A Method for Exploring Occupant-related Uncertainty for Simulation-aided Office Building Design

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Abstract

Quantifying occupant-related uncertainty has been considered a major challenge during simulation-aided building design process. To this end, this paper outlines a reproducible method that aids designers in handling occupant-related inputs during the simulation-aided design process. The proposed method includes three main steps: (1) establishing occupant-related assumptions, (2) evaluating design performance based on the established occupant-related assumptions, and (3) reporting and communicating occupant-related uncertainty to stakeholders. The objective is to provide an easy-to-implement method that can be adopted by building design practitioners and assist in managing uncertainty by identifying opportunities to improve energy and comfort performance during the simulation-aided design process.

Introduction

It is widely recognized amongst researchers and building design practitioners that occupants are a major source of uncertainty during building design and operation (Delzendeh *et al.* 2017; Dong *et al.* 2018). This uncertainty causes the notable performance gap between simulated and actual performance (Gaetani *et al.* 2016; Hoes *et al.* 2009; Yan *et al.* 2017). This uncertainty results from occupant-related assumptions made during design and random/unexpected nature of occupants' behaviour during building operation.

Designers assumptions about occupants' presence and behaviour treats all occupants in all buildings of the same type alike. They usually assume that occupants are simplistic and deterministic systems that are present for a specified period of time, emit a prescribed amount of heat into space, and are homogenously distributed in the building (Gilani *et al.* 2016, 2019). Designers typically use occupant densities and schedules provided in building codes and standards such as the National Energy Code of Canada for Buildings (NECB) (NRC 2015). However, occupants do not use or occupy buildings the way designers assume. They arrive and depart buildings on different times, have different comfort preferences, and are heterogeneously distributed in buildings. Figure 1 demonstrates how occupants influence building design and performance through their interaction with building components and systems. In view of the above issues, the current occupant modelling approaches are considered inaccurate and outdated and require attention from researchers and building designers (Abushakra *et al.* 2004; Ouf *et al.* 2018).

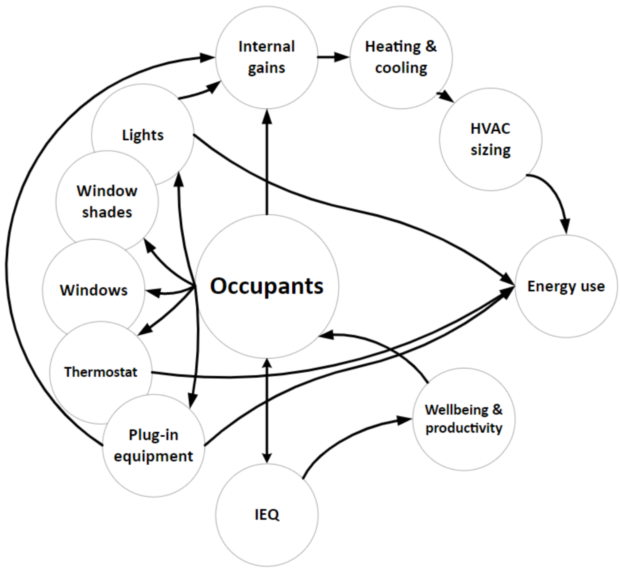

Figure 1: Occupants actual impact on building performance.

To address the consequences of occupant-related uncertainty, researchers have been investigating and quantifying its implications and pursuing improved modelling methods. One approach was to develop data-driven stochastic models in an attempt to accurately model occupants' presence and actions. For instance, statistical models were developed for occupants' lights use such as Lightswitch-2002 model by Reinhart (2004), and window opening by Haldi and Robinson (2009). However, these approaches are yet to be adopted by designers due to their complexity and generalizability as they were developed based on data from single offices under certain conditions (O'Brien *et al.* 2016; Schweiker *et al.* 2011).

Other researchers have worked on developing methods to account for occupants' uncertainty by applying adjustments to the current practice by designers. For example, Sun and Hong (2017) developed a simulation workflow to quantify the impact of occupants on potential energy savings from energy conservation measures (ECMs). The simulation workflow included simulating building energy model under three different occupant behaviour types: austerity, normal, and wasteful. The three behaviour types were developed to reflect three discrete levels of occupants' conscientiousness of the implications of their interactions with building components and systems. The workflow suggested reporting a range of ECM saving as guidance for design decision making.

On another front, Gaetani et al. (2017) argued in a study that the appropriate occupant modelling approach depends largely on the purpose of modelling. The study introduced a strategy to select the fit-for-purpose occupant behaviour modelling (FFP-OBm). The proposed FFP-OBm can be summarised in four major steps: (1) choosing model complexity, (2) defining diversity pattern of uncertain occupant behaviours, (3) sensitivity analysis, and (4) decision making. The strategy was tested on a case study on four office cubicles. Several types of occupant behaviours such as equipment, lighting, thermostat, and blinds use were studied. The results indicated that the strategy was useful in determining the required model complexity as it indicated that increased occupant behaviour modelling complexity is unnecessary in two of the four cases. The study concluded that the proposed methodology is still under development and it has the potential of being implemented in building performance simulation (BPS) tools to ease implementation by design practitioners (Gaetani *et al.* 2017).

Despite the ongoing efforts to develop an improved method to model occupants during design process, there are still several gaps that need to be addressed. Among them, most studies target improving occupant modelling within an energy modeller's scope. In addition, none of the proposed methods is based on practitioners' feedback on occupant modelling and occupant-related assumptions.

To this end, this paper presents a new method for occupant-centric building design which is based on results of a stakeholders' workshop, simulation-based study and the design process documentation of a real office building in Toronto. The method targets key stakeholders involved in building design process such as architects, engineers, and energy modellers. We did not limit the target audience of this method to energy modellers because in practice most of the critical design decisions are made by architects and engineers prior to the involvement of energy modellers (Méndez Echenagucia *et al.* 2015; Miles *et al.* 2001). The late involvement of energy modellers limits their influence on design to minimal changes such as changing glazing type or increasing wall insulation (Abuimara *et al.* 2019).

On the other hand, architects and mechanical engineers who join the design process at early stages can influence the most critical decisions, such as building form, layout and circulation, fenestration sizing and placement, and the heating, ventilation and air conditioning (HVAC) type and configuration. Occupant-related assumptions are typically used in making these decisions, albeit in a relatively coarse and conservative manner. For example, architects use the number of occupants in developing the building layout, planning for egress and determining the overall built-up area. Mechanical engineers use the number of people and their associated lighting and plug-in equipment loads to calculate heating and cooling loads and size HVAC accordingly. The proposed method's ultimate objective is to put occupants' considerations at the core of the building design process.

Methodology

Approach

The proposed method is built and validated upon the findings of a qualitative and quantitative studies conducted over a period of three years.

The qualitative study

The qualitative study was intended to document and evaluate the current practice in modelling occupants and to identify the needs, barriers and possible improvement approaches. The qualitative study included:

(1) A one-day stakeholders' workshop to obtain practitioners feedback on occupant modelling and occupant-related assumptions. The workshop topics included discussing the status quo, identifying the challenges and needs, and proposals for advancing the current practice.
(2) Design process documentation of a case study office building located in Toronto, Canada. The documentation took place through interviews with project stakeholders (owner, architect, mechanical engineer, and energy modeller).

The quantitative Study

The quantitative study was a simulation-based investigation to evaluate the impact of occupant-related assumptions on the design process outcomes. The quantitative study included:

(1) the establishment of an energy model of the case study based on design documents and energy model created by energy modeller,
(2) conducting occupant-centric parametric analysis to assess the impact of occupant related assumptions on shortlisting design parameters /ECMs,
(3) an occupant-centric design optimization study to evaluate the impact of occupant-related assumptions on selecting optimal design parameters/ECMs,
(4) and a study of the implications of interzonal occupants' distribution diversity on comfort and building energy use.

Case study

The case study is an office building located in Toronto, Canada. Figure 2 shows the model for a typical office floor in the building with two different zoning strategies that were used throughout the investigation. Table 1 provides details about the building components and systems used to create the energy model. These details were obtained from the building design documents and energy model created by the designer.

Two different zoning strategies were used: five-zones model and fifteen-zones model. The five-zones model represents the zoning strategy used by the energy modeller and was used in our investigation to assess impact of occupant-related assumption on selection of design parameters (i.e. ECMs) based on their ranking and potential energy savings. The fifteen-zones model was used to assess the impact of occupants' spatial distribution in buildings on occupants' comfort.

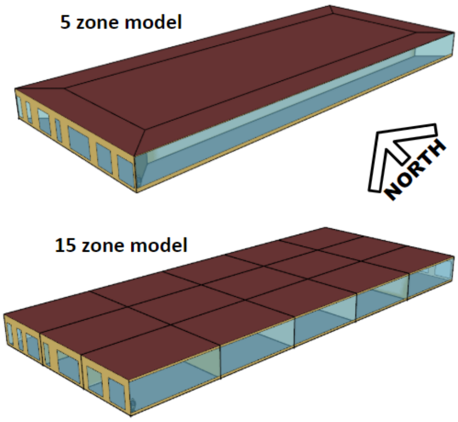

Figure 2:The case study models.

Table 1: Case study specifications.

Item	*Description*
Floor area	1728 m^2
Window to wall ratio (WWR)	46.5% (please break this down by orientation, since its not visible in the figure – sorry, I should have written this as a comment…)
HVAC	Roof-top package unit, natural gas fired condensation boiler, zone level VAV with reheat, hydronic baseboard heaters
Economizer	Differential dry-bulb airside economizer
Heat recovery	Air-to-air heat exchanger
Wall	U -value = 0.245 $W/m^2{\cdot}K$
Window assembly	U-value = 1.9 $W/m^2{\cdot}K$ SHGC = 0.33

The three-step method

An overview of the proposed three-step method is shown in Figure 3.

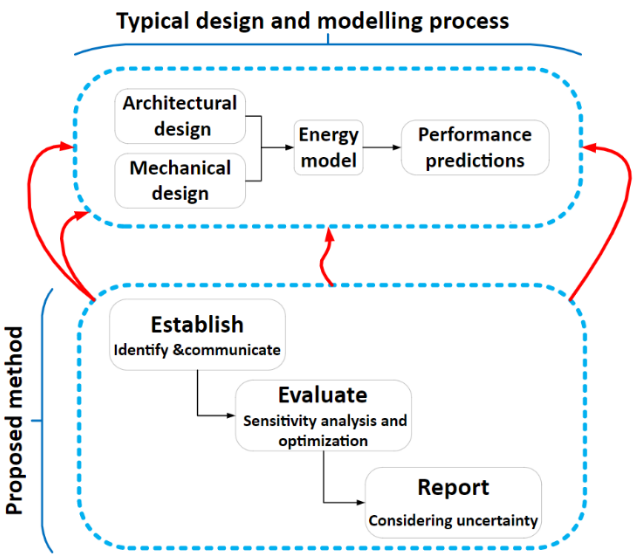

Figure 3:Illustration of how the proposed three-step occupant modelling process can feed in and improve design process.

The first step is to establish occupant-related assumptions which are case specific. The second step is to evaluate the design outcomes taking into consideration the assumptions established in the first step. The third step includes reporting design outcomes considering uncertainty from occupants and occupant-related assumptions. The three-step method is presented for implementation throughout the design process and not only during the energy modelling scope.

1. Establishing and communicating assumptions

The first step of the proposed method is establishing occupant-related assumptions which includes identifying and communicating these assumptions to all design stakeholders. Occupant-related assumptions are generally overlooked during the design process and in particular at the early design stages (Abuimara *et al.* 2018b; Ouf *et al.* 2018; Yan *et al.* 2017).

At early design stages, architects typically use the number and type (e.g. students, office workers) of occupants to determine building size, develop project program, layout, and plan circulation and egress. Mechanical engineers use people heat gains, and lighting and plug-in equipment loads to perform sizing calculation for the selection of HVAC equipment. However, little attention is paid at this early stage for the possible variations of number of people, occupied periods, plug-in equipment and lighting loads, and use of different window shading devices. Table 2 provides examples of common occupant-related assumptions made by designers against reality.

Provided that decisions at early design stages provide an opportunity for initial and operation cost savings (Attia *et al.* 2012), designers need to dedicate sufficient time and effort to identify and define building use patterns including the number of people, time of occupancy, possible domains of interaction with building components and systems (e.g. windows, blinds, thermostats).

Lack of information about occupants is a common challenge that designers face at early design stages of new buildings. Dealing with this challenge requires efficient communication with owner and occupants, if possible.

Considering occupant-related assumptions on early design team meetings is of great importance as it provides the opportunity to discuss their implications on different design tasks. In addition, it ensures that all stakeholders share their experience, thoughts, and plans regarding the role of occupant-related assumptions in design tasks.

Table 2: Occupant related assumption in practice vs reality.

Type of assumption	*Default assumption*	*Reality*
Occupants' presence	Identical schedules for all zones and buildings from same type	Different schedules
Occupants' density	Constant number of people per m^2 based on a code or standard	Differs between buildings and tenants in the same building

Occupants' distribution	Homogeneous	Heterogonous
Lighting use	Constant W/m^2 as per building code	Differs based on building use and type of fixtures
Plug-in equipment	Constant W/m^2 as per building code	Differs based on building use and type of plug in equipment
HVAC operation	Operating hours from 5 am to 10 pm as per building code	Differs based on operators' decisions
Temperature setpoints	Winter (setpoint 22°C, setback 16 °C) Summer (setpoint 24°C, no cooling during unoccupied hours)	Differs based on operators' decisions and occupants' interactions with thermostats
Shading type and operation	Always open	Different patterns of use based on occupants' behaviour (avoid glare, privacy)

Another essential practice during the first step of the proposed method and throughout the design process is to communicate occupant-related assumptions to other design stakeholders to avoid discrepancy. An example of discrepancy in assumptions amongst design stakeholders was identified during documenting the case study design process. Figure 4 demonstrate the disagreement of assumptions made by different designers.

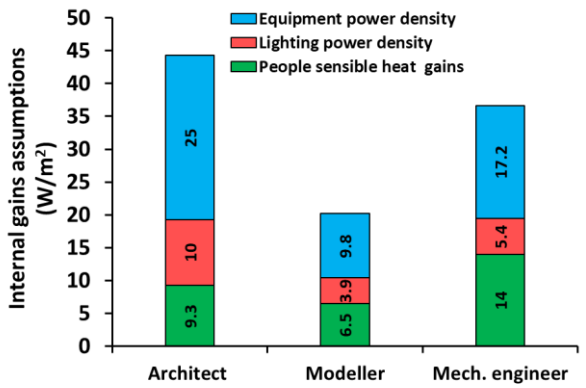

Figure 4:Discrepancy in occupant-related assumptions among design stakeholders.

Thus, the first step of the proposed method should include the following activities:

(1) Identifying occupant-related assumptions based on project type and owner requirements. This includes considering all design milestones, components, and systems that are related to occupants' behaviour.

(2) Collecting occupant-related data from all possible sources. Sources include owner, occupants or occupants' representatives, codes and standards (considering flexibility offered by these codes and standards), and similar buildings in operation. The goal here is to collect as comprehensive information as possible.

(3) Organizing and classifying the collected information to ease the selection of the fit-for-purpose information for modelling.

(4) Developing an information documentation and sharing mechanism to ensure that all design stakeholders are using the same occupant-related assumptions throughout the design process.

2. Evaluating design

Following the establishment of occupant-related assumptions -including communicating them to other design stakeholders- design performance needs to be evaluated under different occupant scenarios. Evaluation here refers to testing and further developing building design under variable occupant scenarios. Variable occupant scenarios can be alternative schedules (e.g. low occupancy, high occupancy, and average occupancy) along with lighting use and plug in equipment use scenarios. It can also include varying the people density, lighting power density, plug-in equipment loads, temperature setpoints, and window blinds control type.

As designers typically choose to abide with building code, building codes (at least in the Canadian context) offer reasonable flexibility when it comes to occupant-related assumptions. For example, the NECB allows adjustments to occupant-related assumptions as long as same assumptions are used in both the building under design and the reference building (NRC 2015).

To have a method that is compatible with designers' approach, this phase has to follow the same workflow of the standard design process. To this end, the simulation-based investigation was conducted in phases that replicates the actual design development workflow. Starting with establishing a representative energy model, selecting design parameters/ECMs that are commonly used in practice (upon a practitioner advice), conducting parametric analysis to shortlist the influential design parameters/ECMs, and design optimization. To this end, this phase includes conducting occupant-centric parametric analysis and design optimization, and evaluation of the impact of variable occupant scenarios on occupants' comfort. Conducting occupant-centric parametric analysis is the process of evaluating design parameters/ECMs in terms of energy use savings under variable occupancy scenarios.

Parametric analysis is a common practice in the process of searching for most influential ECMs. However, this process indicates deterministic savings potential per design parameter/ECM and does not account for the impact of variations of occupancy and occupant behaviour. Therefore, parametric analysis needs to be verified under variable occupant scenarios to ensure the selection of ECMs that suit design objectives or that demonstrates robustness to occupant scenarios.

Figure 5 and Figure 6 present results of occupant-centric parametric analysis conducted on the case study model. In this parametric analysis, the impact of occupant-related assumptions on the potential energy use savings of ECMs were evaluated. The design parameters used in the parametric analysis included envelop-related design parameters such as window glazing type and systems-related parameters such as demand-controlled ventilation (DCV). Figure 5 indicates the results of testing the sensitivity of window type selection to occupant-related assumptions.

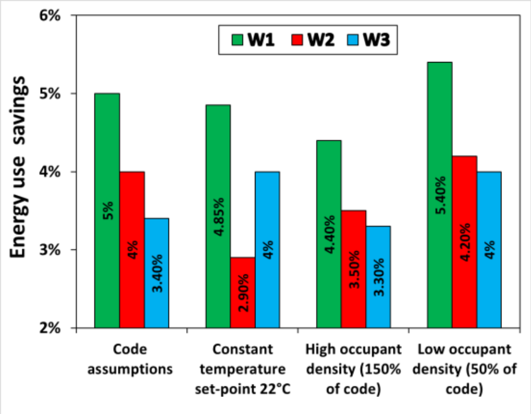

Figure 5: Sensitivity of energy saving potential from three window assemblies to the different occupant related assumptions. W1(U=1.62 W/m²·K, SHGC=0.39), W2(U=2.04 W/m²·K, SHGC=0.58), and W3(U=1.47 W/m²·K, SHGC=0.25).

The results indicate moderate but noticeable sensitivity of window glazing type to four different occupant-related assumptions. While Figure 6 demonstrates substantial sensitivity of the deployment of demand-controlled ventilation (DCV) to occupant-related assumptions as potential energy use savings differed by a factor of five or more. Detailed results of this study were published in Abuimara et al. (2019).

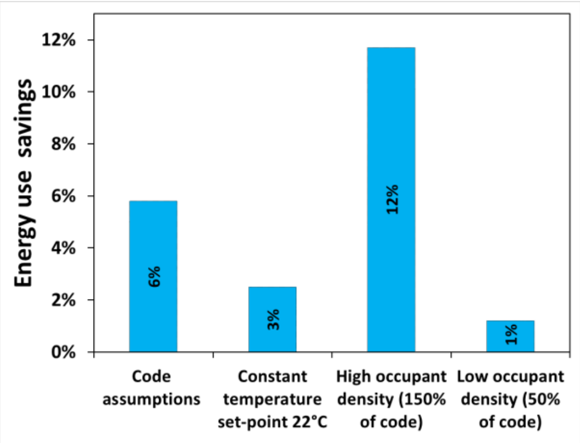

Figure 6: Sensitivity of energy saving potential from DCV to the different occupant related assumptions.

In addition to the occupant-centric parametric analysis, this step includes occupant-centric optimization to assess the impact of variable occupant scenarios on selecting combinations of design parameters/ECMs to produce optimal design. Optimization is typically the stage that follows parametric analysis where designers use combinations of shortlisted design parameters/ECMs to produce design alternatives and select the optimal combination.

In design optimization, designers usually do not consider the impact of occupant-related assumptions and conclude the optimization process to a single optimal design. However, the results of the occupant-centric optimization conducted on the case study model revealed the selection of optimal design was highly sensitive to different occupant scenarios. In the process, occupant scenarios were generated by varying occupancy, lighting, and plug-in equipment schedules. Ten different design parameters/ECMs were used in the optimization process. Figure 7 presents sample results of design optimization under four different occupant scenarios including the standard scenario typically used by designers. The results indicate differences in HVAC energy use per occupant scenario compared to the standard assumptions (i.e. code scenario). The differences in HVAC energy use intensity (EUI) ranged from 4% to 15%.

In addition to HVAC energy performance, occupant-centric optimization results can be used to derive rules for selecting optimal design parameters/ECMs. These rules can be derived using decision trees of multiple optimization results.

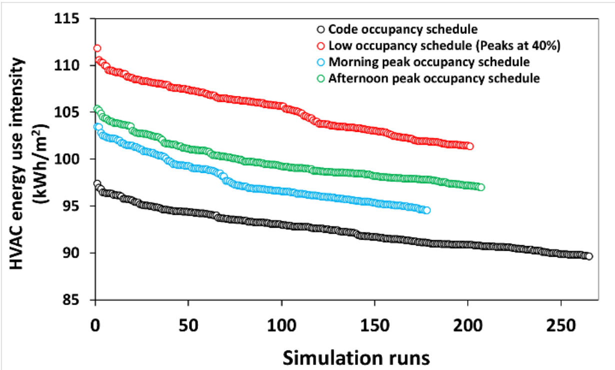

Figure 7: HVAC EUI of design optimization from four optimization runs using four different occupancy schedule scenarios. Each scatter plot represents an optimization run for an occupant scenario. The length of the scatter plot indicates where the optimization run converged to the optimal solution.

Figure 8 shows an example of rules for selecting the size of sidefin shading for a west-facing window. The rules were derived based on optimization results of the case study window design under sixty-four different occupant scenarios. Figure 8 also shows the importance of occupant-related assumptions on selecting certain optimal design parameters/ECMs.

On the other hand, Figure 9 demonstrates that other design parameters/ECMs can show robustness to occupant scenarios as one type of window assembly was found to be the optimal selection for all occupant scenarios. It is worth mentioning here that the results in Figure 8 and Figure 9 shows that one window type is optimal regardless of occupants but should be treated as case specific and should not be generalized without further investigation. However, the methodology followed can be used in the case of office buildings in Canada and similar contexts.

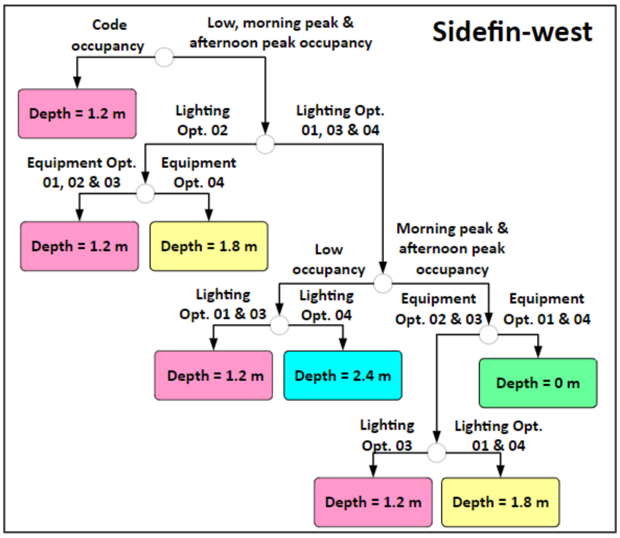

Figure 8: Sample decision tree demonstrates guidelines for selecting optimal sidefin shading size on west-facing façade.

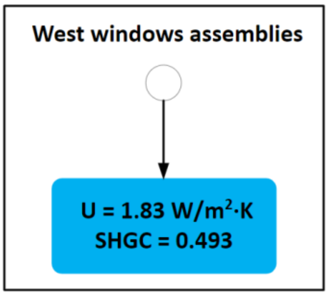

Figure 9: Sample decision tree demonstrates guidelines for selecting optimal window assembly material for west-facing façade.

Figure 10 presents the range of EUI for the sixty-four optimal designs of the same case study occupant-centric optimization. The boxplot demonstrates the substantial variation in the energy performance of optimal designs under different occupant scenario.

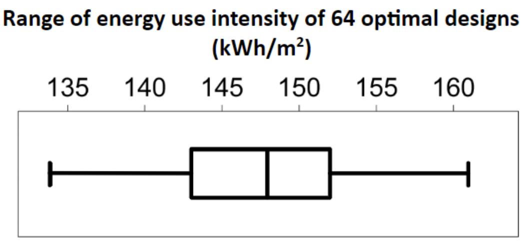

Figure 10: Optimization results distribution for sixty-four different occupant scenarios. The distribution is based on the sixty-four optimal designs.

On another front, during this step of the proposed method, attention should be paid to evaluating the implications of occupants' spatial distribution on comfort. Standard occupant-related assumptions consider that occupants are homogeneously distributed in the building while in reality occupants are heterogeneously distributed in the building as a result of usually having different tenants with various staffing and activities in buildings. This heterogeneous distribution is associated with an elevated level of discomfort as overpopulated zones might experience overheating and underpopulated zones will experience underheating. To verify this, the case study was simulated under variable occupants' distributions. The results indicated a substantial increase (by a factor of five) in the number of discomfort occupied hours. In addition, the heterogeneous distribution resulted in a moderate change in EUI. Figure 11 shows the results of simulating the case study model under ninety-three different occupants' distribution scenarios.

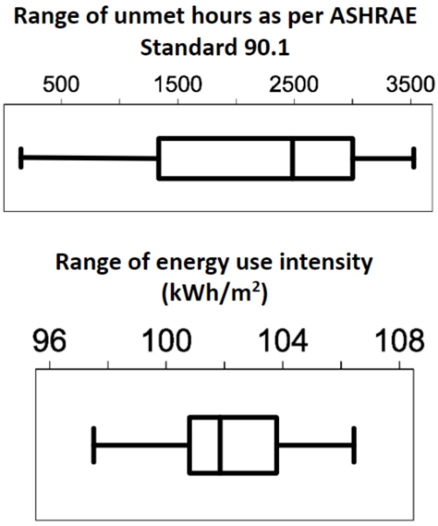

Figure 11: Impact of occupants' distribution on energy (top) and comfort performance (bottom).

Therefore, the proposed method suggests the following activities in the second step:

(1) Iterating parametric analysis under variable occupant scenarios to verify the selection of design parameters / ECMs. Here, we propose testing at least two extreme occupant scenarios (low occupancy and high occupancy) in addition to standard assumptions.
(2) Including occupant-related assumptions as one of the optimization variables to ensure the selection of robust or adaptive design parameters.
(3) Incorporating variable occupant-related assumptions in comfort studies during the development of building design.

3. Reporting design outcomes

Reporting design outcomes is a process that should occur at multiple points starting with presenting an architectural schematic design to clients and ending with final reports and issued for construction drawings. Designers typically tend to report design outcomes with certainty and avoid reporting uncertainty to sustain clients' confidence. This designers' behaviour was reported by practitioners in stakeholders' workshop administered by the authors (Abuimara *et al.* 2018a) and in an international survey by O'Brien *et al.* (2016). However, this behaviour might have an adverse effect when uncertainty in design outcomes leads to a performance gap during operation.

Therefore, we argue here that owner engagement is of great significance when it comes to occupant-related assumptions as it avoids forgoing opportunities in making informed design decisions (Gunay *et al.* 2016).

In early design stages, reporting occupant-related assumptions, their associated uncertainty, and their use in design assists key stakeholders, such as building owners, in making informed decisions. For example, deciding window-to-wall ratio (WWR), adding fixed exterior shading, or selecting the HVAC type, are decided during early design stages and can be influenced by occupant-related assumptions.

In addition, reporting the implications of occupant-related assumptions on design facilitates persuading clients to accept implementing monitoring infrastructures such as submetering of different tenants and different end use categories (e.g. plug-in equipment). Submetering can help identify opportunities to reduce energy use, through occupant engagement and better controls (Bennet & O'Brien 2017).

Generally, the third step of the proposed method suggests the following while reporting design outcomes:

(1) Reporting occupant-related uncertainty to design stakeholders and most importantly to building owner.
(2) Demonstrating advantages of adopting adaptive technologies such as DCV and lighting controls.
(3) Introducing benefits of robust design solutions (e.g. fixed exterior window shading) against disadvantages of using occupant-sensitive ones (e.g. interior blind shades).
(4) Presenting the impact of selecting certain design solutions (e.g. high WWR, full automation of building) on comfort.
(5) Reporting results of worst cases scenario, base case (standard assumptions), and best-case performance instead of deterministic values. In addition, correlating the performance range to an occupancy range can make a solid case in front of clients.

Conclusion

This study outlines a method for accounting for occupant-related uncertainty throughout building design process. The proposed method consists of three steps: establishing occupant-related assumptions, evaluating design under the established assumptions, and reporting design outcomes considering these occupant-related assumptions.

The proposed method is designed for implementation by all key design stakeholders and is not limited to the energy modelling scope. A fundamental aspect of the proposed method is initiating design process based on a unified set of occupant-related assumptions that are shared among all key stakeholders. In addition, the proposed method is not a standalone method, rather to be incorporated in integrated design process by placing occupants at the core of the process. The proposed method was developed based on findings of research conducted over a three-year project and included stakeholders' feedback, design process documentation, and a simulation-based investigation.

The stakeholders' workshop findings and the documentation findings were inline in terms of emphasising the need to improve the current way of handling occupant-related assumptions. The improvement includes considering accurate occupant-related assumptions starting from early design stages where all critical design decisions are made. The findings also indicated the need for developing an effective information exchange mechanism among design stakeholders.

The simulation-based investigations findings indicated selecting design parameters/ ECMs and deciding the optimal ones can be in several cases sensitive to occupant-related assumptions such as DCV. While some other design parameters/ ECMs demonstrated robustness to occupant related assumptions such as increasing building envelop insulation. Overall, the findings underscored the importance of occupant-related assumptions and served as basis for the method presented in this paper.

In order to facilitate the implementation of the proposed method, future work should consider the following:

(1) Applying the method to buildings of different types and in different contexts to verify generalizability.
(2) Developing a tool or a web application that can simulate a base model under multiple occupant scenarios and provide comparison of results. Alternatively, incorporating this feature in BPS tools.

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References

Abuimara, T., O'Brien, W., Gunay, B., Abdelalim, A., Ouf, M., & Gilani, S. (2018a). Modelling Occupants in Buildings: Stakeholders' Workshop on Current Barriers, Challenges and Needs. In *Proceedings of eSim 2018, the 10th conference of IBPSA-Canada*, Montreal,Canada, pp. 312–320.

Abuimara, T., O'Brien, W., Gunay, B., Burpee, H., & Day, J. K. (2018b). Designing for Occupants : A Review of the Integrated Design Practice. In *2018 ACEEE Summer Study on Energy Efficiency in Buildings*, Pacific Grove, CA, pp. 8 (1-12).

Abuimara, T., O'Brien, W., Gunay, B., & Carrizo, J. S. (2019). Towards occupant-centric simulation-aided building design: a case study. *Building Research & Information*, **47**(8), 866–882.

Abushakra, B., Haberl, J. S., & Claridge, D. E. (2004). Overview of existing literature on diversity factors and schedules for energy and cooling load calculations. In *2004 Winter Meeting - Technical and Symposium Papers, American Society of*

Heating, Refrigerating and Air-Conditioning Engineers, pp. 169–181.

Attia, S., Gratia, E., De Herde, A., & Hensen, J. L. M. (2012). Simulation-based decision support tool for early stages of zero-energy building design. *Energy and Buildings*, **49**, 2–15.

Bennet, I. E., & O'Brien, W. (2017). Office building plug and light loads: Comparison of a multi-tenant office tower to conventional assumptions. *Energy and Buildings*, **153**, 461–475.

Delzendeh, E., Wu, S., Lee, A., & Zhou, Y. (2017). The impact of occupants' behaviours on building energy analysis: A research review. *Renewable and Sustainable Energy Reviews*, **80**, 1061–1071.

Dong, B., Yan, D., Li, Z., Jin, Y., Feng, X., & Fontenot, H. (2018). Modeling occupancy and behavior for better building design and operation—A critical review. *Building Simulation*, **11**(5), 899–921.

Gaetani, I., Hoes, P.-J., & Hensen, J. L. M. (2017). Introducing and testing a strategy for fit-for-purpose occupant behavior modeling in a simulation-aided building design process. In *IBPSA Building Simulation Conference*, pp. 761–768.

Gaetani, I., Hoes, P.-J., & Hensen, J. L. M. M. (2016). On the sensitivity to different aspects of occupant behaviour for selecting the appropriate modelling complexity in building performance predictions. *Journal of Building Performance Simulation*, **10**(5–6), 1–11.

Gilani, S., Goldstein, R., Breslav, S., Tessier, A., & O'Brien, W. (2019). Building performance implications of occupant mobility. In V. Corrado & A. Gasparella, eds., *Proceedings of Building Simulation 2019: 16th Conference of IBPSA*, Rome, Italy.

Gilani, S., O'Brien, W., Gunay, H. B., & Carrizo, J. S. (2016). Use of dynamic occupant behavior models in the building design and code compliance processes. *Energy and Buildings*, **117**(November), 260–271.

Gunay, H. B., O'Brien, W., Beausoleil-morrison, I., Gunay, H. B., Brien, W. O., & Beausoleil-morrison, I. (2016). Implementation and comparison of existing occupant behaviour models in EnergyPlus, **1493**(March). doi:10.1080/19401493.2015.1102969

Haldi, F., & Robinson, D. (2009). Interactions with window openings by office occupants. *Building and Environment*, **44**(12), 2378–2395.

Hoes, P., Hensen, J. L. M., Loomans, M., De Vries, B., & Bourgeois, D. (2009). User behavior in whole building simulation. *Energy and Buildings*, **41**(3), 295–302.

Méndez Echenagucia, T., Capozzoli, A., Cascone, Y., & Sassone, M. (2015). The early design stage of a building envelope: Multi-objective search through heating, cooling and lighting energy performance analysis. *Applied Energy*, **154**, 577–591.

Miles, J. C., Sisk, G. M., & Moore, C. J. (2001). The conceptual design of commercial buildings using a genetic algorithm. *Computers & Structures*, **79**(17), 1583–1592.

NRC. (2015). *National Energy Code of Canada for Buidings*, Ottawa, Canada.

O'Brien, W., Gaetani, I., Gilani, S., Carlucci, S., Hoes, P.-J., & Hensen, J. (2016). International survey on current occupant modelling approaches in building performance simulation. *Journal of Building Performance Simulation*, **10**(5–6), 653–671.

Ouf, M., O'Brien, W., & Gunay, H. B. (2018). Improving occupant-related features in building performance simulation tools. *Building Simulation*, **11**(4), 803–817.

Reinhart, C. F. (2004). Lightswitch-2002: a model for manual and automated control of electric lighting and blinds. *Solar Energy*, **77**(1), 15–28.

Schweiker, M., Haldi, F., Shukuya, M., & Robinson, D. (2011). Verification of stochastic models of window opening behaviour for residential buildings. *Journal of Building Performance Simulation*, **5**(1), 55–74.

Sun, K., & Hong, T. (2017). A Framework for Quantifying the Impact of Occupant Behavior on Energy Savings of Energy Conservation Measures A Framework for Quantifying the Impact of Occupant Behavior on Energy Savings of Energy Conservation Measures. *Energy and Buildings*, **146**, 383–396.

Yan, D., Hong, T., Dong, B., … Feng, X. (2017). IEA EBC Annex 66: Definition and simulation of occupant behavior in buildings. *Energy and Buildings*, **156**, 258–270.