Develop a New Approach to Evaluate Energy Savings, Thermal Comfort and IAQ from Occupant-Centric Building Controls

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Abstract. Occupant behavior is identified as one of the key factors influencing the energy use and indoor environmental quality of the building. Occupancy-centric control is famous for its potential to save building energy without sacrificing occupants’ comfort. This study utilized two identical lab spaces, configured as typical open-plan offices, to investigate the performance of the occupancy-centric control in terms of energy-saving, indoor air quality, and thermal comfort. The results have demonstrated that occupancy-centric control could save around 28% total energy, including fan, cooling, and heating energy, with minimal impact on the air quality and thermal comfort.

1. Introduction

In the United States, occupants live and work 87% of their time in buildings [1]. The control of the indoor environment, such as temperature, humidity, ventilation, lighting, etc., plays a significant role in determining energy efficiency and the quality of the indoor environment. In most of the existing buildings, the operation schedule of the lighting and HVAC system is based on a fixed schedule which assumed people come and leave the space at the fixed time of every working day. However, this fixed schedule can be very different from the actual one [2–4]. And therefore, up to 70% of HVAC and lighting energy is wasted in the unoccupied period [5,6], given the fact that energy consumption by the HVAC system in unoccupied space was sometimes higher than occupied one [7]. Although over more than 400+ papers on occupant behavior-related topics in the last decade, only a few case studies are actually from field implementation [8]. Therefore, the research gaps are:

- None of the field experiment studies has a side-by-side comparison to evaluate energy savings from occupant-centric HVAC controls; and
- None of the studies have ever investigated thermal comfort and indoor air quality based on such advanced controls.

Hence, there is an urgent need to develop a new approach to evaluate the aforementioned three building performance metrics altogether in one experiment.

2. Method

2.1. Lab Configuration
This study used the two rooms configured as typical open office space to evaluate the performance of two HVAC control strategies. The two rooms have the same dimension (36.0’ × 20.3’/6.25 × 10.5 m\(^2\)) with 12 cubicles. Both rooms are conditioned by the same numbers of Carrier Air Treatment Modules (ATMs), which can be used to provide cooling/heating with a controlled ventilation rate.

2.2. Occupancy Detection and Simulator

This study mapped the occupancy dynamics measured by the Density people counting sensor from a real office room into the test room. The maximum occupancy is 7. Infrared heating bulbs were used in this study to simulate the heat generated from the occupants. According to ASHRAE standard 55 [9], the total heat generated from each occupants is around 100 W (seated), of which 70% is the sensible part [10]. Assuming the heat generation by a laptop is around 30 W, the total heat generation by an occupant in the office is around 100W. To simulate the occupants’ heat generating in the office, 7 bulbs were placed in the office. A CO\(_2\) distribution system, consisting of a CO\(_2\) cylinder and delivering tubes with mass flow controllers was used to simulate the CO\(_2\) generation by the occupants. Based on a simple calculation [31], 0.9 kg CO\(_2\) were generated per person per day (~300 sccm). Once one more occupant was detected in the room, the CO\(_2\) distribution system would deliver more CO\(_2\) at such generation rate to the office. The resulting CO\(_2\) level in the office space was measured by an INNOVA 1412i photoacoustic gas monitor to evaluate the effect on the indoor air quality. An instrumented thermal manikin was used in this study to investigate the thermal response of an individual with the help of the Clothing Independent Thermal Comfort Model [11–13]. A seven-scale mean thermal vote (MTV) was predicted.

2.3. Control Strategy

Two control strategies are tested and compared in this study, including the baseline control and the occupancy-centric control. The baseline control strategy controls the HVAC system based on a predefined schedule, in which the office is assumed to be occupied between 7:00 am to 7:00 pm. The temperature setpoint during the occupied hour is 23.3 °C (74 °F) with the setback at 26.7 °C (80 °F) and the ventilation setpoint is maintained for 7 occupants as specified by ASHRAE 62.1 [14], all the time. The occupancy-centric control strategy separates everyday into three modes: unoccupied mode, occupied mode and standby mode (Figure 1). The unoccupied mode is activated before the first people come in the morning and after the last people leave in the evening; the occupied mode is activated when the room is occupied; the standby mode is activated when the room temporarily unoccupied during the office hour. Under the unoccupied mode, the room HVAC system will be shut off and the temperature control will be switched to setback. Under the occupied mode, the HVAC system will be turned on with temperature controlled at setpoint and outdoor air flow rate as the one specified by ASHRAE 62.1. Under the standby mode, the HVAC system will be turned on with temperature controlled at standby setback, which is 25 °C (77 °F), and outdoor air flow rate as the one specified by ASHRAE 62.1.
2.4. Data Acquisition
The fan energy was measured by an EG4115 power meter, and the cooling/heating and outdoor air load of the rooms were calculated based on the airflow rate correlated from fan speed and supply/return/outdoor air temperature measured by the thermocouple temperature network.

3. Results and Discussion

3.1. Occupancy Profile and Energy Balance Test
The occupancy counting data collected on Feb 6th, 2020, is presented in Figure 2a. The occupancy count every half hour was used to control the HVAC system. It is indicated that people started to come to the office at 8:00 and leave the office after 17:30, with the maximum occupancy between 14:00 and 15:00.

The energy balance test was conducted to make sure the two rooms of the TIEQ lab worked in the same way and consumed the same amount of energy under the same condition. The difference in fan energy, coil load, and the total energy consumption is -0.9%, -3.4%, and -4.8% (Figure 2b).

3.2. Energy Saving by OCC
It was shown that the weekly energy saving in the fan power, coil load, and total energy were 17.1%, 17.1%, and 28.2% (Figure 3a). An example day was selected to show the time-series data of the fan energy (Figure 3b) and coil load (Figure 3c). It shows that OCC saved most of the fan energy and coil load because it started later and shut down earlier than the baseline case. A simple calculation demonstrates that 95% fan energy and 61.2% coil load saving is due to the shorter operating hour by OCC. One should note that when the occupant came, the lighting was also turned on, which also helped convert the room from heating to cooling.

Figure 1. Occupancy-centric control strategy.

Figure 2. Occupancy profile (a) and energy balance test result (b).
3.3. Air Quality under OCC

It has been accepted that CO₂ exhaled by humans can be a good indicator of indoor air quality. In this study, CO₂ was injected into the space following the occupancy schedule to mimic the CO₂ generated by the occupants. The resulted CO₂ concentrations in the exhaust duct under baseline and OCC are provided in Figure 4a and Figure 4b. It was shown that the highest CO₂ concentration was 560 ppm and 580 ppm for the baseline and OCC, both lower than the 1000 ppm limit. The mean thermal vote of the occupant was shown in Figure 4c. It was indicated that under both baseline and OCC, most of the segments ‘felt’ close to nature (|MTV| < 0.5). The whole-body mean thermal votes under two control strategies were -0.86 and -0.65, respectively. OCC reported a little towards the neutral.

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