Data Intelligent Temperature Optimization
(Temp. Opt. v.4.0)

Henrik Madsen
Dept. Appl. Mathematics and Computer Science, DTU

http://www.citiesinnovation.org
http://www.smart-cities-centre.org
http://www.henrikmadsen.org
Software solutions

Software for combined physical and statistical modelling

Continuous Time Stochastic Modelling (CTSM) is a software package for modelling and simulation of combined physical and statistical models. You find a technical description and the software at CTSM.info.

Software for Model Predictive Control

HPMPC is a toolbox for High-Performance implementation of solvers for Model Predictive Control (MPC). It contains routines for fast solution of MPC and MHE (Moving Horizon Estimation) problems on embedded hardware. The software is available on GitHub.

MPCR is a toolbox for building Model Predictive Controllers written in R, the free statistical software. It contains several examples for different MPC problems and interfaces to opensource solvers in R. The software is available on GitHub.
Topics

Energy systems
- Water
- Markets

Data analytics
- Cloud-based solutions
- Smart buildings

Policy and regulations
- Mobility
Data Management and Cloud Based Solutions
Big Data value chain

<table>
<thead>
<tr>
<th>Sense</th>
<th>Think</th>
<th>Act</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Origins</td>
<td>Data Collection</td>
<td>Analytics:</td>
</tr>
<tr>
<td>The Internet, sensors, machines, etc.</td>
<td>Web log, sensor data, images/audio, RFID and videos, etc.</td>
<td>Technologies supporting data storage</td>
</tr>
<tr>
<td>Data Collection</td>
<td>Data Storage</td>
<td>Predictive analytics, patterns in data, decision making</td>
</tr>
<tr>
<td></td>
<td>Data Storage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analytics:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Consumers:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Business processes, humans, and applications</td>
<td></td>
</tr>
</tbody>
</table>

Sense: Data Origins and Data Collection.
Think: Data Storage and Analytics.
Act: Consumers.
CITIES Data Management System

Virtual Machine – User Interfaces

Ingestion layer

Processing layer

Analytics layer

Visualization layer

Smart meters

Staging area

Data processing platform

Workflow n

Workflow 2

Workflow 1

Worklet

Web app

Visualization

Smart meter data analytics

Consumption time-series

Pattern discovery

Forecasting

Load classification

MADLib analytics toolkit

PostgreSQL

Fig. 1. The system architecture of smart meter data analytics system
Data Intelligent Temperature Optimization for DH Systems (incl. load forecasting)
Model components in load forecasting

Wall: Slow reaction on climate

Windows + ventilation: Fast reaction
PRESS Load Forecast
(Model principles)

Load forecast for time t+k, Pp(t+k), is written:

\[ Pp(t+k) = F_{mur}(Vejr(t+k)) + F_{vv}(Vejr(t+k)) + \\
F_{ar}(Pp(t) - P(t)) + DP(t+k) \]

where

- F_{mur}, F_{vv}, F_{ar} and DP are semi-parametric functions (estimated by PRESS)
- Vejr(t+k) is weather input (measured + forecasts) for time t+k.
- P(t) is measured heat load for time t.
PRESS Load Forecast
(Example)
Weather data and forecasts

Optimize local weather forecast base on:

• Local climate data
• Several MET forecasts
MetFor performance

![Graph showing MetFor performance](image_url)
MetFor forecast example

![Temperature Graph]

- Green line: METFOR
- Yellow line: Kommercielt alternativ

Meeting with Fors. Helsingør Oct. 2017
Models and Controllers
(Highly simplified!)
Characteristics
30%, 40%, 50%

Stationary gain of FIR

Stationary gain of ARX

Pole of ARX
Optimal set-point taking uncertainty into account

Brugertemperatur

Udetemperatur
Characteristics
30%, 40%, 50%

Stationary gain of FIR

Stationary gain of ARX

Pole of ARX
Supply temperature with/without data intelligent control

![Graph showing supply temperature with and without data intelligent control.](image)
Savings
(Reduction of heat loss = 18.3 pct)

<table>
<thead>
<tr>
<th></th>
<th>Varmekøb (GJ)</th>
<th>1000kr</th>
<th>Elkøb (kWh)</th>
<th>1000kr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Før PRESS</td>
<td>653,000</td>
<td>30,750</td>
<td>499,000</td>
<td>648</td>
</tr>
<tr>
<td>Med PRESS</td>
<td>615,000</td>
<td>28,990</td>
<td>648,000</td>
<td>842</td>
</tr>
<tr>
<td>Forskel</td>
<td>37,400</td>
<td>1,760</td>
<td>-149,000</td>
<td>-194</td>
</tr>
</tbody>
</table>

Total besparelse (9 første måneder af normalår): **1,566,000kr**

Besparelse for et normalår:

- $12/9 \times 1,566,000\text{kr} = 2.1 \text{ mill.}$
- Imidlertid står jan.–sept. (75% af året) kun for ca. 65% af graddagen i er normalår.
- $1,566,000\text{kr}/0.65 = 2.4 \text{ mill.}$
Control of Temperatures in DH Systems

Lesson learned:

- Control using simulation of temperature gives up to 10 pct reduction of heat loss.

- Control using data and predictions gives up to 20 pct. reduction of heat loss.
Which approach to use?

- Use **simulation based control if:**
  - No access to data from the DH network
  - Want an evaluation of new operational scenarios

- Use **prediction based control if:**
  - Access to network data online
  - Want to used meteorological forecasts automatically
  - Want to combine MET forecasts with local climate data
  - Want automated update of models
Data Intelligent Temperature Optimization for DH Systems

- Able to take advantage of information in data
- Self-calibrating models for the DH network
- Shows where to upgrade the DH network
- Fast (real time) calculations
- Use DH net for peak shaving and storage
- Able to use online MET forecasts etc.
Data Int. Temp. Opt (v.4.0)

- Big Data Analytics – more specific:
- Take advantage of (smart) meter readings
- Use of all available MET forecast
- Combination of MET forecasts with data from local climate stations
- New grey-box models
For more information ...

See for instance

www.henrikmadsen.org
www.smart-cities-centre.org
www.citiesinnovation.org

...or contact

– Henrik Madsen (DTU Compute)
hmad@dtu.dk