Roadmap for Occupant Modelling in Building Codes and Standards

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Abstract: *Occupants have emerged as a significant source of uncertainty and a leading reason for discrepancies between building performance simulation (BPS) predictions and measured performance. However, occupant modelling in BPS is a relatively young research area and has barely emerged into practice or building codes and standards. Meanwhile, occupant comfort and the impact of behaviour typically remain an afterthought in new building construction – in large part because of the simplicity with which they are treated in building codes and BPS tools. This paper serves as a brief overview of a roadmap that is being developed to guide the path for more realistic occupant modelling in building codes and standards. The paper draws from a survey of BPS users, a stakeholder workshop, and the literature in order to pave the road towards better occupant modelling. The roadmap includes goals, milestones, gaps and barriers, action items, and priorities and timelines.*

Keywords: *occupant modelling and simulation, building performance simulation, building energy codes and standards, roadmap.*

INTRODUCTION

A growing body of building performance simulation (BPS) researchers view occupants as a leading cause of discrepancies between BPS predictions and reality. As such, hundreds of researchers (e.g., members of IEA EBC Annex 66) are working on occupant modelling and simulation to "close the gap" (Sun, Yan et al. 2014). However, another camp of BPS researchers and users has argued that the role of BPS is to predict relative performance (Hensen and Lamberts 2012; Burton 2014). The performance-based compliance path of the current National Energy Code of Canada for Buildings (NECB) (herein, the "Code") relies on annual building simulations to demonstrate that the proposed building achieves equal or better energy performance than a reference building (Sentence 8.4.1.2.(2)) (NRC, 2015). This implies that relative performance predictions are adequate for code compliance purposes. For instance, the Code allows great flexibility on occupant modelling assumptions, so long as they are the same for the reference and design building. For internal loads, Sentence A-8.4.2.7.(1) states "While any internal load values are permitted to be used, those default values should be used in the absence of better information." Reasonably applied deviations from the defaults values are difficult to disprove for the modeller and code official alike. ASHRAE Standard 90.1-2016 (ASHRAE, 2016) takes a stricter stance that the local code authority must approve all deviations from standards; personal communication with modellers in many jurisdictions suggest that strictness varies widely in different locales.

In contrast to the practice focusing on relative performance between the proposed and reference cases, a recent survey of international BPS tool users and developers (O'Brien, Gaetani et al. 2016) suggested that just over half of participants do not agree with the statement "It does not matter if assumptions about occupants in BPS tools fully represent real occupants as long as occupants are represented the same way in all design variants." Ouf and O'Brien (2018) demonstrated the consequence of providing flexibility on occupant modelling: predicted energy savings from various energy efficiency measures can be greatly manipulated by adjusting occupant-related schedules. For instance, energy efficient lighting is more beneficial to annual lighting electricity use reductions if lights are assumed to be on for longer each day.

The current occupant modelling approaches can also have unintended consequences, such as leading design teams towards unwise decisions or operating conditions that increase absolute energy use. Gilani, O'Brien et al. (2016) further showed that simple occupant modelling assumptions may lead to significantly different optimal building designs than if occupants are more accurately characterized. Thus, we argue in this paper that absolute accuracy –in addition to relative accuracy—is critical, as is becoming evident by detailed studies (such as those above). Accuracy in this paper is defined as absolute (not relative) unless otherwise stated.

This paper summarizes a comprehensive roadmap for incorporating occupant modelling into building energy codes and standards. The roadmap follows guidelines laid out by the International Energy Agency (IEA, 2014) which recommends a stakeholder workshop prior to roadmap development. Thus, a stakeholder workshop involving about 30 diverse experts was held in Ottawa on May 1, 2017. The workshop outcomes are described in a companion eSim 2018 paper (Abuimara, O'Brien et al. 2018). The remaining stages of the roadmap are summarized in this paper and shown in Figure 1.

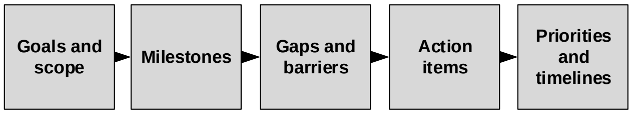

Figure 1: Roadmap outline

The focus of this paper and the underlying project is Canadian office buildings and the NECB, though the findings may generally hold true for other building types, climates, and other codes and standards.

BACKGROUND

Occupancy (i.e., presence) and occupant behaviour modelling in the performance path of the Code is nearly exclusively limited to schedules and densities (e.g., lighting power density and occupant density). The product of the schedule (often expressed as a diversity factor with a maximum value of unity) and the corresponding density is used in the model. For instance, a schedule value of 0.9 at noon and lighting power density of 7.5 W/m^2 results in 6.75 W/m^2 of lighting power for that hour. Researchers and practitioners have observed that current schedule values are several decades old and tend to be conservative (Duarte, Van Den Wymelenberg et al. 2013).

So-called deterministic models (i.e., fixed schedules) have been criticized in the literature for two additional reasons: (1) they neglect uncertainty from occupants and (2) they neglect two-way interactions between occupants and buildings (O’Brien and Gunay 2015). However, these criticisms are founded on the premise that the overarching objective of BPS is to accurately predict building performance and that accuracy is paramount to time and modellers’ skills and knowledge. In the context of building codes, practicality is also necessarily a priority. Current BPS user training tends to be tool-specific, shallow, and focused on application rather than underlying principles (e.g., numerical modelling of heat transfer through a surface) (Beausoleil-Morrison and Hopfe 2016). Increasing complexity of building codes means more room for error, potential modeller education requirements, more difficult model reviews, loophole opportunities, and increasing difficulty in finding a one-size-fits-all approach. The Code Preface lays out a number of questions used to assess the validity of modifications to the Code. They focus on the ability of professionals to implement requirements; enforceability of new requirements; cost of implementation; implications on policy; and, consensus among all stakeholders. Occupant-related modifications should also have a demonstrable benefit over the current requirements. Moreover, through informal communication with the Code committee, it came to light that building features that rely on behaviour to perform well are discouraged from inclusion in the Code.

However, complete omission of uncertainty and dynamic characteristics of state-of-the-art occupant modelling may ultimately result in buildings that are less robust, less comfortable, and have sub-optimal energy design (O’Brien and Gunay 2015). Moreover, occupants’ simplistic treatment in the Code permits the continued narrative that occupants are a passive design constraint or boundary condition rather than active participants in the energy and comfort performance of a building. As an illustrative example, the Code requires that HVAC equipment sizes be incrementally increased if discomfort exceeds a given threshold; rather than pursue a wealth of potential occupant-centric solutions to address discomfort, such as providing adaptive opportunities (e.g., operable windows and exterior solar shading). Similarly, the *unmet hours* discomfort metric reinforces the notion that occupants are passive and ignores the past decades of advancement that show adaptive opportunities greatly increase occupants’ tolerance for a larger indoor temperature range (Brager and de Dear 1998). In general, the authors’ experience at design meetings is that occupants are insufficiently discussed, considering they are the driving purpose for buildings. Until clients demand it, one of the ways to drive better occupant-centric design is through building codes.

Some major questions about occupant modelling in the context of the NECB and other building codes and standards in general include:

- What are the real consequences of current occupant modelling approaches?
- What characteristics are needed from occupant models (e.g., energy impact and number of adaptive actions)?
- In what ways should improved occupant modelling be implemented into the Code?

Occupant model categories

In general, there are four categories of occupant models, as outlined in Table 1 and illustrated in Figure 2. Static models are those for which occupants are treated as inputs and are not affected by the building. Dynamic models are those for which the two-way interactions between occupant and buildings are modelled such that occupants are affected by and respond to the building and conditions (e.g., discomfort). Deterministic models are fixed, in that they yield the same results after each simulation run. Stochastic (random/probabilistic) models yield different results each time a building simulation is run. Stochasticity can be introduced in two ways: (1) at the beginning of a simulation, when occupant parameters or traits are selected from a probability distribution, and/or (2) during run time.

Table 1: The four categories of occupant models and the relevant examples

Static-deterministic (e.g., a fixed lighting schedule)	**Static-stochastic** (e.g., a fixed lighting schedule that is multiplied by a randomly-selected coefficient before each simulation)
Dynamic-deterministic (e.g., a light use model that predicts that lights are turned on below a fixed illuminance threshold)	**Dynamic-stochastic** (e.g., a light use model with a turn-on probability that is between zero and one over a wide range of illuminances)

A full review of occupant-related code requirements is provided in the Gaps and Barriers section. Some example occupant models from codes and standards are summarized in Table 3: Examples of occupant-related code requirements

Code/standard	Model	Model type
IES LM83-2012 (used for LEED) (IESNA 2012)	Window shades	Threshold (dynamic-deterministic)
NECB 2015	Window shades	Always open (static-deterministic)
NECB 2015	Occupancy	Schedule (static-deterministic)

The vast majority of models used in codes and standards are static-deterministic. In contrast, recent scientific literature is focused on dynamic-stochastic that are based on small samples (tens) and mostly aimed at the room-scale. This misalignment can be partly explained by the fact that few researchers have discussed modelling objectives in the context of practical application. Stochastic models are popular in the research community because they predict levels of uncertainty, but this may not be a reasonable expectation for building codes, for which the main objective is to demonstrate code compliance in simple terms (e.g., relative energy use to a code-minimum building). The strengths and weaknesses of each modelling approach are summarized in Table 2.

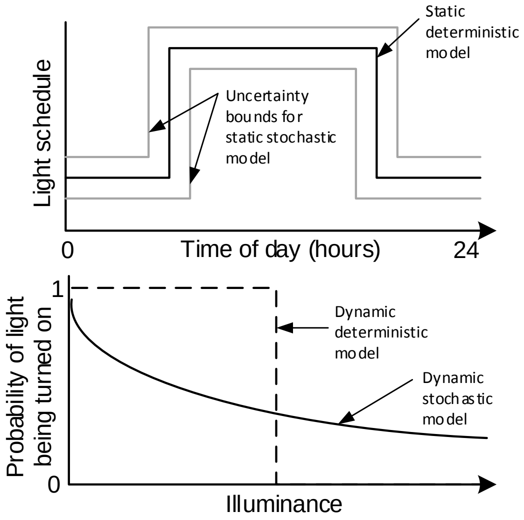

Figure 2: Illustrative examples for four model types: static models (top) and dynamic models (bottom).

Table 2: Strengths and weaknesses of the four categories of occupant models

Model	Strengths	Weaknesses
Static	Simple and suitable for non-adaptive domains (e.g., occupancy, office equipment use)	Neglects impacts of building design on occupants' adaptive actions, and vice versa
Dynamic	Provides understanding of impact of building design on behaviours, and vice versa; allows evaluation of occupant-sensitive design alternatives	Requires greater model detail (e.g., room-scale temperature and illuminance)
Deterministic	Yields the same result for each simulation and thus only requires a single simulation	Does not facilitate characterization of building performance uncertainty
Stochastic	Provides range of feasible results and inter-occupant diversity	Requires approx. 50 to 100 simulations to characterize

		distribution of results

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GOALS AND SCOPE

The main underlying goal of this roadmap is to use building codes to mandate greater emphasis on occupant-related considerations to achieve:

- more accurate energy predictions based on more realistic occupant modelling;
- improved occupant comfort, health, and productivity;
- improved building design and usability; and
- recognition of buildings' ability to adapt to variable occupancy and occupant behaviour.

Specifically, though beyond the current scope, to support all compliance paths (prescriptive, trade-off, and performance) of building codes, the most suitable approach for all occupant-related domains (e.g., occupancy and manual lighting control) shall be determined to balance effectiveness and practicality. The occupant modelling method(s) shall be accompanied by recommendations for incorporating them into the building code. The goal of this roadmap is to reach the point of making evidence-based recommendations based on current knowledge, while identifying future research and development needs.

In the current scope, office occupants are building users whose primary purpose is to carry out workplace activities; they are not building operators. Also, occupant comfort modelling for its own sake is not a priority unless it is a predictor for energy-related behaviours.

MILESTONES

Key milestones to achieve the above goals include:

1. For each occupant-related domain, compile a comprehensive list of current specifications required by the Code.
2. Assess the relative energy impact of occupancy and occupant behaviours across all major Canadian climatic regions in order to prioritize their incorporation into the Code and to identify future research needs.
3. For each occupant-related domain, assess the most suitable method(s) to incorporate said domain into building codes (e.g., updated schedules, new prescriptive requirements).
4. For code modifications, determine specific implementation details such as wording and values).
5. Test new code requirements and modify as required.
6. Propose code changes to the Canadian Commission on Building and Fire Codes (the committee responsible for writing the NECB).

GAPS AND BARRIERS

Four categories of gaps and barriers regarding occupant modelling requirements in the Code are investigated: scope of occupant-related domains that are specified, current schedule and density values, occupant modelling approaches, and procedural requirements.

Gap 1: Current domains

The Code's coverage of the primary occupant-related domains is summarized in Table 4. Not all listed items directly impact energy use (e.g., clothing level). However, for instance, clothing is an important predictor for thermal comfort, which in turn can be used to predict window opening and thermostat adjustment actions.

To date, there has not been an exhaustive study to quantify the relative importance of the listed behaviours across building types, climates, and technologies. A limited number of specific simulation and in situ-based studies have revealed the impact of occupants (Haldi and Robinson 2011). However, prioritizing modifications to building codes will require a comprehensive understanding of the modelling assumptions that are most sensitive to occupants. Put differently, we need to understand the consequences of making poor occupant modelling assumptions and prioritize building code modifications accordingly.

Understanding the interrelationships between domains and the corresponding modelling approach is a significant gap in the literature. For instance, order of adaptive actions is not well understood. For instance, if an occupant faces overheating, will they open a window, turn on a fan, or lower the thermostat setpoint first? The answer is likely complex and depends on effort, effectiveness, cost, permanent, and other contextual factors.

The relative importance of each domain of occupant modelling across climates is non-trivial. In general, predicting internal gains accurately is most important for mild climates (e.g., Victoria, BC) where envelope and ventilation loads are modest. They are least important where the heating and cooling loads are dominated by weather. To contradict this trend, predicting operable window positions is most critical for extreme climates (e.g., Edmonton) because of the potentially high temperature gradient between indoors and out. Thus, there remains a major gap in knowledge about the relationship between climate and occupant modelling priorities.

Table 4: Summary of occupant domains in the Code

Covered	Not covered
• Occupancy (schedule) • Receptacle (plug) loads (schedule) • Elevators and escalators (schedule; included in receptacle loads) • Lighting (schedule; with rules about controls) • Thermostat setpoints (schedule with rules about controls) • Blinds/shades (always open, unless motorized and automated) • Hot water use (schedule)	• Clothing level • Manual operable window • Occupant metabolic rate • Occupant position and orientation within a room • Consumption of hot/cold drinks/food • Use of portable heaters/air conditioners • Use of ceiling/desk fans • Interior/exterior door position

With the trend of increasing building automation – often with remote operators – the importance of operator behaviour and automation systems relative to occupant behaviour also need to be quantified. This importance will vary by building type and size. In general, larger buildings are more likely to have a dedicated operator and a higher degree of automation. For some domains, the above recommended occupant impact study may also reveal that the Code should mandate automation of some systems.

Gap 2: Current values (schedules, densities)

The current Code allows modellers to use the standard schedules listed in Sentence 8.4.3.2.(1) or modify them using “reasonable professional judgement”. However, the same ‘modified’ schedules must be used in both proposed and reference buildings. The occupant-related schedules include: occupancy, lighting, receptacle equipment (which includes elevators and escalators), thermostat setpoints, and service hot water. Despite the flexibility afforded by the Code, O’Brien, Gaetani et al. (2016) suggests that the majority of surveyed modellers use default schedules; this was reinforced at the stakeholder workshop. Thus, these schedules have the potential to have a profound effect.

Tracing schedule and density values back to their origin often reveals that they are several decades old (e.g., Abushakra, Haberl et al. 2004) and based on a surprisingly small sample of data. Between then and now, office space utilization has profoundly changed with regards to technology (Sarfraz and Bach 2017). Personal computer equipment is often restricted to laptops that rely on heavy computing power outside of the conditioned space and lighting efficacy has significantly improved. Meanwhile, the requirement that employees are tied to their office space is significantly diminished, though new space management strategies may lead to higher occupant densities (Morrison and Macky 2017).

Beyond the specific schedules, there is a gap in knowledge about the impact of the schedules regarding energy predictions and impact of energy efficiency measures. The schedules are not limited to direct energy impacts but also impact heating and cooling loads. In fact, heating and cooling loads and resulting part-load HVAC performance are the primary reason that the Code requires internal heat gains to be explicitly modelled. Meanwhile, technologies that improve part-load performance or adapt to different occupancy levels (e.g., demand-controlled ventilation and finer lighting control zone resolution) may be overlooked because simple schedules do not suggest they would be beneficial. For instance, demand-controlled ventilation’s full performance benefits are not fully exhibited with repeating occupancy schedule.

Gap 3: Current modelling methods

As noted in the Introduction, the current Code’s occupant models are limited to static-deterministic (i.e., fixed schedules). The static nature of current schedules means that the Code fails to penalize uncomfortable buildings that frequently trigger energy-adverse behaviours and fails to reward passive features that would reduce such triggers.

For instance, O’Brien and Gunay (2015) showed that daylight availability can be improved by providing fixed shading that reduces window shade-triggering glare. The deterministic nature of current schedules means that the Code is unable to provide ranges of predicted performance resulting from occupant uncertainty and assess a building design’s robustness against this uncertainty. Across the occupant-related domains, there is a gap in knowledge about the ultimate consequences (i.e., poorly designed buildings) of using fixed schedules rather than dynamic models to describe occupants.

It is unclear from the current literature whether the benefit of the stochastic nature of occupant models would sufficiently benefit building codes to justify the added complexity. If the Code required stochastic occupant models, multiple simulation runs (on the order of 50 to 100) would be necessary to estimate the predicted distribution of simulation results. A potential hybrid solution to achieve assessment of robustness without tens of simulations is suggested in the Building Codes subsection below.

The vast majority of occupant models that have been developed in the literature are agent-based models with dynamic traits, meaning that they treat occupants as individual entities who are capable of a number of different behaviours. These models provide a deep insight about how occupants might behave (e.g., their arrival time, when they open windows and turn on lights, etc.). However, it is unclear whether this high degree of resolution is necessary in building codes. If the primary modelling objective is estimating annual comfort and energy performance of building-scale, agent-based models are likely excessive. More research is needed to understand the added benefits of these models and the limitations of simpler approaches in the context of building codes.

Gap 4: Current procedural requirements

The current Code performance approach mandates a single simulation for each of the design and reference building models. This requires a single set of occupant assumptions (e.g., schedules). Even a single stochastic occupant model in the current code would be problematic in this context since such models yield a different result with each run. The Code’s performance-based compliance path requires the proposed design to be compared to the equivalent code minimum reference building. However, there is precedent for sensitivity analysis-based procedural requirements in the performance path of ASHRAE 90.1-2016. Table 11.5.1 reference model performance is based on the average energy result of four model rotations (90 degrees each) if the east or west fenestration area exceeds one quarter of the building’s total fenestration area. More research is needed on the potential for developing procedural changes to accommodate detailed occupant modelling.

Barriers

Aside from the building codes themselves, there are several main barriers to adopting better occupant modelling approaches: BPS tool capabilities, modeller education, modeller and design team acceptance, and time and cost.

There are two ways to incorporate occupant modelling in BPS tools: (1) use existing capabilities (e.g., custom schedules) or (2) develop new features in BPS tools to accommodate more advanced occupant models or related procedures. For the most part, current commercial-grade BPS tools are only suitable for the former approach. Aside from technical ability of BPS tools, many users (80%) have reported the need for greater transparency of occupant-related inputs as well as improved outputs (O’Brien, Gaetani et al. 2016).

If the Code required more advanced occupant modelling, modellers would require more education (e.g., a day-long training course). The state-of-the-art in occupant models require knowledge of probability and statistics and on implanting or inputting the models. O’Brien, Gaetani et al. (2016) indicated that the majority (82%) of surveyed modellers would be willing to participate in advanced training.

Anecdotal evidence from the workshop suggests that there would be significant resistance to use the state-of-the-art agent-based models in everyday building simulation practice. Several workshop participants indicated that they would require more evidence of the benefits of such models and the extent to which they would influence design before they would be willing to use them. There was much greater enthusiasm for updated schedules and other modelling methodologies that are familiar.

ACTION ITEMS

By and large, the literature on occupant behaviour modelling has answered the fundamental research questions necessary for incorporation into building codes (modelling forms, model validation, and data collection methodologies). The recent literature is mostly focused on developing agent-based models with increasingly resolution (e.g., predicting whether an occupant will turn off their computer at the time of departure and whether a residential building occupant is sleeping) (e.g., Wilke, Haldi et al. 2013). For the foreseeable future, such detailed models are unlikely to be suitable for the Code. Thus, the main research questions about occupant modelling for code compliance are of a practical nature. A more significant gap in the research is in reliably modelling occupant comfort (thermal, visual, acoustic, indoor air quality); however, this is beyond the scope of this paper. Thus, two categories of action items remain: applied research and implementation into to the Code.

Applied research

The key applied research action items include:

1. Evaluate the impact of occupancy and occupant behaviours across building types, building sizes, and climates. This process will entail running batch simulations whereby realistic ranges of occupant-related parameters are simulated in conjunction with the office models and later the remaining 16 standard archetype models (US DOE, 2018). This is important for informing how to proceed with code requirements but also in its own right. Many workshop participants stated that they would like to see quantitative evidence of the impact of occupants.
2. Determine the most appropriate occupant modelling approach (previously defined as a balance of accuracy and practicality) by building size/type and occupant-related domain. This should be accomplished using a similar systematic sweep as the previous point. The occupant modelling approach is likely to vary across the three dimensions (building type, building size, and occupant-related domain) shown in Figure 3. Occupants' role in energy consumption of a building depends greatly on building type, in approximate order from most to least in Figure 3. Thus, the optimal occupant resolution is expected to be most important for building types where they play a more active role. Building size is important because uncertainty of energy performance resulting from occupant diversity (e.g., the spectrum of high and low energy users) is significantly greater for small buildings than large buildings. Gilani, O'Brien et al. (2018) found that stochastic light use models in private offices yield as much predictive power as simple rule-based models (i.e., dynamic-deterministic models) beyond 100 occupants because of the *law of big numbers*. Finally, modelling approach should vary by domain. In particular, non-adaptive domains (namely, occupancy and receptacle loads) should be modelled using static approaches; whereas adaptive domains (e.g., window shades and lighting) may be more appropriately modelled as dynamic. For non-adaptive domain, Tahmasebi and Mahdavi (2015) found that specific schedule values are more important for predicting mean energy use than whether a model is stochastic or deterministic.

A small, but growing, set of occupant models that are aimed at codes and standards balance complexity and practicality. For instance, IES LM83 (IESNA 2012) uses simple rule-based (i.e., dynamic-deterministic) control of window shades. This model has one notable limitation that it does not characterize the commonly observed phenomenon that occupants typically do not reopen shades for hours or days after closing them (O'Brien, Kapsis et al. 2013). However, this model penalizes large windows for daylight glare, while remaining relatively simple to understand and implement. Since its inclusion in LEED (Leadership in Energy and Environmental Design) v4, it has been incorporated into several BPS tools, such as IES VE.

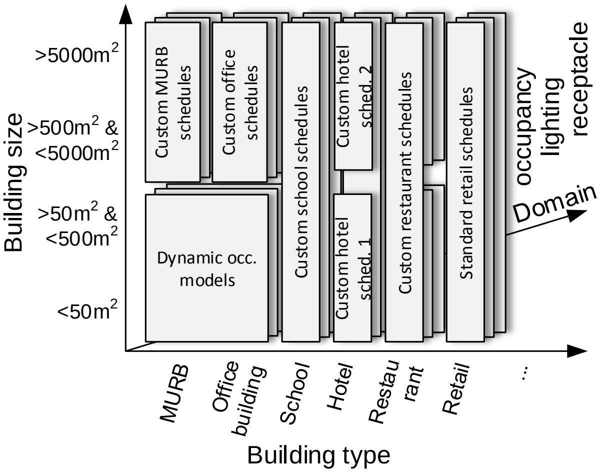


Figure 3: 3D matrix of recommended occupant modelling approaches by building type, building size, and domain (purely for illustrative purposes). Custom schedules are those that are multiplied by some coefficient, for example, depending on certain specifications. A fourth dimension could be climate zone.

3. Collect more Canadian building field data (particularly related to occupancy, lighting and receptacle schedules and power densities). The authors have encountered significant organic efforts among property managers and building owners to collect such data for purposes of environmental reporting and billing. However, the data often lack adequate documentation (i.e., exact scope of metering), contextual factors (e.g., which space is leased), and measurement hardware and software details (e.g., product information, post-processing procedures). We strongly recommend that a committee be formed to coordinate a voluntary program to build a data repository. New data will become available as a result of ASHRAE 90.1-2016's (ASHRAE, 2016) requirement that interior lighting and receptacle loads be separately monitored and recorded at 15-minute intervals or higher temporal resolution. Industry could follow thermostat-maker ecobee's lead to have an opt-in open-data policy for research purposes. Previous data collection models (Abushakra, Haberl et al. 2004) are not very robust and are time consuming in the context of big and open data. Occupancy data remains rarer; however, a number of new robust and low-cost technologies are greatly improving occupant measurement capabilities.

Building codes

There are six methods listed in Table 1 that would allow incorporation of occupant modelling into building codes, in approximate order of increasing complexity.

Increasing complexity does not necessarily translate to "better" and could lead to a number of drawbacks, such as misinterpretation, difficulty of enforcement, or abuse. Thus, we recommend that each occupant domain be investigated for the most appropriate approach(es), balancing accuracy and other benefits without being cumbersome, error-prone, and otherwise too complex. Any recommended modifications to the code should be accompanied by illustrative examples of failures of the current code and how the modification would address it.

For each method, Table 5 provide an example of how a particular occupant domain could be elevated in the Code, along with justification. Where possible, these are based on the authors' research or the literature.

Table 5: Illustrative examples of occupant modelling implementation into the Code

1. Update prescriptive requirements

Domain: Lighting

Current approach: A manual light switch should not cover an area greater than 250 m^2 for spaces of 1000 m^2 or less (Sentence 4.2.2.1.(3)).

Proposed approach: Reduce the 250 m^2 maximum lighting control zone to 100 m^2 (for office spaces).

Justification: Occupancy simulations based on data-driven models have indicated that occupancy may be sparse and considerable unoccupied space may be unnecessarily have lights on.

2. Add prescriptive requirements based on occupant simulation studies

Domain: Operable window opening position

Current approach: No requirement

Proposed approach: Operable windows with an opening area greater than 0.2 m^2 must include a position sensor linked to the building automation system such that the heating and cooling setpoints in the adjoined space are reduced to 10°C and 30°C, respectively, if the window is open for longer than 5 minutes.

Justification: A simulation-based study revealed that sub-optimally-operated windows could increase annual heating and cooling loads by 20%. An unintended consequence of this requirement could be a reduced number of operable windows due to the additional cost. To combat this, a rule-based model could be required for the performance path of the Code which could result in improved comfort and energy performance.

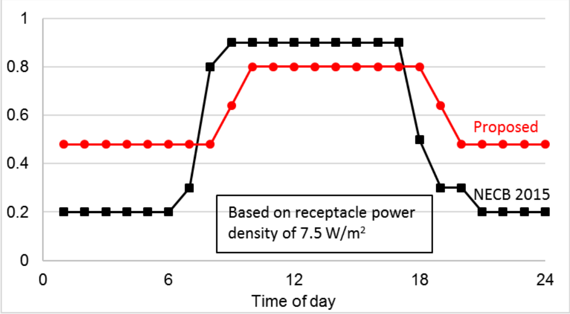
3. Update schedules from field studies

Domain: Receptacle load schedule and density

Current approach: Fixed schedule

Proposed approach: Modify schedule to better reflect recent field data (see graph below). For simplicity, the new proposed schedule is also based on 7.5 W/m^2 as per Table 8.4.3.2.(2) in the Code.

Justification: Field studies have suggested that nighttime plug loads remain high (Gunay, O'Brien et al. 2016; Bennet and O'Brien 2017). While the weekday energy for the current and proposed schedules is reasonably similar (92 W·h/m^2 versus 110 W·h/m^2), the timing of the internal gains has a significant effect on HVAC loads, part-load performance and its energy implications, and indoor temperature during unconditioned periods.



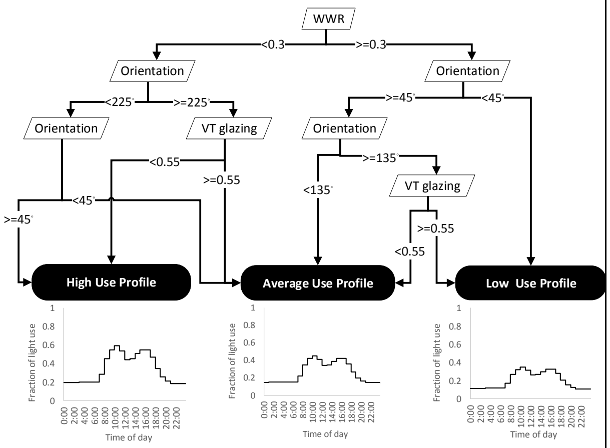
4. Update schedules from simulation studies

Domain: Lighting

Current approach: Static lighting schedules

Proposed approach: Use a decision tree (driven by extensive parametric simulations) to mandate a certain schedule depending on design parameters and climate (e.g., see below).

Justification: Quasi-custom schedules that are informed by detailed occupant simulation studies would yield the benefits of dynamic models (i.e., incorporation of window geometry and window shade effects) without requiring Code users to explicitly model occupants. See example below.



5. Require multiple occupant scenarios Domain: Occupancy, receptacles, lights Current approach: Standard set of schedules used in a single simulation (both for reference and proposed building models) Proposed approach: Three simulations for both the reference and the proposed building shall be run with nothing changed except the standard schedules (Table A-8.4.3.2.(1)) or custom schedules for occupancy, receptacles, and lights. These schedules shall be multiplied by 0.75, 1.0, and 1.25. The reported energy performance of the proposed building relative to the reference building shall be the worst of the three pairs of simulations. Justification: This requirement encourages robustness and adaptability of operating conditions – particularly for HVAC systems. Buildings that are tailored to perform well under just one set of operating conditions are penalized. Comments: While this could be performed manually, it would be preferable to have an automated system.
6. Specify the occupant modelling approach required Domain: Manual movable window shading devices Current approach: Assume shading devices are open unless they are automated. Proposed approach: Use the IES LM83-2012 Standard, which states that shades should be modelled as closed whenever 2% of workplane analysis points receive greater than 1000 lux of direct sunlight (IESNA 2012). Justification: The current approach is significantly different than all field studies performed, which indicate shades are occluded by approximately 50 to 75% on average (Kapsis, O'Brien et al. 2013). The current method exaggerates potential for daylighting and views and inflates solar gains and heating season heat loss through fenestration. If a shade use model is used, it must consider indoor conditions as input(s); models that use outdoor conditions fail to account for window geometry or optical properties.

PRIORITIES AND TIMELINES

The highest priorities are:

1. To perform a comprehensive sensitivity analysis across occupant-related domains. It should include the domains listed in Table 4 and all six NECB Climate Zones (4, 5, 6, 7A, 7B, and 8) that are covered by the Code.
2. Outreach and dissemination to the modelling and development communities as well as the code development committee. This will include simulation-based studies that demonstrate the limitations of current methods as well as a detailed case study performed in collaboration with industry. The case study will involve a process whereby advanced occupant modelling techniques and workflows are hypothetically tested

CONCLUSIONS

This paper provided an overview of a roadmap that is being developed to provide a framework for the advancement occupant modelling in building codes and standards. It described the shortcomings of current approaches, including the consequences of focusing on relative simulation predictions and of occupant-related schedules. Gaps in occupant modelling aspects of the NECB 2015 were identified in the following four categories: occupant-related domains, values (schedules and densities), modelling methods, and procedural requirements. Next, two categories of action items were recommended. First, extensive parametric analyses should be performed across Canadian climate zones and building types to understand the relative impact of occupant-related domains. To validate current assumptions, a systematic data collection and repository campaign should be initiated. Second, the method for inclusion of additional, or advancement of, occupant-related requirements and modelling procedures should be investigated. Six different methods to include occupant modelling into the Code were identified, such as updating schedule values and mandating sensitivity analyses to demonstrate adaptability of buildings. In the short term, two of the approaches could be implemented in the next Code cycle without further field work or research:

- Update occupancy, plug load, and lighting schedules based on recent literature.
- Require a sensitivity procedure on occupancy, plug load, and lighting schedules to demonstrate that the proposed building is adaptive to variable operating conditions.

Following this paper, a two-year, multi-stakeholder research and demonstration project is being conducted to address many of the identified gaps and barriers.

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