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DEMAND RESPONSE OF SPACE HEATING AND VENTILATION – IMPACT ON INDOOR ENVIRONMENTAL QUALITY

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ABSTRACT

Demand response can be utilized within heating and ventilation of buildings to reduce CO_2 emissions and energy costs on both utility and consumer level. During demand response control, some of the indoor environmental parameters (room air temperature or CO_2 concentration) are either increased or decreased. Hence, the demand response is a bargaining process between energy cost savings and acceptable impact on indoor environmental quality.

This study determined the real-time pricing-based demand response impact on indoor air temperature and CO_2 concentration during occupied time in an educational office building. Additionally, the annual energy cost savings were calculated. Both CAV and VAV ventilation designs were included in the study. The following system parameters were controlled: space heating, supply air temperature and airflow rate. The study was conducted by dynamic energy and indoor environmental simulations with the software IDA-ICE 4.7.1.

The simulations showed that demand response of space heating, supply air temperature and airflow rate can be utilized without significantly affecting the indoor environmental quality (room temperature and CO_2 concentration) and still achieve energy cost savings.

Keywords: Demand response, heating, ventilation, indoor environmental quality

1 INTRODUCTION

Demand response can be utilized within heating and ventilation of buildings to reduce CO_2 emissions and energy costs on both utility and consumer level. It can either have an incentive or price based structure. According to Borenstein et. al (2002) and Hu et. al (2015), real-time pricing is the most efficient pricing structure within demand response and therefore it was chosen for this study.

As pointed out by e.g. Wargocki & Wyon (2017) and Seppänen et al. (1999), the indoor environmental quality is strictly related to the performance of workers and sick building symptom. Due to this the impact from demand response should preferably not be noticed by the occupants, but it should at least remain on an acceptable level (Motegi et al., 2007). According to Dreáu & Heiselberg (2016), studies focusing on heating are usually conducted with a simplified model of the building, where the real thermodynamic behavior is not considered. The aim with this study was to conduct a detailed building model simulation with a dynamic simulation tool to provide realistic results on indoor environmental conditions and cost savings.

2 METHODS

The research was conducted by building model simulations of one floor of an educational office building using the software IDA-ICE. The demand response control was executed by two rule-based algorithms. The control algorithms decision-making was based on the outdoor and indoor temperature, the CO_2 concentration in the room air and the control signal generated from the dynamic price information. The control signal was defined according to the moving average method presented by Alimohammadisagvand et al. (2017). The hourly price data used was obtained from Rinne (2017). The space heating was regulated by electronic radiator valves. The indoor air temperature range 20 – 24.5°C was determined as acceptable, with 21°C as the desirable baseline temperature. The supply air temperature during periods out of demand response was defined according to return air temperature (see Figure 1). During demand response control the supply air temperature was 17, 20 or 22 °C depending on heat energy price trend. For the VAV-controlled cases the indoor air CO_2 concentration set-point was 800 or 1200 PPM depending on energy price trend. The ventilation airflow range used was 0.15 – 2.1 l/s, m^2. In the CAV ventilated cases the airflow rate was constantly 2.1 l/s, m^2.

Figure 2 presents an overview of the floor plan. The results from the simulations have been extracted from office room 10. This room was chosen since it is a corner room with much outer wall area and hereby represent the worst-case scenario from a thermal comfort point of view. The building model information and its internal gains are presented in Table 1 and 2 respectively.

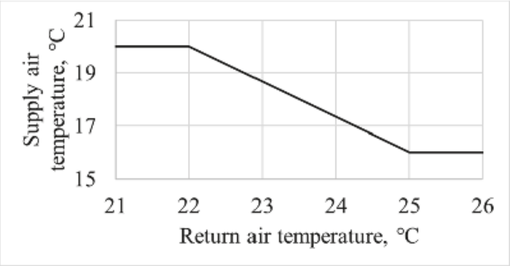

Figure 1. Supply air temperature control

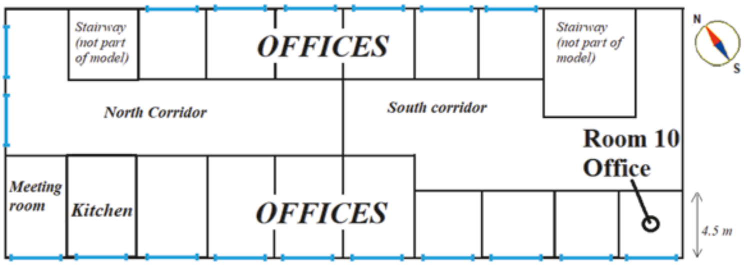

Figure 2. Floor layout of the case study building during periods out of demand response

Table 1. Properties of different structures

U-values (W/m^2, K)			Glazing properties		Air tightness	Ventilation	
External wall	Roof	Windows	g	ST	n_{50} (ACH)	q_v (l/s, m^2)	Schedule
0.38	0.3	1	0.38	0.32	1.6	~2	24/7

Table 2. Internal heat gains

				Schedule
Occupancy ratio	100 %	70 %	40 %	08–16
Total number of occupants present	40	28	16	
Lighting	7.5 W/m^2			
Equipment	50 W/occupant			

Figure 3 presents the algorithm, which controls space heating, supply air temperature and airflow rate either separately or combined. The limiting outdoor temperature ($T_{lim, out}$) is a parameter used to prevent overheating of the building during warmer outdoor conditions and it was set to 0°C. If the 24-hour moving average outdoor temperature ($T_{avr, 24 out}$) is below the limiting outdoor temperature ($T_{lim, out}$) 0°C and the district heat price trend is increasing, heat charging of the building mass is allowed. Heat charging occurs by increasing the space heating set-point ($T_{SH,\ set}$) to maximum ($T_{SH,\ max}$ = 24.5°C). If the price trend is decreasing or flat, the minimum (20°C) or the normal (21°C) set-point is used respectively. If the $T_{avr,\ 24\ out}$ is warmer than $T_{lim,\ out}$, heat loading is not allowed.

When supply air temperature is regarded in the control, the same logic follows as for the space heating. The supply air temperature (T_{sup}) is varying between maximum, minimum and medium ($T_{sup.\ max}$, $T_{sup.\ min}$ and $T_{sup,\ med}$) when $T_{avr,\ 24\ out}$ is below $T_{lim,\ out}$. Otherwise it follows the normal supply air temperature definition ($T_{sup.\ norm.}$, see Figure 1). When VAV ventilation and airflow control is regarded, the algorithm includes a condition allowing cooling by ventilation if both room air (T_{room}) and 24-hour moving average outdoor temperature ($T_{avr,\ 24\ out}$) rises above their respective threshold values. Then airflow (Q_{air}) is set to maximum ($Q_{air,\ max}$). If cooling is not needed, the airflow rate is adjusted according to the indoor air CO_2 set-point ($C_{CO2,\ set}$). If the price trend of either district heat or electricity is decreasing the CO_2 set-point is increased to maximum ($C_{CO2\ max}$). Otherwise the set-point is kept at design value ($C_{CO2\ design}$).

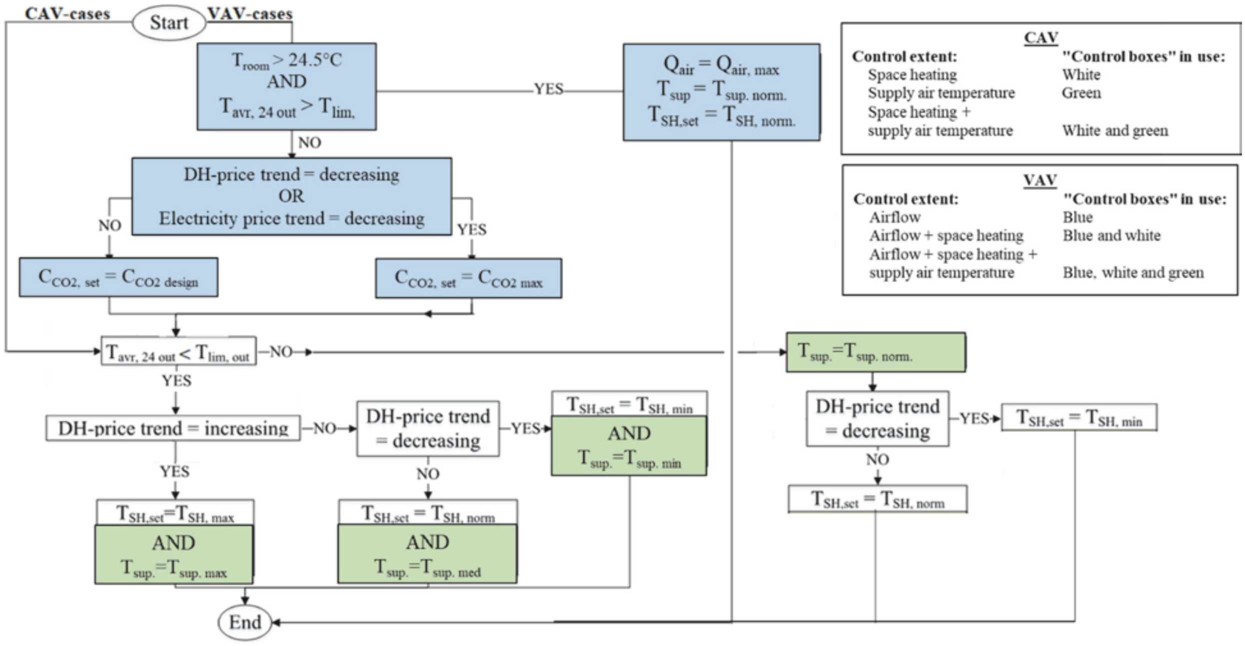

Figure 3. Control algorithm – Space heating, supply air temperature and airflow rate

3 RESULTS

The simulation cases included in this study are presented in Table 3. There is one reference for the CAV ventilated cases and three references for the VAV ventilated cases depending on occupancy ratio. Additionally, another constant temperature set-point case ($T_{SH,\ set}$ = 20°C) was included in the CAV cases for comparison of room air temperature behavior. The abbreviations used are the following; SH for space heating, $T_{sup.}$ for supply air temperature and Q_{air} for airflow rate.

Figure 4 shows the impact from occupancy ratio on indoor air temperature during occupied time in the heating season when the space heating is controlled either by a constant set-point (21°C) or according to the algorithm (space heating control only, see Figure 4). The temperature duration for the two different occupancy ratios are practically identical. Occupancy ratio has a negligible impact on the indoor air temperature during DR-control.

Table 3: Simulation cases

Case	Demand response control			$T_{SH\ set}$ Range	Occupancy ratio
	SH	$T_{sup.}$	Q_{air}		
CAV					
1	*REFERENCE, No demand response*			21	40 %
2	x			20–24.5	
3		x		21	
4	x	x		20–24.5	
5	*No demand response*			20	
VAV					
5a	*REFERENCE, No demand response*			21	40 %
6a			x		
5b	*REFERENCE, No demand response*				70 %
6b			x		
5c	*REFERENCE, No demand response*				100 %
6c			x		

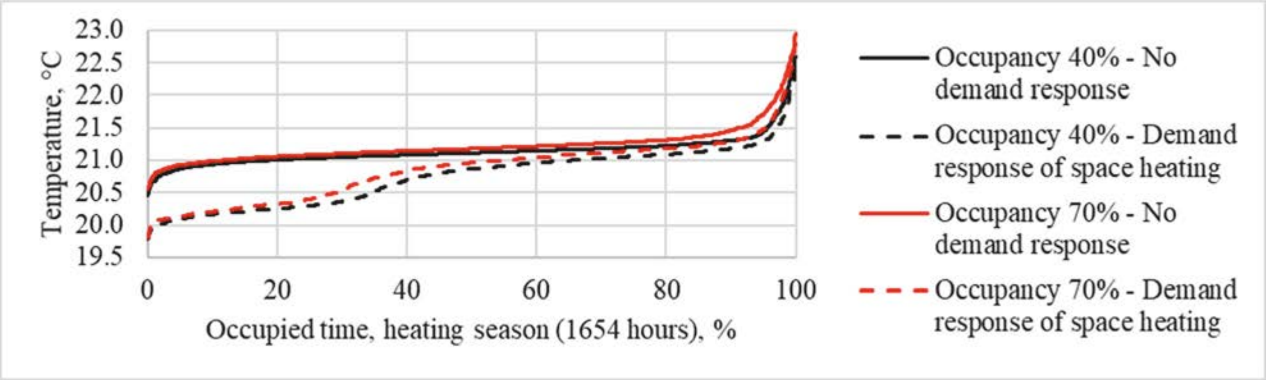

Figure 4. Occupancy ratio impact on indoor air temperature in office room 10

Figure 5 presents the impact of different demand response control elements on indoor air temperature in the CAV ventilated cases compared to the constant temperature set-point cases. Additionally, the annual change in heat energy and cost is shown.

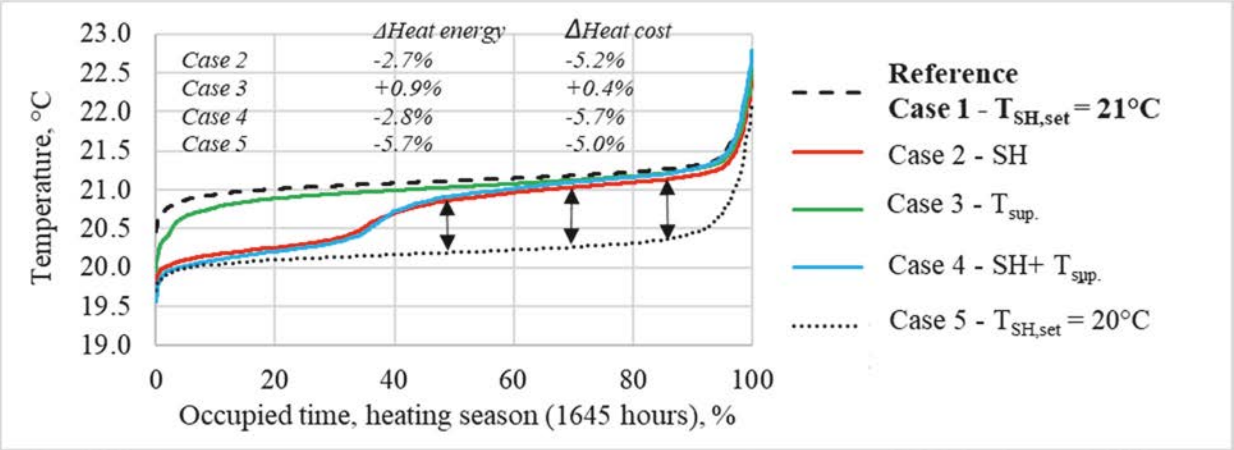

Figure 5. CAV ventilated cases, algorithm A – Impact of demand response control method on indoor air temperature in office room 10

Figure 5 shows that the temperature in the demand response controlled cases (2 – 4) was constantly lower than in the reference case 1 ($T_{SH, set}$ = 21°C). Supply air temperature control (case 3) did not have any significant impact on the room air temperature due to heat compensation from the radiators. The demand response controlled cases (2 & 4) have significantly higher thermal comfort than case 5 ($T_{SH, set}$ = 20°C) at the same time as the heat cost savings are higher.

Figure 6 presents the CO_2-concentration duration curve in the VAV controlled cases for different occupancy ratio. Additionally, the algorithms CO_2-set-point duration is plotted.

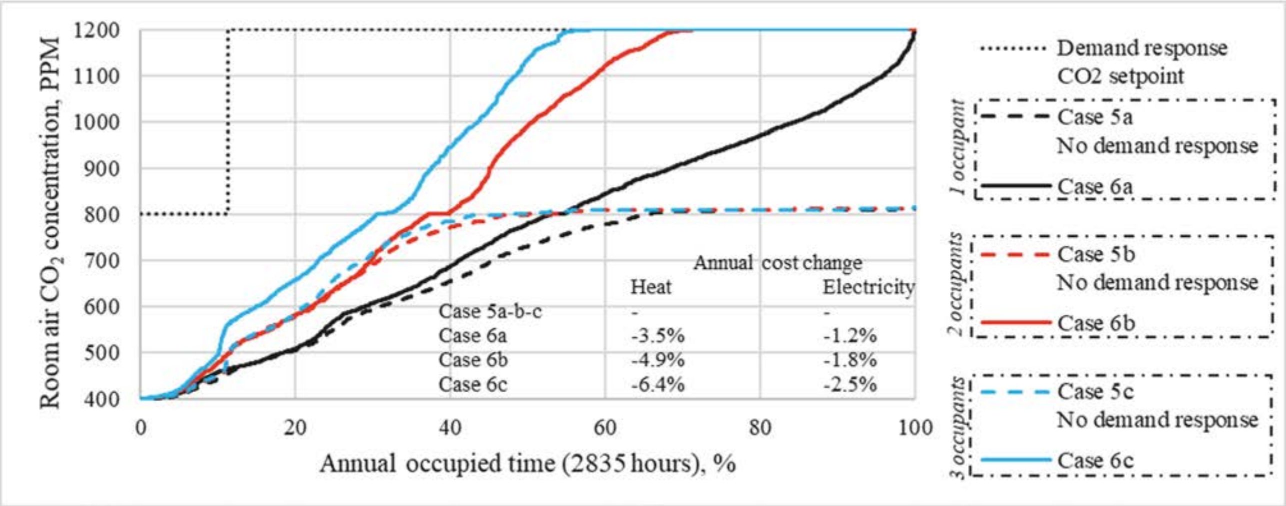

Figure 6. CO_2-concentration in office room 10 during demand response controlled airflow rate for different occupancy ratio

Figure 6 shows that the CO_2 set-point during demand response remains at 1200 PPM for almost 90 % of the occupied time. Regardless of the constantly high set-point, the heat and electricity savings achieved are quite modest. The reason is that the initial ventilation demand is low and hereby an increment in CO_2 set-point does not have a huge impact on the already low airflow rate. The effect from demand response on VAV ventilated systems is strongly related to the number of occupants and the initial ventilation base demand.

4 DISCUSSION

Heat charging to building mass did not occur and conservation (lowering of temperature set-point) was the primary demand response activity. The room air temperature stayed over 20.7°C for more than 50% of the occupied time and still higher heat cost savings were achieved than in the 20°C constant temperature set-point case 5.

The room air temperatures in office buildings is often kept around 22°C during heating season. In such a situation the flexibility of the control would be higher and more potential can be found in both cost savings and thermal comfort. The CO_2 set-point of the algorithm was kept at maximum (1200 PPM) for nearly 90 % of the occupied time. This still maintain acceptable level of iAQ, but is not favorable. It is a result from the control signal generation based on the energy price trends. The high set-point is however not a problem in this particular building, since obviously the realized CO_2 concentration in the room stays below 1200 PPM for 100 %, 70% and 60% of the occupied time depending on occupancy ratio. However, since this feature is building and occupancy dependent it would be wise to include a time constraint regarding how long the CO_2 set-point can be at maximum per day (e.g. 4 hours).

5 CONCLUSIONS

The study showed that space heating and supply air temperature control can be utilized within heating demand response without drastically sacrificing the thermal comfort of the occupants. The temperature during occupied time was kept within the acceptable range. One significant observation was that by demand response of space heating the indoor temperature was kept close to 21°C for over 50 % of the occupied time, while energy cost savings were slightly higher than for a constant temperature set-point case of 20°C.

Regarding demand response control of airflow rate, the determination of the CO_2 set-point should consider a daily time limit for how long the set-point or measured concentration can be at maximum level, otherwise it may result in too long periods with low ventilation rates. In this study the set-point remained at 1200 PPM for 90 % of the occupied time, but the actual room air concentrations stayed at the limit for 1 % – 40 % of the time, depending on occupancy ratio. Energy cost savings increased with higher occupancy ratio due to the higher ventilation base-load while the CO_2 set-point remained unchanged. Demand response controlled airflow rate showed some positive result, but further studies are needed to determine the effect on potential depending on occupancy ratio and ventilation base-load.

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