Agenda and Objectives

Trane Engineers Newsletter Live Series

Central Geothermal System Design and Control

Many people are familiar with geothermal heat pump systems, using small, "geothermal" heat pumps, distributed throughout the building, that are coupled with a ground source heat exchanger. These systems operate very efficiently since heat rejected to the ground loop in the summer is stored and extracted in the winter. Today, project teams are also considering central geothermal systems consisting of one or two chillers coupled with a closed, geothermal loop which exchanges heat with the earth. Such systems offer high energy efficiency, with the additional benefit of centralized maintenance, acoustic advantages, and airside flexibility. This program discusses benefits, challenges, design, and control of central geothermal systems.

Learning objectives:

1. Identify the key differentiators from distributed systems.
2. Summarize the design and operation of central geothermal systems
3. Explain how the system offers airside system flexibility.
4. Identify key design considerations for central geothermal systems.
5. Summarize the energy analysis results comparing central geothermal systems, 90.1 baseline and alternative systems

Agenda:

1) Overview
   a) Compare to distributed systems
2) System discussion
   a) Central system configuration
   b) Central system operation
   c) Central system controls
   d) Key design issues (redundancy, glycol, hybrid sizing etc)
3) Equipment performance requirements
   a) Temps
   b) Cooling/heating flexibility
4) Energy performance/TRACE™ 700
   a) Assumptions
   b) Study results
5) Summary

Presenters

Trane Engineers Newsletter Live Series

Central Geothermal System Design and Control

(2010)

Lee Cline | senior principal systems engineer | Trane

Lee is an engineer in the Systems Engineering Department with over 29 years experience at Trane. His career at Trane started as a factory service engineer for heavy refrigeration, helping to introduce the CVHE centrifugal chiller with electronic controls to the industry. Following that Lee was a member of the team that kicked off the microelectronic building automation and Integrated Comfort Systems controls – ICS - offering at Trane. He continues to push new unit and system control and optimization concepts into the industry. As a Systems Engineer Lee also has the opportunity to discuss HVAC system application and control with owners, engineers and contractors on a daily basis.

Lee has a Bachelors degree in Mechanical Engineering from Michigan Technological University. He is a member of ASHRAE and a Registered Professional Engineer in the State of Wisconsin.

Eric Sturm | C.D.S. marketing engineer | Trane

Eric joined Trane in 2006. He is responsible for driving development of the TRACE software program including compliance with ASHRAE Standards 90.1 and 140. Eric's primary responsibility is assisting customers of Trane's HVAC system design and analysis applications including TRACE 700 and System Analyzer. In addition Eric is a member of Trane's Advanced Engineering Services, providing building simulations for various projects. Eric earned his BSME from University of Wisconsin-Platteville and is a member of ASHRAE.

Mick Schwedler | manager, applications engineering | Trane

Mick joined Trane in 1982 With expertise in system optimization and control, and in chilled-water system design, Mick's primary responsibility is to help designers properly apply Trane products and systems through one-on-one support, technical publications, and seminars. Mick is a past Chair of SSPC 90.1. Mick holds a B.S. and M.S. degree in mechanical engineering.and he is a registered professional engineer in the State of Wisconsin.

Brian Fiegen, | global systems applications leader| Trane

Brian is the Manager of Systems Engineering (Applications Engineering, Systems Engineering, and C.D.S.). Brian joined Trane in 1983, and has held a number of marketing and management positions throughout his career. He has been involved with product development and promotion of air handling and distribution products, systems, and controls throughout much of that time.

Brian is deeply involved in managing Trane's position on key industry issues such as IAQ and sustainable construction. Brian earned his BSME from South Dakota School of Mines and Technology in Rapid City, SD.

Central Geothermal System Design and Control

Continuing Education Credit

- This program is registered with the AIA/CES and USGBC for LEED® continuing professional education. 1.5 CEs earned on completion of this program will be reported to CES Records for AIA members.

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central geothermal systems

Today's Topics

- Overview of central geothermal systems
  - Comparison to distributed systems
- Design and control
  - Configuration
  - Operation
  - Controls
- Design considerations
- Equipment performance requirements
- Energy performance

Today's Presenters

Brian Fiegen
Global Systems Applications Leader

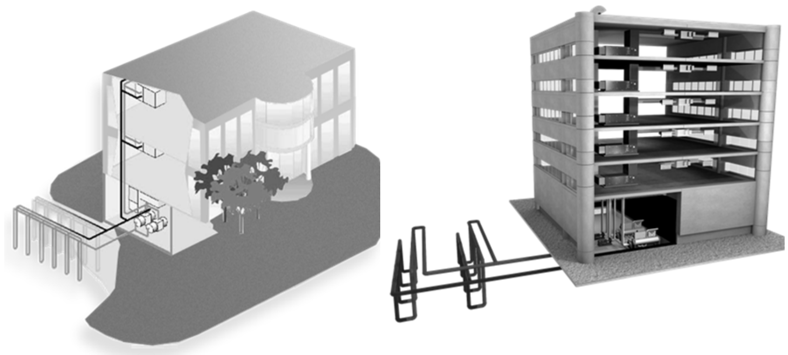
Eric Sturm
C.D.S. Marketing Engineer

Today's Presenters

Lee Cline
Systems Engineer

Mick Schwedler
Applications Engineering Manager

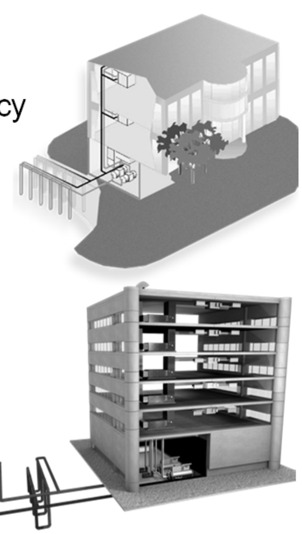
Geothermal Systems



Reasons to Select a Geothermal System

- High system energy efficiency
- Low carbon emissions
- LEED® energy credits
- Attractive financial return
  - Tax incentives

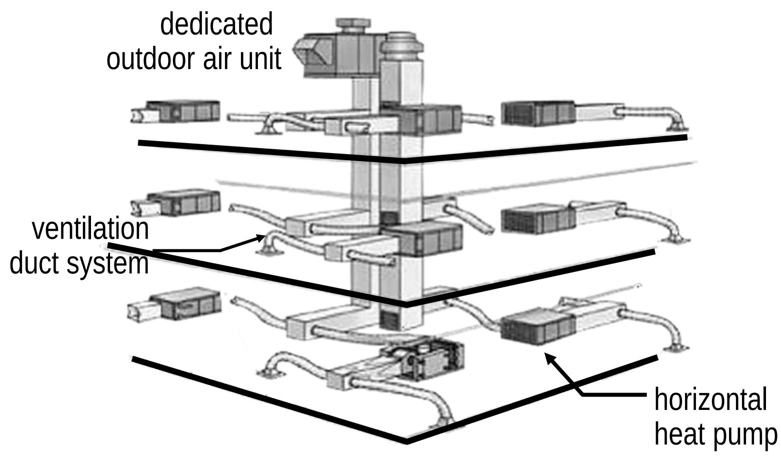
High Energy Efficiency



What Makes Geothermal Systems Efficient?

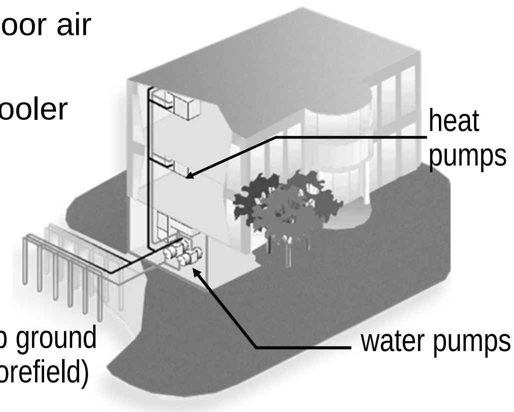
- Earth temperatures
  - Cool heat sink when cooling
  - Warm heat source when heating
- Heat-pump based heating
- Heat-recovery system
  - Share energy between heating and cooling zones
  - Store heat from cooling season
  - Extract heat in the heating season
- Efficient equipment
  - High-efficiency heat pumps

Distributed Heat Pump System



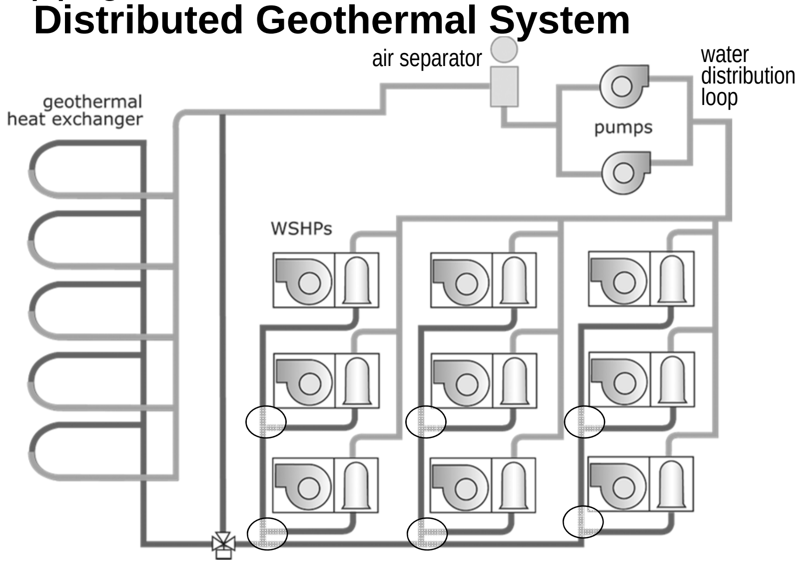
Distributed Geothermal System

- WSHPs
- Dedicated outdoor air units
- Optional fluid cooler
- Water pumps
- Geo heat exchanger



piping

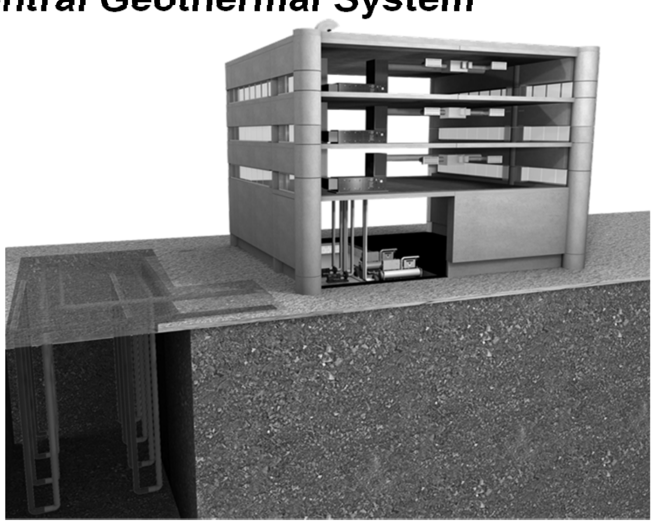
Distributed Geothermal System



Distributed Geothermal System

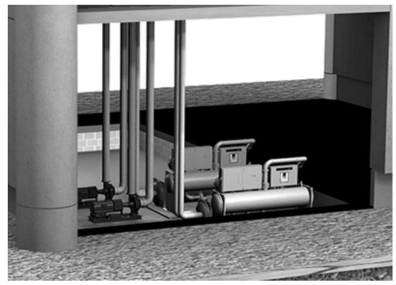
- Advantages
  - Limited floor space requirements
  - Easy to self-service
  - Isolated impact of equipment failure
  - Capacity can be added
  - Simple piping design
- Disadvantages
  - In-space service and maintenance
  - Distributed service and maintenance
  - Acoustics
  - Complex dedicated outdoor air systems
  - Mixing related energy efficiency loss (entropy)
  - Limited air filtration options

Central Geothermal System

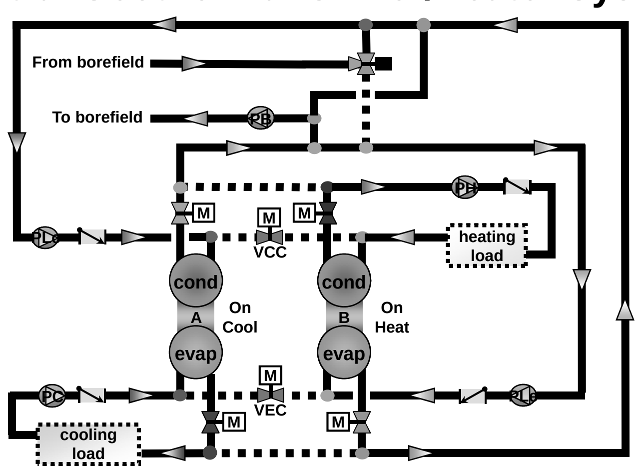


Central Geothermal System

- Heat recovery chillers (chiller/heaters) provide heating and cooling
  - Hydronic four pipe
- Central air handlers
- VAV terminals
- Auxiliary boilers
- Water pumps



piping
Central Geothermal Chiller/Heater System



Bidirectional Cascade Central Geothermal System

- Disadvantages
  - Requires MER space
  - Requires a chiller technician to service the central plant
  - Redundancy must be designed
  - Capacity addition

Bidirectional Cascade Central Geothermal System

- Advantages
  - Service and maintenance occurs in an equipment room
  - Service and maintenance is centralized
  - Acoustics (equipment away from space)
  - Air economizer integrates into air distribution system
  - Efficient cascading of simultaneous energy streams
  - Air filtration flexibility

Geothermal Systems

- An HVAC system with compelling benefits including energy efficiency
- Most geothermal systems utilize distributed near space heat pumps for heating and cooling
- Central geothermal systems are an alternative to traditional distributed geothermal systems
  - Enables centralized service and maintenance
  - Premium efficiency
  - Improved acoustics and IAQ

Central Geothermal System Design and Control

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System Configuration

Central Geothermal System

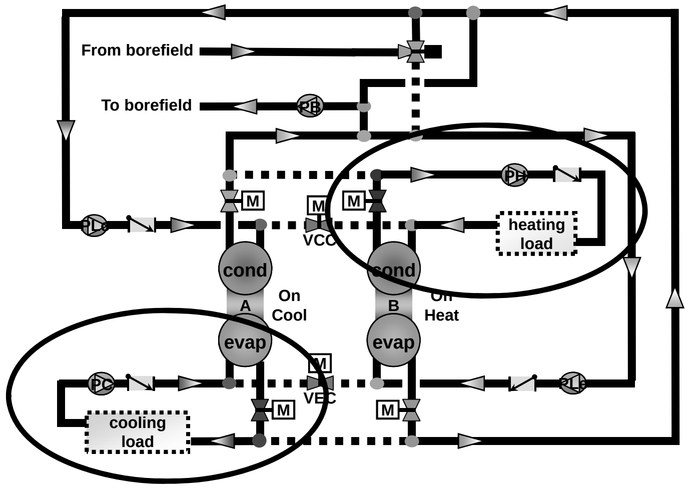
bidirectional cascade

Operation & Control

Goal:

- CGS concept understanding
  - Where does the water go?
- Operating modes
  - Cooling only mode
  - Heating only mode
  - Simultaneous heating/ cooling modes

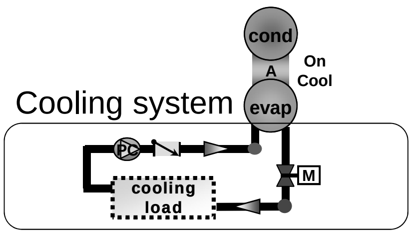
Central Geothermal System



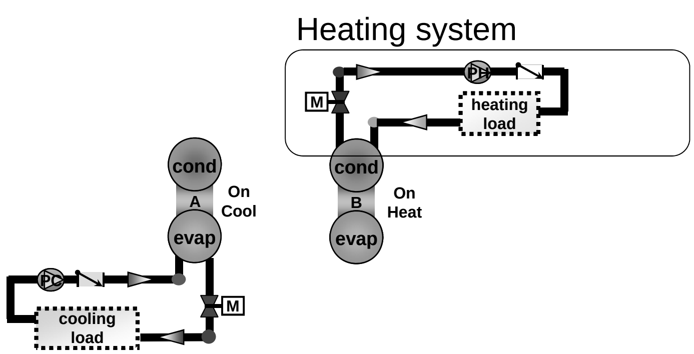
Central Geothermal System Fluid Flow

- Three loops
  - Borefield
  - Condenser energy transfer loop
  - Evaporator energy transfer loop
- Two “energy cascade” paths
  - Chiller condenser to heater evaporator
  - Heater evaporator to chiller condenser
  - Result in more efficient system operation

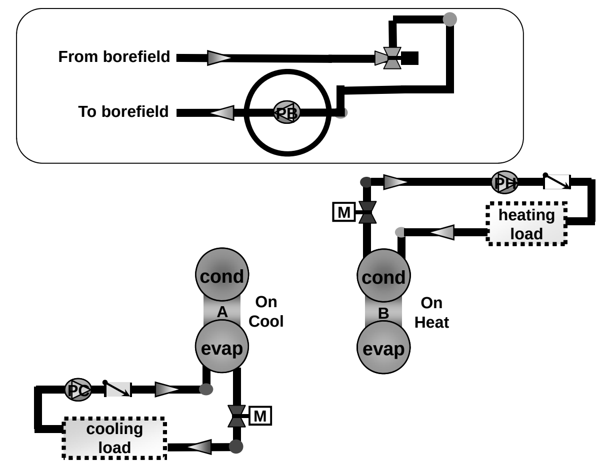
Chilled Water to Building Loads



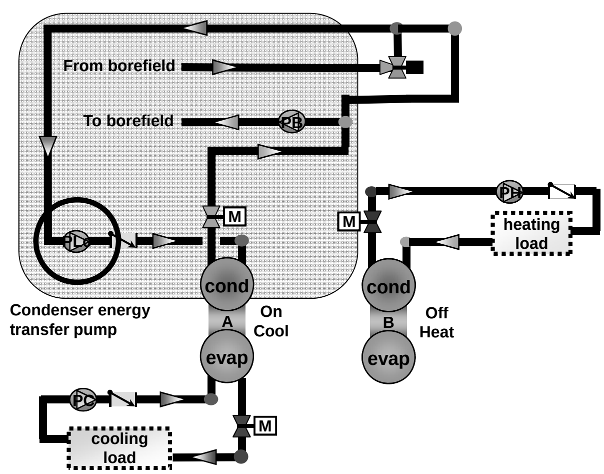
Hot Water to Building Loads



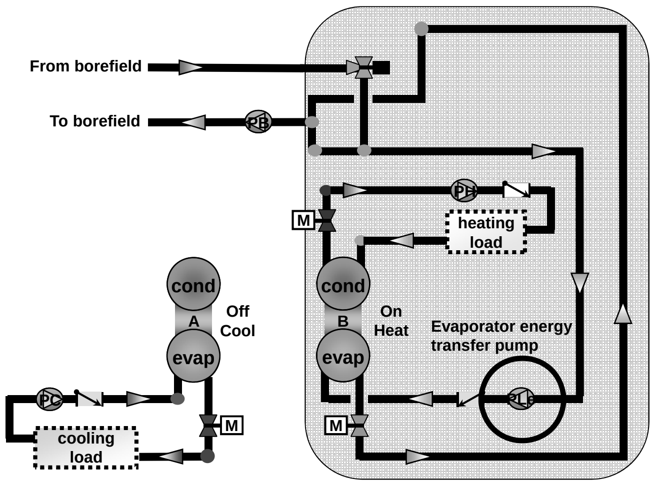
Borefield loop



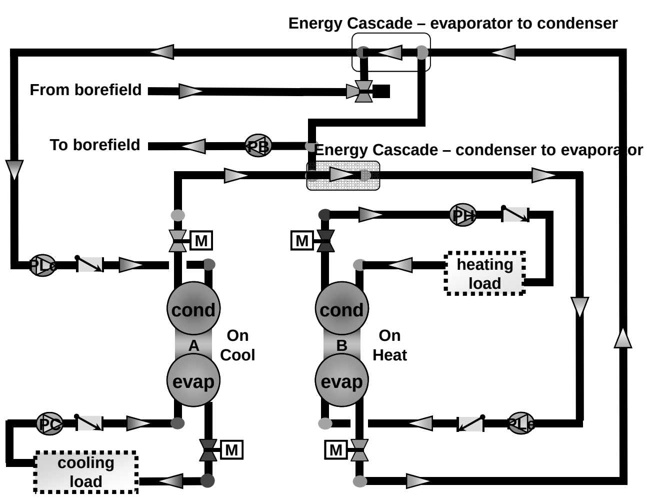
Condenser Energy Transfer Loop



Evaporator Energy Transfer Loop



Two Energy Cascade Paths



Water Flow

- Three loops
  - Borefield
  - Condenser energy transfer loop
  - Evaporator energy transfer loop
- Two “energy cascade” paths
  - Chiller condenser to heater evaporator
  - Heater evaporator to chiller condenser
  - Result in more efficient system operation

Central Geothermal System Design and Control

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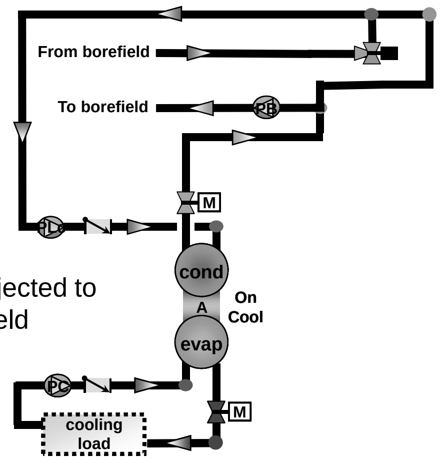
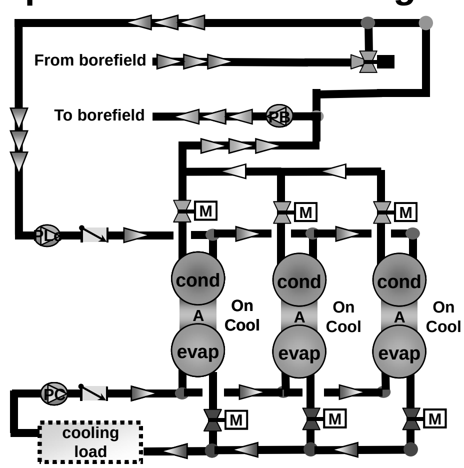
Operation and Control: Cooling Only

Cooling Only Mode Operation



Heat is rejected to the borefield

Multiple Chillers in *Cooling Mode*

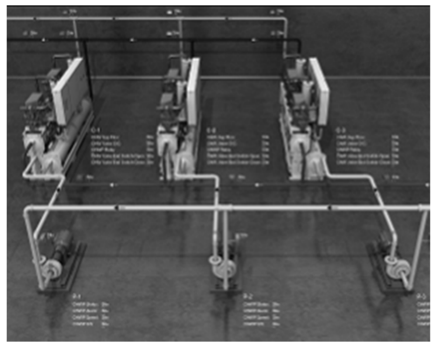


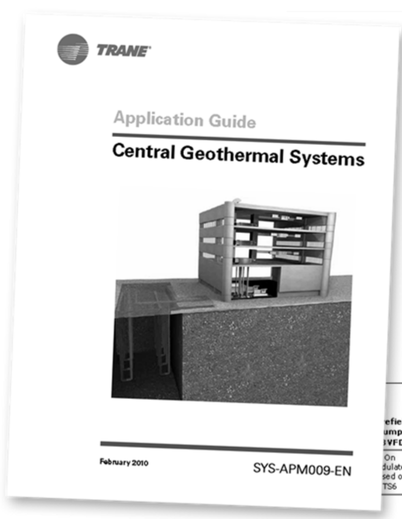
bidirectional cascade control

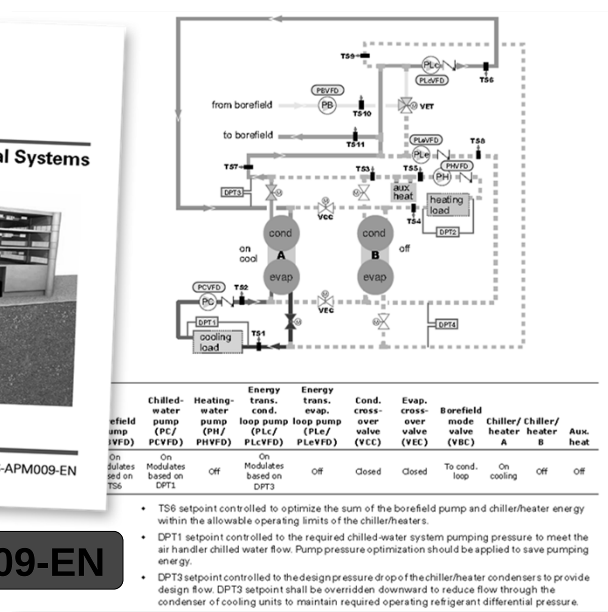
Plant Control

Must respond to:

- Cooling load
- Heating load
- Systems limits
- Unit operating limits
- Pump energy consumption
- Pump VFDs







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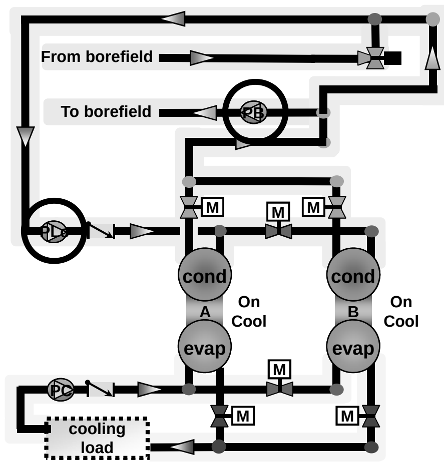
bidirectional cascade control

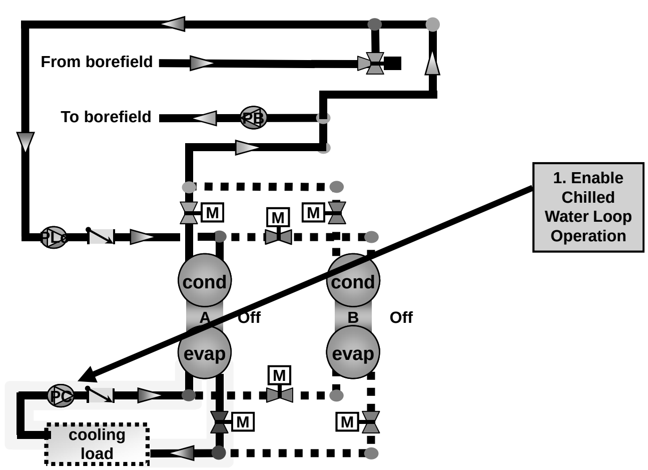
Cooling Only Mode



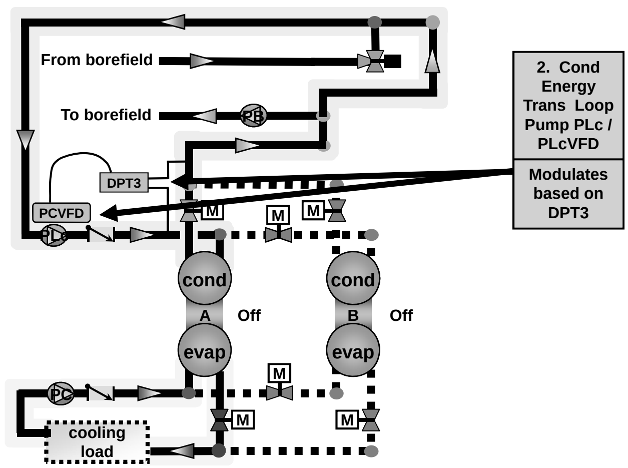
- Chilled water system is controlled to meet the building cooling load
- Condenser Energy Transfer Loop pump (PLc) controlled to maintain design chiller condenser water flow rate
- Heat is rejected to the borefield
- Borefield pump (PB) controlled to maintain entering chiller condenser water temperature

bidirectional cascade control

Cooling Only Mode



bidirectional cascade control
Cooling Only Mode



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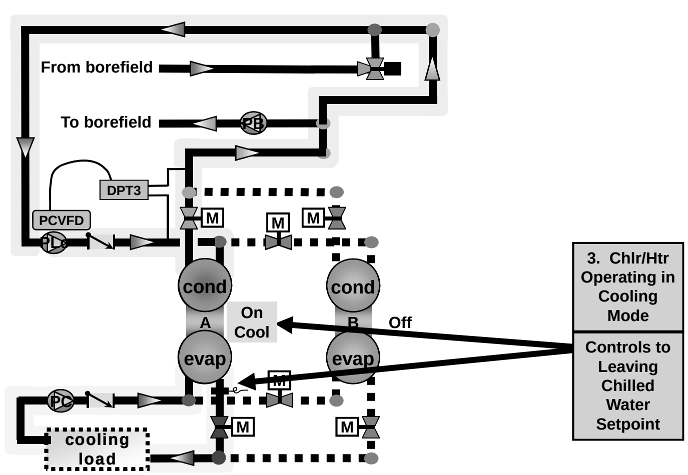
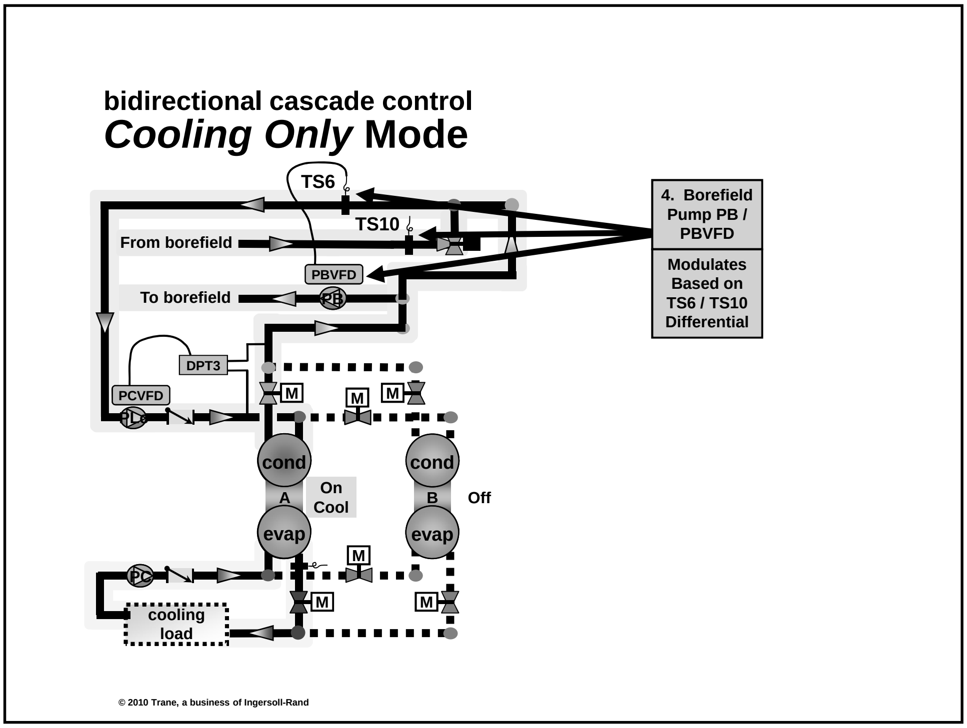
Cooling Only Mode




bidirectional cascade control
Cooling Only Mode
TS6
TS10
From borefield
To borefield
PBVFD
PB
DPT3
PCVFD
PL
M
cond
A
On
Cool
evap
cond
B
Off
evap
PC
cooling load
4. Borefield Pump PB / PBVFD
Modulates Based on TS6 / TS10 Differential
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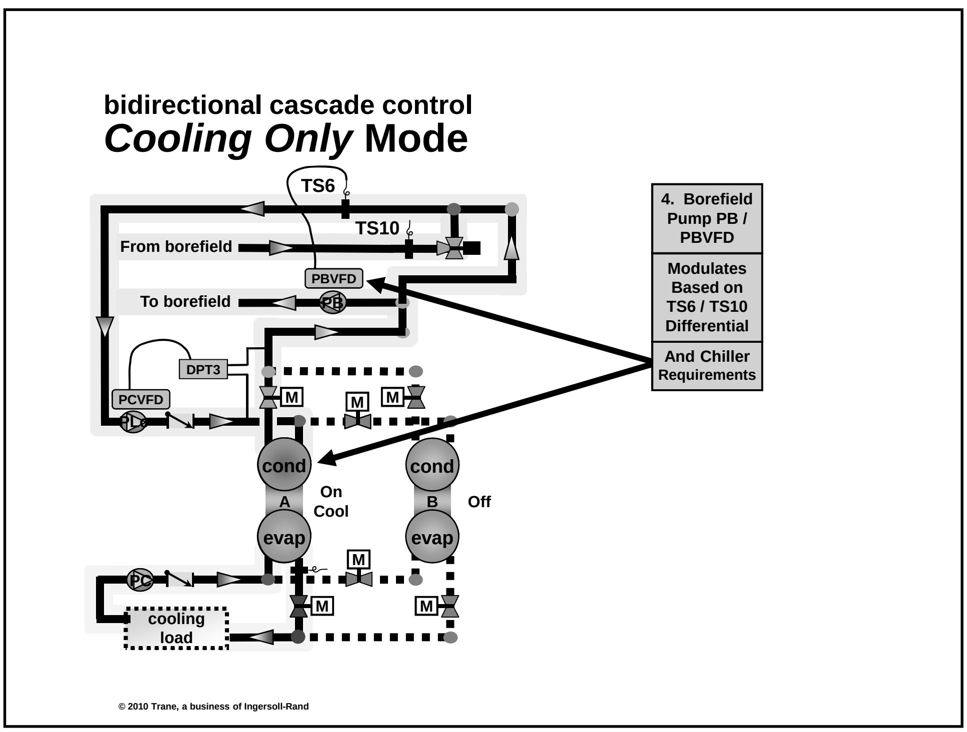
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And Chiller Requirements
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Central Geothermal System Design and Control

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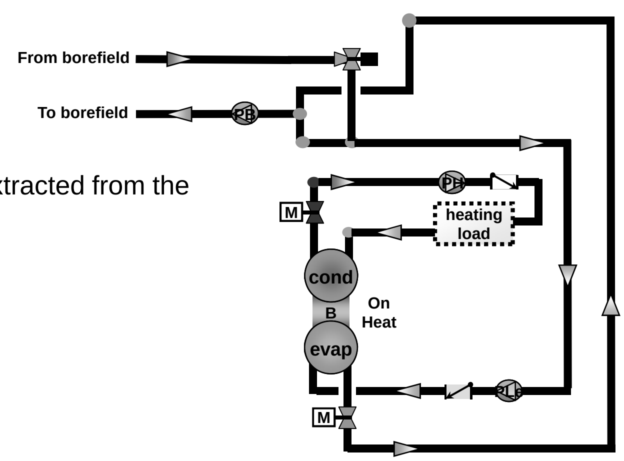
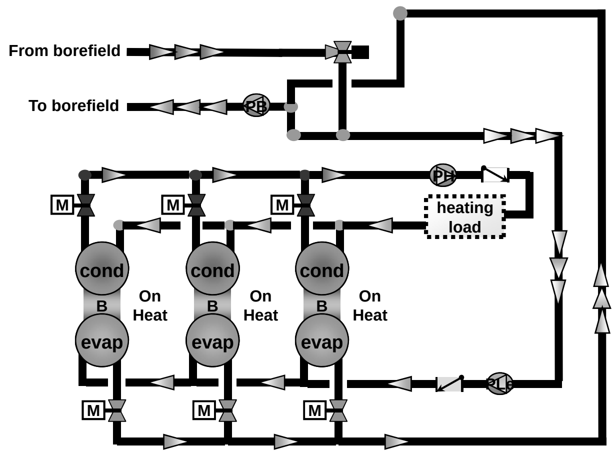
Operation and Control: Heating Only

Heating Only Mode Operation



- Heat is extracted from the borefield

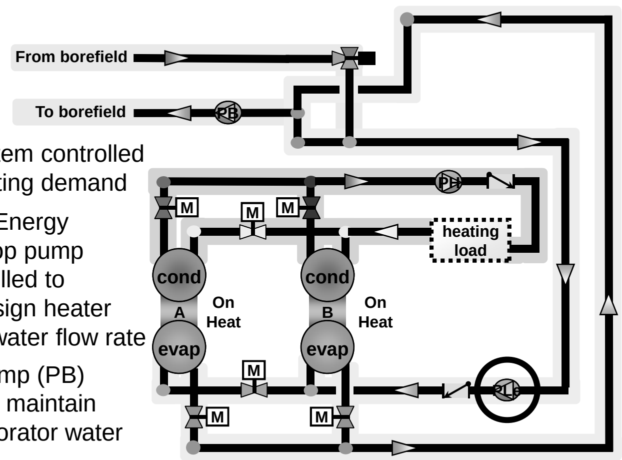
Multiple Chillers in Heating Mode



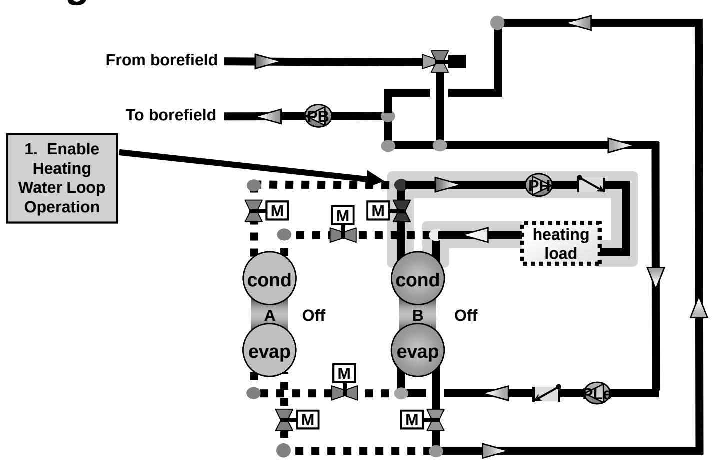
Heating Controls

bidirectional cascade
Heating Mode Control

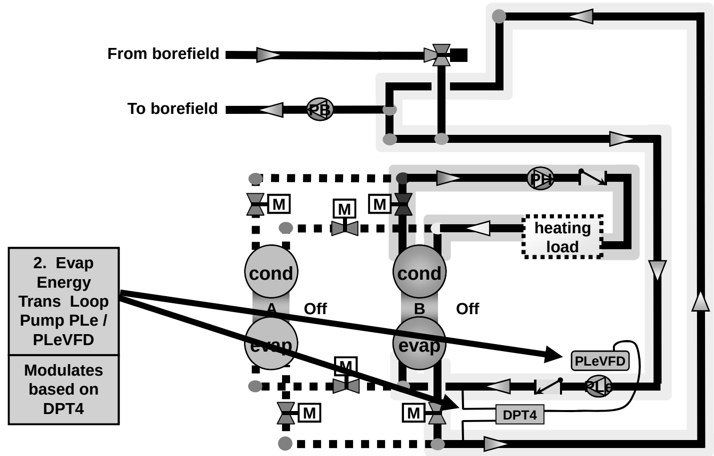
- Heating system controlled to meet heating demand
- Evaporator Energy Transfer Loop pump (PLe) controlled to maintain design heater evaporator water flow rate
- Borefield pump (PB) controlled to maintain heater evaporator water temperature



bidirectional cascade
Heating Mode Control



bidirectional cascade
Heating Mode Control



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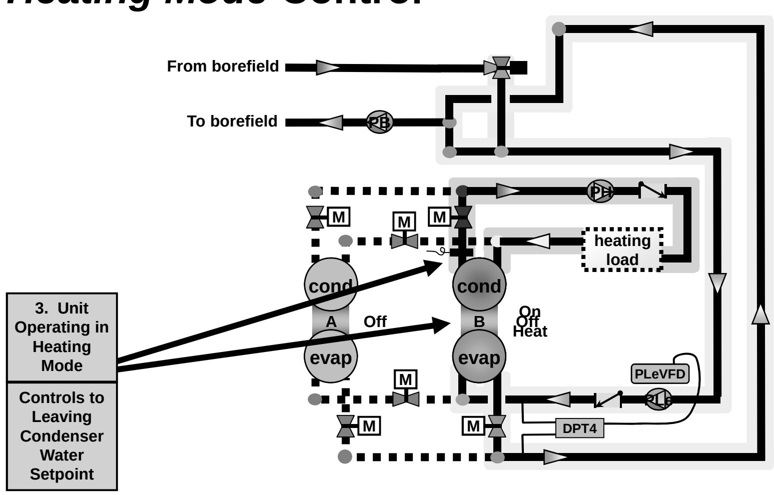
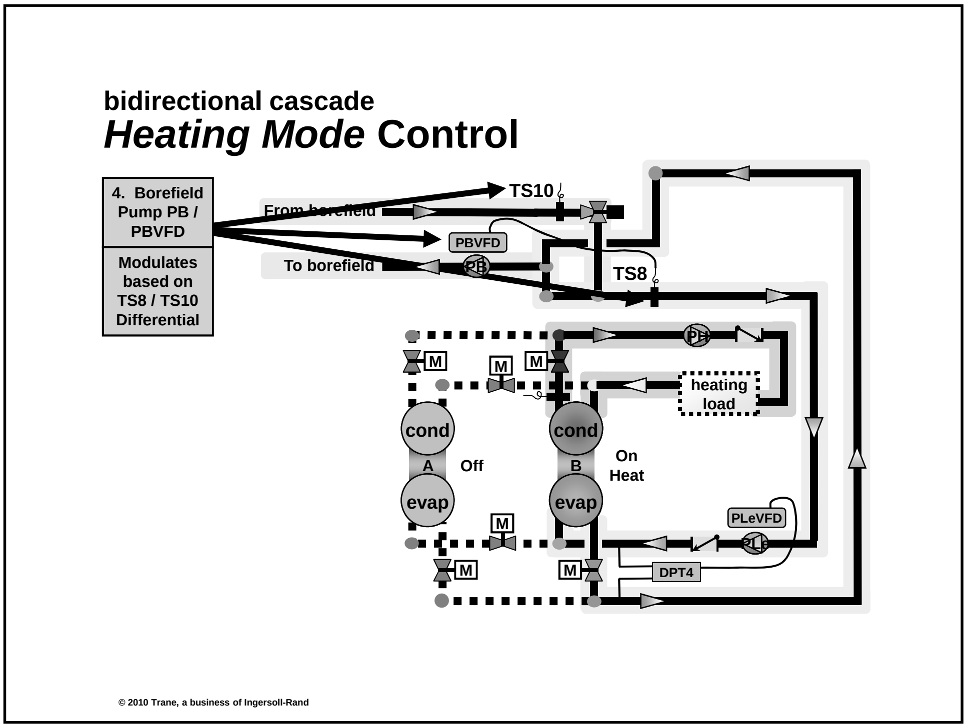
Heating Mode Control

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Heating Mode Control
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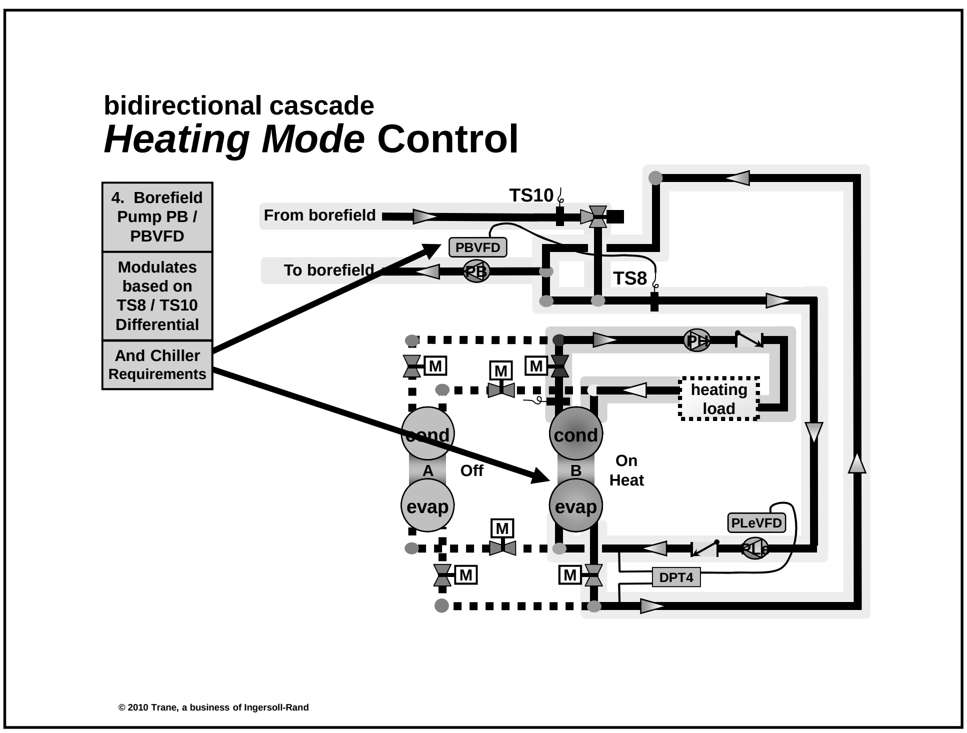
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Simultaneous Cooling and Heating

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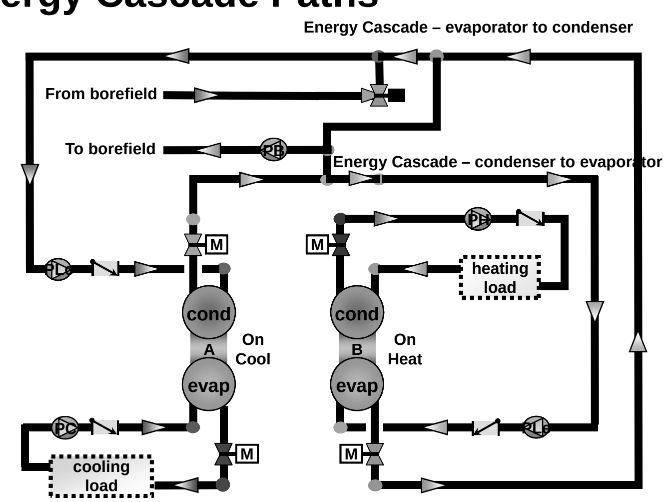
Cooling Dominant

cooling dominant mode

Energy Cascade Paths



Why Is Energy Cascade Beneficial?

- Distributed systems and other central systems
  - Mix this water – resulting in reduced efficiency
- Cascade
  - The chiller's condenser receives cool water – allowing it to operate efficiently
  - The heater's evaporator receives warm water – allowing it to operate efficiently

What Is the Cascade Worth?
Example

- One chiller operating in heat recovery mode
  - Compressor: 81.4 kW
- Two units, cascading energy
  - Chiller compressor: 28.5 kW
  - Heater compressor: 33.5 kW
  - Total of two compressors: 62 kW
  - 23.8% savings!

Simultaneous Cooling and Heating

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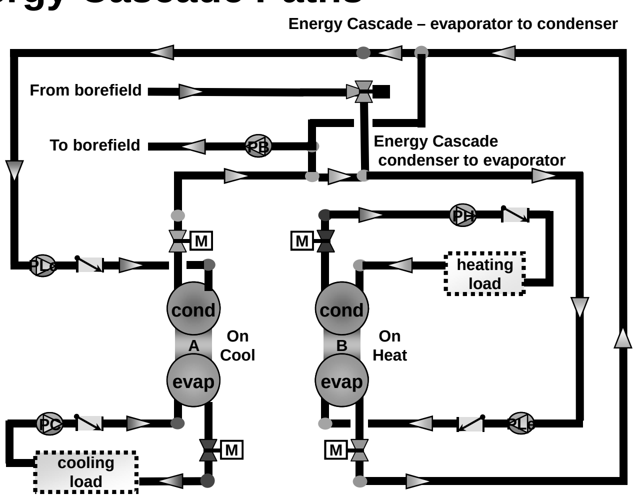
Heating Dominant

heating dominant mode

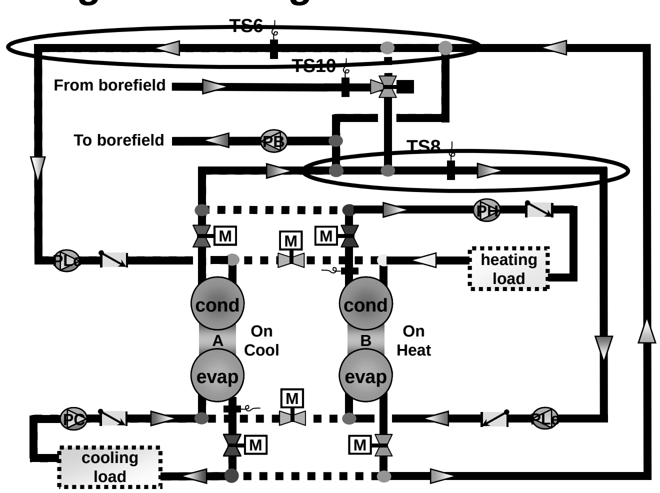
Energy Cascade Paths



Simultaneous Heating/Cooling Controls

simultaneous heating & cooling

Heating or *Cooling* Dominant?



simultaneous heating & cooling

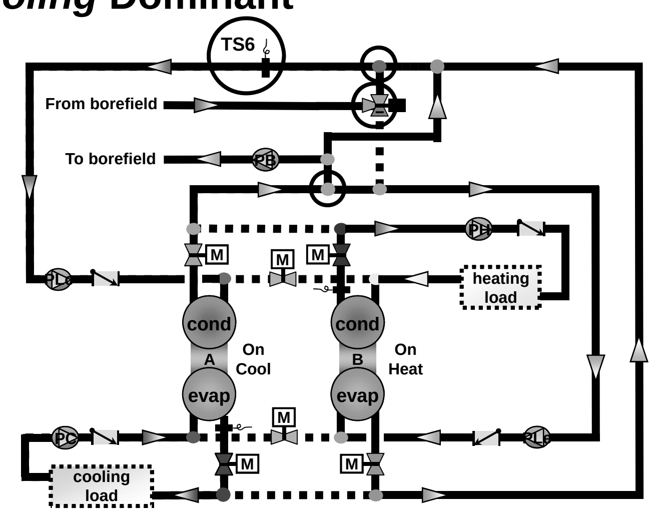
Cooling Dominant

- More BTUs are rejected to the Condenser Energy Transfer loop from the cooling unit(s)…

  than are extracted from the Evaporator Energy Transfer loop by the heating unit(s)
- The system is BTU excess
- The Condenser Energy Transfer loop is warmer than the borefield supply water temperature

simultaneous heating & cooling

Cooling Dominant



simultaneous heating & cooling

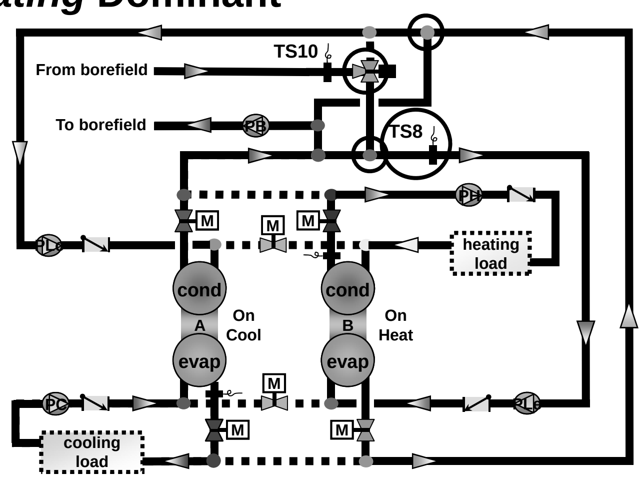
Heating Dominant

- More BTUs are extracted from the Evaporator Energy Transfer loop by the heating unit(s)…

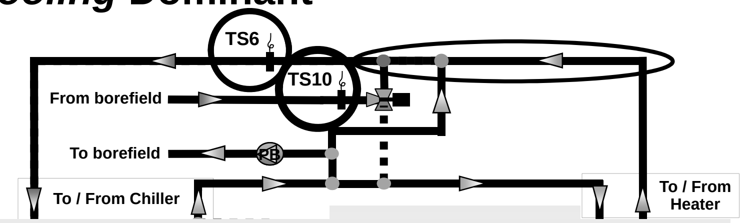
  than are rejected to the Condenser Energy Transfer loop by the cooling unit(s)
- The system is BTU deficit
- The Evaporator Energy Transfer loop is cooler than the borefield supply water temperature

simultaneous heating & cooling

Heating Dominant



simultaneous heating & cooling
Cooling Dominant



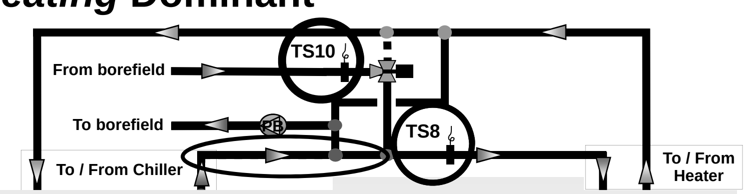
Cooling Dominant

- The system is BTU excess
- The Condenser Energy Transfer loop is warmer than the borefield

Transition to Heating Dominant

- The system becomes BTU deficit
- The Condenser Energy Transfer loop supply temperature drops below the borefield temperature

simultaneous heating & cooling
Heating Dominant



Heating Dominant

- The system is BTU deficit
- The Evaporator Energy Transfer loop is cooler than the borefield

Transition to Cooling Dominant

- The system becomes BTU excess
- The Evaporator Energy Transfer loop supply temperature rises above the borefield temperature

Central Geothermal System Design and Control

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Key Design Issues

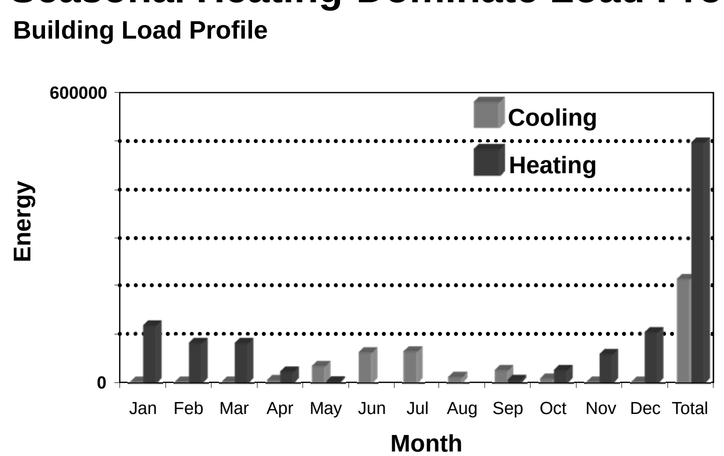
Key Design Issues

- Optimizing life-cycle costs
  - Borefield sizing
    - Supplemental heating
    - Auxiliary heat rejection
  - Load shedding economizer
- Freeze protection

optimizing life-cycle costs
Borefield Sizing

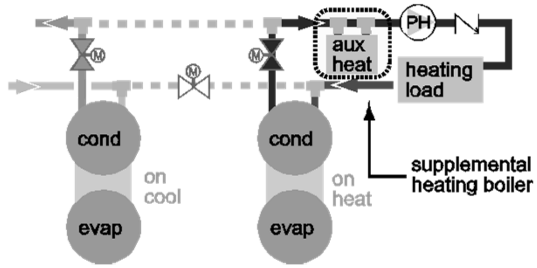
- Peak building demand
- Cumulative building demand
- Optimization
  - Reduce peak demand
  - Balance annual heating and cooling loads
  - Consider a hybrid system design

Seasonal Heating-Dominate Load Profile



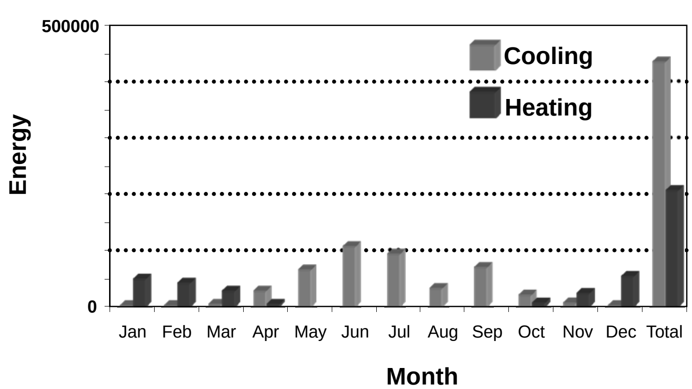
system options
Supplemental Heating

- Boiler downstream of condenser
- Use boiler setpoint several degrees lower than chiller setpoint
  - Avoids boiler "stealing" the load



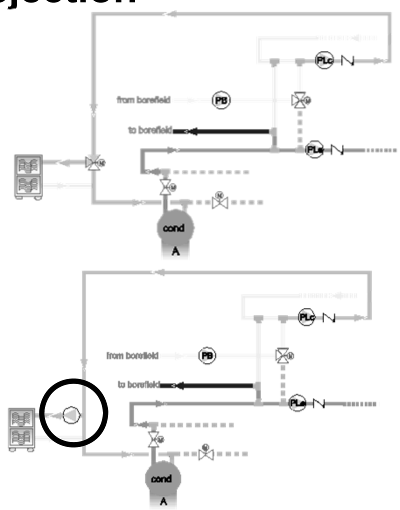
Seasonal Cooling-Dominate Load Profile

Building Load Profile



system options
Auxiliary Energy Rejection

- Use dry cooler or evaporative fluid cooler
  - Keeps fluid loop clean
- Pump options
  - Use energy transfer loop pump
    - Must be sized for tower pressure drop
  - Add separate pump – sidestream
    - Simpler, but additional pump



Building Load Profile Imbalance

- A heating-dominate building
  - Auxiliary heating system (e.g. modular boiler)
  - Load shedding economizer
- A cooling-dominate building
  - Auxiliary energy rejection (e.g. fluid cooler)
  - Add building heating load like domestic hot water
- Optimize the building life-cycle cost
  - Reducing borefield size
  - Increasing borefield utilization for energy efficiency

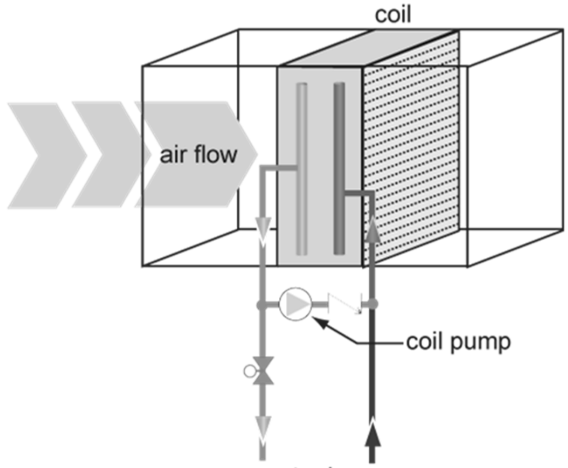
Freeze Protection

- Two considerations
  - Low evaporator temperature protection
  - Air handler coil freezing
- What's unique about the bidirectional geothermal system?
  - All systems and loops are interconnected
  - A decision to use antifreeze impacts all system elements

Freeze Avoidance Strategies

- Low evaporator temperature protection
  - Careful attention to borefield design low temperature limit
  - Limit the leaving evaporator temperature
  - Use supplemental heat (modular boiler) when evaporator temperature drops to the freezing threshold
- Air handler coil freeze protection
  - Freeze stat with full coil face coverage
  - Mixed-air blender
  - Pumped coils

Pumped Coil



Freeze Avoidance Strategies

- Pump and piping placement
  - Place pumps indoors
  - Bury all external piping below frost line

Freeze Avoidance Strategies

- Antifreeze
  - Desirable to avoid if possible
    - Cost and efficiency implications throughout the system
    - Glycol impact is worse for cooling operation than heating due to viscosity change
    - Shell and tube heat exchangers enable a lower evaporator temperature limit than plate and frame heat exchangers
  - If required, minimize its concentration

Considerations Summary

Central Geothermal System Design and Control

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Equipment Performance Requirements

bidirectional cascade

Desired Equipment Capabilities

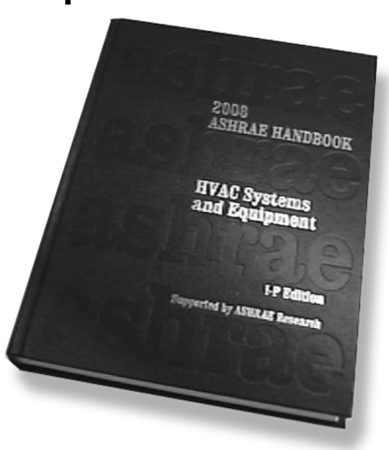
- Efficiency
- Operating Range
  - Temperatures
  - Flow rates
- Control
  - Leaving water temperature stability
  - Ability to switch modes

Unit Efficiency

- Can be up to 18% more efficient than ASHRAE 90.1-2007 requirements
- Dependent on selection conditions
- Make sure unit can unload efficiently while simultaneously making cold chilled water and hot condenser water
  - Centrifugal compressors may surge
  - Positive displacement compressors often a good fit

ASHRAE guidance

Temperatures



"For typical buildings, chillers normally provide hot water for space heating at 105°F to 110°F"

source: 2008 ASHRAE Handbook – HVAC Systems and Equipment, p. 8.20

Example: Positive Affects of Lower Hot Water Temperature

Hot Water Temperature	140°F	130°F	Positive Affect
Cooling Capacity (tons)	131.6	149.1	+ 13.3%
Heating Capacity (MBh)	2255	2422	+ 7.4%
Power (kW)	198.2	185.3	- 6.5% (that's good!)
Heating Efficiency (COP)	3.3	3.8	+ 15.1%

operating range

Temperatures

- Antifreeze (such as glycol)
  - Avoid if possible
  - Minimize amount (10% is better than 25 or 30%)
- Temperatures using water
  - 38°F chilled water
  - 140°F hot water
    - Using 130°F water
      - Increases unit capacity
      - Increases unit efficiency (15% better)
    - 130°F complements condensing boiler requirements
    - Proper question,
      "What hot water temperature do we need?"

operating range
Flows

Evaporator flow

- ASHRAE GreenGuide:
  - 1.2 to 2.0 gpm/ton
    - 12 - 20°F ΔT
- If Variable Primary Flow
  - Ensure adequate turndown
    - Design/Minimum > 2
  - 3-pass evaporator may be advantageous

Condenser flow

- ASHRAE GreenGuide
  - 1.6 to 2.5 gpm/ton
    - 12 - 18°F ΔT

Desirable Unit Controls

- Operate either in cooling or heating mode
- Setpoint stability
  - Unloading compressors maintain setpoints
  - Make 38°F water with no antifreeze
- Switch modes without turning compressor off
- Ability to respond to variable flow if applied in VPF system
  - 30% flow rate change per minute

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TRACE 700™ analysis

What's New in TRACE™ 700 v6.2.5

- Geothermal loop calculation methodologies
- Control algorithms for energy transfer pumps
- Default geothermal chiller-heater equipment
- Two new output reports
  - Geothermal Plant Peak Summary
  - Geothermal Energy Transfer Summary

TRACE 700 output
Geothermal Peak Load Summary

Monthly Peak Heating/Cooling Loads

Alternative: 1 - Optimized EarthWise VAV
Plant: Bidirectional cascade chillers

	Time of Peak Plant Cooling Load					Time of Peak Coincident Cooling/Heating Load				
	Peak Cooling Load tons	Coincident Heating Load mbh	Available Condenser Heat mbh	Outside Air DB/WB (°F)	Date-Time	-- Coincident Cooling Load tons	Peak --- Heating Load mbh	Available Condenser Heat mbh	Outside Air DB/WB (°F)	Date-Time
Jan	55	495	1,233	29/28	Dsn - 8 am	55	495	1,233	29/28	Dsn - 8 am
Feb	99	520	1,442	33/30	Dsn - 8 am	99	520	1,442	33/30	Dsn - 8 am
Mar	140	204	2,023	45/43	Dsn - 8 am	140	204	2,023	45/43	Dsn - 8 am
Apr	188	115	2,232	53/49	Dsn - 8 am	188	115	2,232	53/49	Dsn - 8 am
May	176	156	2,233	67/55	Dsn - 8 am	176	156	2,233	67/55	Dsn - 8 am
Jun	177	72	2,247	86/71	Dsn - 4 pm	177	72	2,247	86/71	Dsn - 4 pm
Jul	190	72	2,249	89/73	Dsn - 4 pm	190	72	2,249	89/73	Dsn - 4 pm
Aug	187	72	2,251	88/73	Dsn - 3 pm	187	72	2,251	88/73	Dsn - 3 pm
Sep	168	73	2,247	83/70	Dsn - 3 pm	168	73	2,247	83/70	Dsn - 3 pm
Oct	196	98	2,233	54/52	Dsn - 8 am	196	98	2,233	54/52	Dsn - 8 am
Nov	156	227	2,232	44/44	Dsn - 8 am	156	227	2,232	44/44	Dsn - 8 am
Dec	99	380	1,442	38/35	Dsn - 8 am	99	380	1,442	38/35	Dsn - 8 am
Annual	196	520	2,251	54/52	Oct/Dsn - 8 am	1,831	2,484	24,062	54/52	Oct/Dsn - 8 am

TRACE 700 output
Geothermal Energy Transfer Summary

Geothermal Energy Transfer Summary
By Trane

Geothermal Plant - Ground-Source Heat Transfer

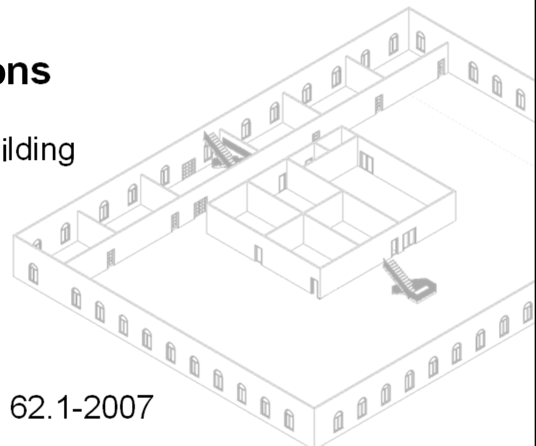
Geothermal Plant - Groui

Alternative: 1 - Optimized Ear
Plant: Bidirectional cascade (

Year: 1

	QExtracted from Geother		Heat Rejected to Auxiliary Cooling				Heat Supplied from Supplemental Boiler			
Month	ton-hrs	kBtu	peak tons	ton-hrs	kBtu	kWh	peak MBH	ton-hrs	kBtu	kWh
Jan	3,749	44,984	0	0	0	0	10	4	53	16
Feb	2,580	30,954	0	0	0	0	0	0	0	0
Mar	1,739	20,867	0	0	0	0	5	0	0	0
Apr	443	5,319	0	0	0	0	5	17	206	60
May	1,637	19,648	0	0	0	0	13	80	964	283
Jun	422	5,068	0	0	0	0	5	15	178	52
Jul	130	1,561	0	0	0	0	3	4	47	14
Aug	453	5,432	0	0	0	0	7	14	167	49
Sep	998	11,977	0	0	0	0	10	38	451	132
Oct	684	8,211	0	0	0	0	5	13	156	46
Nov	1,878	22,538	0	0	0	0	5	0	0	0
Dec	2,660	31,914	0	0	0	0	0	0	0	0
Annual	17,373	208,473	0	0	0	0	13	185	2,223	651

Study Assumptions



- Three-story office building
  - Atlanta, GA
  - Philadelphia, PA
  - St. Louis, MO
- 60,000 square feet
- Complies with ASHRAE 90.1-2007, 62.1-2007

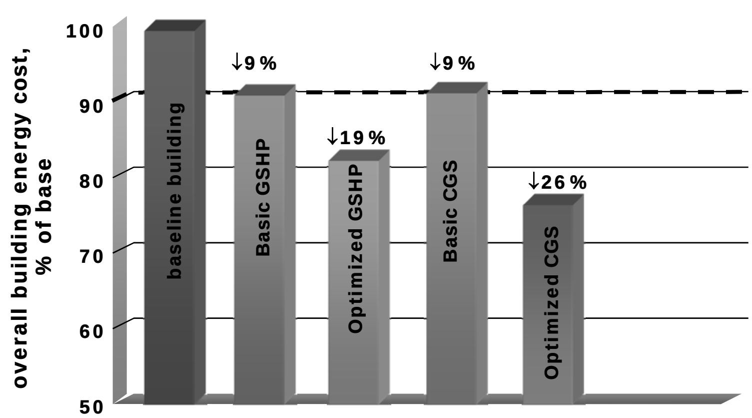
Central Geothermal System Comparison

- Central Geothermal System (CGS)
  - VAV-reheat
  - Enthalpy economizer
  - Primary-secondary flow
- Optimized CGS
  - Increased space setpoint (+1°F)
  - Low-temperature air VAV (with reset)
  - Ventilation reset
  - Enthalpy economizer
  - Variable primary flow
  - Reduced water flow rates

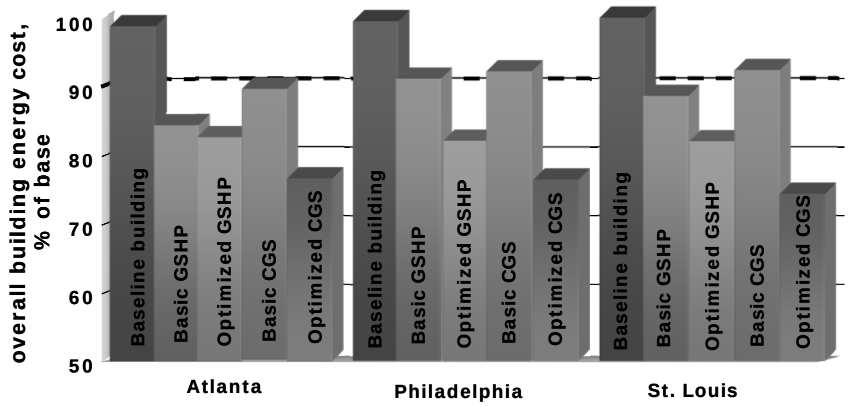
System Comparisons

- 90.1-2007 Appendix G Baseline
  - VAV-reheat, DX cooling, fossil fuel heating
  - No economizer required (all locations)
- Ground Source Heat Pump (GSHP)
  - Dedicated OA to heat pump inlet, room neutral conditions
  - 90.1-2007 minimally compliant equipment
- Optimized GSHP
  - Dedicated OA to space, 55º dew point
  - Total energy wheel

System Comparison Philadelphia



System Comparison
All locations



summary
Central Geothermal Systems

- Advantages
  - Centralize service and maintenance is centralized
  - Superior acoustic options
  - Airside flexibility
- Operation and control
  - Efficient cascading of simultaneous energy streams
  - Efficiently provides both chilled and hot water temperature control
- Equipment with wide operating range is available
- Analysis results show significant savings

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- Insightful topics on HVAC system design:
  - Chilled-water plants
  - Air distribution
  - Refrigerant-to-air systems
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  - Industry standards and LEED
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  - Acoustics
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  - Dehumidification

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