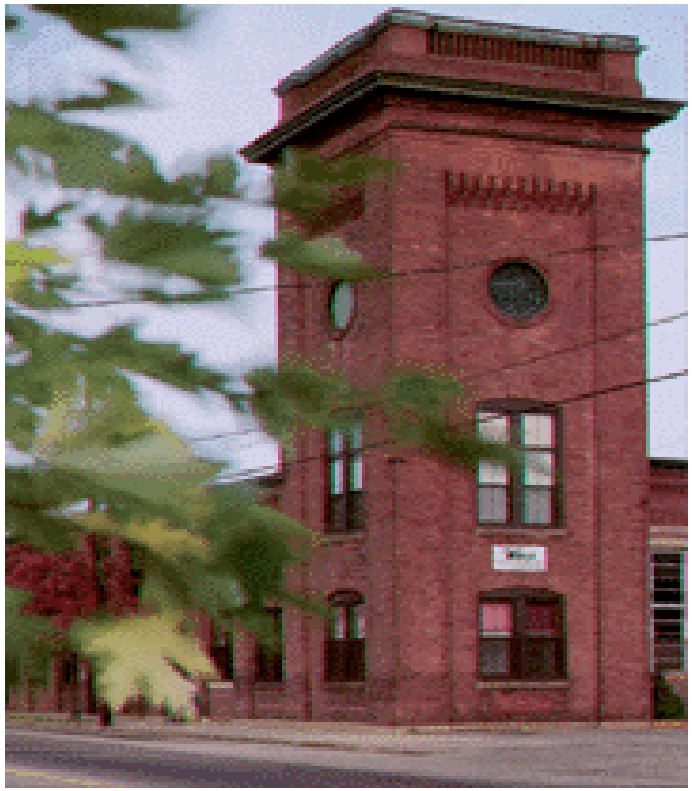

The Solutions Company

HVAC System Efficiencies

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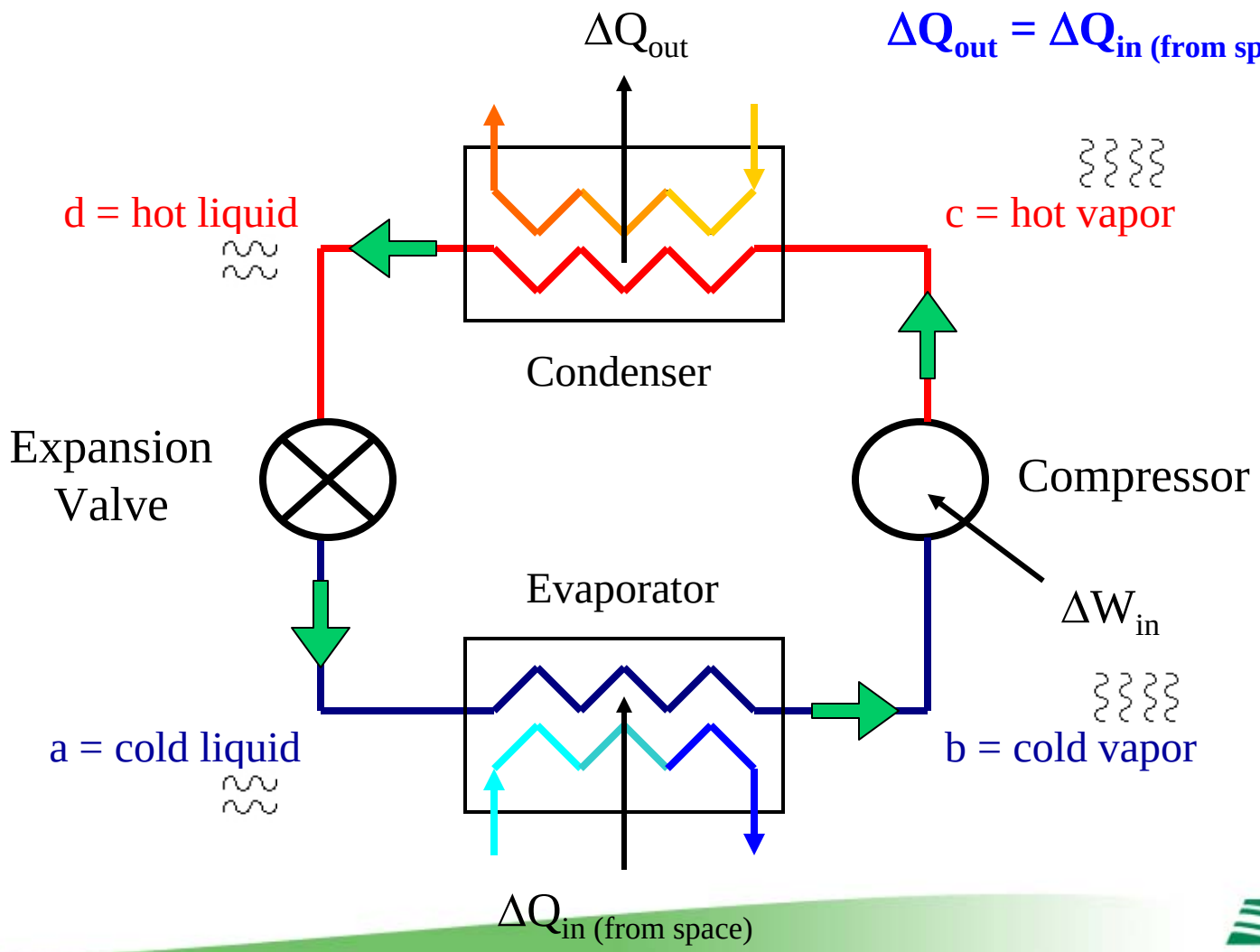
1st Law of Thermodynamics

- **1st Law of Thermodynamics**
  - **Stuff in – stuff out = stuff left**
  - **$(\Delta Q_{in} + \Delta W_{in}) – (\Delta Q_{out} + \Delta W_{out}) = \Delta E$**
    - **Where ΔE = Change in Energy**
    - **ΔQ = Change in heat**
    - **ΔW = Change in Work**
  - **For a closed cycle (power or refrigeration)**
    - **Stuff left = 0 or Stuff in = Stuff out**
    - **$\Delta E = 0$ or $\Delta Q_{in} + \Delta W_{in} = \Delta Q_{0out} + \Delta W_{out}$**

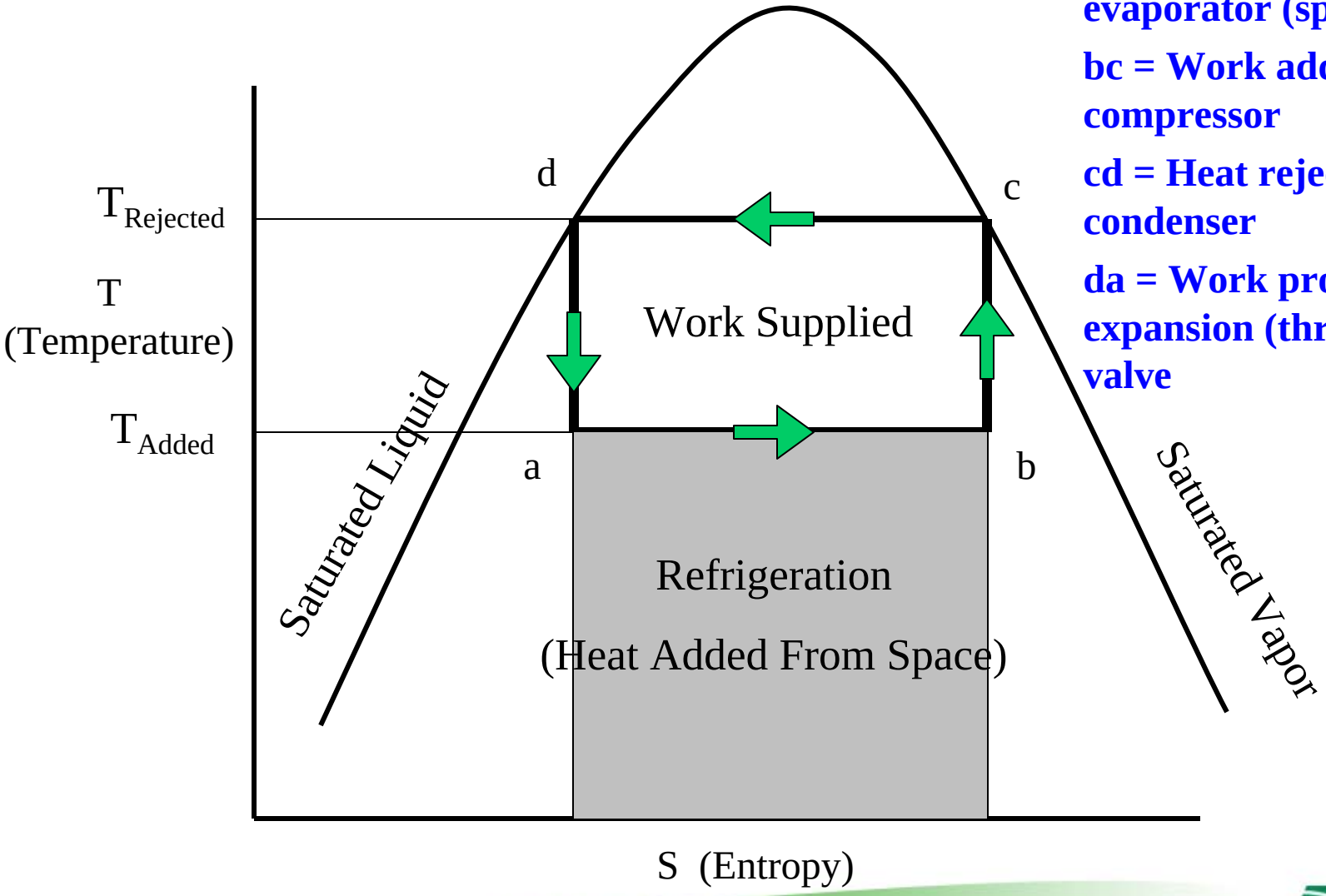
Refrigeration Cycle Flow Diagram

For Process:

$$\Delta Q_{out} = \Delta Q_{in\ (from\ space)} + \Delta W_{in}$$



Carnot Refrigeration Cycle



ab = Heat added from evaporator (space)

bc = Work added by compressor

cd = Heat rejected by condenser

da = Work produced by expansion (throttling) valve

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1st Law of Thermodynamics

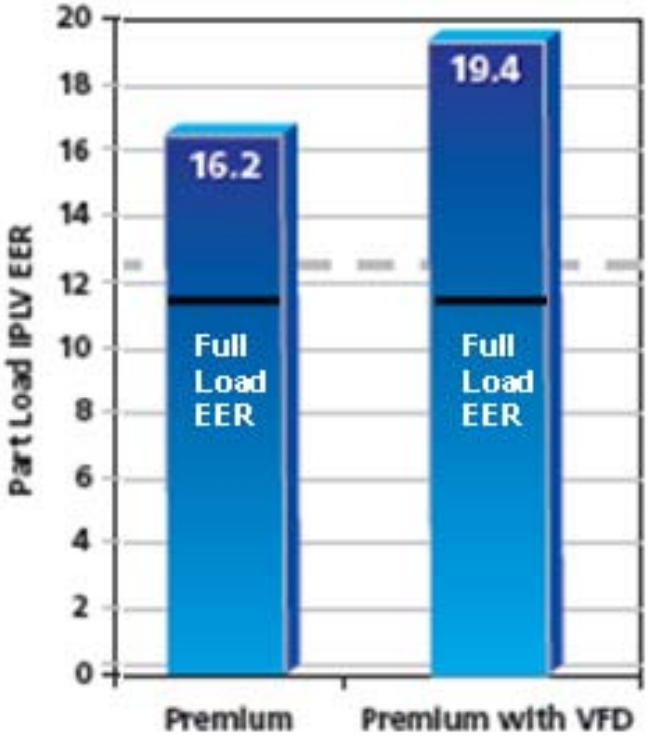
- **1st Law of Thermodynamics as Refrigeration Cycle**
  - **Efficiency = COP (Coefficient of Performance)**
    = Heat rejected (from space)/Work in
    = $\Delta Q_{\text{in from space}}/\Delta W_{\text{in from compressor}}$ (dimensionless)
    = $T_A/(T_R - T_A)$
  - **Where**
    - **T_R = Temperature of heat sink for rejected heat**
    - **Lower the heat sink temperature the higher the efficiency**

1st Law of Thermodynamics

- 1st Law of Thermodynamics as Refrigeration Cycle
  - Efficiency of Heat Sinks
    - Air Cooled
      - Dry bulb air temperature (95F to 110F)
      - Least efficient
    - Water Cooled
      - Wet bulb air temperature (65F to 80F)
      - More efficient
    - Earth Cooled/Geothermal
      - Ground temperature (50F to 75F)
      - Most efficient

1st Law of Thermodynamics

- **Increase in Efficiency for Variable Speed ~20%**



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Equipment Efficiencies

- **AHRI Heat Sink Rating Conditions for Part Load**

Equipment	AHRI Standard	Rating Designation	Ambient Testing Conditions (F)			
			100% Part Load	75% Part Load	50% Part Load	25% Part Load
Chillers, Air Cooled	550/590	IPLV	95	80	65	55
Chillers, Water Cooled	550/590	IPLV	85	75	65	65
Condensing Units, Air Source	365	IPLV	95	81.5	68	65
Heat Pump, Air Source	340/360	IEER	95	81.5	68	65
Heat Pump Geothermal (Closed) Water Loop	Same as 550/590	IEER	85	75	65	65
Heat Pump,Geothermal (Closed) Ground Loop	13256	IEER	77	77	77	77
Heat Pump, Geothermal (Open) Ground Water	13256	IEER	59	59	59	59
Variable Refrigerant Flow, Air Cooled	1230	IEER	95	81.5	68	65
Variable Refrigerant Flow, Water Cooled	1230	IEER	85	73.5	62	55

Equipment Efficiencies

- **AHRI Rating Weighting Conditions for Part Load**

Equipment	AHRI Standard	Rating Designation	Ambient Testing Conditions (F) Weighting Factor			
			100% Part Load	75% Part Load	50% Part Load	25% Part Load
Chillers, Air Cooled	550/590	IPLV	0.01	0.42	0.45	0.12
Chillers, Water Cooled	550/590	IPLV	0.01	0.42	0.45	0.12
Air Source Condensing Unit	365	IPLV	0.01	0.42	0.45	0.12
Air Source Heat Pump	340/360	IEER	0.02	0.617	0.238	0.125
Variable Refrigerant Flow, Air Cooled	1230	IEER	0.02	0.617	0.238	0.125
Variable Refrigerant Flow, Water Cooled	1230	IEER	0.02	0.617	0.238	0.125

Equipment Efficiencies

- **AHRI Energy Source Inclusion for Part Load**

Equipment	AHRI Standard	Rating Designation	Energy Source Inclusion				
			Evaporator Fan	Chilled Water Pump	Refrigerant Pump	Condenser Water Pump	Cooling Tower Fan and Pump
Chillers, Air Cooled	550/590	IPLV	No	No			
Chillers, Water Cooled	550/590	IPLV	No	No		No	No
Air Source Condensing Units	365	IPLV	No				
Air Source Heat Pump	340/360	IEER	Yes				
(Closed) Water Loop	13256	IEER	Yes			No	No
Geothermal (Closed) Gound Loop	13256	IEER	Yes			No	
Geothermal (Open) Ground Water	13256	IEER	Yes			No	
Variable Refrigerant Flow, Air Cooled	1230	IEER	Yes		Minimal		
Variable Refrigerant Flow, Water Cooled	1230	IEER	Yes		Minimal		

System Efficiencies

- **Pumping Energy**
  - **Sample building of 100’ x 100’**
  - **Load at 25 btuh/sq. ft. = 25 x 100’ x 100’ = 250,000 btuh**
- **Hydronic Pump Horsepower**
  - **Flow rate = 250,000 / 500 / 12F ΔT**
    = 42 gpm
  - **Head = 40 ft. for 200 ft. pipe (equivalent length = 200 x 1.5 = 300 ft.)**
  - **Pump HP = 42 gpm x 40 ft / 3960 / .75 pump eff.**
    = 1/2 HP
  - **Pump HP percentage of compressor HP**

    Compressor HP = 250,000 btuh / 5 COP / 3413 btuh/kwh / .75 kw / hp
    = 19.5 hp

    Pump HP percentage of compressor HP = .5 / 19.5
    = 2.5%

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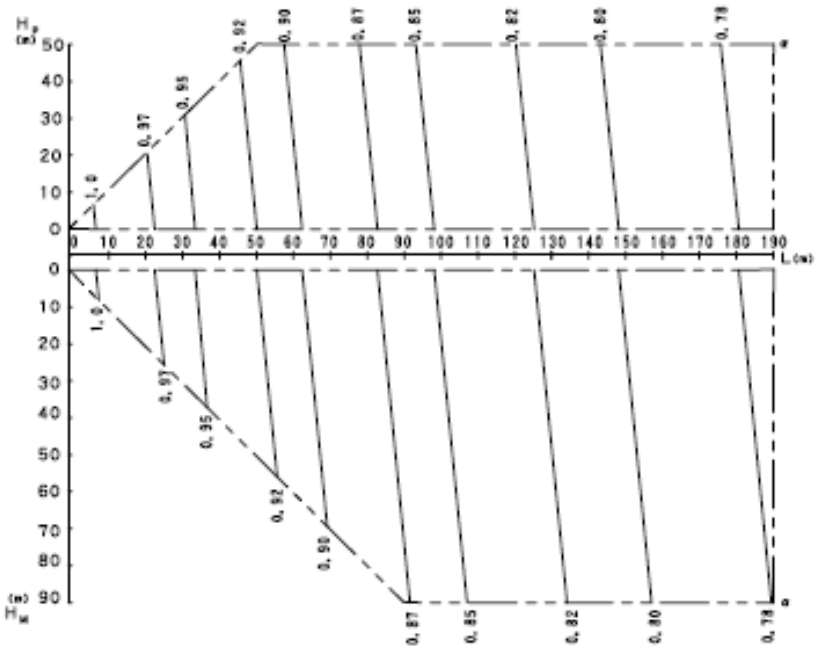
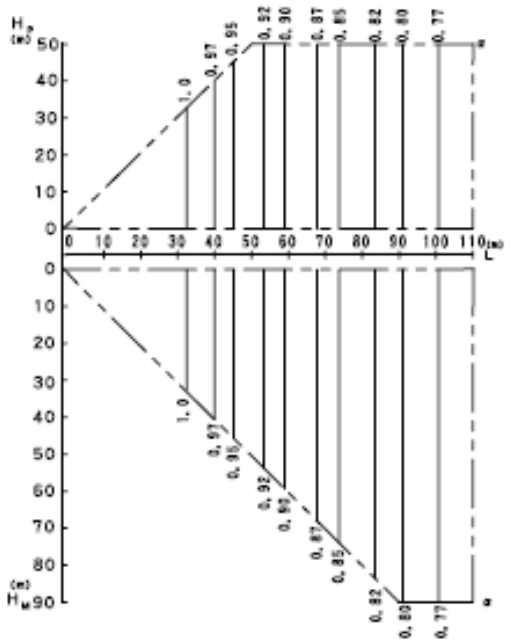
System Efficiencies

- **VRF Refrigerant Pump Horsepower**
  - **Pump HP percentage of compressor HP for 200 ft. (300 eq. ft. ~ 100 m) of refrigerant pipe**
    - **Cooling = 15% (0.85 correction factor)**
    - **Heating = 23% (0.77 correction factor)**

1. Rate of change in cooling capacity



2. Rate of change in heating capacity



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System Efficiencies

- **Part Load Chiller Efficiencies at AHRI Rating Conditions**

WGZ UNIT SIZE	% LOAD	CAPACITY TONS	POWER kWi	EER	IPLV
030A	100.0	31.6	25.0	15.2	20.0
	75.0	23.7	15.4	18.5	
	50.0	15.8	8.9	21.3	
	25.0	7.9	4.6	20.6	
035A	100.0	34.9	27.2	15.4	20.3
	75.0	26.2	17.0	18.5	
	50.0	17.4	9.5	22.1	
	25.0	8.7	5.1	20.5	
040A	100.0	40.1	31.2	15.4	20.3
	75.0	30.1	19.5	18.5	
	50.0	20.1	10.9	22.0	
	25.0	10.0	5.9	20.4	

System Efficiencies

System	EER	Cooling Equip. IPLV	Cooling Equip. IEER	Cooling *System* IEER	Heating *System* HSPF
Air Cooled Systems					
Condensing Units					
Constant Speed	11	14		12	
Rooftop Units					
Constant Speed	11			13	
Variable Speed	13			18	
Chillers					
Constant Speed	12	16		15	
Variable Speed	12	20		18	
VRF					
Variable Speed	13		20	17	8

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System Efficiencies

System	EER	Cooling Equip. IPLV	Cooling Equip. IEER	Cooling *System* IEER	Heating *System* HSPF
Water Cooled Systems					
Chillers					
Constant Speed	24	30		25	
Variable Speed	25	40		35	
Heat Pumps					
Constant Speed	22			26	19
Variable Speed	22			31	19

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System Efficiencies

System	EER	Cooling Equip. IPLV	Cooling Equip. IEER	Cooling *System* IEER	Heating *System* HSPF
Earth/Geothermal Cooled Systems					
Heat Pumps					
Closed Loop					
Constant Speed	22			21	14
Variable Speed	34			33	15
Open Loop					
Constant Speed	22			32	14
Variable Speed	34			44	15

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System Efficiencies

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- First floor
  - VRF
  - Offices and classrooms
- Second floor
  - Geothermal heat pump
  - Offices and meeting rooms

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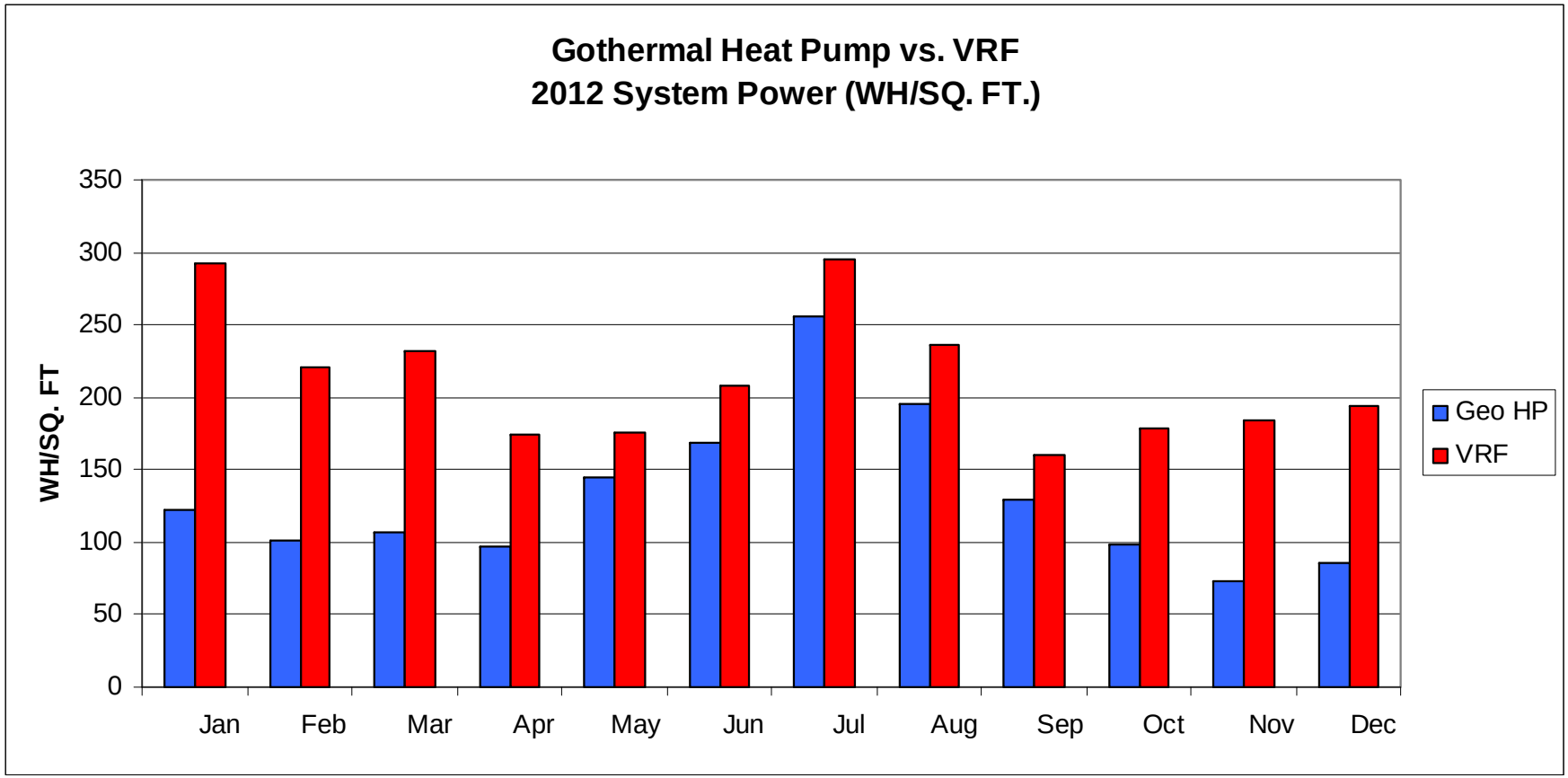
System Efficiencies



ASHRAE Headquarters Building

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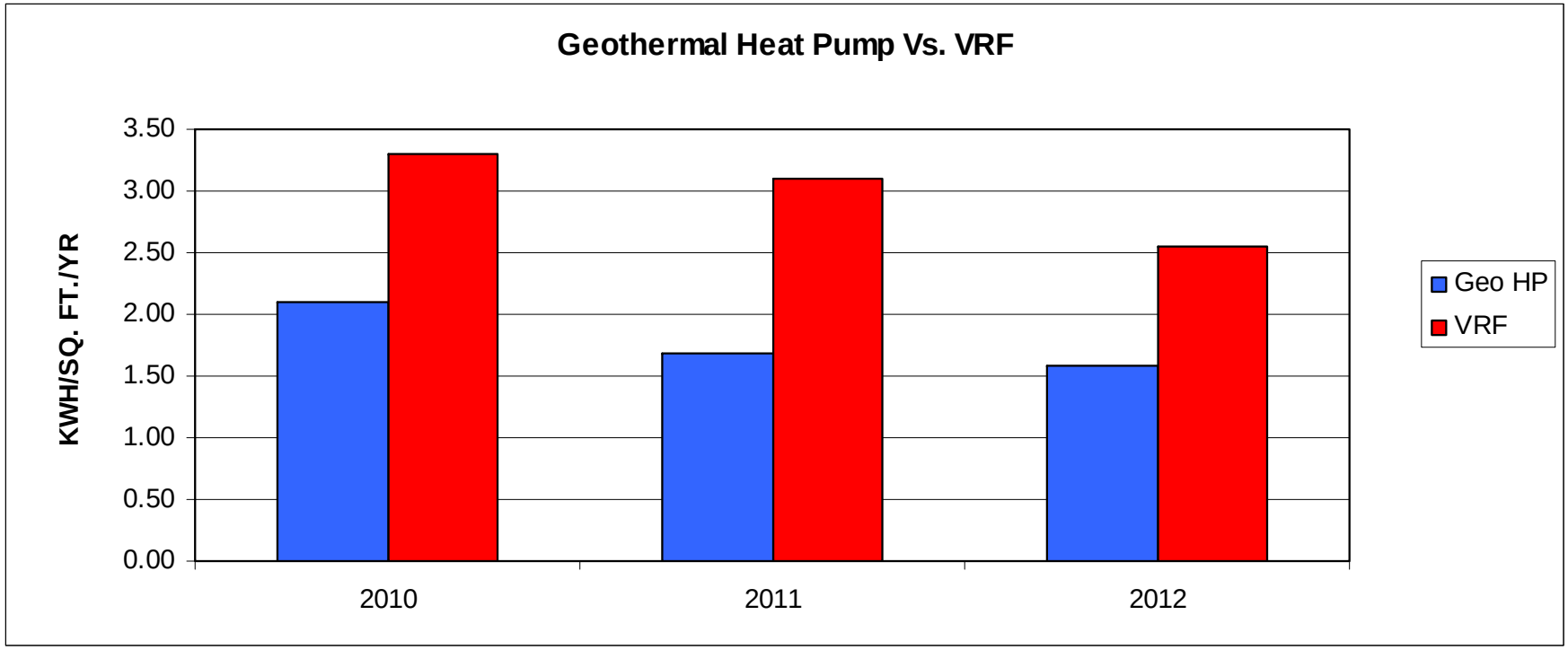
System Efficiencies



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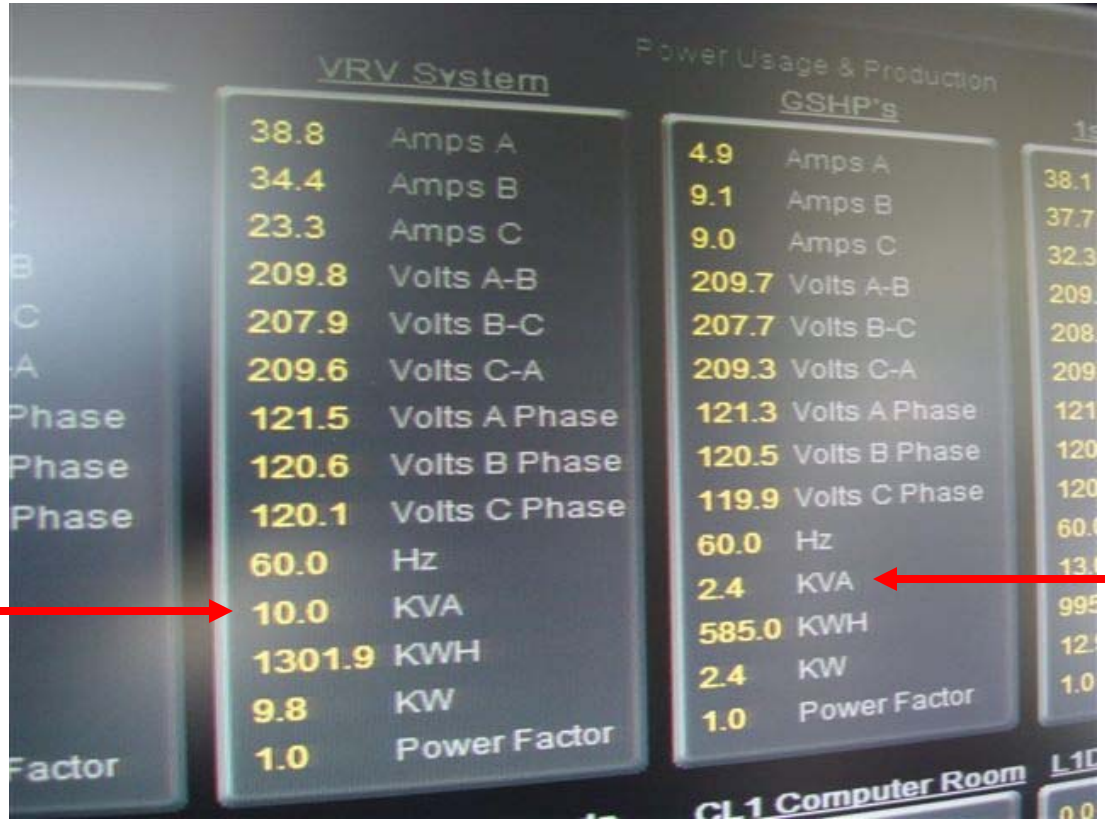
System Efficiencies

VRF

Power Demand

Ambient = 36F



Geo HP

Power Demand

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