Energy efficiency potential of radiant and convective room units with utilization of building thermal mass in cooling design conditions

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Abstract

The demand for high energy efficiency of office buildings has increased the use of demand based HVAC systems. One advanced demand based use of radiant and convective HVAC room units would be the utilization of building thermal mass to reduce cooling design power. This paper presents energy simulation case study of a simplified office building with active chilled beam and chilled ceiling with mixing ventilation. It compares the cooling load and cooling energy consumption in design day with heavy and light construction, and shows the potential for energy efficiency. Both active chilled beam and chilled ceiling system with mixing ventilation were maintaining all office rooms in design room temperature. The chilled ceiling system had more limited cooling capacity, whereas active chilled beam was able to provide cooling also with higher inlet water temperature. The operating schedule and room air temperature set-point had significant effect to the cooling demand especially in the chilled ceiling case with heavy construction. The reduction of the cooling design power by controlling the operating schedule during cooling design days could bring savings in cooling system dimensioning, and possibility to dimension HVAC room units with higher cooling water inlet temperature and reach energy savings from efficient utilization of alternative energy sources.

Keywords - chilled beam, chilled ceiling, energy efficiency, office building

1. Introduction

The demand for high energy efficiency of office buildings has increased the use of demand based HVAC systems. In addition to the traditional control of cooling water flow rate based on room temperature in the air-water

HVAC room units, the most energy efficient method has been to use variable ventilation airflow rates [1]. One advanced demand based use of radiant and convective HVAC room units would be the utilization of building thermal mass to reduce cooling design power [2-4]. This could further increase the energy efficiency. This paper presents energy simulation case study of a simplified office building with active chilled beam [5] and chilled ceiling with mixing ventilation [6,7]. It compares the cooling load and cooling energy consumption in design day and shows the potential for energy efficiency.

2. Methods

The case study office building consisted of four typical office rooms of which external wall and window was directed to south, north, east and west. Geometry of the office building case is shown in the Fig. 1. Office building was located in middle European, temperate climate and had good energy efficient building materials and window characteristics. The building construction data and operating data used in different cases is presented in the Table 1. The effect of thermal mass was studied by having in heavy case all surfaces of room with concrete (room without suspended ceiling), and in light case all surfaces except floor with gypsum board (room with suspended ceiling).

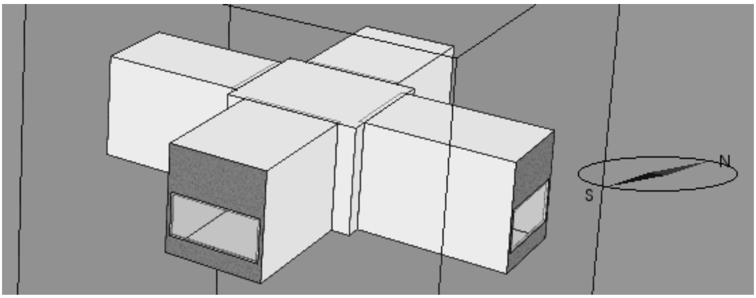

Fig. 1 Geometry of simplified office building

Table 1 Construction details of light and heavy building

	Light building	**Heavy building**
Main building data	Paris weather data, 4 identical office rooms with orientation to east, south, north, west	
Office room data	2.7 m wide, 4 m long, floor area 10.8 m^2, 3 m high in internal floor, connected to corridor with closed door	
Window size	2.5 m wide, 1.2 m high, located 0.5 m from floor (37% of external wall area, incl. frame 0.1 x window)	
Window type	2-glass window with Argon filling and solar control coating behind outer glass	
Window performance	U = 1.1 W/(m^2,K), g = 0.37, T_{vis} = 0.7, No other additional solar shading, frame with U = 2.0 W/(m^2,K)	
External wall heat conductivity and material layers from inside	0.3 W/(K,m^2), render 0.02 m, gypsum 0.02 m, mineral wool 0.12 m, concrete 0.125 m, render 0.03 m	0.3 W/(K,m^2), render 0.01 m, concrete 0.125 m, air gap 0.12 m, mineral wool 0.1 m, concrete 0.125 m, render 0.05 m
Internal wall conductivity and material layers from inside	0.6 W/(K,m^2), gypsum 0.02 m, mineral wool 0.05 m, gypsum 0.02 m	3.6 W/(K,m^2), Render 0.02 m, concrete 0.1 m, render 0.02 m
Internal floor material layers from inside	Floor coating 0.005 m, concrete 0.25 m, stagnant air 0.25 m, false ceiling tile 0.04 m	Floor coating 0.005 m, concrete 0.25 m, render 0.02 m
Infiltration	Wind driven 1 ACH at 50 Pa with pressure coefficients for typical semi-exposed building	
Operating data of internal heat loads	Every day 8 - 18 Number of occupants 2 (1.2 MET) Equipment load 15 W/m^2 Lighting load 10 W/m^2	

Table 2 Operting parameters and cooling design of HVAC room units

	Chilled ceiling	Active chilled beam
Cooling set-point	25 °C (room air temperature)	
Operating data of ventilation system (AHU)	Every day 7 - 19 DOAS: 1.6 l/s,m^2 (17.3 l/s), 16 °C supply air,	
Supply air distribution	Separate ceiling diffuser	Integrated with active chilled beam
Supply air sensible cooling	17 W/m$^2_{floor}$ (187 W)	
Cooling water circulation	**Case 1**: Only during AHU operation hours **Case 2**: All the time with room cooling set-point 25 °C **Case 3**: All the time, set-point 22 °C night time	
Typical[1] max. cooling design water in 15 °C, excl. supply air	Panel area70% of ceiling 63 W/m^2 $_{floor}$ (680 W) $dT_{room-water}$ 9 K dT_{water} 2 K	A.beam L 3 m (2.8 m coil) 102 W/m^2 $_{floor}$ (1100 W) $dT_{room-water}$ 8.7 K, dT_{water} 2.6 K
Typical[1] max. cooling design water in 17 °C, excl. supply air	Panel area70% of ceiling 50 W/m^2 $_{floor}$ (537 W) $dT_{room-mean\ water}$ 7.3 K, dT_{water} 1.5 K	Act.beam 3 m (2.8 m coil) 81 W/m^2 $_{floor}$ (876 W) $dT_{room-mean\ water}$ 7 K, dT_{water} 2.1 K
Typical[1] max. cooling design water in 19 °C, excl. supply air	Panel area70% of ceiling 37 W/m^2 $_{floor}$ (397 W) $dT_{room-mean\ water}$ 5.5 K, dT_{water} 1 K	Act.beam 3 m (2.8 m coil) 61 W/m^2 $_{floor}$ (654 W) $dT_{room-mean\ water}$ 5.2 K, dT_{water} 1.6 K
Typical[1] max. cooling design water in 21 °C, excl. supply air	Panel area70% of ceiling 23 W/m^2 $_{floor}$ (245 W) $dT_{room-mean\ water}$ 3.5 K, dT_{water} < 1 K	Act.beam 3 m (2.8 m coil) 40 W/m^2 $_{floor}$ (433 W) $dT_{room-mean\ water}$ 3.5 K, dT_{water} 1 K
Cooling without AHU operation	No effect to cooling power	~5% → 4.6 W/m$^2_{floor}$ (50 W), $dT_{room-mean\ water}$ 8.7 K
Corridor area connecting office rooms	No ventilation in corridor area, equipped with convective cooling to maintain 25 °C room air temperature all the time	
1) Designed with manufacturer data for typical good chilled ceiling panels and active beam in suspended ceiling, laminar water flow is avoided in selection, water pressure loss <10 kPa, water dT over 1 K (could be bigger with active beam system also with higher inlet water temperature, but 1K for comparison with chilled ceiling, active beam chamber pressure 75 Pa)		

Modern active chilled beam and chilled ceiling system with mixing ventilation were designed into office rooms with realistic performance data. Pictures of the selected HVAC room units are presented in the Fig. 2. Details of operating parameters and cooling design of HVAC room units are presented in the Table 2. Cooling design used in the energy simulation case study was with 15 °C inlet water temperature for both chilled ceiling and active chilled beam. Cooling capacities also with warmer inlet water temperature are shown in order to compare the performance of the HVAC room units, and capability to use warmer inlet water temperature for delivering the requested cooling capacity in different energy simulation cases.

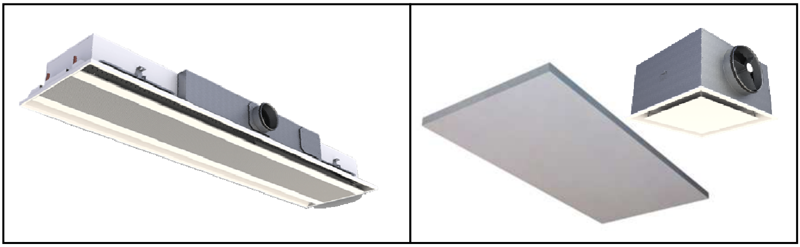

Fig. 2 Active chilled beam (on the left side) and chilled deiling with mixing ventilation HVAC room units (on the right side)

Energy simulation was done with state of the art dynamic simulation software IDA-ICE 4.6, simulating indoor climate conditions and cooling system operation during cooling design day. HVAC system operating schedule was following: ventilation was only used during office hours, and cooling water system was operated 1) only during office hours, 2) all the time with same room temperature set-point and 3) all the time with room temperature set-point lowered by 3 degrees during night time.

3. Results

Design cooling load for individual office rooms in the cases 1-3 is presented in the Figs. 3-5. Time of the maximum cooling load in the office room depended on the orientation of the external wall. The peak cooling demand for chiller in the whole office building is presented in the Fig. 6. The cooling energy consumption for HVAC room unit water during design day is presented in the Table 3.

Both active chilled beam and chilled ceiling system with mixing ventilation were maintaining all office rooms in design room temperature. The chilled ceiling system had more limited cooling capacity, whereas active chilled beam was able to provide cooling also with higher inlet water temperature. The highest cooling demand of 81 W/m^2 (64 W/m^2 for room unit water) was in the east office room of light building with both HVAC room units with the case 1 operating schedule. When building was changed to heavy, the highest cooling demand was dropped by 16%. By using case 2 operating schedule, the highest cooling demand dropped in heavy building to about 60 W/m^2 (25%) with both HVAC room units. With operating schedule 3, the biggest reduction in design cooling demand to about 40 W/m2 was found with chilled ceiling. The design cooling demand for central cooling system could be dropped by 36% by using operating schedule 3 with chilled ceiling in heavy building during design days. The design day cooling energy consumption was increased due to this 7%.

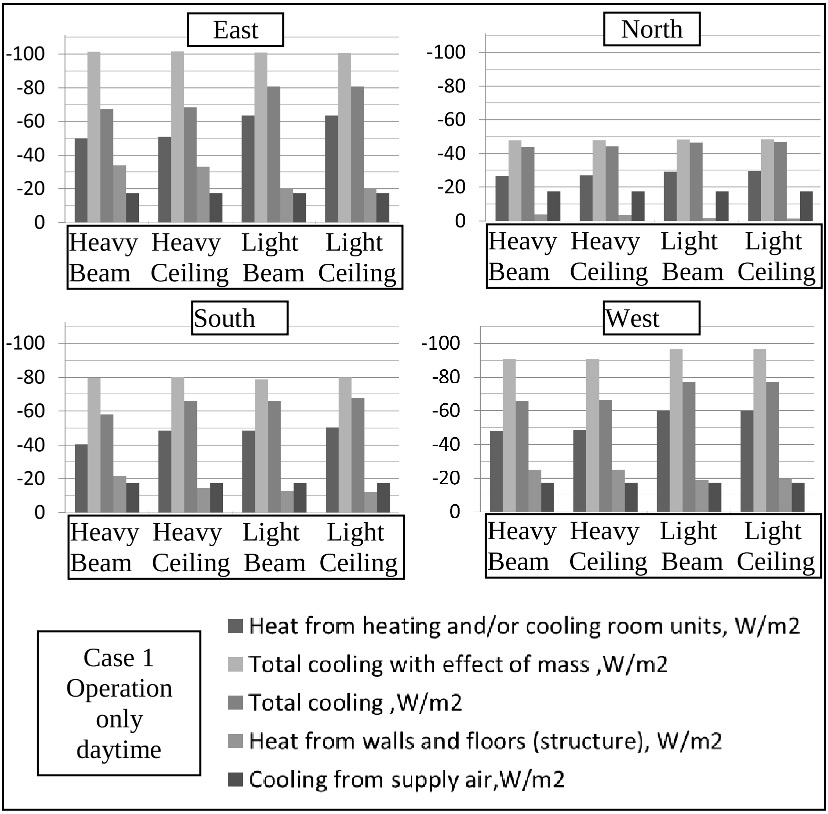

Fig. 3 Cooling demand in case 1

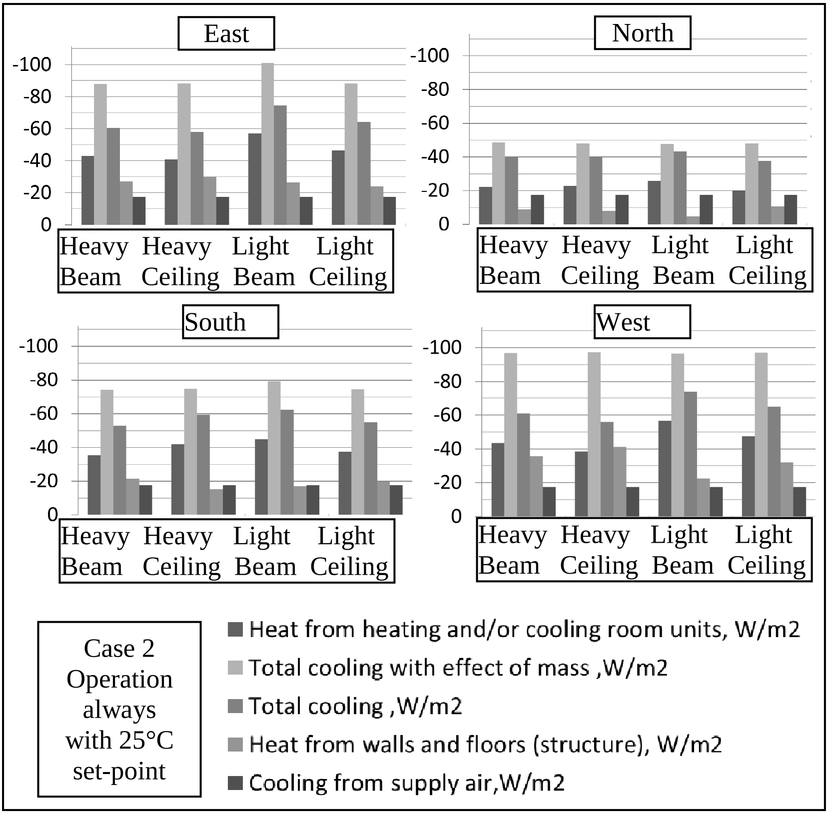

Fig. 4 Cooling demand in case 2

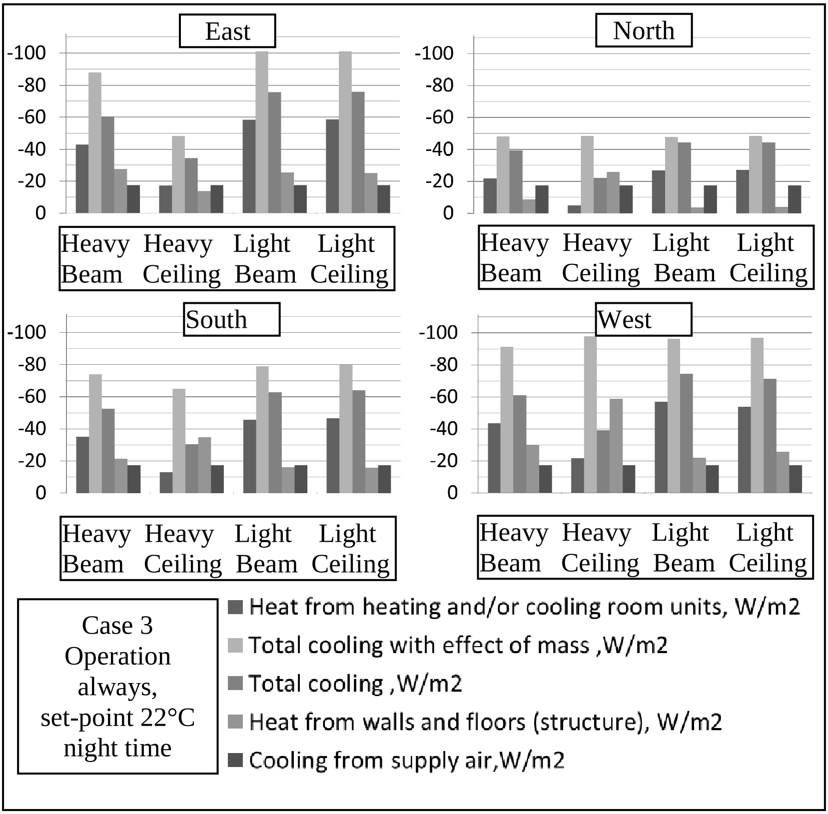

Fig. 5 Cooling demand in case 3

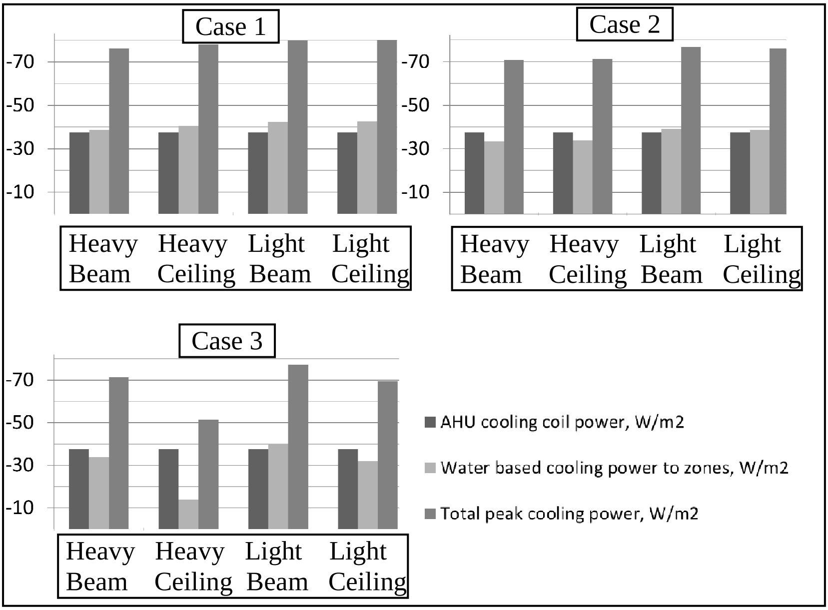

Fig. 6 Chiller peak cooling demand in cases 1-3

Table 3 HVAC room unit cooling energy demand during cooling design day

HVAC room unit cooling energy [kWh]	Case 1	Case 2	Case 3
Heavy, Chilled beam	19.4	19.7	19.7
Heavy, Chilled ceiling	19.5	20.7	21.6
Light, Chilled beam	19.2	19.6	19.7
Light, Chilled ceiling	19.3	19.9	21.4

4. Conclusions

The operating schedule and room air temperature set-point had significant effect to the cooling demand especially in the chilled ceiling case with heavy construction. The chilled beam was able to provide cooling also with higher water temperature. The reduction of the cooling design power by controlling the operating schedule during cooling design days could bring significant savings in cooling system dimensioning, and possibility to dimension HVAC room units with higher cooling water inlet temperature and reach energy savings from efficient utilization of alternative energy sources.

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