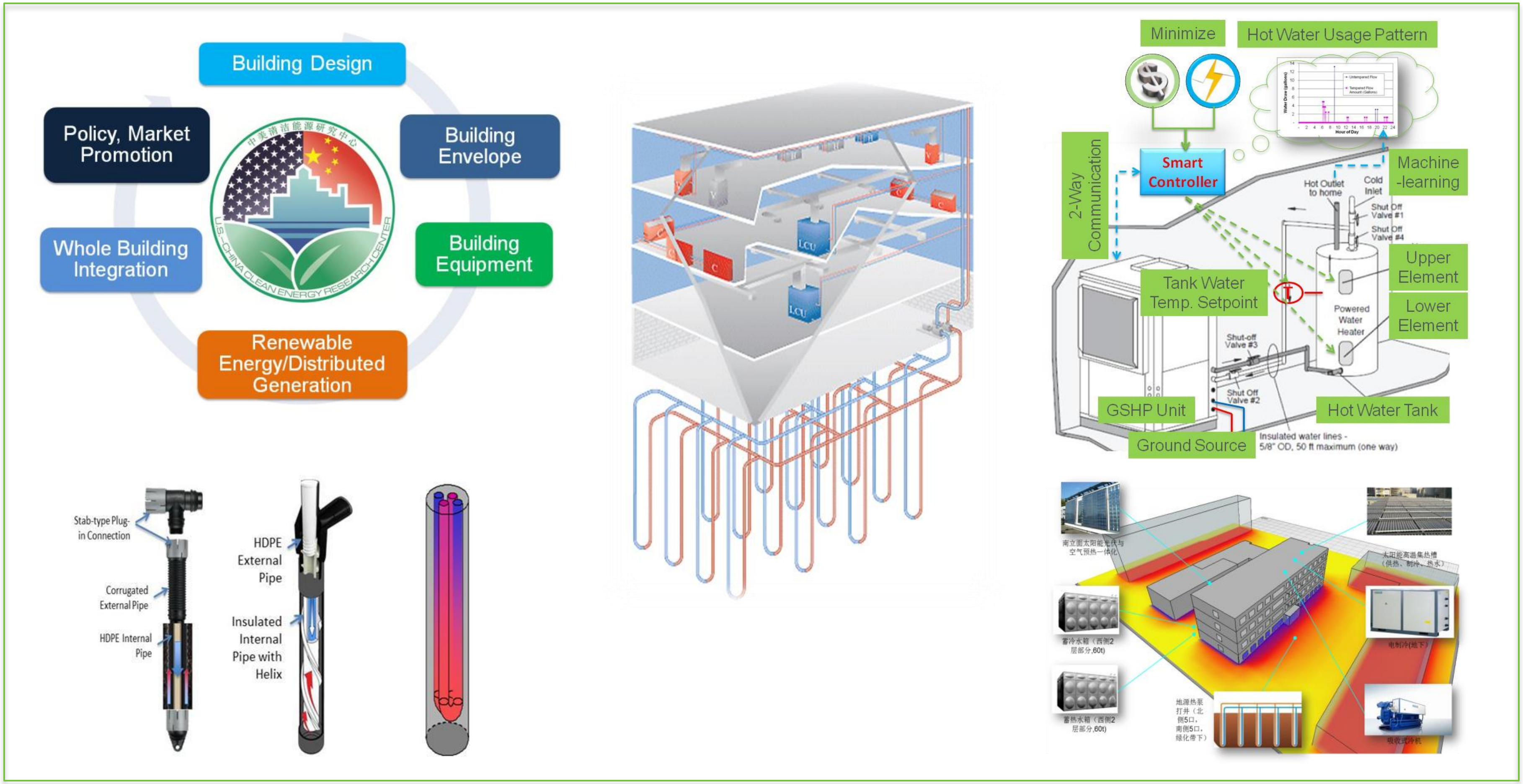
CERC-BEE D2: Advancing GSHP Technology

2014 Building Technologies Office Peer Review



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Project Summary

Timeline:

Start date: 02-Dec-2010

Planned end date: 31-Dec-2015

Key Milestones:

1. GSHP state-of-the-art in US and China; Dec. 2011
2. Characterization of alternative GHXs; Dec. 2012
3. Demo of distributed GSHP systems; Dec. 2013
4. Smart tank controller; Dec. 2014
5. Common loop pump controller; Dec. 2015

Budget:

Total DOE/LBL $ to date: $785K (CY11 - $180K; CY12 - $90K; CY13 - $300K; CY14 - $215K)

Total future DOE/LBL $: CY15 –$350K

Target Market/Audience:

Space conditioning and water heating in residential and commercial buildings.

Key Partners:

ClimateMaster (CRADA)	Chinese Academy of Building Research
Oklahoma State Univ.	Tongji Univ., China
OG&E	Tianjin Univ., China
IGSHPA, GEO	Chongqin Univ., China

Project Goal:

Further advance GSHP technologies by:

1. Exchanging best practices in applications between US and China
2. Identifying lower-cost and performance neutral GHXs
3. Improving controls for GSHP equipment and systems
4. Updating design and simulation tools
5. Demonstrating new technologies

Purpose and Objectives

Problem Statement:
Establish the GSHP state-of-the-art in US and China, identify areas ripe for technology advancement, and advance US technology in a targeted manner

Target Market and Audience:
Space conditioning and water heating in residential and commercial buildings (**21.5** quad Btu primary energy consumption per year in the US). Audience includes personnel involved in the GSHP industry, building owners, and policy makers in both countries.

Impact of Project:
Accelerate GSHP deployment by developing and identifying new technologies to reduce cost and/or improve performance of GSHP systems

1. Near-term (<1 yr): demonstrated cost reduction and performance improvement
2. Intermediate-term (1-3 yrs): commercialization of the new technologies
3. Long-term (3+ yrs): GSHP becomes mainstream in targeted markets

Approach

Approach:

EVALUATE state-of-art in both countries → IDENTIFY needs for technology advancement → in collaboration with US industry

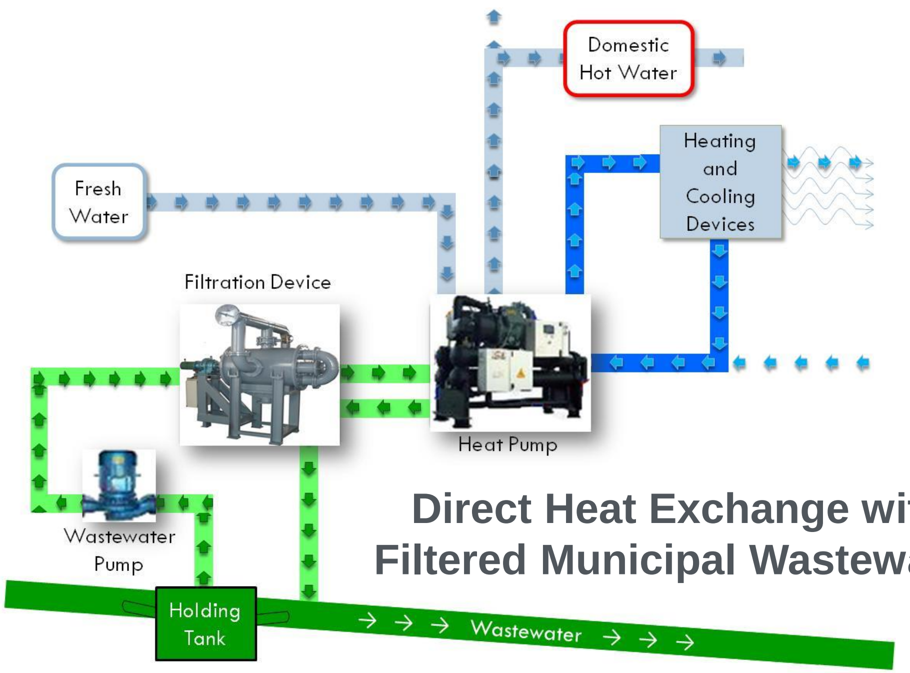
Key Issues: Reduce cost and improve performance of GSHP systems

Distinctive Characteristics: Collaboration between two countries with the largest installation base of GSHP systems and partnership among government, academia, and industry

Progress and Accomplishments

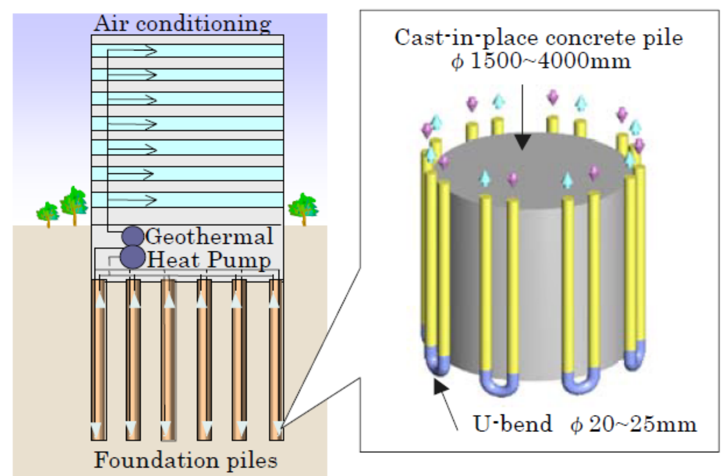
Lessons Learned:

- US and China have different approaches for evaluating performance and assessing benefits of GSHP systems
  - US prefers time-interval measurements during a full year of operation
  - China relies on short-term measurements (e.g., 1 hour for equipment efficiency, 2-3 days for system efficiency, estimated annual efficiency)
- Heat sinks/sources other than the vertical-bore GHX (e.g., groundwater, foundation piles, sewage water, seawater) are more common in China

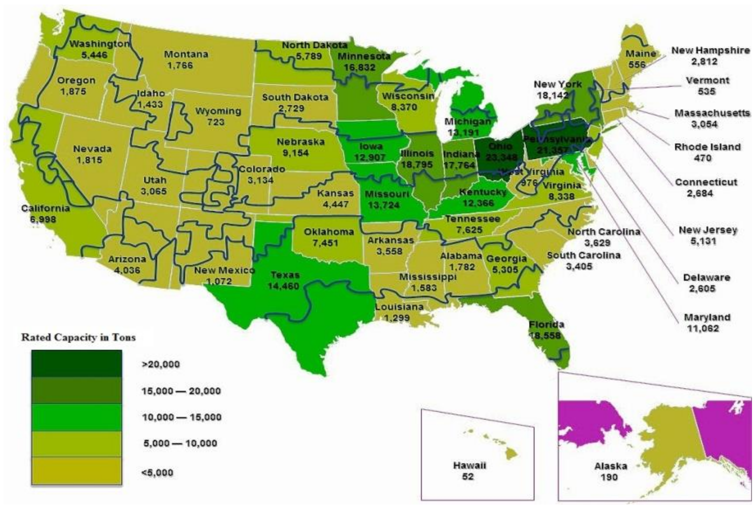


Direct Heat Exchange with Filtered Municipal Wastewater

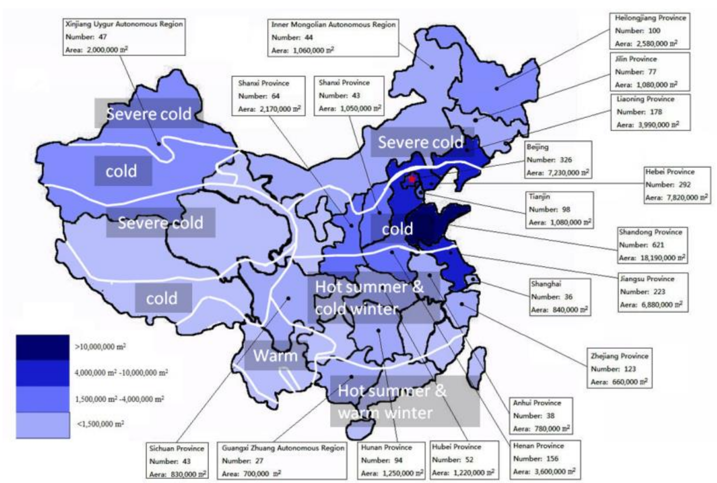
Foundation Pile Heat Exchanger



Progress and Accomplishments



Distribution of 2009 GSHP Shipments in US
(color coded per rated capacity based on EIA 2009 Data)



Distribution of GSHP Applications in China
(color coded per building floor area based on 2009 data)

1. Detailed Understanding of GSHP App. in U.S. & China

GSHP installed-base

- China reached 2.44 billion ft^2 within **one** decade
- About the same has been developed over **four** decades in U.S.

GSHP heat sinks and sources

- China
  - Groundwater (42%)
  - Closed-loop GHX (32%)
  - Surface water and wastewater (26%)
- U.S.
  - Closed-loop GHX (84%)
  - Other (16%)

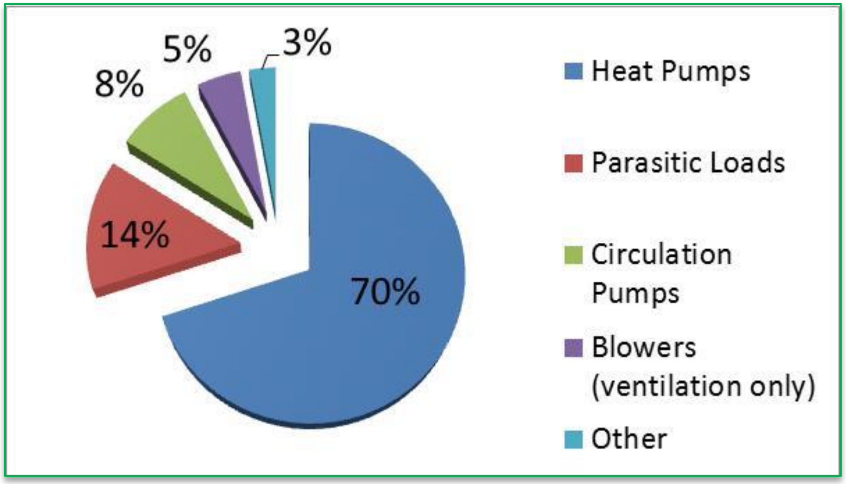
GSHP system configuration

- **Central heat pumps** are predominantly used in China
- **Decentralized heat pumps** (multiple small units) are predominantly used in the U.S.

Progress and Accomplishments

2-1. Performance of ASHRAE HQ Distributed GSHP System

- Analyzed 166 sub-hourly data points for 2 years
- Developed and validated a new method to calculate heating and cooling outputs of each GSHP unit and the associated power draws
- Evaluated the impacts of various pumping controls on GSHP system efficiency
- Calculated each end-use energy of the GSHP system and determined the system efficiency

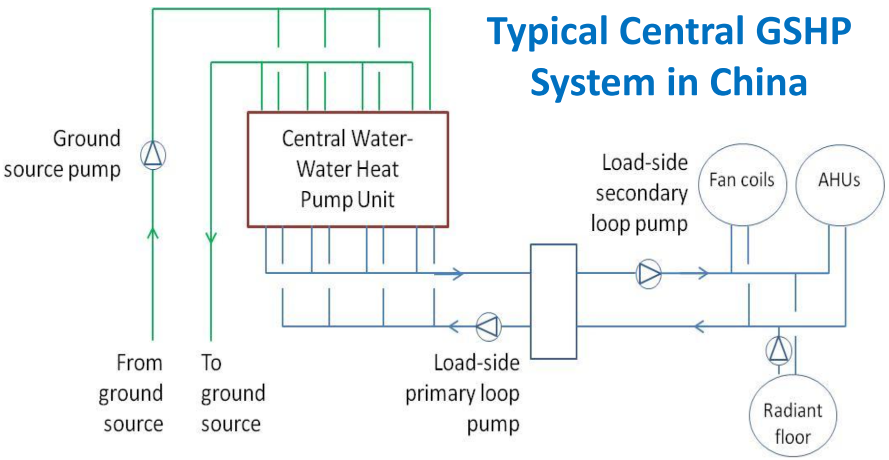


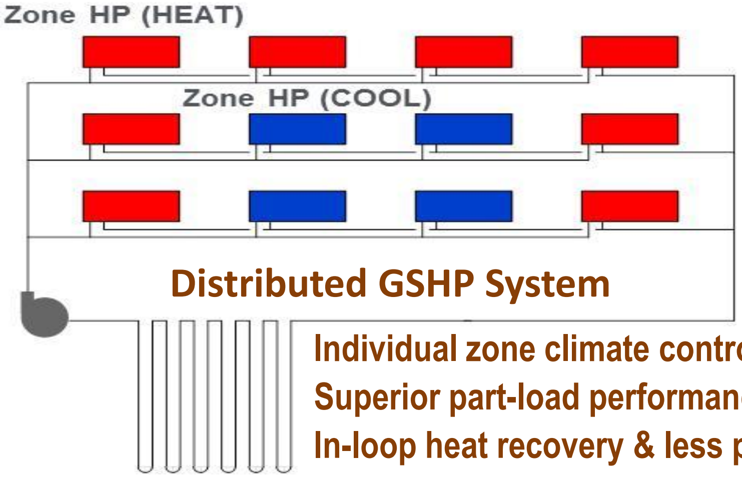
GSHP System Energy Use, KWh
July 1, 2011 – June 20, 2013

	Heating	Cooling
Heating/Cooling Provided, MWh	28.97	142.45
Power Consumed by Heat Pumps, MWh	5.66	27.66
Heat Pump COP	5.12	5.15
Heat Pump EER, Btu/Wh		17.57
Additional power for parasitic loads, pumps and blowers, MWh	2.18	12.13
System COP	3.70	3.58
System EER, Btu/Wh		12.22

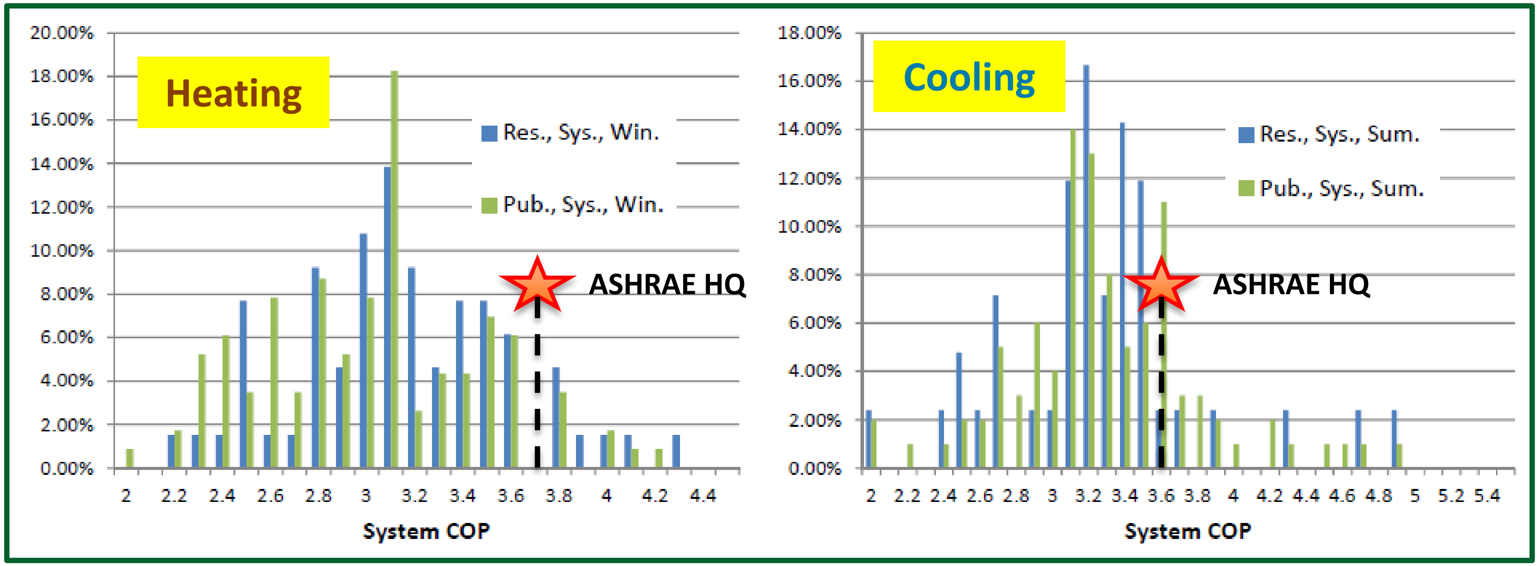
Progress and Accomplishments

2-2. Performance of ASHRAE HQ Distributed GSHP System





Individual zone climate control
Superior part-load performance
In-loop heat recovery & less pumping



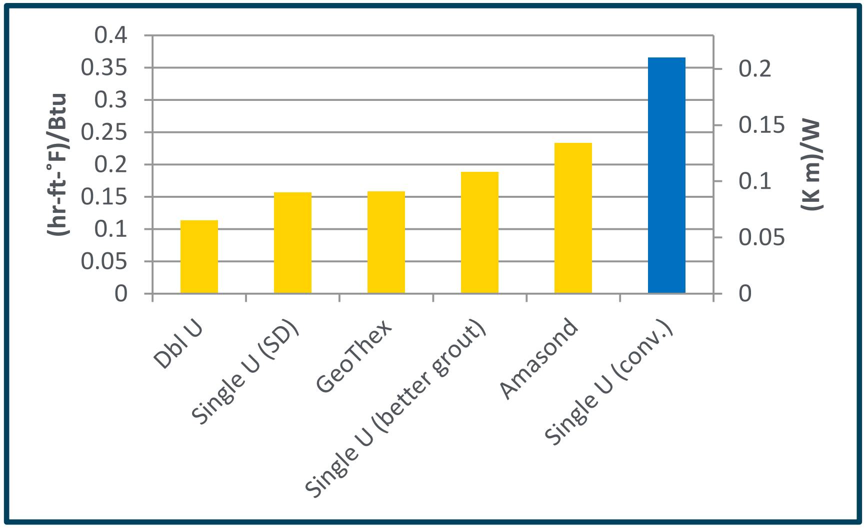
The distributed GSHP system at ASHRAE HQ is more energy efficient than most of the (central) GSHP systems in China (China-side COPs based on a few days data, likely optimistic)

Measured Efficiencies of GSHP Systems in China (Source: Center of Science & Technology of Construction, MoHURD, China)

Progress and Accomplishments

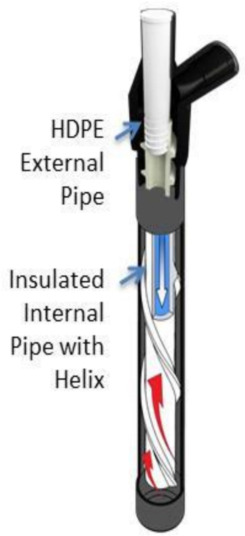
3. Field Test of Alternative GHXs

Tested 8 alterative GHXs and 2 conventional GHXs at 10 nearly identical Habitat for Humanity homes in Oklahoma City from October 2011 though September 2012

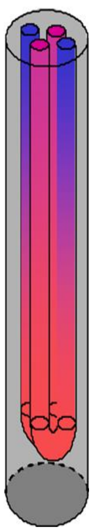


Borehole Thermal Resistance of Tested GHXs

Amasond ® Co-axial loop



GeoThex® Co-axial loop



Double-U loop

Field measurements and calibrated models indicate the **alternative GHXs require 20-30% less borehole length** compared with conventional single U-tube GHX while retaining same performance

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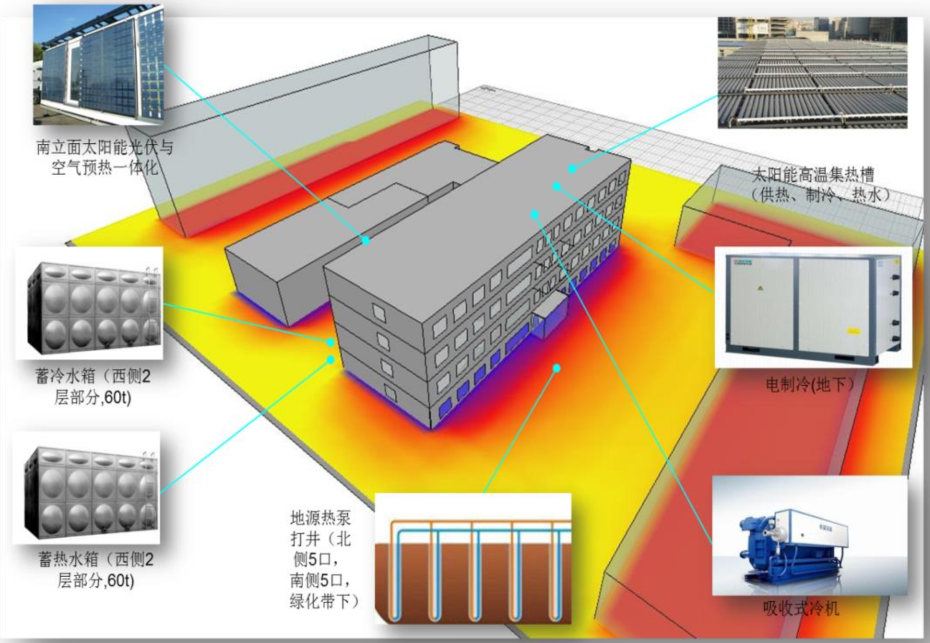
Progress and Accomplishments

4. Demonstrations in China

- CABR’s very low-energy building (VLEB)
  - mixed use office building
  - to be finished in 2014
  - demonstrate ClimateMaster’s advanced GSHP equipment along with other cutting edge technologies
- Analyze data and evaluate performance of the demonstrated GSHP systems
- Potential demos at other selected VLEBs in China



Residential Building

Industrial Building

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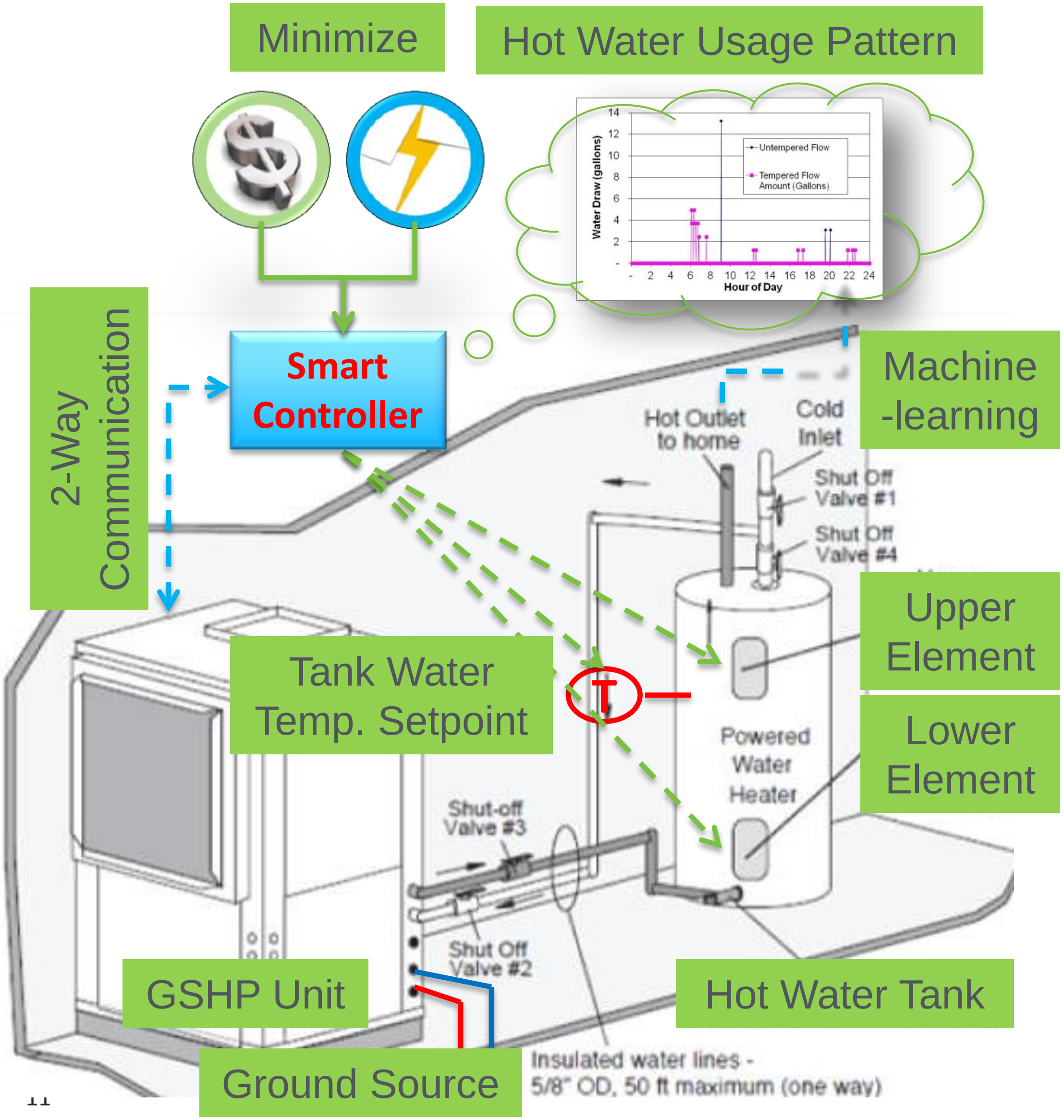
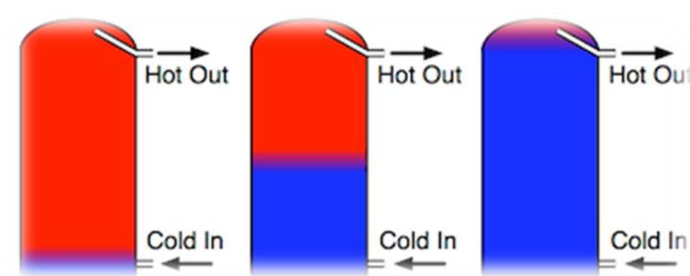
Progress and Accomplishments

5. Smart Control for Hot Water Tank



Minimize energy cost or peak electric demand while delivering needed hot water

- Optimize tank water temperature schedule based on learned pattern of hot water usage
- Maximize tank thermal stratification to improve heat pump efficiency and reduce heat loss



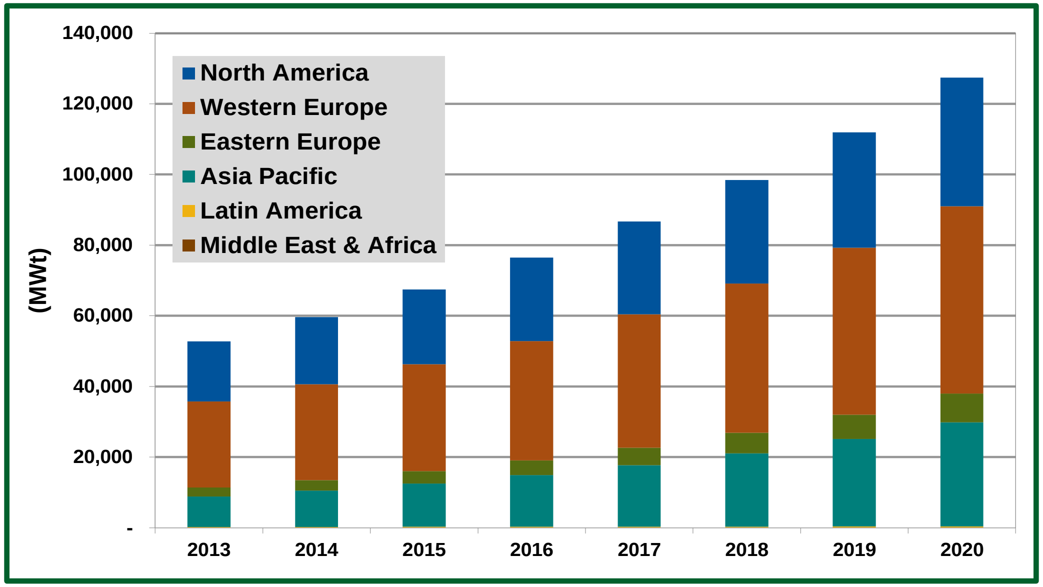
Progress and Accomplishments

Market Impact:

- 20-30% reduction in drilling depth (or land area) of vertical-bore GHXs
- US industry technology included in CERC-BEE demonstrations in China
- Future: Up to 10% increase of water heating efficiency resulting from advanced hot water tank controls
- Future: 10% increase in operational efficiency of distributed GSHP systems by optimizing the common loop pumping controls

Awards/Recognition: Not yet

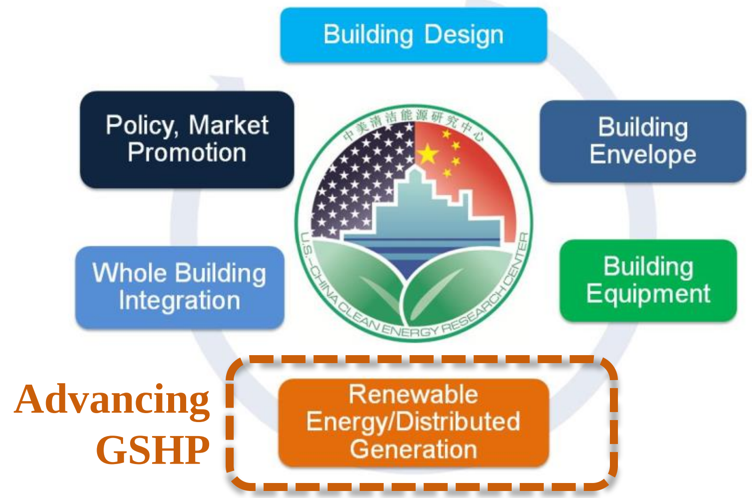
The global GSHP capacity will grow from 46,748 MWt (13.3 million tons) in 2012 to 127,392 MWt (36.2 million tons) in 2020 at a compound annual growth rate of 13.4% between 2013 and 2020. (Source: Navigant Research 2013)



Project Integration and Collaboration

Project Integration:

- Active US-China collaboration since beginning of CERC-BEE program
- Strong US industry engagement (CM, IGSHPA, GEO) and results presented in US-China Joint Workshops and relevant conferences (e.g., IGSHPA, IEA Heat Pump Center, and ASHRAE)



Partners, Subcontractors, and Collaborators:

- Three Chinese universities (Tongji, Tianjin, Chongqin) for comparing GSHP applications in US and China, and CABR for performance analysis of the demonstrated distributed GSHP system
- Oklahoma Gas & Electric, IGSHPA, GEO, Ewbank and Associates, and various vendors of new GHXs for the field characterization of alternative GHXs
- Oklahoma State University for performance analysis of ASHRAE HQ
- ClimateMaster for the advanced control for hot water tank and loop pumps

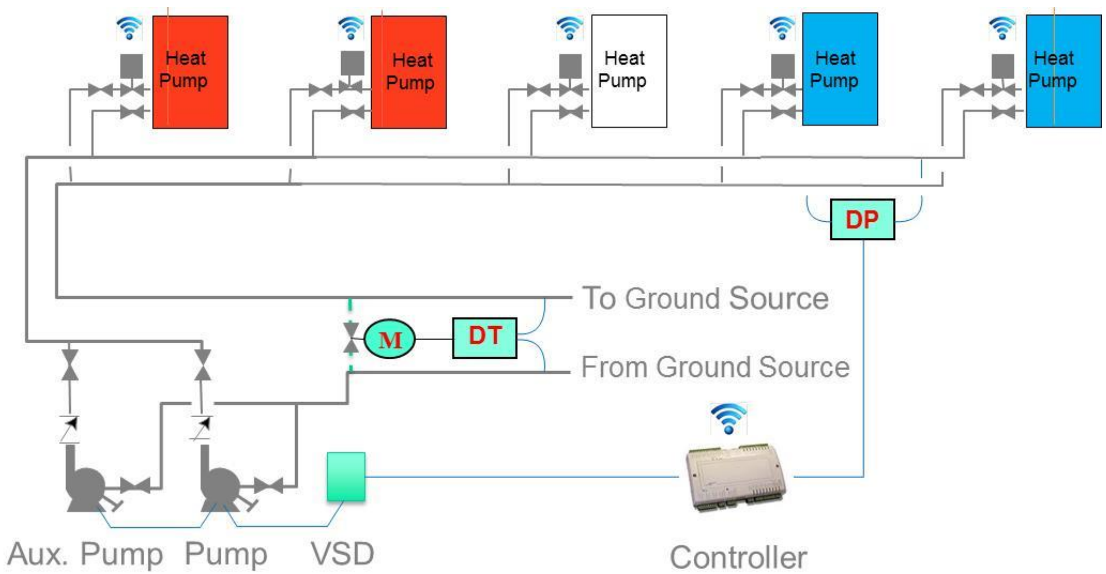
Project Integration and Collaboration

Communications:

- A report on alternative vertical-bore GHXs (ORNL/TM-2013/39) and a companion paper (to be presented at 11th IEA heat pump conference in 2014)
- A paper on the comparison of GSHP applications in China and US (submitted to Journal of Renewable & Sustainable Energy Reviews)
- A paper on performance analysis of the GSHP and VRF system at ASHRAE HQ (to be published at ASHRAE Journal in 2014)
- US-China Joint CERC-BEE workshops
- DOE technical review and industrial advisory board meetings
- Numerous conference calls and in-person meetings/visits with Chinese collaborators and industrial partners

Next Steps and Future Plans

- CY 14
  - Finalize control strategy for hot water tank through lab tests and calibrated computer simulations
  - Assist performance analysis of the demonstrated GSHP system(s) in China
- CY 15
  - Implement a test bed for distributed GSHP systems
  - Develop a fool-proof loop pump controller for distributed GSHP systems



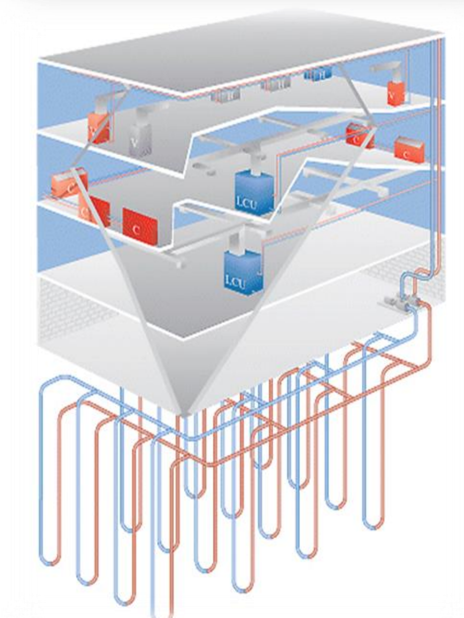
Next Steps and Future Plans

Test Bed for Distributed GSHP Systems

Features:

- First-of-a-kind facility
- Cost share with industrial partners
- Aggressively instrumented
- Multi-zone test bed
- Facilities for data analytics and visualization
- Emulates responses of several sources and sinks*

** Subject to constraints of available budget*



Planned Research in CY 15:

- Field test of the smart tank and pump control
- Validation of system design and simulation tool

Other issues addressable:

- VRF, rooftop VAV, and GSHP side-by-side comparison (systems already installed)
- Optimal design and control of DOAS for distributed GSHP systems

REFERENCE SLIDES

A Project of CERC-BEE (US-China Clean Energy Research Center Building Energy Efficiency Consortium)

Pioneering U.S. China Innovation for Widespread Adoption of Very Low Energy Buildings Through Partnerships and Real World Impact

U.S. Research Leads

U.S. Industrial Partners *(Funding +40% Annual Average Growth Rate)*

Research Strategy → Huge Impact:

- U.S./China construction market ~ 2B m2
- CO_2 savings ~ 100Mt/year by 2025

Technologies, Software → **New Patent Applications**

Demonstration Buildings, Commercial Impact, Tools and Guidebooks → **Market**

Wide Adoption Very Low Energy Buildings → **Policy**

ABOUT: CERC-BEE is a five year, \$50M program created by the U.S. Department of Energy and Chinese Ministry of Science and Technology.

R&D TEAMS: U.S. national laboratories, and U.S. and Chinese universities, and research institutes team up with industry partners to accelerate innovation and deployment.

SELECTED RESEARCH OUTCOMES:

- Launched eight new products and developed two software tools (e.g. Cloud tool for microgrids, 40 new users from China)
- Won R&D Top 100 Award for GSHP by ClimateMaster
- Exceeded IP goals: ~ 25 patents filed, 4 approved; inventions disclosed and more in process (e.g. sprayable liquid flashing, cool roof materials)
- Developed 20 standards (e.g. LBNL involved in new Chinese commercial building code revision)
- Published 135 Chinese and 54+ US academic research papers

Website: cercbee.lbl.gov

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Project Budget

Project Budget: DOE/LBL total $785K CY11-14
Variances: No
Cost to Date: ~$543K through February 2014 (CY11-~$132K, CY12-~$175K, CY13-210K, CY14-26K)
Additional Funding: None expected

Budget History					
CY2011– CY2013 (past)		CY2014 (current)		CY2015 (planned)	
DOE/LBL	Cost-share	DOE	Cost-share	DOE	Cost-share
$570K	$500K	$215K	$300K	$350K	$350K

Project Plan and Schedule

Project Schedule												
Project Start: 02-Dec-2010		Completed Work										
Projected End: 31-Dec-2015		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned)										
		Milestone/Deliverable (Actual)										
	FY2013				FY2014				FY2015			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q1 Milestone: Eval. GSHP system at ASHRAE HQ												
Q2 Milestone: Design lab tests												
Q3 Milestone: Explore smart tank controls												
Q4 Milestone: Demonstration in China												
Current/Future Work												
Q2 Milestone: Validate tank model												
Q3 Milestone: Explore loop pump controls												
Q4 Milestone: Lab test smart tank control												