Development of an Occupancy Schedule for OpenStudio Prototype College Building Model

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Abstract
College buildings have unique characteristics in contrast with school buildings; therefore, defining the realistic occupancy schedule in a prototype college building has significant research opportunities. In this study, actual operating schedules of each space type have been collected, generated based on the class reservation schedule. The results indicate that the use of a typical school building schedule in a college building impairs the granularity of information. The results with the updated occupancy are more realistic because the prototype model is developed by the actual data.

Introduction
The US Department of Energy supports the development of commercial building energy codes and standards, updates processes, and provides technical analyses to support the development. To support commercial building energy research activities and the development of commercial building energy codes and standards, 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 measure-based modification of ASHRAE 90.1–compliant baseline models, analysis of retrofit options, and reporting of energy analysis.

In addition, the OpenStudio prototype building model suite was expanded to include new building prototype models (e.g., supermarket, courthouse, college building). This study improved the occupancy schedule of a prototype college building model based on actual data to provide a realistic model, and this study investigated the effects of changing the occupancy schedule. In particular, the college building model includes various space types with their own occupancy schedules, which follow typical occupancy behaviors of a typical commercial building. However, because the occupancy schedule for the spaces in college buildings is strongly related to class schedule, a significant opportunity exists to improve the typical occupancy schedule to reflect the real occupancy patterns in the building and improve the accuracy of the building energy model.

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. This 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].

The previous studies gathered the occupancy schedules of a housing building and a classroom from one university, and the focus of the research was on energy consumption. However, different universities have different schedules, and actual data from more than one university is necessary to generate an occupancy schedule for the prototype college building 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 discusses the effects caused by occupancy schedule changes. Also, average number of people, mechanical ventilation rate, and energy consumption were compared according to the change of occupancy schedules.
Problem statement
College buildings have unique characteristics in contrast 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) 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.

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, 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 as for primary/secondary schools, to capture the characteristics of a college building model schedule.

Methods
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 actual number of occupants was then determined based on generated occupancy schedules and occupancy density of each space type.

Data collection
Actual schedules of various spaces in a college building were collected to generate the occupancy schedules. 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.

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, and based on the class reservation schedules, four space schedules—classroom, laboratory, art classroom, and lecture hall—were generated.

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 for Monday to Friday.
- No occupancy schedule is defined for Saturday and Sunday.
- The occupancy schedule is defined based on average classroom reservation schedules of the collected universities’ schedules.

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.

Data distribution of the occupancy schedule
Figure 4 shows the box plots of the occupancy schedules in percentage for the classroom, laboratory, art classroom, and lecture hall during the semester, and Figure 5 shows box plots of the schedules in percentage during the summer vacation. The boxes in Figure 4 and Figure 5 indicate the first and third quartile. The horizontal line and × 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, where they provide reservation schedules on their official website, were collected. 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.

Prototype college building model
Simulation model description
Error! Reference source not found. shows the developed prototype college building model. The model is a four-story building, and the total floor area is 6,416 m². All input values, such as thermal performance of the building envelope components, lighting power density, equipment power density, and HVAC system, were determined based on the requirements in ASHRAE Standard 90.1.

Figure 3 Simulation model

Figure 4 Occupancy schedule during the semester
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

<table>
<thead>
<tr>
<th>Space type</th>
<th>Floor area (m²)</th>
<th>Percentage of total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom</td>
<td>1,355</td>
<td>21.1</td>
</tr>
<tr>
<td>Lecture hall</td>
<td>421</td>
<td>6.6</td>
</tr>
<tr>
<td>Laboratory</td>
<td>541</td>
<td>8.4</td>
</tr>
<tr>
<td>Art classroom</td>
<td>1,199</td>
<td>18.7</td>
</tr>
<tr>
<td>Office</td>
<td>1,215</td>
<td>18.9</td>
</tr>
<tr>
<td>Corridor</td>
<td>459</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Figure 5 Occupancy schedule during the summer vacation

Occupancy schedule
Occupancy density
Occupancy density was defined based on the ASHRAE 62.1-2004 and remained the same across the different version of ASHRAE 90.1–compliant models. The number of occupants per area in each space type is listed in Table 2. Classroom and lecture hall have the highest occupancy density with 698.96 people per 1,000 m², followed by conference rooms with 538.2 people per 1,000 m². No occupancy was defined in stairs, storage, corridor, restroom, elevator, or utility.
Table 2 Occupancy density in each space type

<table>
<thead>
<tr>
<th>Space type</th>
<th>Occupancy density (people/1,000 m²)</th>
<th>Space per person (m²/person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom</td>
<td>698.96</td>
<td>1.43</td>
</tr>
<tr>
<td>Lecture hall</td>
<td>698.96</td>
<td>1.43</td>
</tr>
<tr>
<td>Laboratory</td>
<td>269.10</td>
<td>3.72</td>
</tr>
<tr>
<td>Art classroom</td>
<td>215.28</td>
<td>4.65</td>
</tr>
<tr>
<td>Office</td>
<td>53.82</td>
<td>18.58</td>
</tr>
<tr>
<td>Entrance lobby</td>
<td>107.64</td>
<td>9.29</td>
</tr>
<tr>
<td>Conference</td>
<td>538.20</td>
<td>1.86</td>
</tr>
<tr>
<td>Lounge</td>
<td>269.10</td>
<td>3.72</td>
</tr>
<tr>
<td>Media lounge</td>
<td>107.64</td>
<td>9.29</td>
</tr>
</tbody>
</table>

Previous occupancy schedule

Previous occupancy schedules in a 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 3 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 6 through Figure 9.

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 3. OCC_SCH Officess 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 3 Updated occupancy schedules based on space type

<table>
<thead>
<tr>
<th>Space type</th>
<th>Previous schedule</th>
<th>Updated schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>OCC_SCH_Offices</td>
<td>Lecture_OCC_SCH</td>
</tr>
<tr>
<td>Lecture hall</td>
<td>OCC_SCH_Lecture</td>
<td>Lab_OCC_SCH</td>
</tr>
<tr>
<td>Media center</td>
<td>Hall</td>
<td>Class_OCC_SCH</td>
</tr>
<tr>
<td>Laboratory</td>
<td>Art_OCC_SCH</td>
<td>Studio_OCC_SCH</td>
</tr>
<tr>
<td>Classroom</td>
<td>College</td>
<td>Cafe_OCC_SCH</td>
</tr>
<tr>
<td>Art classroom</td>
<td></td>
<td>OCC_SCH</td>
</tr>
<tr>
<td>Lounge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entrance lobby</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6 through Figure 9 show the updated occupancy schedule for classroom, laboratory, art classroom, and lecture hall. Up in Figure 6 through Figure 9 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 occupancy schedule and previous occupancy schedule. The updated occupancy schedule in Figure 6 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. In addition, 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 starts 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 6 Updated occupancy schedule for the classroom

Figure 7 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 8 Updated occupancy schedule for the art classroom

Figure 8 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 9 Updated occupancy schedule for the lecture hall

Figure 9 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 6. 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.

Energy consumption comparison

For the energy consumption analysis, variables that are mainly affected by occupancy schedule were examined. The average occupancy, mechanical ventilation rate influenced by changes in the number of people, and total energy consumption were compared.

Average occupancy

Figure 10 shows the average number of people in the prototype college building model depending on the occupancy schedule. Previous in Figure 10 indicates the previous occupancy schedule, updated indicates the
updated occupancy schedule, and rate indicates the percentage difference of the average number of people between the previous and updated occupancy schedules. After applying the updated occupancy schedule, the average number of people in each space type decreased. The average number decreased rate by 64% in the laboratory, 52% in the art classroom, 46% in the classroom, 42% in the lecture hall, and 40% in the media center. No differences were observed in the office, conference room, lounge, or lobby because the occupancy schedules in those space types were not updated.

Figure 10 Comparison of average number of people

**Mechanical ventilation rate**

The occupancy directly affects ventilation rate because the required ventilation rate is calculated by floor area of the space and occupancy. Figure 11 shows the ventilation rate changes by updating the occupancy schedule. Previous in Figure 11 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 mechanical ventilation rate decreased in all space types in the ASHRAE 62.1-2007 model because of the decreased ventilation requirement in the ASHRAE standard. A significant difference was observed in the lecture hall, around 25% to 32% depending on the version of the ASHRAE 90.1, and the decreased ventilation requirement led to reduced energy consumption.

**Energy consumption comparison**

Figure 12 shows the total energy consumption in each climate zone. Previous, Updated, 2004, 2007, 2010, and 2013 in Figure 12 indicate the same information as in Figure 11. After using the updated occupancy schedule, the total energy consumption increased. In the cold region, there is a more significant increase in energy consumption in the updated occupancy schedule. In climate zones 6A, 7A, and 8A, under the ASHRAE 90.1-2004 model, energy consumption increased approximately 20% to 28% after applying the updated occupancy schedule. In general, energy consumption 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. Again, the purpose of this study was to develop a realistic and representative schedule, not to reduce the energy consumption with the updated schedule.

**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. 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. 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 US will be collected to provide a more reliable occupancy schedule. Also, 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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