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Multi-agent simulation of occupant behavior impact on building energy consumption

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Abstract Building energy consumption and environmental emission are significantly influenced by end-users and building energy simulations tools are used to optimize the performance of the building. Currently, most of the simulation tools considered oversimplified behavior and contribute to the energy gap between the predicted and actual consumption. However, the building energy performance also depends on occupant dynamic behaviors and this tools fails to capture the dynamic occupant behavior. To overcome this, developing a co-simulation platform is an effective approach to integrate an occupant behavior modeling using a multi-agent-based simulation with building energy simulation tools. The co-simulation process is conducted in Building Control Virtual Test bed (BCVTB), a virtual simulation coupling tools that integrate the two separate simulations on a time step basis. This method is applied to a case study of a multi-occupant office building within an Engineering school in France. The result shows the applicability and relevance of the developed platform.

Keywords: occupant behavior, co-simulation, multi-agent, energy simulation, behavior modeling.

1 INTRODUCTION

The world is accelerating towards a severe energy crisis due to high energy demand compared to energy resources [1]. The energy crisis and sustainability have become increasingly crucial topics among academia and industry. With the rising demands for energy use and future concern of scarce energy resources, the need for energy

efficiency is growing steadily [2]. The energy challenge is one of the most significant events of today's society, and governments worldwide have to adopt strategic policies to confront it.

According to the International Energy Agency, residential and commercial building consumes more than 40% of total primary energy and releases 33% of carbon dioxide emissions in the universe [3], [4]. Two-third of the total energy utilized by the building will be used within the households for heating, cooling, and lighting. The edifice is the sector with greater potential and lowest cost for carbon dioxide reduction, and has been named as a key potential contributor to bring down the energy consumption and greenhouse emissions. To be able to optimize building energy performance, researchers need a way to evaluate it.

Traditionally, building energy consumption is analyzed by a simulation tools, which is an effective approach for estimating building performance. Almost all of the simulation tools are considered a static building features for determining building energy performance [5]. For example, the occupants, electric equipment plugin, thermostat point and lighting in an offices follow static patterns without considering the dynamic interaction with the building systems, occupants and environmental factors (weather conditions), to mitigate their discomfort condition.

[6] Shows that occupants influence building energy directly and indirectly by manipulating light, equipment, thermostat, shade, domestic hot water (DHW) and operable windows to maintain their comfort as depicted in Fig. 1.

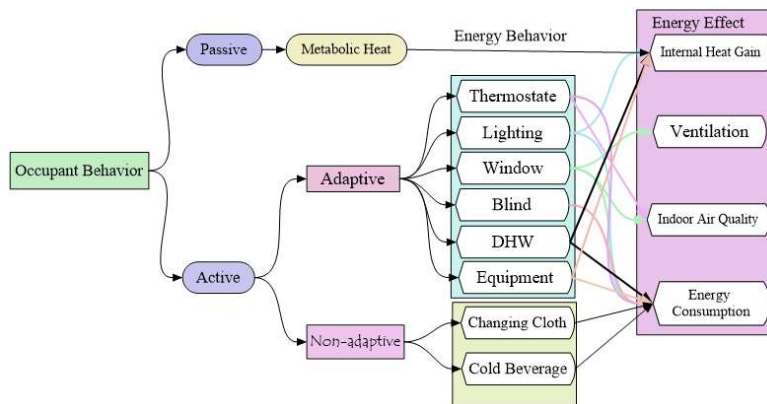


Fig. 1. Occupant type of activities influencing building energy performance.

The main challenge of estimating building energy consumption using simulation tools is the consideration of the dynamics and stochastic behavior of end users and the evaluation of multi-occupant influence. This is indeed a complex endeavor since

buildings are used by different occupancy with a different perception, beliefs and actions [7]. To solve this, multi-agent based simulation has been developed to represent dynamic occupant behavior.

This modeling and evaluation tools is included in a large project FORBOIS2, which will provide environmental sensors data (temperature, carbon dioxide, energy consumption, humidity) and thermography image (heat source and loss) for validating the simulation results. In this paper, we focused on a simple case to validate the approach.

The rest of the paper is structure as follows: Section 2 describes the state of the art on occupant behavior modeling. Sections 3 present on the modeling elements of the multi-agent systems and implementation of the co-simulation environment. Section 4 presents the application case and finally, the conclusions section explain the advantage and limitations of the proposed approach.

2 State of the art

For the last many decade, researchers emphasized the influence of occupant behavior on building energy consumption. For example, Wilde *et al* [8] report that the electricity consumption of an office deviated by 30% from what was simulated. Experimentally measured building energy consumption demonstrated a large energy variation range by a factor of two to five between edifices with the same function and located in the same weather. Brien *et al* [8] performed experimental investigation on one university residence room for two academic years with different occupancy and observed a 20% energy consumption variation for the last two academic years. Hong *et al* [9] has shown that the impact of occupant behavior on building energy use reaches up to 300%. Hani [10] studied the energy auditing for an office and the analysis revealed more energy consumption in non-working hours than working hours. The use of daylight systems or intelligent lighting control by reducing artificial lighting decreases energy use of the building for electricity by about 15% [11]. Commonly in building simulation programs, fixed schedules for typical days are assumed to represent the dynamic occupant behavior (occupancy, lighting) energy use in buildings.

Over the last years, researchers considered the occupant behavior impact on the simulation tool to simulate building performance. For example, Rijal *et al* [12] modeled the probability of window opening in terms of operative indoor/outdoor temperature. Jacob *et al* [13], [14] integrated multi-agent-based occupant behavior modeling into a residential building simulation tools. The dynamic occupant behavior models were developed as a functional mock-up interface (FMI) for co-simulation with energy plus [15]. Mengda *et al* [16] developed a dynamic occupant behavior modeling framework to improve the building energy simulation. The agent-based occupant behavior model is used for validation. However, researchers fo-

cused on the group-level behavior models, mainly used for residential, implementation process instead of performance analysis, and then proposed requirements for future occupant behavior models in order to be used by building an energy simulation tools. In this paper includes, individual-level occupant behavior models developed independently and coupled to building.

Buildings have been portrayed as complex systems involving several kinds of dynamically interacting components that are non-linear, dynamic and complex. The aforementioned driving parameters can be modeled and simulated through thermal dynamic building simulation tools. However, due to its complexity and stochastic nature, it is hard to completely indicate the influence of occupant behavior through dynamic energy performance simulation [16],[15]. Therefore, we need to know a way to pair off the occupant behavior on the building simulation.

Hong *et al.* [17] indicate that co-simulation allows a more realistic and robust representation of occupant behavior and aim to couple two or more simulation tools, offering a data exchange environment between subsystems. Co-simulation offers a flexible solution that allows consideration of network behavior and physical energy system state at the same time and also enables the possibilities of large scale system assessment [18]. Therefore, co-simulation, takes occupant behavior into consideration in energy performance simulation and predicts it more precisely. The aim of this paper is to propose a co-simulation platform to couple occupant behavior modeling using the well-known BRAHMS, a multi-agent-based simulation environment with EnergyPlus, building energy simulation tools and validating this software in order to deal with a complex occupant behavior by considering a simple scenario.

3 DEVELOPMENT OF CO-SIMULATION FRAMEWORK

Modeling dynamic occupant behavior to create situation in the simulation are closer to what could happen in real life of office occupancy. In order to examine these interactions and to express clearly, it is necessary to model and include dynamic occupant behavior in energy simulations.

These behaviors are not activated at regular times. They depend only on the value of some environmental factors. When the physical state of the environment exceeds its threshold value, it makes a psychological state in the users. This initiates the occupants to perform some activities to adjust their environments.

The dynamic occupant behavior is modeled and simulated in BRAHMS, multi-agent based simulation platforms. It is a descriptive language to record and simulate the causal relations of occupant's behavior. Moreover, it is a fully fledged multi-agent, rule-based, activity programming language[19].

This multi-agent environment uses a belief-desire-intention (BDI) approach, with an accent on the belief base of agents. It also makes a clear distinction between facts

and beliefs. This is useful to model the rational action of humans. Agents can have needs and can perform activities based on their needs and can also communicate for the fulfillment of various needs. The outside context and the inside psychology state are perceived by the agent as a thoughtful frame, which becomes its need [19], [20]. This need is carried by the workframe through primitive or composite activities.

The Brahms environment defines *agents* and *objects* that we map to *human occupants* and *building devices*. It also provides a rich geographical model which is used to model the various location in the building simulation and the travel between them. Therefore the multi-agent model has three types of concepts:

- *Area*, that represents the various places where occupants and objects are. They have facts corresponding to the environment variables (temperature, light), which come from the building simulation.
- *Agents*, that correspond to the human occupants. They have beliefs about their goals and current environment variables (temperature, humidity, light level, etc...). They execute *work frames* that contain activities to achieve their goals.
- *Object*, that models the building actuators, such as lights, thermostat, HVAC, windows, etc... They have states that will be sent to the building simulation.

The interaction between the three types of entities is as follow:

- At each simulation time-step of the energy simulation software, variables are received and used to set the facts of the area.
- Occupants can detect these facts and react by triggering a work frame. In these work frames, they express their needs for a change of a building device.
- Device perceives and reacts to the needs of the occupants, by changing their state.
- The state of the devices, and some simulation parameters such as the number of occupants in an area is collected and send to the building simulation software.

EnergyPlus is a new building performance simulation program that combines the best capabilities and features. EnergyPlus comprises a completely new code written in Fortran 90. Energy Plus is a broadly used building simulation tools that allows

the analysis of energy throughout the building and the thermal load [21] on a sub-hourly basis [22].

It is important to outline that in Energy Plus does not exist a visual interface that allows users to see and concept the building. In this case, third-party software tools need to be used.

The Co-simulation environment couple the occupant behavior model, BRAHMS, multi-agent-based modeling, with energy plus. A java application has been developed for this application. It communicates with the BRAHMS virtual machine using the Java application programming interface (JAPI) of the BRAHMS platform. Using JAPI, the co-simulation environment is able to start the agents, and alter the facts and belief base. On the other side, it communicates with EnergyPlus using the Building Control Virtual Testbed (BCVTB) interface by exchanging packets formatted using the Ptolemy II standard over a TCP socket.

The information interchange between BRAHMS and Energyplus is duplicated in Fig. 2. Energy plus simulates zone-based level and passes output environmental features such as illuminance to the BRAHMS as input to model occupant behavior. From the BRAHMS, the occupant behavior model output which includes occupancy schedule and building equipment statuses are sent back to the energy plus and used for the next time steps. The whole process of information exchange is transmitted through building control virtual testbed (BCVTB). The process repeats until the simulation end time is reached.

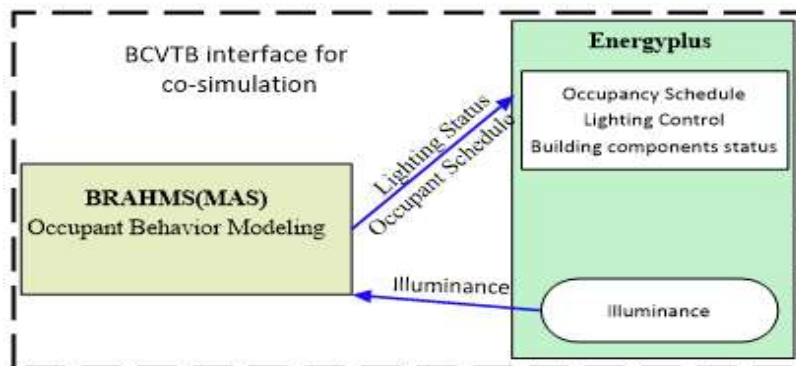


Fig. 2. Data flow of BRAHMS and Energyplus co-simulation framework.

4 APPLICATION

To test the applicability and significant of the developed platform, a simple behavior scenario and case study are conducted.

4.1 Occupant Behavior Scenario

The process scenario is presented in Fig. 3. When an occupant enters the room, this agent had a perception of indoor light from the room and this triggers physical perceptions like visual comfort such as the agent feels dark or light, For example, the occupant perceives light intensity of the room and compares with a reference of the external illuminance threshold. If the illuminance extracted from the simulation tools is less than the threshold, the agent interacts with the light device to turn on. The output of the light device is then resend to the simulation for the next time step.

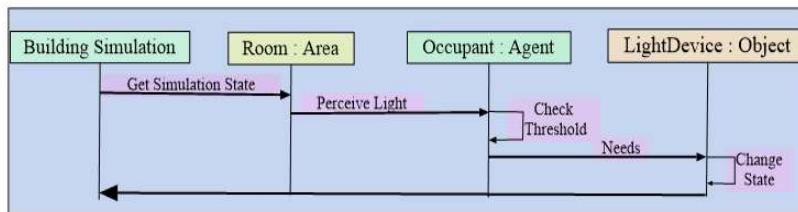


Fig. 3. MAS to Energy Performance Simulation.

4.2 Case Study

To test the platform, a small case study is conducted. The educational building which consists of four adjacent multi-user office is selected to test the coupled simulation. It is located in Epinal, France.

- Each office had one external wall with window facing NorthEast direction and has a rectangular shape with a floor area of 206.3 m².
- The offices are occupied by 1 to 3 persons in this study depending on the purpose of the office. Its 3D view is shown in Fig. 4.
- The simulation coupling is conducted at the room level. The simulation period is for a whole year (from January to December 2019).
- The weather data used for this simulation is extracted from online source.
- The time step for this simulation is set 10 min.

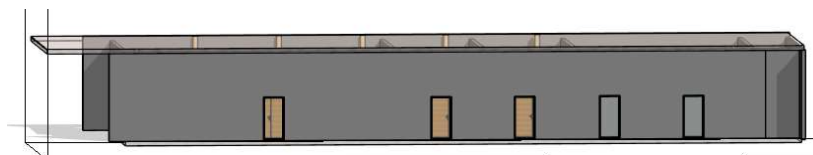


Fig. 4. 3D view of the building

4.3 Simulation and Results

The model has been made applied to a simple case study, with one occupant controlling the lighting in an office room. The control of the temperature was done using a thermostat controlling a HVAC (Heating, Ventilation and air conditioning) systems, maintaining temperature in the range of 22-23⁰C.

The activity executed when the agent is in the office room is a compound activity: It contains several repeating workframe competing for execution. The first one is to simulate the work task that the occupant does (with some delay) and the second one pertains to turning the lighting on/off. The two workframe are triggered by the value of the room light level and also by the belief they set, to avoid repeating execution.

So, when the illuminance of the room is less than the threshold, the agent adds a belief to its belief base meaning that he needs light, and that triggers an action with the lighting device to light on. Result of this from BRAHMS simulation environment is shown in Fig. 5: In the timeline view of agents, the location of the agent is shown at the top, while below its workframe (in blue) and activities (in green, or orange for compound activities).

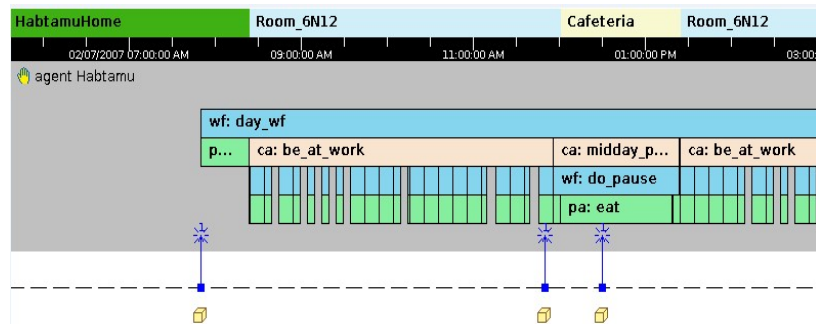


Fig. 5. Simulation result of an occupant behavior example lighting control

The occupant execute a main workframe that corresponds to his day routine: like at arrival, departure and concerning with the illuminance. All these periods are implemented using activities. Using stochastic values for the duration of these activities enable to create randomness for the arrival, lunch and departure. A clock object is added to the multi-agent system to send notification for the period of the day (morning, afternoon, evening) changes.

The simulation was run over a year with a time step of 10 minute interval. The whole year simulation result is difficult to represent in a single illustration, hence a sample result is extracted to show the relation of the various features as in the Fig. 6. The figure shows how the occupant reacts to change indoor illuminance, and how it influences the energy consumption in an office building, which is the determinant factor in the lighting device status.

The occupancy schedule is shown with the white area generated by a blue broken line, and the occupant behavior schedule is represented with the green area created by a small green broken line, which varies depending on the value of the illuminance indicated by the purple line. For example, when the agent departs from the office for lunch or belief that the illuminance is beyond the threshold (9:00 to 11:00 and 15:00 -17:00), they try to switch off the light, else the reverse will happen. Lighting and occupancy value is represented by a Boolean number (0 for off, and 1 for on).

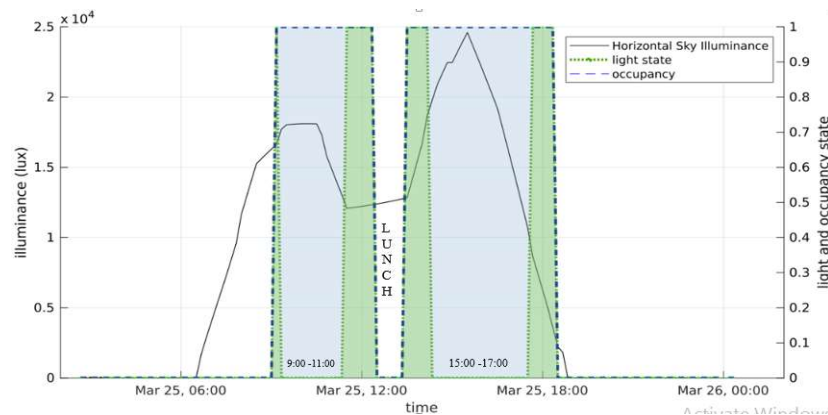


Fig. 6. Lighting relationship with illuminance and occupancy

The energy consumption using co-simulation, which considers dynamic occupant behavior, is much lower than that of simulation considering occupancy factors in deterministic or predefined schedule as presented in Fig. 7. 30 to 40% energy consumption saving is expected by integrating dynamic occupant behavior.

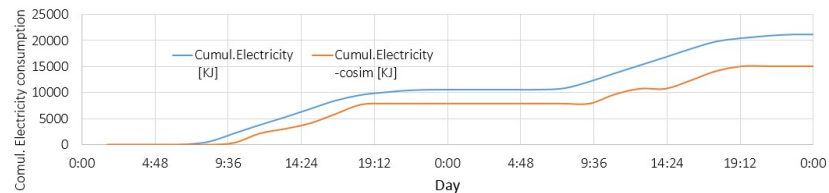


Fig. 7. Occupant behavior Impact on electricity consumption in lighting and equipment.

5 CONCLUSION AND FUTURE WORKS

The main contribution of this study is to test the applicability and relevance of our approach in modeling the occupant's behavior and co-simulation environment. The key concepts are to employ three types of entities: area, occupants and devices. The latter two implement their behaviors using work-frames that compete for execution. The capacity to recursively embed the workframe in activity seems very promising to simply describe occupant behaviors.

The case study shows that this modeling approach enables us to create a simple case. The results confirm the literature: occupants' behavior can have a big impact on energy consumption, even in a simple case.

This case study has also shown some limitations of the Brahms multi-agent environment. The major one is the inability to run several workframe in parallel. This is completely realistic for cognition-intensive activities (e.g. reading), but when dealing with modeling of building occupants, it is very important to process perceptions continuously, in parallel with the workframe execution. Another limitation is also the poor expressivity of Brahms language (e.g. there is currently no support for more than two operands or for nested arithmetic expressions). The maintenance status of the Brahms software is also a concern for us.

We are therefore planning to develop a new simulation package specifically adapted to building occupants that would keep the good aspects of Brahms while overcoming its limitations.

In future works, we aim at working with more complex simulations to test the scalability of our modeling approach. An open issue is also to create a robust reference model for inter-occupants interactions (e.g. how they take into account the action of other neighbor occupants).

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