Aalto University
School of Engineering

Demand response of space heating using model predictive control in an office building

27.9.2018

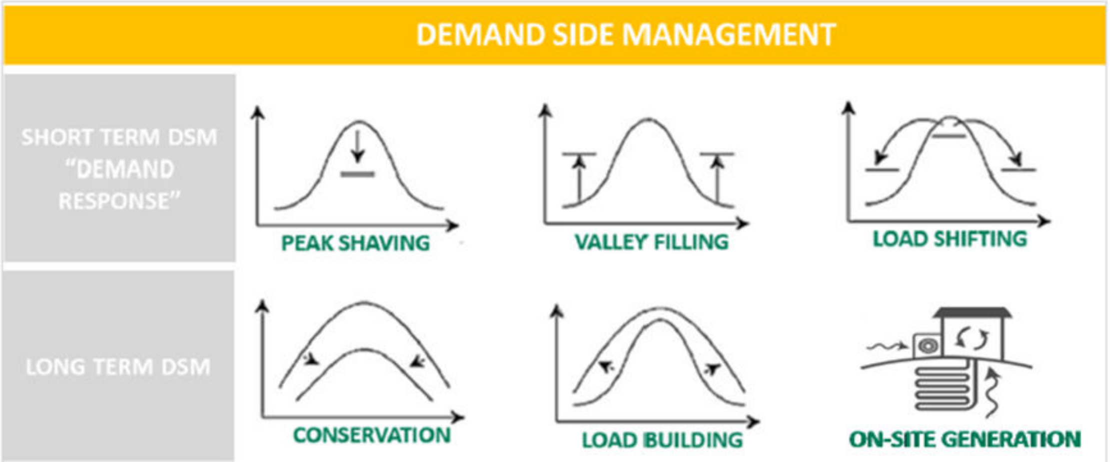
Aleksi Mäki, Juha Jokisalo, Risto Kosonen

Contents

1. Demand side management and demand response

Demand side management (DSM) can be defined as a set of methods which try to improve and optimize the energy system by changing the time pattern and/or magnitude of the load at the side of energy consumption

Long-term DSM: the consumers load is modified permanently
Short-term DSM or demand response: the load is changed temporarily.



2. Motivation and objectives

Motivation

- Benefits from demand response:
  - reduced CO2 emissions
  - increased network stability and efficiency (allows more RES)
  - cost savings for building owners and energy producers

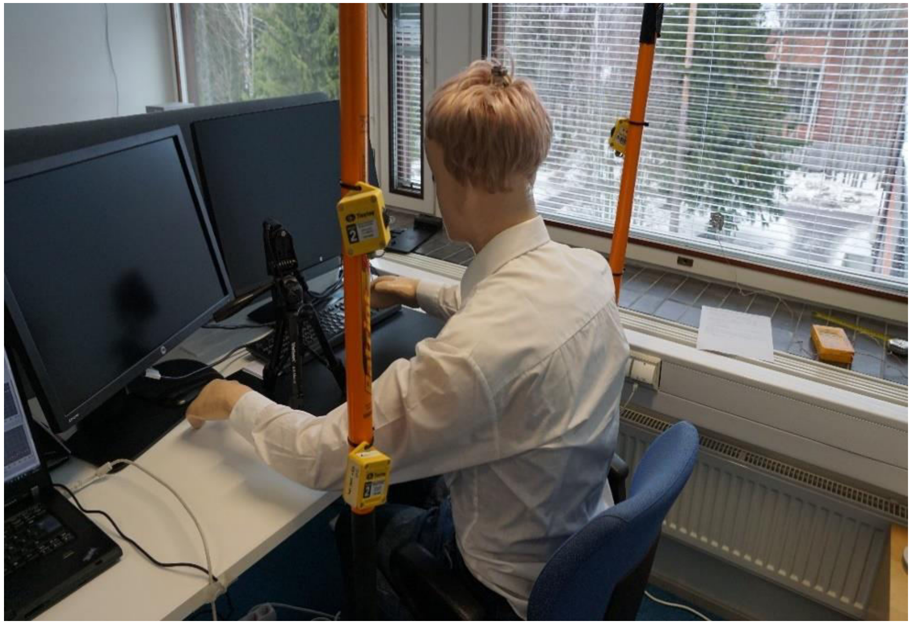
Objectives

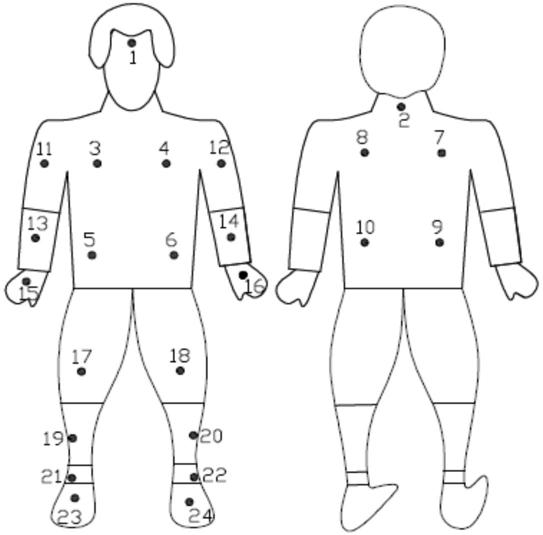
- Build model predictive control algorithm for district heating demand response
- Estimate the DR potential in the perspective of heating cost savings, energy flexibility and thermal comfort
- Study restrictions due to local thermal discomfort in workstations adjacent to windows and apply them in the DR algorithm

Scope

- Space heating, District heating
- Case building Otakaari 4, 4th floor

3. The local thermal comfort constraint





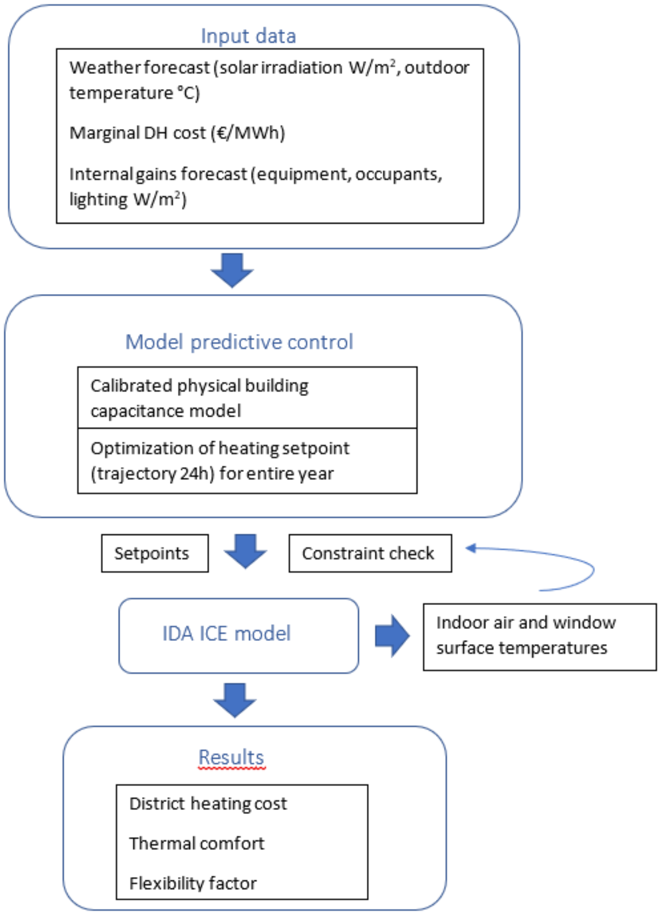
3. The local thermal comfort constraint

- Window inner surface temperature of 15 °C was found to be a restrictive temperature below which the convective downward airflows caused draft.
- If the heating power from the radiators was sufficient, the convective airflows were blocked by the thermal plumes
- A control constraint was applied in the DR algorithm that defined the minimum space heating power whenever the window surface temperature dropped below 15 °C.
- The outdoor temperature when the restrictive surface temperature was reached is dependent on the window construction.

Window surface temperature °C	U-value of the window W/m2K	Exterior temperature °C
15	0.6	-25
15	0.8	-13.8
15	**1**	**-7.0**
15	1.5	2.0
15	2	6.5
15	2.5	9.2

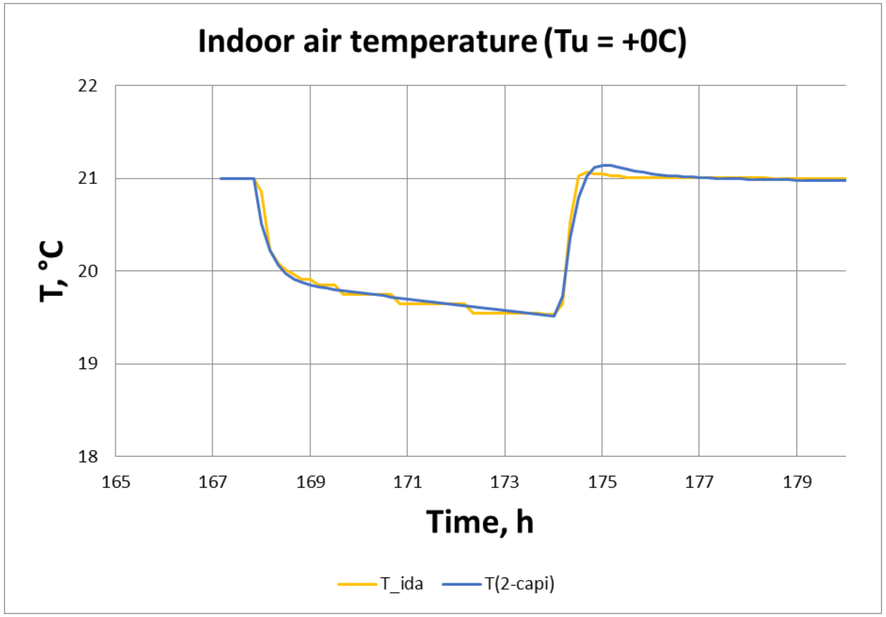
4. Model predictive control

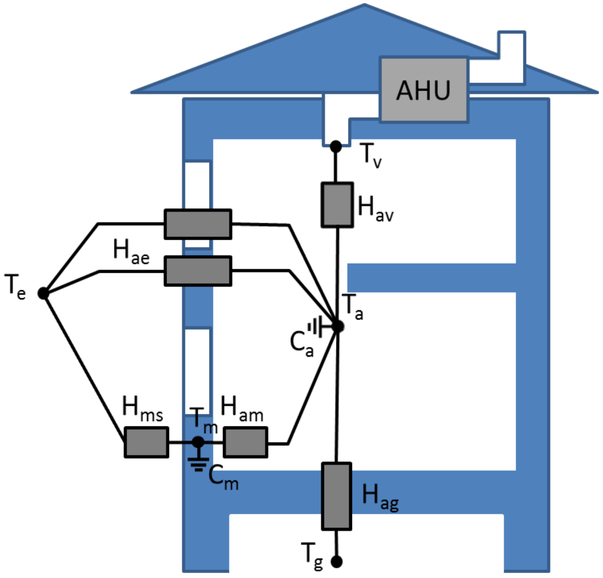
- Input data: weather forecast, DH marginal price, forecast of internal gains
- Two capacitance physical building model calibrated with ida ice simulation results
- Multiobjective optimization of setpoint trajectory with prediction horizon of 12 or 24 hours (objects: cost, flexibility factor and thermal comfort)
- Ida ice simulation with optimal setpoints and thermal comfort feedback
- Analysis of results

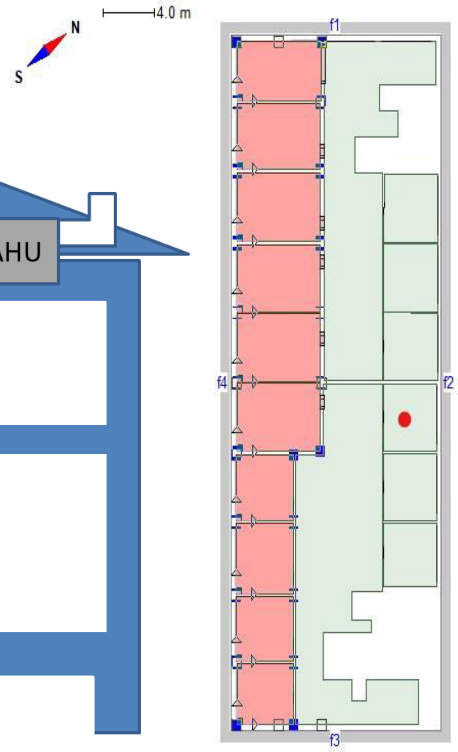


4. Calibrated physical building model

- Simple 2-capacitance model
- Calibrated against the IDA ICE model







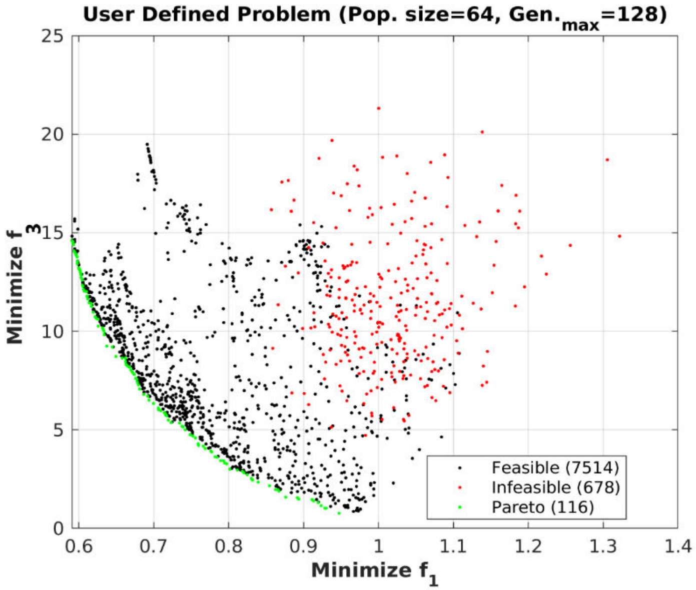
4. MOO – Multiobjective optimization

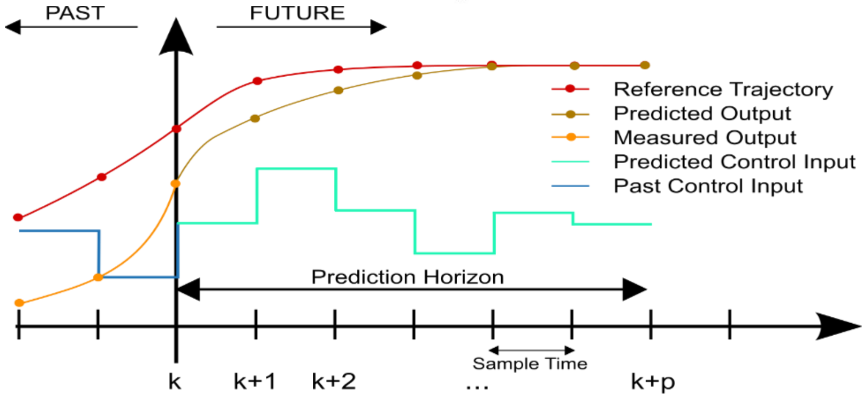
Objectives:
f1=heating cost or flexibility factor (12/24 h)
f3=discomfort (squared deviation from optimal air temperature, Finnish indoor climate classification S2)

Optimization variable: space heating setpoint for t=1,2,…n h

Choose of optimal setpoint trajectory from pareto optimal solutions

Prediction horizon (12h or 24h)
Control horizon (1h)





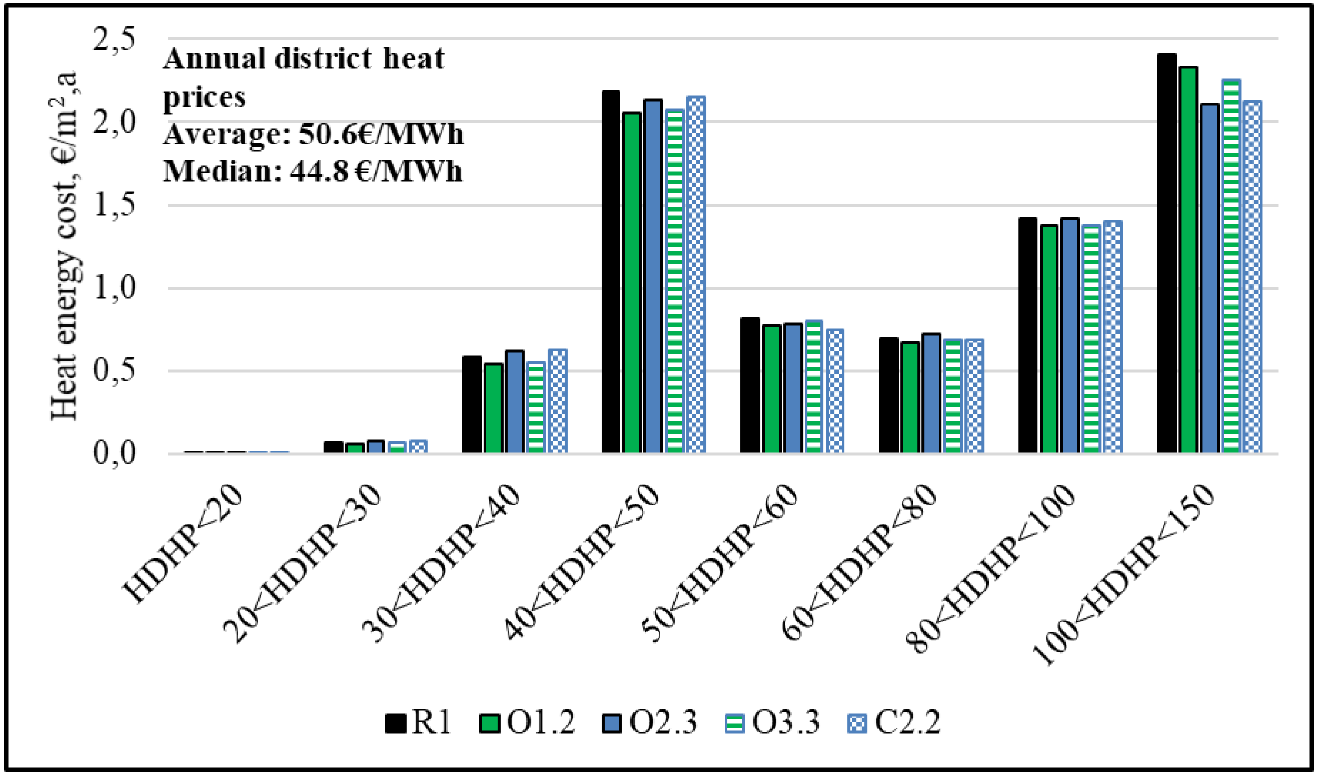
4. Simulation cases

- Reference cases without demand response
  - setpoints 20°C or 21°C
  - Two window constructions (U=1 W/m2K and U=2.7 W/m2K)
- Demand response cases
  - Different optimization objectives
  - 12h or 24h prediction horizon
  - Setpoint ranges either [20-23], [20-21] or [20-24.5] °C
- Influence of windows and local thermal comfort restriction
  - Two window construction
  - Two heating power restriction when window surface T < 15 °C :
    - min 30% from the max instantaneous heating power
    - min 50% from the max instantaneous heating power

5. Simulation results

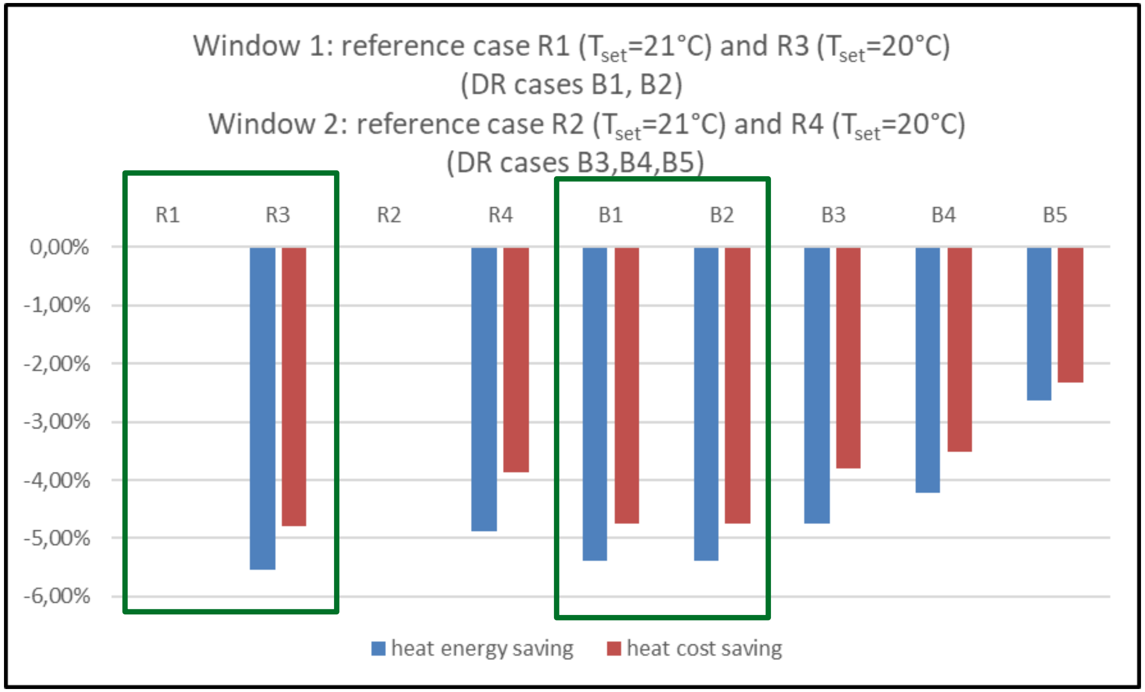
- The maximum heat cost saving
  - Cases optimizing costs -4.8% compared to reference case
  - Cases optimizing flexibility -4.3% compared to reference case
- Optimization objective heating cost
  - > energy conservation
- Optimization objective energy flexibility
  - > load shifting
- All cases:
  - Acceptable thermal conditions
  - Decreased heating costs and equal or increased energy flexibility

5. Simulation results



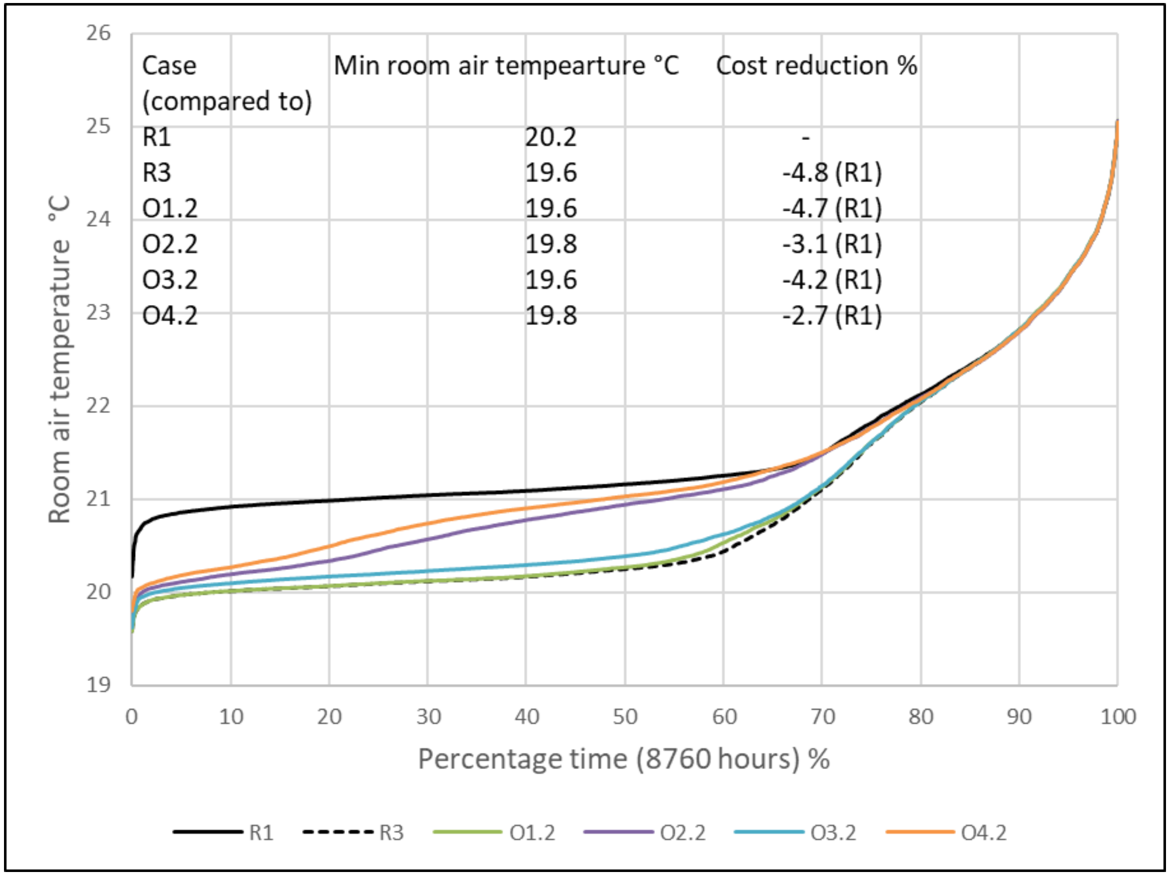
Black column (R1): Reference case, constant space heating setpoint 21°C
Blue columns (O2.3 and C2.2): max energy flexibility as one objective
Green columns (O1.2 and O3.3): min heating cost as one objective

5. Simulation results



Window restriction – Heating above min power when cold windows:
Energy efficient window 1 (Green box): neglectable effect to DR potential
Poor window 2 (No box):
- min 30 % heating power -> minor effect to DR potential
- min 50 % heating power -> noticeable effect to DR potential

5. Simulation results



6. Conclusions

- All the studied cases resulted in heating cost savings and equal or increased energy flexibility
- Thermal comfort was maintained at acceptable level
- The convective downward airflows from windows may cause draught in workstations near windows
- However, even small heating power from radiators was found to be sufficient to block the downdraughts and therefore this phenomenon has minor influence to overall DR potential
- The highest uncertainties are linked to: DH price and adjustability to different buildings

Thank you

Any questions?

Contacts:
Aleksi Mäki
aleksi.maki@aalto.fi