

P*R*E*S*S

PRognose og EnergiStyrings System

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Overview

- Introduction
- Optimal operation of DH systems
- On-line prediction of heat load
- Control of supply temperature
- Results at Roskilde District Heating Utility using PRESS
- Conclusions
- Demonstration

Introduction

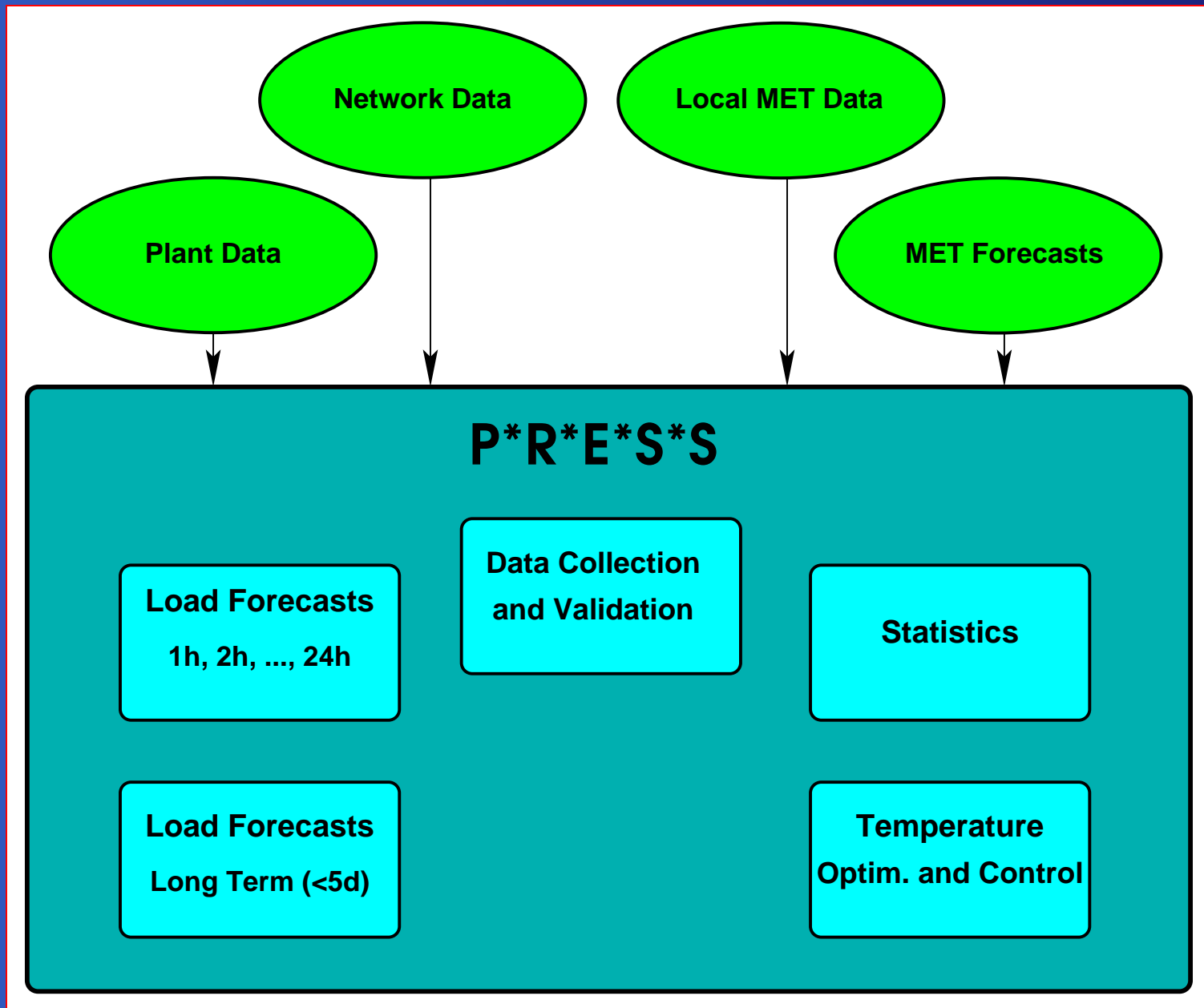
In Denmark close to 60% of the domestic heating installations are supplied from DH systems, hence the subject of optimal operation of DH utilities has a huge economic potential.

A DH system consists of three primary parts:

- One or more central heat producing units
- A distribution network (DNW)
- Consumer installations for space heating and hot tap water production.

Optimal operation of a DH utility implies that the operation of all three parts in the system should be optimized.

PRESS – Overview



Optimal operation of DNW

The operational cost for the DNW is minimized by optimizing the criterion:

$$C_t^{DN} = \min E \left\{ \sum_{i=1}^N [P_{t+i}^{heat} (E_{t+i}^{loss} + E_{t+i}^{cons}) + C_{t+i}^{pump}] \right\}$$

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where heat price = fun ($T^s, T^r, \nabla E^{diur}$), consumer load is given, heat loss $\propto \int_A T_a^{dnw} da$ and pumping costs $\sim 10\%$ of heat loss costs. The following restrictions must be observed:

$$T_{c,t+i}^{in} \geq T_{c,min}^{in}(T_{t+i}^a) \quad \forall c \in A, \quad i = 1..N$$

$$q_{t+i} \leq q_{max} \quad i = 1..N$$

where $T_{c,t+i}^{in}$ is consumer inlet temperature and q_{t+i} is flow rate at the supply point.



Optimal operation of DNW (cont.)

The stated stochastic optimization criterion can be reduced to the simpler

The operational costs of the distribution network can be optimized by minimizing the supply temperature under the restriction that flow rate and consumer inlet temperatures are kept within acceptable bounds.

under the assumption that

- diurnal peak load and return temperature do not increase,
- large and frequent fluctuations in the supply temperature are avoided.

On-line predictions of local ambient temperature and heat load are essential.

On-line predictions of heat load

- A module for short term predictions (up to 24 hours)
- A module for long term prediction (up to, say, 5 days)
- Takes into account:
 - Local ambient temperature.
 - Local wind speed.
 - Local solar radiation.
 - Available (on-line) MET forecasts.
 - Systematic variations in heat consumption.
 - Accumulated heat in the net.

Control of supply temperature

The stochastic optimization problem is converted to a set of control problems:

- one flow controller and,
- a number of network temperature controllers,

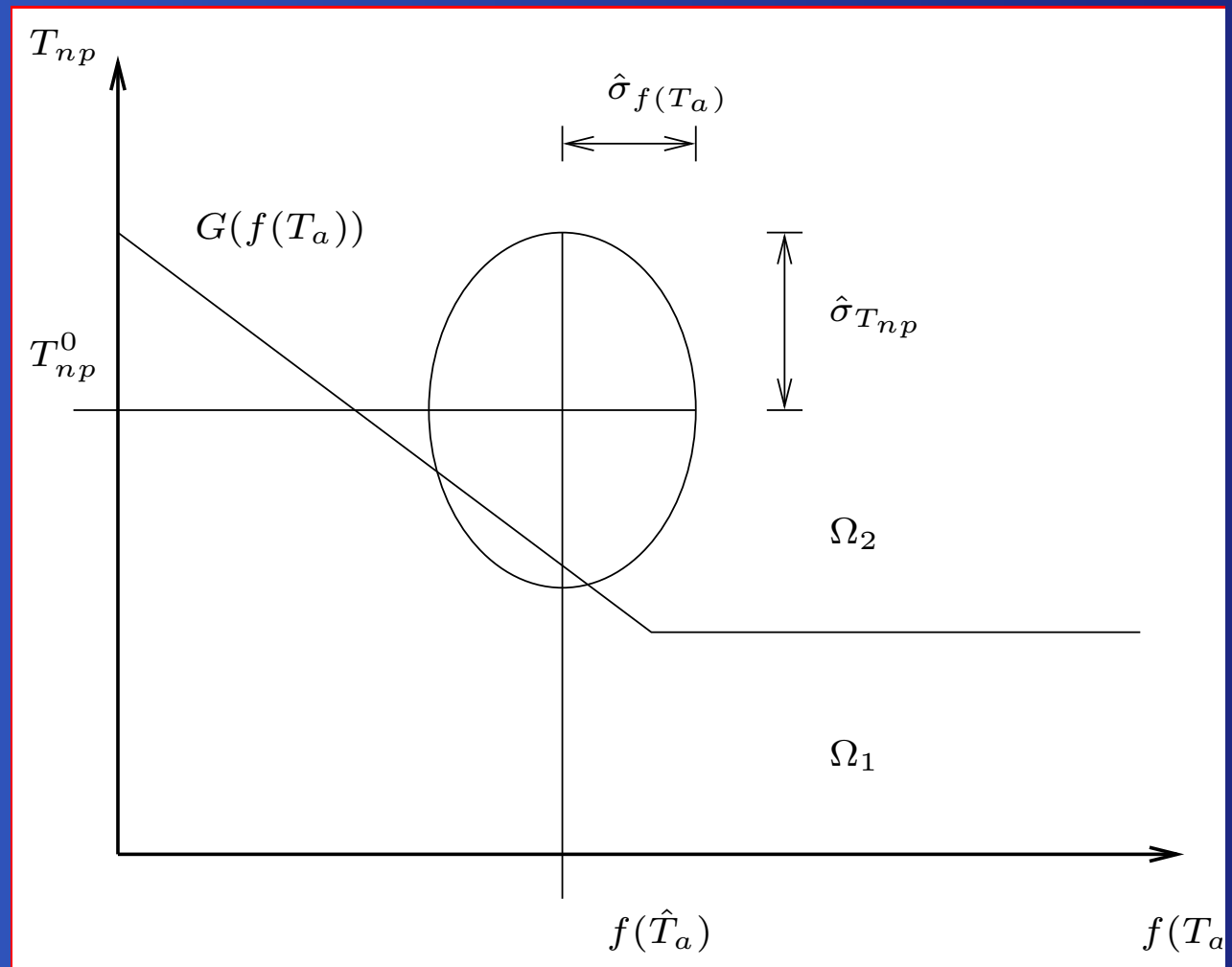
where the restrictions of the optimization problem acts as reference values for the controllers. The reference values are determined so that the probability of violating a restriction is less than a fixed (small) value.

The supply temperature is found as the maximum of the required supply temperature for the individual controllers. Furthermore the supply temperature is subject to:

- restrictions in rate of change,
- minimum and maximum values, and
- a diurnal increase to reduce peak loads.

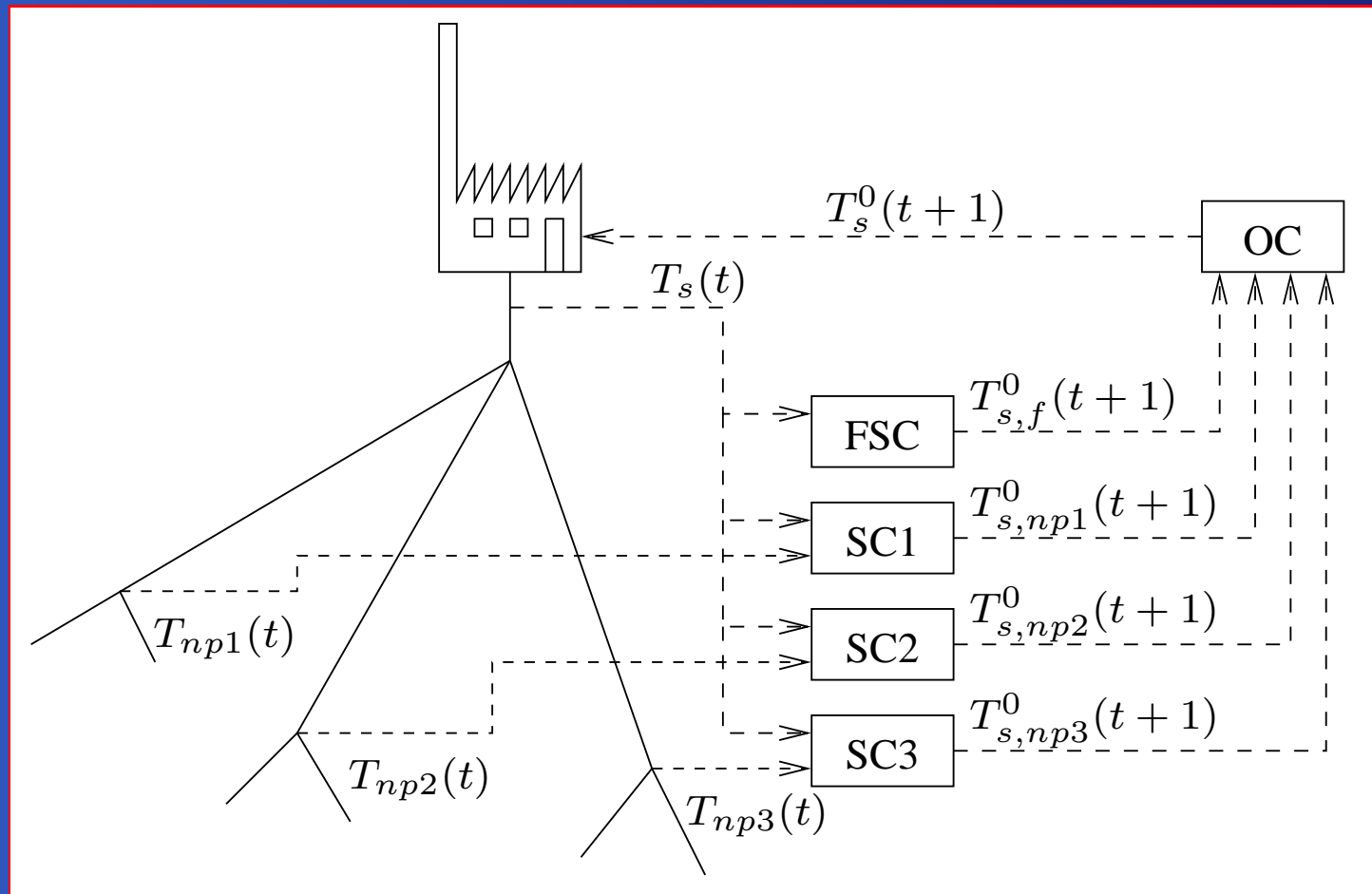


Reference net-point temperature curve



- Notice: The prediction ambient temperature is low-pass filtered.

Control of supply temperature (cont.)



Control of supply temperature (cont.)

The netpoint temperature control is implemented using the XGPC controller:

$$\min_{\mathbf{u}_t} J(\mathbf{\Gamma}_t, \mathbf{\Lambda}_t, \omega_t; t, \mathbf{u}_t) = E[(\mathbf{y}_t - \mathbf{y}_t^0)^T \mathbf{\Gamma}_t (\mathbf{y}_t - \mathbf{y}_t^0) + \mathbf{u}_t^T \mathbf{\Lambda}_t \mathbf{u}_t + 2\omega_t^T \mathbf{y}_t]$$
$$\mathbf{y}_t = \mathbf{H}_t \mathbf{u}_t + \mathbf{v}_t + \mathbf{e}_t$$

The flow rate control is implemented using the relation $p_t = c_w q_t (T_t^s - T_t^r)$. The supply temperature is found as

$$T_{t+1}^s = \sum_{i=1}^{N_u} w_i \left[\hat{T}_{t+i|t}^r + \frac{\hat{p}_{t+i|t}}{c_w q^0} \right] .$$

Control of supply temperature (cont.)

- The netpoint temperature controller is implemented using the eXtended Generalized Predictive Controller (XGPC).
 - The XGPC handles time-varying systems.
 - Time-varying and unknown time delays are handled by the XGPC controller.
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- The controllers use the predicted heat load and the predicted outdoor air temperature from the prediction module of PRESS.

The Roskilde district heating utility

Some facts regarding the Roskilde district heating utility are:

- Supply area is Roskilde City and suburbs.
- Heat is supplied by VEKS (CHP and waste incineration).
- Annual heat purchase is 1,700,000 GJ.
- Annual electricity purchase is 1,500,000 kWh.
- Maximum load is 110 MW.
- Heat loss in distribution network $\sim 22\%$ (2000).
- Prior to PRESS the supply temperature was changed periodically by the operators.



Calculation of savings

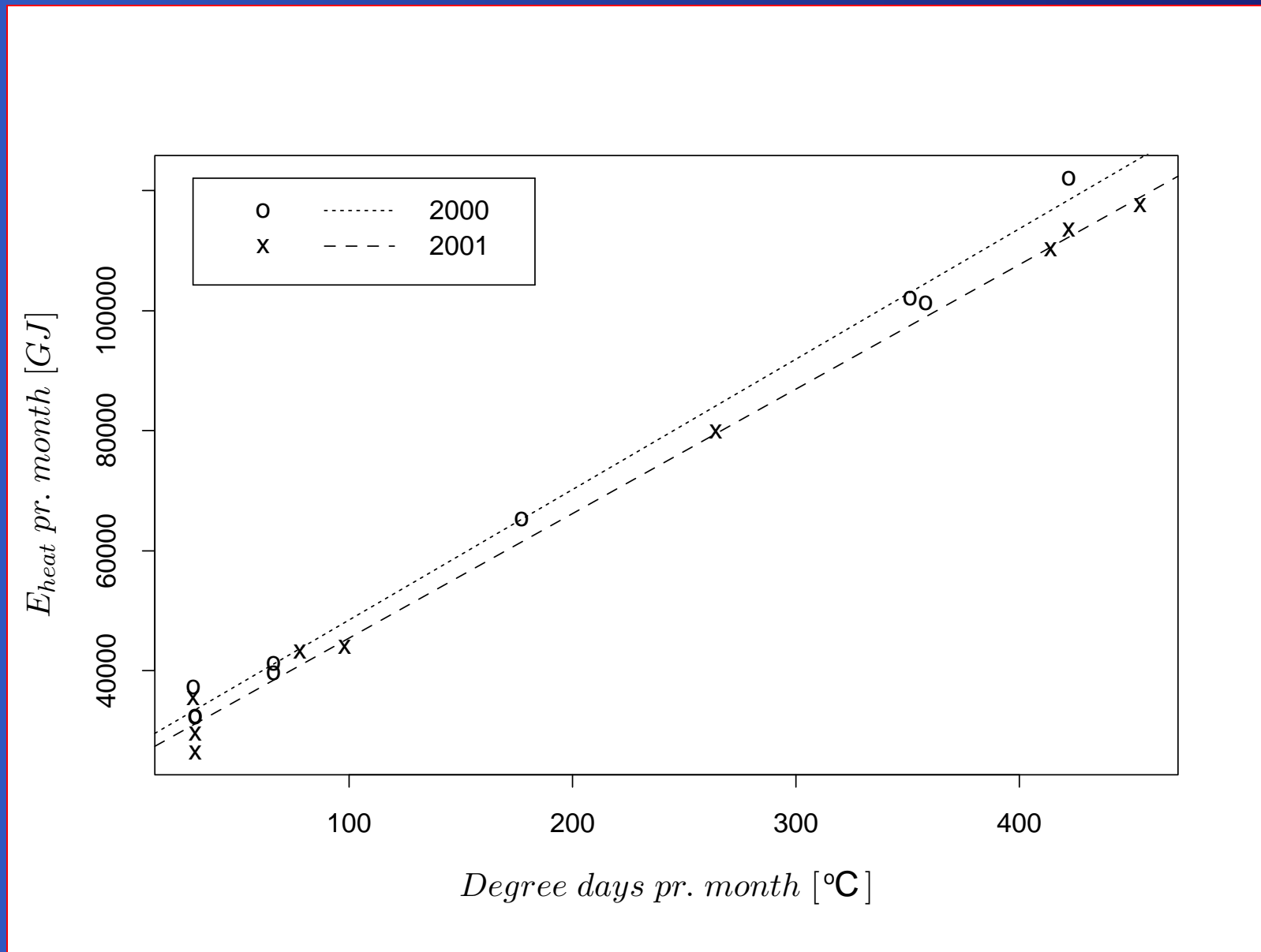
The savings obtained by PRESS have been estimated by:

- Modelling heat purchase (energy) as fct. of degree days per month before and after PRESS.
- Modelling elec. purchase (energy) as fct. of degree days per month before and after PRESS.
- Correct observed purchases to standard year.
- Check that return temperature and peak load unaffected by PRESS (ie. the energy price is unchanged).

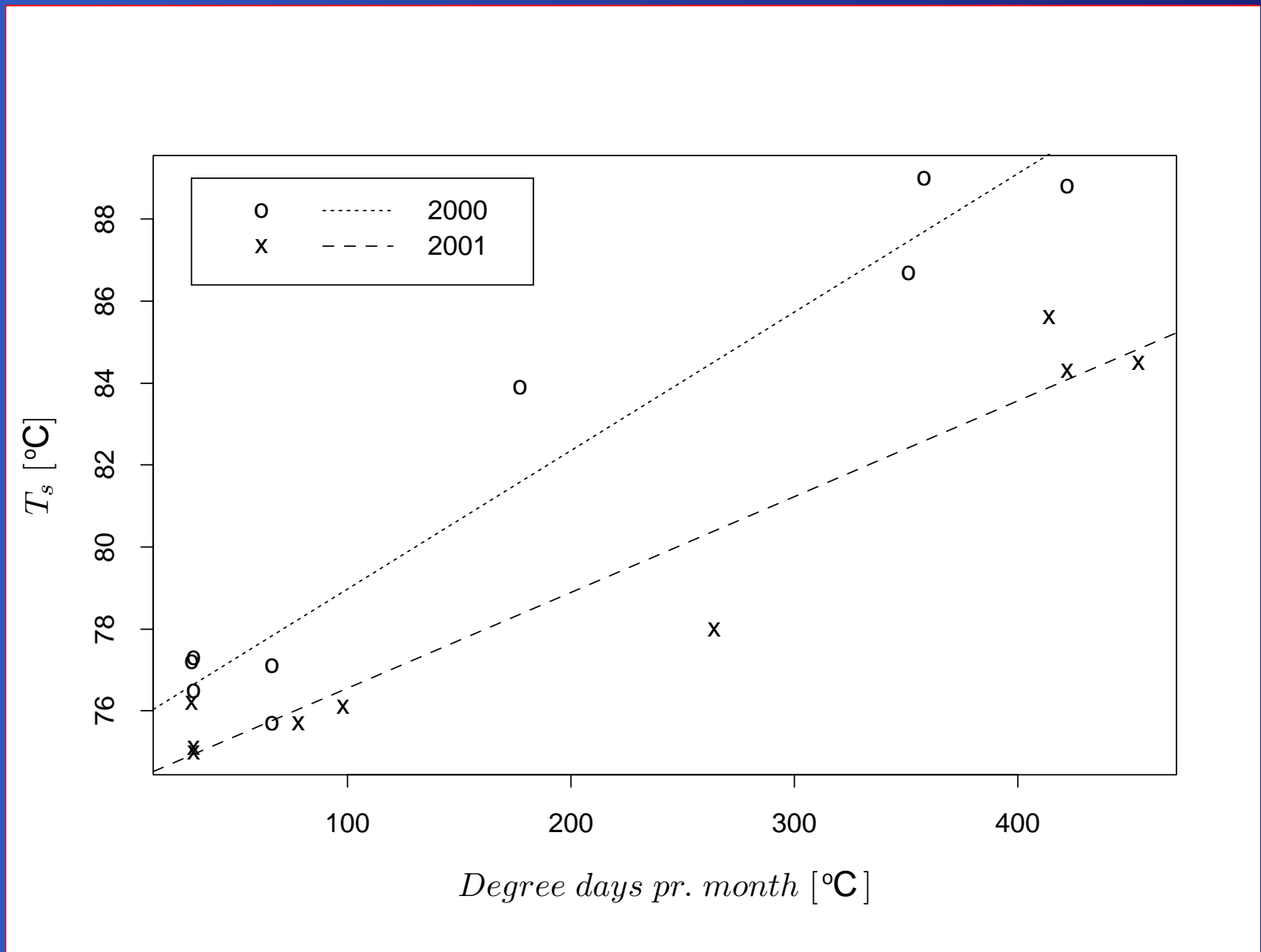
Degree days for a month is calculated as

$$\sum_{\text{Days in month}} \max(0, 17 - \bar{T}_a^{diur})$$

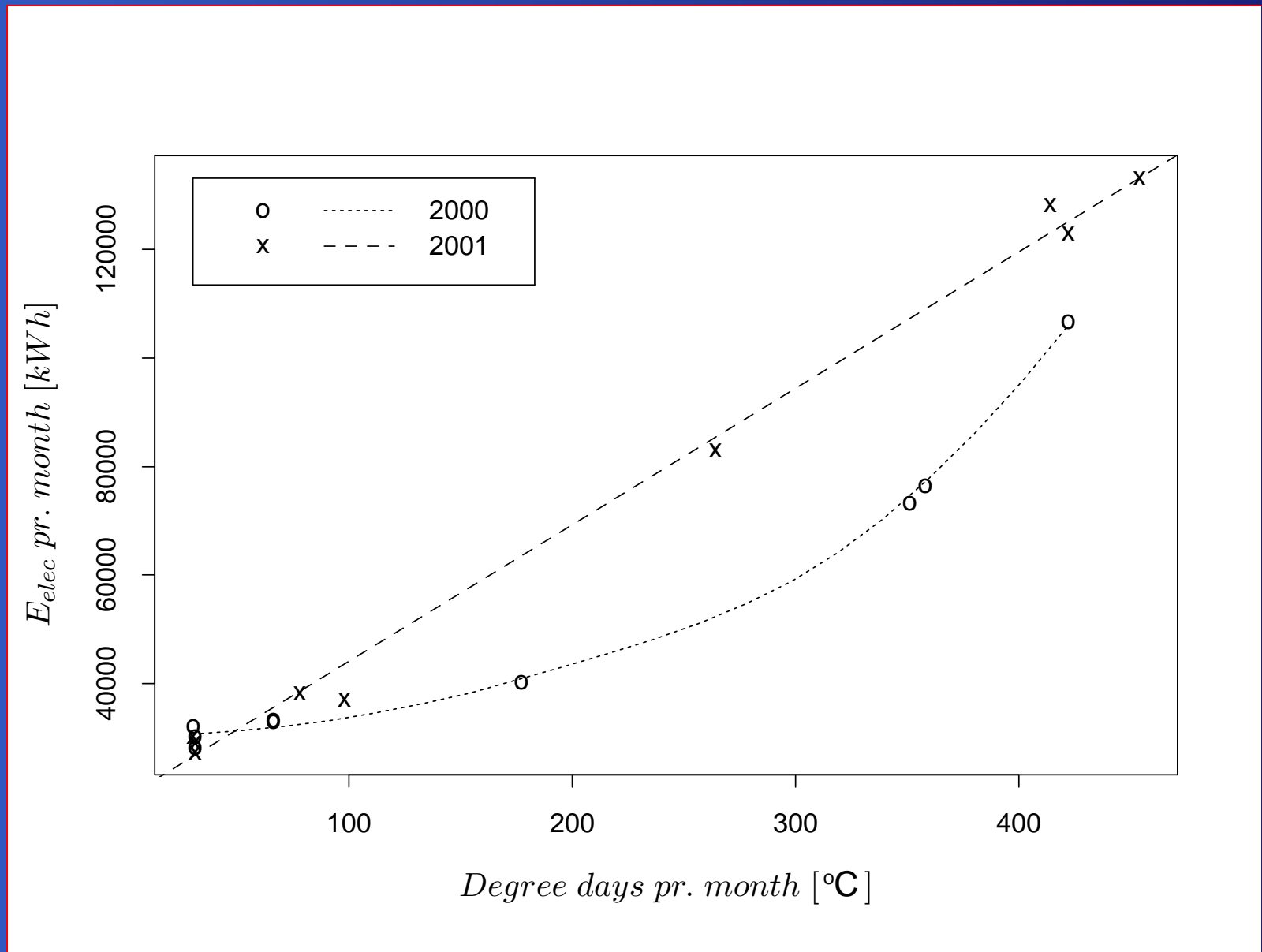
Heat purchase versus degree days



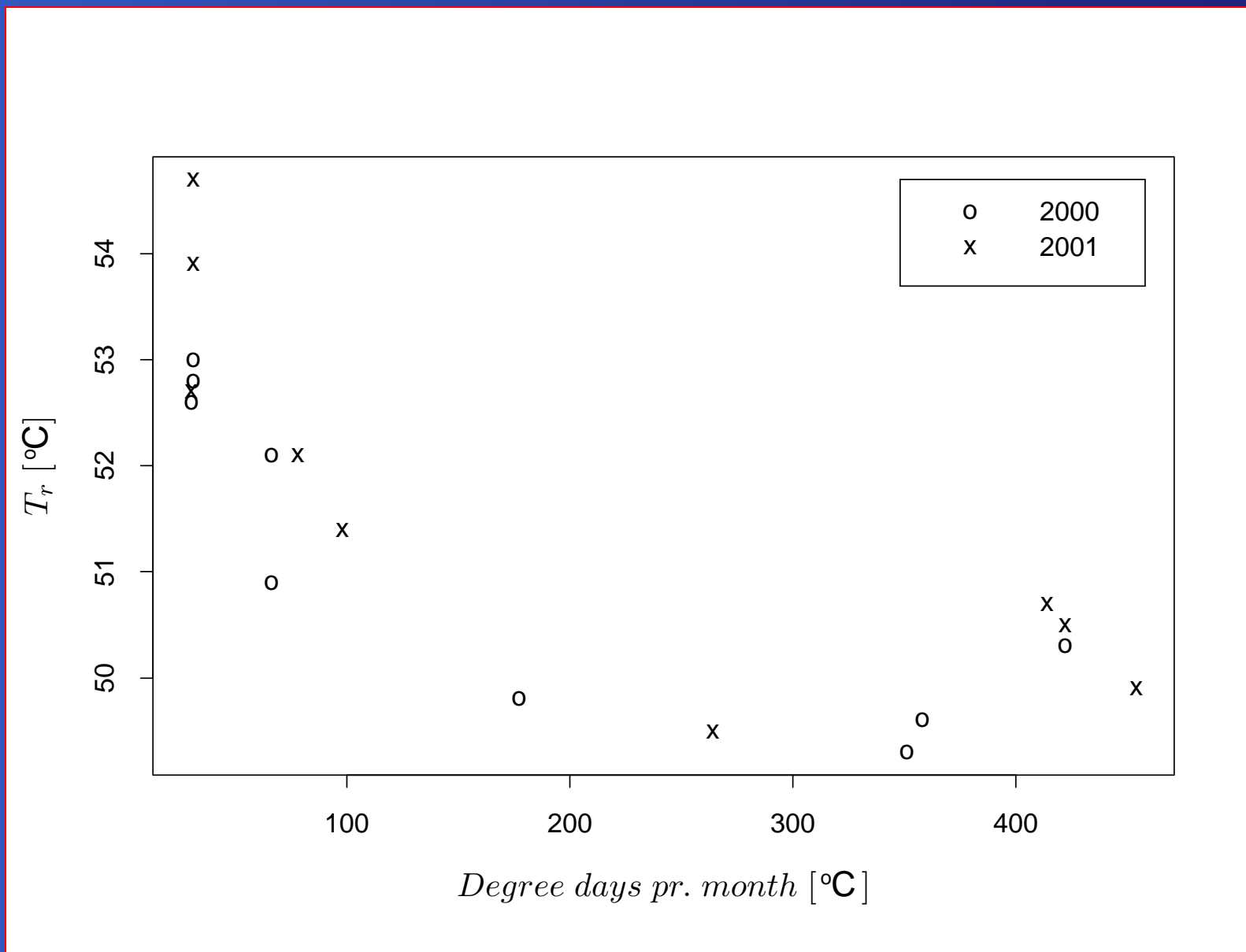
Supply temperature versus degree days



Electricity purchase versus degree days



Return temperature versus degree days



Calculation of savings (cont.)

The estimated heat purchase as function of degree days is (given as):

$$2000 : E_{mon}^{heat} = 217 \frac{GJ}{^{\circ}C} T_{mon}^{dd} + 26700 GJ$$

$$2001 : E_{mon}^{heat} = 208 \frac{GJ}{^{\circ}C} T_{mon}^{dd} + 24700 GJ$$

The estimated electricity purchase as function of degree days is (given as):

$$2000 : E_{mon}^{elec} = \hat{f}(T_{mon}^{dd})$$

$$2001 : E_{mon}^{elec} = 251 \frac{kWh}{^{\circ}C} T_{mon}^{dd} + 19000 kWh .$$

where $\hat{f}()$ is an estimated local regression line using a second order polynomial approximation.



Calculation of savings (cont.)

Using the estimated functions for each of the first nine months of a normal year before and after the installation of PRESS gives:

- A difference in heat purchase of -37,400 GJ corresponding to a reduction in heating costs of 1,760,000 Dkr.
- A difference in electricity purchase of 149,000 kWh corresponding to an increase in electricity costs of 194,000 Dkr.
- An estimated reduction of the operational costs corresponds to 1,566,000 Dkr for the first nine months of a normal year.

The savings are calculated assuming that the cost per unit energy is unchanged.

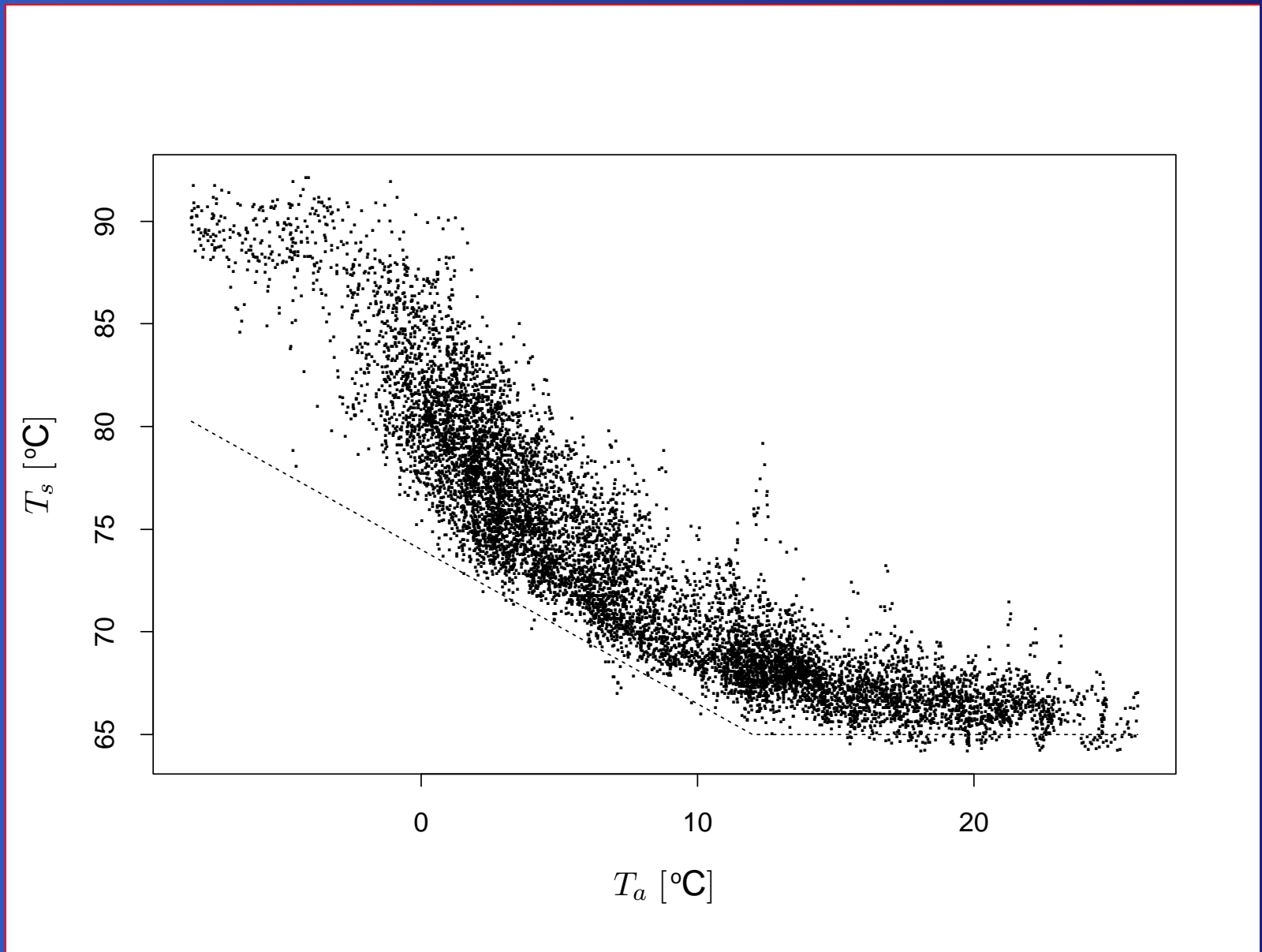
Evaluation of quality of control

The control quality is assessed by evaluating how well the controller has observed the restrictions:

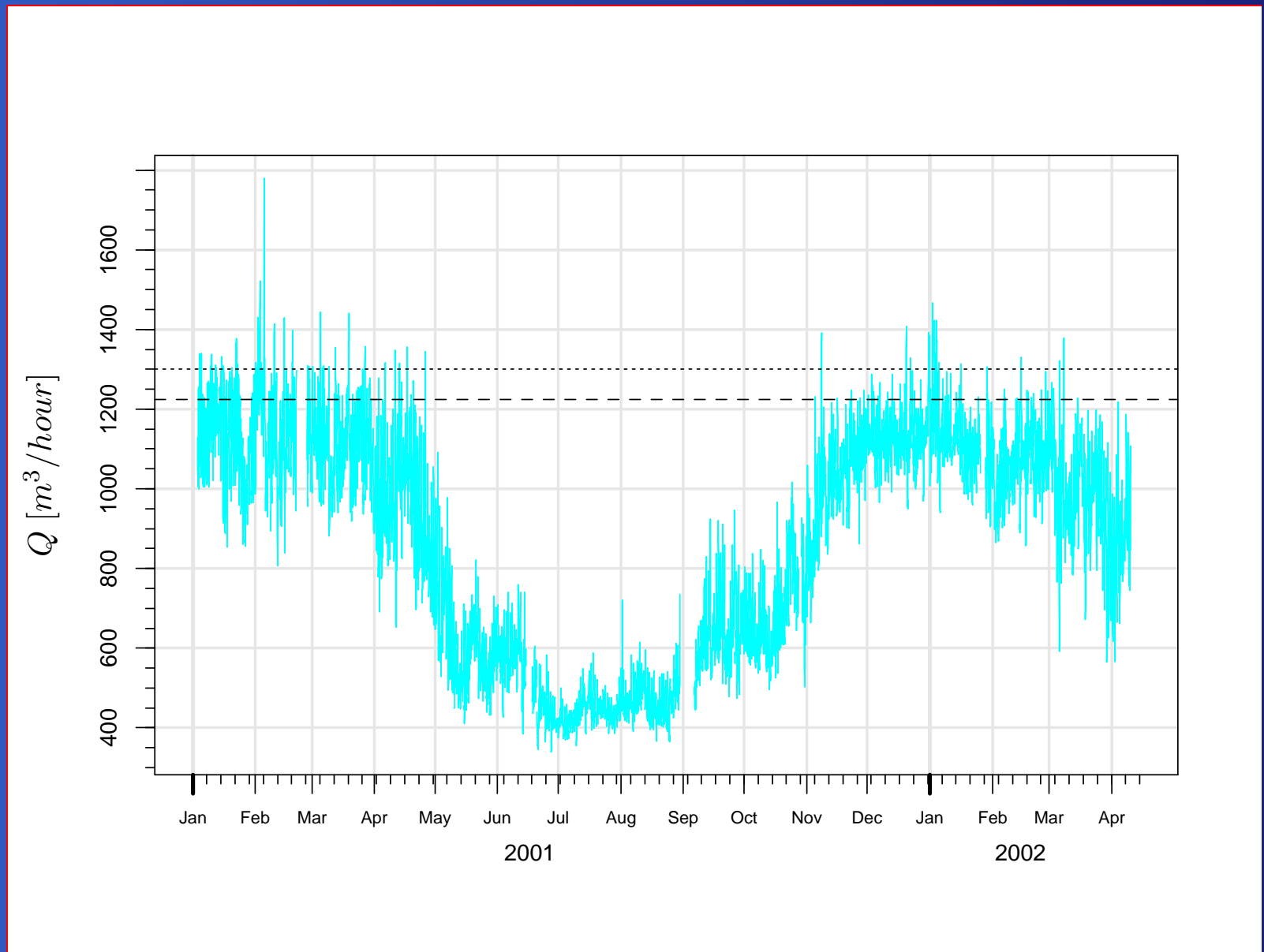
- The net-point temperature minimum limits.
- The flow maximum limit.

For the Roskilde installation the flow limit has been selected to avoid starting a secondary pump, i.e. the flow limit is not a capacity limit. In periods with high load the flow limit will be exceeded.

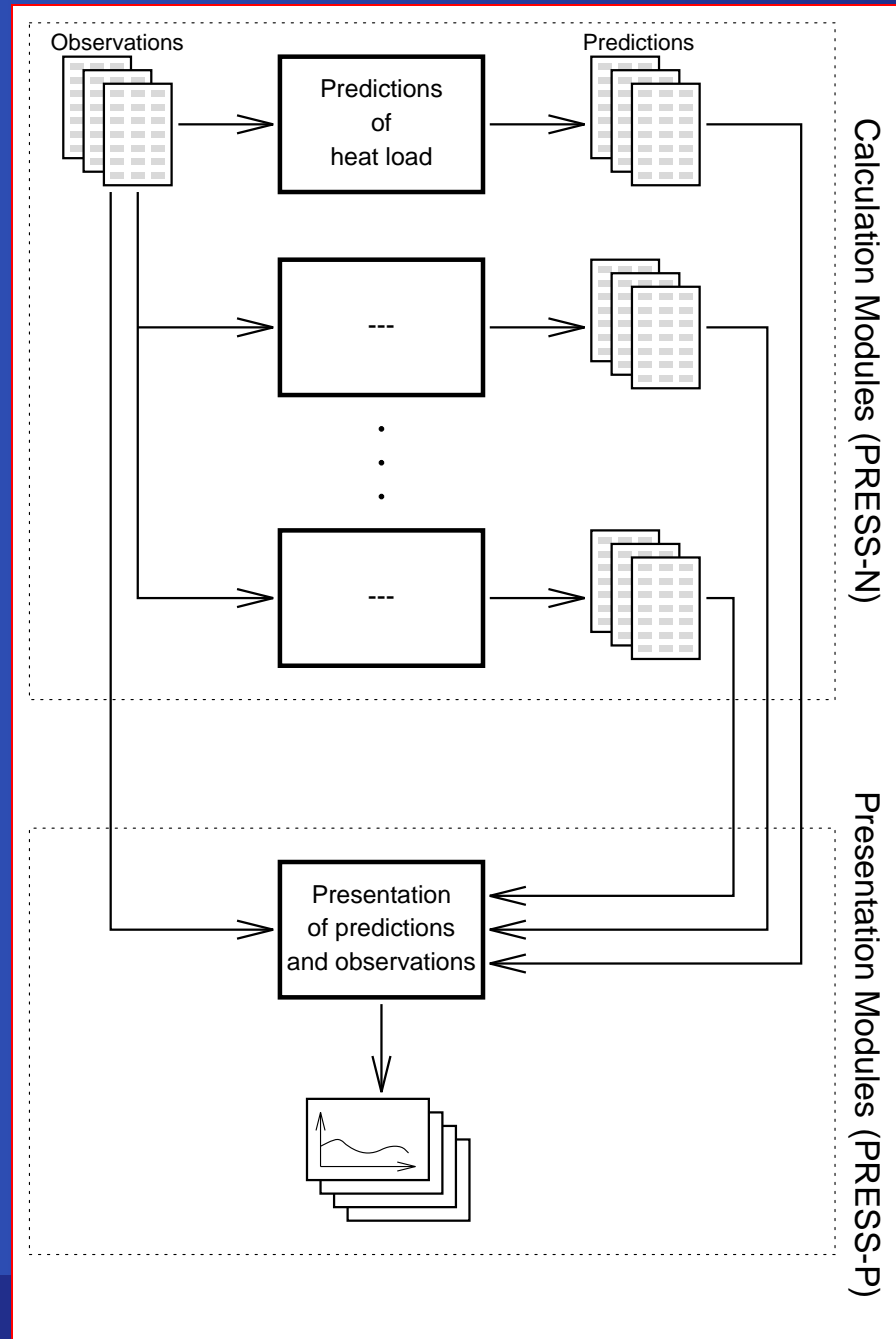
Net-point temp. versus diurnal mean air temp



Flow rate versus time



The flow of data and calculations



Conclusions

A system, PRESS, for optimizing the operation of DNWs has been presented. PRESS minimizes the supply temperature based on feedback from the DNW. In Roskilde the use of PRESS has resulted in the following benefits:

- A substantial reduction in energy costs ($\sim 1,500,000$ Dkr for the 9 months period considered),
- An improved quality of control.

In general we see

- The obtained reduction of supply temperature is of the order 3 to 10 degrees.
- Reduction of peak load.
- Less need for secondary production units.
- The system detects pipe-lines where an upgrade is most beneficial.

