Energy Savings of Occupancy-Based Controls in Office Buildings

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Abstract

Variable-air-volume (VAV) systems are used in many office buildings. The terminal's minimum air flowrate set point is an important parameter that has significant impact on energy consumption and indoor air quality. Conventional controls usually have the terminal's minimum air flowrate at a constant, irrespective of the occupancy status. Such practice may cause energy waste, ventilation and thermal comfort problems. This paper examines the potential of energy savings by occupancy-based controls (OBCs). The sensed occupancy information, either presence or the people count, is used to determine the air flowrate of terminal boxes, the thermostat set points, and the lighting as well. Using EnergyPlus, energy savings of OBC strategies are evaluated for representative existing medium office buildings in the U.S. Simulation results show that for the location of Baltimore, MD, the use of air-side economizer or not does indeed have significant impact on the comparison between the two OBC strategies. The OBC based on the occupant presence has about 13% whole-building energy savings no matter whether the air-side economizer is used in the AHU operation. However, for the OBC based on the people count, the percentage of energy savings increases from 13% for the case of not using air-side economizer to 23% for the case of using air-side economizer.

Introduction

VAV systems are widely used in commercial buildings. According to the recent commercial building energy consumption survey (EIA 2016), buildings with VAV systems represent 41% of all U.S. commercial building floor space and account for 51% of the commercial sector primary energy use. In a VAV system, outdoor air (OA) enters the air-handling unit (AHU) through an outdoor-air damper and is then mixed with the air returned from the space. The mixed air sequentially passes through a filter, a heating coil (if present), and a cooling coil, which are used to maintain the supply air at a predefined temperature set point in the supply duct downstream of the supply fan. In addition to AHUs, VAV terminal boxes are an integrated part of the VAV system. A terminal box usually serves a building zone (which can be a single room or multiple rooms) by controlling the air flowrate to the zone and reheating the air if it is too cool for the zone served. Terminal boxes are sized to address the design thermal load (usually the cooling load). The terminal's

minimum air flowrate set point is an important parameter that has significant impact on energy consumption and indoor air quality. In principle, this parameter value needs to be determined by the maximum flow to satisfy the heating load and the ventilation requirement. However, in practice, control system integrators and installers often set the terminal minimum air flowrate between 30% and 50% of its maximum flowrate (Cho and Liu 2009; Stein 2005). The minimum setting is maintained as a constant during system operation, which potentially leads to two major issues related to ventilation. First, the rule-of-thumb setting cannot guarantee to meet space ventilation requirement, as will be demonstrated later in the paper. Second, because building occupancy varies dynamically over time, setting a constant minimum air flowrate may result in over ventilation during times when space has less than the maximum occupancy or is unoccupied at all. The over ventilation causes energy waste and even discomfort for occupants in some spaces (e.g., conference rooms) from over-cooling (Taylor and Stein 2004; Zhu et al. 2000).

To cope with the variations in occupancy, the ASHRAE Standard 62.1 on ventilation for acceptable indoor air quality (ASHRAE 2016) allows dynamic reset of the outdoor air flowrate in response to the change of zone population. The standard also lists four example approaches that can be used to account for occupant information: 1) direct count of people; 2) presence of people; 3) time-of-day schedule; and 4) CO₂-based occupancy estimation. Many occupancy-based control (OBC) strategies have been proposed and evaluated in literature (e.g., Lin and Lau. 2014; Taylor 2006).

According to the information requirements and complexity, OBC strategies can be classified into two categories: rule-based control and model predictive control. Rule-based control requires instantaneous occupancy measurements (presence/absence or number of occupants) to calculate the control inputs. The sensed occupancy information together with other measurements (e.g., space air temperature) are used as feedback signals to override the control settings. For example, Balaji et al. (2013) leveraged the occupants' mobile devices to detect which rooms are occupied. The thermostat set points are relaxed for 1.1°C if the room is unoccupied. Based on one-day experiment in a university campus building, they obtained 17.8% electrical energy savings for HVAC systems from the application of occupancy-based controls to 23% zones in that building. Goyal et al. (2013) used the

measured occupancy instead of the design occupancy to calculate the minimum air flowrate of the occupancy-associated VAV terminal box. Meanwhile, the temperature set points are relaxed if a zone is unoccupied. Based on the MATLAB simulation for a single zone in three typical days (i.e., cold, hot, and mild), Goyal et al. obtained 50% HVAC energy savings for that zone relative to the baseline terminal control with a minimum air flow fixed at 40% of its design flow rate. This rule-based OBC strategy was further tested in a campus building (Brooks et al. 2015) in Gainesville, FL. The field test was performed on 12 fully actuated zones (i.e., each zone is served by a single terminal unit) for six days in April. The experimental results showed that the rule-based OBC achieved 37% HVAC energy savings, 30% of which came from heating.

Model predictive control (MPC) requires predictions of occupancy (presence/absence or the number of occupants) at future times and solves an optimization problem to determine the control inputs. These control inputs are implemented at the current time t_k and their corresponding outputs are measured. Using the measured outputs, the control inputs at the next time t_{k+1} are calculated by solving the optimization problem again for the next k time steps. The entire process is repeated at the time t_{k+1} . To solve the optimization problem, MPC requires a dynamic model and predictions of exogenous inputs such as weather and occupancy. Oldewurtel et al. (2013) compared various types of MPC strategies for the control of lighting, window blinds and HVAC in office buildings. Their simulation results showed that the MPC based on perfect prediction over a 3-day time horizon had a savings potential of up to 34% if five out of 15 days are vacant on the average. A large portion of this savings potential can be captured by using the default occupancy schedule as prediction and adjusting lighting and ventilation to instantaneous measurements of occupancy status. Similar observations were made in another study (Goyal et al. 2013), where the MPC controller using perfect occupancy prediction over a 24-hour time horizon led additional 1-13% energy savings relative to the rule-based controller.

In this paper, we extend the previous work by Zhang et al. (2013) to estimate the energy savings of rule-based OBC strategies using the whole building simulation program EnergyPlus. The sensed occupancy information, either presence or the people count, is used to determine the air flowrate of terminal boxes, the thermostat set points, and the lighting as well. We hereinafter refer the detection of occupancy presence (occupied or unoccupied) as common occupancy sensors and the detection of the number of people as advanced occupancy sensors. Occupancy-based control (OBC) strategies based on the above two kinds of sensors are proposed and evaluated using building simulation. Their results are compared with the baseline of not using occupancy-based controls.

Building model description

The medium office building model originates from the commercial reference building models developed by the U.S. Department of Energy (Deru et al. 2011). The reference building models offer three vintages: new construction in compliance with ASHRAE Standard 90.1-2004, existing buildings constructed in 1980s, and existing buildings constructed before 1980. According to the latest commercial building energy consumption survey conducted in 2012 (EIA 2016), the median age of medium office buildings (floor area between 2,300 m² and 18,500 m²) in the U.S. was approximately 32 years. Assuming that this median age has not changed appreciably between 2012 and 2019, the median year in which currently-standing medium office buildings were built is 1987. Ideally, the building modelled to estimate likely energy savings from retrofit with OBC would be the average medium office building built in 1987 but in its present 2019 condition. Such a requirement, however, cannot be met by none of the three vintage models of reference buildings. Thus, an alternate procedure (Zhang et al. 2013) is used to define a representative medium office building for this study. Starting with the reference medium office building model for new construction, adjustments were made to bring the model closer to the characteristics that might be expected for a building constructed in 1987 but has been upgraded over the last 32 years. The changes (see Table 1) were selected mostly based on the professional judgment of the authors of this paper because no data sufficient to support specification of such changes were found to be available.

The resulting model represents a three-story office building with approximately 5000 m² of total floor area. Figure 1 illustrates an axonometric view of the building and its floor zoning. The building has 1.2 m plenum spaces above each floor and a continuous band of windows for a total window-to-wall fraction of 33%. Perimeter zones are delineated by the orientation of each façade. Each perimeter zone is 4.6 m deep. On each floor, perimeter zone 1 (Figure 1) is used as the conference room while the other three perimeter zones are private offices and the core zone is for open-plan offices. According to ASHRAE Standard 62.1, the occupant density is modelled as 5 and 50 people per 100 m², respectively for the offices and conference rooms; the OA ventilation rate is 0.0025 m³/s per person and 0.0003 m³/s per m² space area for both offices and conference rooms.

Three packaged direct-expansion rooftop VAV air-handling units with gas furnaces serve the medium office building, one for each floor. The units have a rated energy efficiency ratio of 10.1 for cooling and rated thermal efficiency of 0.8 for heating. Persily et al. (2005) conducted a ventilation field study in U.S. office buildings and found that for those AHUs without economizers 1) the mean ratio of the design OA flowrate to the supply air flowrate is 0.19; and 2) the mean ratio of the measured OA intake to the design intake is 1.37. This means the mean measured OA fraction is 26%. Therefore, the AHUs in the model have their OA dampers

at the minimum position to maintain OA intake at a fixed 25% of the supply air unless in the air-side economizing mode. Pressure-independent VAV terminal boxes are used in the model. The maximum air flowrate of each VAV box is autosized by EnergyPlus according to the thermal load. Following the common practice and design recommendations (Pang et al. 2017), all terminal boxes have hot-water reheat and the single-maximum control logic. The minimum air flowrate is set at 30% of the maximum for terminal boxes serving offices and at 50% for those serving conference rooms. The scheduled system operation hours are from 6:00 am to 10:00 pm on weekdays and from 6:00 am to 6:00 pm on Saturdays, with the first two hours for space warming up or cooling down. During these operation hours, the zone thermostat set points are 23.9°C for cooling and 21.1°C for heating. A 5.6°C set back or set up is used during scheduled system off hours.

(a) Floor plan and zoning

(b) Isometric view

Figure 1: Modelled medium office building: (a) floor plan and zoning; (b) isometric view.

Occupancy modelling

Realistic modelling of occupancy is critical to the evaluation of the impact of OBC strategies. The most common approach of considering occupancy in building energy simulation programs is by using occupancy profiles. Daily occupancy profiles are usually defined differently on weekdays and weekends for office buildings. A daily profile (either for a weekday or weekend) consists of 24 hourly values, each of which

corresponds to a fraction of the design maximum occupancy. The weekday and weekend daily profiles are repeated across the entire year for all occupants in all spaces (e.g., offices and conference rooms). Using this simplified approach to study occupancy-based controls has the following weaknesses. First, the temporal variation of occupancy pattern is neglected although late arrivals, early departures, and unpredicted presence on weekends are not uncommon in office buildings. Second, the spatial variation of occupancy pattern is neglected although the reality is that different offices and conference rooms may have their own schedules. To address the problems of using repetitive occupancy profiles, the stochastic model for simulating occupant presence from Page et al. (2008) is employed in this work. The Page occupancy model considers occupant presence as an inhomogeneous Markov chain with probabilities of transition $T_{ij}(t)$, defined as:

$$T_{ij}(t) = P(X_{t+1} = i | X_t = j) \quad (1)$$

where, X_t is the random variable for the state of occupant presence at time step t , and i and j take values 0 (absent) or 1 (present).

Based on the profile of probability of occupant presence and a parameter of mobility μ , the time-dependent conditional probability in Eq. 1 can be further expressed as (Page et al. 2008):

$$T_{01}(t) = \frac{\mu-1}{\mu+1} P(t) + P(t+1) \quad (2)$$

$$T_{11}(t) = \frac{P(t)-1}{P(t)} \left[\frac{\mu-1}{\mu+1} P(t) + P(t+1) \right] + \frac{P(t+1)}{P(t)} \quad (3)$$

In Equations 2 and 3, $P(t)$ and $P(t+1)$ are the probability of presence respectively at time step t and $t+1$. Their values are from the predefined occupancy profiles as illustrated in Figure 2 and Figure 3. The occupancy profile for offices is from Wang et al. (2005) while the profile for conference rooms is from Hart (2012). The parameter of mobility μ is defined as the ratio between of the probability of change of the state of presence over that of no change. Page et al. (2008) suggested to define constant values for three levels of mobility (low, medium, and high), but the values were not given. This paper used a value of 0.25 for the parameter μ , which is the mean value used in (Gunay et al. 2015) when comparing different occupancy models.

The Page occupancy model simulates the patterns of presence of each occupant individually. To obtain the occupancy pattern for a zone, each occupant in that zone is simulated separately and the produced patterns of presence are then summed together. For example, the peak number of occupants in Zone 2 (Figure 1) is calculated to be 7. The page occupancy model needs to be ran 7 times to obtain that zone's occupancy profile. The outcome of occupancy modelling includes the occupancy patterns for all 15 zones, which are different from each other. All occupancy patterns have a time step of 15 minutes, instead of one hour as used in the average occupancy profiles. The generated annual occupancy

patterns are used as the inputs of the EnergyPlus simulation program for both control strategies to be discussed below.

Figure 2: The probability of occupant presence in offices.

Figure 3: The probability of occupant presence in conference rooms.

Control strategies

We now describe the baseline control and the two occupancy-based control strategies (one is for conventional occupancy sensors that detect presence only and the other is for advanced occupancy sensors that detect the number of people). These control strategies differ in the following aspects: 1) the minimum air flowrate settings of terminal boxes, 2) the thermostat set points, and 3) the lighting control.

Baseline control

The baseline control does not rely on occupancy information at all. Thus, the terminal box has a constant minimum air flow setting (i.e., 30% of the maximum for offices and 50% for conference rooms) and implements a single-maximum control logic. This means that the terminal air flowrate is adjusted between the maximum and the minimum to address the cooling load. The terminal air flowrate is maintained at the minimum setting when the space temperature is below the cooling set point, which includes both the deadband mode and the heating mode. The reheat coil valve is closed during the deadband mode but modulated opening towards increasing the zone temperature to the heating set point until the valve is fully open or the discharge air temperature from the terminal box reaches the upper limit at 35°C. The thermostat set points in all zones follow the schedule as defined in the section of model description. Similarly, interior lighting

follows a predefined schedule as shown in Figure 4, where the hourly values indicate the fraction of peak lighting power density.

Figure 4: Interior lighting profiles used in the baseline model for both offices and conference rooms.

Conventional OBC

The conventional OBC modifies the baseline control depending on the space type and the space occupancy status. Major changes relative to the baseline control include the following:

- Minimum terminal air flow setting. For private offices and conference rooms, the minimum air flowrate is reset to zero when no people is detected in any of the spaces served by the terminal box. Accompanying the change of minimum terminal air flowrate, the dual-maximum control logic replaces the single-maximum control logic used in the baseline. This means that the thermal load can drive a higher terminal air flowrate than the minimum setting. It is worth noting that setting the minimum air flowrate to zero violates the current ventilation standard that requires the area outdoor air rate during scheduled building operation hours even if the space is unoccupied. This problem could be addressed by setting the minimum air flowrate according to the area ventilation component, but we use zero setting to explore the potential savings from conventional OBC. For open-plan offices, the minimum air flowrate is kept the same as the baseline control because the probability of being unoccupied in large open-plan offices is relatively low.
- Thermostat set points. For conference rooms, the thermostat set points are reset to 25°C for cooling and 20°C for heating if the space is unoccupied. Although some time delay (say 15 minutes) is generally needed in the field to reset thermostat set points after the space is detected to be unoccupied, it is not considered in the simulation at the current stage. The thermostat set points are not reset for offices.
- Lighting control. Conventional OBC for lighting turns lights on when occupants enter a room and off following a delay after all occupants leave the room. Delay times of approximately 15 minutes are usually used to help ensure that lights are not turned off while occupants are still in the room. In the conventional OBC, lighting controls are applied in conference rooms and private offices. Von Neida et al. (2001) investigated the potential of lighting energy savings in different

space types by applying occupancy-based lighting control with varied delay times. About 24% lighting energy savings were obtained for both conference rooms and private offices for a time delay of 15 minutes. To consider the occupancy-based control for lighting in the simulation, we revised the lighting schedule during building operation hours (8:00 am to 10:00 pm) using the following equation:

$$LtgSch_{OBC,i} = LtgSch_{base,i} * (1 - SavingPer) \quad (4)$$

where, $LtgSch_{OBC,i}$ and $LtgSch_{base,i}$ refers to the lighting schedule at hour i for the case of occupancy-based lighting control and the baseline control, respectively. The $SavingPer$ takes the value of 24% for conventional OBC. As an example, Figure 4 shows the baseline lighting schedule being 0.9 from 8:00 to 17:00 during weekdays. The lighting schedule is changed to $0.9 * (1 - 0.24) = 0.684$ for the conventional OBC simulation.

Advanced OBC

The advanced OBC improves further from the conventional OBC based on the number of occupants detected in spaces. Major differences relative to the conventional OBC are highlighted in the following:

- Minimum terminal air flow setting. The zone outdoor air requirement at any time ($V_{oz,t}$) is calculated as:

$$V_{oz,t} = \frac{R_p P_{z,t} + R_a A_z}{E_z} \quad (5)$$

where, R_p and R_a represents the OA rate required per person and per area; A_z is the zone floor area in m^2 ; $P_{z,t}$ is the zone population at time t ; and E_z is the zone air distribution effectiveness. In this work, the value of 1 is used for E_z in the simulation.

The zone primary air flowrate ($V_{pz,t}$) needed to meet the ventilation requirement is then calculated as:

$$V_{pz,t} = \frac{V_{oz,t}}{Z_p} \quad (6)$$

where, Z_p indicates the zone primary outdoor air fraction. For single-duct VAV systems as used in this work, Z_p is the same as the OA fraction at the AHU.

Under the advanced OBC, $V_{pz,t}$ calculated from Eq. 6 is used as the minimum air flowrate for terminal boxes. The actual number of people is used in conference rooms and open-plan offices, where a single large space is served by one or more terminal units (one terminal per zone assumed in the simulation model). For a terminal unit serving multiple spaces such as private offices, the number of people is zero if none of the offices in that zone is occupied; otherwise, the design zone population is used in Eq. 5 if any of the offices in that zone is occupied. In comparison with the conventional OBC, the advanced OBC always satisfies zone ventilation requirement during building operation hours even if the space is not occupied. Certainly, $V_{pz,t}$ can by no means exceed the maximum terminal air flowrate.

- Thermostat set points. This aspect of control is similar to that used for the conventional OBC. The only difference is that the spaces for resetting thermostat set points are expanded to include both conference rooms and private offices.
- Lighting control. Considering that the advanced occupancy sensors have the (potential) ability to precisely identify when a room is vacated, the delay time between all occupants leaving the room and turning off lights is significantly reduced from 15 minutes to 5 seconds (Zhang et al. 2013). Again, occupancy-based lighting control is applied to conference rooms and private offices only. The approach to lighting control simulation is identical to the one used for conventional OBC. However, because Von Neida et al. (2001) did not provide lighting energy savings for a time delay of 5 seconds, a linear regression was made to correlate the lighting energy saving and the time delay based on available data. The regression equation was then employed to estimate the lighting energy saving corresponding to the time delay of 5 seconds, which was 50.9% for conference rooms and 34.9% for private offices. More details about the regression can be found in Appendix A-3 of the report (Zhang et al. 2013).

Simulation results and discussions

The medium office building model is simulated in EnergyPlus. We selected Baltimore, MD as the location for energy simulations because it represents a mixed climate (i.e., cold winter and hot summer) in the U.S. Percentages of energy savings from the OBC strategies are presented against the original baseline model.

In the original baseline model, terminal boxes are autosized by EnergyPlus according the zone thermal loads at design conditions. AHU OA fraction is maintained at 25% unless air-side economizer is used and the weather condition is favourable for economizing. Using air-side economizer or not is expected to affect the results because the minimum terminal air flowrate for the advanced OBC depends on the OA fraction (see Eq. 6). Thus, the baseline model and the two OBC models are simulated for two scenarios: no air-side economizer and with air-side economizer. If air-side economizer is used, differential dry-bulb is the control option.

The baseline has an energy use intensity of 647 MJ/m² for the case of not using economizer and 625 MJ/m² for the case of using economizer. Figure 5 shows the annual energy savings of the two OBC strategies relative to the original baseline, where “Con-OBC” and “Adv-OBC” represent conventional OBC and advanced OBC, respectively. The numbers above the bars indicate the percentage of whole-building energy savings. Figure 5 leads to the following observations:

- Using air-side economizer or not does indeed have significant impact on the comparison between the two OBC strategies. If air-side economizer is not used in the AHU operation, the two OBC strategies have minor difference in energy savings: 85 MJ/m² per year for the

conventional OBC vs. 89 MJ/m² per year for the advanced OBC. However, if air-side economizer based on differential dry-bulb control is used, there is much higher difference in energy savings: 78 MJ/m² per year for the conventional OBC vs. 146 MJ/m² per year for the advanced OBC. This phenomenon can be explained by Eq. 6, which indicates the larger value of OA fraction (Z_p), the smaller value of the minimum terminal air flowrate. Because the use of air-side economizer potentially increases Z_p from 25% to 100%, the minimum terminal air flow under advanced OBC can be much lower than that under conventional OBC, thereby leading more energy savings.

- All energy savings come from four energy end uses (i.e., cooling, fan, lighting, and heating) but with different levels of contributions. Detailed calculations indicate that across the four control cases, 10%~18% of annual energy savings is due to cooling, about 5% due to fan, 11%~18% due to lighting, while 61%~74% due to heating. The heating energy here can be understood solely as terminal reheating energy as the central heating energy used by AHUs are negligible, let alone its difference across different control cases.

Figure 5: Annual energy savings of different end uses from occupancy-based controls.

Under the conventional OBC strategy, the minimum terminal air flowrate is unchanged from the baseline if any of the spaces in the zone is occupied. However, the minimum air flowrate is reset to zero for the terminal units serving conference rooms and private offices whenever all spaces in that zone are totally unoccupied. Both the baseline and the conventional OBC control strategy do not guarantee the satisfaction of ventilation standard when the zones are in the modes of heating, deadband and low cooling. On the contrary, the advanced OBC guarantees the satisfaction of ventilation standard in principle. The situation of zone ventilation is analyzed for different control cases. Generally, zones on the top floor have higher thermal loads because of the roof exposure. Higher thermal loads means higher terminal air flow and thereby less ventilation problems. Therefore, we selected the top floor zones to provide a conservative comparison between the advanced OBC and the other two cases. Of all time steps that the zones are occupied, Figure 6 shows the distribution of four ventilation situations according to the differences between actual provided OA and OA

requirement calculated from Eq. 5. The green bar indicates that the zone ventilation meets the requirement while the blue, orange and red bars indicate the zone ventilation is below the requirement by less than 10%, between 10% and 20%, and more than 20%, respectively. Figure 6 shows that the advanced OBC meets the ventilation requirement for all zones. Both baseline and the conventional OBC have many hours not meeting the ventilation requirement, which is especially the case for perimeter ZN 1 (conference room) and the core zone. The core zone's ventilation requirement was not met for more than 80% of the time across the whole year when the open-plan office is occupied.

Figure 6: Ventilation comparison of top floor zones for different control cases.

Conclusions

Many commercial products are available on the market to detect whether a space is occupied or not. Advanced occupancy sensors for people counting are also available although they are expensive at the moment. With these two different kinds of occupancy sensors, it is important to devise occupancy-based control (OBC) strategies and estimate their potential benefits. A model that represents a currently-standing medium office building constructed in late 1980s was used in this OBC research. Major conclusions from this work include:

- For the climate conditions in Baltimore, MD, the conventional OBC can save whole building energy use by 13% while the advanced OBC can save energy up to 23%.
- The percentage of energy savings due to the advanced OBC depends on whether the baseline AHUs have air-side economizer controls. Using air-side economizers or in general increasing the AHU OA fraction will lead to more energy savings. Most of the energy savings come from the reduction of terminal reheating.
- In addition to energy savings, the advanced OBC satisfies the zone ventilation during all occupied hours across the whole year. However, neither the conventional OBC nor the baseline guarantees the satisfaction of zone ventilation requirement.

In this paper, the advanced OBC strategy has a major focus on terminal box controls via the change of terminal minimum air flowrate. Since AHU OA fraction has a significant impact on the energy savings of the advanced OBC, it is worthwhile to combine the terminal air flow

control and the AHU OA flow control together for the purpose of system optimization. The second avenue of future research lies in the occupancy modelling. Although a stochastic occupancy model was used to consider the temporal and spatial variation of occupancy patterns. The model does not consider the movement of occupants from one zone to the other. Therefore, it is worthwhile to consider more sophisticated occupancy models such as the occupancy simulator by Chen et al. (2017) in future work. Lastly, the simulation assumes that all sensor and actuators work perfect (e.g. no air leakages when the terminal damper fully closes and the occupancy sensor can detect the occupancy status or the number of occupants accurately), it would be interesting to investigate the impact of sensor and actuator uncertainty on the results.

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Table 1: Changes to the medium office reference model to create a building model that approximates a medium office building constructed in 1987 as it would exist in 2019 and the rational for each change.

Category	Change	Rational
Zone description	Specific space types (conference room, private office, and open-plan office) are assigned to the thermal zones.	The use of distinct space types i.e., conference rooms, private offices and open-plan offices, enables evaluation of the savings associated with OBC based on the unique occupancy patterns and ventilation requirement of different spaces.
	The occupancy profiles are modified for private offices, open-plan offices, and conference rooms to consider spatial and temporal variations.	To address the problem of using an average weekly occupancy profile to represent all occupants for all times
HVAC sizing	Terminal-box size (flow rate and reheat) sizing factor is increased from 1.0 to 1.2.	The larger size for the terminal boxes more realistically represents a late 1980s office building.
	Lighting peak load power density (LPD) is scaled to 133% of the LPD required by Standard 90.1-2004 for HVAC sizing. The LPD for calculating lighting energy consumption is unchanged from the reference model.	The HVAC system in a late 1980s building would have been sized for the less efficient lighting of the era. Lamps and lighting fixtures are assumed to have been replaced with more efficient ones since building construction in 1989, but retrofit of HVAC components, primarily the terminal box, is assumed to have been considered too expensive to have been replaced in most buildings.
	Peak plug load density is scaled to 140% of the Standards 90.1-2004 prototype plug load density for HVAC sizing. Plug load density for modeling energy consumption is unchanged from the reference model.	The HVAC system in a late 1980s building would have been sized for a higher plug load densities of that era. Expensive HVAC system replacement, such as for terminal boxes, are less likely to have been done.
Outdoor air flowrate at air-handling units	The outdoor air flowrate is changed from a constant (sum of zone outdoor air requirements) to 25% of supply air flowrate.	Outdoor-air flow station is not commonly used in the field.
Terminal box settings	The minimum air-flow rate for conference rooms is changed from 30% to 50% of the design peak flow rate.	Implementation of this procedure is based common practices with for conference room minimum damper positions presented by Yu et al. (2007) and Stein (2005).
	The control of maximum discharge air temperature is added.	Discharge air temperature from terminal boxes should keep below a certain limit to avoid stratification and short circulation of conditioned air.