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International review of occupant aspects of building energy codes and standards

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Abstract

Occupants are recipients of building services and have direct influence on building operation and performance. However, occupants are often addressed in simplified ways in building energy codes and standards that do not reflect the latest knowledge and scientific literature. This article describes an international review that we performed on 23 regions' building energy codes and standards. We took two approaches: a quantitative approach focused on comparing occupant-related schedules, densities, and other values, and a qualitative approach whereby written requirements were analyzed. The results indicate major differences between code requirements or key modeling assumptions for code compliance (e.g., by a factor of two or more for plug load and occupant densities). Our review also revealed that few codes refer to occupants explicitly and requirements for building usability are rare. Based on the review and literature, we make some recommendations for how future codes could be adapted to better incorporate occupants.

Introduction

Building codes and standards are a necessary and effective means to elevate the performance aspects of new building designs. Indeed, the past several decades have seen great strides regarding the continuous improvement in energy efficiency requirements. ASHRAE Standard 90.1, for example, has decreased its energy use intensity requirements by about 50% since the first edition in 1975 (Liu, Rosenberg et al. 2018). Assuming they are properly enforced, building energy codes and standards (herein referred to as codes) are one of the most effective ways to improve the energy performance of buildings (Chirarattananon, Chaiwiwatworakul et al. 2010, Jacobsen and Kotchen 2013, Evans, Roshchanka et al. 2017).

As for most building energy codes and standards around the world, energy savings have mainly been achieved through building envelopes, HVAC, and lighting requirements. However, occupants remain a challenging aspect of building codes and standards. On the one hand, occupants play a greater role in high-performance buildings as building features approach practical or cost-optimal limits. On the other hand, the number, type, and nature of occupants is uncertain during design and we cannot necessarily count on them to behave "well" in the sense of energy. However, the challenge lies in the fact that occupants not only affect building energy use, but they can skew the way energy efficiency measures affect performance. For example, the energy savings from demand controlled ventilation depends heavily on occupancy patterns (O'Brien and Gunay 2019).

In the past decade, a growing contingent of international researchers have assessed the state of occupant modeling in building simulation practice (Yan, O'Brien et al. 2015, O'Brien, Gaetani et al. 2016, Yan, Hong et al. 2017). Key points include:

- Contrary to standard occupancy schedules and densities, occupancy is much more variable in reality. Moreover, common assumptions about occupants tend to be conservative.

- Occupant behavior is diverse and uncertain, but often predictable in a probabilistic sense, because occupants often behave in certain patterns to continuously improve their comfort.
- Occupants should be recognized as active participants in buildings rather than mere sources of heat and air contaminants. In essence, occupants should be treated as being in a two-way relationship with buildings, rather than a boundary condition like weather.
- Building design can influence occupant behavior, whereas this is often forgotten during the design process.
- If inaccurate assumptions are made about occupants during design, there is a risk for designers to make sub-optimal or non-robust design decisions.

To a large extent, the criticisms of current occupant modeling and design practice can similarly be applied to building energy codes and standards. This article takes an international perspective in reviewing the occupant aspects of building codes and standards. It answers questions such as: How do codes deal with occupants and how do these vary by country? What assumptions are made about occupants' energy-related behaviors? What features can we learn from existing codes to possibly enhance others? In all, 23 regions' building codes and standards were reviewed for this article, as part of a large project of the International Energy Agency-Energy in Buildings and Communities Annex 79: Occupant Centric Building Design and Operation (O'Brien, Wagner et al. 2020). These are summarized in the map in Figure 1. For simplicity, we focused on office buildings, though the work could be extended to other building types. Considering the magnitude of this review effort and the number of languages involved, we had the privilege to work with many international reviewers (refer to Acknowledgements and O'Brien, Tahmasebi et al. (2020)).

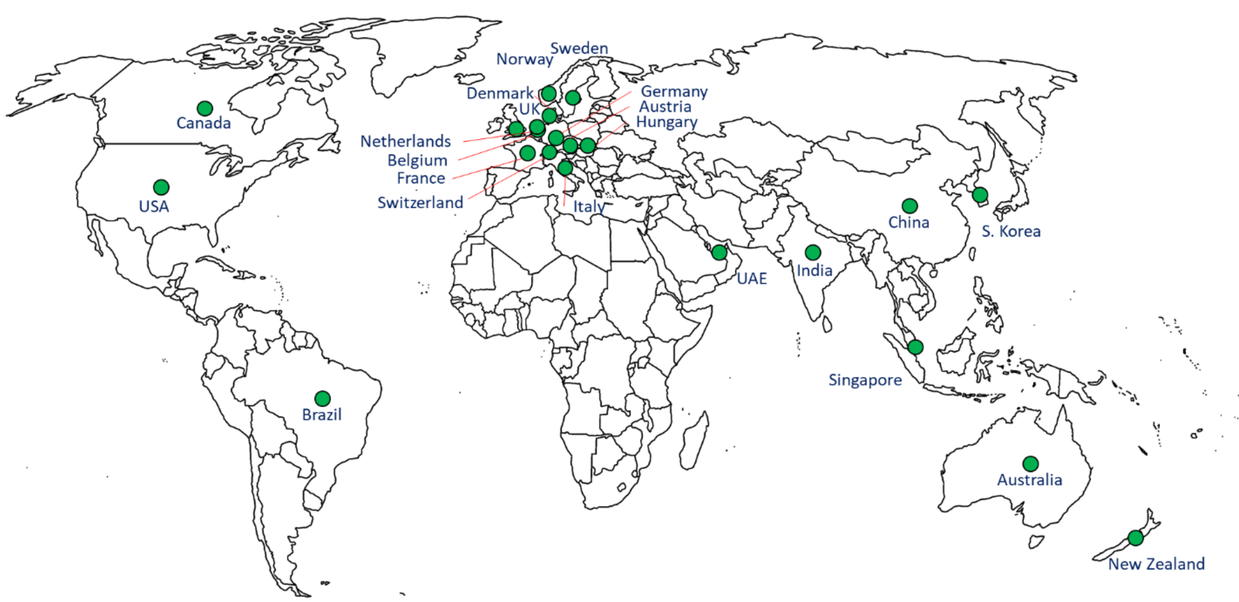

Figure 1: Map of regions' building energy codes and standards that were reviewed.

Methodology

Like ASHRAE Standard 90.1, many building codes and standards around the world provide two main options for code compliance: the performance path and the prescriptive path. The performance paths tend to define occupants and their behaviors using schedules and densities, whereas prescriptive paths often involve more qualitative rules. In study, we review both types of requirements.

We performed the review in two phases. Phase 1 was quantitative and focused on comparing the numerical occupant-related assumptions or requirements (e.g., schedules, densities, and setpoints). The areas that were considered are schedules and densities/values for occupancy, cooling and heating temperature setpoints, plug loads, lighting, domestic hot water, illuminance, and ventilation rates. Only those codes with specifications of this nature were included for each comparison. Note that such requirements may appear in reference to either prescriptive or performance paths. For example, lighting power density is a prescriptive requirement but also to be used in the reference building model.

Phase 2 was broader and asked the contributors to provide occupant-related specifications. They were asked to list at least five instances where the code refers directly or indirectly to occupants. These requirements were assessed systematically to understand how occupants are referred to, how occupants are defined, and which systems are assumed to be controlled by occupants.

Results

Phase 1

For Phase 1, Figures 2 to 4 provide the comparisons of occupancy, lighting, and plug loads with the densities and corresponding schedules. As can be seen, the densities vary by a factor of two or more across countries even though the most extreme countries have similar standards of living. The schedules are generally not as diverse, though some have a ramp up period, while others have abrupt steps in the morning. These two situations are likely to significantly affect HVAC equipment sizing and peak loads. We performed some investigation into the cause of the discrepancies and found a few hints. Most notably, several of the codes with the highest occupancy densities were revealed to originate from safety and egress values. That is, the values are likely chosen as conservative given the relative importance of egress in emergencies vs. energy performance.

It is also noteworthy that the occupancy schedules reach 100% or near 100% of the nominal or full capacity, whereas the literature suggests half or two-thirds of capacity is much more common in office buildings (Duarte, Van Den Wymelenberg et al. 2013, Tahmasebi and Mahdavi 2017). Of course, we can expect significant changes in occupancy in the future due to COVID-19 policies and behaviors.

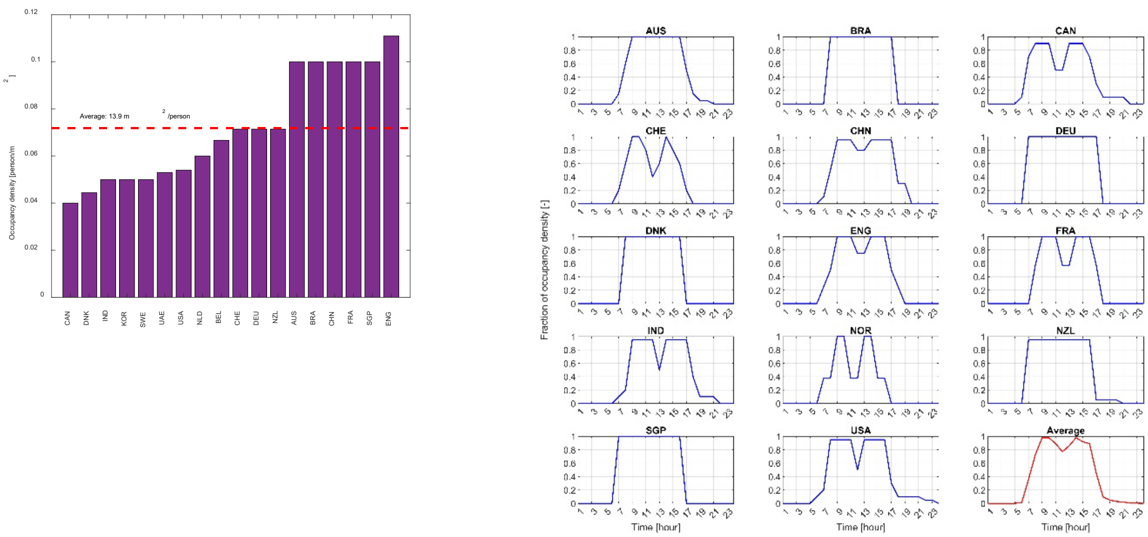

Figure 2: Office occupant density values and schedules provided by the reviewed codes

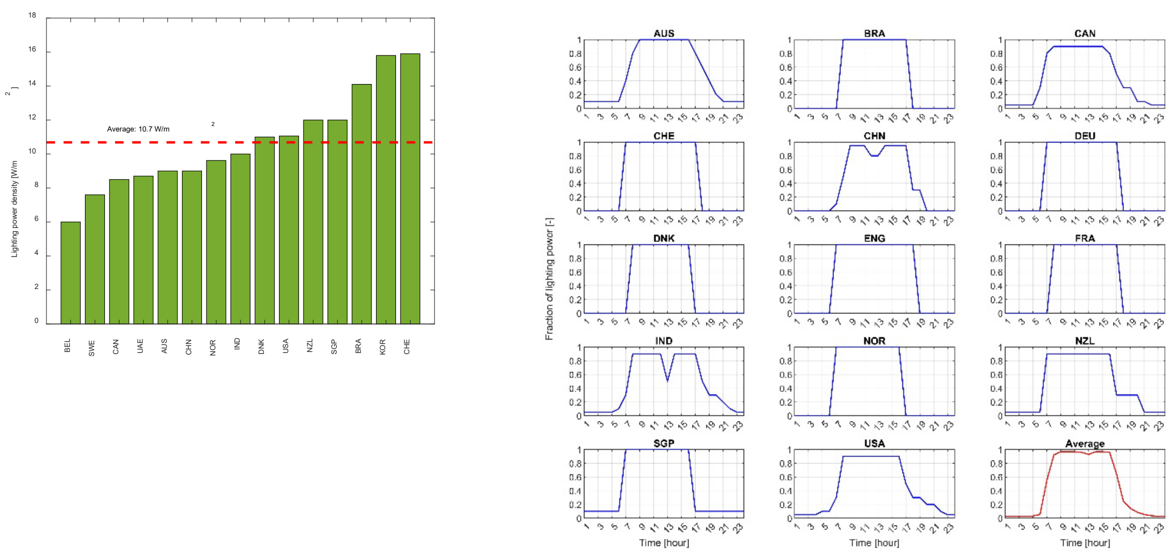

Figure 3: Office lighting power density values and schedules provided by the reviewed codes

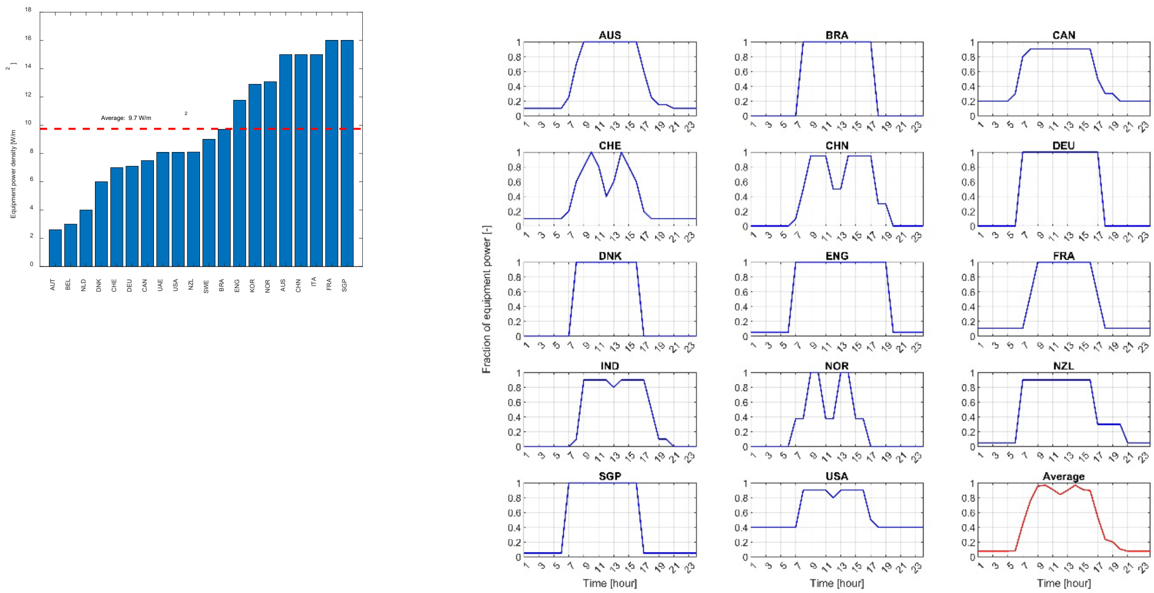

Figure 4: Office equipment power density values and schedules provided by the reviewed codes

Figure 5 shows the heating and cooling setpoints and corresponding setbacks for the reviewed codes and standards. While the values are quite inconsistent, there are some expected patterns. For instance, Canada and the US have relatively high heating setpoints and low cooling setpoints, while European and Asian countries tend to have slightly less energy-intensive setpoints. These differences can generally be linked to climate and culture, typical HVAC equipment and operation practice, and general population climate expectations (e.g., Americans tend to expect mechanical cooling and heating in office buildings year-round (Cole and Lorch 2003)).

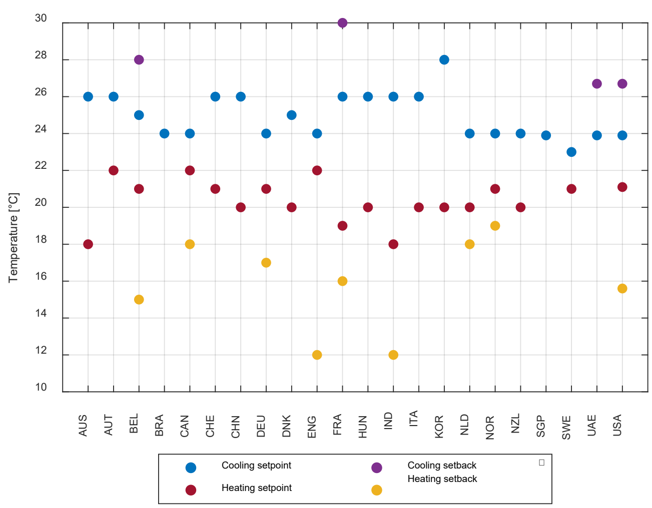

Figure 5: The heating and cooling setpoint and setback temperatures in the reviewed codes. Absence of points on the graph mean setpoints are not specified (i.e., the equipment can be turned off).

Phase 2

For Phase 2, 167 occupant-related specifications were collected from the 23 reviewed codes. Many of the contributors noted that occupants are not explicitly mentioned, but rather implied through terms like *occupancy*, *occupancy sensors*, and the degree of *automated* vs. *manual control* required for a system. While the terminology surrounding occupants may seem inconsequential, it reinforces our premise that occupants are not viewed as active and reactive agents in buildings during the design process. While this is practical for the purpose of code enforcement, it nevertheless may misguide designers.

On the question of how occupants are assumed to behave (regarding energy-related actions), there is a wide range of modeling approaches in the performance path of the reviewed codes. The most common, by far, is using schedules and densities (as uncovered in Phase 1). However, some other approaches were discovered, such as rule-based models (e.g., occupant opens window above certain indoor air temperature) or simply assuming a system is not used at all (e.g., window shades are always open).

Though it was not reviewed directly, the authors note that IES LM 83 (a daylighting standard commonly used for LEED) (IESNA 2012) is a good example of a more advanced occupant model, in that it requires blinds to be modeled as closed above a certain illuminance threshold. This is important for discrediting exceptionally large windows that are likely to cause daylight glare and for which occupants would likely close blinds anyway (Reinhart, Mardaljevic et al. 2006). In general, codes are significantly simpler than what much of the leading scientific literature (e.g., stochastic agent-based occupant models) provide about occupants and their energy-related behaviors.

Of particular interest to the authors was the underlying implied or explicit expectation about whether occupants can be relied upon to reduce energy use. For example, the French energy code assumes that window shades are controlled quite optimally. In contrast the Canadian code that was reviewed uses the phrasing "…provided it can be quantified and is not dependent on occupant behaviour", which implies that occupants cannot be relied on to save energy. In a more subtle way, the performance path of ASHRAE Standard 90.1 states "In no case shall schedules differ where the controls are manual." This implies that the standard does not credit design as a means to affect energy-related occupant behavior. For example, savings might be achieved by providing signage or increasing lighting control zone size resolution.

More than half of the reviewed codes either require or give credit to demand controlled ventilation and/or occupancy-based lighting controls. While this is promising, previous work indicted that the current occupancy schedules for office buildings mandated by building codes likely underestimate the benefit of occupancy-adaptive technologies and therefore may lead to lower penetration of these technologies (O'Brien and Gunay 2019).

Among the reviewed codes, one of the more interesting features that is credited (by Dubai Municipality (2016)) is a user guide for the building (aimed at occupants) that explains building systems and sustainability features as well as rational human-building interactions.

Recommendations

Based the review and broader literature, we present some ways in which building codes could evolve to better incorporate occupants. These are in approximate ascending order of difficulty to implement and enforce.

1. Add prescriptive requirements: Based on field or simulation studies on occupants and their interactions with buildings, additional prescriptive requirements could be included (e.g., occupancy-based controls, specifications for interface usability and accessibility).

2. Update schedules and densities based on new field data: Using extensive data from existing buildings (e.g., smart meter data, building automation systems, smart phone tracking), occupant-related schedules and/or densities could be updated. As an example, Abdeen, O'Brien et al. (2020) used several 1000 homes of thermostat data to show that household setpoints are several degrees Celsius cooler than currently specified by the National Building Code of Canada.

3. Require multiple occupant scenarios to be modeled: Specific to the performance path of building codes, it could be required that two or more occupancy scenarios be modeled and that the average or least energy savings versus the reference building be reported. In this way, buildings would be more robust against uncertain occupancy and would be better rewarded for adapting to occupancy.

4. Increase occupant modeling requirements: In contrast to the predominant schedule-based occupant modeling approach, new requirements could be added to better reflect reality. For example, rule-based models could be required to define operable window use and window shades. In doing so, the impact of building design features on occupants' energy-related behavior could be quantified more accurately (i.e., recognizing the two-way interaction between occupants and buildings).

Ultimately, changes made to building codes should improve the status quo, be feasible for practitioners to apply, rely on consistent and replicable procedures, and be enforceable by officials. The authors feel that the most advanced occupant models in the literature, which involve modeling actions of individual occupants, are currently too complex for building code purposes. For example, such models are often stochastic, meaning that they produce a different result each time they are run and require many simulation runs to produce a meaningful reference results range. However, the authors believe that the above-mentioned recommendations strike a good balance between complexity and applicability to enhance the representation of occupants in building codes and standards.

One of the notable omissions from most of the reviewed codes is requirements for building usability by occupants. That is, requirements for building systems and interfaces to be available, intuitive, effective, and accessible to occupants. Ideally, building systems should easily allow occupants to save energy. While some usability characteristics may seem more relevant to safety-related requirements, they are also important for energy performance. Systems that are inconvenient or difficult to use are less likely to be used in expected ways. A notable example of a code requirement that involves usability is in ASHRAE Standard 90.1 (ASHRAE, 2019) and National Energy Codes for Buildings of Canada (NRC, 2017), which requires that light switches be positioned such that their user be able to see the controlled lights. This is important so that occupants receive feedback that the light has been turned on or off as they use the switch.

Conclusion

This article provided an overview of a comprehensive review of 23 building codes and standards from around the world with a focus on occupant-related aspects. It showed major discrepancies between occupant-related densities (e.g., occupancy and plug loads) and rather significant differences between schedules. The study also found that occupants are treated in fairly implicit ways rather than explicitly considering them as active agents in buildings. While many building codes reward or require specific occupancy-adaptive technologies (e.g., demand controlled ventilation), there are few requirements for usability of interfaces and building systems. The article concluded with recommendations for how building codes could be enhanced to better incorporate occupant behavior, ranging from simply updating schedules and densities to mandating more advanced occupant modeling methods. With these recommendations adopted, buildings will have a higher chance of achieving energy and comfort performance targets. Future work should extend beyond occupants to consider how operator behavior affects energy performance and the gap between design and measured performance.

Interested readers are encouraged to refer to O'Brien, Tahmasebi et al. (2020), which provides much greater detail than the current article.

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