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A Framework to Improve Occupant Modeling Capabilities in Building Simulation Tools

Mohamed M. Ouf[1], William O'Brien[1], H. Burak Gunay[1]

[1] Carleton University, Ottawa, ON Canada

Abstract: *Previous studies demonstrated the benefits of detailed occupant modelling. However, its uptake in building simulation practice has been relatively slow, partially due to the limited occupant-related features of building performance simulation (BPS) tools. Based on the outcomes of a stakeholder workshop and an international survey that focused on occupant modelling, we provide detailed recommendations to improve occupant-related features in BPS tools. We also present a case study demonstrating the suggested occupant-related features to apply multiple occupancy assumptions, and integrate occupant behaviour models from the literature. Results are presented as part of a mock-up graphical user interface (GUI) to demonstrate potential features of BPS tools given the suggested occupant-related improvements. These suggested improvements for BPS tools enable users to assess proposed designs' sensitivity to different occupancy scenarios, and are relevant to practitioners, researchers, and BPS tool developers as part of the efforts to improve detailed occupant modelling in practice.*

Keywords: *Building performance simulation; Occupancy; Occupant behaviour; Building simulation software tools; Occupant modelling*

INTRODUCTION

Occupancy and occupant behaviour (OB) can cause significant variations in buildings' energy consumption. They can impact energy consumption in offices by a factor of two or more (Feng et al., 2015; Haldi and Robinson, 2011; Norford et al., 1994; Oca and Hong, 2014; Reinhart, 2004). Because of this, accurately representing occupants in building performance simulation (BPS) tools is an important issue. According to Clarke and Hensen, (2015), BPS tools should be able to 1) provide an accurate representation of the dynamic, connected and non-linear physical processes that govern building performance, 2) couple the various domain models that take place in building operations to represent the interactions between them, and 3) support a virtual design process through interactive manipulation of design hypotheses against performance feedback given in real time. Therefore, accurate representation of occupants is needed to achieve all three objectives.

Occupants' presence and actions are typically modelled in a very simplistic way in today's building simulation practice (O'Brien et al., 2017b). Occupants are merely considered as internal heat sources and passive recipients of indoor environmental conditions in BPS. This simplistic approach is emphasized by current building codes and standards, which provide default schedules for occupants' presence, light and equipment use (ASHRAE 90.1, 2013; National Research Council, 2015). However, rules for modelling occupants and their adaptive actions are rarely provided in or required by these codes and standards, which is one of the reasons behind the slow uptake of detailed occupant modelling. The limited capabilities of current BPS tools are another challenge facing detailed occupant modelling in building simulation practice. The goal of this paper is to analyze occupant-related capabilities of common BPS tools, and present recommendations to improve them. Throughout the paper, we refer to users of BPS tools as 'users', and occupants simulated in BPS tools, as 'occupants'.

In a recent stakeholder workshop with 25 Canadian building simulation practitioners and researchers, the topic of occupant modelling in BPS was discussed in more detail. According to the workshop participants, they typically rely on default occupant-related assumptions when modelling for code compliance or green building certifications. These default assumptions are provided in building energy codes and standards such as the National Energy Code of Canada for Buildings (NECB) or ASHRAE standard 90.1. More details about the workshop findings and participants' feedback are reported by Abuimara et al. (2018). A recent survey of 274 building simulation practitioners in 36 countries also reported that occupant-related assumptions used in practice are generally very simplistic (O'Brien et al., 2017b), which confirms the findings of the stakeholder workshop. Most survey respondents (75%) believed today's BPS tools should have more occupant-related features, even if this requires substantially more user inputs and effort (O'Brien et al., 2017b).

This paper presents detailed recommendations to improve occupant representation in BPS tools, based on anecdotal results from the survey and workshop. The recommendations aim to streamline detailed occupant modelling for users of BPS tools, and to partially address the issue of limited occupant modelling in practice. Using a prototype office building model as a case study, the final

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section of this paper demonstrates the suggested occupant-related features by manually applying several occupancy assumptions, and integrating different occupant models. Results are presented as part of a mock-up graphical user interface (GUI) to demonstrate the suggested improved capabilities of BPS tools. These recommendations are relevant to building simulation practitioners, researchers, and BPS tools' developers as part of the efforts to improve occupant modelling in practice.

The scope of analyzing occupant-related inputs in BPS tools focuses on five common ones. Based on survey results, the following BPS tools were identified as the most common since each of them was used by at least 20% of the respondents: EnergyPlus V8.8, OpenStudio V2.3, DesignBuilder V5.0, IES VE V2017, and eQUEST V3.65. Two of these tools (DesignBuilder and OpenStudio) will be referred to as EnergyPlus-based tools since they use EnergyPlus as their simulation engine, while providing a graphical interface. Although their features are similar to a great extent, some of the features available in EnergyPlus may not be readily available in EnergyPlus-based tools.

BACKGROUND

Standards, such as ASHRAE 90.1, mandate that BPS tools used for compliance "shall explicitly model hourly variations in occupancy, lighting and equipment power, as well as thermostat setpoints" (ASHRAE 90.1, 2013). Therefore, the basic features to represent these occupant-related inputs in a deterministic way are fairly consistent among BPS tools (Cowie et al., 2016). Users can specify the number of occupants and an hourly presence schedule, as well as schedules for thermostat setpoints. Lighting and plug-load equipment can also be represented with design peak power and hourly schedules specifying the percentage of this peak power used at each hour. Additional capabilities to represent more detailed aspects of OB may be available in different BPS tools. Users can describe the use of windows, shading devices, and other operable systems using deterministic rules based on indoor and outdoor environmental parameters and/or schedules (Cowie et al., 2016). The level of detail used to describe these actions varies between BPS tools. Some do not allow modelling of certain occupants' actions (e.g. opening windows), and most do not allow users to describe these actions using probabilistic, rather than deterministic rules (Gunay et al., 2016; Lindner et al., 2017).

Previous studies collected long-term observation data from existing buildings to develop mathematical occupant models that describe or predict occupancy and OB (Haldi and Robinson, 2010; Page et al., 2008; Wang et al., 2005). Unless specific models are embedded within the BPS tool, user-modifications are required to integrate these occupant models in BPS tools. Representing occupants in BPS tools can generally be achieved using two main approaches summarized in Figure 1. Users need to customize partial codes to overwrite default controls and use stochastic mathematical formulae to describe occupants following the user-modifications approach (Hong et al., 2017; Yan et al., 2015). Hong et al., (2017) summarized the different user-modification approaches and indicated that co-simulation offers greater flexibility for integrating occupant models. It allows distinct components to be simulated by different simulation tools running simultaneously and exchanging information (Wetter, 2008). Despite its advantages, co-simulation still requires advanced user experience; an issue that was raised during the stakeholder workshop and in survey results (O'Brien et al., 2017b). An alternative approach to represent occupants in BPS, which is presented in this paper, focuses on occupant-related direct inputs in BPS tools. These inputs enable users to evaluate the effect of various occupant-related assumptions on their designs at a higher level, which can accelerate the uptake of detailed occupant modelling in building simulation practice.

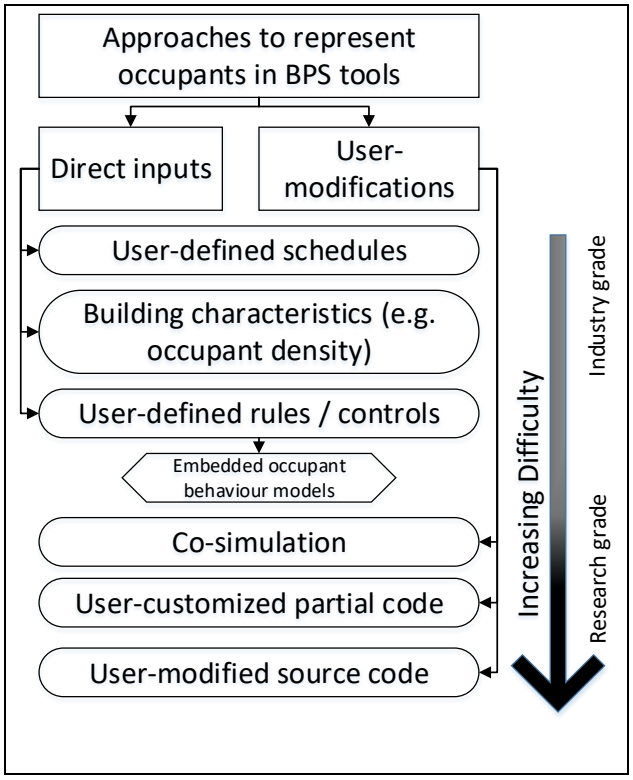

Figure 1 Approaches to represent occupants in BPS tools

IMPROVING OCCUPANT-RELATED FEATURES IN COMMON BPS TOOLS

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To improve occupants' representation in BPS tools, each stage of the BPS process in Figure 2 is considered in detail. For each stage, the current limitations in common BPS tools are discussed, followed by suggestions to streamline occupant modelling, and to provide additional features that improve occupant modelling capabilities. The recommendations to streamline occupant modelling are not presented for the modelling process stage of BPS, since this category of recommendations (i.e. streamlining occupant modelling) mainly deals with the user interaction with BPS tools (i.e. inputs and outputs).

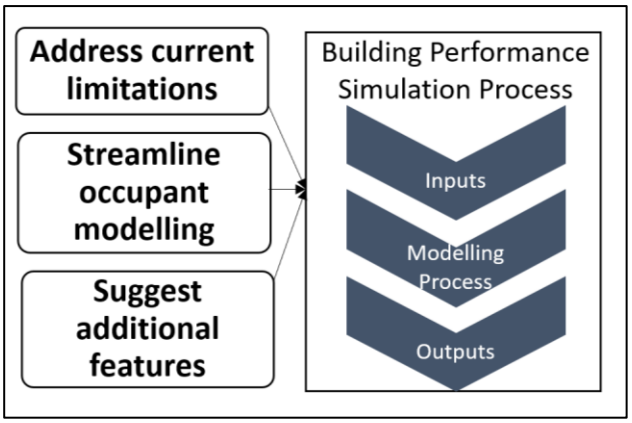

Figure 2 Framework for upgrading occupant modelling features in BPS tools

Recommendations for BPS Inputs

Address current limitations

One of the limitations of common BPS tools is their inability to simulate occupants' presence and actions using probabilistic rather than deterministic inputs. Workshop participants emphasized that probabilistic inputs are not always required, depending on the purpose of BPS. However, an option for choosing between deterministic or probabilistic modelling approaches is beneficial to demonstrate the effect of occupants. One way to address this issue is enabling users to specify BPS inputs as a mean ± standard deviation rather than a fixed value. Thus, the values for inputs will be randomly selected by the BPS tool based on user-defined distributions. For example, to define daily occupancy schedules, users would specify the average number of occupants at each hour and a standard deviation.

Some BPS tools (e.g. EnergyPlus) already allow users to specify a probability for controls of operable building components, namely windows and daylighting controls. However, this feature is not enabled for other building components (e.g. blinds) and should be introduced in other BPS tools. Probabilistic inputs are generally more representative of occupants, since their actions do not automatically take place whenever the appropriate conditions are met. However, using probabilistic inputs requires users to run multiple simulations to characterize the effect of occupants on energy consumption. Therefore, another recommendation for BPS tools is automating this process of running multiple simulations and analyzing their results, which was one of the obstacles raised by workshop participants.

Streamline occupant modelling

One of the recommendations to streamline occupant modelling in BPS tools is providing pre-defined occupancy types as inputs. These high-level occupancy types automatically populate schedules and building controls based on pre-defined rules and assumptions. This recommendation was made by some workshop participants who indicated that general assumptions for active, passive, and average occupants, can be adequate to generate a range for their buildings' performance under different occupancy scenarios. An alternative suggestion by some workshop participants was using a continuous distribution representing the spectrum of occupant types, which are randomly sampled by BPS tools, using the Monte Carlo method. In this case, multiple simulations will be automatically run to quickly quantify the effect of different occupancy scenarios which helps practitioners increase the robustness of their designs against occupant-related sources of uncertainty.

Another recommendation to streamline occupant modelling is embedding occupant models in BPS tools. Results from the survey and workshop suggest that using occupant models is limited in practice due to the difficulty and time this requires. Respondents indicated that clients are not willing to increase project budgets to allow designers (i.e. BPS users) to fully investigate the effect of occupants. Embedding occupant models in BPS tools requires significant collaborations between tools' developers and researchers, but these features can increase the uptake of occupant modelling in building simulation practice. BPS users will also need to be familiar with occupant models and their basic assumptions to use them appropriately. Some of the workshop participants indicated they are already not fully aware of all the current features of the BPS tools they use. This means users would require more extensive training on occupant modelling specifically if the occupant models are embedded within BPS tools.

Suggest additional features

Another tier of recommended occupant-related inputs depends on the explicit representation of occupants as 'agents' within the modelling process of BPS. By simulating actual occupants within the building, BPS users can specify details about their comfort ranges, typical

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positions within building spaces, and the likelihood of taking adaptive actions. One of the survey respondents explained that current BPS tools deal with occupants as 'robots', although current advances in programming and artificial intelligence offer great opportunities to simulate the uncertainties in human behaviour. By enabling users to specify occupants' behavioural attributes, BPS tools can simulate active occupants who react to uncomfortable indoor conditions by taking adaptive actions.

Other recommended inputs include specifying occupants' demographics (e.g. gender, age and occupation) which affect their comfort preferences, metabolic rates and simulated behaviour. In schools, retirement homes, and other building types where these demographics are predictable, these inputs allow BPS users to simulate expected occupancy scenarios more accurately. One of the issues raised during the workshop was the immaturity of visual, acoustic and thermal comfort modelling capabilities in BPS tools. Therefore, additional occupant-related inputs can address these issues, with the help of more research on physiological and other factors that influence occupants' comfort and behaviour.

Recommendations for BPS Modelling Process

Address current limitations

Common BPS tools only consider occupants as sources of heat gain, which is one of their limitations. Although this modelling approach is useful for simulating thermal loads which is sufficient for some BPS purposes, it does not simulate other aspects of occupancy such as their actions, arrivals or departures. For example, BPS tools do not normally account for the duration of occupant absence at each departure event, which is a necessary variable for some occupant models (Reinhart, 2004). This limitation increases the difficulty of integrating occupancy models in BPS tools and accounting for inter-occupant diversity during simulations (O'Brien et al., 2016). One of the recommendations to overcome this limitation is simulating occupants' presence using agent-based modelling as an alternative, where details about each occupant or groups of occupants (for larger zones) can be specified.

Other limitations raised by some workshop participants include the modelling process of some building components controlled by occupants. For example, shading controls in common BPS tools only allow users to simulate two positions (fully opened or fully retracted) (da Silva et al., 2015). Although users of BPS tools can work around this limitation by subdividing the glazing area into multiple windows, this approach is exhaustive and more time-consuming. Alternatively, BPS tools should enable users to specify the fraction of windows to be covered by blinds. Another limitation regarding shading controls is assessing conditions that lead to opening or closing blinds at each time-step. This approach tends to overestimate the interaction between occupants and blinds, and is only representative for automatic blind controls. One way to overcome this limitation is allowing users to specify a minimum duration, during which blinds' positions will not be changed, which was observed in existing building where occupants change blinds' position (Bennet et al., 2014; O'Brien and Gunay, 2015).

Another issue raised by survey respondents and workshop participants is the additional time required to run multiple simulations and analyze their results to characterize the effect of occupants. To complement the recommendations for enabling probabilistic inputs or integrating occupant models, BPS tools should automate the process of running multiple simulations and processing their results. Cloud computing can also be utilized to minimize the time required for running these simulations. OpenStudio and IES VE already provide this functionality for parametric analyses of design alternatives, unlike the other BPS tools evaluated in this paper. Therefore, one of the recommendations is expanding cloud computing functionality in BPS tools, especially if running multiple stochastic occupant simulations is required.

Suggest additional features

One of the issue that were raised during the workshop is the potential mismatch between the timing of occupants' adaptive actions such as closing blinds and their physical presence. Although this modelling approach is representative for automated building systems, it does not represent occupants' interaction with building systems since it does not recognize their presence as a condition for these interactions to take place. Overcoming this issue can be achieved following the recommendation to enable an alternative agent-based modelling approach. This will allow BPS users to explicitly specify that controls for certain building systems (e.g. blinds) are only activated if simulated occupants are present.

One of the workshop participants suggested an idea for modelling occupants' comfort from their perspective rather than from the building's or zone's perspective. Currently, comfort metrics are assessed by placing fixed sensors in each building zone during BPS. By shifting to an agent-based modelling approach, simulated occupants can act as mobile sensors that move within different parts of the building or zone. Daylight glare for an occupant near a window would be different if this occupant moves further into the room. Therefore, by simulating individual occupants' movement, the conditions experienced by them, and their adaptive response to these conditions, this

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recommendation aims to represent occupants in more detail. Eventually, this process enables users of BPS tools to provide more robust designs by determining the effect of different design options on occupants' comfort and their adaptive actions, which ultimately affect energy consumption

Recommendations for BPS Outputs

Address current limitations

Discussions during the workshop highlighted that current occupant-related BPS outputs are still underdeveloped relative to other domains such as energy performance, or indoor environmental quality. To address this limitation, additional occupant-centric performance metrics should be enabled in BPS tools. For example, assessing unmet hours, where at least one zone has an unmet cooling/ heating load, should account for occupancy in these zones. Carlucci, (2013) introduced the thermal discomfort index which assesses whole-building performance by weighting the zonal indices by the number of people that occupy each zone for each hour. Other performance metrics include evaluating building energy use per capita, or assessing building utilization which were suggested by O'Brien et al., (2017a). Another set of occupant-centric performance metrics can assess the ratio of energy use during occupied and unoccupied hours, by calculating an 'Overnight Ratio' to quantify nighttime to daytime plug load power (Harris and Higgins, 2013). Although some of these occupant-centric metrics can be calculated from detailed BPS results, adding them to standard BPS output metrics encourages users to address occupant-related issues during the design phase.

Streamline occupant modelling

The survey responses indicated that box and whisker plot is the most preferred method for communicating uncertainty. However, since the survey only targeted building simulation practitioners and researchers, results may not indicate the preferences of other building stakeholders (e.g. owners). BPS tools should enable different visualization options that are automatically produced to facilitate communicating uncertainties in building performance due to occupants. Depending on the target audience and preferences, BPS users can then choose from these visualization options to present results of automated multiple simulations.

Another issue that was raised in the survey responses and during the workshop is the ability to assess proposed designs' sensitivity to different occupant-related variables. For example, the way occupants use artificial lights can change depending on building orientation and window to wall ratio, which ultimately affects their electricity consumption. By incorporating models to account for OB given different design parameters, BPS tools should enable users to evaluate their designs' sensitivity to occupants.

Suggest additional features

Suggestions during the workshop to evaluate building performance from an occupant perspective give rise to another tier of BPS outputs that focus on occupants' experience in the building. For example, BPS tools should quantify the number of adaptive actions taken by occupants in each simulation to be used as a metric for reporting comfort (Gunay et al., 2017). This approach for producing BPS outputs that are based on individual occupants' experiences can also assess the robustness of building design. For example, one of the suggested building performance metrics in the literature is daylight autonomy, which quantifies the fraction of occupied hours during which daylight is adequate to offset electric lights (O'Brien et al., 2017a). Combining this metric with individual occupants' light use behaviour, can help designers choose design strategies to improve occupants' experience and comfort.

CASE STUDY

To showcase some of the suggested recommendations to improve occupant modelling in BPS tools, a mock-up GUI is presented in Figure 3. The envisioned GUI allows users to simply select different occupancy assumptions and integrate them in their simulations. The tool would generate and visualize outputs of different occupancy assumptions after post-processing the results, without additional work by the users.

The presented GUI should not be considered a prototype for standalone BPS tool. It merely demonstrates some of the suggested features that can and should be integrated in common BPS tools. Further testing and development of these software applications is a necessary step towards streamlining occupant modelling in BPS tools. In particular, aspects such as usability of the suggested features, and user experience should be tested. The development process should also follow the usage-centered design approach, which puts more focus on task accomplishment (Constantine and Lockwood, 2002). Therefore, issues such as user distraction due to redundant information, and application tolerance to prevent errors wherever possible must be addressed (Constantine and Lockwood, 2002)

The case study was based on simulating a prototype medium office building model developed by Natural Resources Canada using EnergyPlus V8.8, and set in Ottawa, Ontario, Canada (ASHRAE climate zone 6). This

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medium office building model shown in the top left corner of the GUI in Figure 3 represents a three-story rectangular building with an overall area of 4,982 m^2 and complies with the requirements of NECB 2011. The building has a window-to-wall ratio of 33 percent with fenestration distributed evenly across all four façades. The HVAC system type used is a variable air volume (VAV) system with a natural gas boiler and electric chiller.

To perform a sensitivity analysis based on three occupancy scenarios, occupancy, lighting and equipment use schedules were changed from standard assumptions prescribed in NECB 2011. The three schedule types used were based on collected data from an existing office building in Ottawa (Bennet and O'Brien, 2017). These schedules (scenarios 1, 2, and 3) represented minimum, average, and maximum occupancy, light and equipment use, for each hour on weekdays. Furthermore, the minimum, average, and maximum occupant, equipment, and lighting power densities found on different floors in that building were used. For lighting power densities, occupancy scenarios 1, 2 and 3 used 3.3, 5.2, and 8.5 W/m^2, respectively. For equipment density, occupancy scenarios 1, 2 and 3 used 2.5, 6.3, and 9.4 W/m^2, respectively. For occupancy scenario 3, thermostat set-points were also assumed to be constant 24/7 (i.e. no set-back) to represent energy inefficient occupancy.

Three occupant models were then implemented using the EMS feature in EnergyPlus to generate unique occupancy and lighting schedules. These models were 1) occupancy (Wang et al., 2011), 2) light use (Reinhart, 2004), and 3) blinds use (Haldi and Robinson, 2010). Details of the implementation of stochastic occupant models can be found in (Gunay et al., 2016). Incorporating these occupant models in BPS tools, would require users to specify the means and standard deviations of these parameters (e.g. arrival and departure times, coffee break durations, etc.) as shown in the bottom left corner of the GUI in Figure 3, otherwise default values can be used.

As shown in Figure 3, users are provided with features to apply occupancy scenarios and occupant models on their proposed designs, then select building zones at which these assumptions will be applied. The suggested features enable users to modify some of the underlying parameters of these occupancy scenarios, if more relevant information is available. For occupancy scenarios, annual energy consumption profiles are automatically produced by the BPS tool showing the marginal increase in energy consumption due to these assumptions as shown in the top right chart of the GUI in Figure 3. The suggested features enable users to switch to monthly or daily views to visualize the variations in energy consumption due to occupants at finer temporal resolutions. Variations at these higher resolutions are expected to be more profound, which enables users to identify the seasons or times of day at which energy consumption varies the most, and address it. The suggested outputs also include heating and cooling demand, lighting and plug loads use, indoor air temperatures, and a summary of the building's overall energy use intensity (EUI), shown as a range based on the three occupancy assumptions. These visualizations can help in optimizing building design, as they allow users to test their models' resilience against extreme occupancy scenarios. Users have the option of loading multiple designs and applying the same scenarios on them to compare their performance under different occupancy scenarios.

Other suggested features enable users to implement stochastic occupant models embedded within the BPS tools. However, users may still be required to input some assumptions to run these models and tailor them to their proposed design. For example, the occupancy model by Wang et al., (2011) requires users to specify the average and standard deviation for arrival, departure and break times as well as their durations as shown in the bottom left section of the GUI in Figure 3. The suggested features also notify users if activating other models is mandatory. For example, Reinhart, (2004) light switch model simulates light use behaviour based on occupants' departure and arrival events, which need to be generated using an occupancy model. Additionally, the suggested features notify users if using multiple occupant models simultaneously is not possible, especially if these models simulate the same behaviour. For example, users can not implement two different models for using lights simultaneously.

To represent the diversity of occupants, users are required to specify the number of simulations. Alternatively, a default for running simulations until their results' distribution converges could be used. The suggested features enable users to view a box and whisker plot for lighting, or equipment electricity use, heating, or cooling loads, as well as overall energy consumption. A sample of these charts for annual electricity consumption is shown in the bottom right section of the GUI in Figure 3. Additional output features include occupant-centric metrics such as quantifying the number of adaptive actions taken by occupants to identify building designs that trigger more disruptive actions. Occupant-centric metrics also include normalizing energy consumption per occupant, and assessing light utilization ratio which quantifies the relationship between light use and occupancy (O'Brien et al., 2017a).

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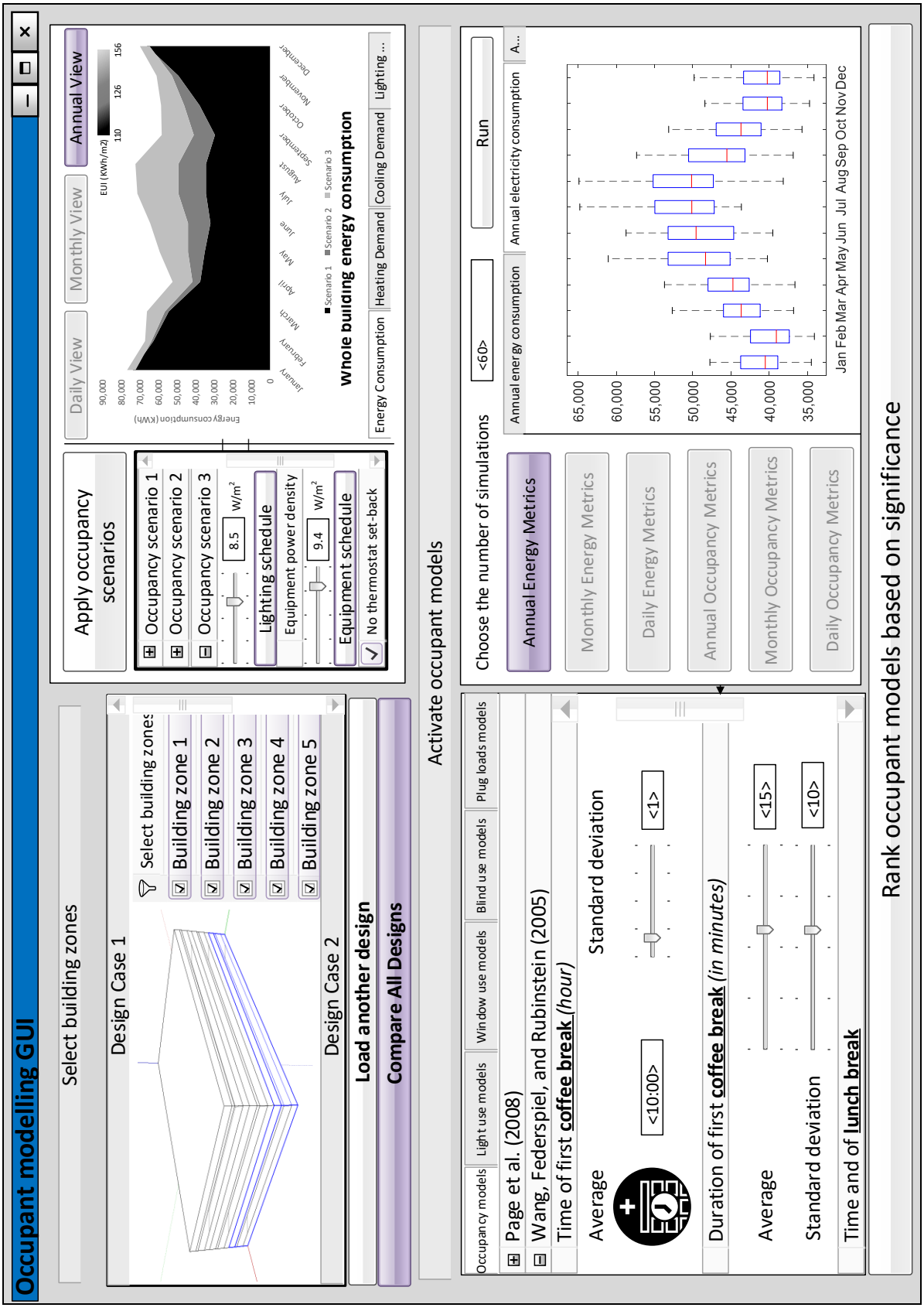

Figure 3 Mock-up of the graphical user interface (GUI) to streamline occupant modelling

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To enable a parametric evaluation approach of different design options, the suggested features enable users to compare the same set of occupant-related assumption on different building designs. After specifying the assumptions for occupancy scenarios and occupant models, suggested features enable users to load several designs and apply the same assumptions on them. The automatically generated results and charts for each design case allow users to quickly evaluate these designs' sensitivity to occupants.

CONCLUSION AND FUTURE WORK

The recommendations aimed to improve occupant modelling capabilities of BPS tools with the objectives of 1) simplifying the process for users, 2) improving the accuracy of occupants' representation in BPS, and 3) assisting designers in making better informed design decisions that take occupants into account. Ultimately, integrating detailed occupant modelling in BPS can proceed in two directions. The first is tailoring occupant models to the capabilities of common BPS tools, and integrating them within the simulation process of these tools. The second is changing BPS tools' capabilities to accommodate detailed occupant modelling, which is what the recommendations presented in this paper focused on. The first approach is mostly geared towards the research community, where modifications to the simulation process in BPS tools are achieved through user-defined scripts or via co-simulation. This approach serves as a short-term solution for detailed occupant representation in BPS. However, it requires more work by BPS users, which is one of the reasons for its slow uptake in building simulation practice. The recommendations presented in this paper aim to address this issue in the long-term by following the second approach which entails changing BPS tools' capabilities. They were based on discussions at a stakeholder workshop, anecdotal results from an international survey, a comprehensive survey of the literature, and the authors' experience. In summary, these recommendations suggest.

- *Increasing occupant-related direct inputs in BPS tools.* Recommendations focused on occupant-related direct inputs to BPS tools to streamline this process for building simulation practitioners, as opposed to the current approach which relies on user-modifications.
- *Automating the process of running multiple simulations and analyzing their results*. These features can be programmed into BPS tools and would significantly decrease the time required to analyze results from multiple simulations to characterize the effect of occupant behaviour.
- *Adding more occupant-centric outputs*. These outputs will allow designers to consider the performance of their designs from an occupant-centric perspective rather than only focusing on energy performance.
- *Streamlining user experience by improving the user-interface of BPS tools.* Current advances in Building Information Modelling (BIM) can be utilized and integrated within BPS tools to simplify this process for users through a user-friendly interface.

Other issues remain to be addressed to increase the uptake of detailed occupant modelling in building simulation practice, which include:

- *Demonstrating the importance of occupant modelling to building simulation practitioners.* The ability to improve design robustness, and assess resilience under extreme conditions by modelling occupants' adaptive behaviour under multiple scenarios, should be demonstrated to designers to spark interest in detailed occupant modelling.
- *Verifying the accuracy of existing occupant models and developing new ones*. Research and development on occupant models is still at a very early stage, thus developing new and more robust ones must follow a more comprehensive and collaborative approach to address the exact needs of building simulation practitioners.
- *Updating building energy codes and standards.* Additional requirements to model occupants' actions and assess buildings' sensitivity to them, can ensure that practitioners will use these added features in BPS tools for detailed occupant modelling.

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