Smart Building Heating, Cooling and Power Generation with Solar Geothermal Combined Heat Pump System

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2University of Science and Technology, Korea
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17 May 2017, Wednesday
13:55 ~ 14:15
Session : 2.5 Combination
Overview

• Introduction
  ❖ 4th Energy Revolution (Cyber Energy Cloud with IoT Local Micro Generation)
  ❖ Smart Solar Geothermal Hybrid Tri-generation Technology

• Objectives
  ❖ Multi-Load Tri-generation System Impact over the typical reference system
  ❖ Fuzzy Logic Control Impact over the typical On-Off system

• Expected Results
  ❖ Primary Energy Intensity (EI) (kWh/m²a) saving based on ISO 9459
  ❖ EI saving impact of Tri-generation with a Smart FL controller

• Future Studies
  ❖ TTC (Twin Test Cell) for SET/IET model validation and demonstration
  ❖ Further Seasonal Test for nZEB EI rating model verification and development
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Introduction

**Today: One-Way Power Plant**

- POWER PLANT
- TRANSMISSION & DISTRIBUTION
- RESIDENTIAL
- COMMERCIAL
- INDUSTRIAL

**Emerging: Two-Way Energy Cloud**

- Wind Farm with Energy Storage
- Utility/Community Solar
- Power Plants
- Geothermal Energy
- Electric Vehicles
- Homes with Solar PV and Storage
- Factory with Natural Gas Combined Heat and Power

**Home Energy: How the "Home PowerStation" works**

1. A gasometer in the basement of the house triggers a generator to produce electricity. The heat which is produced warms up the water in a thermal storage tank, which can then be used for washing, cleaning or heating.
2. A data line connects the power plant to a control center. This connects 100,000 small power stations and regulates the electricity that feeds into the public power grid.
Introduction

- Smart Fuzzy Logic Tri-generation with solar geothermal (PVTG) hybrid system

- Compare the energy savings of the Smart FL Tri-generation system:
  1) Tri-generation system and the typical heating, cooling and power system
  2) Smart FL control system and the typical On-Off control system
Reference System Information

- Conventional Boiler and Chiller System as the Reference Case

1. **Site**
   - Incheon (Korea)

2. **Building**
   - Houses
   - Offices

3. **System**

   ![Diagram of Conventional Boiler and Chiller System]

   - **Main Component**
     - Quantity:
       - #1: House/Office 1/1
       - #2: Fan coil 2
       - #3: Main pump 1
       - #4: Boiler 1
       - #5: Chiller 1
       - #6: DHW pump 1
       - #7: DHW tank 1
       - #8: Flow meter/sensor/valves N/A

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Tri-Gen System Information

- PVT-GSHP: Solar Geothermal Combined Heat Pump System

1. Site
   Incheon (Korea)

2. Building
   - 5 Houses (200m² x 5)
   - 2 Offices (500m² x 2)

3. System

<table>
<thead>
<tr>
<th>#</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Main component</td>
<td>House/Office</td>
<td>Fan coil unit</td>
<td>Main pump</td>
<td>GSHP</td>
<td>GSHP pump</td>
<td>GS-Tank pump</td>
<td>PVT pump</td>
<td>Solar-tank pump</td>
<td>Hot water tank</td>
</tr>
<tr>
<td></td>
<td>Quantity</td>
<td>n/m</td>
<td>n+m</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Diagram showing flow of heat and energy with various components connected, including PVT and GSHP systems.
### System Simulation Options

<table>
<thead>
<tr>
<th>Cases</th>
<th>Heating and Cooling Systems (Houses and Offices Load Sharing)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Cooling</strong></td>
<td><strong>Heating</strong></td>
</tr>
<tr>
<td>Case 1</td>
<td>Chiller + Fan-Coil</td>
<td>Boiler + Fan-Coil</td>
</tr>
<tr>
<td>Case 2</td>
<td>GSHP + Fan-Coil</td>
<td>GSHP + Fan-Coil</td>
</tr>
<tr>
<td>Case 3</td>
<td>GSHP + Fan-Coil</td>
<td>PV/T- GSHP + Fan-Coil</td>
</tr>
</tbody>
</table>

- **Heating and Cooling Area**: 5 Houses : 1,000m² / 2 Offices : 1,000m²
- **Building Specification**: ASHRAE Standard 90.1-2011 (Climate zone 4)
- **TRNSYS 17 Case Study**: IPMVP 4.4.2, ISO 9459, 13790
## Simulation Result

### Reference VS Tri-Generation

<table>
<thead>
<tr>
<th>Incheon (Load Sharing)</th>
<th>Five Houses + Two Offices (5x200 m² + 2x500 m² = 2000 m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy Intensity (kWh/m²-yr)</strong></td>
<td>Case 1 Boiler+Chiller</td>
</tr>
<tr>
<td>SIMPLE SUM (REFERENCE)</td>
<td>GSHP</td>
</tr>
<tr>
<td>Space + DHW Heating</td>
<td>N. Gas</td>
</tr>
<tr>
<td>Electricity</td>
<td>-</td>
</tr>
<tr>
<td>Space cooling</td>
<td>Electricity</td>
</tr>
<tr>
<td>Fans</td>
<td></td>
</tr>
<tr>
<td>Pumps</td>
<td></td>
</tr>
<tr>
<td>Non HVAC (lighting, equip.)</td>
<td></td>
</tr>
<tr>
<td>Electricity Production</td>
<td></td>
</tr>
<tr>
<td>Total (Net) Energy Use</td>
<td></td>
</tr>
<tr>
<td>Energy Savings</td>
<td></td>
</tr>
<tr>
<td>Energy Savings (%)</td>
<td></td>
</tr>
<tr>
<td>Annual COP</td>
<td></td>
</tr>
</tbody>
</table>
Simulation Result

- **Reference vs Tri-Generation**

![Graph showing energy consumption and production for Incheon](image-url)
Fuzzy Logic Control Strategy

- Linguistic description of fuzzy logic system inputs and output

<table>
<thead>
<tr>
<th>Hot water temperature in HW storage tank</th>
<th>L (low)</th>
<th>M (medium)</th>
<th>H(high)</th>
<th>VH(very high)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold water temperature in CW storage tank</td>
<td>VL(very low)</td>
<td>L (low)</td>
<td>M (medium)</td>
<td>H(high)</td>
</tr>
<tr>
<td>Room temperature difference between its actual value and set-point</td>
<td>Large Neg.</td>
<td>Small Neg.</td>
<td>None</td>
<td>Small Pos.</td>
</tr>
<tr>
<td>GSHP operation state</td>
<td>Off</td>
<td>L (low)</td>
<td>M (medium)</td>
<td>H(high)</td>
</tr>
</tbody>
</table>

- Fuzzy logic control strategies for GSHP system (If-Then Rules)

<table>
<thead>
<tr>
<th>Hot Water Storage Tank Temp.</th>
<th>Lg Neg.</th>
<th>Sm Neg.</th>
<th>None</th>
<th>Sm Pos.</th>
<th>Lg Pos.</th>
</tr>
</thead>
<tbody>
<tr>
<td>VL</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>L</td>
<td>H</td>
<td>H</td>
<td>M</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>M</td>
<td>H</td>
<td>M</td>
<td>L</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>H</td>
<td>M</td>
<td>L</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>VH</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cold Water Storage Tank Temp.</th>
<th>Lg Neg.</th>
<th>Sm Neg.</th>
<th>None</th>
<th>Sm Pos.</th>
<th>Lg Pos.</th>
</tr>
</thead>
<tbody>
<tr>
<td>VL</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>L</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>M</td>
<td>OFF</td>
<td>OFF</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>H</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>
Fuzzy Logic Control Strategy

- Membership function and fuzzy logic control surface

(a) Hot water tank temperature
(b) Cold water tank temperature
(c) Room temperature difference
(d) GSHP operational state

(a) Heating mode
(b) Cooling mode
System Simulation Options

• Simulation option

<table>
<thead>
<tr>
<th>Cases</th>
<th>GSHP</th>
<th>PVT</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-Off</td>
<td>On-Off</td>
<td>On-Off</td>
</tr>
<tr>
<td>FL (A)</td>
<td>Fuzzy Logic</td>
<td>Fuzzy Logic</td>
</tr>
<tr>
<td>FL (B)</td>
<td>Fuzzy Logic</td>
<td>On-Off</td>
</tr>
</tbody>
</table>

• System description

- Heating and Cooling Area: 5 Houses: 1000m² / 2 Offices: 1000m²
- Building Specification: ASHRAE Standard 90.1-2011 (Climate zone 4)
- Model Development: TRNSYS 17
- Control Development: Matlab Fuzzy Logic Toolbox
Simulation Result

- Fuzzy Logic VS On-Off
Conclusions

• **Smart Solar Geothermal Tri-generation (TG) technology has been introduced**
  - PVT-GSHP hybrid system to produce Heating, Cooling and Power
  - Smart Fuzzy Logic(FL) control system to match a varying load demand

• **Energy Intensity Comparison study has been performed**
  - TG system up to 70.4 % energy saving over the reference boiler chiller case
  - FL system up to 11.1 % energy saving over the reference On-Off case

• **Further work includes**
  - TG IET (with and w/o FL) and SET model validations with TTC seasonal test
  - LCC analysis and optimization with the utility rates (gas and electricity)
Thank you

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Acknowledgement

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