Energy Prediction Impact of the Space Level Occupancy Schedule for a Primary School

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Abstract

By using the same occupant schedule for all spaces, a building level occupancy schedule in building energy modelling can reduce the cost and time of data collection, especially for large-scale simulations or when detailed occupancy data cannot be obtained. However, by describing the unique occupancy status in each space, a space level schedule can better reflect real-world scenarios. This research investigates the energy prediction impact of a space level occupancy schedule for primary school modelling in 16 ASHRAE climate zones. The results show that when switched from a building level to a space level occupancy schedule, the energy prediction difference is between -1.0% and 0.8%. Generally, the predicted building energy consumption using a space level occupancy schedule is higher than when using a building level occupancy schedule in hot and warm climate zones, but lower in other climate zones.

Key Innovations

- Design a space level occupancy schedule for a primary school, which reflects occupant presence and movement in the primary school.
- Investigate the necessity of developing a space level occupancy schedule for the primary school.

Practical Implications

If simulation practitioners want a rough energy prediction for a primary school, a building level occupancy schedule is recommended. But we should keep in mind that the predicted energy use is lower than the actual energy consumption in hot climate zones and higher in cold climate zones. If simulation practitioners want a more accurate energy prediction, a space level occupancy schedule is suggested. Occupancy data on each space in the building is required to develop the space level occupancy schedule.

1. Introduction

Building energy modelling is an effective method to improve building energy performance (Li and Wen, 2014; Hong et al., 2020; Harish and Kumar, 2016; Peeters et al., 2009). EnergyPlus, a whole building energy modelling program, provides engineers, architects, and researchers with a tool to model energy consumption for heating, cooling, ventilation, and lighting. The United States Department of Energy (DOE) has invested $83 million to develop EnergyPlus since 1997 (DOE, 2021). It is projected that the integrated design using EnergyPlus has the potential to save 234 billion kWh a year in the U.S. by 2030 (DOE, 2021).

Building level or space level occupancy schedules could be applied in the EnergyPlus models to describe occupancy status (the number of occupants at a particular time) in a building. Building level occupancy schedules set the same occupant schedule for all spaces of the building. Space level occupancy schedules describe the unique occupancy status in each space of the building.

Developing space level occupancy schedules is expensive in terms of both cost and time. Occupants move around inside the building very frequently (Martinaitis et al., 2015; Andersen et al., 2014), for example, to visit restrooms, other office spaces, or auxiliary spaces. It is difficult to achieve an accurate representation of real-world building operation (Coakley et al., 2014). Developing unique occupancy patterns in each space requires sensor installation at the entrance of every space. However, developing building level occupancy schedules only requires occupant data for the whole building. Installing sensors at the entrance of the building is enough. Therefore, we tend to use building level occupancy schedules to reduce cost and time, especially for modelling on a large scale (Ye et al., 2020; Huang et al., 2020) or when detailed occupancy data cannot be obtained (Wang et al., 2020). For example, Attia et al. (2020) created school energy models using building level occupancy schedules.

However, adopting space level occupancy schedules in building models brings the predicted energy use closer to actual energy consumption. In reality, actual occupancy patterns in the spaces of a building may differ significantly from each other (Chen et al., 2018). Brackney et al. (2018) pointed out that occupants are significant sources of thermal loads in a building. The research of Chen et al. (2018) and Brackney et al. (2018) shows that space level occupancy schedules indicate the real-world scenarios, which makes the simulated and actual building performance more consistent. But the difference in predicted energy consumption between using space level occupancy schedules and building level occupancy schedules has not been investigated yet. As a part of IEA Annex 66, Yan et al. (2017) investigated space level occupancy schedules and the influence of occupants on building performance. They assumed that occupant controls the operation of building (e.g., plug loads, lighting). But there are many commercial buildings that have not implemented occupant-centric control. And prototype building models have not involved the occupant-centric control (DOE, 2020).

The objective of this study is to explore the necessity of developing space level occupancy schedules for buildings without occupant-centric control. The occupancy schedule does not impact other schedules (e.g., lighting schedule) in this research. A primary school energy model in Colorado, U.S. is used as an example to evaluate the energy prediction impact of space level occupancy schedules. Then the evaluation is expanded to other 14 different climate zones. The remainder of this paper is structured as follows. Section 2 introduces the research methods. Section 3 presents the space level occupancy schedule and building level occupancy schedule for the primary school EnergyPlus model and the energy prediction results from using these two occupancy schedules. Section 4 discusses the difference between these two occupancy schedules. Lastly, Section 5 concludes with the findings of this paper and discusses of future work.

2. Method

Figure 1 presents the general workflow for evaluating the impact on energy prediction of using the space level occupancy schedule. First, a building level and a space level occupancy schedule will be developed. Then, the impact on energy prediction will be evaluated. To make these two occupancy schedules comparable, the same occupancy status in one building is described using these two schedules.

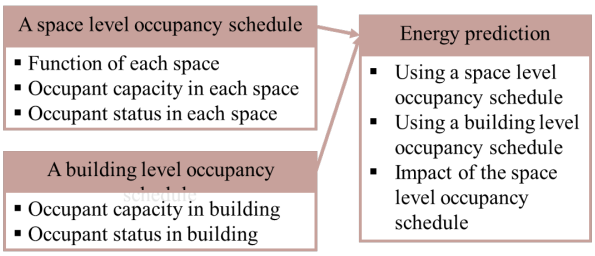


Figure 1: General workflow.

A space level occupancy schedule describes the occupant status (the number of occupants at a particular time) in each space of the building. First, the function of each space in the building is identified. Then, occupant capacity in each space is determined. Finally, the occupant status in each space is developed according to occupant movement patterns.

A building level occupancy schedule describes the occupant status in the whole building. The occupant capacity and occupant status in the whole building need to be determined. To make the two occupancy schedules comparable, occupant capacity in the whole building must equal the sum of the occupant capacity in all spaces, and the number of occupants in the whole building must equal the sum of occupants in all spaces.

The impact on energy prediction from using the space level occupancy schedule is quantified by comparing energy prediction using a space level occupancy schedule and a building level occupancy schedule. The impact on energy prediction (I) of the space level schedule can be expressed:

$$I = \frac{E_s - E_h}{E_h} \times 100\%, \tag{1}$$

where, E_s is the predicted energy consumption using the space level occupancy schedule; and E_h is the predicted energy consumption using the building level occupancy schedule.

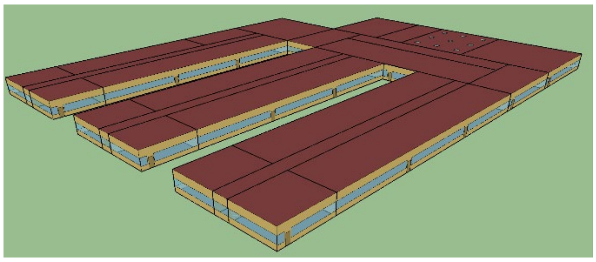
3. Occupancy schedule development and evaluation

3.1. Develop a space level occupancy schedule

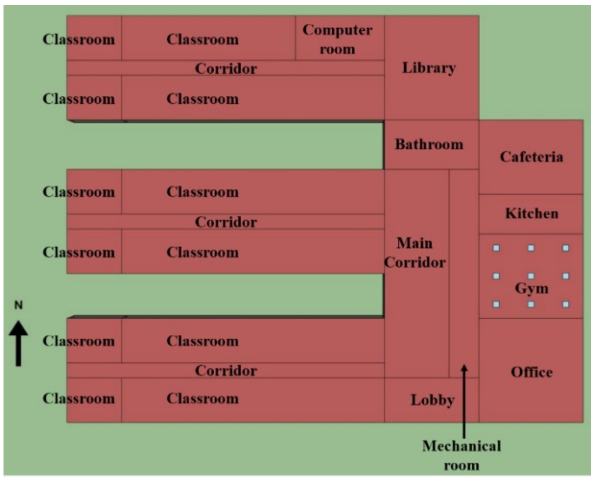
This subsection will develop a space level occupancy schedule to reflect occupant presence and movement in a building. There are three parts: 1) define the function of each space in the building; 2) determine occupant capacity in each space; and 3) describe occupant status in each space.

Function of each space in the building

Figure 2 shows the geometry, thermal zones, and space types of the Commercial Prototype Building Model for a primary school (DOE, 2020), which consists of 10 types of space: (1) classroom; (2) computer room; (3) library; (4) bathroom; (5) cafeteria; (6) kitchen; (7) gym; (8) office; (9) mechanical room; and (10) corridor, main corridor, and lobby.



(a) Geometry



(b) Thermal zones and space types

Figure 2: Geometry, thermal zones, and space types of the Commercial Prototype Building Model for a primary school.

In the U.S., a primary school usually has six grades: kindergarten, first grade, second grade, third grade, fourth grade, and fifth grade. Therefore, the classroom areas are further assigned to the six grades with 12 spaces, as shown in Figure 3.

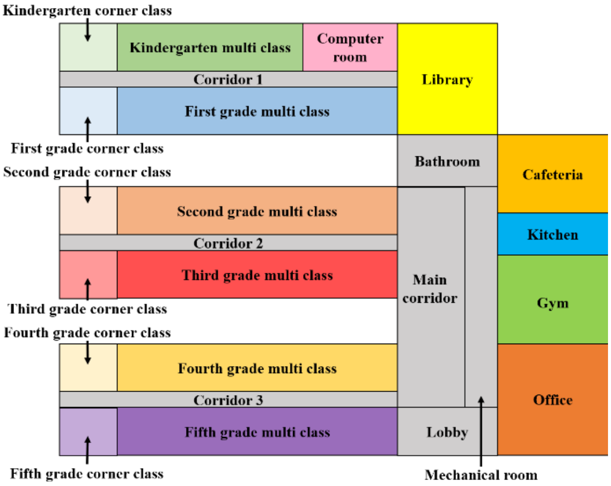


Figure 3: Space arrangement of the Commercial Prototype Building Model for a primary school.

<u>Occupant capacity in each space</u>

Corridors, the bathroom, the mechanical room, and the lobby have temporary presence of occupants, while classrooms, the computer room, the library, the cafeteria, the gym, the office, and the kitchen have constant presence of occupants. Therefore, the occupant capacity of corridors, the bathroom, the mechanical room, and the lobby are set to zero. Occupant capacity in other spaces is determined by the floor area of each space and the occupant density defined in the Commercial Prototype Building Model for a primary school (DOE, 2020), as shown in Table 1. The *occupant capacity* in each space is obtained by multiplying *occupant density* and *area*, as shown in Table 1.

<u>Occupant status in each space</u>

According to the curriculum requirements in Colorado, U.S. (Colorado Department of Education, 2013), students should take reading, writing, math, physical education, science, and social studies. Reading, writing, and math can be taught in the classroom. Reading can also be taught in the library. Physical education is taught in the gym. Science and social studies are taught in the computer room. The following are the rules for occupant movement in the primary school:

1) Classes in kindergarten are from 9:00 to 15:00. Most students arrive at school at 9:00. Some students arrive early at 8:00. Most students leave the school after 15:00. Some students go to the library for late pickup.
2) Classes in the first through fifth grades are from 9:00 to 16:00. Most students arrive at school at 9:00. Some students arrive early at 8:00. Most students leave the school after 16:00. Some students go to the library for late pickup.
3) Students in kindergarten, first grade, and second grade have lunch from 11:00 to 12:00. Most students go to the cafeteria for lunch. Some students leave the school for lunch.
4) Students in third, fourth, and fifth grades have lunch from 12:00 to 13:00. Most students go to the cafeteria for lunch. Some students leave the school for lunch.
5) Students spend most of their time in the classroom. They also go to the computer room to take science and social studies, to the library for reading, and to the gym for physical education.

Based on these five rules, we define the *number of occupants* in each space at a particular time for 1 week. For example, the occupant status on Monday for the primary school is shown in Table 1. The colour in the table indicates occupant movement in the building. For example, 25 occupants move from the kinder corner class to the library at 9:00. Summer break is from June 15th to September 14th. Therefore, the weekly schedule we developed is applied from January 1st to June 14th, and September 15th to December 31st.

Based on occupant capacity and the number of occupants in each space at a particular time, the space level occupancy schedule can be obtained. A *value of the occupancy schedule* in each space at a particular time is obtained through dividing the *number of occupants* at that time by the *occupant capacity*. For example, the space level occupancy schedule on Monday for the primary school is shown in Table 2.

Table 1: The number of occupants in each space at a particular time on Monday for primary school.

Space type	Occupant density [person/m²][1]	Area [m²][1]	Occupant capacity [person]	Number of occupants at a particular time[2]												
				1~7	8	9	10	11	12	13	14	15	16	17	18	19~24
Kinder corner class	0.269	99	27	0	4	0	25	0	25	0	25	3	0	0	0	0
Kinder multi class	0.269	315	85	0	12	78	52	0	78	0	78	9	0	0	0	0
First grade corner class	0.108	99	27	0	4	25	0	0	25	25	25	25	3	0	0	0
First grade multi class	1.076	477	128	0	18	120	120	0	90	120	120	120	12	0	0	0
Second grade corner class	0.420	99	27	0	4	25	25	0	0	25	25	25	3	0	0	0
Second grade multi class	0.054	477	128	0	18	120	120	0	120	90	120	120	12	0	0	0
Third grade corner class	0.161	99	27	0	4	25	25	0	0	25	25	0	3	0	0	0
Third grade multi class	0.295	477	128	0	18	120	120	120	0	120	90	0	12	0	0	0
Fourth grade corner class	0.269	99	27	0	4	25	25	25	0	0	0	25	3	0	0	0
Fourth grade multi class	0.269	477	128	0	18	120	120	90	0	120	0	120	12	0	0	0
Fifth grade corner class	0.108	99	27	0	4	25	25	25	0	25	0	25	3	0	0	0
Fifth grade multi class	1.076	477	128	0	18	120	120	120	0	120	120	90	12	0	0	0
Computer room	0.420	162	43	0	0	0	26	30	30	30	30	30	0	0	0	0
Library	0.054	399	43	0	0	25	25	25	25	25	25	10	36	36	2	0

Space type	Occupant density [person/m²][1]	Area [m²][1]	Occupant capacity [person]	Number of occupants at a particular time[2]												
				1~7	8	9	10	11	12	13	14	15	16	17	18	19~24
Cafeteria	0.161	315	339	0	0	0	0	262	290	0	0	0	0	0	0	0
Gym	0.295	357	150	0	0	0	0	0	0	103	145	145	0	0	0	0
Office	0.269	441	24	0	2	24	24	11	11	24	24	24	11	11	11	0
Kitchen	0.269	168	27	0	0	26	26	26	26	26	0	0	0	0	0	0
Whole building	-	5,136	1,513	0	128	878	878	734	720	878	852	771	122	47	13	0

[1] Commercial Prototype Building Model for the primary school (DOE, 2020)
[2] Curriculum requirements in Colorado, U.S. (Colorado Department of Education, 2013)

: Occupant movement from classroom to computer room.

: Occupant movement from classroom to library.

: Occupant movement from classroom to cafeteria.

: Occupant movement from classroom to gym.

Table 2: A space level occupancy schedule and a building level occupancy schedule on Monday for primary school.

Occupancy schedule type	Space type	Occupant density [person/m²]	Value of occupancy schedule at a particular time												
			1~7	8	9	10	11	12	13	14	15	16	17	18	19~24
Space level	Kinder corner class	0.269	0.0	0.1	0.0	0.9	0.0	0.9	0.0	0.9	0.1	0.0	0.0	0.0	0.0
	Kinder multi class	0.269	0.0	0.1	0.9	0.6	0.0	0.9	0.0	0.9	0.1	0.0	0.0	0.0	0.0
	First grade corner class	0.269	0.0	0.1	0.9	0.0	0.0	0.9	0.9	0.9	0.9	0.1	0.0	0.0	0.0
	First grade multi class	0.269	0.0	0.1	0.9	0.9	0.0	0.7	0.9	0.9	0.9	0.1	0.0	0.0	0.0
	Second grade corner class	0.269	0.0	0.1	0.9	0.9	0.0	0.0	0.9	0.9	0.9	0.1	0.0	0.0	0.0
	Second grade multi class	0.269	0.0	0.1	0.9	0.9	0.0	0.9	0.7	0.9	0.9	0.1	0.0	0.0	0.0
	Third grade corner class	0.269	0.0	0.1	0.9	0.9	0.0	0.0	0.9	0.9	0.0	0.1	0.0	0.0	0.0
	Third grade multi class	0.269	0.0	0.1	0.9	0.9	0.9	0.0	0.9	0.7	0.0	0.1	0.0	0.0	0.0
	Fourth grade corner class	0.269	0.0	0.1	0.9	0.9	0.9	0.0	0.0	0.0	0.9	0.1	0.0	0.0	0.0
	Fourth grade multi class	0.269	0.0	0.1	0.9	0.9	0.7	0.0	0.9	0.0	0.9	0.1	0.0	0.0	0.0
	Fifth grade corner class	0.269	0.0	0.1	0.9	0.9	0.9	0.0	0.9	0.0	0.9	0.1	0.0	0.0	0.0
	Fifth grade multi class	0.269	0.0	0.1	0.9	0.9	0.9	0.0	0.9	0.9	0.7	0.1	0.0	0.0	0.0
	Computer room	0.269	0.0	0.0	0.0	0.6	0.7	0.7	0.7	0.7	0.7	0.0	0.0	0.0	0.0
	Library	0.108	0.0	0.0	0.6	0.6	0.6	0.6	0.6	0.6	0.2	0.8	0.8	0.0	0.0
	Cafeteria	1.076	0.0	0.0	0.0	0.0	0.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Gym	0.420	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.0	1.0	0.0	0.0	0.0	0.0
	Office	0.054	0.0	0.1	1.0	1.0	0.5	0.5	1.0	1.0	1.0	0.5	0.5	0.5	0.0
	Kitchen	0.161	0.0	0.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Building level	Whole building	0.295	0.0	0.1	0.6	0.6	0.5	0.5	0.6	0.6	0.5	0.1	0.0	0.0	0.0

Table 3. Key parameters of the Commercial Prototype Building Model for a primary school.

Parameter Name	Value
Total floor area	6,871 m²
Aspect ratio	1.3
Number of floors	1
Window-to-wall ratio	35% for all facades
Floor-to-floor height	3.96 m
Exterior wall type	Steel-frame walls
Roof type	Built-up roof
Windows	Hypothetical windows with weighted U-factor and solar heat gain coefficient
Lighting power density	Classroom: 9.90 W/m²; Computer room: 9.90 W/m²; Library: 8.40 W/m²; Cafeteria: 6.78 W/m²; Gym: 5.38 W/m²; Office: 10.01 W/m²; Kitchen: 11.41 W/m²; Mechanical room: 10.23 W/m²; Bathroom: 9.15 W/m²; Lobby: 10.76 W/m²; Corridor: 7.10 W/m²
Plug and process load density	Classroom, computer room, library: 15.00 W/m²; Cafeteria: 25.39 W/m²; Gym: 5 W/m²; Office: 10.80 W/m²; Kitchen: 199.29 W/m²; Mechanical room: 10.00 W/m²; Bathroom, lobby, corridor: 4.00 W/m²
Heating type	Gas furnace inside packaged air conditioning unit
Cooling type	Packaged air conditioning unit
Thermostat setpoint	24°C cooling/21°C heating

Table 4: Energy prediction of primary school using different occupancy schedules.

Climate Zone	Climate	Representative city	Site energy use intensity EUI (MJ/m²-yr)		The energy prediction impact of space level schedule (I)
			Building level schedule	Space level schedule	
1A	Very Hot Humid	Honolulu, HI	947.5	954.7	0.8%
2A	Hot Humid	Tampa, FL	908.8	911.0	0.2%
2B	Hot Dry	Tucson, AZ	785.1	787.2	0.3%

Climate Zone	Climate	Representative city	Site energy use intensity EUI (MJ/m²-yr)		The energy prediction impact of space level schedule (I)
			Building level schedule	Space level schedule	
3A	Warm Humid	Atlanta, GA	860.2	861.4	0.1%
3B	Warm Dry	El Paso, TX	743.2	744.1	0.1%
3C	Warm Marine	San Diego, CA	724.2	728.3	0.6%
4A	Mixed Humid	New York, NY	957.3	951.7	-0.6%
4B	Mixed Dry	Albuquerque, NM	764.8	763.0	-0.2%
4C	Mixed Marine	Seattle, WA	827.7	819.4	-1.0%
5A	Cool Humid	Buffalo, NY	1002.9	995.2	-0.8%
5B	Cool Dry	Denver, CO	845.1	840.2	-0.6%
5C	Cool Marine	Port Angeles, WA	836.2	827.5	-1.0%
6A	Cold Humid	Rochester, MN	1166.3	1157.9	-0.7%
6B	Cold Dry	Great Falls, MO	991.5	982.7	-0.9%
7A	Very Cold	International Falls, MN	1248.0	1239.0	-0.7%
8A	Subarctic/Arctic	Fairbanks, AK	1457.8	1448.2	-0.7%

3.2. Develop a building level occupancy schedule

This subsection will develop a building level occupancy schedule to reflect only the total occupant presence in a building. For building level occupancy schedule, we assume that occupant status is obtained by counting the number of occupants in the entrance of building. Therefore, occupant status of each space cannot be obtained. In this research, building level schedule evenly distributes the occupants among all spaces in the building. The building level occupancy schedule can be developed by considering the *occupant capacity* and the *number of occupants* in the whole building at each hour. A *value of the building level occupancy schedule* at a particular time t (V_t) can be calculated as follows:

$$V_t = \sum_{i=1}^{n} \frac{N_{it}}{C_i},\ t = 1,2,\dots,24 \tag{2}$$

where, C_i is the *occupant capacity* in space i; N_{it} is the *number of occupants* in space i at time t; $\sum_{i=1}^{n} C_i$ is the number of occupants in the whole building; and $\sum_{i=1}^{n} N_{it}$ is the number of occupants in the whole building at time t. In a real case, the number of occupants in the whole building can be obtained by installing one sensor in the entrance of the building. In this case, we sum up the number of occupants in each space to determine the number of occupants in the whole building.

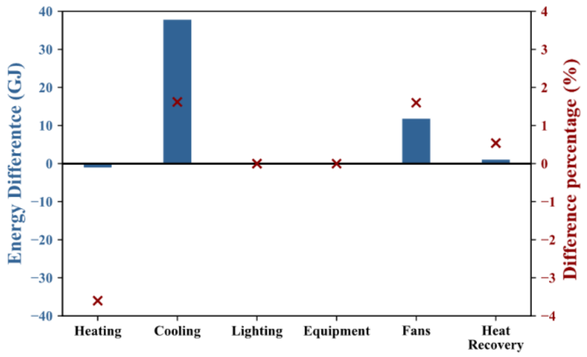
The building level occupancy schedule for 1 week is developed by applying equation (2). For example, the building level schedule on Monday for the primary school is shown in Table 2. The yearly schedule rule for the building level occupancy schedule is the same as the rule for the space level schedule. Summer break is from June 15th to September 14th. Therefore, the weekly schedule we developed is applied from January 1st to June 14th, and September 15th to December 31st.

3.3. Evaluate the impact on energy prediction

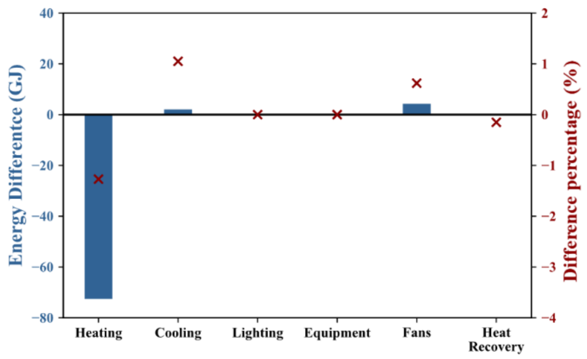
This subsection will evaluate the energy prediction impact of the space level occupancy schedule by comparing the energy prediction using a space level occupancy schedule and a building level occupancy schedule. The Commercial Prototype Building Model for a primary school (DOE, 2020) is used to evaluate the energy prediction impact of the space level occupancy schedule. Table 3 lists the key parameters of the Commercial Prototype Building Model for a primary school. Currently, many commercial buildings/primary school buildings do not implement occupant-centric control. The plug loads; lighting; water usage; and heating, ventilation, and air conditioning (HVAC) are operated based on designed schedules, which is not impacted by the actual occupancy schedule. In the real-world, plug loads and lighting energy correlate with occupant presence in some way. But the impact of occupant on lighting, HVAC is not significant for primary school. In this research, the occupancy schedule only impacts the thermal load generated by occupants. The schedules for plug loads, lighting, water usage, and HVAC are all building level schedules for two types of models: primary school building model using a space level occupancy schedule and primary school building model using a building level occupancy schedule.

The energy prediction for the primary school from using the space level occupancy schedule and the building level occupancy schedule is shown in Table 4. Table 4 shows that the impact on energy prediction from using the space level occupancy schedule for the primary school is between -1.0% to 0.8%. The difference in energy prediction using the space level and the building level occupancy schedules is not very significant. Therefore, if a simulation practitioner wants a rough energy prediction for a primary school, a building level occupancy schedule is recommended because data collection is easier compared with a space level schedule. If the simulation practitioner wants a more accurate energy prediction, a space level occupancy schedule is suggested.

The difference and difference percentage in predicted end use energy between using the space level and the building level occupancy schedules in climate zones 1A and 8A is illustrated in Figure 4. A positive value means predicted energy consumption using the space level occupancy schedule is higher than when using the building level occupancy schedule. A negative value means predicted energy consumption using the space level occupancy schedule is lower than when using the building level occupancy schedule. Figure 4 shows that the space level schedule increases the energy consumption for cooling and decreases the energy consumption for heating. For climate zone 1A, although the predicted heating energy consumption using the space level occupancy schedule is slightly lower than when using the building level occupancy schedule, the change percentage of heating energy consumption is the biggest one. Occupants are one source of heat emissions in the building (Clevenger and Haymaker, 2006; Bruce-Konuah et al., 2019; Tien et al., 2020; Ioannou and Itard, 2015). A building level occupancy schedule assumes that occupants are evenly distributed in the building, while a space level occupancy schedule assumes that occupants are unevenly distributed in the building. Since a space level occupancy schedule increases the energy consumption for cooling and decreases the energy consumption for heating, we can conclude that unevenly distributed heat emission increases energy consumption for cooling and decreases energy consumption for heating.



(a) Climate zone 1A

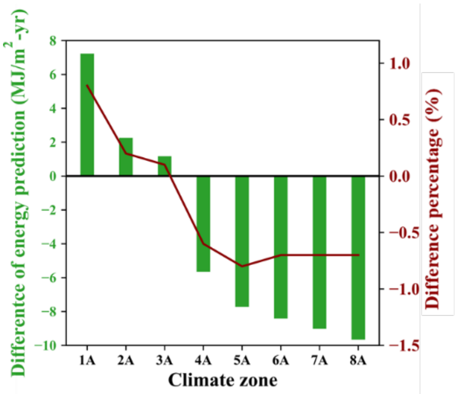


(b) Climate zone 8A

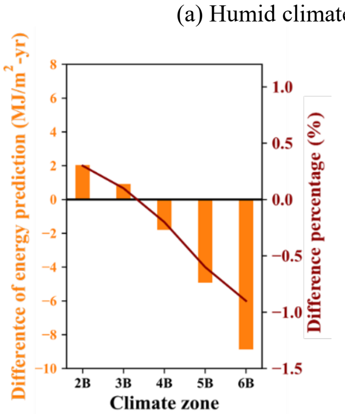
Figure 4. Difference in predicted end use energy between using the space level and the building level occupancy schedule.

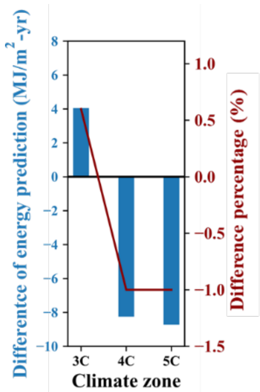
The difference in predicted energy consumption between using the space level occupancy schedule and the building level occupancy schedule is further illustrated in Figure 5. Compared with the building level occupancy schedule, the impact on energy prediction from the space level occupancy schedule for the primary school is positive in hot and warm climate zones, while it is negative in mixed, cool, cold, and subarctic/arctic climate zones. This is because a space level schedule increases the energy consumption for cooling and decreases the energy consumption for heating. Therefore, the predicted energy consumption will be increased in cooling dominant areas (hot and warm climate zones) when using a space level occupancy schedule. And it will be decreased in heating dominant areas (mixed, cool, cold, and subarctic/arctic climate zones) when using a space level occupancy schedule.

Figure 5 shows the trend of predicted energy differences and difference percentage with the change of climate temperature. For humid climate zones (A), dry climate zones (B), and marine climate zones (C), the difference and difference percentage in predicted energy consumption between using the space level and the building level occupancy schedule becomes more significant when the climate becomes hotter or colder. It is because a space level schedule increases the energy consumption for cooling and decreases the energy consumption for heating. When the climate becomes hotter, energy consumed for cooling increases. Thus, the energy difference caused by the space level occupancy schedule increases accordingly. When the climate becomes colder, energy consumed for heating increases. Thus, the energy difference caused by the space level occupancy increases accordingly. Therefore, it is especially important to develop a space level occupancy schedule in extreme hot and cold climate zones.



(a) Humid climate zones





(b) Dry climate zones (c) Marine climate zones

Figure 5. Difference of predicted energy consumption using the space level and the building level occupancy schedule.

The power demand using the building level and the space level occupancy schedule on May 1st (Monday) in climate zone 1A is shown in Figure 6. Because the cooling source is electricity and heating source is natural gas for the primary school, we select the cooling dominated climate, climate zone 1A to analyse the impact on power demand using the space level occupancy schedule. Figure 6 shows that the space level occupancy schedule increases the peak power from 11:00 to 16:00.

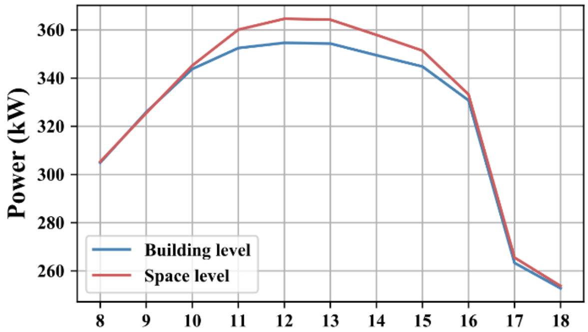


Figure 6. Power demand using the building level and the space level occupancy schedule on May 1st (Monday).

4. Discussion

A building level occupancy schedule is still applicable for building energy modelling if it is correct, reasonable, and representative. Data collection for a space level occupancy schedule requires more time and money, especially for a large-scale building energy simulation. This research shows that the predicted energy consumption difference is from -1.0% to 0.8% when switched from a building level to a space level occupancy schedule. But it does not mean an occupancy schedule is not important for building energy modelling. Both the building level occupancy schedule and the space level occupancy schedule that this research developed utilize the same occupant status in the whole building. A building level occupancy schedule can be used as a simplified method for building energy modelling if it utilizes the real occupant status in the building.

When applying a building level occupancy schedule in building energy modelling, we should keep in mind that the predicted energy is lower than actual energy consumption in hot climate zones and higher in cold climate zones; for hot climate zones, the predicted peak power is lower than the actual peak power. Therefore, model calibration is especially required when applying a building level occupancy schedule in building energy modelling.

The impact on energy prediction using a space level occupancy schedule will become more significant when occupant-centric controls are applied in the building. Applying occupant-centric control means that the occupancy schedule will impact the operation of lighting, plug loads, and HVAC. Energy consumption for lighting can be reduced by as much as 60% through an occupant dependent lighting control strategy (de Bakker et al., 2017). Pang et al. (2020) found that occupant-centric HVAC controls led to an energy saving ratio of between 19% and 45% for the Medium Office prototype building in the U.S. This research does not consider occupant-centric controls. Occupancy schedule only impacts the thermal load generated by occupants. If occupant-centric controls are applied in the building energy modelling, the occupancy schedule will also impact the use of lights, plug loads, and HVAC controls. Then the energy prediction difference using a building level and a space level occupancy schedule will become more significant.

The energy prediction impact of the space level occupancy schedule would be different for other cases. But the trend of predicted energy differences with the change of climate temperature concluded in this research could be applied to other cases. We recommend focusing on the very hot or very cold climate zones at first when studying the energy prediction impact of the space level occupancy schedule for other cases. Because the energy prediction impact of the space level occupancy schedule is more significant in the very hot or very cold climate zones.

5. Conclusion

This paper evaluates the energy prediction impact of a space level occupancy schedule for the primary school EnergyPlus model. To fulfil the target, a space level occupancy schedule is developed for the primary school. A building level occupancy schedule is developed as a comparative study. Compared with the building level occupancy schedule, the impact on energy prediction from using the space level occupancy schedule for the primary school is between -1.0% and 8%. The outcomes summarized in this paper can help simulation practitioner select appropriate occupancy schedule type. The building level occupancy schedule is recommended, if simulation practitioners want a rough energy prediction for a primary school without occupant-centric controls. But the difference in predicted energy using a space level and a building level occupancy schedule becomes more significant when the climate becomes hotter or colder.

The limitation of this paper is that occupant-centric controls are not considered in this research. The impact on energy prediction using a space level occupancy schedule will become more significant when occupant-centric controls are applied in the building. The current prototype EnergyPlus models have not involved occupant-centric controls, but more and more research is contributing to the occupant-centric controls study (Pang et al., 2020; Tabadkani et al., 2020; et al., 2020; Naylor et al., 2018). In the future, the energy prediction impact of a space level occupancy schedule will be studied for buildings with occupant-centric controls.

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