

Occupancy Schedule Development and its Effect on OpenStudio Prototype College Building Model

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College buildings have unique characteristics compared with school buildings. Therefore, defining the realistic occupancy schedule in a prototype college building has significant research opportunities. In this study, the actual operating schedules of each space type were collected and generated based on the class reservation schedule and compared with the previous reference schedule (primary/secondary school). The schedules were analyzed for their effect on the OpenStudio prototype college building model. The findings highlight that the use of a typical school building schedule in a college building impairs the granularity of information. The analysis shows significant differences between the previous occupancy schedule and the updated occupancy schedule of the college building, leading to a considerable decrease in occupancy density. Furthermore, the effect of these occupancy pattern changes on the prototype building model is examined. The variations were observed in minimum ventilation requirements, the average mechanical ventilation rate, and energy consumption attributed to changes in occupancy density.

Keywords: College building; OpenStudio prototype model; occupancy; energy consumption; mechanical ventilation rate

Introduction

Building energy consumption accounts for 40% of global energy consumption and 16% of energy-related carbon emissions in the United States (Li et al. 2023; Huang et al. 2022). To combat climate change and reduce energy-related carbon emissions, improving energy efficiency plays a significant role (Ruparathna et al. 2016; Abdelazim

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et al. 2017). Building energy analysis provides an in-depth understanding of building energy performance which can lead to reducing the excessive energy consumption of the building, evaluating new technologies, and optimizing the building component design (Parker et al 2017). Performing the analysis for both new and existing buildings starts with a prototype building energy model and it is often used as a baseline in analysis (Yunyang et al. 2019).

The U.S. Department of Energy (US DOE) published several sets of prototype building models and continuous efforts have been made to convert 16 prototype building models to OpenStudio prototype buildings. Redefining the prototype building models in OpenStudio can generate EnergyPlus input files and has various advantages. One advantage is that OpenStudio allows the measure-based modification of American Society of Heating, Refrigerating, and Air-Conditioning (ASHRAE 90.1)–compliant baseline models, analysis of retrofit options, and reporting of energy analysis (Im et al. 2019a).

Although a comprehensive collection of prototype building energy models exists in the U.S., there are still some building types that are absent, such as religious worship buildings and college or university buildings. These building types account for 20% of energy usage in the commercial building sector and encompass around 20% of the total floor space (Thornton et al 2011). To address the constraints, the OpenStudio prototype building model suite was expanded to include new building prototype models (e.g., supermarket (Im et al. 2019b), courthouse (Malhortra et al. 2019), college building (Bae et al. 2022a), and detailed offices (Im et al. 2019a). To define a new OpenStudio Standard prototype model, the typical characteristics of the building need to be identified using existing resources such as the Commercial Building Energy Consumption Survey data (US Energy Information Administration 2003) and building

design guide, code, and regulation. Once the typical characteristics are identified, the details of the building and system characteristics are referenced from existing ASHRAE Standard 90.1 (ASHRAE 2004a). When defining the characteristics of the building and system, actual data or relevant resources are reviewed and used to define the typical characteristics of the prototype model.

College buildings have unique characteristics compared with school buildings, including the following: (1) college buildings include various space types, such as research, student working facilities, and other auxiliary areas to support teaching activities; (2) the types and sizes of college classrooms are varied based on the number of students enrolled in different courses; and (3) college buildings include various space types with their own occupancy schedules depending on the number of students enrolled (Bae et al. 2022b).

However, because of the absence of detailed college building schedule data, college building models often reference the primary/secondary school occupancy schedule. The main difference between primary/secondary schools and college buildings is that the teaching spaces of college buildings are occupied based on registered students' schedules, and the occupancy of each space is varied over time compared with the single schedule of primary/secondary schools. Therefore, to capture the characteristics of a college building model schedule, the spaces that are primarily affected by the registered students' schedules, such as classrooms, studios, and laboratories, should have their own schedules based on actual classroom registration data rather than using a single schedule such as that for primary/secondary schools.

Occupant behavior leads to building occupancy, which is one of the most important factors with significant implications for building energy usage. This has been receiving increasing attention in building energy modeling community. Previous studies

have examined occupancy schedules and their effect on energy consumption. Lin presented a preliminary exploration into the effect of occupancy trends for a sustainable campus housing building. That study focused on the occupant behavior in a college housing building based on the outdoor weather patterns (Lin 2017). Chhajed conducted research related to the sensitivity of building energy simulations with building occupancy for a college building. The key finding of this research was that occupancy schedules do not significantly affect annual energy consumption (Chhajed. 2014). Selvacanabady and Judd (Selvacanabady and Judd 2017) evaluated the influence of occupancy on building energy use and energy use intensity in a federal office building using actual occupancy hours instead of using the number of occupants for each hour. Their research shows that direct energy usage proportionally increased with the number of occupants, such as plug load for additional computers, because of an increase in occupancy.

Also, different methodologies or approaches to extract occupancy information have been performed by many researchers. Lu et al. (Lu et al. 2021) extracted the typical occupancy schedules from a social network and developed data-driven models to predict the hourly energy usage of a museum. This research showed that extracted occupancy information could improve the accuracy of the hourly energy usage prediction to a small extent. D'Oca and Hong (D'Oca and Hong 2015) developed a data mining framework to obtain occupancy schedules using 10 min interval occupancy data from 16 offices. Their results concluded that the occupancy rules and schedules are representative and can be used for building energy modeling programs. Diao et al. (Diao et al. 2017) proposed the methodology using k-modes clustering and demographic-based probability neural networks and identified 10 distinctive behavior patterns. The results showed that the proposed behavior model provides a more accurate and reliable

schedule than ASHRAE standard schedules. Mirzabeigi and Razkenari (Mirzabeigi and Razken 2021) gathered information from a public educational building by integrating the occupant counts at the room level along with indoor environmental quality data. They developed a framework to assess various machine learning algorithms and compared their performance against the traditional static schedules in the ASHRAE standard 90.1. Parker et al. (Parker et al. 2017) extracted metadata such as personal location data and developed a methodology for generating occupancy schedules tailored for specific buildings, groups of buildings, and building archetypes.

The previous studies gathered the occupancy schedules of a housing building and a classroom from one university or extracted the occupancy data using various technologies from one case study building. Also, the focus of the research was on energy consumption or did not compare the effect on existing prototype models. Because different universities have different schedules, actual data from more than one university is necessary to generate an occupancy schedule for the prototype college building model that represents the typical college building model.

The occupants play a critical role in the building operation. Their behavior and input are essential for achieving the targeted overall building performance. Several studies introduced various control systems and modeling approach to effectively support occupants' thermal comfort and energy savings in buildings. The studies highlighted the energy influence of occupant behavior, showcasing the implementation of personalized control systems and dashboards for building systems like HVAC, lighting, and plug loads (Chenari et al 2016; Zhao et al 2014). Therefore, accurate occupancy information is important especially for the prototype model which serves as a fundamental reference in numerous studies. To provide a realistic model, the college building prototype building model employed real-world data and enhanced the

occupancy schedule of a prototype college building model. This study investigated the effects of changing the occupancy schedule. In particular, the occupancy schedules for the teaching spaces in college buildings are strongly related to class schedules, a significant opportunity exists to improve the occupancy schedule to reflect the real occupancy patterns in the building and enhance the precision of the building energy model.

The goal of this study is to generate the occupancy schedules of each type of classroom based on the space registration schedules from 10 universities to provide a reliable prototype college building model. Because the number of occupants affects the internal heat gain and ventilation rate directly, defining the realistic schedule in the prototype building model would create significant research opportunities to use the prototype building model and further explore suitable energy-saving measures. This study focuses on how to generate an occupancy schedule and how to develop the prototype college building model, and the study also discusses the effects caused by occupancy schedule changes. Additionally, changes in occupancy density, mechanical ventilation rate, and energy consumption were compared according to the change of occupancy schedules.

Methodology

To capture realistic occupant behavior in the prototype college building model, actual operating schedules of each space type were collected, and occupancy schedules were generated on a weekly schedule during the semester and summer vacation. The generated occupancy schedule was then applied to the prototype college building model. The prototype college building model was modeled based on updated college

occupancy schedules for four versions of ASHRAE Standard 90.1—2004, 2007, 2010, 2013— in 19 climate locations.

Development of occupancy schedule

Data collection

To develop the actual schedules of various spaces, especially in teaching spaces in a college building, class reservation information from different universities was used. The class reservation schedules of the various spaces for the fall semester were collected from 10 universities in the United States as shown, in Figure 1. The red star shows the location of the university.



Figure 1. The location of the universities.

Figure 2 shows the process to generate the occupancy schedules. The class reservation schedules from 10 universities were collected from the official university website or personal contacts. The classroom reservation data is grouped with its space type and used to identify the use of rooms in hourly schedules during the semester and the summer vacation. Four distinct space schedules—classroom, laboratory, art classroom, and lecture hall—were identified in this process. The numbers shown below

each space type show the number of data collected for each space type. Occupancy of each space type is determined per each university and each space type schedules are averaged across 10 universities. Space occupancy in each university shows a significantly different usage pattern of the classroom depending on the school or building, and each schedule is representative of each building and university. For this reason, the mean value of occupancy is used to determine the probability of occupancy of the space instead of the median value of occupancy to capture the generalized use of each space type.

Based on the classroom reservation schedule, the classroom operational hours were determined, and the hourly occupancy schedules were calculated by dividing classroom operational hours into 60 min and then generating the daily occupancy schedules of all classrooms based on the hourly schedules. To generate the weekly occupancy schedules, the average daily schedules from Monday to Friday were used.

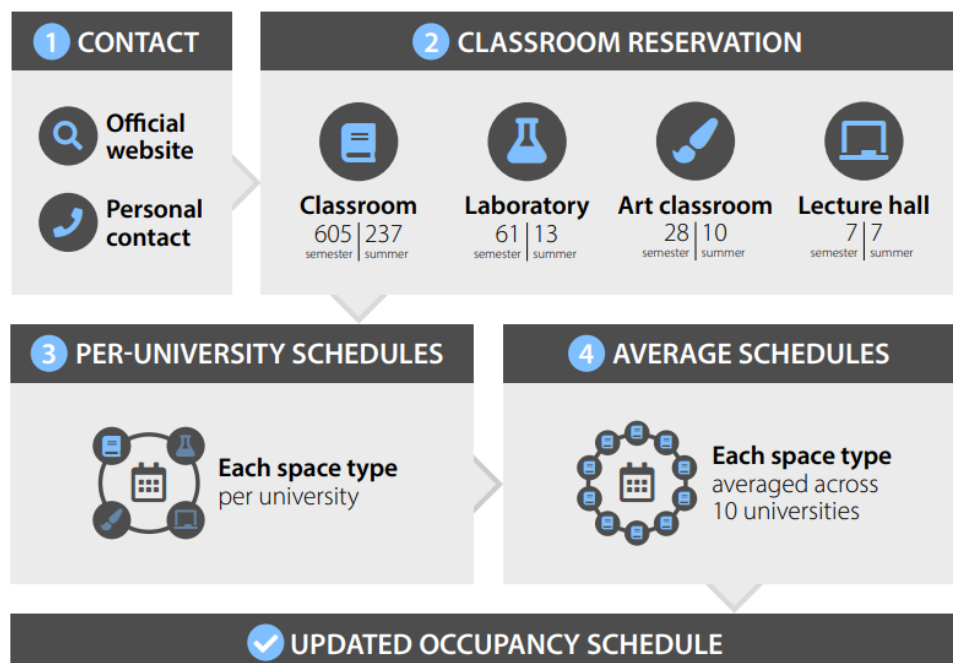


Figure 2. Data process procedure.

The following assumptions were made to generate a typical occupancy schedule.

- The fall semester represents a typical semester schedule.
- The summer schedule starts on June 1 and ends on August 31.
- The weekly schedule is defined as Monday to Friday.
- No occupancy schedule is defined on Saturday and Sunday.
- The occupancy schedule is defined based on average classroom reservation schedules of the collected universities' schedules.

Data distribution of the occupancy schedule

Figure 3 shows the box plots of the occupancy schedules as percentages for the classroom, laboratory, art classroom, and lecture hall during the semester. Figure 4 shows box plots of the schedules in percentages during the summer vacation. The boxes in Figure 3 and Figure 4 indicate the first and third quartiles. The horizontal line and × symbol indicate the median and mean value of the registration schedule, respectively. In total, 605 classroom reservation schedules, 61 laboratory reservation schedules, 28 art classroom reservation schedules, and 7 lecture hall reservation schedules for the 2021 fall semester from 10 universities were collected.

To determine the occupancy schedules for the summer vacation, classroom, laboratory, art classroom, and lecture hall reservation schedules for the 2019 summer session, when universities had summer sessions on campus, were collected. In total, 237 classroom reservation schedules, 13 laboratory reservation schedules, 10 art classroom reservation schedules, and 7 lecture hall reservation schedules from three universities were collected where they provide reservation schedules on their official website.

Overall, spaces to support teaching activities are significantly underoccupied during the summer vacation compared with the typical operational hours during the semester.

Also, hourly schedules of the classroom, art classroom, and lecture hall show significant variations during occupied hours, which means the use of rooms is notably different in each space for each university.

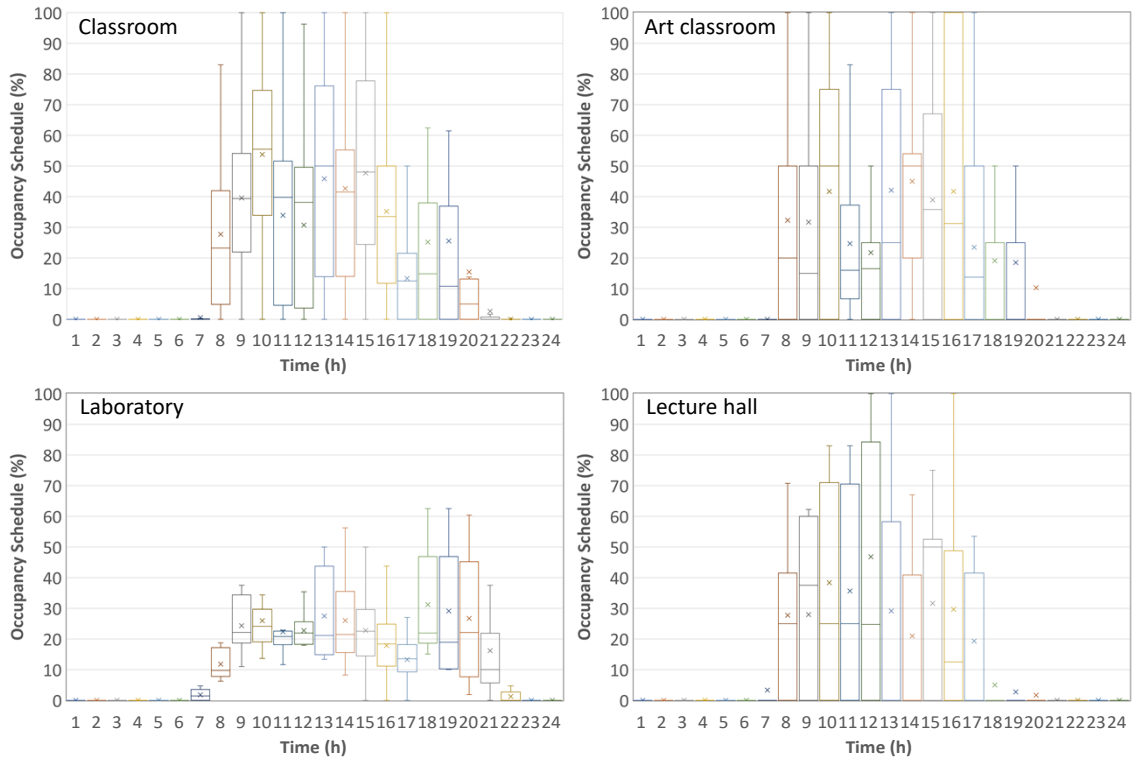


Figure 3. Occupancy schedule during the semester.

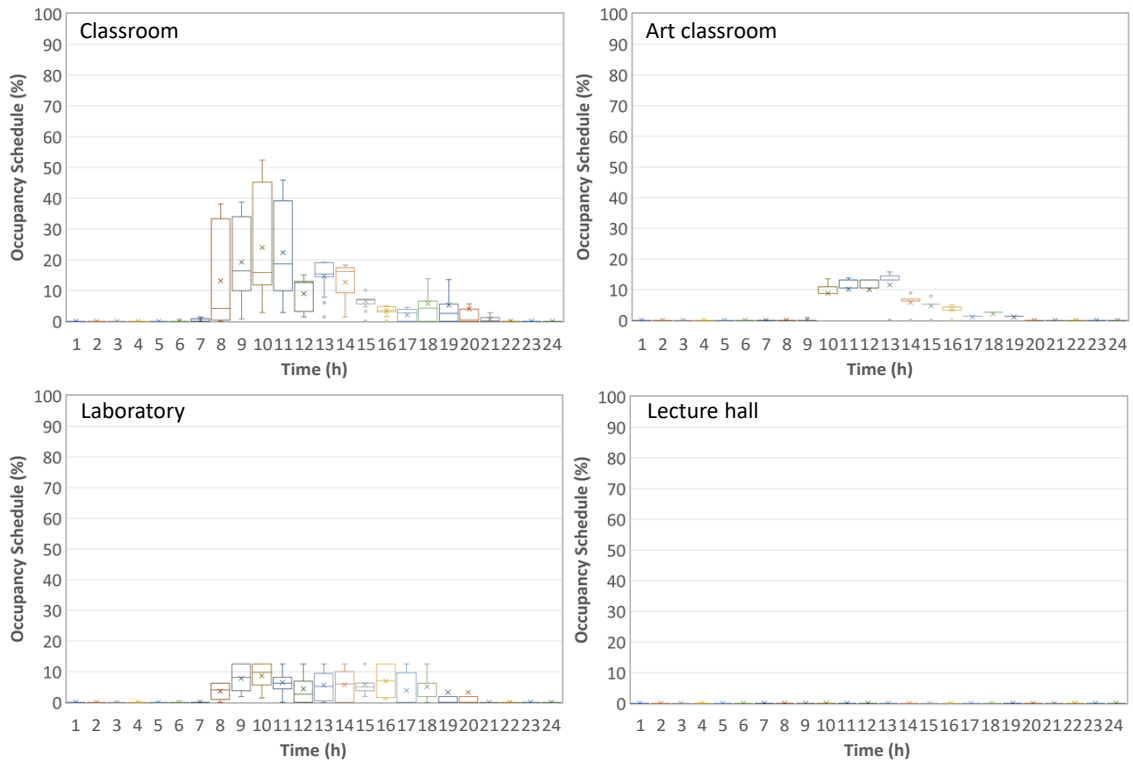


Figure 4. Occupancy schedule during the summer vacation.

Prototype college building model

Prototype model development

To define the OpenStudio Standard prototype model, the typical characteristics of the building need to be identified using existing resources such as Commercial Building Energy Consumption Survey data, as well as building design guide, code, and regulation. Once the typical characteristics are identified, the details of characteristics are referenced from the existing ASHRAE Standard 90.1. The systematic approach was developed and applied to previously developed OpenStudio Standard prototype models, and the same methodology was applied to the college prototype building model.

Simulation model description

Figure 5 shows the developed OpenStudio Standard prototype college building model. The model is a four-story building, and the total floor area is 6,416 m² with a total conditioned building area of 6,369 m². The building was modeled with a mass wall construction, built-up roof, and slab floor. The thermal properties of the building envelope, such as the roof, exterior wall, and floor, were determined based on the requirements in ASHRAE Standard 90.1 for each ASHRAE climate region. The lighting power densities and the electric equipment load were referenced were determined based on the requirements in ASHRAE Standard 90.1 and the existing OpenStudio prototype model based on the primary use of the space. The defined model characteristics based on ASHRAE Standard 90.1 for each ASHRAE climate region can be archived from GitHub (Lopez et al. 2016).

The design air infiltration was set to 0.001 m³/(s m²) of above-grade exterior wall surface area, and door opening infiltration in the lobby was modeled using the empirical model developed by Upham et al. (Upham et al. 2000). The existence of a vestibule was determined based on ASHRAE Standard 90.1 requirements. The door opening infiltration rates were 4.22 m³/s with the vestibule and 4.22 m³/s without the vestibule during the semester.

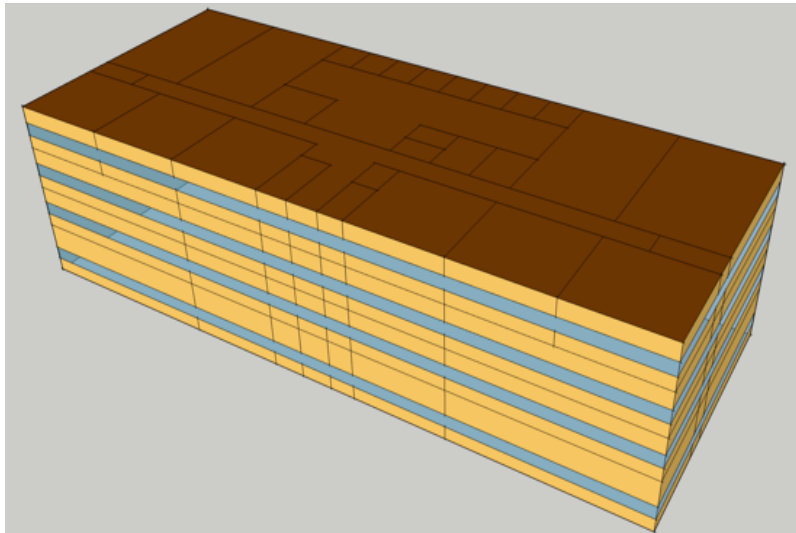


Figure 5. Prototype college building simulation model.

Space type

Table 1 lists the floor area and percentage of different space types in the prototype college building energy model. The largest portion of the building is devoted to classrooms, studios, and offices. The office space type consists of a faculty office, open office, and closed office. The restroom space type consists of a faculty restroom, student restroom, and staff restroom. Classrooms account for the largest space with 21.1% of the total area, followed by offices with 18.9%, art classrooms with 18.7%, laboratories with 8.4%, corridors with 7.2%, and lecture halls with 6.6%. Teaching spaces such as classrooms, lecture halls, laboratories, and art classrooms account for 54.8% of the total area of the prototype college building model.

Table 1. Floor area and area percentage of prototype college building model

Space type	Floor area (m ²)	Percentage of total (%)
Classroom	1,355	21.1
Lecture hall	421	6.6
Laboratory	541	8.4
Art classroom	1,199	18.7
Office	1,215	18.9
Corridor	459	7.2
Conference	138	2.2
Lounge	180	2.8
Media center	270	4.2
Stairs	175	2.7
Storage	75	1.2
Entrance lobby	75	1.2
Restroom	233	3.6
Elevator shaft	48	0.7
Utility	33	0.5
Total	6,416	100.0

Figures 6 through 8 show the prototype college building model layout of each floor. The layout of the second floor and third floor are the same. The media center and cafeteria are located on the first floor, along with a large space type such as a lecture hall or large classroom. Art classrooms are located on the second floor, and laboratories are located on the third floor. Classrooms are located on the second and third floors, and faculty offices are located on the second, third, and fourth floors.

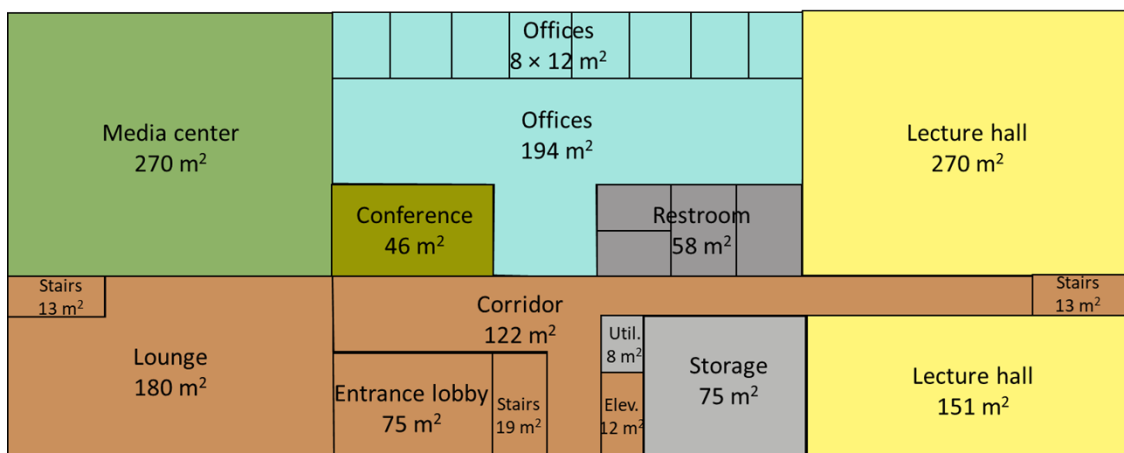


Figure 6. Prototype college building model layout of the first floor.

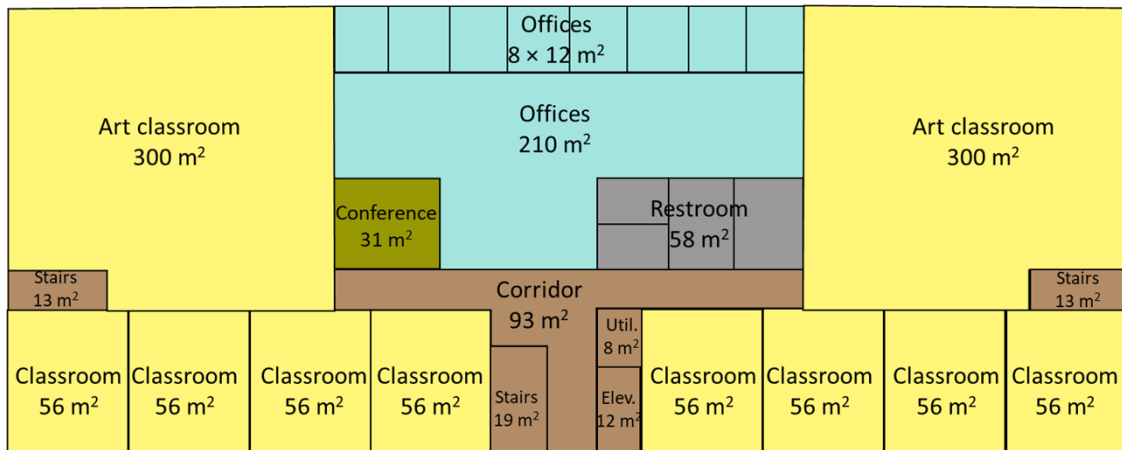


Figure 7. Prototype college building model layout of the second and third floor.

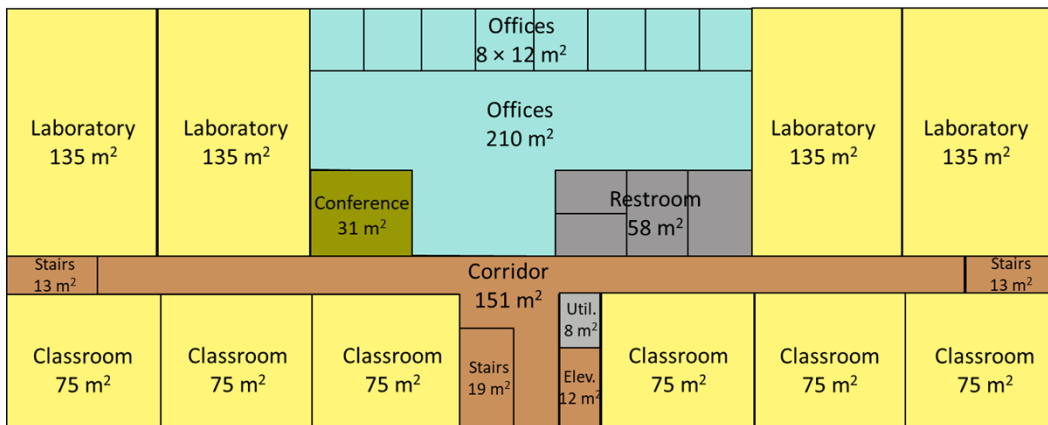


Figure 8. Prototype college building model layout of the fourth floor.

HVAC system

Figure 9 shows the HVAC system diagram of the prototype college building. The HVAC system was modeled based on the requirements of ASHRAE Standard 90.1 versions. An energy recovery ventilator was installed in the HVAC system for the Standard 90.1-2010 and 90.1-2013 models based on ASHRAE Standard 90.1 requirements. There were three water loops—a condenser water loop between the cooling tower and chiller, a chilled water loop between the chiller and cooling coils, and a hot water loop between the gas boiler and main heating/reheat coils. The HVAC

system of the prototype college building model comprised one gas boiler, four main heating coils (water), 113 reheat coils (water) for heating, one variable speed cooling tower, one electric chiller, and four main cooling coils (water) for cooling. Also, four variable air volume fans were used for the main HVAC systems. Table 2 lists the components of the HVAC system.

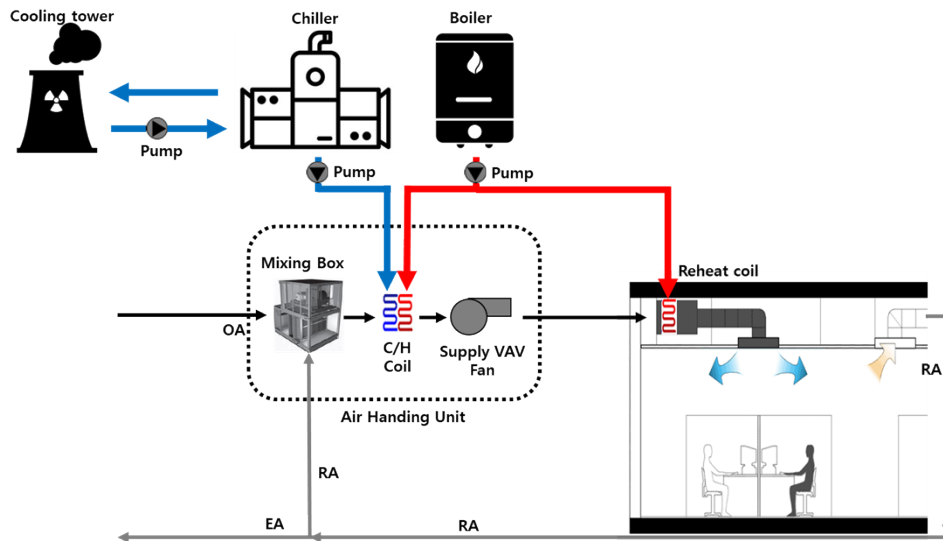


Figure 9. HVAC system diagram. OA: outdoor air; RA: return air; EA: exhaust air; C/H: cooling/heating; VAV: variable air volume.

Table 2. Number of components of the HVAC system.

Component name	Number of components
Cooling tower	1
Chiller	1
Boiler	1
Main heating coil	4
Cooling coil	4
Reheat coil	113
Variable air volume box	113
Fan	4 (variable air volume)
Pump	2 variable speed and 3 constant speed
Energy recovery ventilator	0 or 4 (depending on the ASHRAE version and climate zone)

The system efficiency and auxiliary equipment requirements (i.e., economizers, demand control ventilation, energy recovery, and pumps) were determined based on the

requirements of ASHRAE Standard 90.1. All the autosized values of the HVAC system were determined by the summer and winter design days. Set points of the supply air temperature, chilled water temperature, and hot water temperature were constant at 12.8°C, 6.7°C, and 82.2°C, respectively.

Prototype college building occupancy

Prototype building model occupancy is determined by occupancy density and occupancy schedule. The actual number of occupants was calculated by multiplying the occupancy density of each space type and the occupancy schedule of the given hour of the day.

Occupancy density

Occupancy density was defined based on ASHRAE Standard 62.1-2004 (ASHRAE 2004b) and remained the same across the different versions of ASHRAE Standard 90.1-compliant models. The number of occupants per area in each space type is listed in Table 3. The classroom and lecture hall have the highest occupancy density with 699.0 people per 1,000 m², followed by conference rooms with 538.2 people per 1,000 m². No occupancy was defined in the stairs, storage, corridor, restroom, elevator, or utility.

Table 3. Occupancy density in each space type.

Space type	Occupancy density (#/1,000 m²)	Space per person (m²/person)
Classroom	699.0	1.4
Lecture hall	699.0	1.4
Laboratory	269.1	3.7
Art classroom	215.3	4.7
Office	53.8	18.6
Entrance lobby	107.6	9.3
Conference	538.2	1.9
Lounge	269.1	3.7
Media center	107.6	9.3

Occupancy schedule

Previous occupancy schedule

Previous occupancy schedules in an OpenStudio prototype college building model were referenced from occupancy schedules of a prototype secondary school building model. Three occupancy schedules were used for the whole building. Table 4 shows the occupancy schedules based on the space type.

The occupancy schedule for the office was used only for the office space. The occupancy schedule for the lecture theater was used for the lecture hall and media center and was the same as the occupancy schedule for the auditorium in an OpenStudio prototype secondary school building model. The occupancy schedule for the college building was used for the classroom, laboratory, art classroom, lounge, conference, and entrance lobby.

The previous occupancy schedules for the college building and offices were 95% from 9 a.m. to 5 p.m. and 15% from 5 p.m. to 9 p.m. during the semester. During the summer vacation, occupancy schedules for the college building were 15% from 9 a.m. to 9 p.m., whereas the schedules for the office were 50% from 9 a.m. to 5 p.m. and 15% from 5 p.m. to 9 p.m. When the summer session was held during the summer vacation, the occupancy schedule was not 0, but it was significantly lower than that during the semester.

The occupancy schedules in the lecture hall shows a different pattern from those of the college building and office. The occupancy schedules of the lecture hall were 5% from 9 a.m. to 3 p.m. and 95% from 4 p.m. to 8 p.m. during the semester. During the summer vacation, the occupancy schedules were 15% from 9 a.m. to 5 p.m. and 35% from 6 p.m. to 7 p.m. The previous occupancy schedules of the semester and summer vacation are shown in Figure 10 through Figure 13.

Updated occupancy schedule

As described in the previous section, the class registration schedules of the classroom, laboratory, art classroom, and lecture hall were collected from official websites and personal contacts to develop the new occupancy schedules. In the previous college building model, three occupancy schedules covered the whole prototype college building model. The updated prototype college building model uses seven occupancy schedules, including updated occupancy schedules of the classroom, laboratory, art classroom, and lecture hall, as shown in Table 4. *OCC_SCH_Offices* in the updated section is the same as the previous occupancy schedule, and *Cafe_OCC_SCH* is from the occupancy schedule for the cafeteria in the prototype secondary school building model. *Lecture_OCC_SCH*, *Lab_OCC_SCH*, *Class_OCC_SCH*, and *Studio_OCC_SCH* are generated based on the actual classroom reservation schedules.

Table 4. Updated occupancy schedules based on space type

Space type	Previous schedule	Updated schedule
Office	OCC_SCH_Offices	OCC_SCH_Offices
Lecture hall	OCC_SCH_Lecture Hall	Lecture_OCC_SCH
Media center		
Laboratory	OCC_SCH_College	Lab_OCC_SCH
Classroom		Class_OCC_SCH
Art classroom		Studio_OCC_SCH
Lounge		Cafe_OCC_SCH
Conference		OCC_SCH
Entrance lobby		

Figure 10 through Figure 13 show the updated occupancy schedule for classroom, laboratory, art classroom, and lecture hall. *Up* in Figure 10 through Figure 13 indicates the updated occupancy schedule, *Pre* indicates the previous occupancy schedule, *Sem* indicates the schedule for the semester, and *Sum* indicates the schedule for the summer vacation. Significant differences were observed between the updated and previous occupancy schedules.

The updated occupancy schedule in Figure 10 shows that the classroom is significantly unoccupied (lower than 50% occupancy) compared with the previous occupancy schedule. Because classes in the college are not all held at the same time, the occupancy schedule of the classroom in the college building during the semester is lower than 50%, which means that fewer than 50% of the classrooms in the college building are occupied at the same time. Additionally, the updated schedule shows a relatively low occupancy schedule during lunch and dinner times, and the occupancy schedule increased from 6 p.m. to 7 p.m. because of classes in the evening. Also, the previous occupancy schedule started at 9 a.m., but the updated occupancy schedule starts at 8 a.m. During the summer vacation, the updated occupancy schedule shows that the classroom is occupied 16% from 8 a.m. to 2 p.m. because of the summer session and only occupied by 5% from 3 p.m. to 8 p.m.

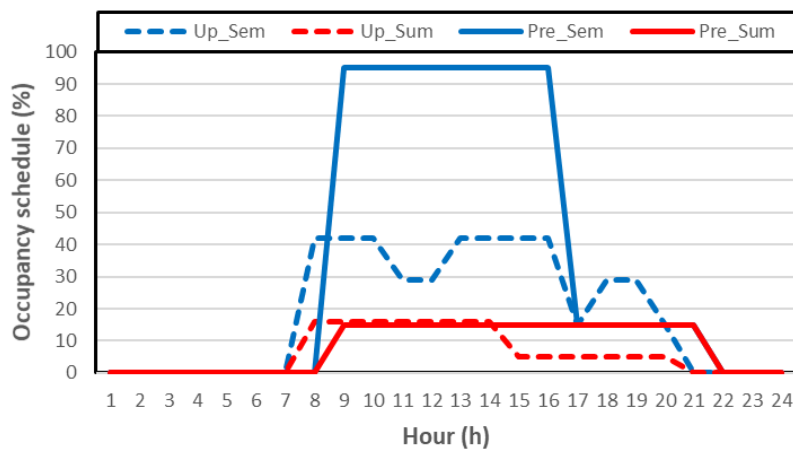


Figure 10. Updated occupancy schedule for the classroom.

Figure 11 shows the updated occupancy schedule for the laboratory. The updated occupancy schedule pattern for the laboratory is similar to that of the classroom. During the semester, the updated occupancy schedule for the laboratory is 25% occupancy from 8 a.m. to 3 p.m. and 6 p.m. to 8 p.m., which is one-fourth of the

previous occupancy schedule, and 16% occupancy from 4 p.m. to 5 p.m. During the summer vacation, the pattern of the updated occupancy schedule is similar to the previous occupancy schedule; the updated occupancy schedule shows 5% occupancy, which is one-third of the previous occupancy schedule.

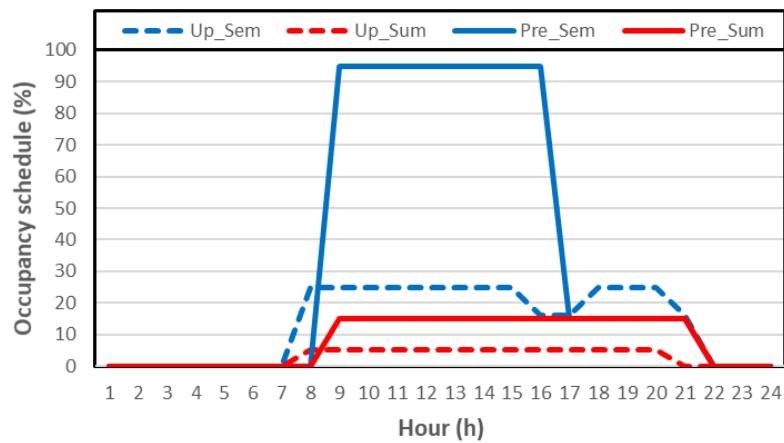


Figure 11. Updated occupancy schedule for the laboratory.

Figure 12 shows the updated occupancy schedule for the art classroom. The updated occupancy is 37% occupancy from 8 a.m. to 5 p.m., except for at lunch time (11 a.m. to 12 p.m.). During lunch time and after 5 p.m., the occupancy is 19%. During the summer vacation, the updated occupancy is 6% from 10 a.m. to 7 p.m.

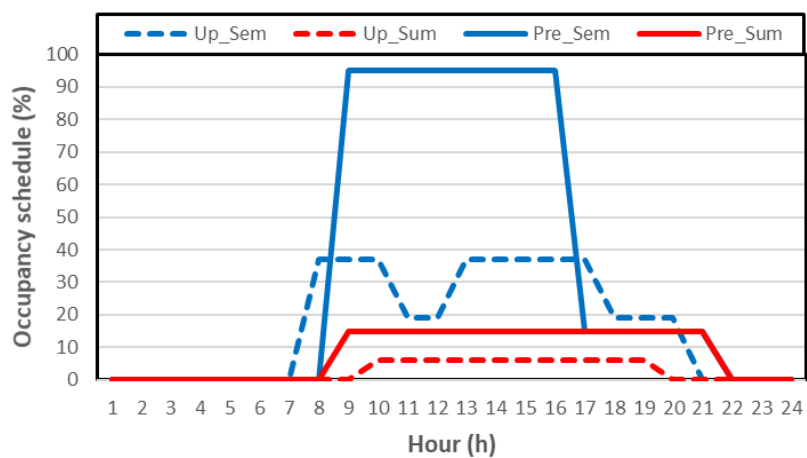


Figure 12. Updated occupancy schedule for the art classroom.

Figure 13 shows the updated occupancy schedule for the lecture hall. The pattern of the updated occupancy schedule for the lecture hall is completely different from that of the previous occupancy schedule. Unlike the previous occupancy schedule, which has an occupancy peak from 3:00 p.m. to 8:00 p.m., the updated occupancy schedule is 0% after 5:00 p.m., which means that there is no registration after 5 p.m. anywhere in the seven lecture halls examined in this study. The lecture hall, which is a larger space than the common classroom, is generally used for large-scale classes. Therefore, the occupancy is lower than that of the classroom in Figure 10. According to the collected data, the occupancy schedule is 0% during the summer vacation because there is no registration of the lecture hall in the summer session.

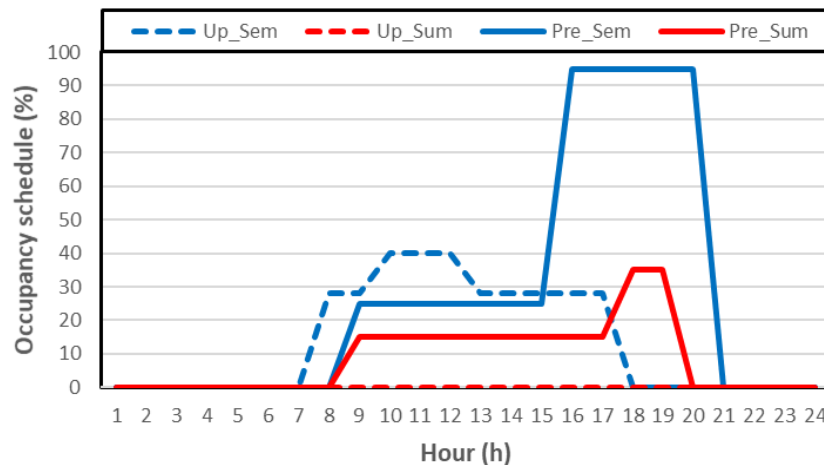
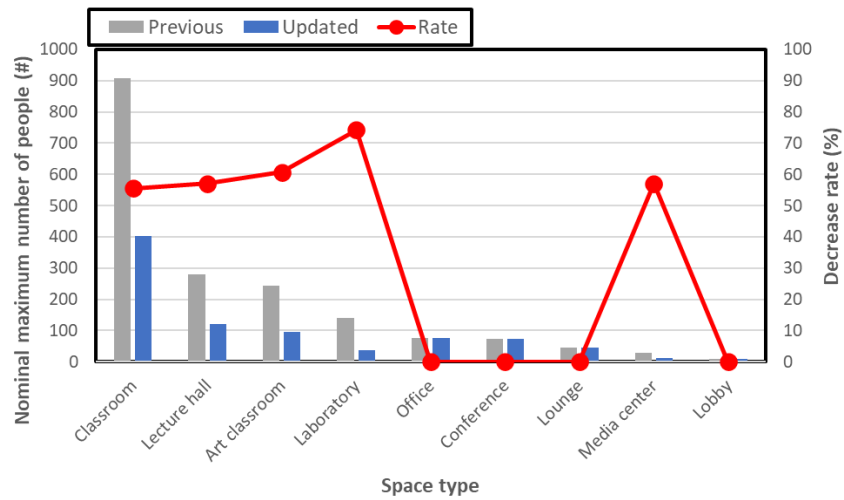


Figure 13. Updated occupancy schedule for the lecture hall.

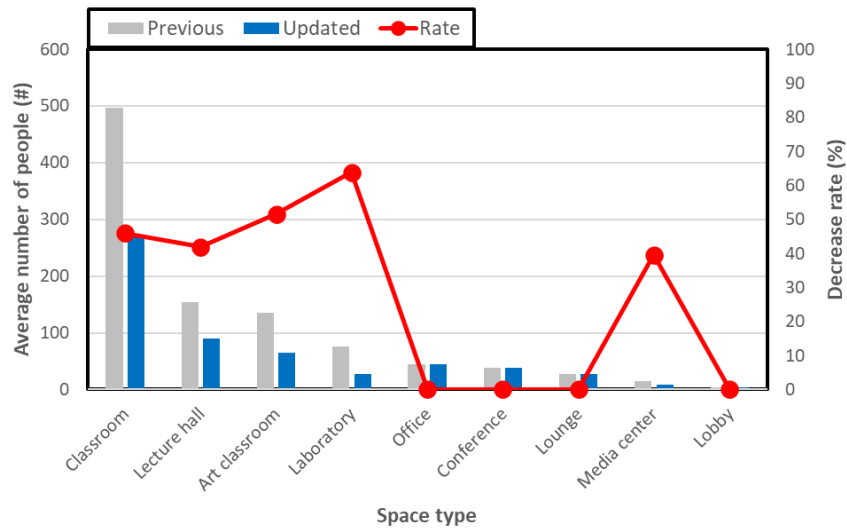
Maximum and average occupancy

Figure 14 shows the nominal maximum number of people and the average number of people in the prototype college building model depending on the occupancy schedule. *Previous* in Figure 14 indicates the previous occupancy schedule, *updated* indicates the

updated occupancy schedule, and *rate* indicates the percentage difference of the number of people between the previous and updated occupancy schedules.



(a)



(b)

Figure 14. (a) Comparison of the nominal maximum number of people. (b) Comparison of the average number of people.

After applying the updated occupancy schedule, the nominal maximum number of people and the average number of people in each space type significantly decreased. The maximum number decreased at a rate of 74% in the laboratory, 60% in the art classroom, 57% in the lecture hall, and 57% in the classroom. The average number

decreased at a rate of 64% in the laboratory, 52% in the art classroom, 46% in the classroom, 42% in the lecture hall, and 40% in the media center. These results also showed a different pattern of decrease depending on the space type. The changes of the occupant presence pattern in each space type resulted in changes of the average number of people in each space type. No differences were observed in the office, conference room, lounge, or lobby because the occupancy schedules in those space types were not updated.

Discussion

Door opening infiltration rate

Building entrance doors are one of the sources of infiltration and result in significant energy loss (Bae et al. 2021). The door opening infiltration rate can be expressed as a function of door opening frequency, and it is directly related to the number of people using the door. Figure 15 shows that the door opening infiltration rate changes by updating the occupancy schedule. *Previous* in Figure 15 indicates the previous occupancy schedule, *Updated* indicates the updated occupancy schedule, *Vest* indicates vestibule, *Sem* indicates the semester, and *Sum* indicates the summer vacation.

The peak occupancy decreased from 1,780 to 848 during the semester and from 313 to 136 during the summer. The decrease of the peak occupancy results in a decrease of the door opening infiltration rate from 9.87 m³/s to 5.89 m³/s during the semester and 2.79 m³/s to 1.49 m³/s during the summer vacation without a vestibule. The peak occupancy decrease rate was 52% during the semester and 57% during the summer vacation, and the occupancy decrease results in a door opening infiltration decrease of 40% during the semester and 46% during the summer vacation without a vestibule and 45% during the semester and 49% during the summer vacation with a vestibule

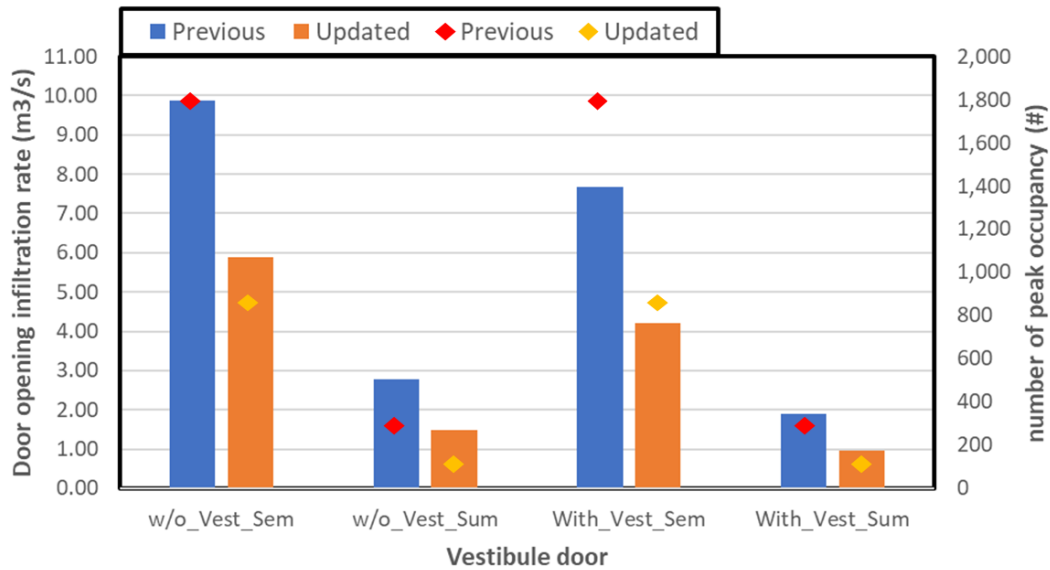


Figure 15. Comparison of door-opening infiltration rate.

Mechanical ventilation rate

The occupancy directly affects the ventilation rate because the required ventilation rate is calculated by the floor area of the space and occupancy. Figure 16 and Figure 17 show the minimum ventilation rate and average ventilation changes by updating the occupancy schedule. *Previous* in Figure 16 and Figure 17 indicates the previous occupancy schedule, *Updated* indicates the updated occupancy schedule, and *2004*, *2007*, *2010*, and *2013* indicate the version of ASHRAE Standard 90.1. Climate zone 4A was selected to compare the ventilation rate based on the occupancy schedule changes. Only space types—where the occupancy schedule is updated—were selected. The minimum required ventilation rate has been changed after updating the occupancy schedules, and the minimum required ventilation rates were increased in the art classroom and laboratory approximately 7% to 24% depending on the version of ASHRAE Standard 90.1 except for ASHRAE Standard 90.1-2004. Because the pattern of the presence of the occupancy has changed, as shown in Figure 10 through Figure 13, the number of persons, including the minimum and maximum of each space type, and

the time of the hours of occupancy have also been changed, resulting in changes of the minimum air ventilation requirement of the college building model.

Because the average number of occupants has decreased, the average mechanical ventilation rate is expected to decrease, as well. Figure 17 shows the average mechanical ventilation rate changes in the climate zone 4A model. The average mechanical ventilation rate decreased in all space types in the ASHRAE Standard 62.1-2007 model because of the decreased ventilation requirement in the ASHRAE standard. A significant difference was observed in the lecture hall—approximately 25% to 32% depending on the version of ASHRAE Standard 90.1—and the decreased ventilation requirement led to reduced energy consumption.

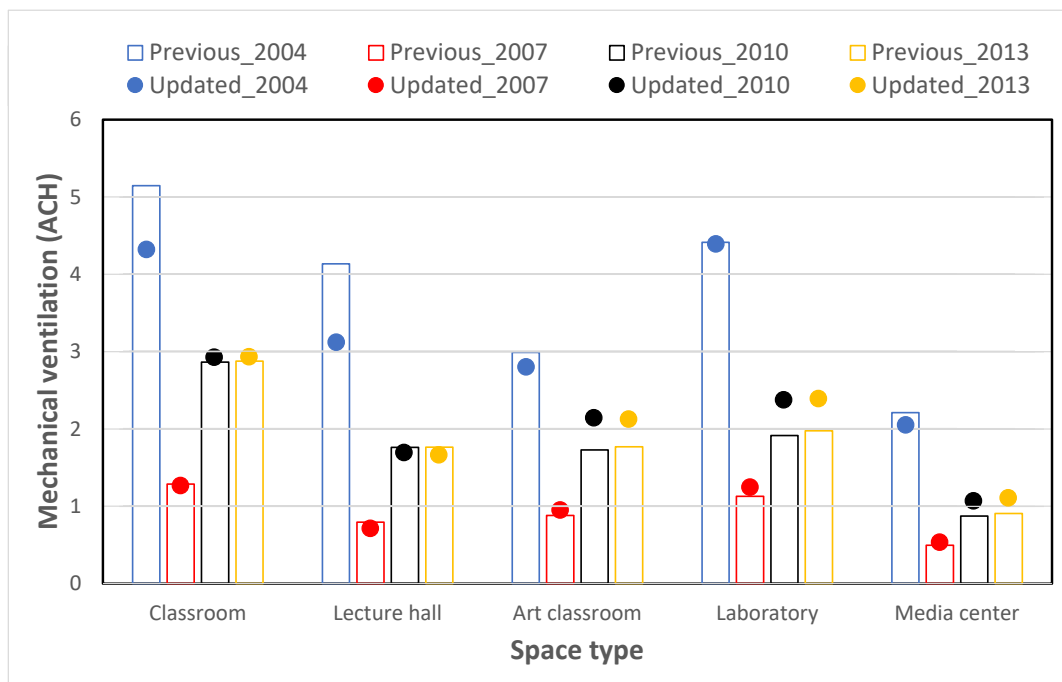


Figure 16. Minimum mechanical ventilation rate comparison.

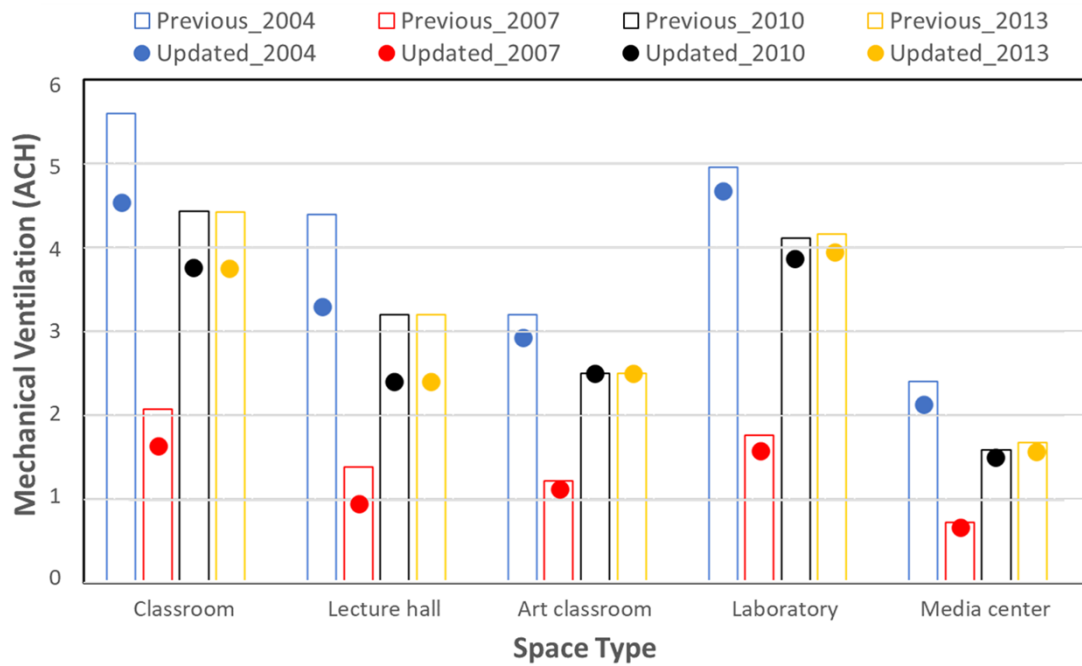


Figure 17. Average mechanical ventilation rate comparison.

Energy consumption comparison

Figure 18 shows the total energy consumption in each climate zone. *Previous, Updated, 2004, 2007, 2010, and 2013* in Figure 18 indicate the same information as in Figure 16 and Figure 17. After using the updated occupancy schedule, the total energy consumption increased. The cold region had a more significant increase in energy consumption in the updated occupancy schedule. In climate zones 6A, 7A, and 8A, under the ASHRAE Standard 90.1-2004 model, energy consumption increased approximately 20% to 28% after applying the updated occupancy schedule. In general, energy consumption changed approximately -12.3% to 2.6% when compared with the previous occupancy schedule. This change is mainly because even if the ventilation rate is decreased, the building is occupied from 1 h earlier in the updated occupancy schedule, so the HVAC system is turned on 1 h earlier than in the previous model, and it results in an additional hour of HVAC operation. Also, the occupancy pattern changes affect changes in minimum ventilation requirements, as shown in the previous section,

and these changes result in adding an additional heating or cooling load and led to an increase of energy consumption. Again, the purpose of this study was to develop a realistic and representative schedule, not to reduce the energy consumption with the updated schedule.

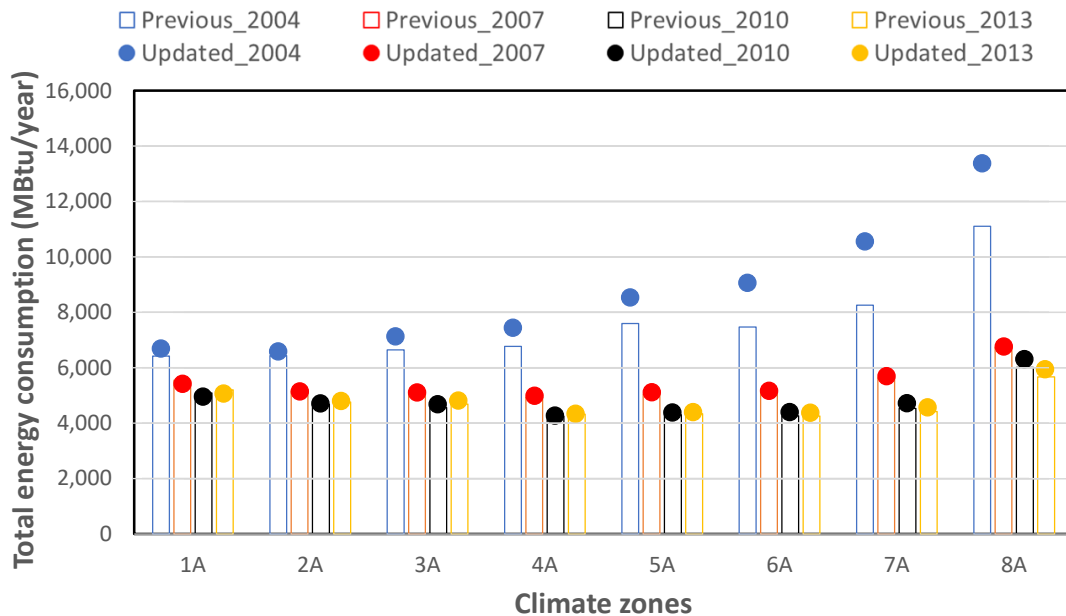


Figure 18. Total energy consumption comparison.

Conclusion

The goal of this study was to develop an occupancy schedule of a college building based on the actual space registration schedules in universities and applied to the prototype college building model. The results indicate that the use of a typical commercial building schedule or school building schedule in a college building impairs the granularity of information. The updated occupancy information shows that occupancy density has reduced significantly. Also, the pattern of the occupancy presence was significantly different, and, therefore, it affected minimum ventilation requirements and the average mechanical ventilation rate. Although energy

consumption increased after applying the updated occupancy schedule, this result is more accurate because the prototype model is developed by the actual data.

In future studies, more registration information from universities across the United States will be collected to provide a more reliable occupancy schedule. Also, the indirect effect of occupancy changes, such as plug load or advanced lighting system (e.g., occupancy sensor and dimming control), will be further investigated, and the effects on energy consumption and energy saving measures with respect to updates on occupancy schedule will be examined in detail.

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