Høje-Taastrup Kommune Living Lab: Optimizing the indoor climate at two public schools, Parkskolen & Borgerskolen

ABOUT THE LIVING LAB:
The Høje-Taastrup Kommune Living Lab is divided into two test areas: Parkskolen and Borgerskolen.The indoor climate of these two schools will be closely monitored through indoor climate meters in all the schools' classrooms.

In general, certain premises are heavily burdened by temperature fluctuations and high CO2 levels. Most rooms have problems at peak times and at extreme temperatures outside. Only a small number of the premises are working optimally. Many of the problems are due to the gradual expansion of the school, ventilation systems, building style and older windows.

FACTS - BORGERSKOLEN:
Type of living lab: Building
Size: 13,835 m2, test area: 1,525 m2

RESULTS - BORGERSKOLEN:
Implementation of the OS2iot platform for basic smart city digital infrastructure.

Full indoor climate and consumption data infrastructure setup such that gathered data is available in real time by researchers at DTU Compute.

Full smart thermostat deployment in all rooms that sends and receives data in real time. This enabled the researchers to carry out experiments and generate data. This helped them estimate mathematical models and representations of the of the building's indoor climate.

Development of a (grey-box) model of the building's indoor air climate. This model used aggregated (averaged) building indoor air temperature data. The model were used for optimising the operations of the indoor climate system of the building. Results indicate district heating return temperature decrease, which means less economic penalty. Together with energy savings, this amounts to economic savings between 10-15%.

Model established with data from experiments on building level a grey-box model for prediction of building level heat load and return temperature were developed.

So-called nonlinear ARX-related models were developed to describe the indoor air temperature of individual rooms. This was necessary due to significantly different dynamics of the room's air temperature.

Savings approx. 10% due to flexibility.

FACTS - PARKSKOLEN:
Type of living lab: Building
Size: 7,763 m2

RESULTS – PARKSKOLEN:
Established data collection from the existing CTS system. This involves supply temperatures for most heating units as well as motor valve positions. Data collection for the energy consumption of Parkskolen has been established with daily datapoints on the consumption for the whole building.

With this data, methods for splitting the building energy consumption into the individual heating units has been explored with good correlation capabilities on the total daily load when using motor valve positions as parameters for the estimation.

Performance analysis reports for facility/energy managers has been developed for similar buildings but has not been deployed on Parkskolen due to lack of detailed energy data (across sub-installations and with at least hourly resolution).

PERSPECTIVES FOR THE FUTURE:
Deployment of the OS2iot platform enables easy scaling of the developed solutions to many other municipalities .

The new 19 degrees "regime" is a driver for the demand for data driven solutions.

The indoor climate methods are now implemented in a relatively large number of schools and offices in Denmark - and also in Hong Kong and the US.

Høje-Taastrup Kommune · DTU · ENFOR · NEOGRID TECHNOLOGIES

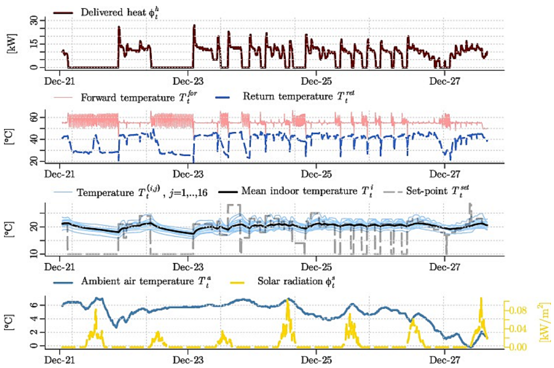
Publications related to the living lab can be found at www.flexibleenergydenmark.com/further-information/knowledge-bank/publications/

TECHNICAL SETUP - BORGERSKOLEN:
Center Denmark provided a platform for hosting cloud based data collection and real-time control for Borgerskolen. Data flows both ways from multiple sensor platforms and MQTT connections from the municipality hosted BMS in the building.

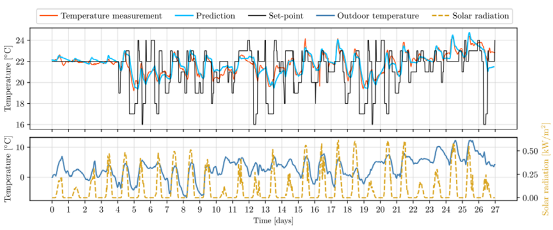
TECHNICAL SETUP - PARKSKOLEN:
At Parkskolen data is shared with the Center Denmark platform hourly through a sftp-connection.

MODELS
The results from Borgerskolen mainly evolved around developing models for the indoor air temperature that are suited for optimal control. The main result is that the price-based control of a building connected to district heating has been demonstrated successfully and indicates that significant economic savings are available. However, the learnings were that the implemented building level control is too coarse to unleash the full potential and to guarantee temperature levels on room level. These main learnings have been described in an article. New models on room level were developed and they will be used in a distributed control setup in future works where the building level control works together with the room level controls.

The following figure shows the building level experiment that was used for identifying and estimating the building level model. It was carried out during the winter and thus less to no sun was present, which is not ideal for estimating the sun's influence on the building indoor air temperature.



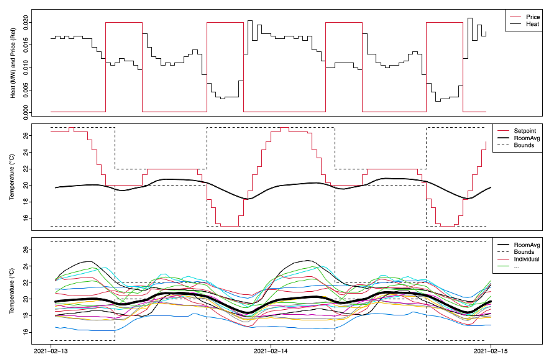
Room level experiment and predictions are shown in the following figure. The main result of the room level modelling is that they look suitable for control pruposes. Future work will involve employing such room level control in combination with the building level control in a simulation study together. We need this simulation step to investigate the potential of the idea before carrying it out in the real world.



Model predictive control problem formulation:

$$
\begin{aligned}
\min_{\boldsymbol{x},u,\boldsymbol{s}} \quad & \varphi_k = \int_{t_k}^{t_k+T} \ell(\boldsymbol{x}(t), u(t), \boldsymbol{d}(t), s(t))\mathrm{d}t, \\
s.t. \quad & \boldsymbol{x}(t_k) = \hat{\boldsymbol{x}}_{k|k}, \\
& \mathrm{d}\boldsymbol{x}(t) = f(\boldsymbol{x}(t), u(t), \boldsymbol{d}(t))\mathrm{d}t, && t \in \mathcal{T}_k, \\
& u_{\min}(t) \le u(t) \le u_{\max}(t), && t \in \mathcal{T}_k, \\
& \Delta u_{\min}(t) \le \Delta u(t) \le \Delta u_{\max}(t), && t \in \mathcal{T}_k, \\
& T_{\min}(t) \le T_{\mathrm{i}}(t) + s(t) \le T_{\max}(t), && t \in \mathcal{T}_k,
\end{aligned}
$$

The model predictive control results is shown below. As mentioned earlier, the dynamics of the temperature in the individual rooms are significantly different. This pose a problem on the aggregated building level control and indicates that some room level adjustments and controls are necessary for this to work. This will be investigated in the future.



FED is a Danish digitization project, funded by Innovation Fund Denmark, aimed at turning Danish power consumption flexible to enable utilization of excess power from wind turbines and solar cells.

The project brings together Denmark's foremost researchers, organizations, supply companies, software companies and a number of living labs that provide data for the project.

FED FLEXIBLE ENERGY DENMARK

Innovation Fund Denmark