Demonstration and Performance Monitoring of Foundation Heat Exchangers (FHX) in Low Load, High Performance Research Homes

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Oak Ridge National Laboratory

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ACKNOWLEDGEMENT

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PRESENTATION OVERVIEW

- INTRODUCTION
- FIELD TEST OF THE FOUNDATION HEAT EXCHANGER (FHX) CONCEPT
- FOUNDATION HEAT EXCHANGER PERFORMANCE MEASUREMENTS
- ADDITIONAL FINDINGS AND COST COMPARISON
- SUMMARY
INTRODUCTION: Background

• **Ground Source Heat Pump Systems**: 
  - One of the most energy efficient technologies for space conditioning and water heating
  - **Barrier**: Cost premium of GSHP
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- **Foundation Heat Exchanger (FHX)**  
  - Utilizing construction trench
INTRODUCTION: Background

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  - One of the most energy efficient technologies for space conditioning and water heating
  - **Barrier**: Cost premium of GSHP

- **Foundation Heat Exchanger (FHX)**  
  - Utilizing construction trench

- **Why FHX for Low-load energy efficient homes**  
  - Low space conditioning loads  
    - Ideal for FHX implementation with minimum supplement excavation
INTRODUCTION: Research Objectives

- **Development of FHX Model and Design Tool**
  - Detailed description/results in several papers (Spitler et al. 2010, Xing et al. 2010, 2011, 2012, Spitler et al. 2010)

- **Demonstration of the FHX in full size houses (proof of concept):**
  - Design, construction and demonstration of FHX in two research houses in Oak Ridge, TN.
  - Performance monitoring results after one year of operation
FIELD TEST: Two Research Houses

- Identical 3,700 sqft floor plan
- Unoccupied houses with simulated occupancy (i.e., simulated MELs, DHW uses, and occupant’s internal heat gain)
- Different envelope strategies:
  - Structural Integrated Panels (SIPs)
  - Optimal Value Framing (OVF)
- Very low air leakage and high R-values
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  - Structural Integrated Panels (SIPs)
  - Optimal Value Framing (OVF)
- Very low air leakage and high R-values
- Low space conditioning loads (i.e., 2 ton installed vs. 4 to 5 ton for similar houses around)
- Ideal for FHX implementation with minimum supplement excavation
FIELD TEST: Two Research Houses

- **Space Conditioning and DHW Systems**
  - 2 ton WAHP (space conditioning) and 1 ½ WWHP (DHW) connected to FHX/HGHX

House 1 (SIP)

House 1 (OVF)
FIELD TEST: FHX Design

Loop configuration:
$\frac{3}{4}$ inch diameter high-density polyethylene (HDPE) pipes (three fluid circuits – out and back)

Residential Load Calculation:
Manual J and S
FIELD TEST: FHX Design

Loop configuration:
¾ inch diameter high-density polyethylene (HDPE) pipes (three fluid circuits – out and back)

Residential Load Calculation:
Manual J and S

Conventional HGHX Loop Design Tool
Max/Min EFT (F): 95 and 30F
FIELD TEST: FHX Design

Loop configuration:
¾ inch diameter high-density polyethylene (HDPE) pipes (three fluid circuits – out and back)

Residential Load Calculation:
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Conventional HGHX Loop Design Tool
Max/Min EFT (F): 95 and 30F

Required Length of the Trench (ft)
SIP House: 300 ft
OVF House: 360 ft
FIELD TEST: FHX Design

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¾ inch diameter high-density polyethylene (HDPE) pipes (three fluid circuits – out and back)

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Manual J and S

Conventional HGHX Loop Design Tool
Max/Min EFT (F): 95 and 30F

Required Length of the Trench (ft)
SIP House: 300 ft
OVF House: 360 ft

Construction Excavation (ft)
SIP house: 180 ft (60% of total)
OVF house: 180 ft (50% of total)

Additional Excavation (ft)
FIELD TEST: FHX Design

Layout of FHX and HGHX at House 1 (SIP) (Numbers show measurement points)

Layout of FHX and HGHX at House 2 (OVF) (Numbers show measurement points)
FIELD TEST: FHX Design

Layout of FHX and HGHX at House 1 (SIP) (Numbers show measurement points)

Layout of FHX and HGHX at House 2 (OVF) (Numbers show measurement points)
FIELD TEST: Construction and Measurement Setup

• Purpose: Model validation and FHX energy performance analysis
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- **Purpose:** Model validation and FHX energy performance analysis
- **Measurement points for FHX (15 min resolution)**
FIELD TEST: Construction and Measurement Setup

- Model validation and FHX energy performance analysis
- Measurement points for FHX (15 min resolution)
FIELD TEST: Construction and Measurement Setup

- Model validation and FHX energy performance analysis
- Measurement points for FHX (15 min resolution)
# RESULTS: Performance measurements (Year 1)

<table>
<thead>
<tr>
<th></th>
<th>House 1 (SIP)</th>
<th>House 2 (OVF)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cooling/Heating Thermostat</strong></td>
<td>76F/71F (Maintained)</td>
<td>76F/71F (Maintained)</td>
</tr>
<tr>
<td><strong>Supplemental electric resistance heating</strong></td>
<td>None</td>
<td>66kWh</td>
</tr>
<tr>
<td><strong>Annual Average Cooling System EER (including pumping)</strong></td>
<td>14.3</td>
<td>14.0</td>
</tr>
<tr>
<td><strong>Annual Average Heating System COP (including pumping)</strong></td>
<td>3.6</td>
<td>3.6</td>
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<td><strong>Average DHW COP</strong></td>
<td>3.1</td>
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RESULTS: Performance measurements (Year 1)

House 1

- Heating COP
- Cooling COP
- Average EFT (F)

House 2

- Heating COP
- Cooling COP
- Average EFT (F)
RESULTS: Performance measurements (Year 1)
RESULTS: Performance measurements (Year 1)

- FHX measurements
  - Annual maximum and minimum EFTs (within design range)
    - House 1: 93.2 F, and 33.4F, respectively.
    - House 2: 90.3 F, and 33.7F, respectively.
  - Average Delta T for cooling and heating
    - Cooling: -5.7F
    - Heating: 3.7F
  - Annual heat transfer between WAHP/WWHP and Ground
    - Near zero (well balanced) → No significant long term operation penalty expected.
RESULTS: Heat Transfer (House 1) (Year 1)
Additional Findings and Cost Comparison

- **50% to 60%** of the total ground loop was installed in existing construction excavation or utility trenches → *extra trench excavation needed*

- **100%** of the total ground loop could be installed only using existing construction excavation

- **Cost Comparison (GHX portion)**

<table>
<thead>
<tr>
<th>Type</th>
<th>Vertical Loop</th>
<th>Horizontal Loop</th>
<th>FHX</th>
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<tr>
<td>Installation Cost</td>
<td>$3,000/ton</td>
<td>$2,250/ton</td>
<td>$1,000/ton</td>
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Summary/Conclusion

• GSHP and Market barrier
• Foundation Heat Exchanger Concept – cost reduction & performance
• Demonstration and performance measurements of FHX in two side-by-side, three-level, occupancy simulated research houses
• 50% to 60% of the total ground loop could be installed in existing construction excavation or utility trenches for the study houses
• 100% of the total ground loop could be installed only using existing construction excavation if under the slab excavation would be used for GHX installation
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<td><strong>System COP (including pumping)</strong></td>
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Thanks,

Questions and Comments,

Piljae Im

imp1@ornl.gov
## Envelope component

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<th>House 1 Structural Insulated Panel (SIP) Strategy</th>
<th>House 2 Optimal Value Framing (OVF) Strategy</th>
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<tr>
<td><strong>Roof</strong></td>
<td>IRR standing seam metal</td>
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</tr>
<tr>
<td><strong>Roof deck</strong></td>
<td>SIPS</td>
<td>Foil facing on phenolic foam</td>
</tr>
<tr>
<td><strong>Roof Deck Ventilation</strong></td>
<td>Open at eave and ridge above sheathing</td>
<td>Open at soffit and ridge below sheathing</td>
</tr>
<tr>
<td><strong>Attic</strong></td>
<td>R-35 Cathedral (SIPs 10 in.)</td>
<td>R-50 Cathedral (aged phenolic) 24 in. O.C.</td>
</tr>
<tr>
<td><strong>Wall</strong></td>
<td>R-21 SIPS (6 in. thick)</td>
<td>R-21</td>
</tr>
<tr>
<td><strong>Wall cavity</strong></td>
<td>SIP (EPS)</td>
<td>Flash &amp; batt (½ in. foam with R-16 batt)</td>
</tr>
<tr>
<td><strong>Window</strong></td>
<td>triple pane, third pane removable</td>
<td>triple pane, third pane removable</td>
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<td><strong>Floor</strong></td>
<td>20 in. truss between basement &amp; first floor with installed ductwork and 18 in. truss between first and second floor.</td>
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<td><strong>Foundation</strong></td>
<td>Basement</td>
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</tr>
<tr>
<td><strong>Weather-resistive barrier</strong></td>
<td>Applied</td>
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<td><strong>Foundation wall above grade</strong></td>
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