Simulation based analysis on the influence of occupants' presence on energy consumption of office buildings

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ABSTRACT

This paper quantitatively evaluates how occupancy schedule influence the energy performance of office buildings while considering the relation with the building size and the configuration of HVAC system. For this purpose, we randomly selected 1584 office workers with different occupancy schedule from a database. Then we assumed three sets of office buildings that accommodate the 1584 workers and estimated energy consumption of the buildings. The simulation result shows, the active floor rate in the larger buildings are higher than that in the smaller buildings, in particular at night. Due to this, the larger buildings resulted the longer operation time of the HVAC systems and the larger energy consumption. In addition to this, we compare the energy consumption of the buildings with 1584 typical occupancy schedules and the empirical schedules from the database in order to clarify the impact of occupancy schedule. The simulation resulted that the occupancy schedule has more influences on the larger buildings. The energy consumption of the buildings with the typical schedules resulted significantly smaller than that with the empirical schedules. This is due to that the typical case causes the lower active floor area rate.

KEYWORDS

Occupant behavior, equipment operation, office building, building size

INTRODUCTION

Occupant behavior is one of the most important determining factor of energy consumption of buildings. In the case of office buildings, its influence can be seen in two ways. First, energy is consumed by appliances that directly operated by office workers, such as personal computers. The second, energy is indirectly consumed by the building facility, including lighting and HVAC systems, that is operated to condition indoor environment for work in the zone in which the occupant is present. The indirect consumption is more complicated than the direct one because energy consumed by the presence of a single worker is different as follows.

To illustrate the structure, the situation is taken in which only one worker is in a zone of an office building. The lighting and HVAC system are operated in the zone. The

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lighting energy consumption is determined by the number of lighting device equipped in the zone. Thus, energy consumption depends on the size of the zone. The amount of heat supplied to the zone by the HVAC system is also determined by the zone size. The difference from the lighting is that the physical property of the zone affects the heat demand. The heat is produced by the HVAC system connected to the zone. The system can be a packaged air-conditioner that produce heat in an outdoor unit and the produced heat is delivered to an indoor unit equipped in the zone. The system can be a central HVAC system that have a heat source system serving all zones in the building. Packaged system and central HVAC system have different energy performance to produce a same amount of heat. More importantly, a same amount of change in heat demand changes the load factor of the heat source systems differently. In central HVAC systems, the load factor is very low if the system serves a large scale building when only one zone is operated. It is not so in the packaged system, since the load factor is determined only by the heat load of the zone and the capacity of the outdoor unit.

This illustration implies that the building specification especially building size, the configuration of HVAC system, and the occupant behavior are three important factor determining the energy consumption for conditioning the indoor environment. The purpose of this paper is to understand the relationship between the three elements.

METHODOLOGY

The authors employed a building performance simulation to analyze the relationship between the building property, HVAC system configuration and occupant behavior. We first designed some simulation conditions for each factor and combined them to develop a number of simulation cases. By comparing the energy consumption and energy performance, the relationship was quantitatively evaluated. For simulation, EnergyPlus was used.

First, we assumed three sets of office buildings. The buildings have different size, the small, the medium, and the large. These three sets of buildings accommodate 1584 office workers. Every building has same occupancy density (0.07 person/m^2). The large building accommodates these workers by only one building. For the other building sizes, a number of buildings are assumed. Each office worker was given a realistic occupancy schedule based on empirical data as explained below. In order to evaluate the influence of the occupancy schedule, energy consumption was also calculated under the assumption in which all occupants follow a typical occupancy schedule. We also examined the impact of the configuration of HVAC systems by assuming different types of HVAC systems.

For the evaluation, the indicators listed in Table 1 were used to illustrate the structure determining energy consumption. The active floor area rate means the proportion of the total area of operated space in the total area of office space. System COP is the ratio of the total amount of heat provided to the conditioned space and the total amount of primary energy consumption of HVAC systems.

In this simulation, every performance from HVAC systems is simulated under air conditioning setpoint temperature, which are 22°C for cooling and 26°C for heating.

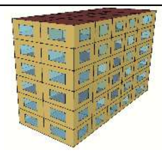
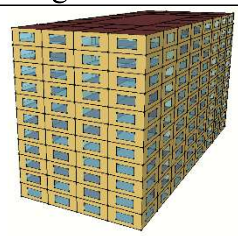
Table 1. *Evaluation indicators*

Evaluation indicators	Definition
Annual primary energy consumption (MJ/m^2)	Annual primary energy consumption per total floor area
Active floor area rate (%)	The proportion of operated floor area in total utility area
HVAC system COP	the ratio of the total amount of heat provided to the conditioned space and the total amount of primary energy consumption of HVAC systems

The Specification of assumed buildings

Table 2 lists the specification of the buildings. As mentioned above, to accommodate 1584 workers, a different number of buildings was assumed. The three building models have different size and floor plan. However, other physical conditions, such as insulation levels, weather condition, are all common.

Table 2. *The specification of the assumed buildings*

Building size	Small	Medium	Large
Characteristics			
Number of buildings	88	11	1
Total envelope area	348 m^2	3258 m^2	31240 m^2
Number of floors	3	6	11
Number of rooms per floor	3	4	6
Averaged room floor area	28 m^2	49 m^2	341 m^2
Number of zones per room	1	2	4
Number of occupants per room	2	6	24

The configuration of HVAC systems

In this study, we assumed three configurations of HVAC systems as listed in Table 3. The packaged air conditioner consists of an outdoor unit and an indoor unit. Each outdoor unit of a packaged conditioner serves one zone. The multi-split type air conditioners have an outdoor unit and multiple indoor units serving a number of zones. The central HVAC system consists of compression chillers, boilers, water pipes, pumps, air handling units and fan coil units.

Based on a statistic on the share of HVAC systems, we assumed the packaged air conditioner and multi-split type air conditioner for the small building. For the medium and the large buildings, we assumed all of the above-mentioned HVAC systems. For the medium building with central HVAC system, we assumed the system consists of one chiller, one boiler and fan coil units system. For the large building with central HVAC system, we assumed the system consists of three chillers, three boilers and the combined system using air-handling units and fan coil units. Figure 1 illustrates the system configuration at the floor level and the floor plan of each building model.

Table 3. The configuration of HVAC systems

Type	Air conditioning unit	Heat source equipment	
		Cooling	Heating
Distributed system	Packaged-unit (Constant air volume) Multi-split (Constant air volume)	Variable refrigerant system Cooling COP: 2.77; Heating COP: 3.41	
Central system	Fan coil unit (Constant air volume) Air handling unit (Variable air volume)	Turbo chiller COP: 5.5	Gas boiler Efficiency: 0.9

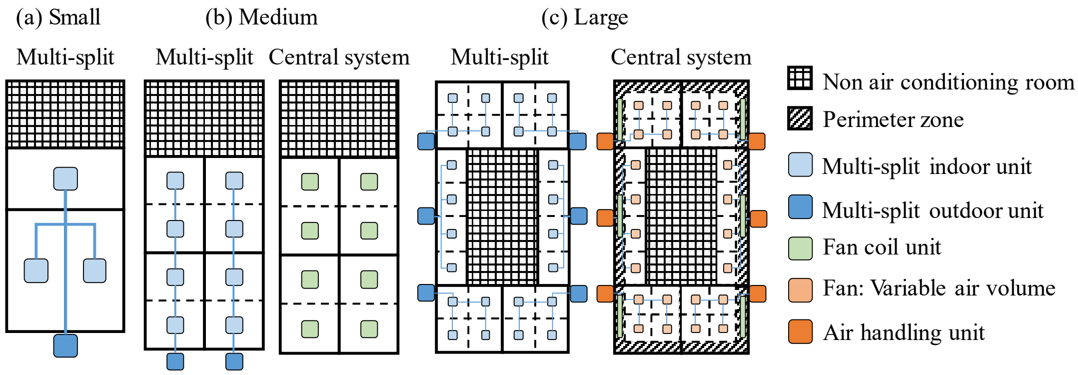


***Figure 1.** Floor plan and system configuration of HVAC systems at the floor level*

Assumption of occupancy schedule

As mentioned above, we assume 1584 office workers for this study. The occupancy schedule of each office worker was determined based on the 5th Keihanshin Metropolitan Region person trip survey (2010). In the survey, the respondents were asked to report their demographic information, the departure and arrival place and time, the purpose of all trips they made on the surveyed day.

We first extracted samples containing the following conditions: 1) the respondent is an office worker, and 2) the respondent has a trip to an office building for work. Figure 3 shows the distribution of the arrival time from office, departure time to office and the duration while the respondent is being at office. Then, 1584 occupancy schedules were randomly selected and given to each agent assumed in the simulations. The location of office space of each office worker was also randomly selected while assuming the constant occupancy intensity in the zones.

The occupancy schedule of the assumed occupants is shown in Figure 2. As shown in the figure, a natural time variation was made in the occupancy. The peak in the number of occupants staying at the office is 1100. In addition to this, there are 5 ~ 20 workers even in the midnight. The figure shows the typical occupancy schedule assumed to evaluate the impact of the assumption of occupancy. We assumed that 1584 office workers all arrive at 8:00 and depart at 18:00 as shown in Figure 2.

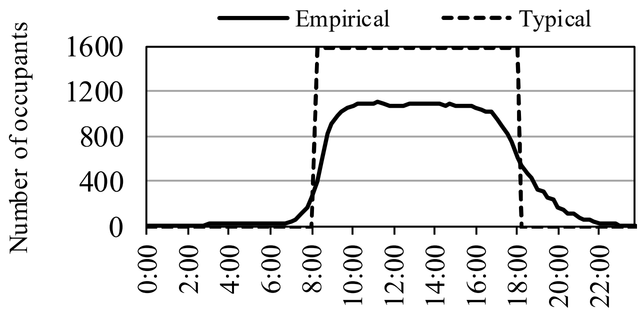


Figure 2. *Typical occupancy schedule and empirical occupancy schedule*

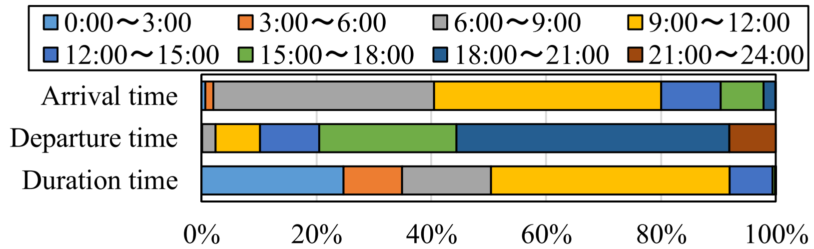


Figure 3. *Frequency distribution of arrival time, departure time and duration time*

EVALUATION OF THE IMPACT OF BUILDING SIZE

The active floor area rate

Figure 4 shows active floor area rate of the buildings. The small buildings' active floor area rate does not reach 100 % even during the peak-time. This is because the number of occupants using a zone is small and the occupancy of each office worker is more reflected in the operation of zones. This is due to the assumption in which the zone is to be operated while one or more office worker is being present in the zone. In contrast, the large building has the highest active floor rate at night. This is attributed to that the number of office worker in a zone is the largest as shown in Table 2. Thus, the operation of HVAC system and lighting differs significantly from the case in which the typical occupancy schedule is assumed as shown by the dotted line.

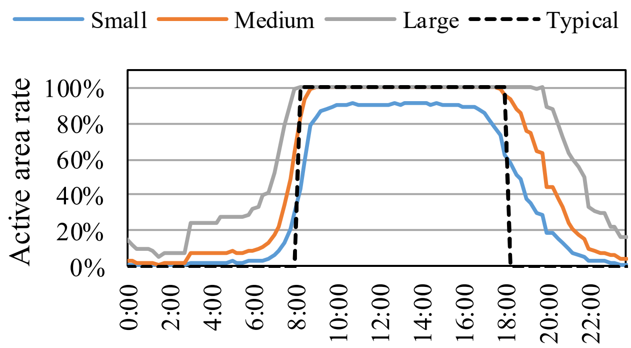


Figure 4 *The active floor area rate*

Heat load, electricity and HVAC system COP

Figure 5 shows the estimated cooling demand, electricity consumption and system COP of the buildings on a representative day in August. The HVAC electricity consumption is determined by cooling demand and the energy conversion performance of HVAC system. The small building has high cooling demand, shown by the red lines, during daytime due to the high wall area facing atmosphere per floor area. However, cooling demand is smaller during night due to the small active floor area rate. In contrast, the large building has smaller cooling demand during daytime but higher demand during night. This higher cooling demand is attributed to the higher active floor area rate.

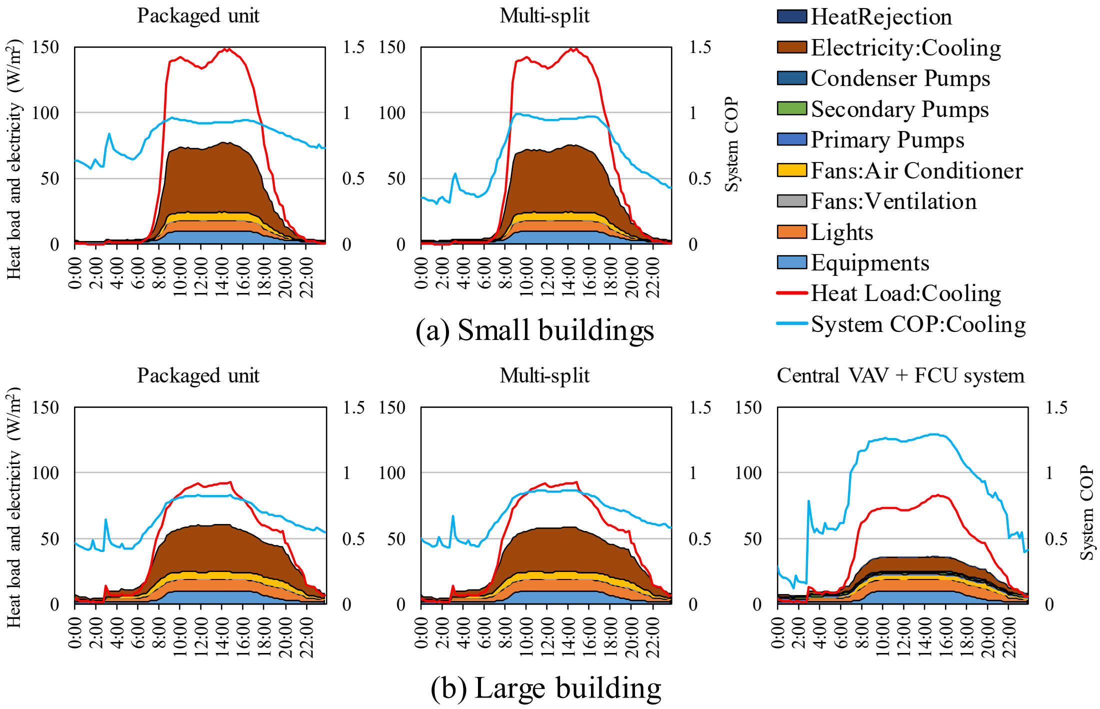


Figure 5. *Heat load, electricity and system COP on a representative day in August in the building with empirical schedules at August day*

Focusing on the HVAC system, the deterioration in the system COP, shown by the blue lines, is significant during night in the central HVAC system, while it is not so in the packaged and the multi-split air conditioning systems. This can be attributed to the low part load factor of the central heat source plant that is operated while at least one room is operated. This resulted in low energy performance of refrigerators, pumps and cooling towers.

Figure 6 shows the annual primary energy consumption per floor area and its composition. If large building equips the packaged or multi-split air-conditioning system, the consumption of the large building is higher. However, it the large building equip the central HVAC system, the primary energy consumption become the smallest due to the high system COP shown in Figure 5.

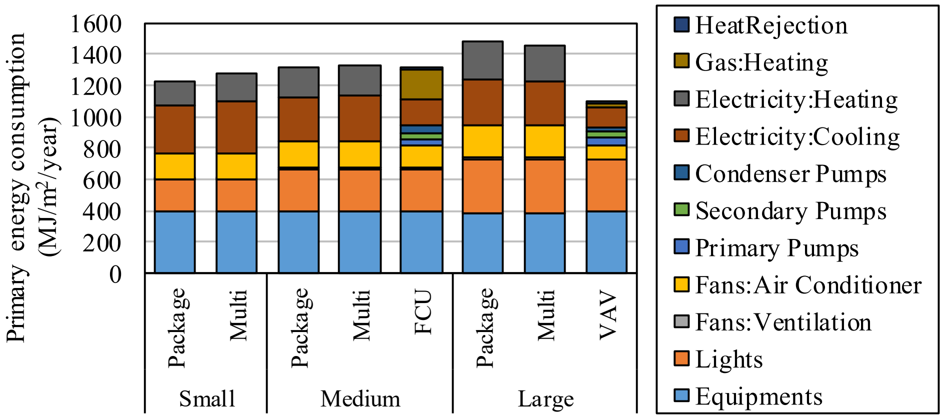


Figure 6. *Annual primary energy consumption*

EVALUATION OF THE IMPACT OF OCCUPANCY SCHEDULE

This chapter evaluates the impact of the occupancy schedule by comparing the energy consumption between the case using the empirical occupancy schedule based on the person trip survey and the typical schedule.

Figure 7 shows the estimated electricity demand on a representative day in August. The case with the typical schedule has higher electricity demand during daytime and lower during night compared to the empirical schedule. This can be mainly due to the higher intensity of activity during daytime and the longer hours while HVAC system is not operated. However, the system COP is higher in the typical schedule case due to the higher part load factor, as shown in Figure 8 in the frequency distribution of heat load of the large building.

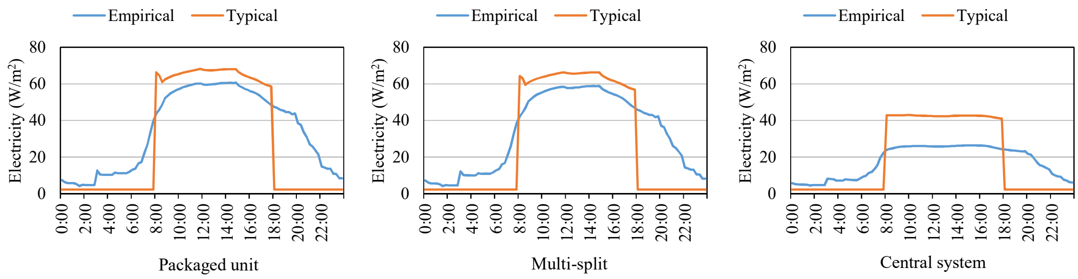


Figure 7. *The comparison of the electricity on a representative day in summer in the large building with different schedule type*

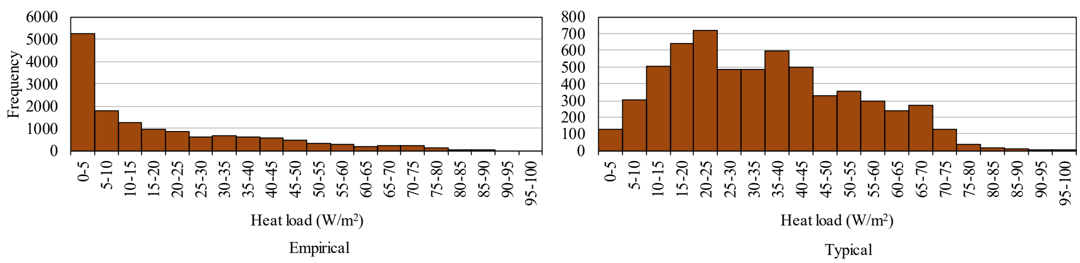


Figure 8. *Frequency distribution of heat load in the large building with central HVAC system*

Figure 9 shows the annual primary energy and its composition in the empirical schedule case and the typical schedule case. In the small buildings, the energy consumption of the empirical case is smaller than the typical case. This is due to that the integration number of occupants and the active floor area rate per day of the typical cases is larger than those of the empirical cases, shown in Figure 2 and Figure 4. In contrast, the medium and large buildings with empirical schedules consume larger energy than those with the typical schedules. As mentioned above, this is due to the active floor area rate is higher in the empirical case, in particular at night. This cause the longer operation time of HVAC system and the larger energy consumption. This result implies that the occupants' behavior has more influences on the larger buildings.

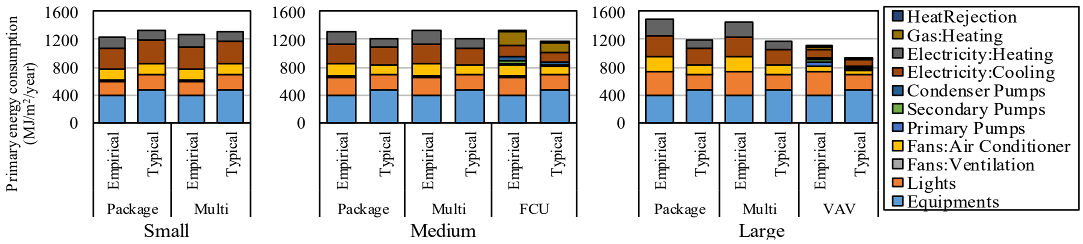


Figure 9. *Annual primary energy consumption from the empirical schedule case and the typical schedule case*

CONCLUSION

Building size, configuration of HVAC system and occupants' behavior are important determining factors of energy demand of office buildings. This paper showed the relationship between the factors by using building performance simulation. The following results were obtained:

(1) The proportion of active floor area in the total office area differs among buildings with different size, in particular at night when occupant presence rate is low. Due to this structure, larger buildings cause larger active floor rate at night than smaller buildings.

(2) This result cannot be obtained in the simulation using the typical occupancy schedules because typical schedule cannot reflect the difference in the operation condition caused by the difference with building size.

(3) The result implies that the occupants' behavior have more influences on the larger buildings. The typical schedule simulation causes higher part load operation than that of empirical schedule, in particular in the larger buildings. In addition to this, empirical schedule cause the longer operation time of HVAC systems and the larger energy consumption.

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REFERENCES

Keihanshin Metropolitan area traffic planning conference; 5th Keihanshin Metropolitan Region person trip survey, 2010