Status of the Geothermal Industry
A Hydrogeologist's Perspective

Presented to

NEIWPCC

New England Interstate Water Pollution Control Commission

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Geothermal Innovation

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Outline

troductions
ptimizing the Earth Couple
- The importance of groundwater flow
- Underground Thermal Energy Storage
  - »Borehole Thermal Energy Storage (BTES)
  - »Aquifer Thermal Energy Storage (ATES)

ne Swedish and Dutch Geothermal Experience
nvironmental Impacts
nergy Efficiency and Economics
ummary & Conclusions

A Hydrogeologist's Perspective

Mark A. Worthington, Principal Hydrogeologist

Professional Background
- MS Hydrology and Water Resources, University of Arizona
- Hydrogeologist with 24 years environmental consulting experience in New England
- MA LSP, ME CG, LEED AP, IGSHPA accredited
- Adjunct Instructor at Massachusetts Maritime Academy
- Charter / Board Member of NEGPA

Formed Underground Energy, LLC in 2009
- Goal is to commercialize underground thermal energy storage in US

Geothermal Industry Observations:
- Residential market dominated by drillers and HVAC contractors
- Commercial / Institutional market dominated by mechanical engineers
- Primary improvements in geothermal cost/performance will come from optimizing the Earth coup
  - Secondary will be evolutionary improvements in drilling technology

Environmental Hydrogeologist	Geothermal Hydrogeologist
Perform Hydrogeologic Investigations	Perform Hydrogeologic Investigations
Manage Remediation Projects	Manage Geothermal Projects
Delineate contaminant plumes	Design beneficial thermal plumes
Remediate contaminant plumes	Operate beneficial thermal plumes
Render LSP opinions	Render LSP opinions

Components of a Conventional Ground-Source Heat Pump System

terior HVAC

Heat Pump

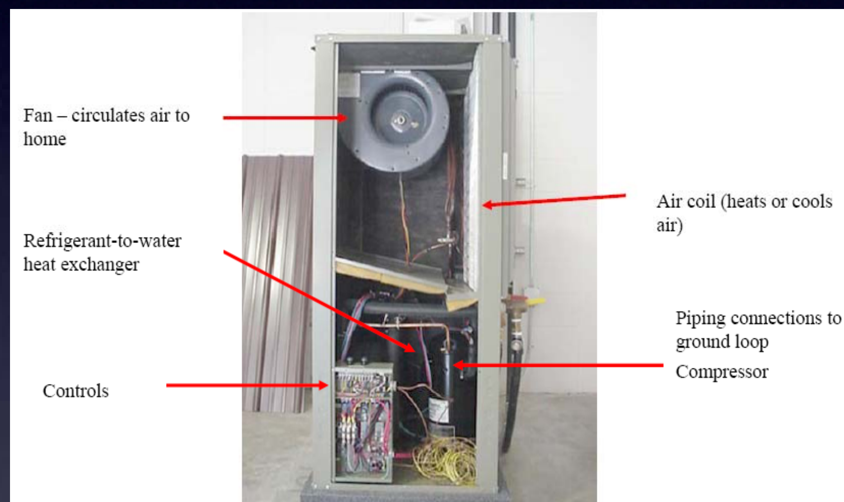
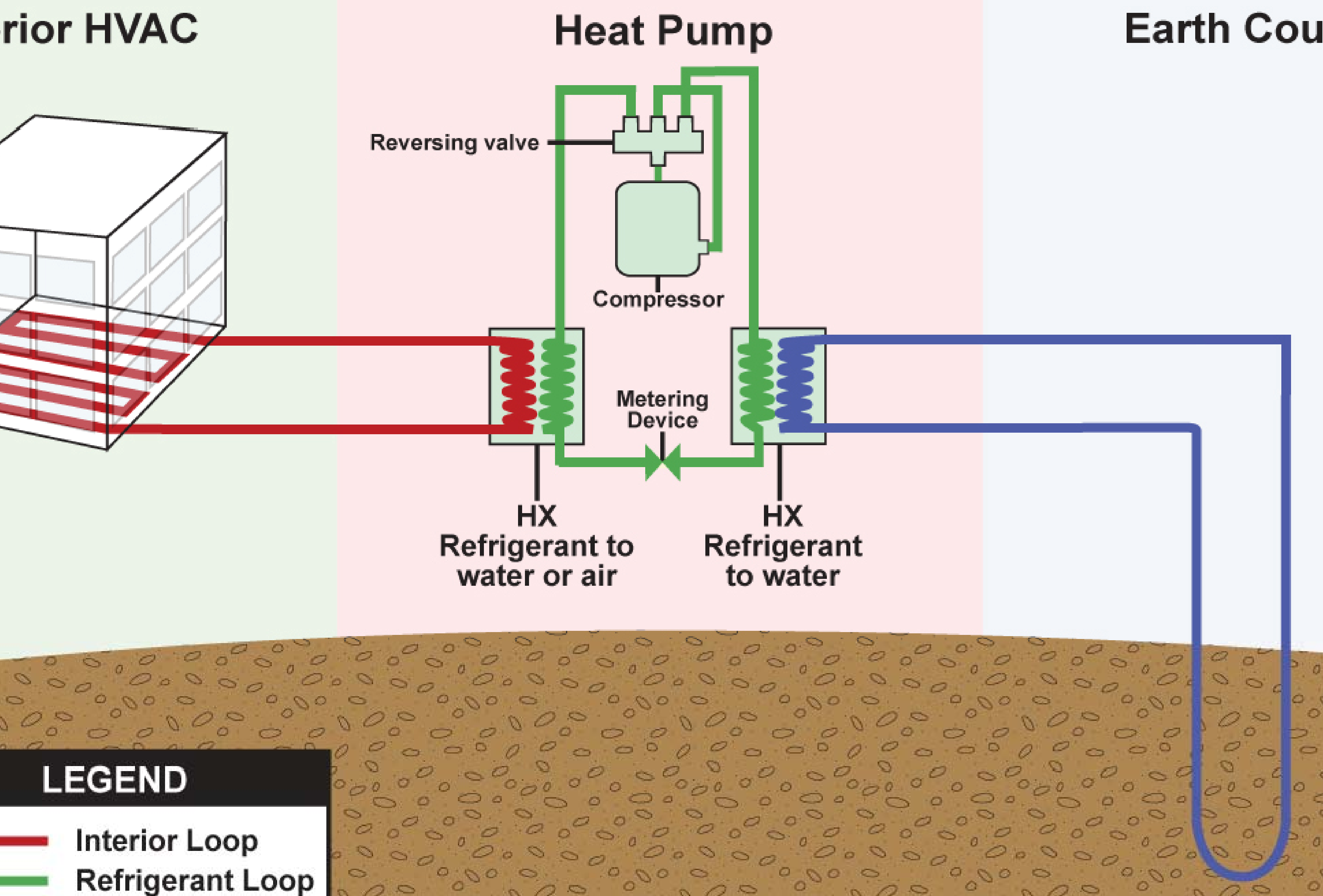


Figure 4
Typical Water-to-air Heat Pump Unit
(Kavanaugh, 2008)

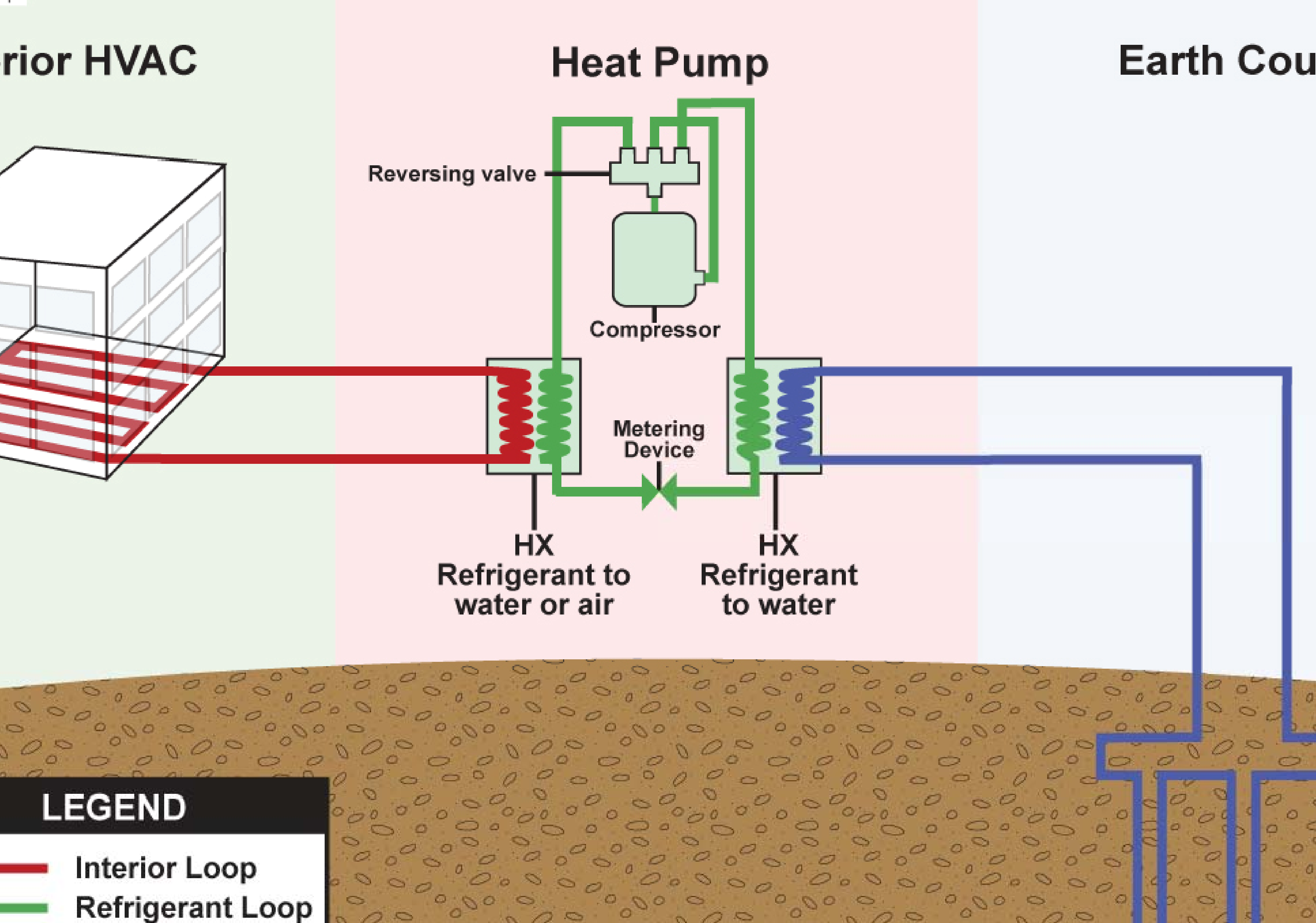
Ideally, the ground exchange loop increases the efficiency of the heat pump

Earth Coupl
Ground Heat Excl
Ground Loo

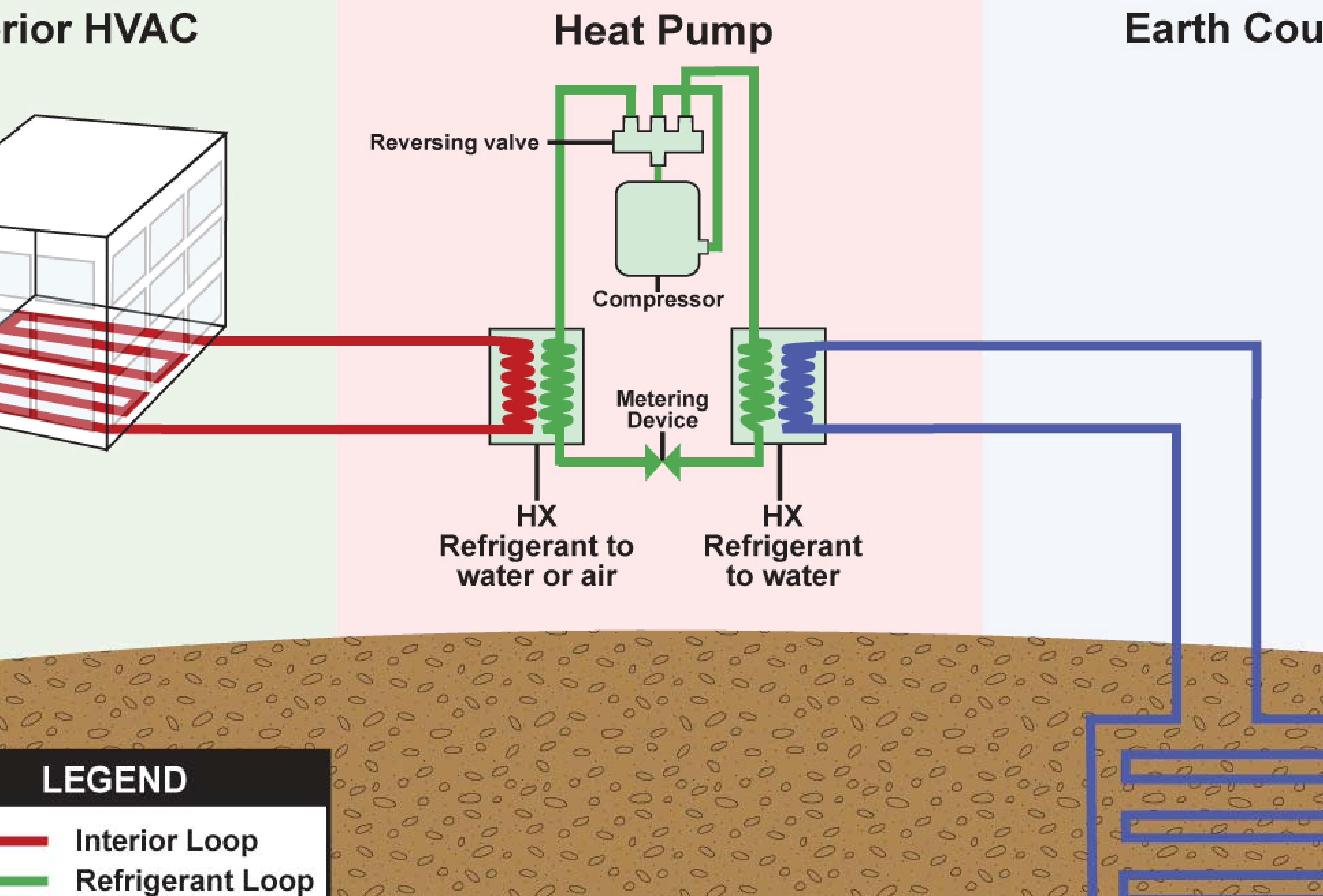
Heating and Cooling System



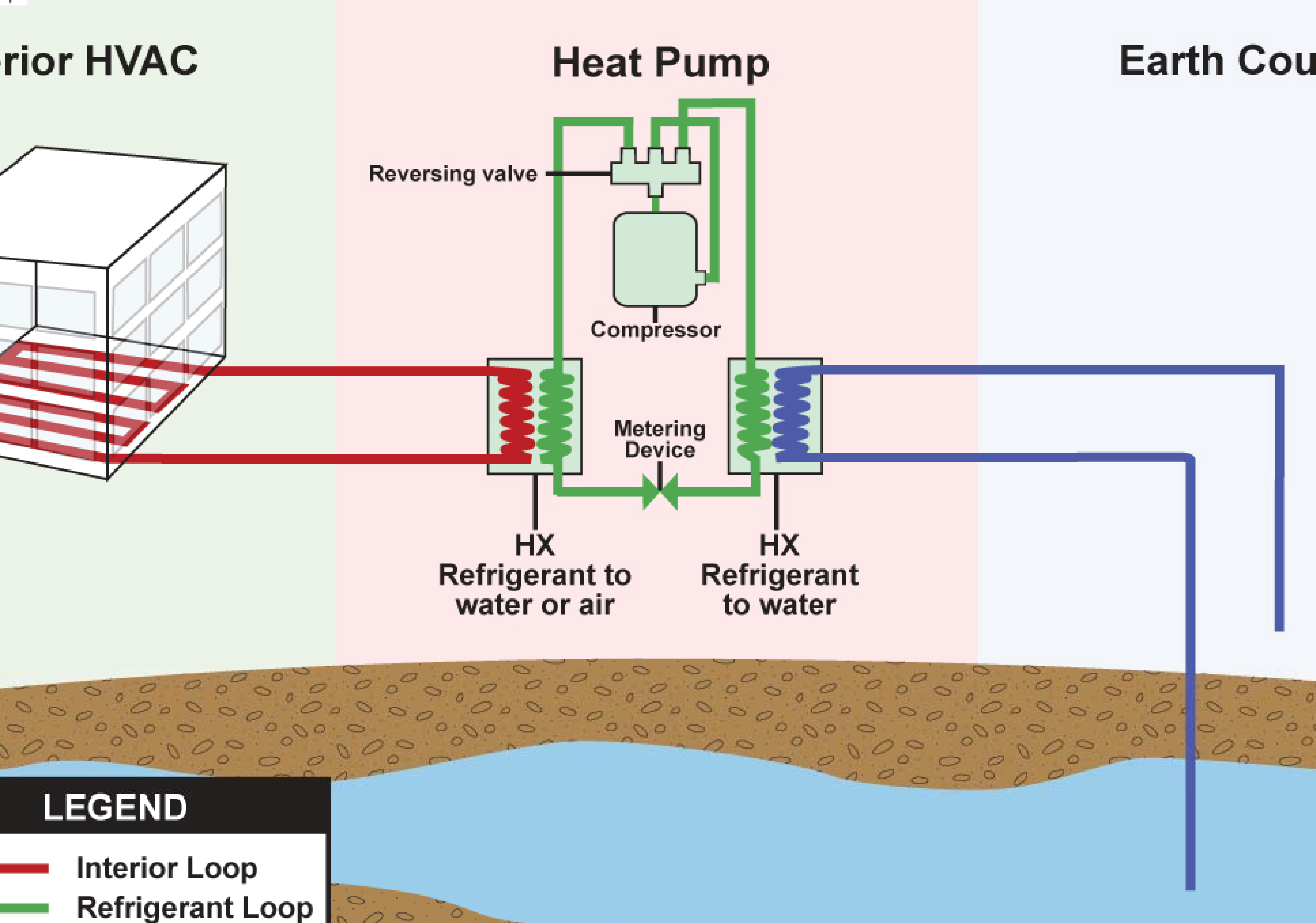
Closed-Loop System

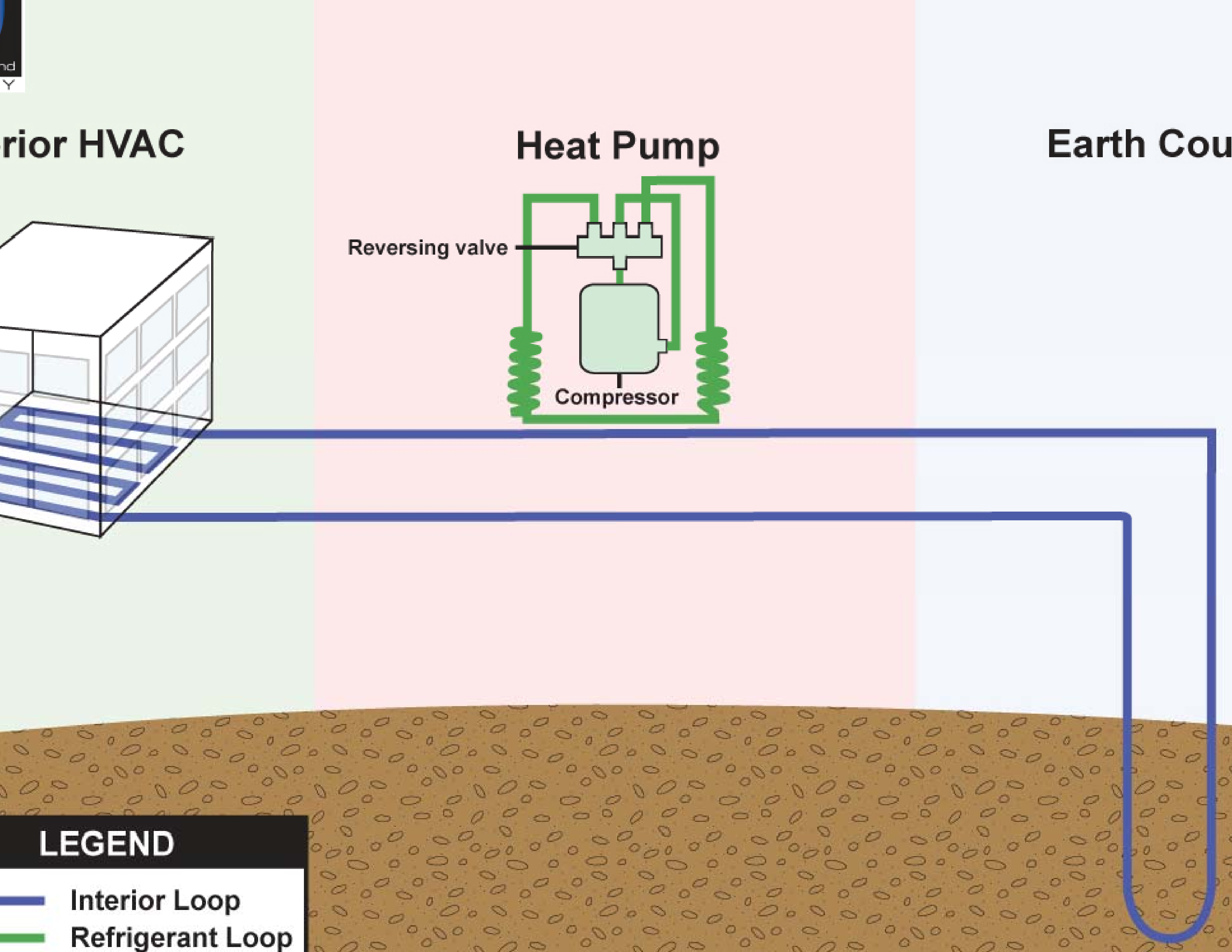


Closed-Loop System



Open-Loop System




rior HVAC
Heat Pump
Earth Cou
Reversing valve
Compressor
LEGEND
Interior Loop
Refrigerant Loop

Groundwater Flow and the Earth Coup

Advective heat transport via groundwater flow is usually the dominant heat transfer mechanism in Earth-coupled system

If the system is designed to dissipate thermal energy into the subsurface, then a high rate of groundwater flow is desirabl

If the system is designed to store thermal energy in the subsurface, then a low rate of groundwater flow is desirable.

For large (> 150 ton) systems, a simple groundwater study may be the best first step in designing the system.

Seasonal Thermal Energy Storage

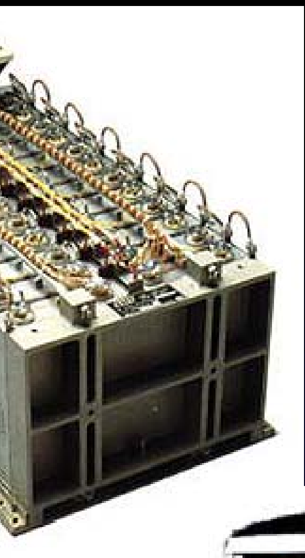
Ice house in Boxborough, MA

Ice storage in Iran

oncept:

- Transfer heat to/from water during hot or cold weather
- Inject the water into a borehole array (BTES) or an aquifer (ATES) for seasonal thermal energy storage
- Recover stored hot or cold water and use it in any application where it

Medium?



Underground Thermal Energy Storage (UTES)

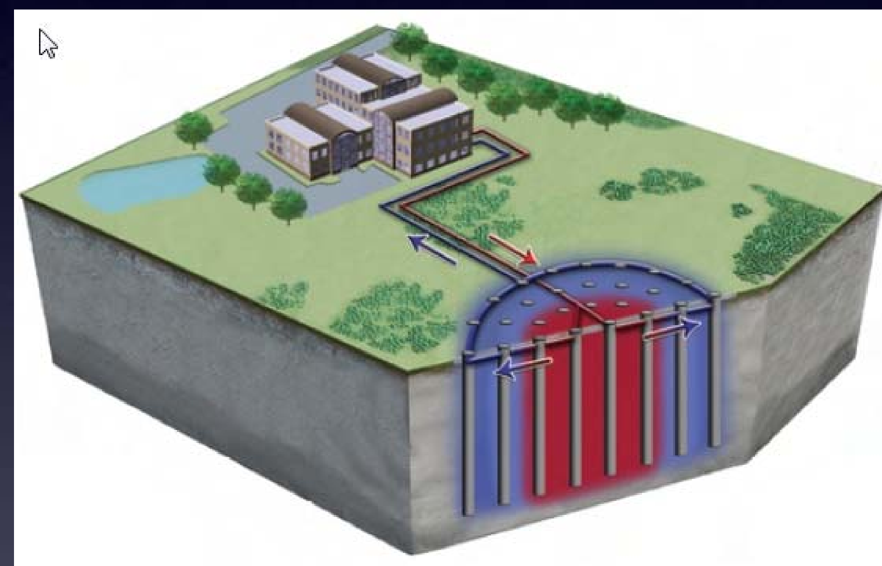
uifer Thermal Energy Storage

TES

- Open Loop (hydraulically balanced)
- Seasonal flow reversal (well-to-well)
- Groundwater storage medium
- Economic efficiencies of scale

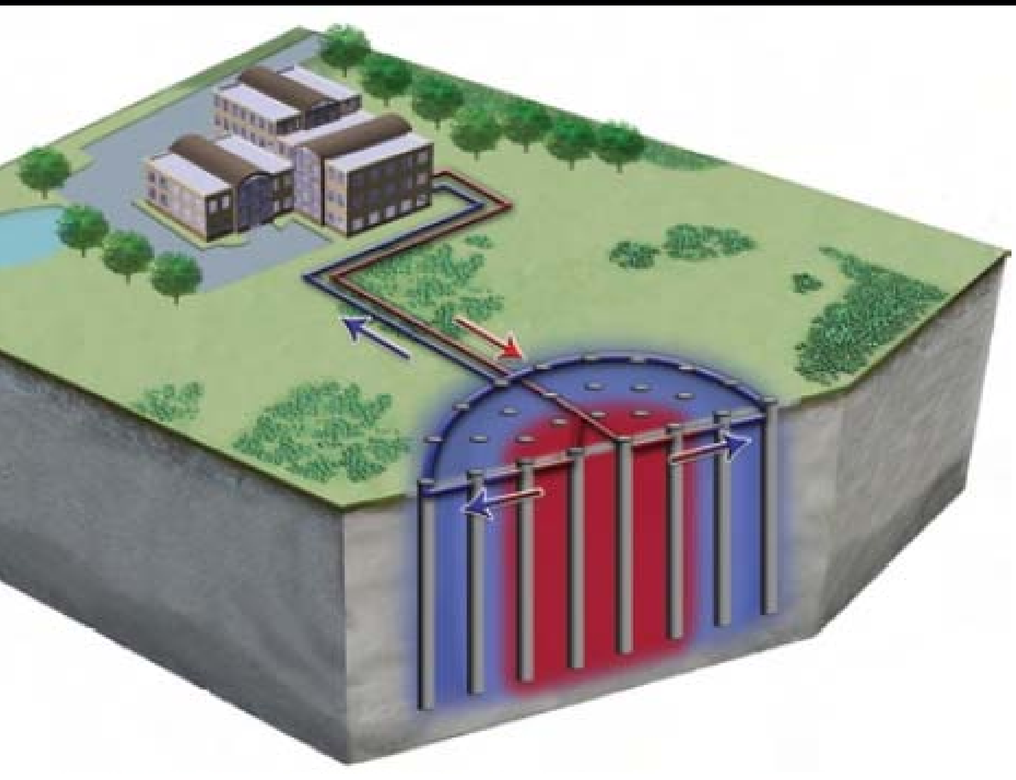
Borehole Thermal Energy Sto

BTES

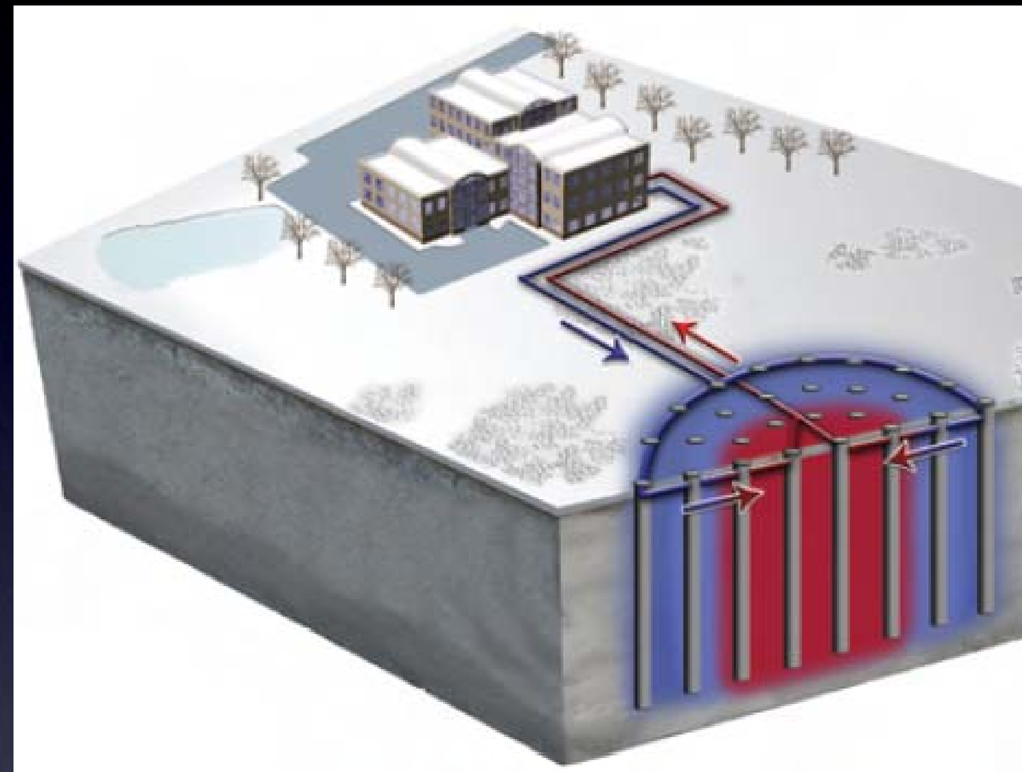


- Closed loop
- Seasonal flow reversal (GHX)
- Soil/rock storage medium
- Cost varies with thermal capacit

Summer

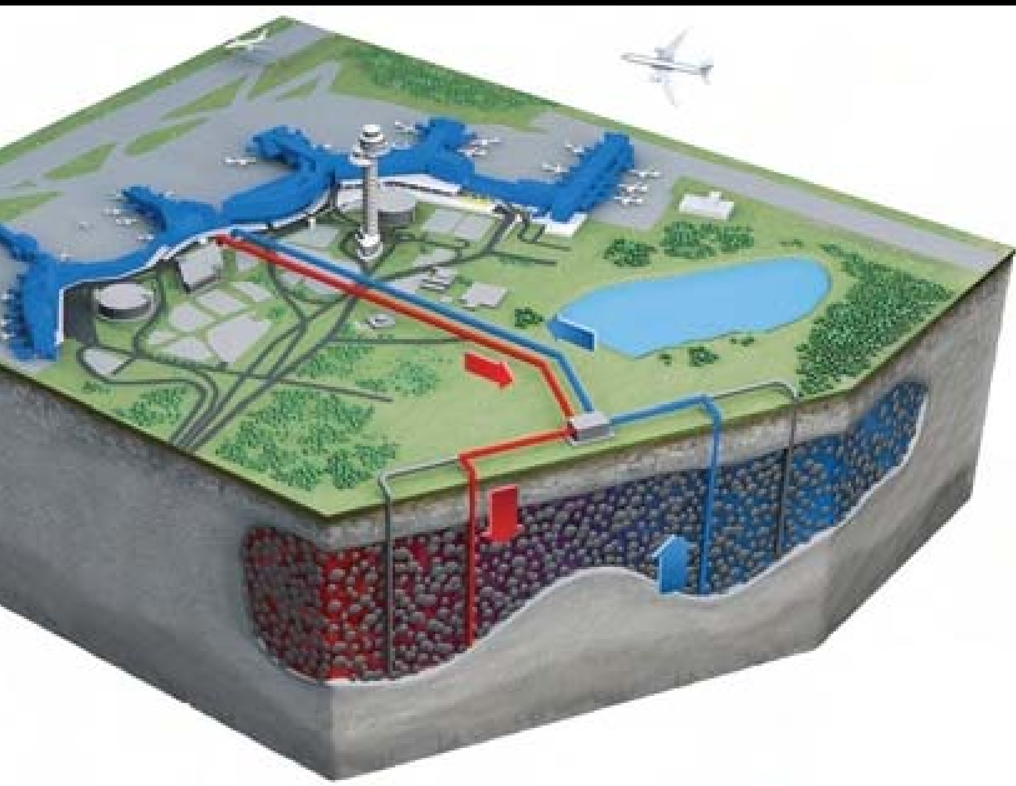


Winter

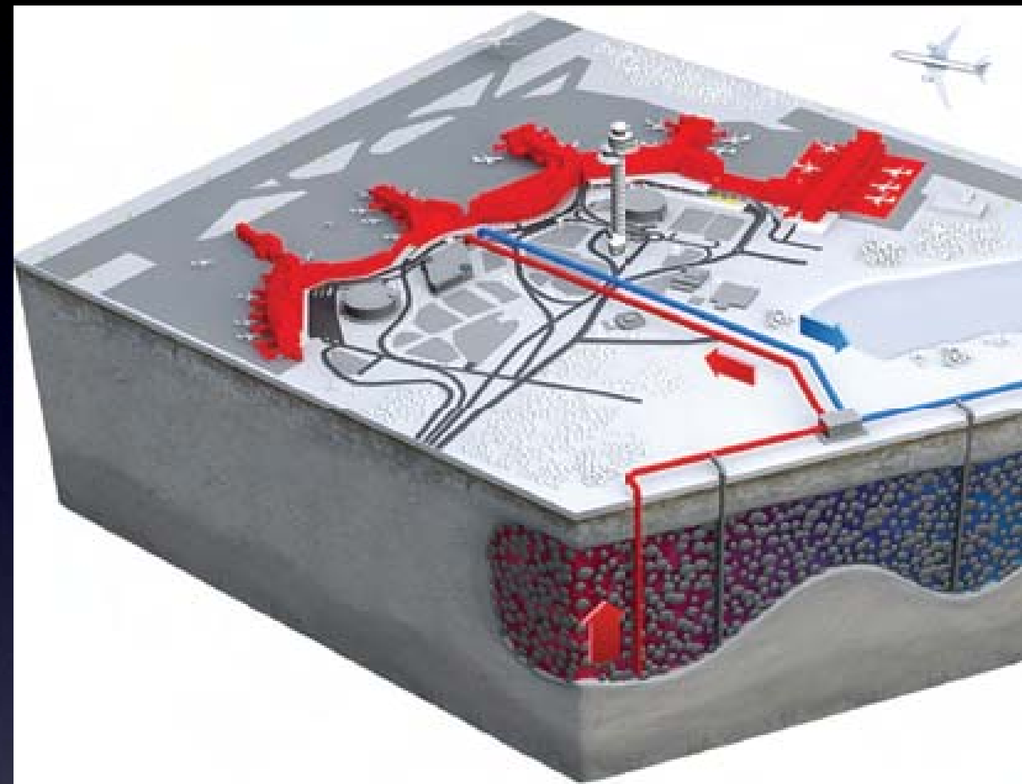


Closed loop
Radial array configuration – may use multiple arra
Seasonal reversal of flow within the loop
Small footprint on storage site

Summer



Winter



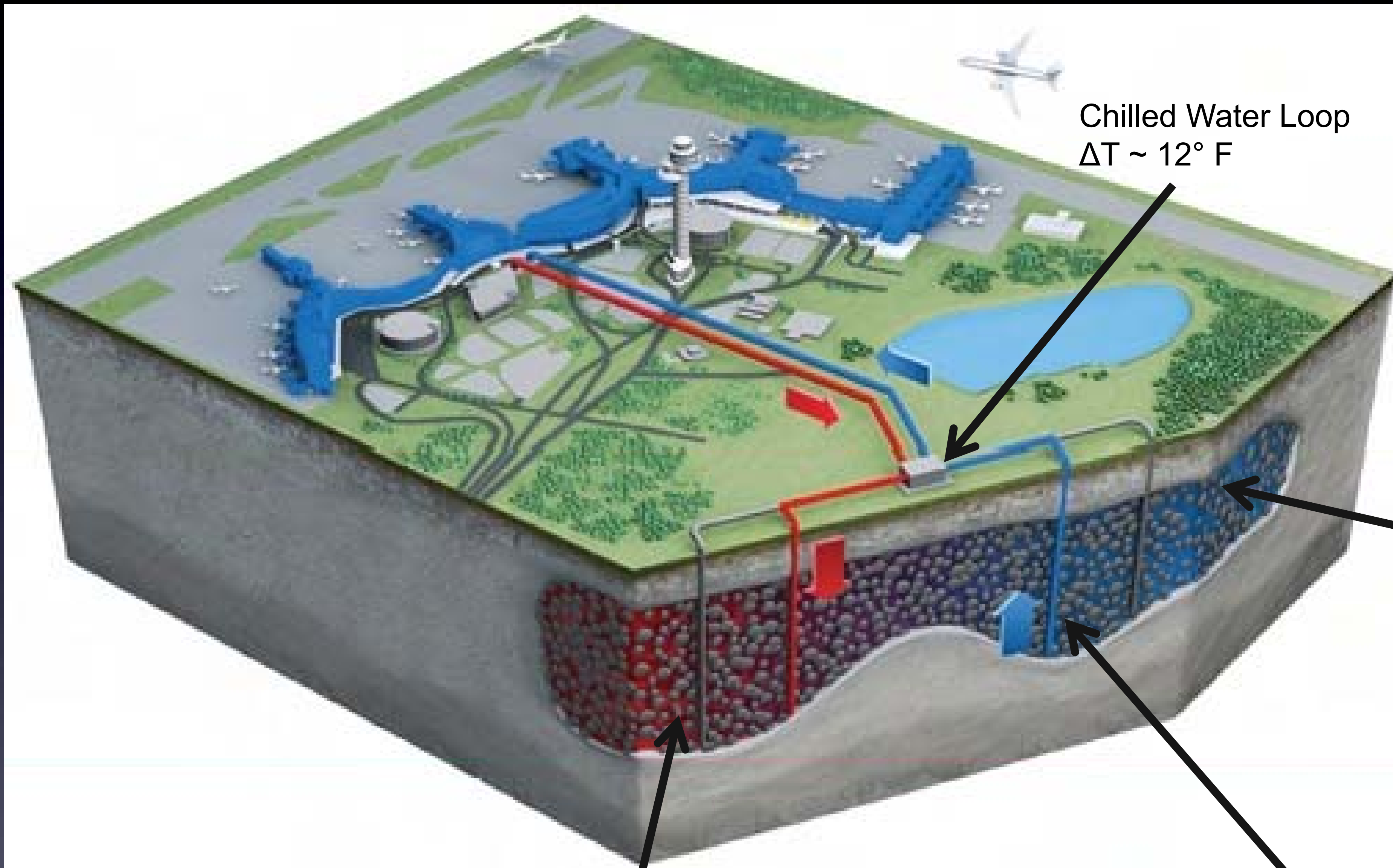
Seasonal thermal energy storage enabled by:

- High heat capacity of (ground)water
- Dynamics of fluid flow in porous media
- Low ΔT, low advection
- Hydraulic modeling and management of aquifer

Open loop with separate warm and cold stores

Seasonal reversal of warm and cold withdrawal / injection

ATES for Cooling



TES Technical Requiremen

A suitable temperate climate with seasonally variable thermal lo

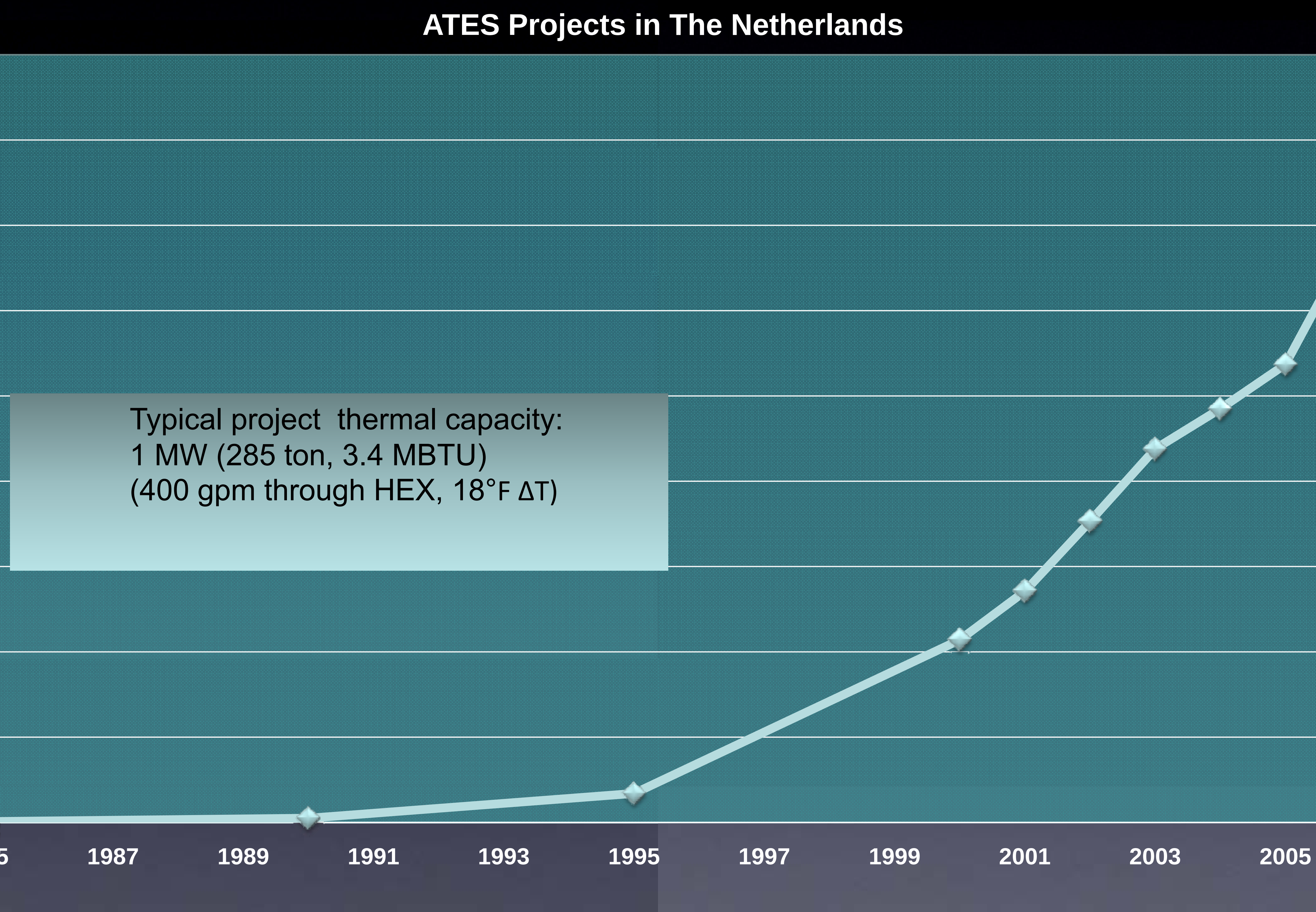
An Aquifer!

- High transmissivity (T = Kb)
- Reasonable depth / thickness
- Reasonable hydraulic gradient ($dh/dx \leq 10^{-3}$)
- Acceptable water quality
- Space for cold and warm store areas

Favorable regulatory climate

Practitioner team with appropriate experience and skill set

ES Growth in The Netherland



ES Growth in The Netherland

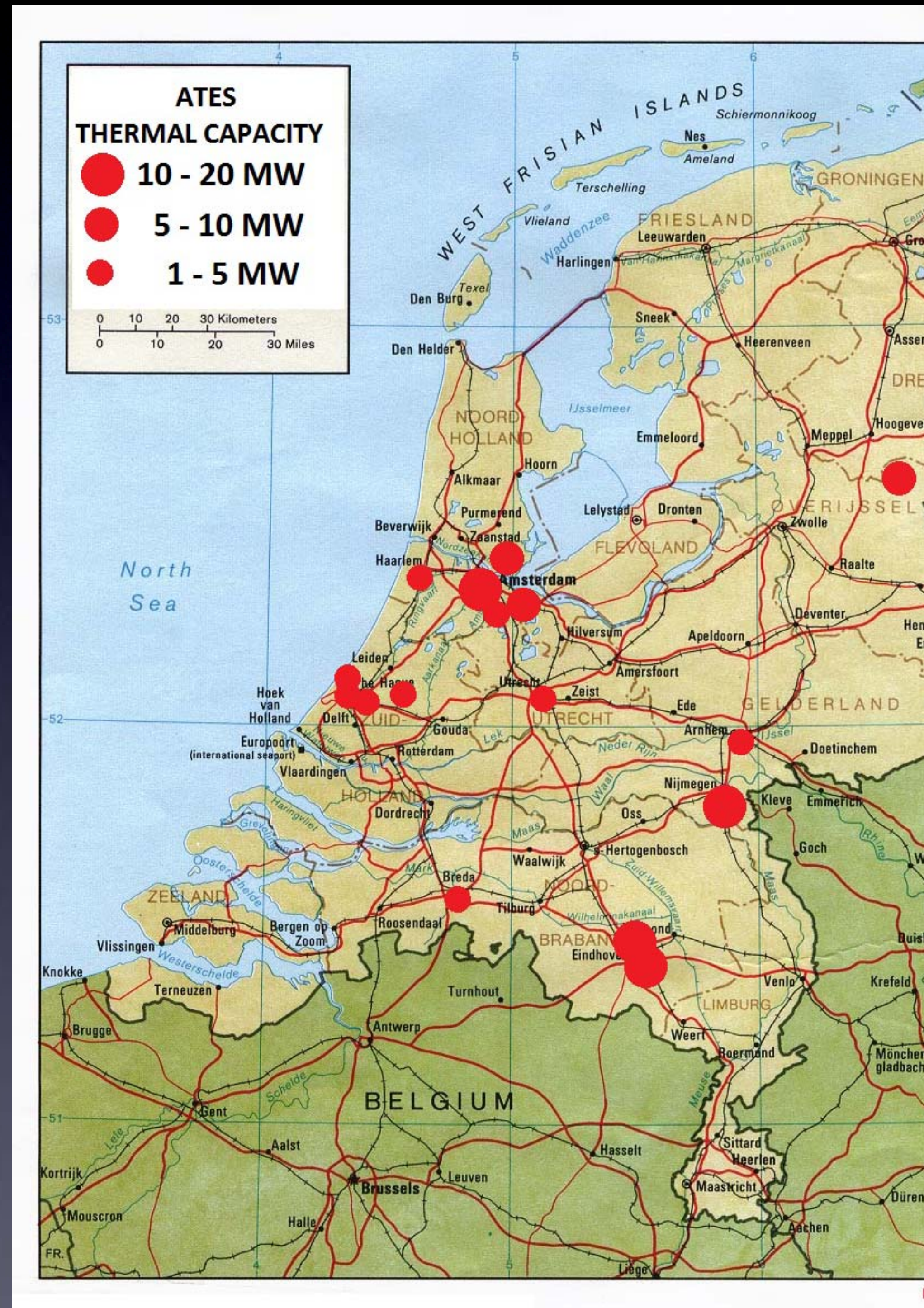
1990

2000

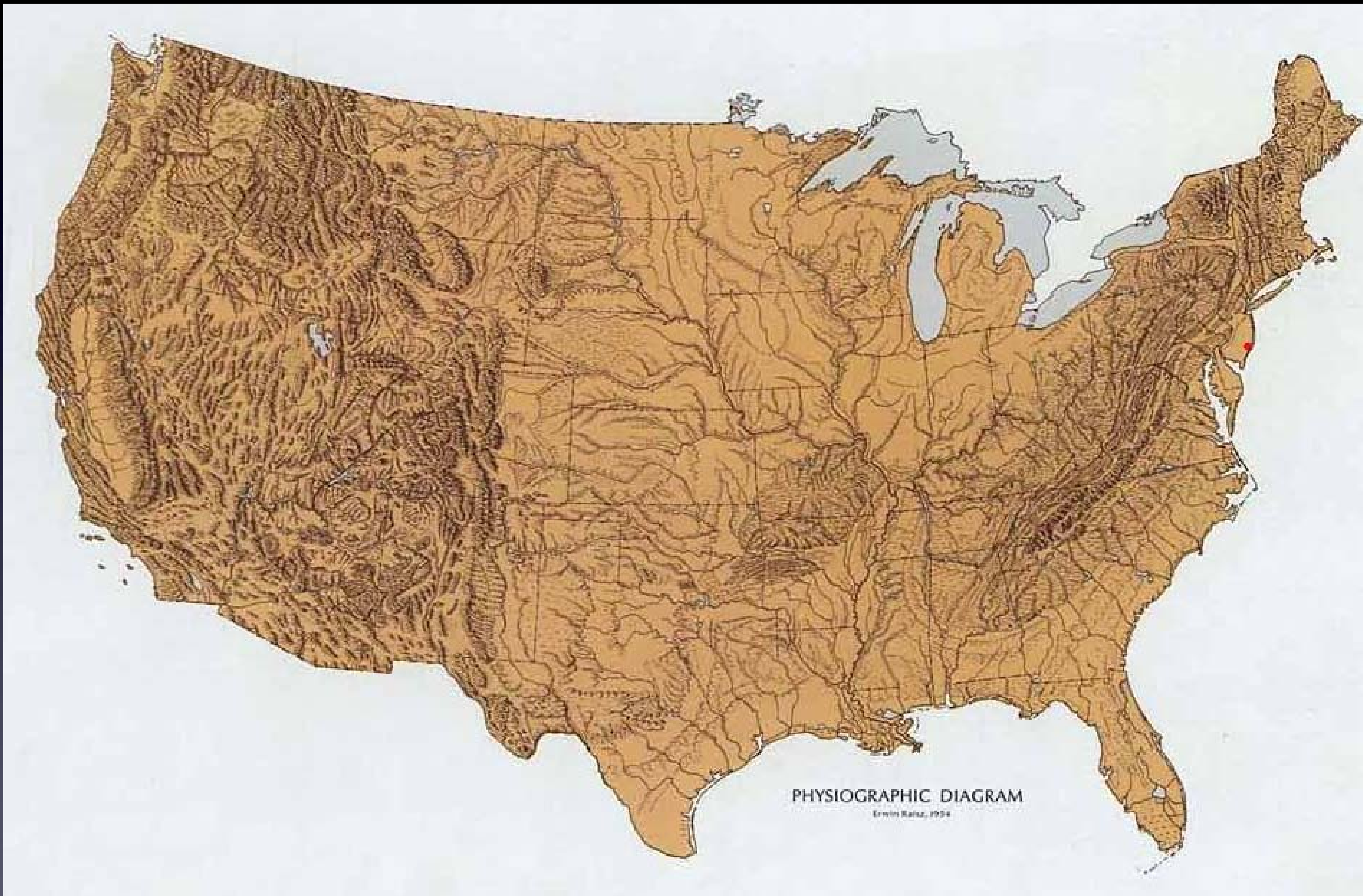
2010

Systems in The Netherlands

- ustrial park – Hardenberg (5.0 MW)
- ent office park - The Hague (3.0 MW)
- k housing project – Haarlem (1.5 MW)
- mixed development – Breda (4.0 MW)
- ade Wharf mixed developm. – Amsterdam (4.0 MW)
- Campus – Eindhoven (20 MW)
- housing project I – The Hague (1.2 MW)
- Campus – Utrecht (3.5 MW)
- mixed development – Amsterdam (6.5 MW)
- gh-Tech Campus – Eindhoven (10 MW)
- e mixed development – Arnhem (construction stage, 3.8 MW)
- pus – Amsterdam (construction stage, 15 MW)
- hospital – Nijmegen (construction stage, 15 MW)
- housing project II – The Hague (0.9 MW)
- housing project – Zoetermeer (1.3 MW)

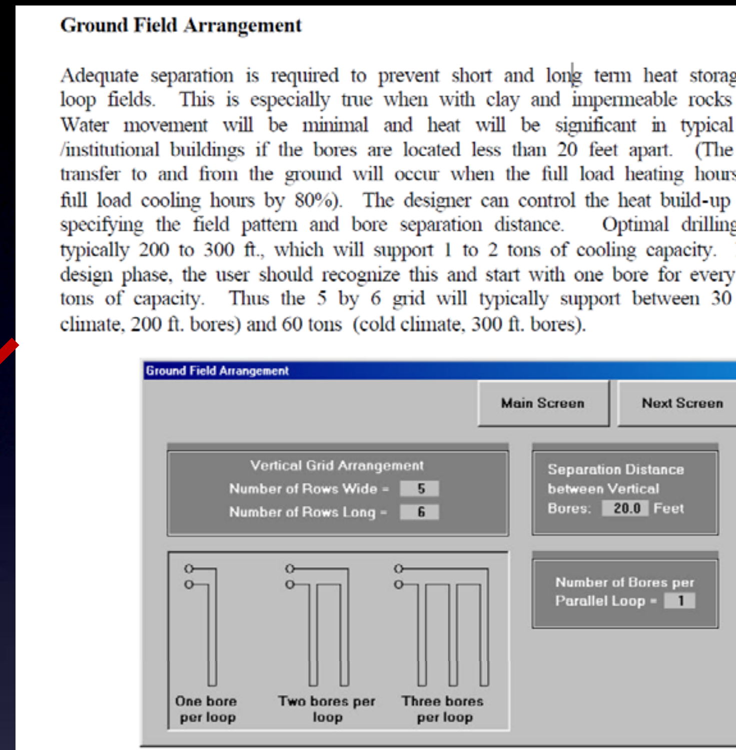


Systems in The United States



Richard Stockton College, Pomona, NJ ([illegible] MW)

Geothermal Design Practic


Ground Field Arrangement

Adequate separation is required to prevent short and long term heat storag
loop fields. This is especially true when with clay and impermeable rocks
Water movement will be minimal and heat will be significant in typical
/institutional buildings if the bores are located less than 20 feet apart. (The
transfer to and from the ground will occur when the full load heating hours
full load cooling hours by 80%). The designer can control the heat build-up
specifying the field pattern and bore separation distance. Optimal drilling
typically 200 to 300 ft., which will support 1 to 2 tons of cooling capacity.
design phase, the user should recognize this and start with one bore for every
tons of capacity. Thus the 5 by 6 grid will typically support between 30
climate, 200 ft. bores) and 60 tons (cold climate, 300 ft. bores).

"Adequate separation is required to ***prevent*** *short and lo*
term heat storage effects in loop fields. This is especially
when with clay and impermeable rocks are present. Wat
movement will be minimal and heat will be significant in t
commercial /institutional buildings if the bores are locate
than 20 feet apart."

ound Heat Exchanger Design Practic

A

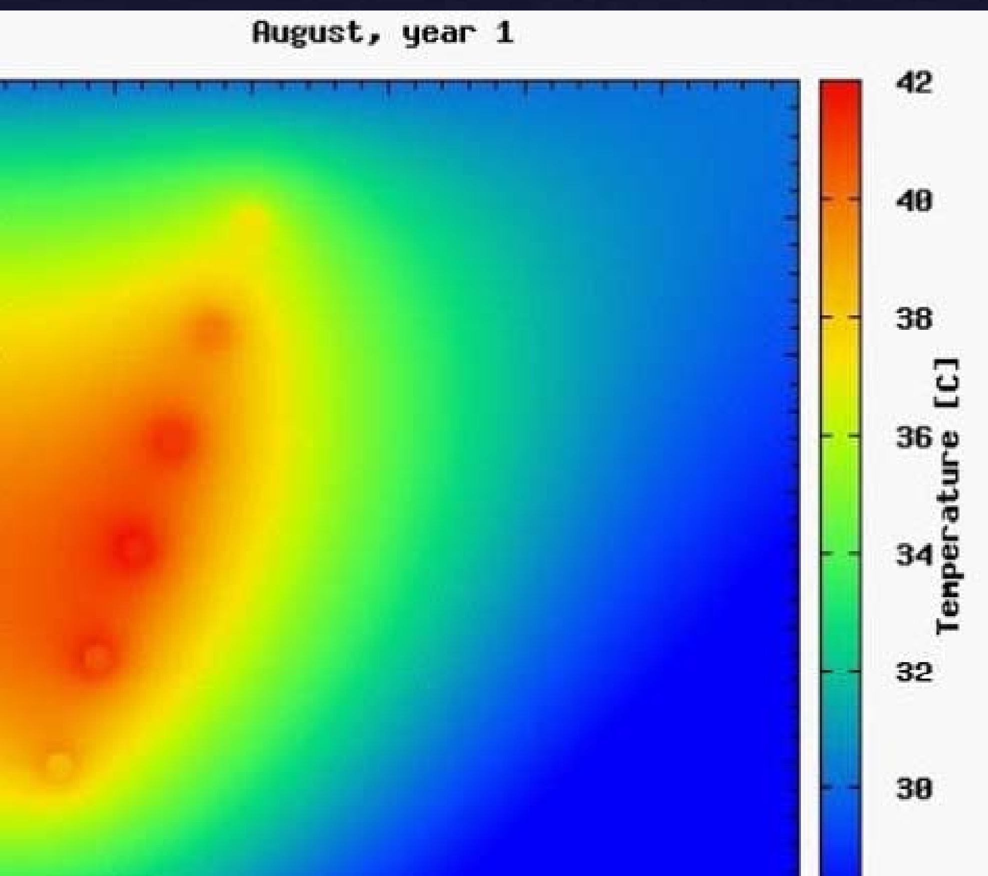
GHX is used as a radiator

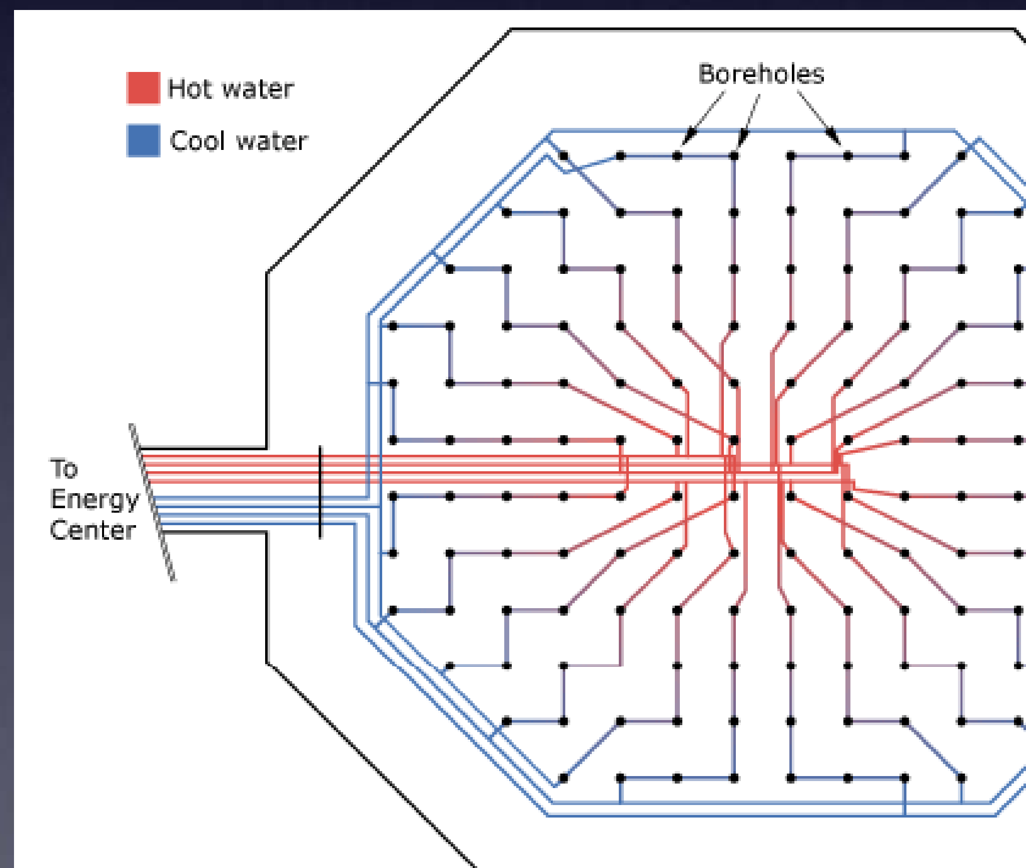
s heat or cold is simply conducted and ted away – thermal balance is NOT atically ensured

Europe

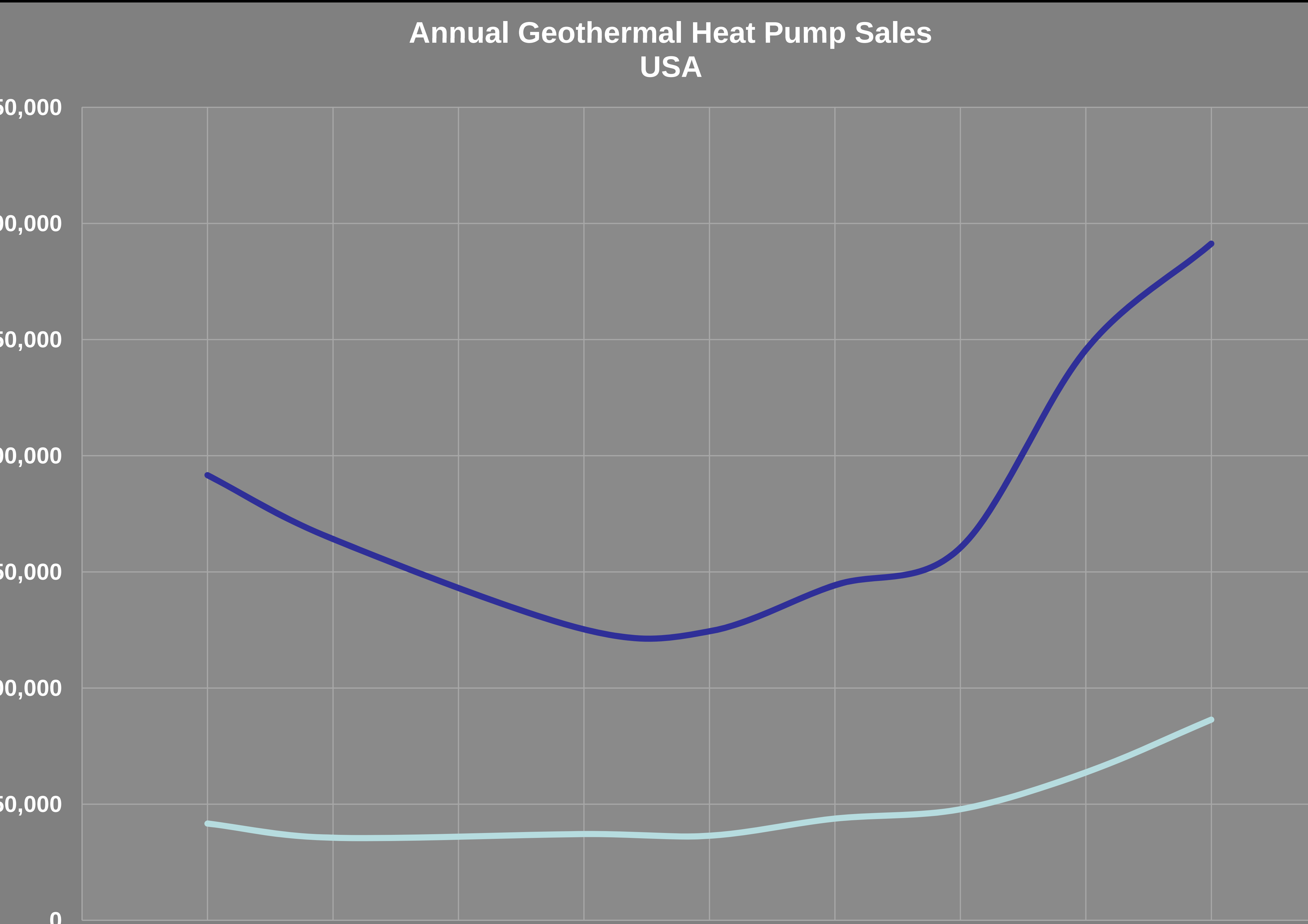
GHX is used as a thermal battery

Excess heat or cold stored seasonally, thermal balance easily achieved through combination of design and operation parameters



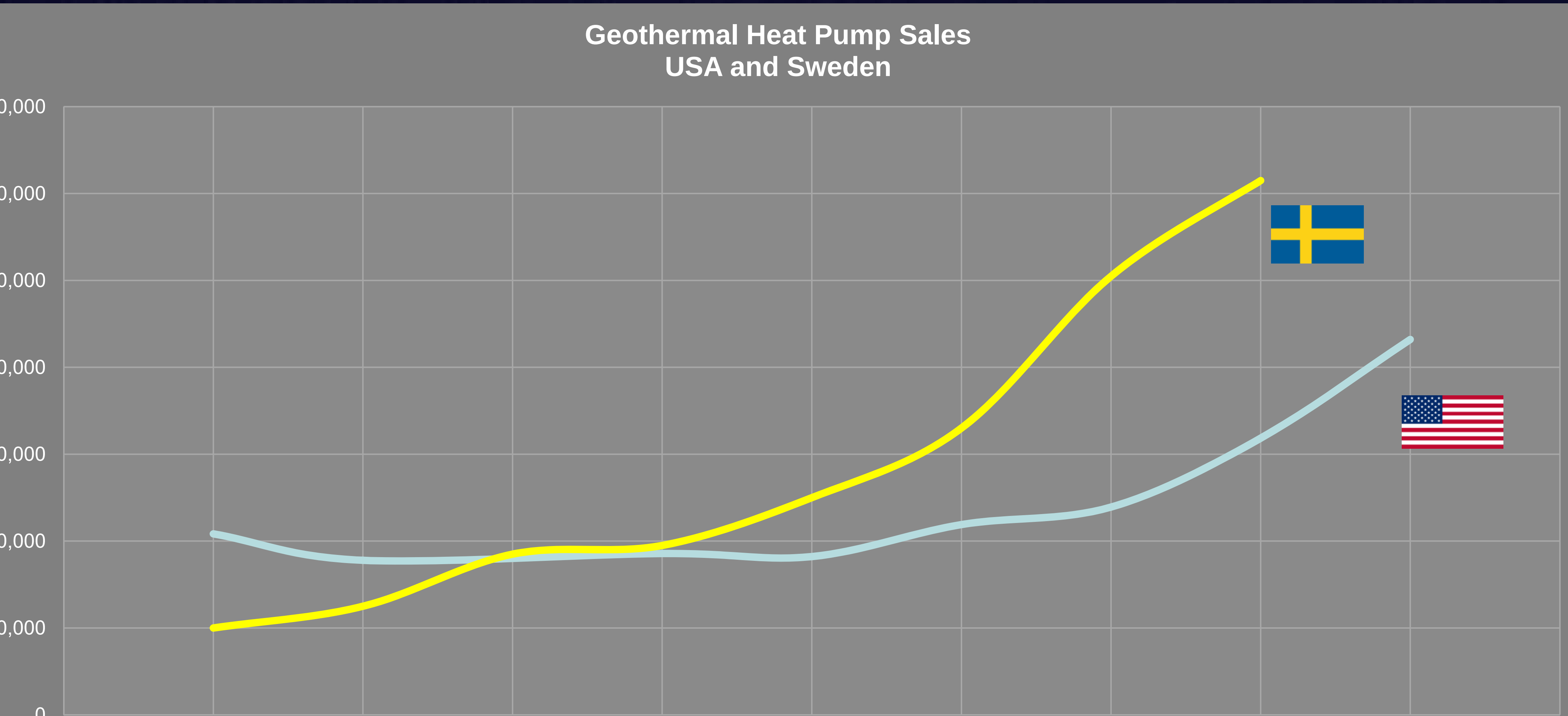


Geothermal Growth in USA



A Tale of Two Countries

	USA	Sweden	USA/Sweden Ratio
Population (2000)	281,421,906	8,986,400	31
GDP in $ Billions (2008)	14,330	513	28



Geothermal for LEED Certified Building

- "The LEED® (Leadership in Energy and Environmental Design) Green Building Rating System is the nationally accepted benchmark for the design, construction, and operation of high performance green buildings

- LEED Measures:

– Sustainable Sites	(26 pts)
– Water Efficiency	(10 pts)
– Energy & Atmosphere	(35 pts)
– Materials & Resources	(14 pts)
– Indoor Environmental Quality	(15 pts)
– Innovation in Design	(6 pts)
– Regional Priority	(4 pts)

- LEED NC Certification Levels

– Platinum	80+ pts
– Gold	60-79 pts
– Silver	50-59 pts

ATES Environmental Impacts

Beneficial Impacts

- Reduced fossil fuel consumption
  - Decreased CO_2 emissions
  - Decreased chance of oil spills and acid rain
- Reduced heat island effect in summer
- Reduced use of biocides and chemicals in cooling plants
- Aesthetic and noise reduction benefits
- Consistent with sustainability objectives (e.g., LEED)

Potential Adverse Impacts and Recommended Mitigation:

- Thermal – use modest ΔT
- Hydrologic (wetlands) – site warm store closest to wetlands
- Displacement of Existing Groundwater Contaminant Plumes – site cold and warm wells on same streamline

ATES System Economics

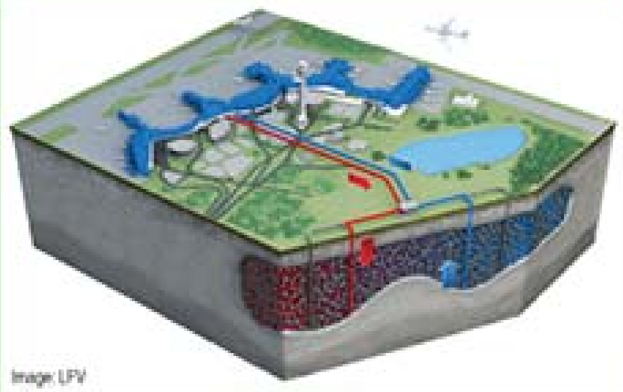
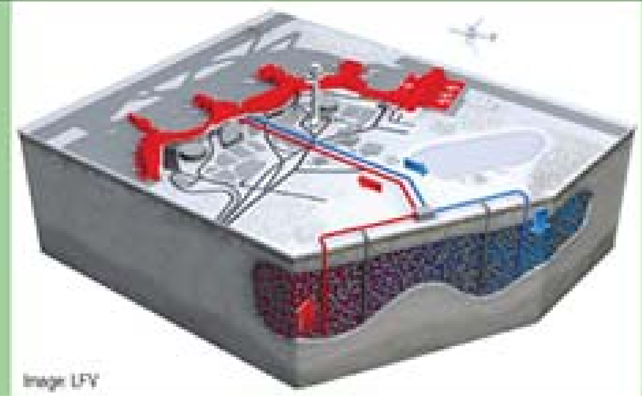
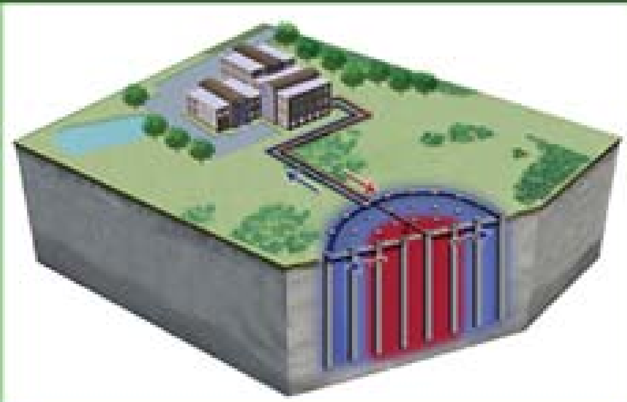
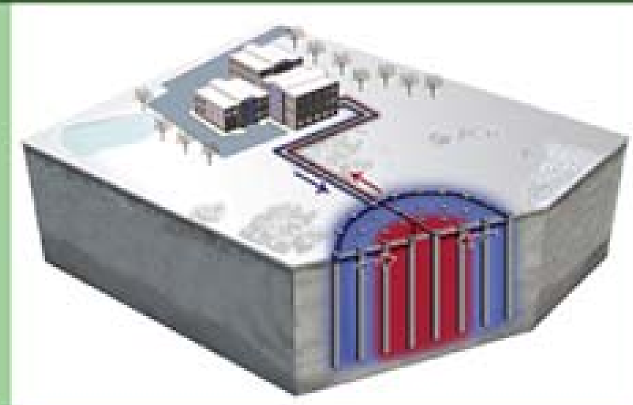
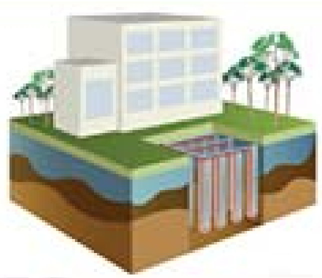
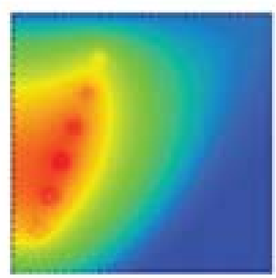
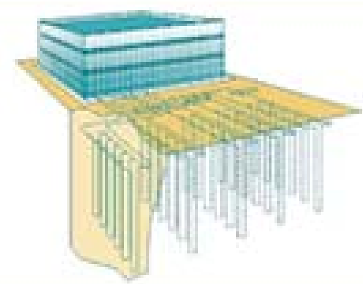
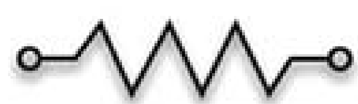
xpected Project Economics

- $1M to $2M typical expected project value (~1 MW)
- Estimate 6-10 year simple payback
- Financial incentives (commercial systems)
  - » 10% geothermal property tax credit
  - » Accelerated depreciation
  - » utility rebates

nergy Savings with ATES System

- Cooling:
  - » 60-80% saving on electricity consumption for chilling
  - » 80-90% reduction of electrical peak for chilling
- Heating:
  - » 20-30% saving on primary energy consumption for hea

ermal Energy Storage - The Future of Efficient Buildings

	Summer Cooling	Winter Heating	COP	Capital Cost	Life Cycle Cost
TES rmal age)			8-20	$$$	$$
TES rmal age)			4-7	$$$	$$$
SHP GHX sign	 		3-4	$$$	$$$$
ating onal ning	 		1-3	$	$$$$$$

Conclusions

The US residential geothermal industry is dominated by HVAC contractors and drillers. The Earth couples used in these systems are usually not complex or difficult to design or install.

The US commercial and institutional geothermal industry is dominated by mechanical engineers and contractors who may not have a detailed understanding of the Earth couple, particularly with respect to the role of advective heat transport via groundwater flow.

Underground thermal energy storage technology enables more efficient Earth coupling, resulting i significant savings in cost, energy and CO2 emissions.

ATES in cooling mode is the most efficient means of seasonal thermal energy storage, typically achieving COP values of 15-20. ATES should be considered for projects that are situated on an aquifer and that have a thermal capacity over 150 tons.

Regulators should identify ways to streamline high-efficiency geothermal projects that offer a significant energy efficiency benefit.

We anticipate that UTES projects in the US will be economically attractive and that adaptation of the technology will follow a similar trend as has been observed in Northern Europe.

The largest impediment to geothermal market penetration is high initial cost and reluctance in marketplace for projects with a payback greater than 5 years. Inexpensive natural gas doesn't help.

Thank You!

Knowing is not enough; we must apply.
Willing is not enough; we must do.