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An Agent-Based Occupancy Simulator for Building Performance Simulation

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ABSTRACT

Traditionally, in building energy modeling (BEM) programs, occupancy inputs are deterministic and less indicative of real world scenarios, contributing to discrepancies between simulated and actual energy use in buildings. This paper presents an agent-based occupancy simulator, which models each occupant as an agent with specified movement events and statistics of space uses. To reduce the amount of data inputs, the simulator allows users to group occupants with similar behaviors as an occupant type, and spaces with similar function as a space type. It is a web-based application with friendly graphical user interface, cloud computing, and data storage. A case study is presented to demonstrate the usage of the occupancy simulator and its integration with EnergyPlus and obFMU. It first shows the required data inputs and the results from the occupancy simulator. Then, the generated occupant schedules are used in the EnergyPlus and obFMU simulation to evaluate the impacts of occupant behavior on building energy performance. The simulation results indicate that the occupancy simulator can capture the diversity of space's occupancy behavior rather than the static weekly profiles, and can generate realistic occupancy schedules to support building performance simulation.

INTRODUCTION

Traditionally, in building energy modeling (BEM) programs, occupancy inputs are deterministic and less indicative of real world scenarios, contributing to discrepancies between simulated and actual energy use in buildings. The International Energy Agency (IEA) Energy in the Buildings and Communities Program (EBC) Annex 53 (Total Energy Use in Buildings: Analysis & Evaluation Methods) pointed out that occupants' activities and behavior is one of the six key factors directly influencing building energy use. Occupant behavior is now widely recognized as a major contributing factor to uncertainty of building performance (Yan et al., 2015). The occupant behaviors can be organized into two categories: occupancy and occupants' interactions with building systems (Wang et al., 2011). The occupancy determines the location of each occupant during each time period. When occupants are located in a space, they may be able to control the building systems (such as lights, HVAC, and windows), and therefore impact the energy consumption.

The occupancy simulation is the foundation of occupant behavior research. Wang et al. (2011) introduced a novel approach for building occupancy simulation based on Homogeneous Markov chain model, which simulates the stochastic movement of occupants. The model can generate location for each occupant and the occupancy of each space of a building. The model was implemented using a mathematical analysis software package as a proof of concept. Later on, Feng et al. (2015) updated and implemented the model in C++, an object-oriented programming language. The software module can be used as a stand-alone application to pre-calculate occupancy schedules, or be integrated into building energy modeling programs as a dynamic link library. Hong et al. (2015a) further integrated the occupancy simulation model into the occupant behavior functional mockup unit (obFMU) for co-simulation with BEM programs.

The above mentioned occupancy simulation tools are all desktop applications, which are hard to maintain and only compatible

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with certain operation systems such as Windows, Mac, or Linux. This paper introduced an agent-based occupancy simulator for building performance simulation. The occupancy simulator is a web application hosted in a central sever. Users don't need to download and install the application and it ensures the latest version of App be used.

METHODS

Figure 1 presents the software architecture of the occupancy simulator. The agent-based web application was built upon Ruby on Rails (rubyonrails.org), an open-source web framework with model-view-controller (MVC) software architecture. The (1) viewer generates html pages for users to see in web browsers. The (2) controller handles the commands from users, performs necessary calculations, updates the data model, and refreshes the (1) viewer. The (3) data model defines the data structure and the methods to update/extract data to/from the (4) database. The (4) database stores users' inputs as well as the results. One control command named "Simulate" triggers the movement simulation. For this command, the (2) controller generates an (7) occupant model in XML format based on the occupant behavior (OB) XML Schema (Hong et al. 2015b), which is developed on top of the OB DNAS (drives, needs, actions and systems) framework (Hong et al., 2015c). The (7) occupant model is used as input by the (8) movement solver to generate the (9) occupancy results in CSV and EnergyPlus IDF objects formats. The results are imported back to the (3) data model, stored in the (4) database, and displayed in the (1) viewer. The generated occupant schedules at the space level can be used by BEM programs to better predict the energy performance of buildings.

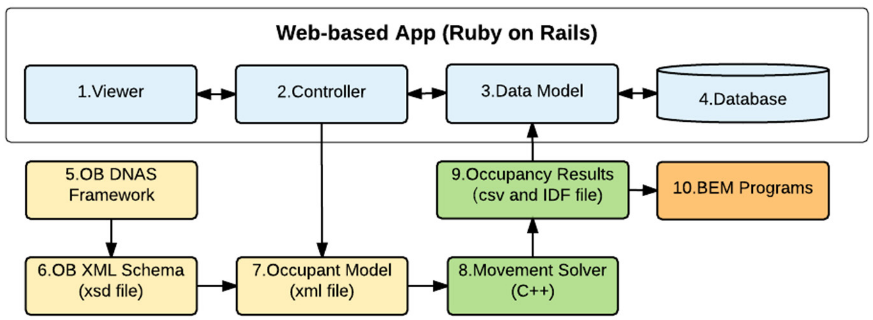


Figure 1 Software architecture of occupancy simulator

Figure 2 shows the *Introduction* page of the occupancy simulator. The simulator includes a top bar, a tab bar, and a main content area. The top bar provides links to several related projects, and shows the unique session number for each simulation case. The session number can be used to retrieve all the information related to the simulation case, including inputs and results. The tab bar organizes data into multiple pages based on the data structure of the simulator (Figure 3), including *Introduction*, *Start New*, *Spaces*, *Space Type*, *Occupant Type*, *Simulation*, and *Team*. Moreover, the main content area shows the detail information of the selected page.

To reduce the amount of data inputs, the simulator allows users to group occupants with similar behaviors as an *OccupantType*, and spaces with similar functions as a *SpaceType*. Figure 3 shows the data structure of the occupancy simulator. The simulator creates a *Building* instance for each simulation case, which includes a session number and multiple instances of *Spaces*. Each *Spaces* has an area, a multiplier, and a *SpaceType*. The multiplier determines the number of similar spaces in the building. The *SpaceType* defines the occupancy density, the *Meeting* events for meeting room, and the percentage of each *Occupants*. The parameters for each *Meeting* event include the average meeting duration and the probability of occurrence. Each *Occupants* has an *OccupantType*, which defines the *MovementBehavior* of the occupants. The *MovementBehavior* defines the spaces occupancy and the events for Arrival, Go to Lunch, Back from Lunch, and Departure. The spaces occupancy includes the percentages of time and the average durations for the cases when the occupant stays in Own Office, Other Office, Auxiliary Rooms, and Outdoor. For each event, it defines the typical time when the event occurs and the variation. Based on the information, the occupant simulator simulates the location of each occupant at each time step based on the first-order homogeneous Markov chain model introduced in Wang et al. (2011) and Feng et al. (2015).

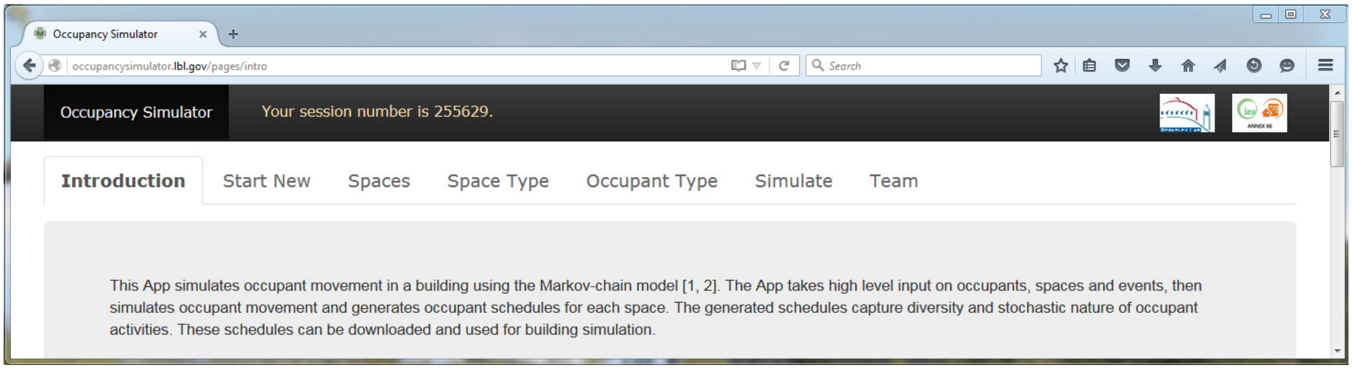


Figure 2 *Introduction* page of occupancy simulator

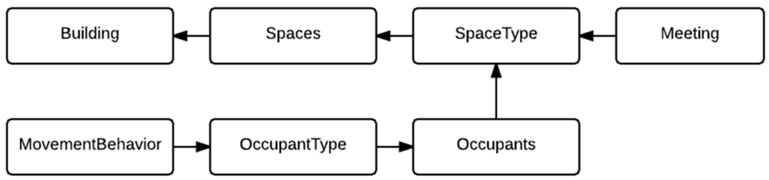


Figure 3 Data structure of occupancy simulator

CASE STUDY

A 44 m (144.4 ft) (L) × 20 m (65.6 ft) (W) × 3.5 m (114.8 ft) (H) one-story office building located in Miami, USA, is used for the case study. Miami has a hot and humid climate (ASHRAE Climate Zone 1A) with daily average dry bulb temperature of 19.4 °C (66.9 °F) for January and 28.1 °C (82.6 °F) for July. Figure 4 shows the plan view of the office building, including the number of occupants in their own offices. An EnergyPlus (Crawley et al., 2000) model is developed based on minimum requirements of ANSI/ASHRAE/IESNA 90.1-2013 (ANSI/ASHRAE/IESNA, 2013) for small offices.

A case study is presented to demonstrate the usage of the occupancy simulator and its integration with EnergyPlus and obFMU. It first shows the required data inputs and the results from the occupancy simulator. Then, the generated occupant schedules are used in the EnergyPlus and obFMU models to evaluate the impacts of occupancy behavior on building energy performance simulation.

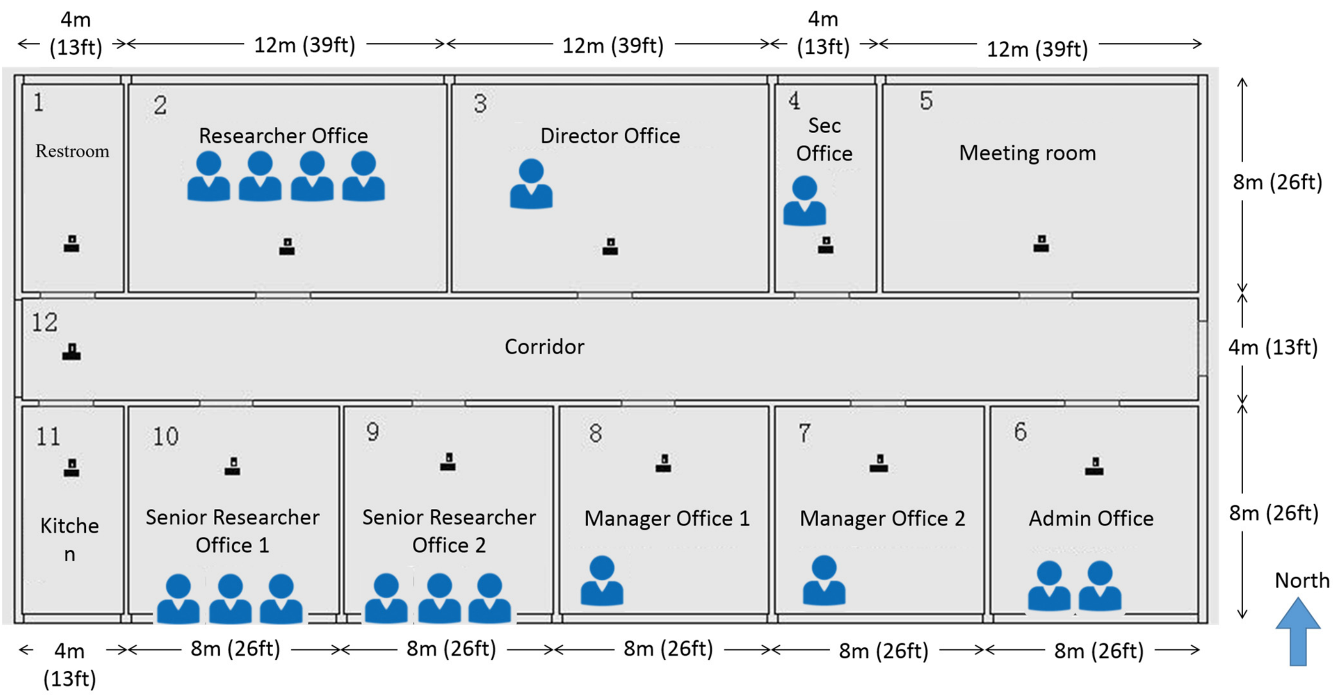


Figure 4 Schematic of the office building

Occupancy Simulation

Figure 5 shows the main content of the *Start New* page. To start a new analysis, we need to provide the building type and floor area, which are "Office – Small" and 880 m^2 (9472 ft^2) in this case. Figure 6 shows the snapshot of the *Spaces* page, which provides the space type, area, and multiplier of each space. Users need to provide the occupant density and the occupant types for "Office" space type (Figure 7). For "Meeting room" space type, the meeting events and the minimum and maximum number of occupants are required. Figure 8 shows the example of "Researcher" occupant type, which requires the typical time and variation of the events and the space occupancy information.

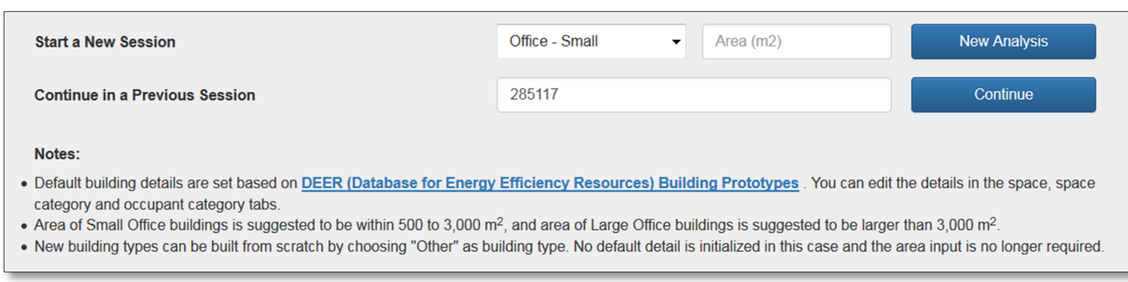


Figure 5 Main content of the *Start New* page

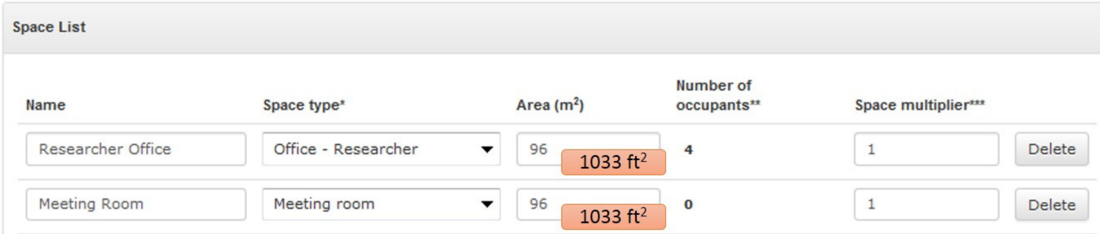


Figure 6 Snapshot of the *Spaces* page

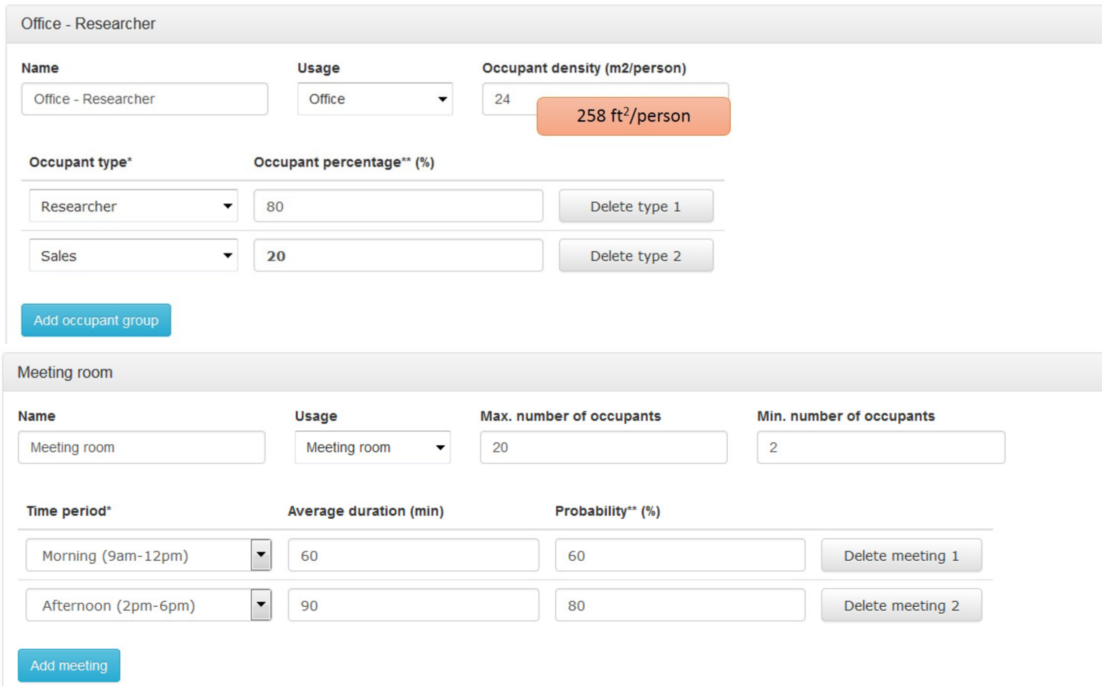


Figure 7 Example of "Office" and "Meeting room" in the *Space Type* page

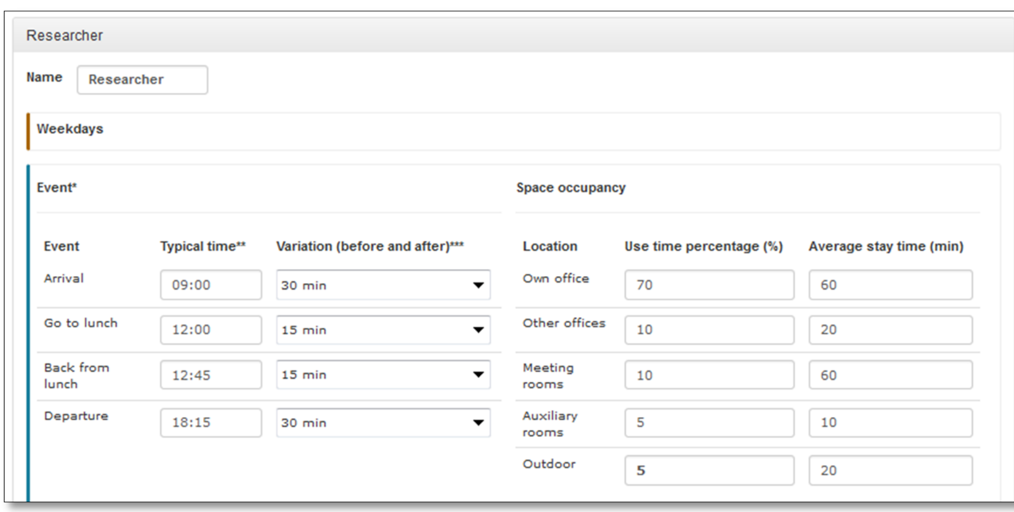


Figure 8 Example of "Researcher" in the *Occupant Type* page

After all the input information is collected, users can specify the simulation period, time step, and holidays in the *Simulate* page (Figure 9). It takes about one minute to run an annual simulation for this case. The results can be viewed in the *Simulate* page, with the customization of results period and room/whole building (Figure 10). Users also can download the results of occupant schedules in CSV and EnergyPlus IDF objects formats, and further use them in building performance simulation.

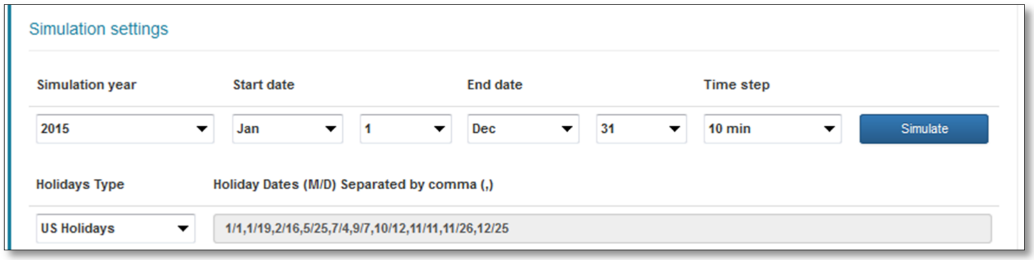


Figure 9 Simulation settings in the *Simulate* page

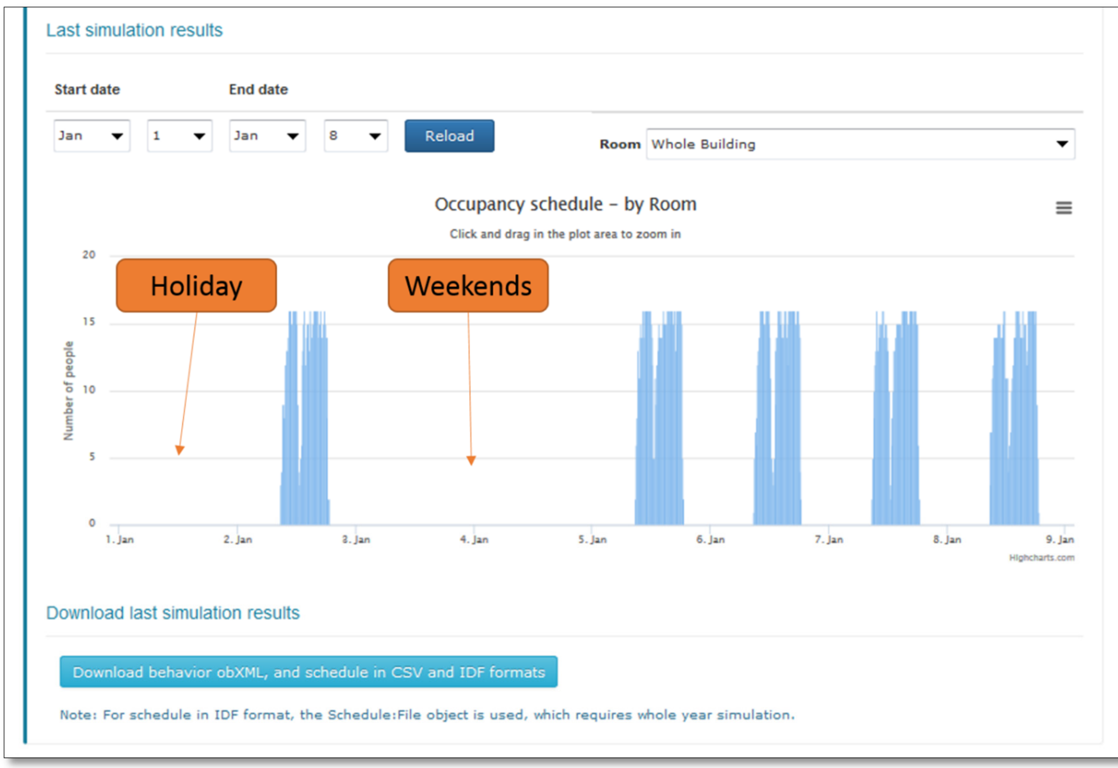


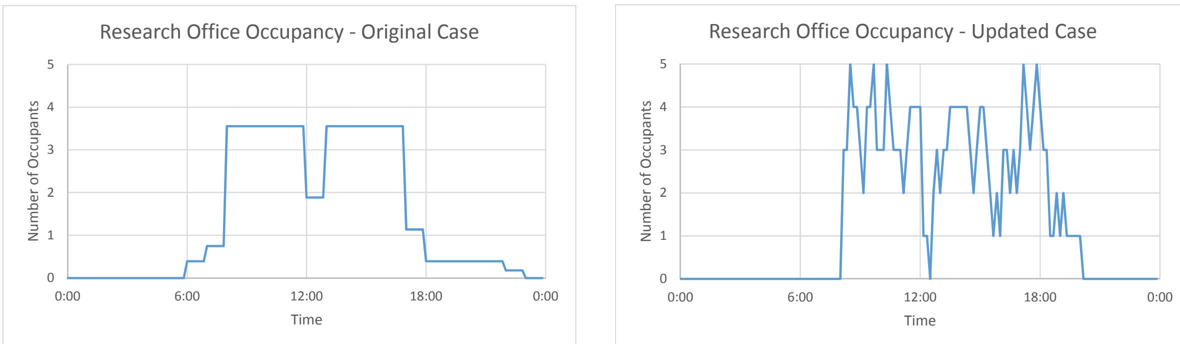
Figure 10 Occupancy simulation results view in the *Simulate* page

ENERGY SIMULATION RESULTS

In the case study, two energy simulation models are generated, the original case and the updated case. The original case uses EnergyPlus with traditional weekly occupancy profiles and lighting schedules. The updated case replaces the occupant schedules with those generated by the occupancy simulator, and simulates the occupant's lighting control behaviors using obFMU. The updated case is simulated using EnergyPlus and obFMU via co-simulation. The occupant schedules and the lighting energy consumption of the Researcher Office for both simulation cases are compared.

Comparison of occupant schedules

Figure 11 shows the occupant schedules of Researcher Office for both simulation cases on Jan 6th. The aggregated people hours are 34.3 people*hours for the original case, and 34.7 people*hours for the updated case. Although the aggregated people*hours are quite close, the updated case can capture events when and who enter or leave the room and when the room is vacant. That event information can be used by BEM programs to better evaluate the energy saving potential of technologies especially those controlled by occupancy sensors.

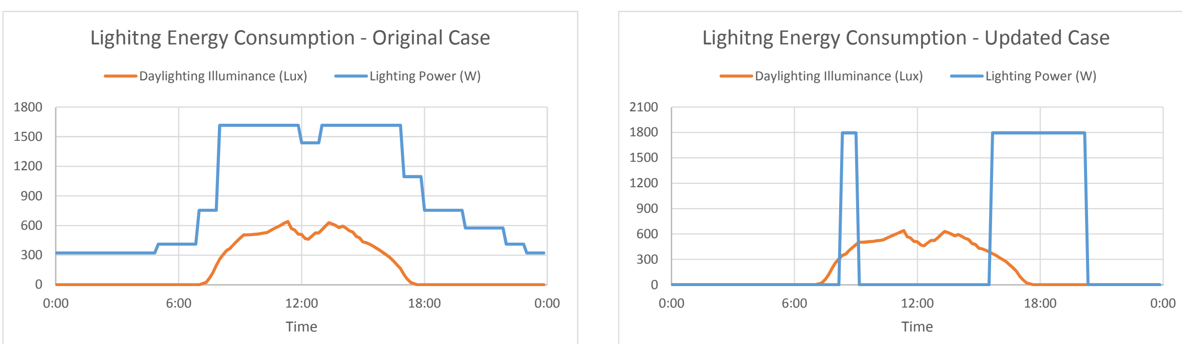


(a) The original case (b) The update case

Figure 11 Occupancy schedules of Researcher Office for both simulation cases on Jan 6th

Comparison of lighting energy consumption

Figure 12 shows the lighting energy consumption of the Research Office for both simulation cases on Jan 6th. For the original case, the prototype weekly lighting schedules are used. The lights are almost always on during the working hours. For the updated case, the occupants determine whether to turn on the lights based on the daylight level. This behavior is modeled in the obFMU. The results show that the lights are only turned on during the early morning and late afternoon when outdoor is dark. The updated case can help capture the diversity of the occupancy behavior rather than the static weekly profiles.



(a) The original case (b) The update case

Figure 12 Lighting energy consumption of the Researcher Office for both simulation cases on Jan 6th

DISCUSSION

There are several limitations of the current occupancy simulator. It uses the Markov chain model to simulate the occupant movement behavior, which does not consider occupants' walking time from one space to another. It doesn't support personal vacations or leaves.

CONCLUSION

This paper introduces the occupancy simulator, an agent-based web application, which can be used to better understand the impacts of occupant behavior on building energy performance. It is freely available to the public. The simulator organizes the data in an object-oriented way with hierarchy based on building physical and occupant behavior. It has a friendly web-based graphical user interface to input data and view results. Moreover, it provides the results export function for users to use them in building performance simulation. The case study also indicates that the occupant simulator can capture the diversity of occupancy behavior rather than the static weekly profiles, and can generate realistic occupancy schedules to support building performance simulation.

ACKNOWLEDGMENTS

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