ITERATIVE SIMULATION AND OPTIMIZATION APPROACH FOR ENERGY PERFORMANCE EVALUATION OF GROUND SOURCE HEAT PUMP SYSTEMS

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Copenhagen, 13th of September 2017

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**Aim**: Modelling approaches

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<thead>
<tr>
<th>SIMULATION</th>
<th>OPTIMIZATION</th>
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<tr>
<td>+ <strong>Accurate representation</strong> of systems real behaviour</td>
<td>+ <strong>High quality</strong> of the solutions</td>
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<td>+ <strong>Implementation flexibility</strong></td>
<td>+ <strong>Implementation simplicity</strong></td>
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<td>+ Well adapted for sensitivity analysis</td>
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<tr>
<td>- <strong>Difficult to achieve high quality solutions</strong> (operation strategy, design)</td>
<td>- <strong>Limitation of the implementation</strong> due to linear formulation constraints =&gt; risk of oversimplification</td>
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<td>- <strong>Time intensive modelling process</strong></td>
<td>- <strong>Difficulty to interpret the results</strong></td>
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<td>- Requires <strong>deep understanding</strong> of the systems’ behaviour</td>
<td>- <strong>Perfect foresight</strong> assumption</td>
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<td>- Limitation of the <strong>formulation of the objective function</strong></td>
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REAL ENERGY SYSTEMS

MONITORING

ITERATION 1
SIMULATION
Implemented in Matlab
Systems' operational behaviour
Defined operation strategy
Outputs:
• Long term operation evaluation
• Sensitivity: borehole regeneration rates

ITERATION 2
OPTIMIZATION
Implemented in AIMMS
Systems' operational behaviour and limits
Objective function
Output:
• Optimized systems' operation strategies

ITERATION 3
SIMULATION
Implemented in Matlab
Systems' operational behaviour
Best case systems' operation
Outputs:
• Long term evaluation of optimized operation

Introduction  It. 1: Simulation  It. 2: Optimization  It. 3: Simulation  Discussion  Conclusions
Iteration 1, simulation: Modelling

**Systems’ components:**
- **Ground** surrounding the borehole
- **Borehole heat exchanger system**
- **Heat pump (HP)**
- **Storage tanks**: space heating (SH) and domestic hot water (DHW)
- **Pumps**
- **Photovoltaics panels (PV) / Hybrid panels (PV/T)**

Simulation of the 1st year of operation
+ 30 years of operation
Outputs:
- Parameters calibration:
  - Storage tanks sizes
  - Storage tank standing losses
  - Heat pump production capacity
- Values of the coefficient of performance of the heat pump and PV efficiency
New optimization models:
- Implemented as MILP problem in AIMMS
- Representing the systems operational behaviour and limits
- Based on simulations’ results.

⇒ Define the HP and storage tanks operation that optimize the objective function.

The objective function is defined as the operational carbon emissions minimization:

$$Carbon_{total} = \sum_{t} (E_{HP}^{grid}(t, i) \cdot CF_{grid} - E_{PVT}^{grid}(t, i) \cdot CF_{PV,prod})$$

Carbon factors for CH-mix and PV produced from KBOB Liste Ökobilanzdaten in Baubereich 2009-1-2016
Iteration 2, optimization: Parameters integration

Linear constraints formulation ⇒ **COPs** of HP and **PV efficiency** are not dynamically calculated

⇒ COPs of HP and PV efficiency are extracted from simulation results
⇒ Different levels of precision in the definition of the parameters integrated in the models:

**Level 1**: Constant parameters over the year
**Level 2**: Hourly defined parameters
Iteration 2, optimization: Electricity balance

⇒ Significant increase of the PV produced electricity self-consumption

Load cover factor: (26%) 51% (PV self used el. / tot el. consumption)
Supply cover factor: (23%) 49% (PV self used el. / tot PV produced el.)
⇒ **SH storage tank** is more used (40% of the heat production for SH purposes)
Higher share of the SH heat production for **storage tank supply in the hot season**

**Iteration 2, optimization**: Heat pump operation

**Simulation 1**

**Optimization 2**
Outputs:
- Heat pump operation strategy that minimize the carbon emissions of the energy system operation
Comparing *optimization results* (iteration 2) and *simulated optimized HP operation* (iteration 3)

- **PV efficiency:**
  - Constant PV efficiency (level 1): Hourly defined efficiency (level 2): negligible difference (0.0245 %)

- **COP:**

![Comparison of PV production with level 1 and level 2 $\eta_{PV}$](image)
Iteration 3, simulation: Comparison optimization it.2 and simulation it. 3

Electricity balance:
- **Electricity bought from the grid:**
  Underestimation in the optimization result for summer
- **Electricity sold to the grid:**
  Underestimation in the optimization result in the coldest months

⇒ In absolute values: low difference.

⇒ From short time variations of the COP
Iteration 3, simulation: comparison of simulation it.1 and it.3

**Ground temperature:**
- slightly higher temperature decrease
  ⇒ more heat produced

**COP:**
- COP it. 3 slightly lower than it.1

**Electricity consumption:**
- It.3: Higher electricity consumption
**Discussion**: Iterative process

**Contributions:**
- More **accurate** parameters integrated
- Information on systems’ operational behaviour and limits

**Limitations:**
- COPs as daily mean; shorter variation needs to be dynamically defined

**Contributions:**
- HP production **profile** that minimize the greenhouse gas emissions of the operation

**Limitations:**
- Difference in the results of optimization and simulation
- Different models, HP operation profile **not completely compatible** (storage tank temperatures)
On the iterative modelling approach:

+ Iterative approach **combines benefits** from both modelling methods:
  
  **Simulation** model provides an accurate virtual representation of the energy systems; well adapted for sensitivity analysis
  
  **Optimization** model provides a high quality operation strategy

- Increasing level of precision of the parameters improves the accuracy of the results
- Time intensive approach due to the implementation in different software

*Future work:* Limitations in the interactions that need to be investigated

*Thank you for the attention!*