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HVAC energy saving in IPS-enabled large space: An occupancy distribution based demand-driven control approach

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Abstract

Occupancy attracts an increasing attention in recent building energy efficiency research through enabling more sophisticated control strategies. With the development of latest indoor positing systems (IPS), the facility managers are able to detect the geospatial distribution of building occupants. Based on such information, this paper proposes a demand-driven control system for HVAC control in large spaces to reconcile occupants' thermal comfort demand and energy consumption. Comparing to conventional temperature and CO2 based HVAC control systems, the new approach integrates the indoor positions of occupants and a demand-oriented and PID-based ventilation control mechanism. An computational fluid dynamic simulation is constructed to valid the proposed control system. Air supply flow rate and temperature distribution are captured for three sample cases that have even and uneven occupancy distributions in the simulation. By avoiding overcooling and unnecessary cooling, the proposed approach could save a significant amount of electrical consumption from HVAC operation.

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Keyword: occupancy distribution, build energy efficiency, temperature distribution, indoor positioning system

1. Introduction

In all energy-consuming sectors, buildings account for the largest percentage. Comparing to residential buildings, energy conservation in commercial buildings is more difficult since they normally have complicated HVAC systems installed [1]. Since HVAC systems provide the major thermal service and accounts for a great portion of energy consumption, eliminating unnecessary electronic wastes in HVAC systems holds the key of improving energy efficiency in commercial buildings [2]. In recent years, occupancy detection has caught much attention in building energy load assessment, especially in large

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spaces, where multiple air diffusors installed. The various occupancy pattern in large spaces results in frequent insufficient cooling and over-cooling issues [3, 4, 5]. Up to now, researchers have proposed many demand-based control algorithms, which capture occupancy information with motion and carbon dioxide sensors. Data mining algorithms also have been developed to assess the occupancy pattern from aggregated data [6]. Temperature sensors at human breathing level are another popular close loop control inputs for facility demand driven operation [5]. Lin and Claridge proposed such temperature-based Days Exceeding Threshold-Toa (DET-Toa) method to detect persisting small increase or decrease in the normal building energy consumption [7]. Zeng et al. developed a data-driven predictive model to balance the temperature and air static pressure setting point to optimize HVAC energy consumption [8]. However, current temperature based demand-oriented control systems lack high-resolution occupancy information to refine their control accuracy and reliability [3, 9]. In this research, we intend to introduce one occupancy distribution based control algorithm and explore its performance under various occupancy distribution patterns. In a preliminary experiment, three different occupancy distribution scenarios are simulated and examined. Air supply rate and temperature distribution are assessed to discuss the energy saving potential of the proposed algorithm.

2. Model configuration

In the simulated test bed, variable air volume (VAV) air-conditioning system is chosen to enable flexible control. Fluent Airpak was employed to simulate temperature distribution of airflow pattern under different control strategies. Fluent Airpak is one of the most popular commercial CFD software used in the research related to building mechanical systems to simulate the airflow, air quality and contaminates.

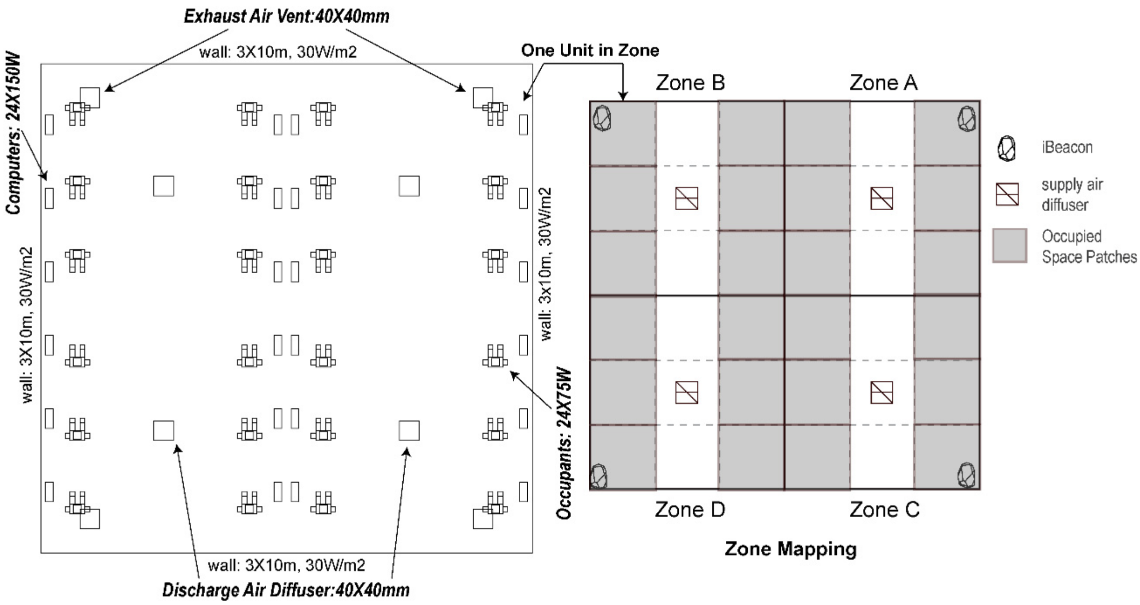


Fig.1. The model specifications and zone mapping of simulation space

In large rooms, such as the room in Fig. 1, the space are normally divided into multiple thermal zones, which served by individual VAV boxes. Flexible adjustment in air supply rate are enabled to serve different thermal comfort requirement. Fig. 1 shows the specifications and zone mapping of the simulated space.

The physical sizes of this model are 10m in length, 10m in width and 3m in height with total 24 occupants and 24 computers. The VAV system setup supply type as mixing ventilation with steady, incompressible and well-mixed airflows. The default ambient temperature outside the room is set as 35℃ and indoor air temperature setting point is 25.5℃. Four 40mm x 40mm supply air diffusers are placed in the corresponding zones and each one is conditioned by a independently controlled VAV box. The heat sources inside the room include walls (30W/m2), occupants (75 W each), and computers (150 W each). Indoor temperatures are captured by the wireless sensors installed at human breathing level. An ibeacon-based indoor positioning system is installed to track the occupants presence and position. The whole office space was mapped to small patches for the ease of position tracking. The operating schedule of computers is associated with the occupancy schedule. Transfer function method (TFM) is adopted to calculate the cooling load [10].

3. Methodology

Fig. 2 shows the proposed demand-driven control algorithm proposed by this research. The control loop contains two assessment stages for each zone:

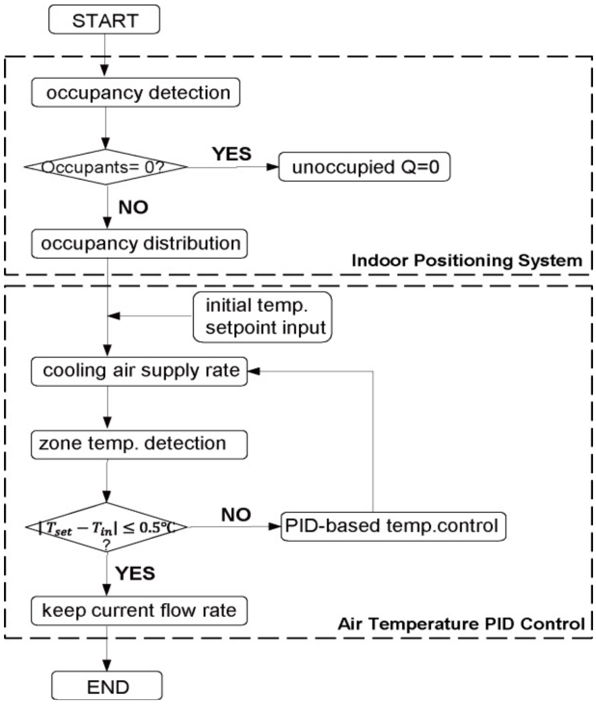


Fig.2. The supervised demand-driven control algorithm

In stage I, the number of occupied patches in each zone is aggregated by the IPS system. For unoccupied zone, where has no occupants, VAV box is deemed as “off”. If the system detects any occupied patch, the assessment will proceed to stage II.

In stage II, required inputs include the designated supply air temperature and instantaneous indoor temperature. With temperature sensors, which installed at breathing level, zone average temperature would be compared with the indoor temperature setting point. PID based temperature control and feedback loop will be used to adjust the airflow rate and eliminate tracking errors. Supply airflow rate of each operating VAV box is adjusted independently for its own thermal zone in this stage. Once zone temperature reaches it setting threshold, the VAV box will maintain the current air flow rate until occupancy distribution is updated.

In this proposed algorithm, occupancy distribution is prerequisite for automatic operation of the VAV system. The objective of the system control is matching uneven load distribution with sufficient supply air and avoiding unnecessary thermal interference in unoccupied zones.

4. Results and analysis

The preliminary experiment examines three cases with four occupancy distribution types to validate occupancy distribution based VAV system operation. The distribution pattern of occupancy is categorized as (1) even distribution, in which all four zones are to some level occupied and (2) uneven distribution, in which at least one zone is unoccupied. The occupancy data is collected from a field test with the help of IPS system.

Fig. 3 shows space layouts and temperature distributions of four scenarios in one of the three cases (case 12). Consistent to previous definition, three scenarios (S01, S03, and S04) are uneven distribution while S02 is even distribution scenario at room level. Temperature distribution displayed in Fig. 3 shows the temperature in unoccupied zones is higher than it in occupied zones since influence on temperature from wall heat flux cannot be ignored. Comparatively, S02 with even distribution, even if not fully occupied, requires continuous operation of VAV boxes to maintain its thermal distribution. Therefore, by turning off the VAV boxes at unoccupied zones, the system intentionally avoid providing services to unoccupied zones and let their indoor temperature high.

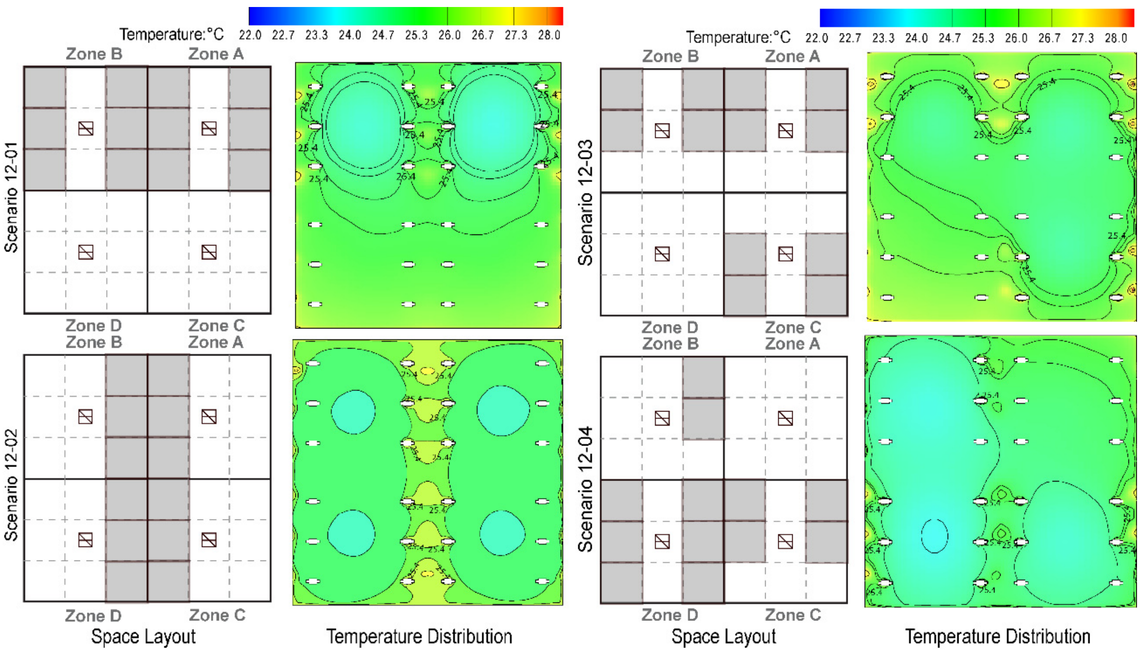
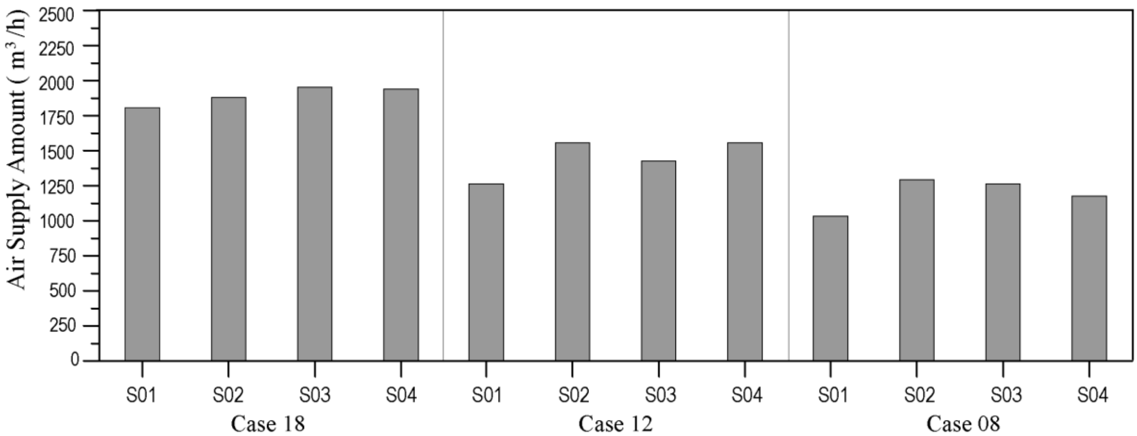


Fig. 3. Space layout and temperature distribution in the four scenarios of case 12

Fig. 4 lists conditioned air supply rate (m3/h) at equilibrium when temperature distribution is stable. The number of occupants in each zone for each case is also listed in the table. The case index indicates the total number of occupants in that case, for instance, case 12 means there are 12 occupants shown up in that case. In fig. 4, although the number of occupants in some scenarios are the same, cooling air supply is varied due to their distribution. Take Case 12 as an example, it can be observed that energy load would be different even though heat source is same. Traditional control system adopts the number of residents in a thermal zone to operate the HVAC without regarding their spatial distribution, however, our study demonstrates that with the same number of occupants their thermal requirements could be different.



	Na	Nb	Nc	Nd			Na	Nb	Nc	Nd			Na	Nb	Nc	Nd	
S01	6	6	6	0	uneven	S01	6	6	0	0	uneven	S01	4	4	0	0	uneven
S02	4	4	4	6	even	S02	3	3	3	3	even	S02	2	2	2	2	even
S03	2	5	5	6	even	S03	4	4	4	0	uneven	S03	1	1	2	4	even
S04	3	3	6	6	even	S04	0	2	4	6	uneven	S04	2	0	4	2	uneven

Fig. 4. The air supply amount and the number of occupants in each scenario of three cases.

5. Conclusion

This study proposes a demand-driven control system integrates a real-time positioning system and a multi-zone PID control algorithm to optimize building HVAC operation with space occupancy distribution. Three occupancy cases, each with four different scenarios are simulated. The results of a CFD simulation shows that with the information of occupancy distribution, energy consumption of VAV system can be dramatically reduced. Monitoring and controlling VAV boxes based on the proposed algorithm could avoid over-cooling in the unoccupied compare to conventional operation approach. In addition, such control system with IPS also can be extended to other building service systems and enable more sophisticated control design.

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References

[1] N. N. A. Bakar, M. Y. Hassan, H. Abdullah, H. A. Rahman, M. P. Abdullah, F. Hussin, and M. Bandi, "Energy efficiency index as an indicator for measuring building energy performance: A review," Renew. Sustain. Energy Rev., vol. 44, pp. 1–11, 2015.

[2] L. Pérez-Lombard, J. Ortiz, and C. Pout, "A review on buildings energy consumption information," Energy Build., vol. 40, pp. 394–8, 2008.

[3] S. S. Kwok and E. W. Lee, "A study of the importance of occupancy to building cooling load in prediction by the intelligent approach," Energy Convers. Manag., vol. 52, pp. 2555–64, 2011.

[4] V. Congrats and F. Kulick, "HVAC system optimization with CO 2 concentration control using genetic algorithms," Energy Build., vol. 41, pp. 571–7, 2009.

[5] P. Zhou, G. Huang, and Z. Li, "Demand-based temperature control of large-scale rooms aided by wireless sensor network: Energy saving potential analysis," Energy Build., vol. 68, pp. 532–40, 2014.

[6] J. Zhang, G. Liu, R, Lutes, M. Brambley, Energy-saving for occupancy-based control (OBC) of Variable-Air-Volume(VAV) Systems, in PNNL-22072, 2013. pp. 1-79, Virginia, The United States of America.

[7] Guanjing Lin, David E. Claridge, A temperature-based approach to detect abnormal building energy consumption, Energy and Buildings 93(2015)110-8.

[8] Yaohui Zeng, Zijun Zhang, Andrew Kusiak, Predictive modeling and optimization of a multi-zone HVAC system with data mining and firefly algorithms, Energy 86(2015)393-402.

[9] N. Li, G. Calis, B. Becerik-Gerber, Measuring and monitoring occupancy with an RFID based system for demand-driven HVAC operations, Automation in construction, 24(2012) 89-99.

[10] G. P. Mitalas, "Transfer function method of calculating cooling loads, heat extraction and space temperature," Ashrae J., vol. 14, pp. 54–56, 1973.

Biography

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