Price responsive predictive control of a heat pump in a family house

Jacopo Parvizi, Erik Baasch Sørensen, Martin Clausen, Henrik Madsen.
Department of Applied Mathematics and Computer Science

Abstract

The methods applied in this study show how to reduce the energy costs for the local house demand modeling and controlling a heat pump. Flexible demand side response is set to achieve a balance between energy production and consumption using a market price responsive controller.

Introduction

The proposed solution utilizes a water tank as a buffer to store the energy produced by the heat pump when the price of the electricity is low, which is then used for space heating and hot tap water together with the energy accumulated by the solar collector. Models for the heat pump and water tank, accounting for their stochastic and dynamic features, are identified using stochastic differential equations. These models are then implemented in an economic model predictive controller which is then tested in an experiment performed on a real family house building in Denmark.

Figure 1: Test Facility

Installation

At the Grundfos Test Facility, the heating system is composed of the following elements:

- 600 l Stratified Hot Water Tank
- 7.2 m^2 Solar Thermal Collector
- Heat Pump - $7kW$ with Variable Speed Compressor
- Domestic Hot Water Grundfos Fresh Water Module
- District Heating Backup
- Local Weather Station
- Kamstrup Multical Heat Meters

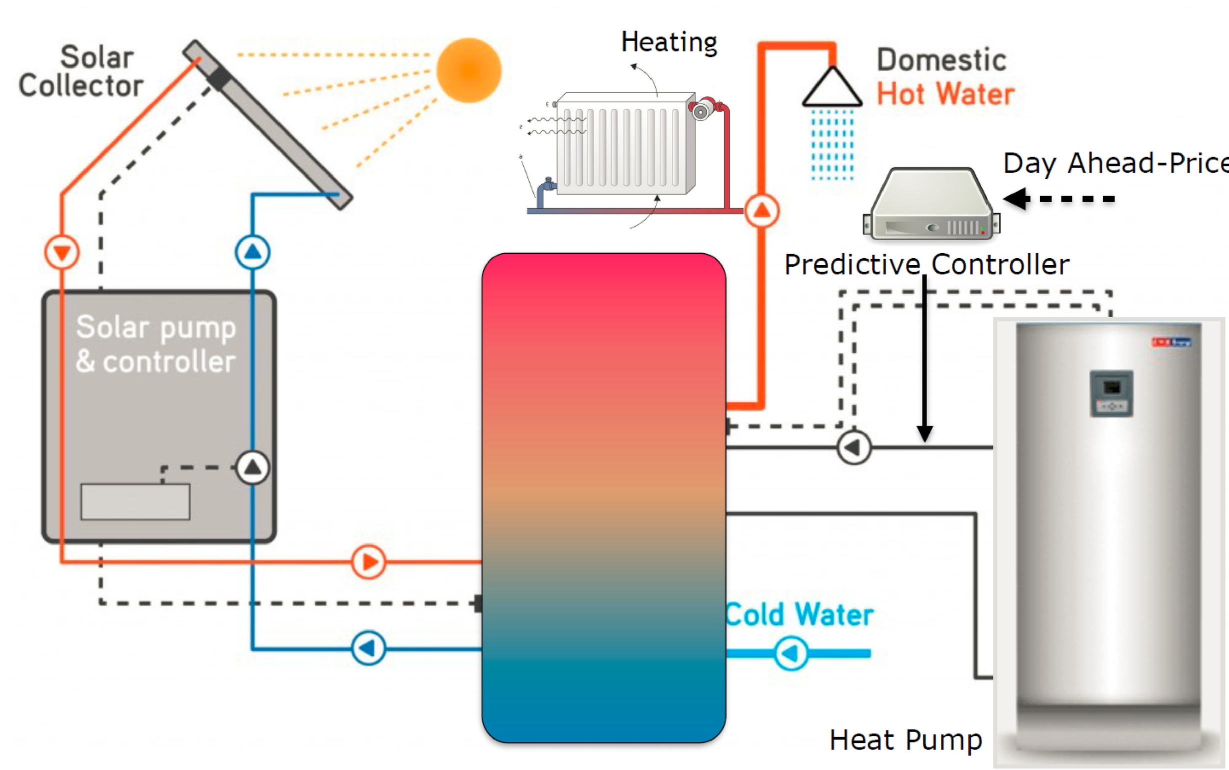

Figure 2: Installation schematics

Interface

An interface is used to keep track of the multiple signals. In the first panel are illustrated signals fed into the controller, while in the second the user can analyse the forecasts produced for the next 24 hours.

Figure 3: Controller Interface

Water Tank

To control the temperature in the water tank a Stochastic Differential Equation model is defined based on its heat dynamics.

$$\frac{dT_{tank}}{dt} = \frac{1}{C_{tank}R_t}(T_{room}-T_{tank}) + \frac{1}{C_{tank}}Q_{solar} \qquad (1a)$$

$$-\frac{1}{C_{tank}}Q_{house} + \frac{1}{C_{tank}}Q_{in} + \sigma_{E_1}\frac{dW}{dt} \qquad (1b)$$

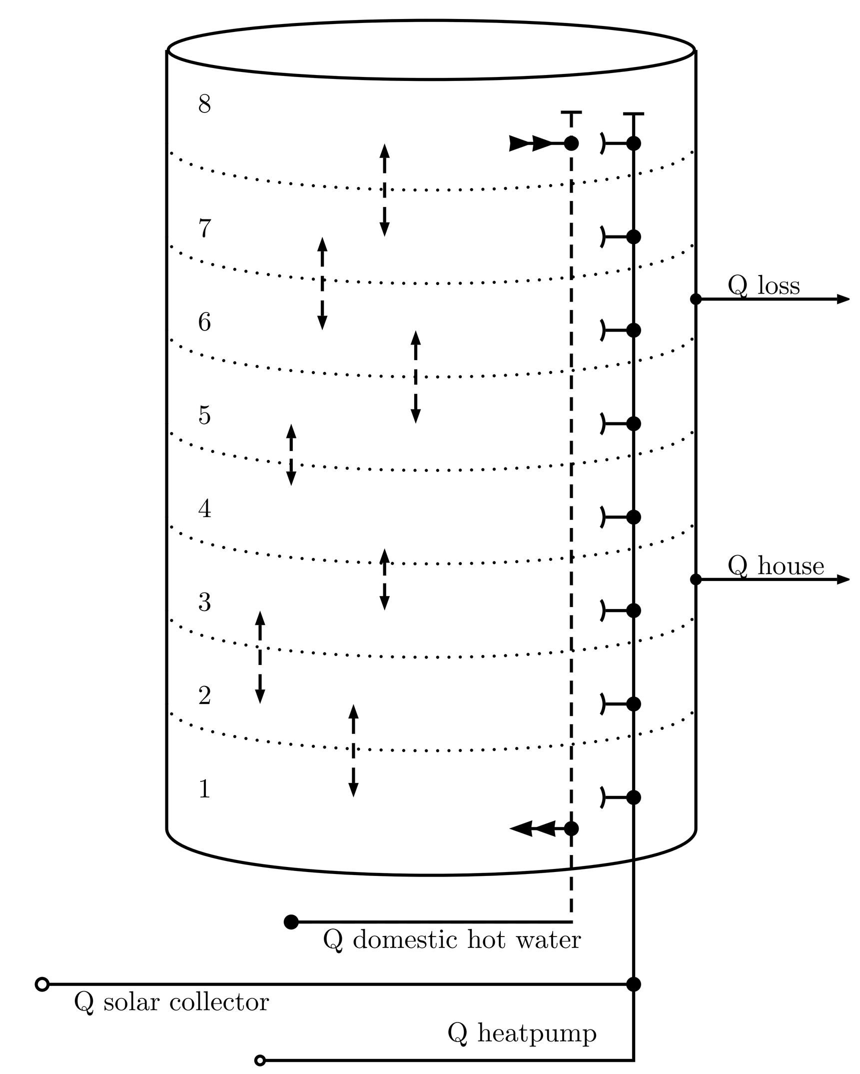

Figure 4: Water Tank Inputs and Outputs

In Figure 5 the one step ahead predictions are computed to analyze the tank model performances.

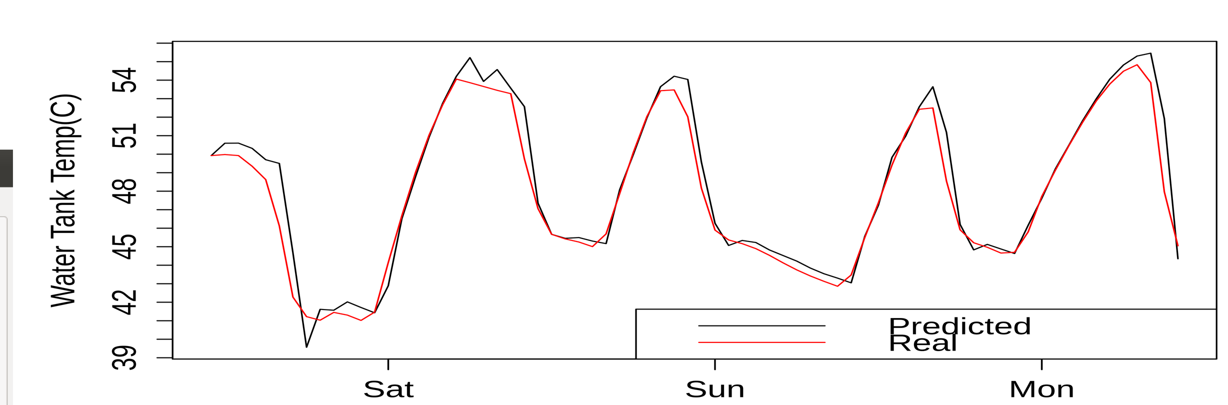

Figure 5: One step ahead model predictions

Model Predictive Control

The Predictive controller uses 24 hours ahead forecasts of the spot price, house combined heat-load and tap water consumptions and, solar thermal power production.

The Economic MPC problem, with the constraints and the model, can be summarized into the following formal formulation:

$$\min_{\{u_k\}_{k=0}^{N-1}} \phi = \Sigma_{k=0}^{N-1} p' u_k \qquad (2a)$$

$$\text{Subject to} \quad x_{k+1} = Ax_k + Bu_k + Ed_k \qquad (2b)$$

$$y_k = Cx_k \qquad (2c)$$

$$u_{min} \le u_k \le u_{max} \qquad (2d)$$

$$\Delta u_{min} \le \Delta u_k \le \Delta u_{max} \qquad (2e)$$

$$y_{min} \le y_k \le y_{max} \qquad (2f)$$

The top part of Figure 6 illustrates the average water temp y in red and the requested house load, d, in blue. The bottom figure illustrates the price trajectory, p, in green and the control signals, u, in red.

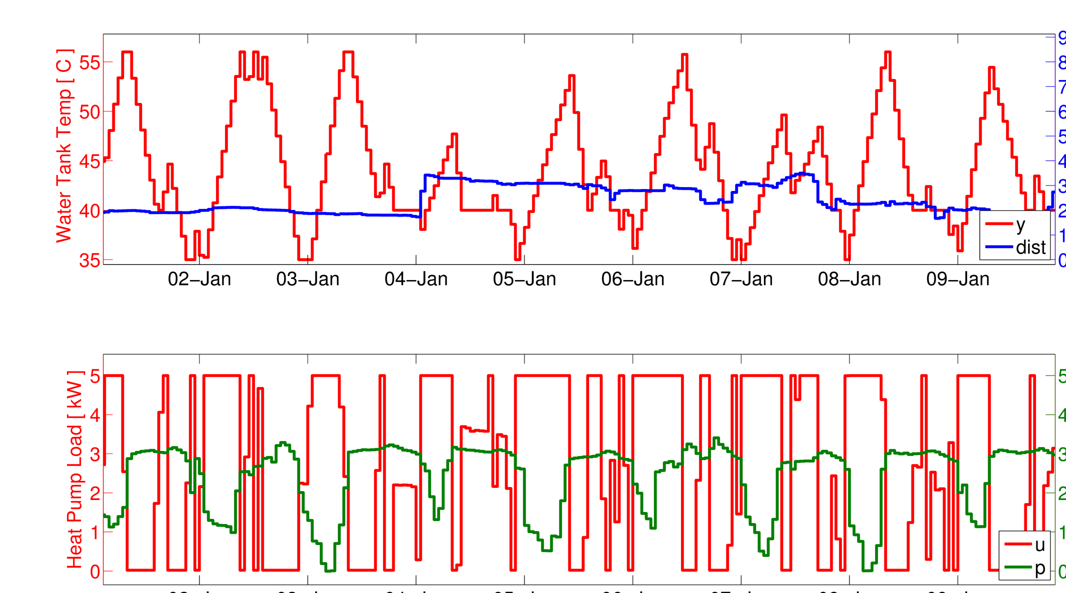

Figure 6: Controller performances

Savings

Two different EMPC strategies were compared in order to estimate the economic savings achieved: flat tariff against dynamic tariffs. The potential and achieved economic savings are shown in Table 1.

	2013	2014
EMPC	11%	16%
flat tariff	3%	8%

Table 1: Economic savings: dynamic vs flat tariff