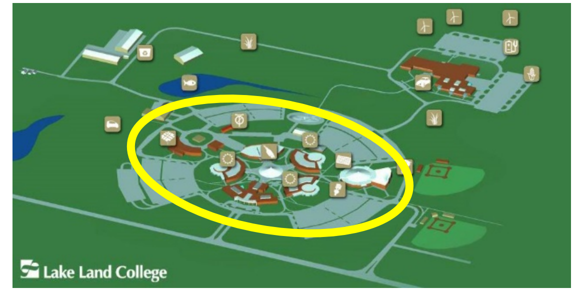




Corporate Campus Results

- Significant information and publicity provided during design and construction
- Little information available after occupation
- A master's thesis indicated that loop fields 3 and 4 were added to cool off overheated systems
- Possibly over-estimated amount of load diversity
- Would be useful to investigate Lessons Learned
- **Like the Indiana system, the ground loop in this District Geo System in a northern climate overheated.**

Lake Land College, Mattoon, IL
300 Acre Campus 7,400 Students
Goal: Self-Sustaining Campus



- Installed 3000 ft., 12 in. Central Circular Loop (2008)
- Phase 1 (2012) 240-ton GSHPs, 140 bores @ 350 ft., 2-100 kW Wind Turbines, 10 PV panels
- Projected savings: 850,000 kWh, 556 M-tons carbon, 70,000 therms natural gas
- 2014 Added PV arrays (2016 savings ≈ \$3000/month)
- 2016 Turbine Hit by Lighting & Removed, 2nd Turbine Performance Poor
- Board felt best success with PV and recommended additions
- Pleased with GSHPs but additions not apparent

Most Recent Lake Land Case Study

PROJECT HIGHLIGHTS

- Demand Control ventilation
- Building Automation System
- Natural Gas Boilers
- LED Lighting
- Mechanical Upgrades
- HVAC Controls
- Project Cost- $70,000,000
- Contract Term- 14 years

No mention of GSHPs

Investigation of Lessons Learned would be Prudent

https://secureservercdn.net/104.238.69.231/2p3.241.myftpupload.com/wp-content/uploads/2020/08/Lake-Land-College-Case-Study.pdf

How/Why Community Heat Pump Systems Can Be Better (or Just as Bad But Cost More)

Better

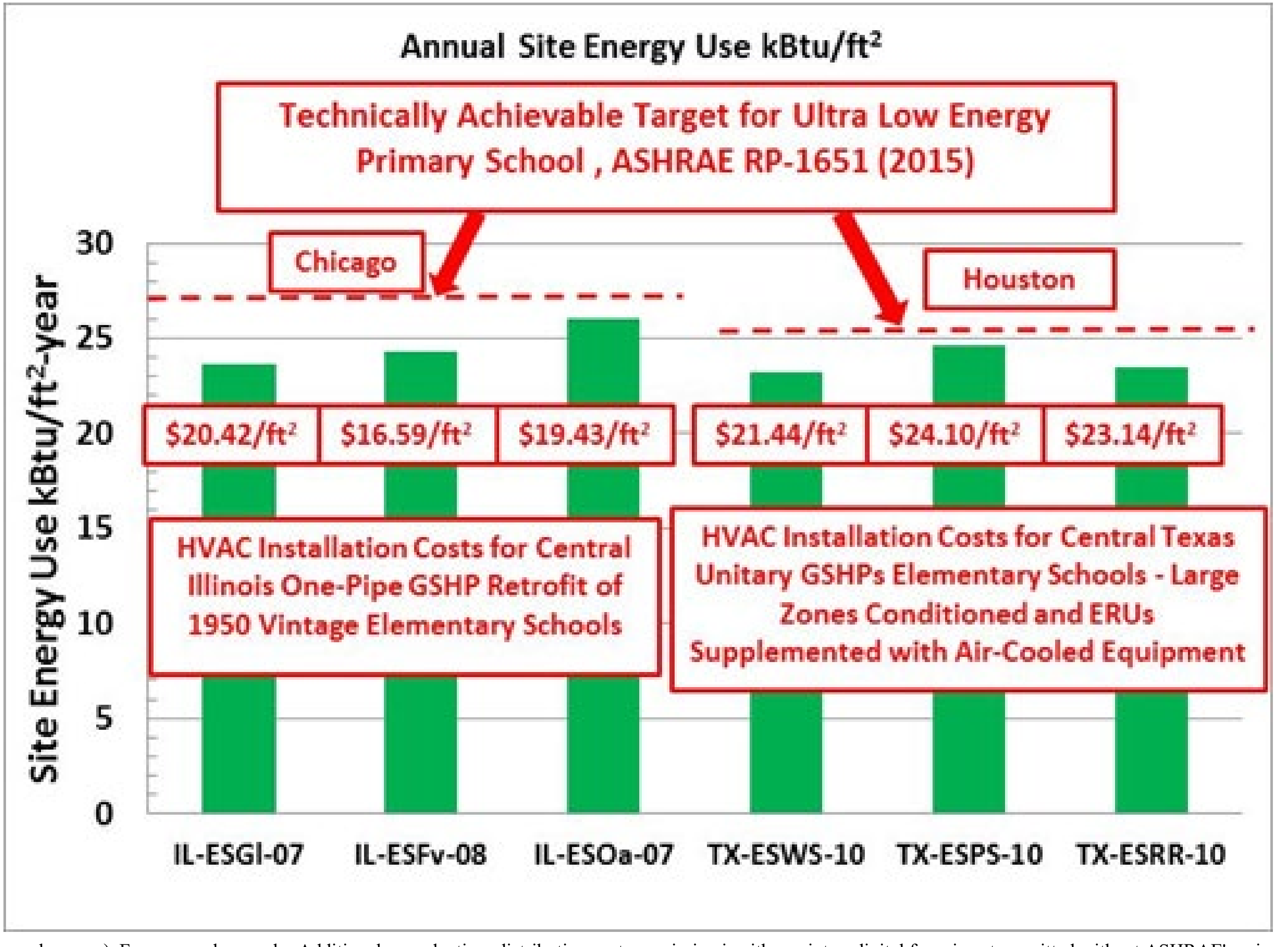
- Energy is Provided by the Ground, Surface Water, Ground Water, Waste Heat Streams
- Annual and Daily Loads are/or can be Reasonably Balanced
- Apply Concepts of Simplicity (30% of CBECS) GSHPs

As Bad or Worse

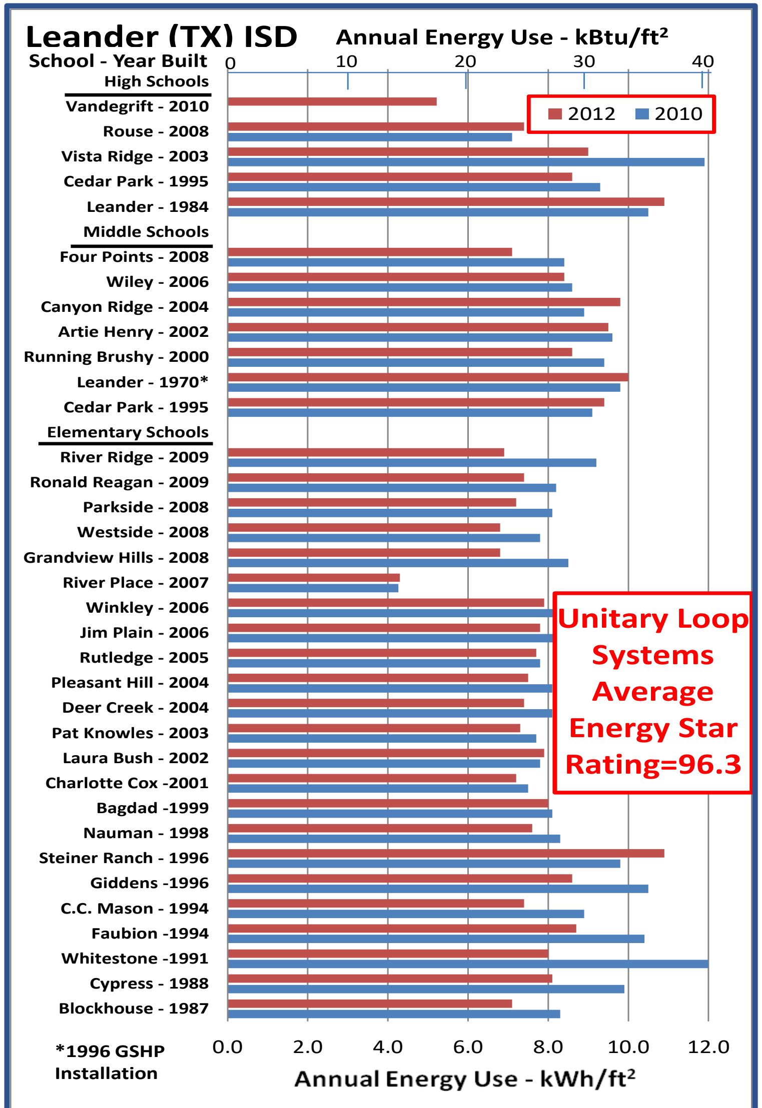
- Big Fans (AHUs) and Lots of Little Ones (FPVAV Terminals)
- Big Pumps and Lots of Them
- Controls that are Out of Control and Tech Support is Limited
- Highly Imbalanced Annual and Daily Loads
- Installed in Areas with Poorly Documented Existing Utilities

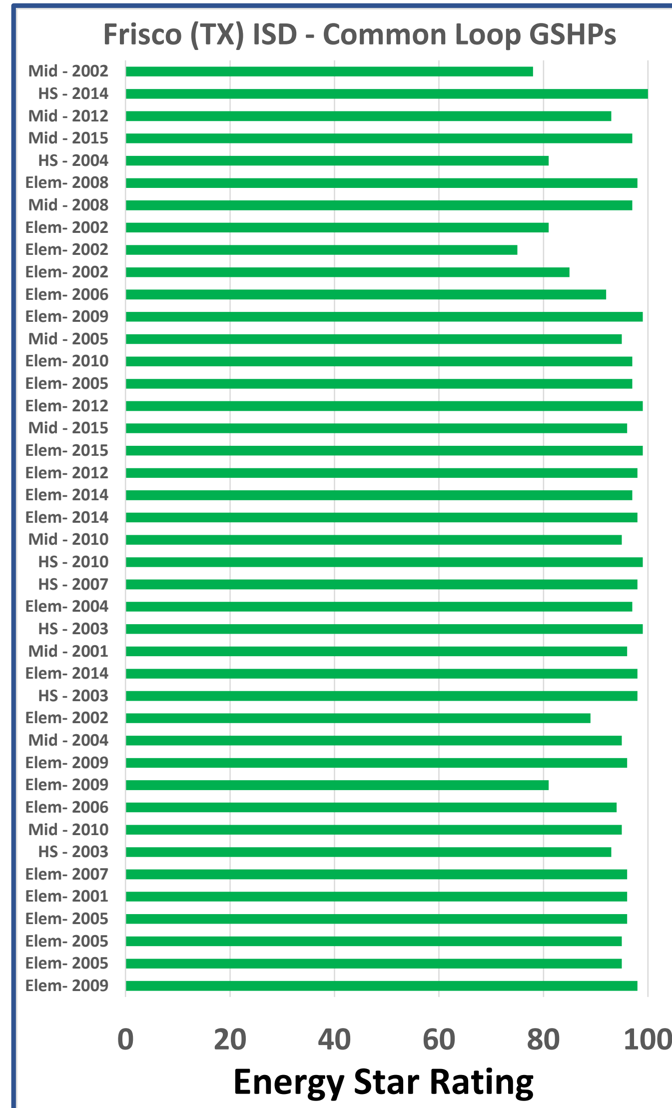
Outstanding GSHPs That Use 30% of CBECS Average

ASHRAE RP-1651: What is Possible If Cost not a Constraint? Already Achieved with Low Cost GSHPs Before the Project



Unitary and Common Loop GSHPs Energy Star

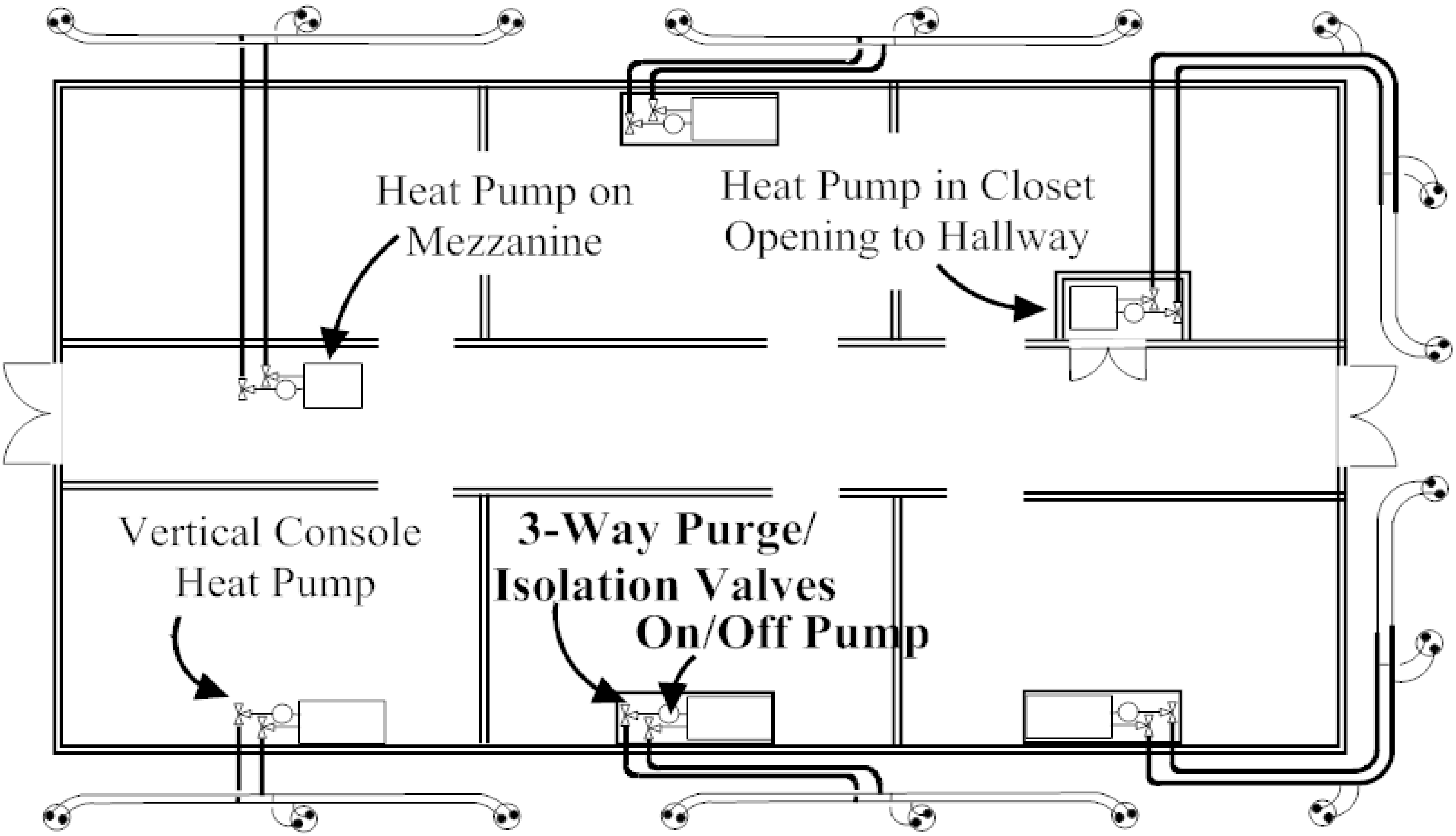




Impact of Quality Engineers and Contractors Lower Cost, Higher Efficiency - 286 GSHP Campuses

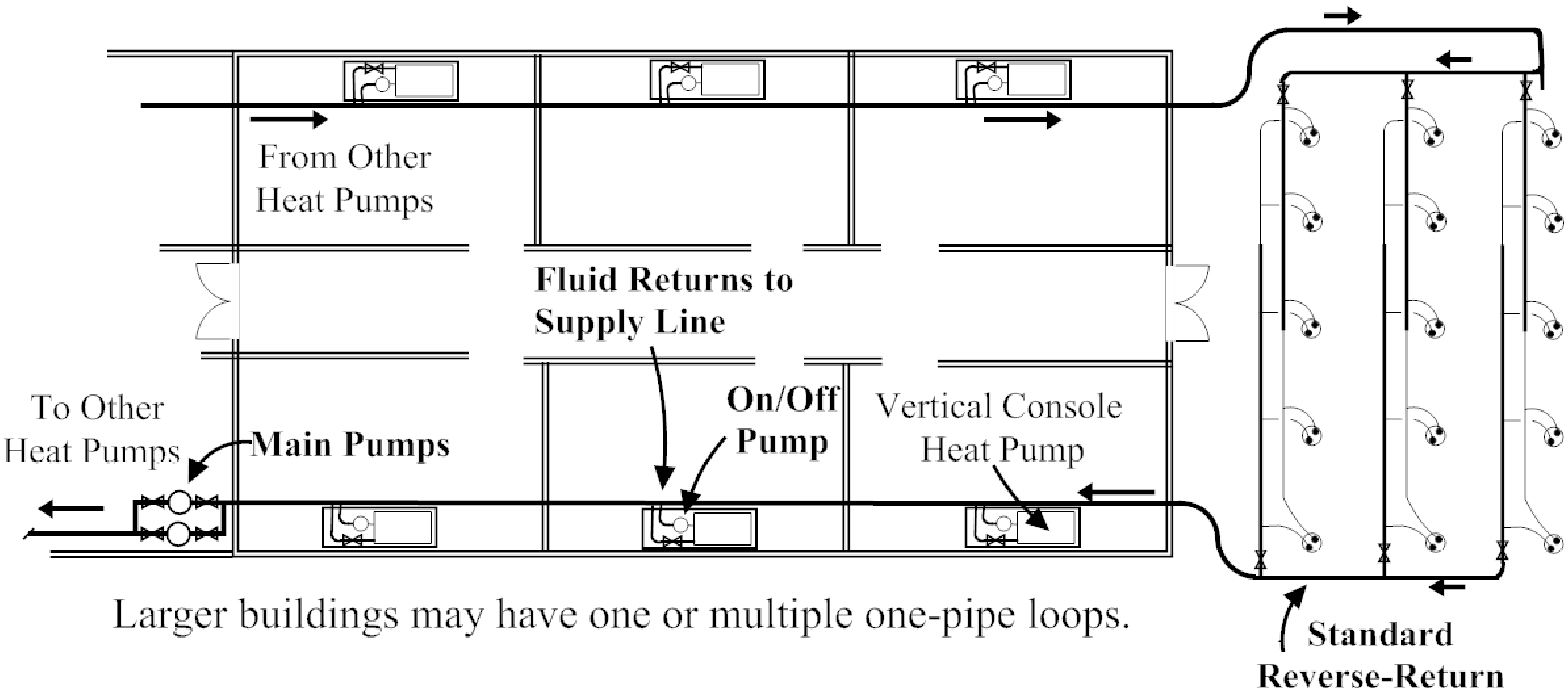
- **1. Frisco ISD, TX - 62 campuses**
- **2. Keller ISD, TX - 30 campuses**
- **3. Grand Prairie ISD, TX - 30 campuses**
- **4. Dallas ISD, TX - 26 campuses**
- **5. Fort Worth ISD, TX - 6 campuses**
- **6. Burleson ISD, TX - 6 campuses**
- **7. Mansfield ISD, TX - 20 campuses**
- **8. Eagle Mountain Saginaw, TX - 12 campuses**
- **9. Denton ISD, TX - 10 campuses**
- **10. Birdville IS, TX D - 32 campuses**
- **11. Carroll ISD, TX - 6 campuses**
- **12. Glynn County ISD, GA - 4 campuses**
- **13. Adams 5 Star district, CO - 2 campuses**
- **14. Washington Elementary District, AZ- 2 campuses**
- **15. Valley Stream #24, Long Island, NY - 1**
- **16. Georgetown ISD, TX - 4 campuses**
- **17. Liberty Hill ISD , TX - 4 campuses**
- **18. Gainesville ISD, TX - 1 campus**
- **19. Whiteface ISD ,TX - 2 campuses**
- **20. White Settlement ISD, TX - 1**
- **21. Allen ISD ,TX - 4 campuses**
- **22. Waxahachie ISD, TX - 3 campuses**
- **23. Lovejoy ISD, TX - 1 campus**
- **24. Azle ISD, TX - 1 campus**
- **25. Aledo ISD, TX - 1 campus**
- **26. Pflugerville ISD, TX - 1 campus**
- **27. Plano ISD, TX - 2 campuses**

Unitary (Distributed) Loop GSHP
Can This 25 kBtu/ft^2 Option be Integrated to CHP Systems?



One-Pipe Loop GSHP

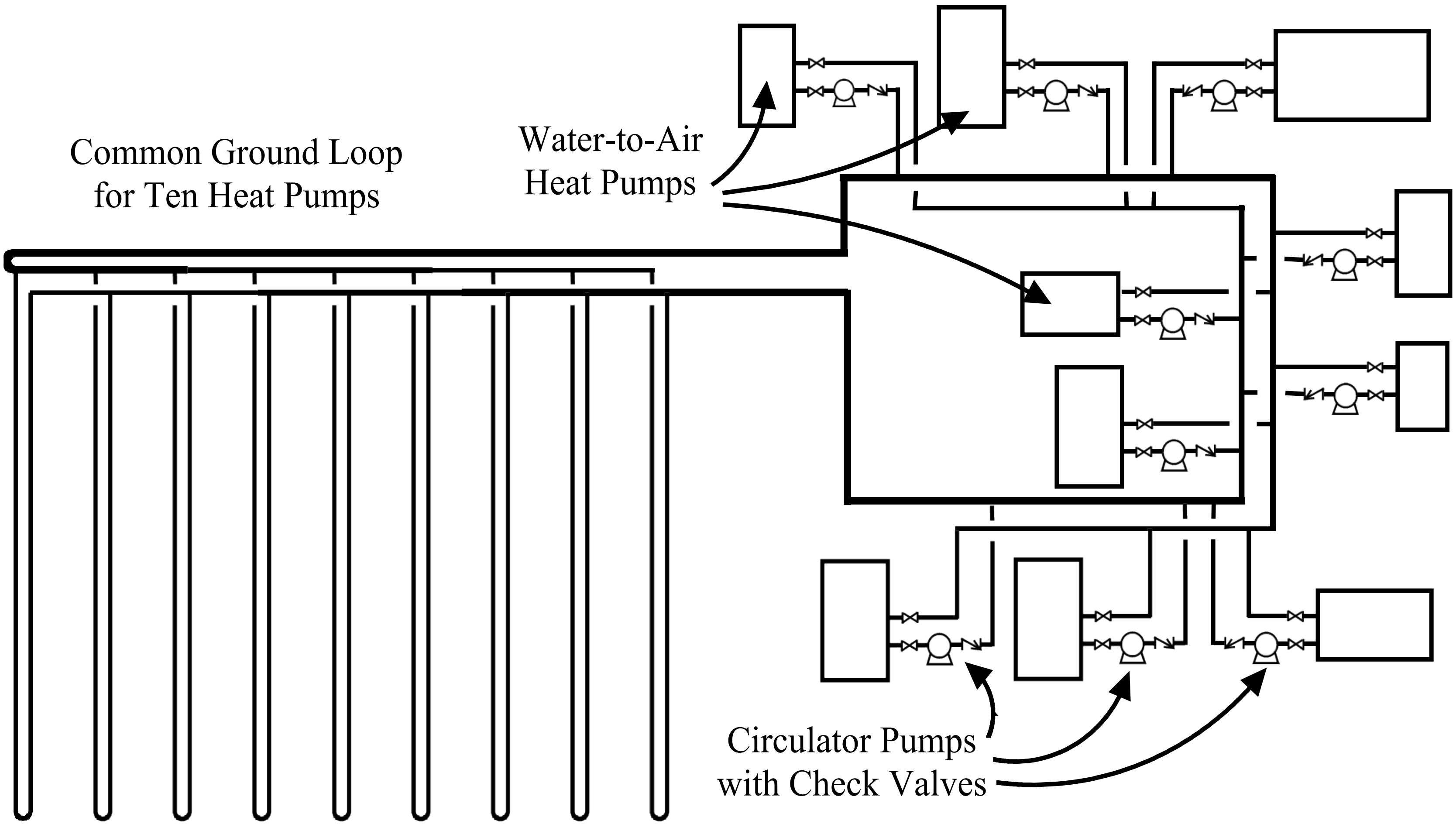
Can This 25 kBtu/ft^2 Option Be Integrated to CHP Systems?



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

Common Loop Loop GSHP

Can This 25 kBtu/ft^2 Option Be Integrated to CHP Systems?



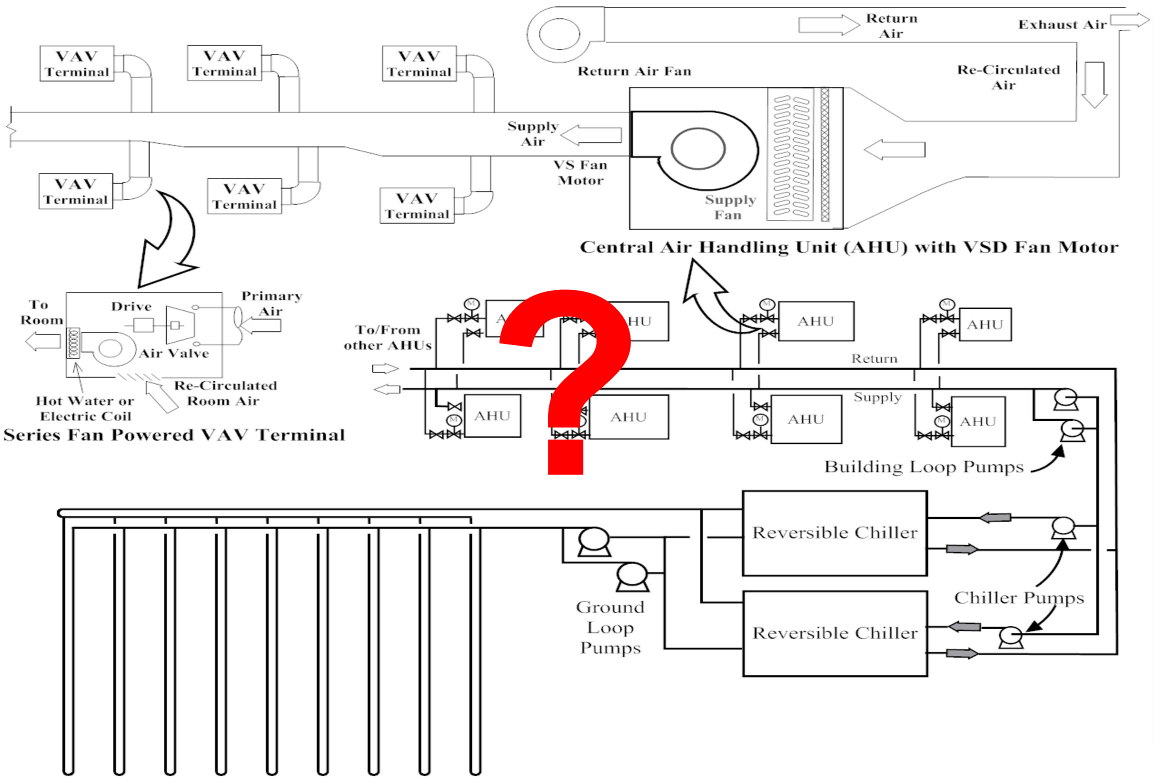
All the GSHP Systems in These Energy Star 90+ Rated Schools Are Simple Designs

- Simplicity Makes GSHPs Efficient, Affordable, Reliable
- No Variable Speed Heat Pumps
- No Digital Compressor Heat Pumps
- No Multi-Capacity Heat Pumps
- No Variable-Speed Pump Motor Drives
- ECM motors on newer heat pump fans but Leander techs dislike them (more expensive, more difficult to replace, and anecdotally fail more frequently)
- Controls are simple as possible because:

Frisco ISD has 72 buildings & 6 HVAC techs

Leander ISD has 72 buildings & 6 HVAC techs

Chilled/Hot Water VAV Connected to Ground Loop CBECS Data Indicate This Type of System on Average Consumes Over 100 kBtu/ft^2



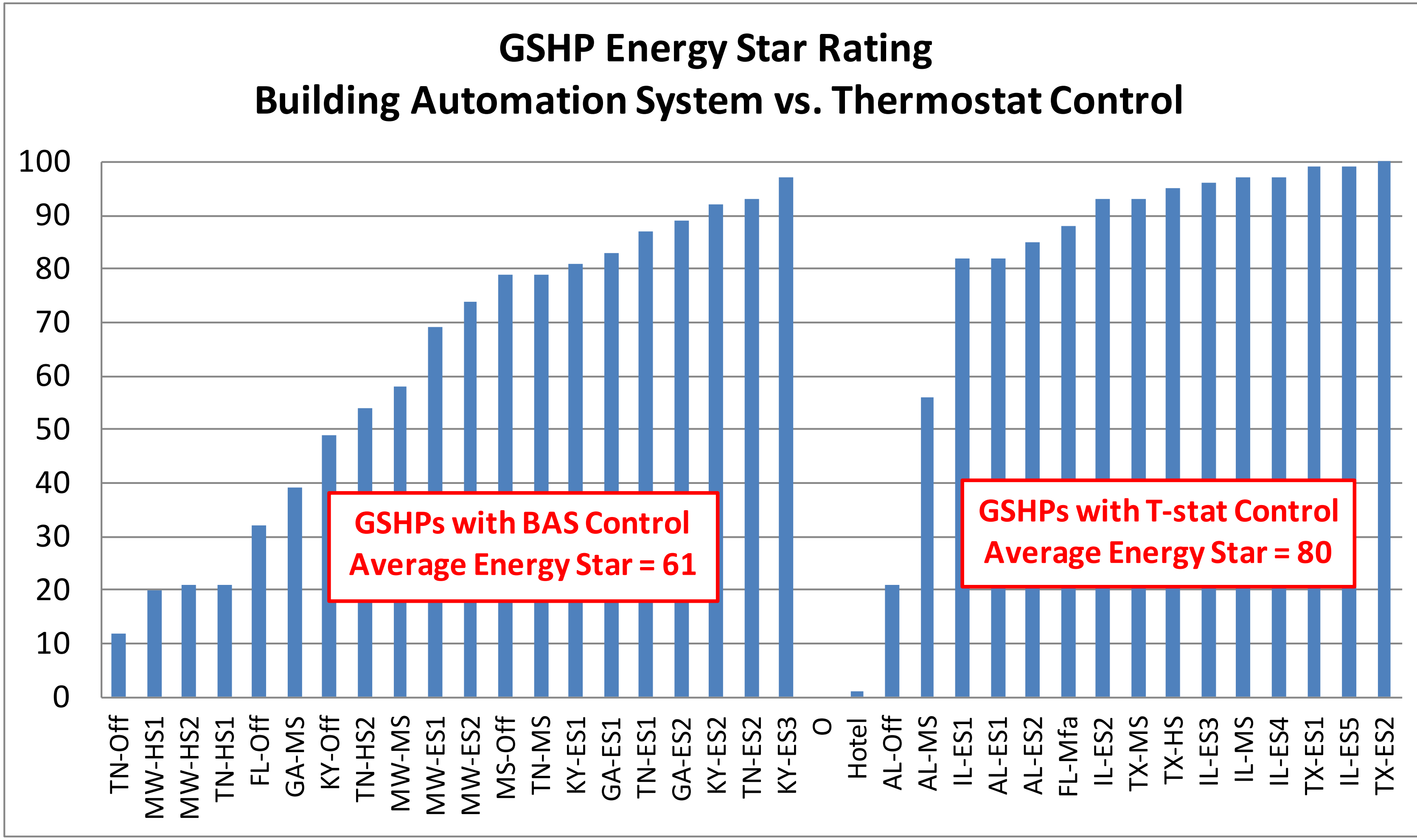
- Lots of Fans and Pumps means:
- High Installation Costs
- Low Energy Star Rating
- Complex Control and Maintenance
- Popular with Novice GSHP Engineers and Equipment Vendors
- EERs less than Window Air Conditioners

For a GSHP System to Be Efficient, the HVAC System Must Be Efficient.

For a GSHP System to be Affordable, the HVAC System Must Be Affordable.

HVAC Standards don't recognize that cost, kW and kWh are additive.

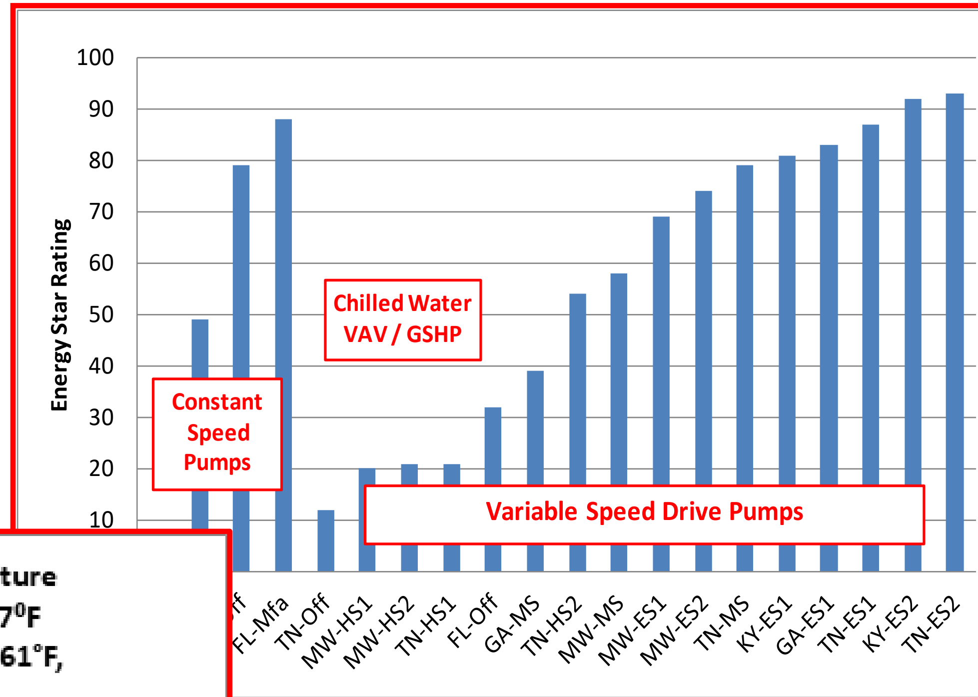
Long Term GSHP Performance Field Study Impact of Controls

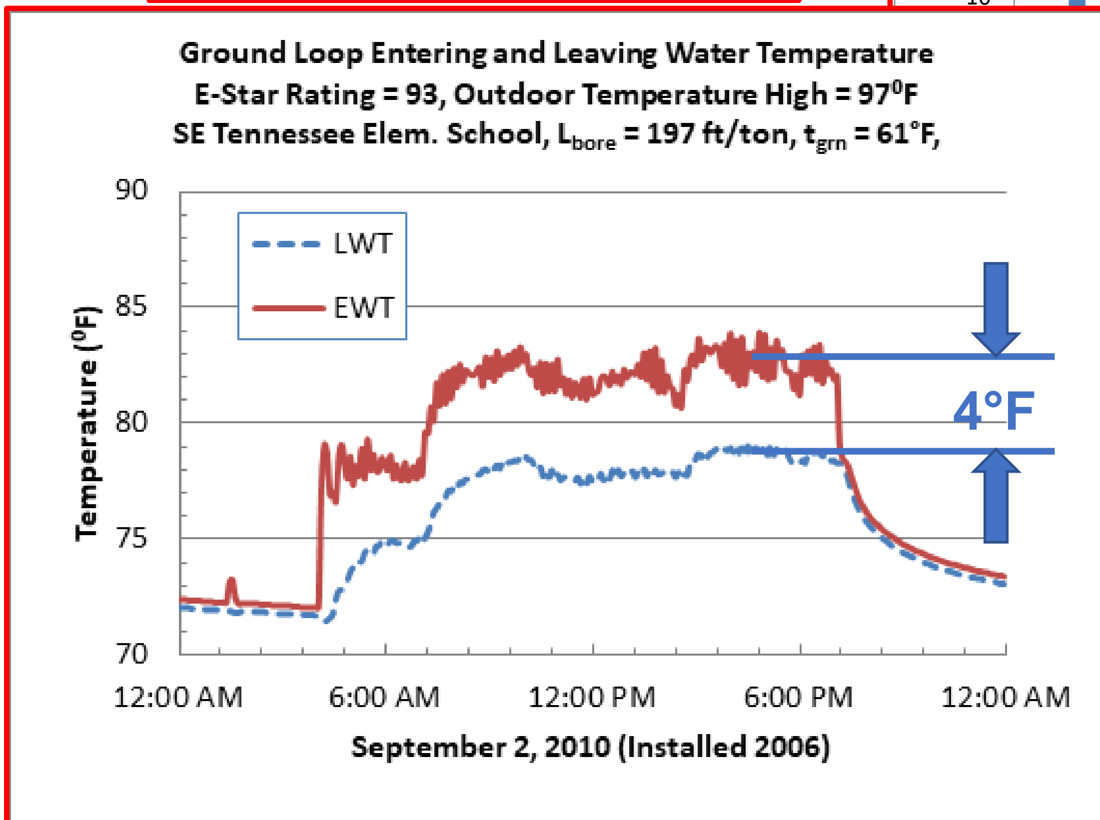


http://geokiss.com/wp-content/uploads/2018/06/LongTermGSHPsPt2.pdf

Long Term GSHP Performance Study Variable Speed Drives

Controls Need Continuous TLC to Function Well





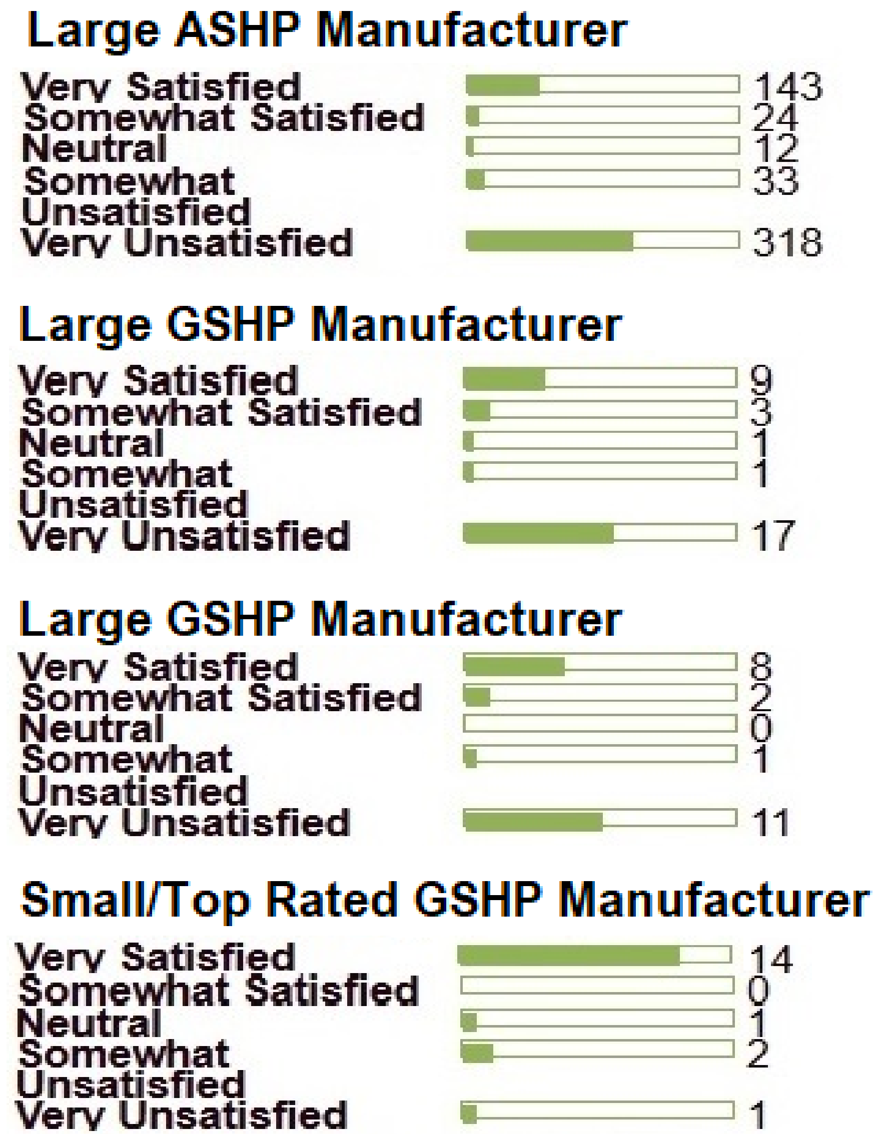
Variable Speed Drives Performed No Better Than Constant Speed

Δt at Design Load = 4°F Pumps Grossly Oversized and DP Sensor Ports Plugged or Misplaced

Loss of Quality 1960 -70 US Cars and 2020 HVAC?

Chevrolet Vega

- **Introduced in 1970**
- **By May '72, 6 out of 7 recalled**
- **Ran hot, 6 qt. coolant capacity**
- **Oil burner via valve stems, distorted cylinders**
- **Defective axles, balky throttles, problems causing fires**
- **"Car that nearly destroyed GM" (Popular Mechanics)**



Source: Furnace Compare

Does Complexity **Lead to** Dissatisfaction?

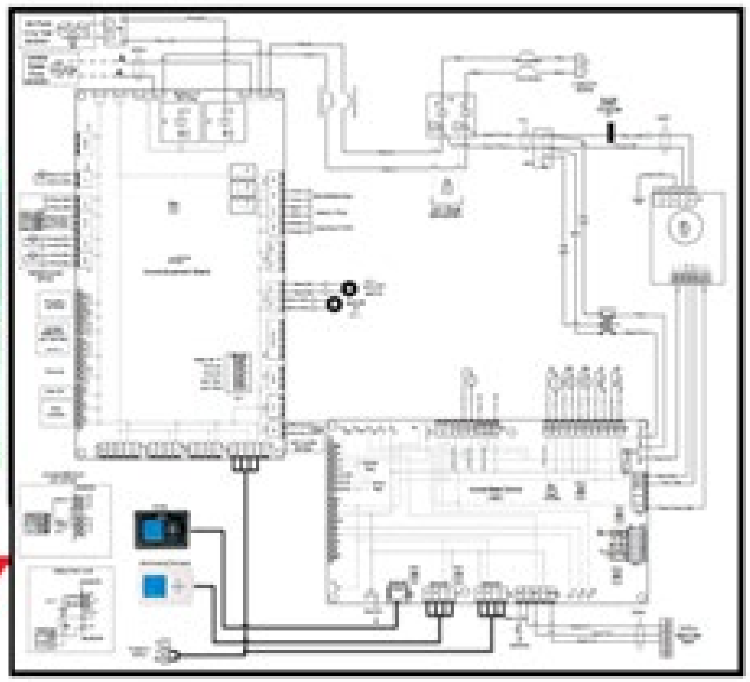
Variable –Speed Water-to-Air Heat Pump Control Circuit, Page 1 of 7

Control Circuit Single-Speed Water-to-Air Heat Pump Small/Top Rated GSHP Manufacturer

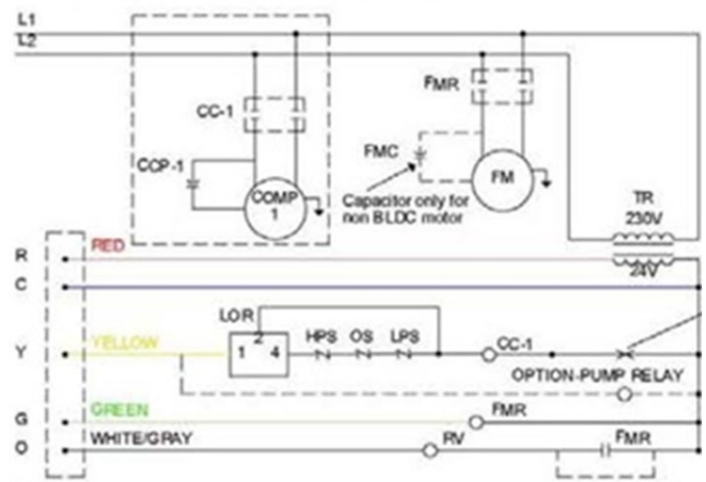
Variable Speed WAHP Controls

Main Control Boards

Wiring Schematics (Page 1 of 7)



Single Speed WAHP Wiring Diagram - Horizonal Unit

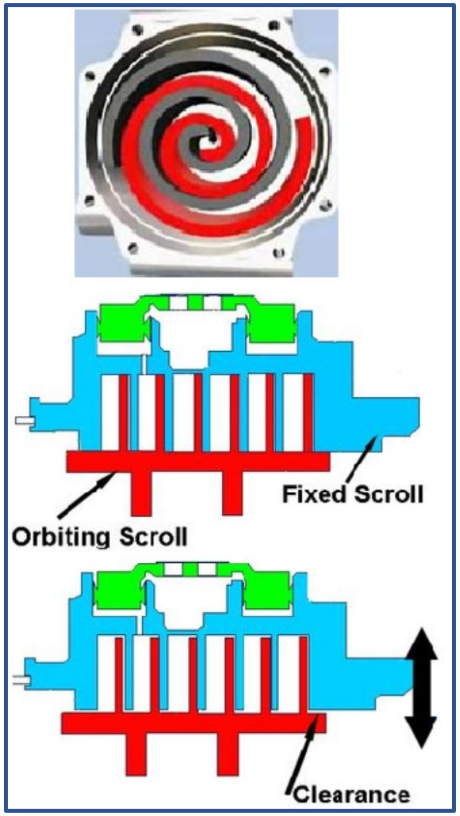


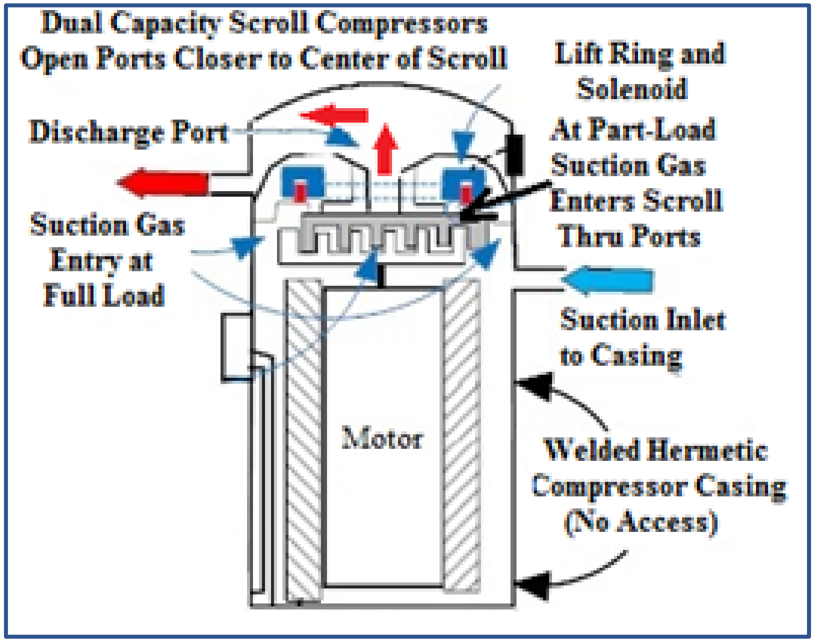
All components non-proprietary, locally available, and typical stocked in service vehicles. Compatible with off-the-shelf thermostats.

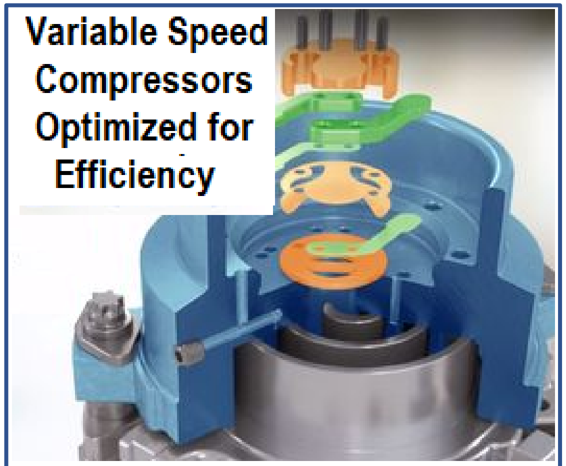
Advanced Technology Compressor Heat Pumps

A digital scroll compressor has both orbital motion and up and down movement (modulation). Will it last a long as conventical long-life scrolls?

- Are more expensive
- More difficult for a $25/hour technician to service
- Contain additional components inside the sealed hermetic casing
- Proprietary circuit boards often not available locally and/or after warranty period expires
- More likely to require service/earlier replacement than single-speed scroll compressors



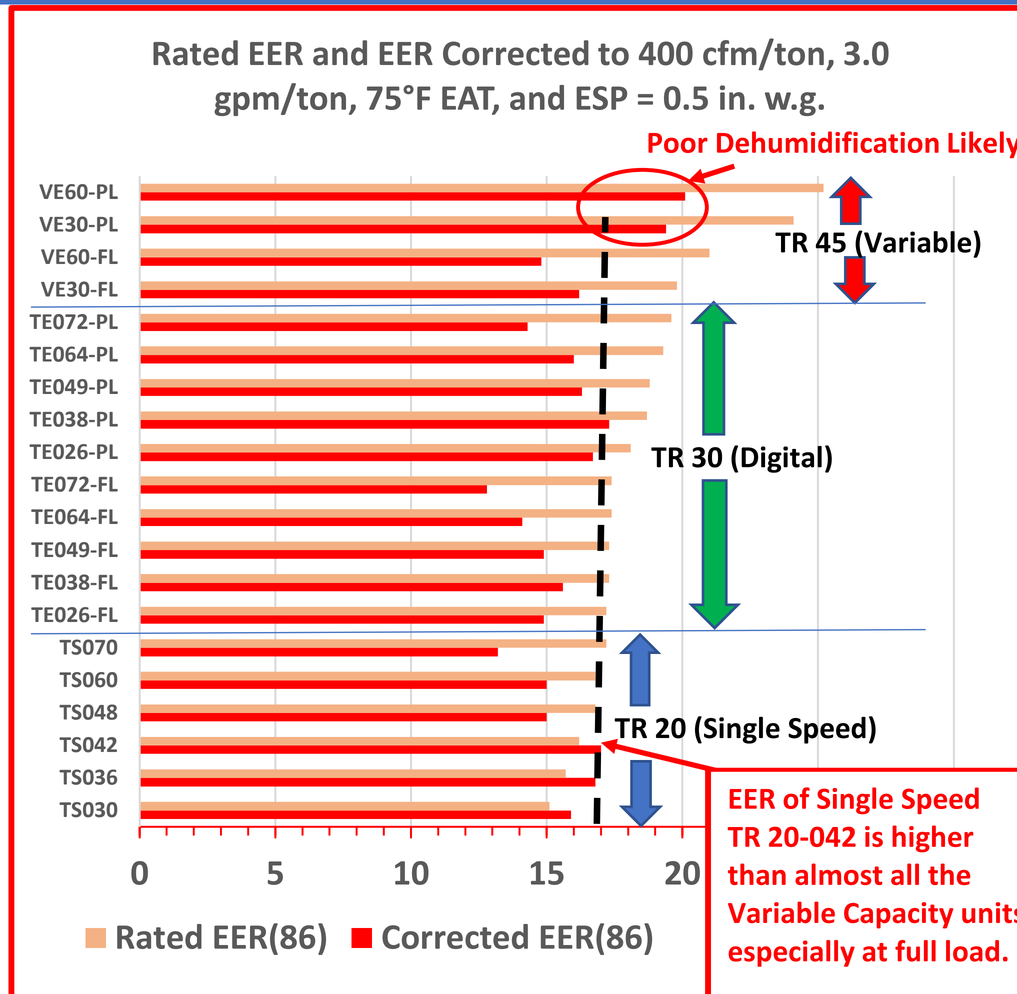




- Operate at Higher Speeds
- HVE Valve
- Intermediate Discharge Valve
- Postive Displacement Oil Pump

Simple, single-speed units have the equal efficiencies to multi- and variable-speed units when air and water flow rates are equivalent, power to distribute air and water is included, and entering air conditions corrected.

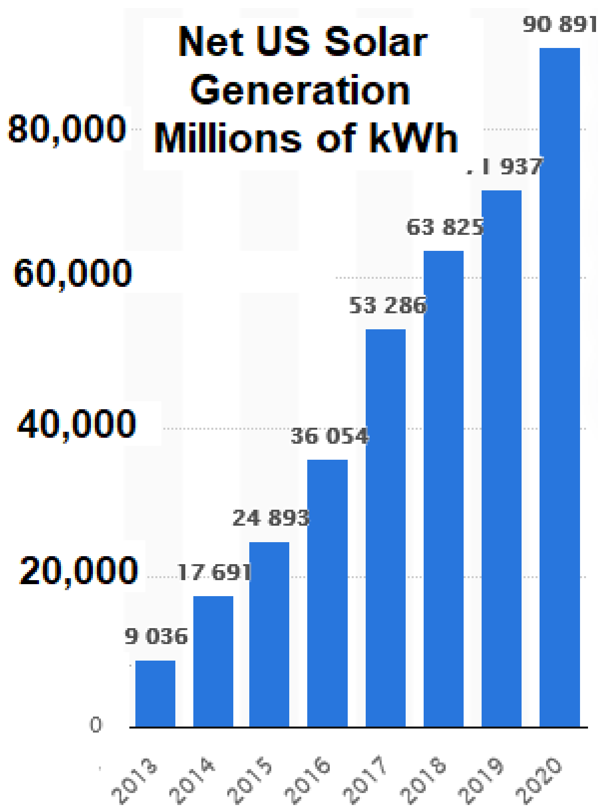
Details Presented in Webinar 8

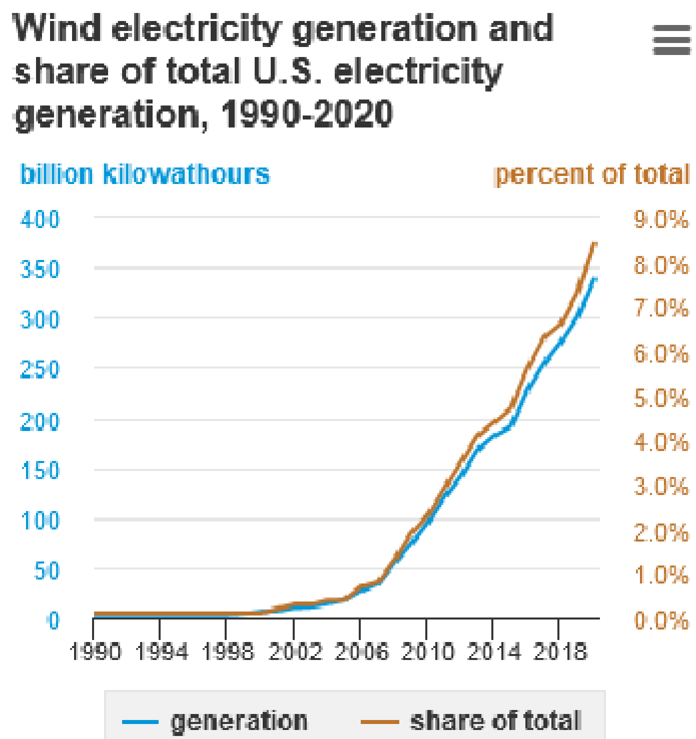


Where Can Community GSHPs Make Sense

- In applications with very high diversity (i.e. ice rink in a community with high heating load, buildings with large water heating loads when cooling load is dominant, server rooms in cold climates)
- In applications where conditions provide a substitute for a large ground loop (flooded mine, deep lake, waste heat stream, shallow abundant ground water, etc.)
- Buildings in close proximity with simultaneous heating and cooling
- Integrated with local solar PV grids that can also provide long term GSHP energy balance in colder climates
- Integrated with local wind energy generators that minimize utility distribution cost (micro-grids)

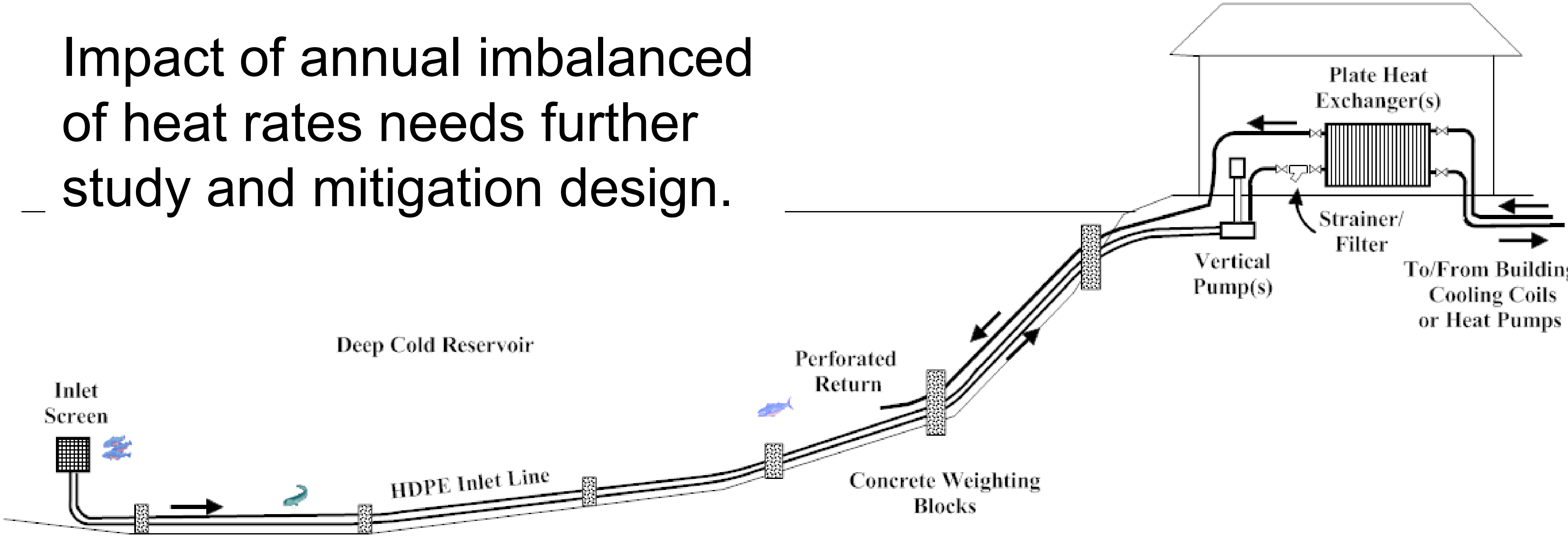
Integrating Community GSHPs with Renewable Energy





District Open Loop in Deep Reservoirs or Seawater
(Heating Operation Very Limited with Deep Reservoirs*)

Impact of annual imbalanced of heat rates needs further study and mitigation design.

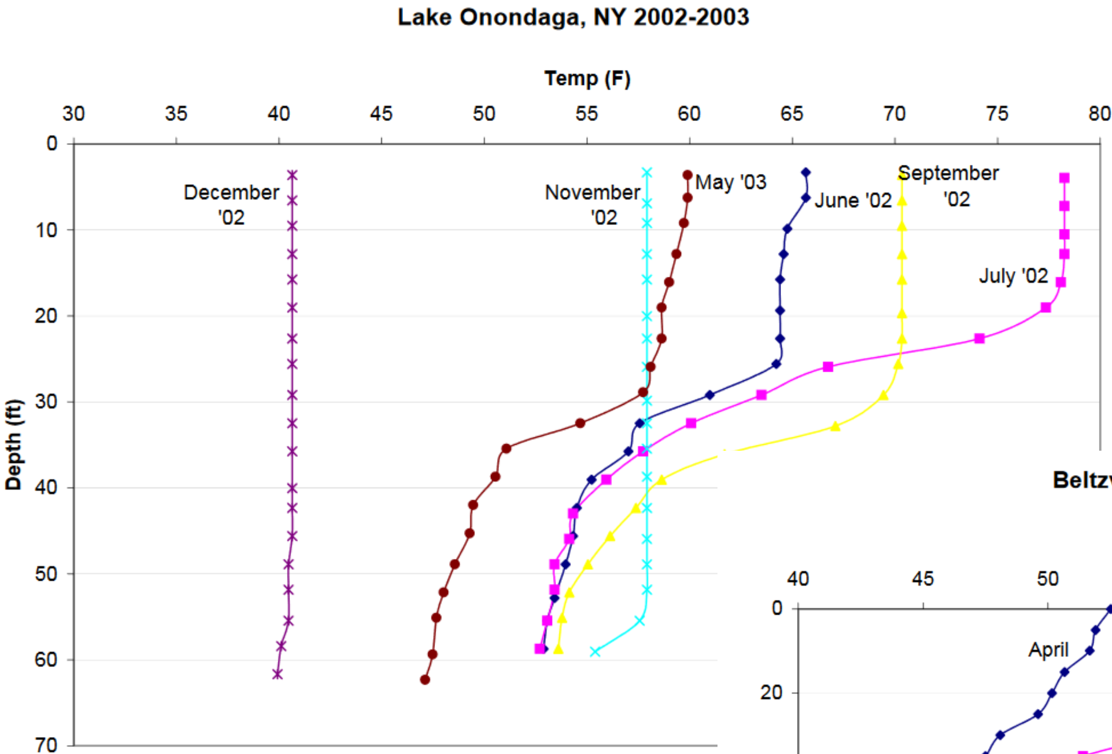


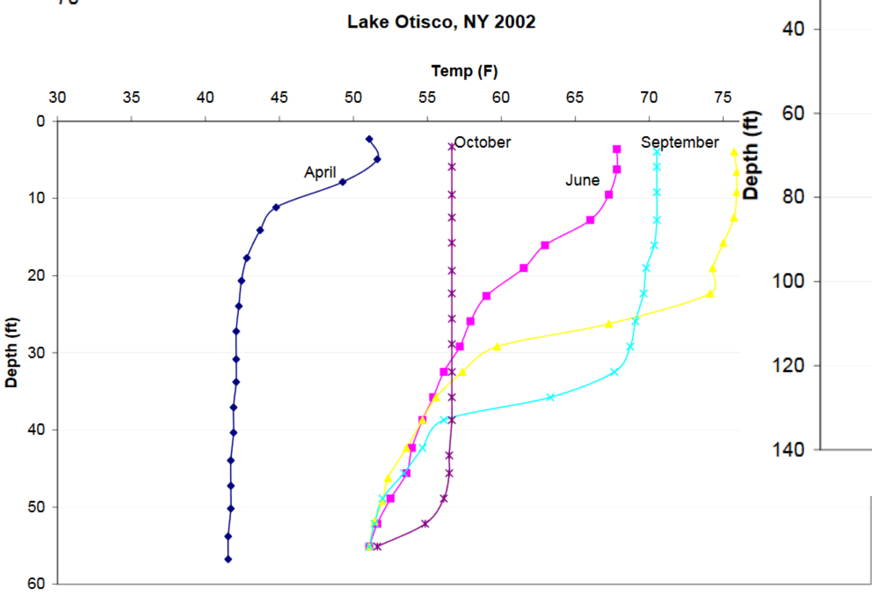
*** In heating for open loop surface water heat pumps:**

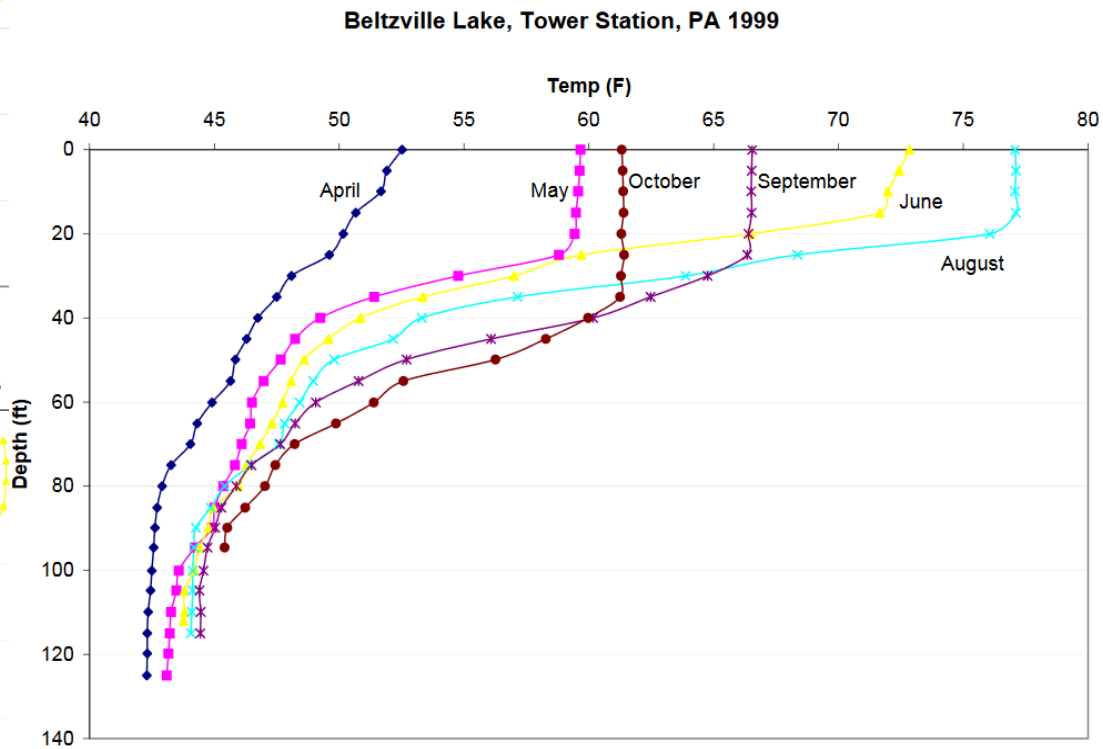
- **Coil Leaving Water Temperature (°F) ≈ Entering Water Temp (°F) – 18 ÷ gpm/ton (For EWT = 39°F: LWT = 39°F – 18/3 = 33°F)**
- **LWT must be 3°F to 5°F (1.5 to 3 °C) above 32°F (0°C) to prevent frost on water coil**
- **Thus, minimum EWT must be at least 42°F (6°C), which does not occur in many lakes.**

Northeast Lake Temperatures

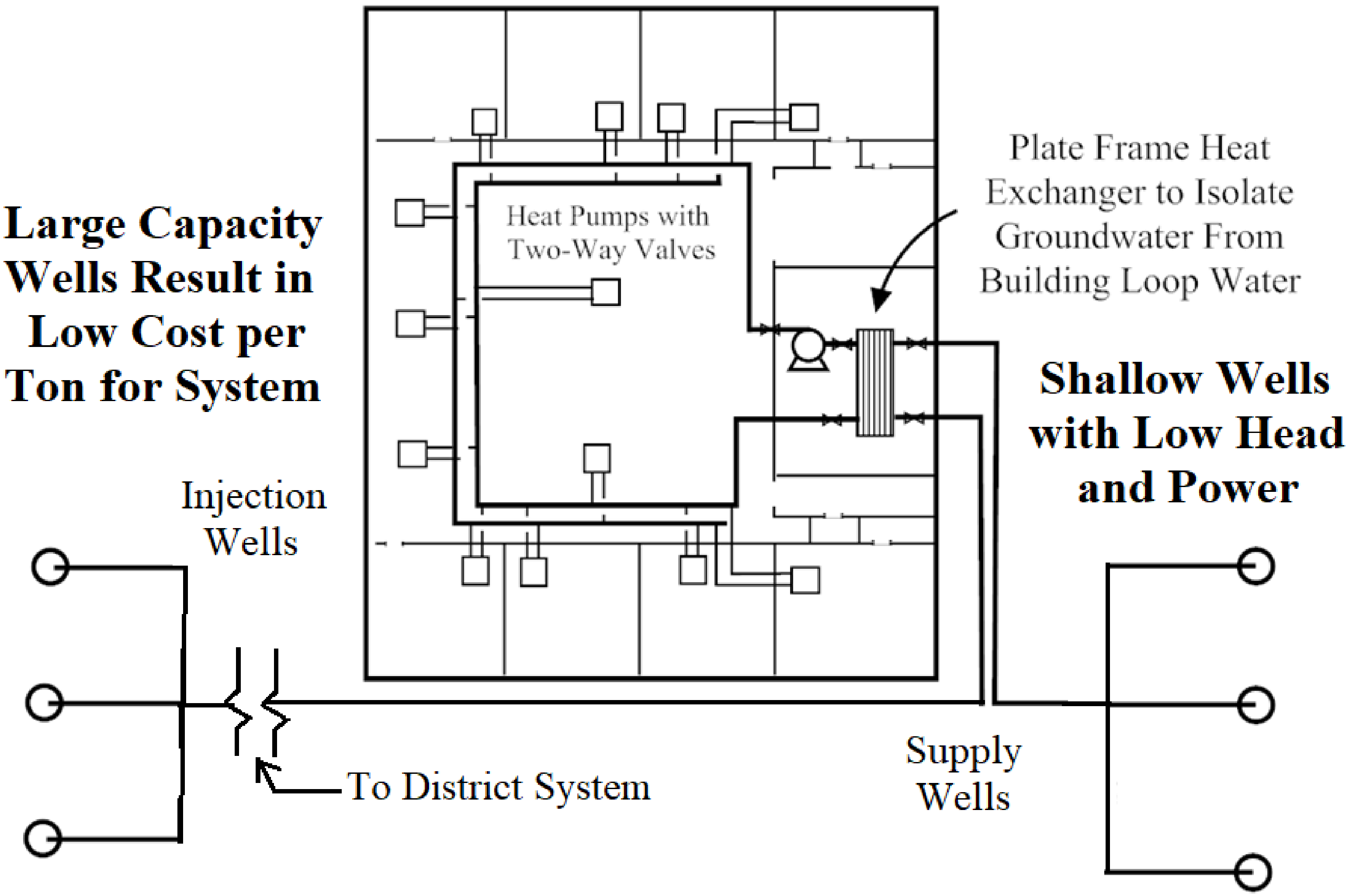
http://geokiss.com/wp-content/uploads/2018/07/Lake_Onondaga_NY.pdf







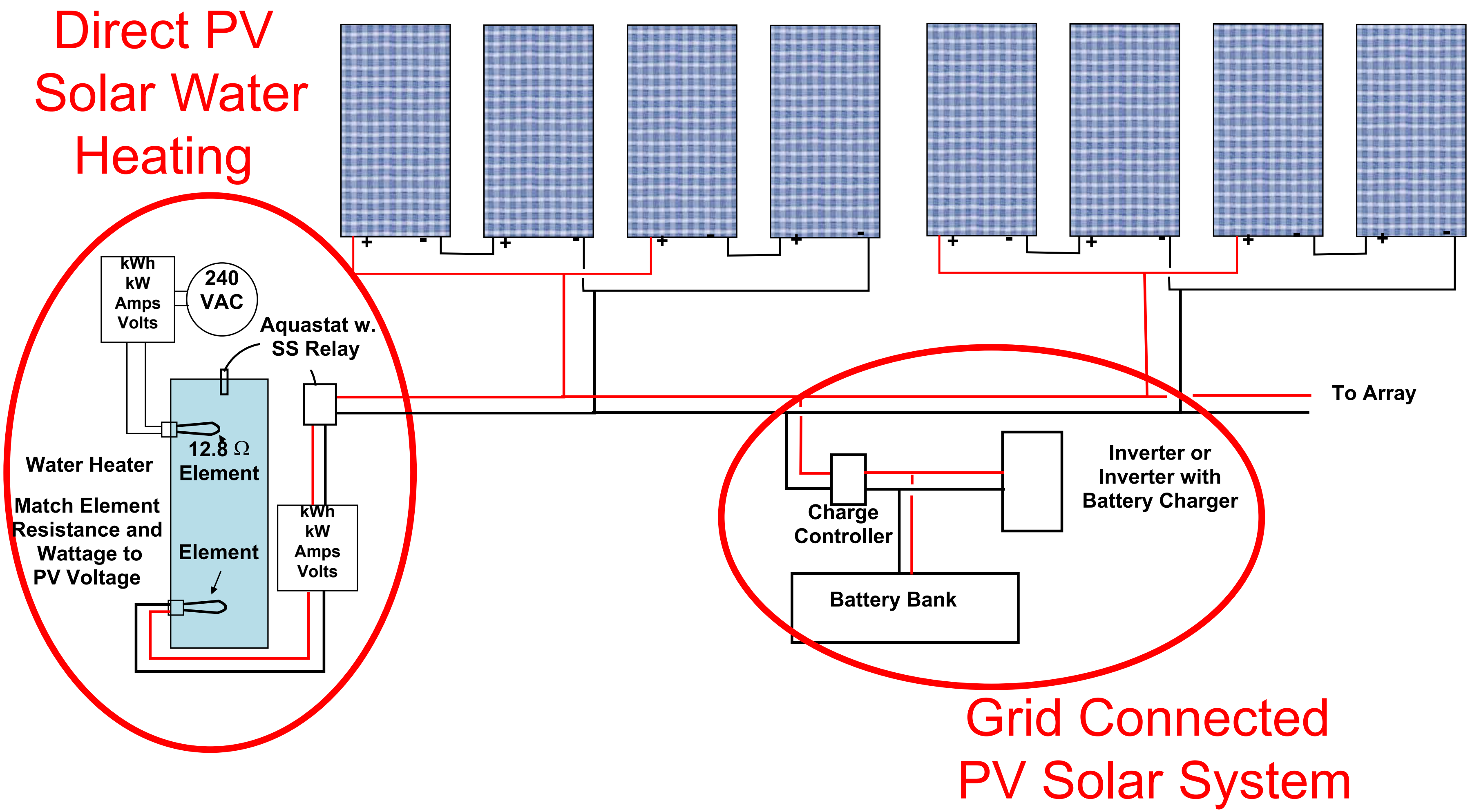
District Energy Shallow Groundwater Heat Pump (or Flooded Mine Water)



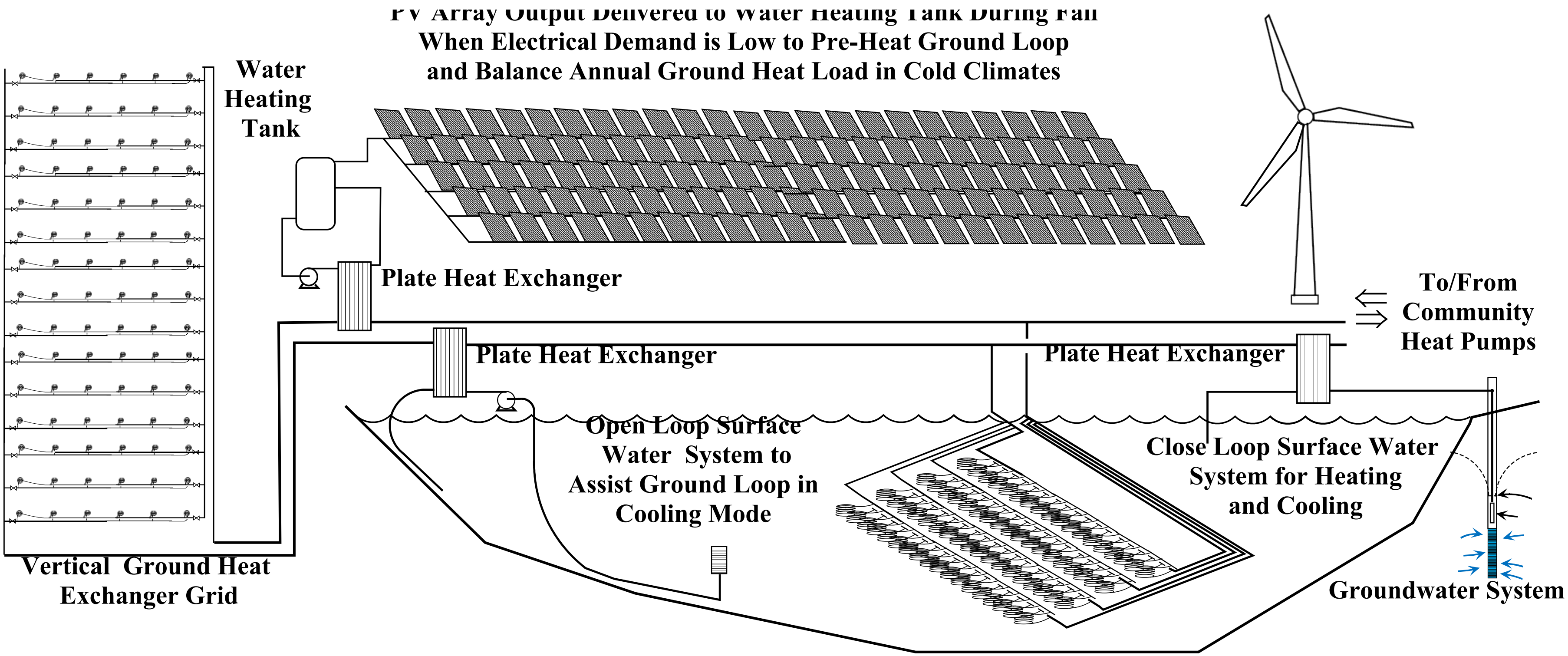
Water Heating to Balance Heat Loads

- In cooling mode dominant CHP systems, generate water heating requirements with loop heat pumps
- In heating mode dominant CHP systems, generate water heating requirements with direct solar PV and
- Use excess direct solar PV output to heat water to supplement ground loop temperature

Direct PV Solar Water Heating
Lower Cost – Higher Efficiency in Cold Climates



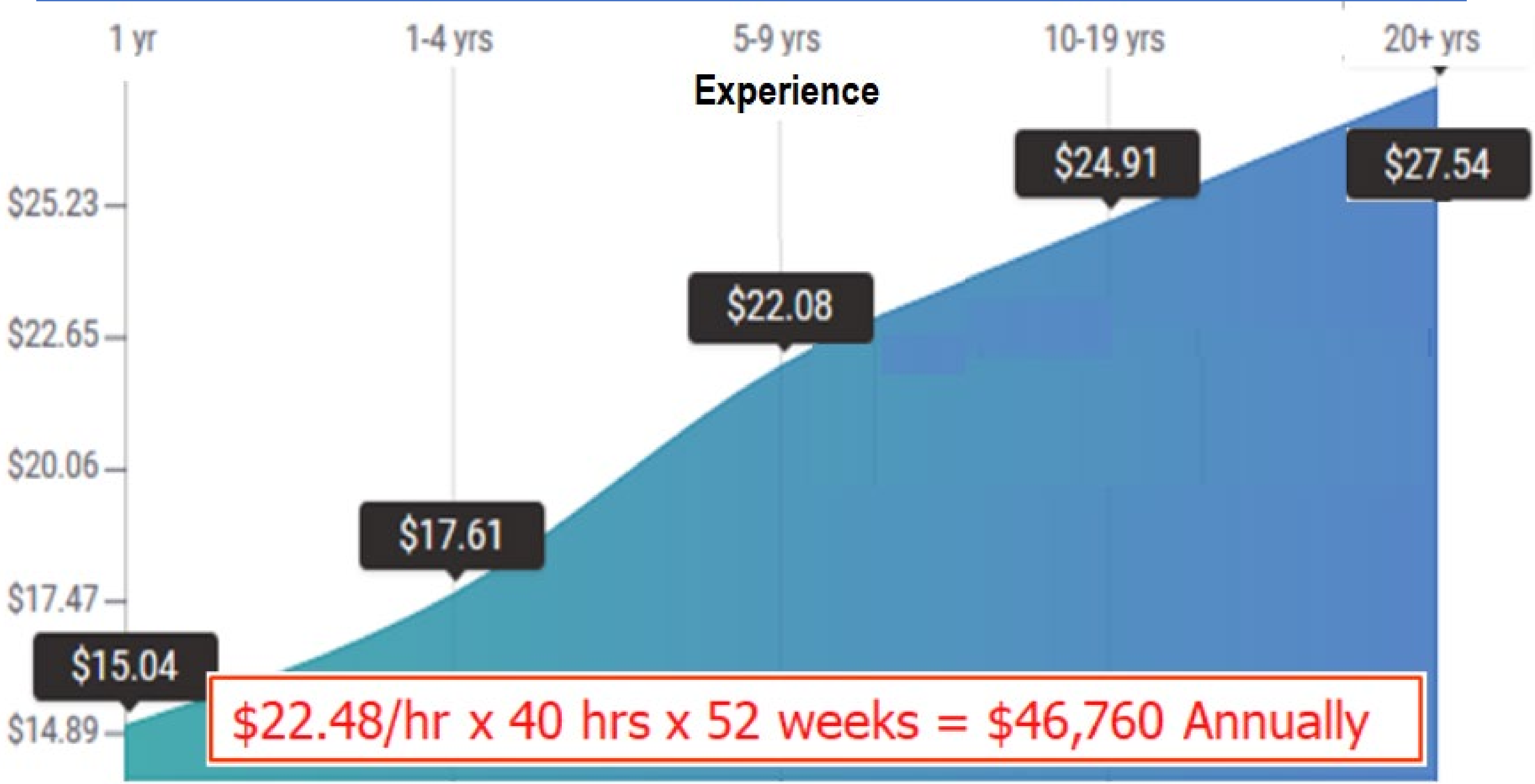
Unless Extreme Diversity is Available, the Cost of a Circuiting a Stand-Alone Ground Loop Will Likely Costs More Than Multiple Individual Loops.



Nature May Offer Alternative Sources That Make Community Heat Pumps Viable

A Challenge - Base Pay for Technicians

Techs capable of servicing complex controls and equipment will command more than $25/hour.



A Challenge – Cost of Installing Large Central Headers May Offset Savings of Reduced Vertical Loop Lengths

State	No. Bores	Depth (ft.)	Vaults	Vert. Loop-$/ft.	Total-$/ft.	**Header Cost**
KY	220	300	1	$3.65	$6.22	41%
KY	126	300	3	$3.27	$9.22	65%
IA	160	290	1	$5.09	$8.98	43%
IA	240	204	1	$4.21	$7.72	45%
TN	286	240	1	$4.80	$8.19	41%
TN	144	300	2	$4.45	$7.61	42%
NY	150	300	0	$5.55	$9.98	44%
IN	152	300	1	$5.70	$10.55	46%
TN	486	250	0	$3.70	$7.96	54%
TN	176	300	0	$4.50	$8.41	46%
MI	50	300	0	$4.95	$9.65	49%
NE	416	330	1	$4.40	$8.74	50%
KY	?	?	5	$6.90	$11.84	42%
IN	?	?	0	$4.65	$9.16	49%
TN	230	300	0	$6.50	$10.95	41%
Averages				**$4.82**	**$9.01**	**47%**

Reference: Development of Guidelines for the Selection and Design of the Pumping/Piping Subsystem for GCHP Systems (ASHRAE RP-1217) Final Report 2003

A Challenge – Assembling Qualified Design Teams

- A recipe for disaster: Selecting large engineering and architectural firms with minimal **documented** GSHP success for the design of the building HVAC and envelope and a secondary (subservient) firm for design of the exterior GSHP heat exchanger system.
- It is difficult to find firms with adequate resources to provide optimal designs for both the building HVAC and exterior heat loop.
- A community heat pump system adds a third area of required expertise, the district loop.
- In my 40+ years of investigating underperforming GSHPs, the HVAC system is more often the primary reason for poor outcomes rather than the exterior heat exchanger (sometimes it is both).
- Through vetting of design teams that demonstrate past successful larger GSHP projects is essential.

Conclusions

- In some cases, district GSHPs have been applied with less than expected performance.
- It is prudent to expand critical investigations of other district GSHPs in order to determine when and where community heat pump systems are viable.
- It is prudent to accurately determine building heat load diversity and **SYSTEM** EER and COP including all components.
- Simple, well designed GSHP systems have been operating at annual site energy use of less than 30 $kBtu/ft^2$ with lower installation costs than some conventional HVAC systems.
- District GSHP systems have a challenge to match the cost and performance of simple distributed loop systems unless large heat load diversity, central heat sink/sources, and/or alternative energy resources are available.

Join us for the next webinar in the series:

- Date: January 12, 2022
- Topic: What is the System Efficiency of a Community Heat Pump System and How it is Calculated?

Register at https://www.ashrae.org/CHPSWebinars

NYSERDA Resources

- Funding Opportunity PON 4614
- Fact Sheets of Prior Winners at PON 4614
- List of Solution Providers focused on this Marketplace
- Report regarding Regulatory Issues affecting this Marketplace
- Please see www.nyserda.ny.gov/district-thermal-systems

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