Demand response of space heating for a district heated office building in Finland





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The benefits of demand response control of space heating were evaluated for a district heated office building. A rule-based demand response control strategy was introduced. Based on the results, district heat energy costs were reduced by 9.6% through demand response control of space heating without sacrificing thermal comfort.

Keywords: district heating; demand response, rule-based control, marginal cost

Introduction

In Finland, district heat accounted for 45% of the market for space heating in public, commercial, and residential buildings in 2020 (Finnish Energy 2022). Initiatives aimed at the energy sector's decarbonization should be developed since Finland plans to be carbon neutral by 2035 (Finnish Government 2019).

Demand side management is the approach linked to integration of more renewable energies in the future. It could adjust consumer demand to follow the unstable energy generation by renewable sources (Gelazanskas and Gamage, 2014). Consumers can gain monetary benefits simultaneously.

However, few studies have taken advantage of dynamic marginal costs of district heating generation for building-level demand response. Therefore, a rule-based demand response control strategy was designed based on dynamic district heat prices calculated by the marginal costs. The aim is to investigate the benefits that can be gained for a district heated building. In this study, a Finnish office building was selected for analysis.

Building simulation process

Figure 1 introduces the demand response process of space heating. Control signals were determined by the variation of dynamic district heat prices.

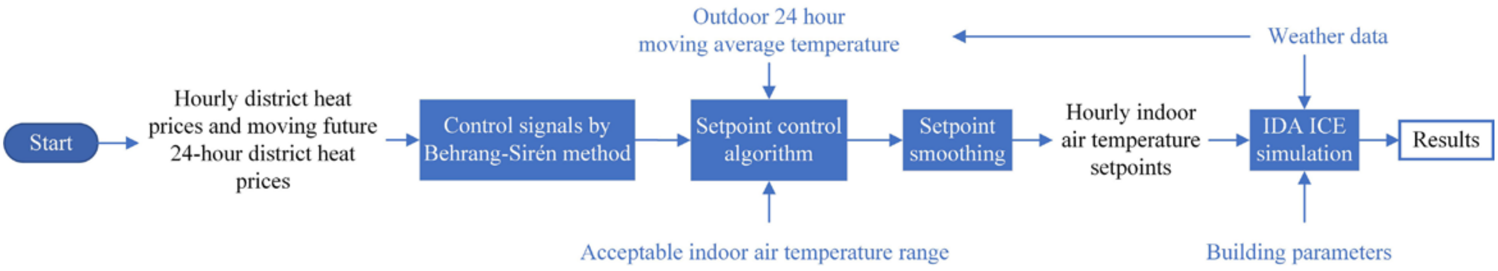

Figure 1. Demand response control process of space heating.

In order to shift the space heating demand, several indoor air temperature setpoints were chosen for the demand response control. To further avoid the rebound effect, the setpoint smoothing approach was used based on the study of Ju et al. (2021).

Simulated building

A typical Finnish office building constructed in 1980s in Espoo was chosen in this study. It has been renovated several times. **Table 1** lists the building parameters. It was connected to a conventional high-temperature DH network to cover space heating by water radiators, ventilation, and domestic hot water (DHW). The U-values were defined by the Finnish building code (Ministry of the Environment, 1985). The designed indoor air temperature was set at 21°C during the heating season (Ministry of the Environment, 2016).

Table 1. *Properties of the simulated office building.*

Parameters	Office Building
Heated net floor area (m^2)	2383
Floor number	4
Envelope area (m^2)	3855
Window/envelope area	9.5%
U-Value of external walls ($W/m^2 \cdot K$)	0.28
U-Value of roof ($W/m^2 \cdot K$)	0.22
U-Value of ground slab($W/m^2 \cdot K$)	0.36
U-Value of windows ($W/m^2 \cdot K$)	1.00
Air leakage rate, n_{50} (1/h)	1.60
Usage time	8 a.m.–4 p.m. (workdays)
DHW heating energy demand (kWh/m^2)	6
Actual peak heating power demand (kW)	113.2

District heat prices and weather data

The demand response benefits during the heating season from October 2021 to April 2022 were analyzed in this study. The hourly DH prices with 24% VAT are shown in **Figure 2**. The details of the district heat price which was calculated based on the marginal cost of a district heating production in Espoo are shown in (Ju et al., 2023). The maximum price was 192.5 €/MWh. The weather data was gained from the Finnish Meteorological Institute (2023) for the same period. The minimum outdoor temperature was −19.8°C.

Demand response control algorithm

In study, Behrang-Sirén method shown in Equation (1) was used to determine the price trend for controling the indoor air temperature setpoints (Alimohammadisagvand et al., 2016). It assumed that the moving future 24-hour price was known. The price trend was decreasing (−1), increasing (+1), and flat (0). A marginal value of 15 €/MWh was selected for more sensitive to price variation.

$$\begin{aligned}&If\ HEP < HEP_{avr}^{+1,+24} - marginal\ value, Then\ CS = +1\\&Elseif\ HEP > HEP_{avr}^{+1,+24}, Then\ CS = -1\\&Else\ CS = 0\\&End\ If\end{aligned} \quad (1)$$

where *HEP* is hourly energy (district heat) price, €/MWh; HEP_{avr}^{+1+24} is the moving future 24-hour district heat price, €/MWh.

Figure 3 shows the demand response control algorithm. The hourly indoor air temperatures were controlled by the space heating system. When the

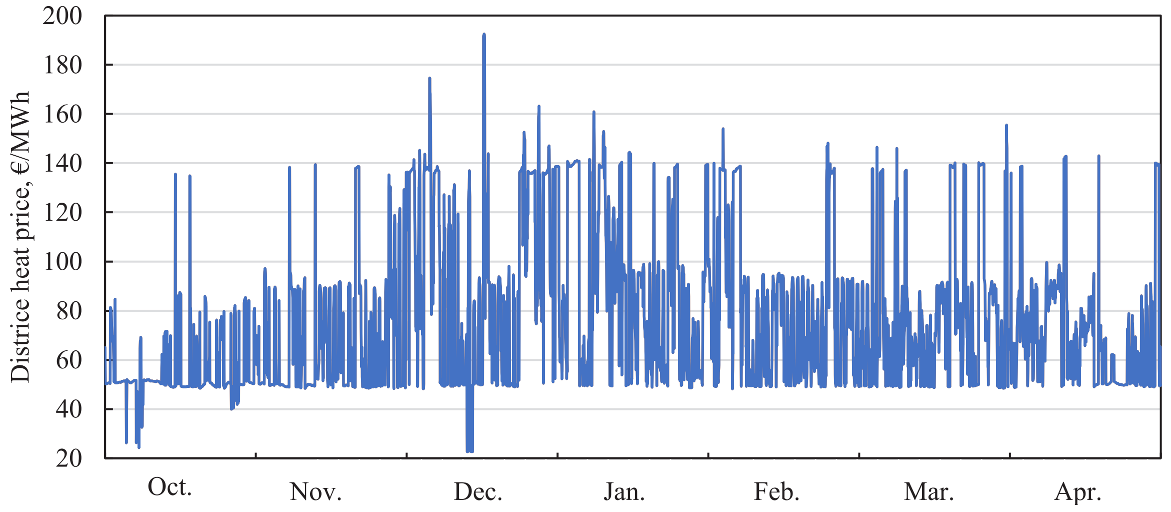

Figure 2. Dynamic district heat price during the heating season.

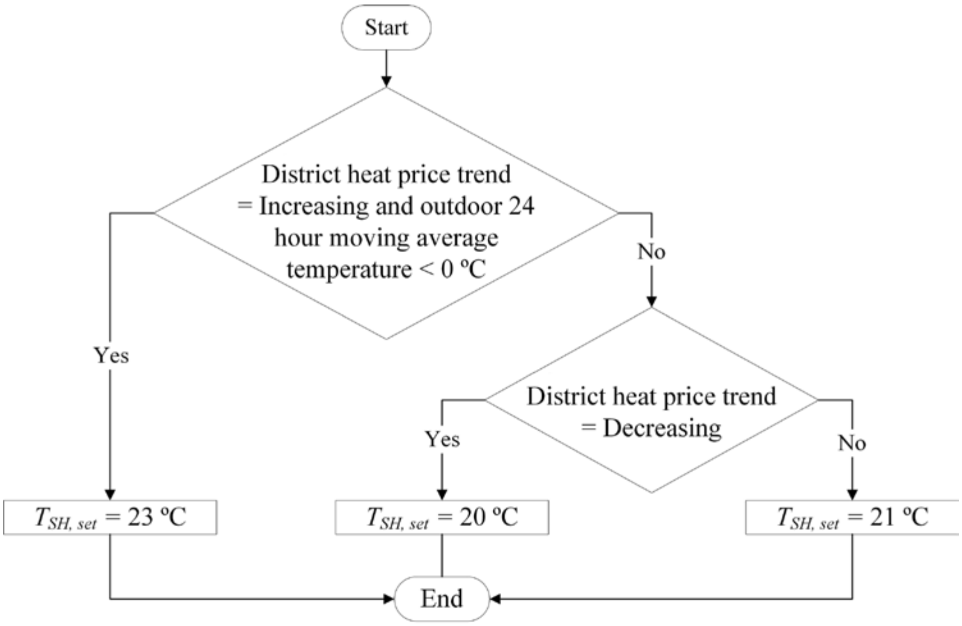

Figure 3. Setpoint control algorithm for space heating.

price trend was decreasing (high-price period), the indoor air temperature was at 20°C. It was set based on the thermal environmental category II of standard SFS-EN 16798-1 (2019). When the price trend was flat, the indoor air temperature setpoint was 21°C. The maximum indoor air temperature setpoint was 23°C for the increasing price trend (low-price period) (Suhonen et al., 2020). To prevent overheating, the outdoor 24-hour moving average temperature should be below 0°C or the indoor air temperature would not increase (Martin, 2017).

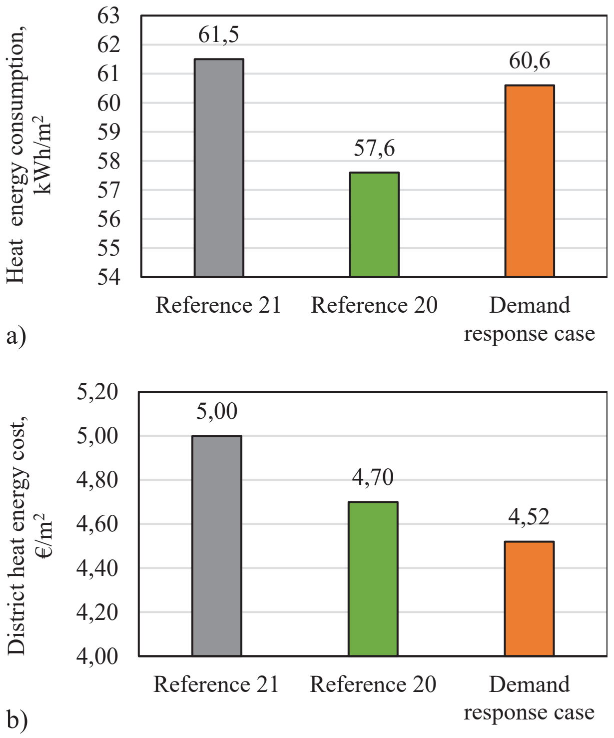

Figure 4. a) heat energy consumption; b) district heat energy cost.

Results

Figure 4 collects the heat energy consumption and district heat energy cost during the heating season with and without demand response. For the reference case Reference 21, the indoor air temperature was kept at 21°C. There is another reference with 20°C indoor air temperature setpoint for comparison. The district heat energy cost was calculated based on the district heat prices (**see Figure 2**). It illustrates that decreasing 1°C of the indoor air temperature reduces the heat energy consumption by 3.9 kWh/m^2 (6.2% compare with the reference case 21). However, although the demand response case only cuts the consumption by 0.9 kWh/m^2 (1.4%), it saves more of the district heat energy cost. The cost saving is about 0.5 €/m^2 which is 9.6%. Excluding the cost saving by decreasing the indoor are temperature, demand response control gained additional savings by storing heat during low-price period and using them when the district heat price was high.

Figure 5 presents the heating season duration of indoor air temperatures of the office building's coldest room.

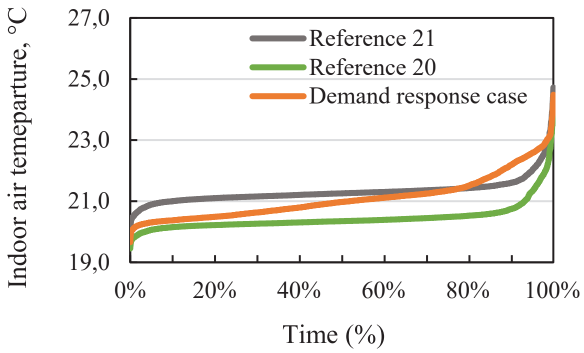

Figure 5. Duration curves of indoor air temperatures for the coldest room during the heating season.

For the reference 20 case, the minimum temperature is 19.5°C. Occupants stay in a lower indoor air temperature longer than in other cases. For the demand response case, the minimum temperature is 19.7°C. The difference to 20°C (the minimum indoor air temperature of the acceptable temperature range) is negligible. Therefore, the demand response control works without sacrificing thermal comfort.

Conclusion

In this study, a district heated Finnish office building was selected to investigate demand response benefits. A rule-based demand response control strategy was designed based on dynamic district heat prices. The results show that the demand response control saves district heat energy costs by 9.6% without compromising thermal comfort. ■

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