Heat pump system control: the potential improvement based on perfect prediction of weather forecast and user occupancy

D. Rolando, H. Madani, G. Braida, R. Tomasetig, Z. Mohammadi
Smart control strategies for heat pump systems

Smarta kontrollstrategier för värme pumpsystem

Project manager: Hatef Madani
Researcher: Davide Rolando
Main goal
Turn a heat pump system into a smart and user-friendly heating solution for future smart buildings.

Sub-goals
Evaluating and testing how the heat pump controller can use the weather forecast, people’s behavior to maximize the comfort, minimize the operating cost and maximize the system efficiency.

Different control strategies are developed and evaluated via modeling and field measurement.
Implementation: project team

Heat Pump manufactures

Danfoss  NIBE  BOSCH  ETM

KYLTEKNIK AB

Control companies

HESCH  ElectroTest Sweden AB

Consulting companies

BENGT DAHLGREN  Nowab
Research questions

Available information

• How the people behave in the next few hours?
• What the ambient temperature and solar radiation are in the next few hours?
• How the building and the heating system behave (time lag, decrement factor)?

What a controller can do?

Control logic approach
Rule-based
Conceptual model

- Internal gain forecast
- DHW consumption forecast
- Ambient temperature forecast
- Solar radiation forecast

Controller

DHW consumption

Building

Weather

Human Behaviour

Thermal storage tank

Heat Pump + Auxiliary Heater

Borehole Heat Exchanger
System layout

Implementation

TRNSYS simulation tool
Model elements

**Controller**

- Heating curve
- Space heating: Degree-minute logic
- DHW: On/Off hysteresis controller

**Heating curve**

The required supply temperature \( T_{supply}^R \) is calculated as a function of the ambient temperature.
Improvement potential study of a heating system controller for a single-family house considering:

- Domestic Hot Water (DHW) consumption forecast
- Internal gain from people activity
DHW profile: Stochastic Bottom-up Model for German Households

- Four people family
- Single family house
- Stockholm weather

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DHW dynamic schedule

DHW dynamic schedule calculation based on stochastic profile

DHW Schedule

\[ \Delta t_{\text{schedule},i} = \frac{E_{\text{Draw-off},i}}{\dot{Q}_{\text{HP,avg}}} \cdot \eta \]

\[ N_{\text{time step } ON,i} = \frac{\Delta t_{\text{schedule},i}}{\Delta t_{\text{step}}} \]

Results:
Electric energy saving: \(~5.7\%\)
Internal gain

Stochastic occupancy profile

Gain from metabolic rate and appliances

Lighting: up to 250W based on occupancy and time

Test periods: October, January, April

Analysis: Constant solar radiation (average value for each test period)

Heating Curve adjustment based on the internal gain forecast

Internal gain and HC modulation: Results

Results:
Electric energy saving (over three analysed periods): 5.7 - 6.8%
Goal

Study the improvement potential of a heating system controller for a single-family house considering:

- Solar radiation (perfect prediction)
- Ambient temperature (perfect prediction)
System model

Input

Weather station: Stockholm (Arlanda)

Typical meteorological year

Meteonorm data:
- Historical series on 30 years
- Design Outdoor Temperature (DOT): -18 °C
- Main parameters:
  - Ambient temperature
  - Solar radiation on tilted surfaces

Assumptions

Perfect prediction of solar radiation and ambient temperature

Analysed period

Heating season

Implementation

TRNSYS numerical simulations

Heating curve adjustment
Results:

Electric energy saving (heating season): \(\sim 15\%\)
Ongoing activities

HP  Heat Pump
BHE  Borehole Heat Exchanger
DHW  Domestic Hot Water
SH  Space heating
AH  Auxiliary Heater
# Ongoing activities: case studies

<table>
<thead>
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<th>Variable speed</th>
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<td>Floor heating</td>
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- **Heat Pump (compressor):** Single speed
- **Secondary fluid circulation pump:** Single speed
- **Heat Pump (heat source):** Ground source, Air source
- **Input data (measurement):** Instantaneous, Predictive
- **System layout:** "European" (combi tank), "Swedish" (DHW tank)
- **Building type:** High energy building, Normal
- **Rule based approach:** Non-adaptive, Adaptive
- **Heating distribution system:** Radiators, Floor heating
- **Input (additional):** Solar radiation (inst/pred), Ambient temp. (inst/pred), Internal gain (inst/pred), DHW (pred.)
Ongoing activities

Variable speed heat pump

Controller (space heating)
- *Heating curve supply temperature*
- *PID controller to set the compressor frequency*
- *Room temperature sensor*

Controller (DHW)
- *Fixed hysteresis*
- *Fixed compressor speed*
**Ongoing activities**

- **Qcond_ave**: 5.44 kW
- **P_ave**: 1.64 kW
- **SPF**: 3.33
- **Aux heater time**: 27.55 h
- **HP time**: 309.05 h
- **Aux %**: 8.9%
Ongoing activities

With room temperature sensor

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<tr>
<td>P_ave</td>
<td>1.27 kW</td>
</tr>
<tr>
<td>SPF</td>
<td>3.84</td>
</tr>
<tr>
<td>Aux heater time</td>
<td>0.00 h</td>
</tr>
<tr>
<td>HP time</td>
<td>322.20 h</td>
</tr>
<tr>
<td>Aux %</td>
<td>0.0%</td>
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- Room temperature deadband: 1.5 °C
- SPF increase: >10%
- -1.5 | +1.5 degrees
Ongoing activities

Second phase of the research project

Field measurement

• System monitoring
  • Model validation
  • Control logic improvement

• Test of new control logics on a real system

• Test of control device prototypes
Conclusions

Dynamic simulation models of heat pump heating systems have been developed with the aim of investigating new control logics able to improve the system performances.

Additional input variables based on the perfect prediction of DHW, internal gain, ambient temperature and solar radiation have been considered in order to investigate the energy saving potential of advanced rule-based control strategies.

The results show an energy saving potential up to 15% given by the employment of rule-based control logic that exploits the perfect prediction and the instantaneous measurement of the solar radiation.

The developed algorithms will be employed in a number of test installations during the second phase of the project.
“Smart control strategies for heat pump systems”
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Thanks!