NY-GEO 2024

APRIL 8-9 | ALBANY NY

Ground Heat Exchanger Design Principles and Design Tools

Presenter: **Ryan Carda, P.E., CGD,** Dandelion Energy

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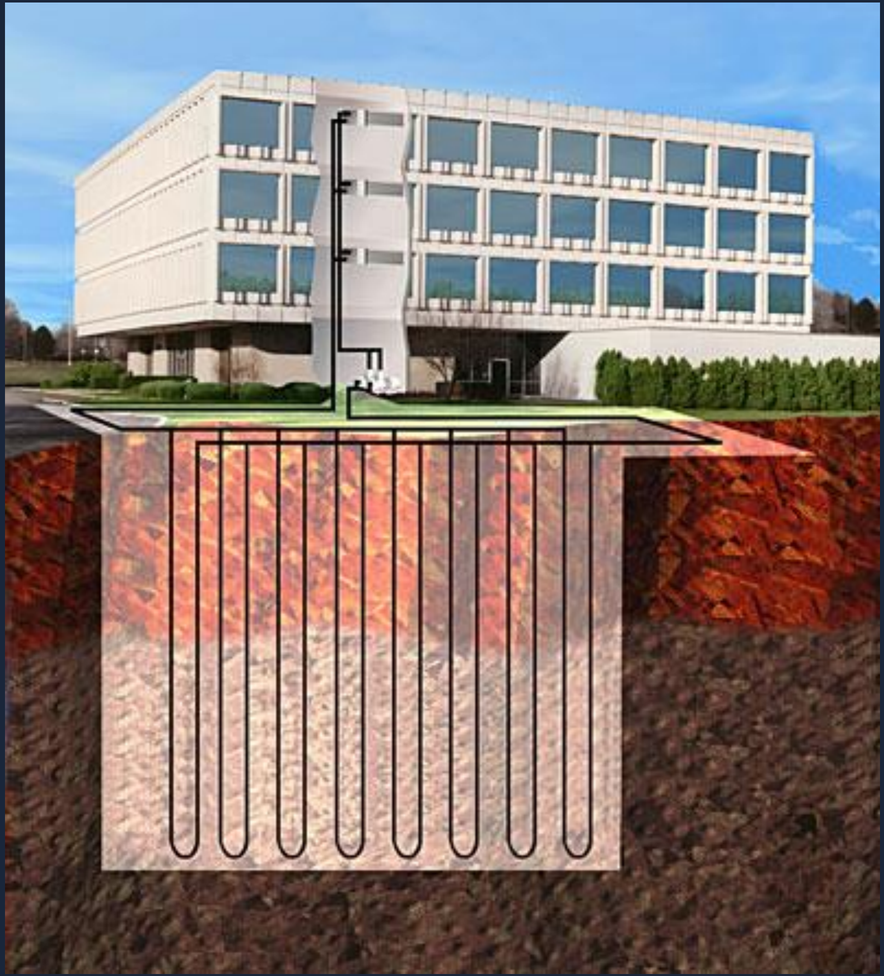
DESIGN TRACK - CEU CREDIT ELIGIBLE @ 11:00 AM

Intro to Commercial Ground Loop Design

Ryan Carda, Sr. Director of Engineering, New Construction



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Goals for today

01. Discuss engineering duties in a commercial GSHP application

02. Describe best practices in evaluating GSHP systems for commercial applications

03. Discuss the basic rules for ground loop design and layout

04. Perform a design example using software

Industry Training and Tools

What is IGSHPA?

- Non-profit, member-driven organization established in 1987 to advance ground source heat pump (GSHP) technology on local, state, national and international levels.

Training courses

- Certified Geoexchange Designer (CGD)
- Accredited Installer (AI)
- And much more

Software (igshpa.org/software)

- Directory of available software

IGSHPA®

igshpa.org

Is it feasible?

Fit technology to the application:

- Understand product types and capabilities
- Economic analysis – compare to conventional HVAC:
  - First cost analysis, consider:
    - Energy analysis & annual operating costs
    - Annual maintenance costs
    - Include incentives – tax credits, depreciation, etc.
  - Life cycle cost analysis, consider:
    - Service life expectancies
    - Fuel inflation rates
- Long-term maintenance considerations are generally not given proper attention.
  - ASHRAE 1237-TRP suggests that there are considerable savings with geo.

Pre-modeling a system

Required to perform feasibility study

- Estimate building loads, equipment requirements, energy usage & GHEX size
- For retrofit, determine how to integrate GSHP with existing

Review possible GHEX options

- Determine geological conditions
    - Via test hole or other geological survey resources
- Estimate GHEX requirements, size/location/available area, system flow rates, manifold use, etc.

The design process

- Design and Energy Loads
  - Determine heating/cooling design loads
  - Determine building energy requirements
- Size and select GSHP equipment for each zone
- Layout and design the GHEX
  - Vertically-bored is the focus for today
- Iterate GHEX design for economics
  - Adjustments to zone loads
  - Changes to GHEX design and layout
- Header and supply/return piping design
  - Layout for flushing and head loss
- Pumping system sizing and design

Design starts with building load

- Start with building heating/cooling loads
  - Space
  - Fresh air
  - Hot water
- Not the same as installed capacity
  - Must consider time of day to find instantaneous peak
- Do not use rules of thumb
  - Tend to overestimate heating/cooling requirements
- Perform energy analysis calculations
  - Use hourly analysis program to model building
    - Carrier HAP / Trane TRACE / eQuest / EnergyPlus
  - Ground loads are needed for design

Commercial load calculation methods

Many different methods have been developed:

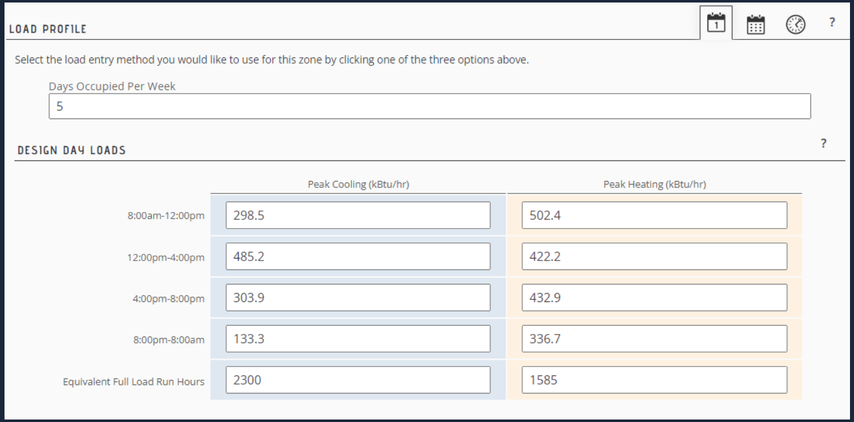
- ASHRAE
  - Heat Balance (HB) Method - most accurate, least used
  - RTS (Radiant Time Series) - simplified version of HB
  - Transfer Function Method – more oriented toward hourly analysis
  - CLTD (Cooling Load Temperature Difference) is simplified, tabular version of TFM and TETD in single-step technique
    - Simplifications such as “cooling load factors” limit applicability to specific building/construction types
  - TETD/TA also simplified version of TFM
    - Accuracy depends on subjective input of thermal storage characteristics
- ACCA
  - Manual N and MJ8 (derived from CLTD)
  - Manual J is not appropriate for commercial applications (residential only)
- Refer to ASHRAE 942-RP for comparisons. Also outlined in ASHRAE Fundamentals Handbook

Formatting loads for Software entry

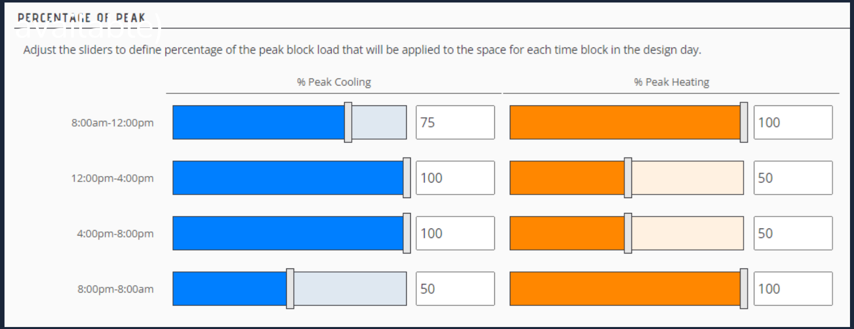
- Peak Heating and Cooling Loads
  - Design day broken into 4 time blocks.
  - Need instantaneous peak and when it occurs (time of day)

- Annual equivalent full-load run hours (FLRHs)
  - Used to calculate energy extracted from/rejected to GHEX
    - Heating FLRHs: Energy Added / Peak Heating Load
    - Cooling FLRHs Energy Removed / Peak Cooling Load
  - Dimensional Analysis → (kBtu) / (kBtu/hr) = hr

Peak load entry by time of day



Estimated load breakdown (no hourly model



FLRHs

If no energy analysis is available, estimate based on Dr. Steve Kavanaugh's ASHRAE-sponsored research:

Equivalent Full Load Cooling and Heating Hours

Values on low end of range assume units off during unoccupied hours in cooling season and 10°F set-back in heating. Values on high end assume no set-back control. Unoccupied ventilation air and internal loads minimized for both high and low range values.

	Nine Month Schools		Office – 8 to 5 Five Days / Week		Retail – 8 to 10 Seven Days / Week	
Annual Hours	**1300 - 1500**		**2200 - 2400**		**2800 - 3600**	
	Cooling	Heating	Cooling	Heating	Cooling	Heating
Atlanta	590-830	200-290	950-1360	480-690	1300-1860	380-600
Baltimore	410-610	320-460	690-1080	720-890	880-1480	570-770
Bismarck	150-250	460-500	250-540	950-990	340-780	810-900
Boston	300-510	450-520	450-970	960-1000	610-1380	760-870
Charleston,WV	430-570	310-440	620-1140	770-840	820-1600	620-730
Charlotte	510-730	200-320	940-1340	530-780	1280-1830	420-670
Chicago	280-410	390-470	420-780	820-920	550-1090	670-810
Dallas	620-890	120-200	1100-1580	340-520	1460-2090	280-440
Detroit	230-360	400-480	390-820	970-1020	530-1170	790-900
Fairbanks, AK	25-50	560-630	60-200	1050-1170	110-320	930-1090
Great Falls, MT	130-220	360-430	210-490	820-890	290-710	680-800
Hilo, HI	970-1390	0	1800-2580	15-25	2260-3370	10-15
Houston	670-1000	90-130	1240-1770	250-350	1600-2290	190-300
Indianapolis	380-560	400-480	560-1000	840-920	730-1410	690-820
Los Angeles	610-910	80-160	1140-1670	370-580	1650-2350	250-440
Louisville	470-670	290-430	770-1250	710-830	1000-1720	570-720
Madison	210-310	390-470	320-640	840-900	420-900	700-800
Memphis	580-830	170-240	950-1350	420-600	1250-1780	330-510
Miami	950-1300	10	1500-2150	35-45	1920-2740	25-40
Minneapolis	200-300	420-500	320-610	860-950	430-870	720-860
Montgomery	630-910	120-180	1060-1510	330-470	1390-1990	250-400
Nashville	520-740	250-320	830-1280	590-680	1030-1710	470-590
New Orleans	690-990	70-110	1200-1720	230-320	1570-2240	160-260
New York	360-550	350-440	540-1040	790-870	720-1480	630-760
Omaha	310-440	330-400	480-820	720-800	610-1130	600-720
Phoenix	710-1020	70-110	1130-1610	210-290	1430-2090	170-250
Pittsburgh	300-530	470-500	440-920	910-950	600-1310	750-840
Portland, ME	190-300	400-480	310-630	880-980	410-900	710-870
Richmond, VA	510-730	270-410	880-1310	660-820	1110-1770	520-710
Sacramento	600-850	220-360	1000-1430	640-990	1390-2020	480-830
Salt Lake City	410-710	520-540	510-1090	1040-1060	660-1520	830-930
Seattle	260-460	460-650	440-1200	1270-1370	710-1860	960-1170
St. Louis	390-550	280-400	680-1100	710-800	850-1500	570-700
Tampa	780-1110	40-60	1440-2000	140-190	1780-2560	100-160
Tulsa	540-770	240-300	830-1300	560-620	1030-1730	450-540

Consider hybrid options

Take advantage of all available options to optimize operating & installation cost

- Combine loop types to lower cost
- Integrate with cooling tower or boiler to reduce system size
  - Look at % load vs % energy
- Integrate snow melt to dump excess heat
- Decouple OA loads (especially in northern climates)
- Thermal energy storage
- The list goes on and on…

Vertical closed loop GHEX design

Input parameters:

- Soil/Rock Formation Properties
  - Formation temperature (Ts)
  - Formation thermal conductivity (ks)
  - Formation thermal diffusivity (αs)
- Design EWTs
  - Common defaults are 30F (min) & 90F (max)
- Borehole Considerations
  - Borehole diameter
  - Grout Thermal Conductivity
- Layout Considerations
  - Loop size vs number of bores
  - Maximum borehole depth
  - Number of circuits (break into even multiples when possible)
  - Bore spacing

Understand the site & local geology

- Know limitations of GHEX configurations given the available space
- Identify local installation assets & expertise
  - What is appropriate for local soil / drilling conditions?
  - Bedrock or unconsolidated?
  - Mud vs air drilling?
  - Max drilling depths?
  - How to fit in available space?
- Decide if a FTC test needed
  - System >25 tons

Soil Properties

Three ways to obtain

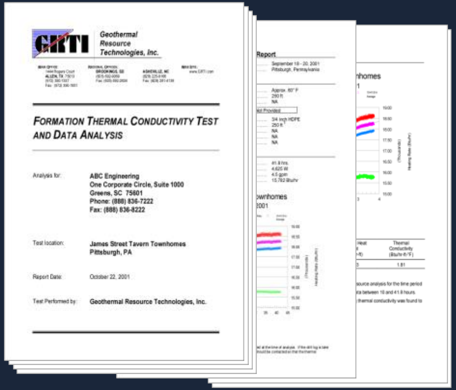
- Tabled data
  - Soil type lookup (USGS or other)
- Drilling log data from geologic survey
  - Correlate drill log to soil/rock type thermal conductivity
- Field test (FTC, in-situ test)
  - Requires installation of a test borehole to desired depth
    - Can be incorporated into the rest of the field in the future
  - Provides direct measurement of formation temperature, thermal conductivity and thermal diffusivity
  - Provides an understanding of the drilling conditions

FTC testing is a three step process

Step 1: Install the test bore

Step 2: Run the test

Step 3: Analyze the data and generate a report



Geothermal Resource Technologies, Inc.

FORMATION THERMAL CONDUCTIVITY TEST AND DATA ANALYSIS

Analysis for: ABC Engineering
One Corporate Circle, Suite 1000
Greens, SC 75601
Phone: (888) 836-7222
Fax: (888) 836-8222

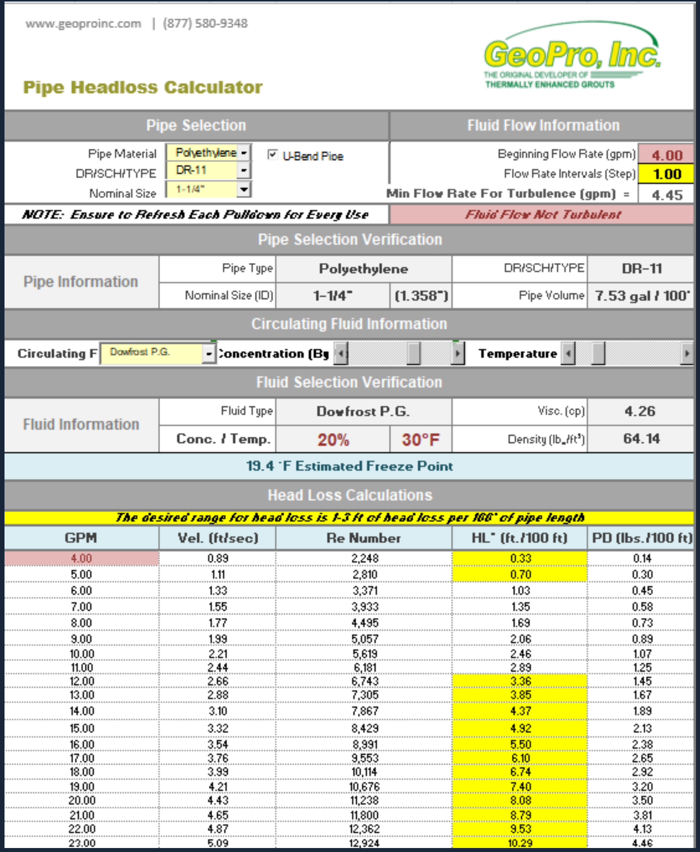
Test location: James Street Tavern Townhomes
Pittsburgh, PA

Report Date: October 22, 2001

Test Performed by: Geothermal Resource Technologies, Inc.

Determining number of bores

- Design flow 3 gpm/ton
  - Based on instantaneous peak, not installed capacity
- Min number of bores based on head loss
  - Target head loss range 1-3 ft (per 100ft)
- Max number of bores based on turbulence
  - 2,500 min Reynold's number
- Example
  - Peak flow = 300 gpm
    - Fluid type = 20% propylene glycol (at 30F)
    - 1.25" (DR11) PE4710 ubends
    - Min flow for turbulence = 4.5 gpm
    - Max flow due to head loss = 11 gpm
  - Allowable range = 28 - 66 bores



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Pipe Headloss Calculator

Pipe Selection

Pipe Material: Polyethylene
DR/SCH/TYPE: DR-11
Nominal Size: 1-1/4"
☑ U-Bend Pipe

Fluid Flow Information

Beginning Flow Rate (gpm): 4.00
Flow Rate Intervals (Step): 1.00
Min Flow Rate For Turbulence (gpm) = 4.45

NOTE: Ensure to Refresh Each Pulldown for Every Use

Fluid Flow Not Turbulent

Pipe Selection Verification

Pipe Information	Pipe Type	Polyethylene		DR/SCH/TYPE	DR-11
	Nominal Size (ID)	1-1/4"	(1.358")	Pipe Volume	7.53 gal / 100'

Circulating Fluid Information

Circulating F: Dowfrost P.G. | Concentration (By | Temperature

Fluid Selection Verification

Fluid Information	Fluid Type	Dowfrost P.G.		Visc. (cp)	4.26
	Conc. / Temp.	20%	30°F	Density (lb$_m$/ft^3)	64.14

19.4 °F Estimated Freeze Point

Head Loss Calculations

The desired range for head loss is 1-3 ft of head loss per 100' of pipe length

GPM	Vel. (ft/sec)	Re Number	HL* (ft./100 ft)	PD (lbs./100 ft)
4.00	0.89	2,248	0.33	0.14
5.00	1.11	2,810	0.70	0.30
6.00	1.33	3,371	1.03	0.45
7.00	1.55	3,933	1.35	0.58
8.00	1.77	4,495	1.69	0.73
9.00	1.99	5,057	2.06	0.89
10.00	2.21	5,619	2.46	1.07
11.00	2.44	6,181	2.89	1.25
12.00	2.66	6,743	3.36	1.45
13.00	2.88	7,305	3.85	1.67
14.00	3.10	7,867	4.37	1.89
15.00	3.32	8,429	4.92	2.13
16.00	3.54	8,991	5.50	2.38
17.00	3.76	9,553	6.10	2.65
18.00	3.99	10,114	6.74	2.92
19.00	4.21	10,676	7.40	3.20
20.00	4.43	11,238	8.08	3.50
21.00	4.65	11,800	8.79	3.81
22.00	4.87	12,362	9.53	4.13
23.00	5.09	12,924	10.29	4.46

https://geoproinc.com/resources/documents/GeoProIncHeadLossTables.xls

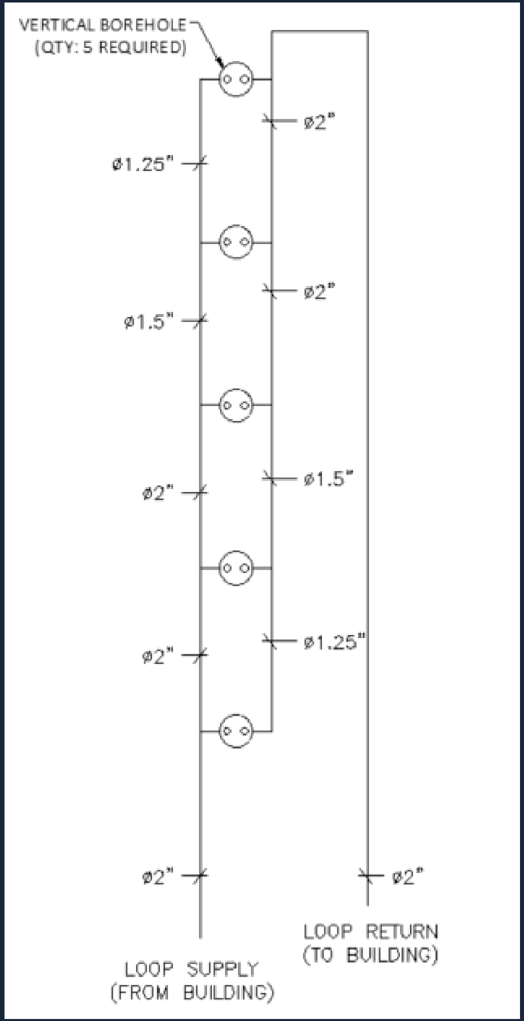
Determining # of circuits

- Break ground loop into even multiples
- Select pipe size based on head loss
  - Target head loss range 1-3 ft (per 100ft)
  - Turbulence not needed for supply-returns
- Example
  - Peak flow = 300 gpm
  - Assumed 40 bore layout. It couple be broken into
    - 2 circuits of 20 bores (150 gpm/circuit)
    - 4 circuits of 10 bores (75 gpm/circuit)
    - 5 circuits of 8 bores (60 gpm/circuit)
    - ...and so on
  - Considerations:
    - SDSURR for flushing and flow balance
    - Mechanical room space
    - Manifold redundancy

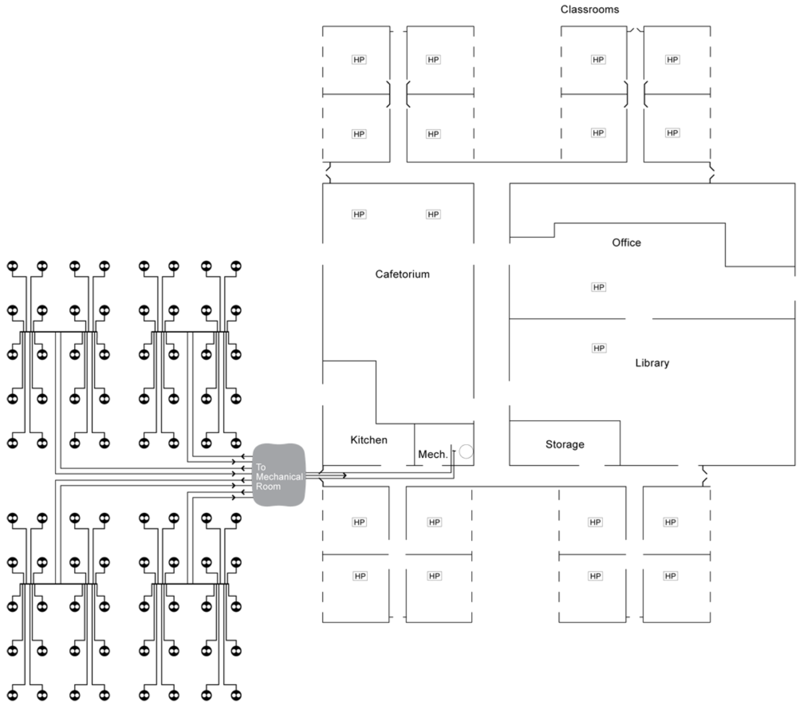
Flow Capacities for Various HDPE Pipe Sizes to achieve 1-3 feet (per 100 feet) - 20% PG at 30F

Nom. Pipe Dia.	Dimension Ratio (DR)	
	DR11	DR15.5
2	16 - 30	19 - 36
3	45 - 88	54 - 102
4	90 - 170	108 - 202
6	260 - 480	308 - 570

Sample SDSURR layout

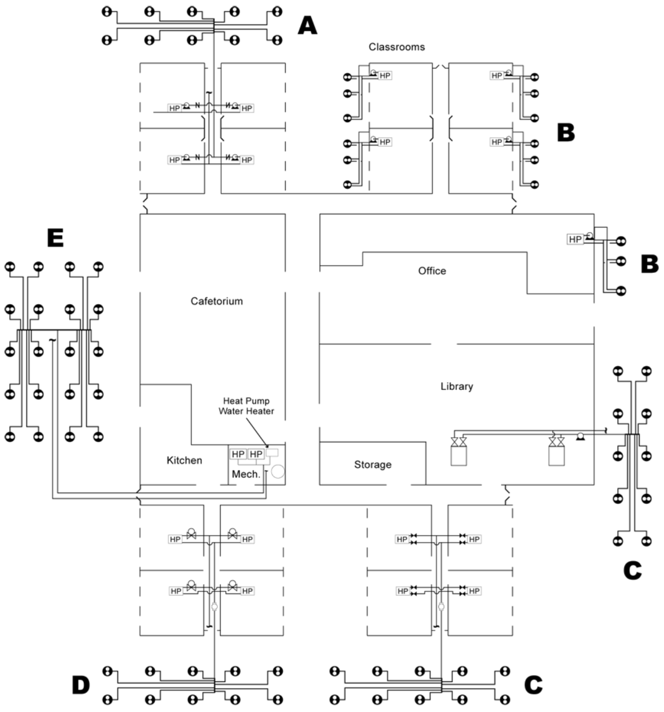


Centralized layout



- Main advantages:
  - Benefit from building diversity – energy sharing
  - Single manifold
- Main disadvantages:
  - Larger pipe sizes
  - If pump fails, may bring entire system offline (without redundancy)
  - Large pump is inefficient at low flow operating conditions

Decentralized layout



Alternatives to central loop ground-coupled heat pumps.

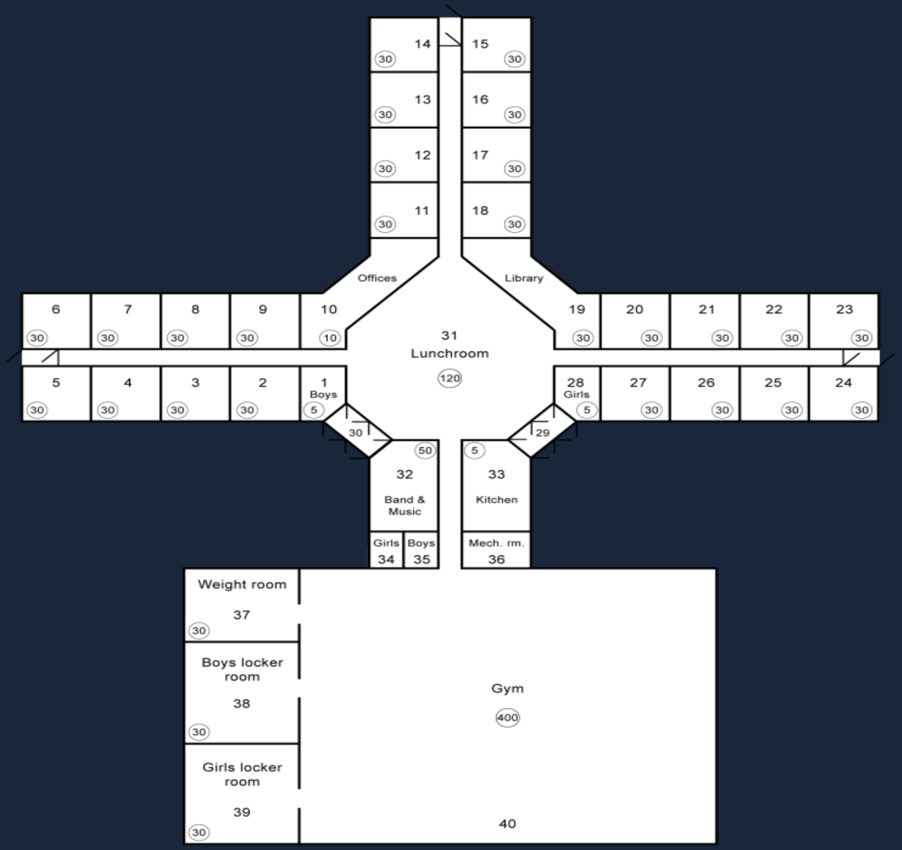
A. One local loop, multiple heat pumps with pump and check valve on each unit.
B. Multiple Individual loops, heat pumps, and circulator pumps.
C. Multiple units with one local pump that operates when one or more units is on.
D. Multiple units with two-way valves, one local loop, and VS pump.
E. Heat pumps and water heater on same loop to balance local load.

- Main advantages:
  - Smaller pipe sizes
  - Simple controls
  - If one pump fails, rest of system can still operate
- Main disadvantages:
  - Loss of benefit from diversity
  - More pumps to operate & maintain
  - Multiple manifolds

Design example: School in Mankato MN (164,000 sf)

ASHRAE Design Conditions:
- 99% htg = -8.1F
- 0.4% clg = 89.8F (db)/ 73.4F (wb)

Floor plan:



Peak load scenarios

Key decision…how to handle OA

- Option 1: Preheat OA to 70 in htg & 100% geo in clg

Block	Pk Clg Lds		Block	Pk Htg Lds	
8-12	1,768	MBH	8-12	2,179	MBH
12-4	1,778	MBH	12-4	1,362	MBH
4-8	1,656	MBH	4-8	1,362	MBH
8-8	823	MBH	8-8	2,179	MBH

Clg Ener =	685,647,580	Btu	Htg Ener =	2,051,112,000	Btu
AEFLCH =	386	hrs	AEFLHH =	941	hrs

- Option 2: Preheat OA to 40 in htg & 100% geo in clg

Block	Pk Clg Lds		Block	Pk Htg Lds	
8-12	1,768	MBH	8-12	2,600	MBH
12-4	1,778	MBH	12-4	1,802	MBH
4-8	1,656	MBH	4-8	1,563	MBH
8-8	823	MBH	8-8	2,179	MBH

Clg Ener =	685,647,580	Btu	Htg Ener =	2,656,390,508	Btu
AEFLCH =	386	hrs	AEFLHH =	1022	hrs

- Option 3: No preheat - 100% OA w/ geo

Block	Pk Clg Lds		Block	Pk Htg Lds	
8-12	1,768	MBH	8-12	3,274	MBH
12-4	1,778	MBH	12-4	2,507	MBH
4-8	1,656	MBH	4-8	1,885	MBH
8-8	823	MBH	8-8	2,179	MBH

Clg Ener =	685,647,580	Btu	Htg Ener =	2,896,712,291	Btu
AEFLCH =	386	hrs	AEFLHH =	885	hrs

Thank You!

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