Common fallacies in representation of occupants in building performance simulation

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Abstract

This keynote address offers a number of critical observations with regard to the representation of occupants' presence and behaviour in building performance simulation applications, tools, and processes. The objective is to contribute to a more reflective attitude and to further productive discussions of the subject in the relevant research community

1. Introduction

In this keynote presentation, I would like to briefly address a number of critical issues with regard to the representation of occupants' presence and behaviour in building performance simulation models.

As the use of the first person singular pronoun in this presentation implies, I do not intend to provide here a strictly technical treatment of the subject (i.e., one that follows the typical structure of a scientific contribution with obligatory parts such as hypothesis, research design, experiments, analysis, conclusion, references, etc.). Rather, the impetus behind this talk comes mainly from personal experiences in the course of various professional interactions with colleagues and students, as well as in my role as reviewer of various topically related conference and journal papers. In the course of these interactions and activities, I have observed a number of explicitly stated and tacitly implied opinions, beliefs, and attitudes, which I consider to be at least partially fallacious or misguided. In order to avoid the impression of bias or *ad hominem* criticism, I have abstained from pinpointing specific papers, individuals, or software implementations. The intention is to discuss the logical consistency and empirical validity of ideas and models and not personal proclivities.

It is perhaps appropriate to state upfront my two main reasons to raise these issues. Firstly, I suspect that certain fallacies have led – and are still leading to – misguided tendencies in representation of building occupants in performance simulation and may thus impede sound progress in this area. Secondly, I hope to contribute to a healthy and enlightening debate, which – thorough thoughtful consideration of the pertinent arguments – could deepen the level of discourse and research quality in the field.

A number of my comments may appear to be self-evident – particularly to scientists not directly from the field. These include, specifically, references to some of basic principles of logical discourse and scientific research. However, past experiences lead me to the conclusion that perhaps occasionally even the obvious needs to be stated.

2. Background

Let us consider the thermal performance of buildings and related simulation procedures, models, and tools. To conduct performance simulation, typically four sets of model assumptions are required, i.e., representations of the building fabric (i), its systems (ii), internal (occupancy-driven) processes (iii), and external (climatic) boundary conditions (iv). These representations and associated specific data sets are then supplied to the simulation application's algorithmic core (mathematical formulation of the pertinent physical processes). It can be cogently argued that the quality of performance simulation, i.e., its fidelity and reliability in representation of

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reality, depends on both the soundness of the algorithmic core and the accuracy of the aforementioned model input assumptions.

I shall not discuss here the validity considerations of simulation tools' algorithms for the representation of the physical (e.g., heat transfer) processes. Rather, I shall focus on the representational matters pertaining to building occupants. The thermal performance of buildings is not only affected by the people’s presence as a source of (sensible and latent) heat (the so-called passive effect), but is also influenced by their actions, including use of water, operation of appliances, and manipulation of building control devices for heating, cooling, ventilation, and lighting (the so-called active effect).

There has been arguably significant progress made in the last decades concerning methods and practices for specification of building geometry, material properties, and external (weather) conditions. Yet modelling practices pertaining to people’s presence and behaviour in buildings are still in need of substantial improvement. Only relatively recently the detailed consideration of the effects of people’s presence and their actions on buildings' performance has become a key topic in simulation research and application. There is still a lack of well-established and widely shared methods and standards for representing people in the building simulation practice.

It seems to me that the ongoing research efforts to develop more detailed and more robust building occupants' presence and (control) action models suffer in part from both conceptual fallacies and methodical shortcomings.

In the remainder of the present treatment, I would like to offer some related random thoughts and observations, meant as a constructive contribution toward a deeper and more systematic approach toward incorporation of occupancy-related representations in building performance simulation. To improve readability and simplify formulations, I shall henceforth refer to models of occupants' presence and (control-oriented) behaviour in buildings as occupancy-related models.

3. Some random observations

3.1 Occupancy and energy use

The motivation and background section of many recent contributions regarding occupancy-related models mention the following: Data on energy use of similar buildings (e.g. row house units of similar size and orientation located in the same site) often display a remarkable variance. The authors then infer from this observation that given the similarity of all the other factors, occupancy-related circumstances must be responsible for the variance. There is not a fundamental problem with such a conjecture per se. In such situations, the variation in the patterns of presence and behaviour of buildings' occupants may indeed explain – at least as a key contributing factor – the bulk of the variation in energy use data. But the assertion is often followed by the claim that more detailed and more sophisticated occupancy-related models would have facilitated more accurate energy use predictions. Therein lies a potential misunderstanding.

The actual energy use of a building is the result of a large number of influencing factors subject to various levels of uncertainty and unpredictability. More detailed and realistic representations of occupancy-related processes in buildings and their statistical fluctuations can shed much useful light on statistical variance of energy use patterns. However, I see no reason to suggest that they would necessarily result in accurate long-term energy use predictions of individual buildings. Strictly speaking, the energy use of a specific building cannot be predicted beyond a rather short time horizon: Alone the chaotic nature of weather patterns makes long-term building energy performance predictions infeasible, notwithstanding the quality of the building, systems, and occupancy-related models.

3.2 The so-called deterministic simulation

Recently, one reads and hears a criticism of conventional performance simulation as being "deterministic". The idea appears to be as follows: Conventionally, a fixed set of input variable values are fed into the simulation and a fixed set of indicator values are obtained as output. This makes simulation deterministic and a misrepresentation of the inherently uncertain reality. But in this seemingly straightforward assertion lies another potential fallacy.

Let us explore this matter more closely. Most algorithmic representations of the physical phenomena in building performance simulation (expressed, typically, in terms of differential equations) are indeed deterministic in nature. For that matter, even the second-order partial differential equations of Quantum Mechanics (which is popularly perceived as non-deterministic) are as such deterministic. For instance, the Schrödinger equation describes the deterministic evolution of the "wave function" of a particle. Of course, even the exact knowledge of the wave function does not remove the uncertainty of a specific measurement on the wave function. Going back to the nether regions of building-related heat transfer, we can argue that the non-deterministic nature of the model input variables does not make the computational core of a simulation model (the partial differential heat transfer equations) non-deterministic. You can of course generate a statistical variance in the output of a deterministic model, if you subject the model to a variance (statistical fluctuations) in input variables. And doing such a thing may be quite expedient (it is called sensitivity analysis). But the recent use of the determinism parlance, which – in the philosophy of science – has all kinds of specific connotations (as associated with, for example, Pierre-Simon Laplace), is fairly irrelevant (if not misleading), when unreflectively applied to building performance simulation discourse.

I do not think that the simulation experts, who have been regularly computing certain fixed numbers for the values of various building performance indicators for a given fixed set of input variables have been ignorant to the fact that all engineering computation is subject to uncertainty. Probably, they were also not thinking that people really do "deterministically" enter and leave buildings or simultaneously open and close windows like a pack of robots that follow strictly some script according to diversity profiles found in various codes and guidelines.

Now, it may or may not be a proper procedure to compare the simulation-based (fixed) value of a performance indicator (say, annual area-specific heating demand of a building) with a respective (likewise) code-based threshold value. But it is important to understand the logic and purpose of such comparisons. In many instances, they are geared toward benchmarking (comparison of calculated and mandated values of certain performance indicators) and not about making specific predictions pertaining to the performance of a building during a specific period of time.

3.3 Variance in, variance out

Assuming you have confidence in your simulation model’s fidelity in representing physical (i.e., heat transfer) processes, you still need to worry about the uncertainty of input assumptions and how they may affect your simulation results. As mentioned earlier, sensitivity analysis is one tool that can provide you with a sense of your model’s behaviour in the face of the variance of model input assumptions. It is thus entirely reasonable to explore the implications of occupancy-related uncertainties for the outcome of thermal simulation runs. Rather than using just standard diversity profiles, you could use a variety of methods and approaches to "randomise" occupancy-related input data. So where is the fallacy here? None, or not one yet.

The problem starts, when the source of assumed variance (spread of an input variable’s values) is not empirically substantiated. Probabilistically induced variations in simulation results via fluctuations of input data can be argued to be informative to the extent that empirical basis of such fluctuations is trustworthy or representative. It seems fallacious to me, to argue that by the virtue of introducing some kind of stochastic variations in simulation input assumptions (irrespective of their grounding in reality), more trustworthy or reliable building performance predictions can be made. There is one thing to explore the behaviour of a model via systematic input-output mapping based on generic (or arbitrary) statistical distributions, but entirely another thing to claim such exercise augments predictive capacity with regard to the performance of specific buildings under specific circumstances. We can avoid such misconceptions in part via general reflections on the complexity of human behavior, especially in socially relevant contexts. More specifically, we must assiduously upheld the proper scientific requirements pertaining to model development and evaluation. These include, amongst others, careful collection and preparation of representative observational data, clean separation of underlying data sets for *a)* model generation and *b)* model evaluation, and candid declaration of model limitations as well as proper description of the model application scope.

With regard to models' reliability and predictive performance, ultimately, double-blind studies (where the empirical data collection, the model development, and the comparison of measurements and predictions are done by separate agents) or round-robin tests would be most convincing. I think we can and should do a better job in this area.

3.4 About use cases

3.4.1 Occupancy-related model options and simulation application scenarios

Let us further explore the relevance of the use cases of building performance simulation with regard to occupancy-related models deployed. It seems to me that neither the choice of the occupancy-related models, nor the choice of the criteria for gauging their reliability is independent of the simulation's use case. Focusing on thermal building performance simulation, we can think, right off the bat, of multiple application scenarios:

- Simulation studies can target components of a building (say, for thermal bridge analyses), parts of a building (for example, simulation of a typical floor of a high-rise building), whole buildings, or even groups of buildings (district or urban simulation).
- We can distinguish application scenarios in view of the deployment phase of simulation (e.g., preliminary design support, detailed design support, systems design support, building/system operation support).
- We can distinguish application scenarios in view of the spatial (e.g., single-zone versus multi-zone) and temporal resolution (e.g., 15 minute intervals versus hourly simulations).
- Application scenarios could be also distinguished in terms of the ultimate use of the computed parameter (generating an energy certificate, benchmarking a design proposal with regard to applicable standardised performance criteria, comparison of alternative designs at a certain stage of the building design process, design and sizing of buildings' mechanical equipment, real-time use of recurrent dynamic simulations in a predictive building systems control routine).

The above cursory list provides an impression of the considerable diversity of simulation-based building performance assessment scenarios. It seems to me that the dependency of occupancy-related model selection (and the associated evaluation criteria) on the type and nature of the specific simulation use case at hand is insufficiently understood.

To explore this point more thoroughly, consider the case of the applicability of two different representational approaches of occupancy-related processes. Let us call them "non-probabilistic" (NP) and "probabilistic" (PR). The NP approach is typically expressed in terms of code-based diversity profiles, which – as I mentioned before – are sometimes (or one could say notoriously) referred to as deterministic. The PR approach aims at representational formalizations, which are intended to capture the arguably stochastic nature of actual occupancy-related processes. Independent of the question of the predictive performance of PR methods, are they to be exclusively applied in all simulation-based performance queries? Let us consider, in the following two sections, a few exemplary instances.

3.4.2 Code compliance and benchmarking

What kind of occupancy-related simulation input assumptions would make sense, when simulation is used to provide values for a number of aggregate performance indicators (such as buildings' annual heating and cooling loads) that are declared, for example, in energy certificate documents? Note that such aggregate indicators are typically meant to benchmark a specific building design brief against applicable codes, standards, and guidelines. Naturally, this is done under "standardized" conditions pertaining to external climate (typically represented in terms of a standard weather file), but what about occupancy? The use of a PR model would generate, per definition, more or less different occupancy-related input data for each simulation run, resulting in correspondingly different simulation results. This could represent a problem not only for code-based compliance checking, but also for the performance analyses of design alternatives, when the aim is to compare multiple (alternative) designs irrespective of variance in contextual boundary conditions (weather) and occupancy. Presumably, one can argue that the repeated simulation runs (with incorporated PR models) would ultimately converge to stable values for aggregate performance indicators. But the question is if this use scenario and the kind of time, effort, and (often non-existent) background occupancy information it requires can actually generate any convincing added (procedural or predictive) value.

3.4.3 Spatial and temporal distribution of thermal loads and capacities

Consider now a different use case. We know that variance in occupancy-related patterns over time and location can be quite significant. Such variance can be critically important, for example, when we would like to gauge the dynamics of thermal loads in various zones of a building and deduce the correspondingly required capacities of building's thermal control systems. Toward capturing the temporal and zonal variations of thermal loads toward design, sizing, and configuration of indoor climate control systems, we would surely benefit from the deployment of appropriate PR methods. It seems to me that in this instance, using rigid NP models of user presence and behavior that ignore associated stochastic fluctuations (and the resulting uncertainties) would be rather problematic. While dealing with the requirement of providing sufficient heating and cooling capacity to different zones of a building in an efficient manner, the variability of required thermal loads needs to be systematically explored. This cannot be based on spatially and temporally averaged occupancy assumptions.

3.4.4 Design versus control

As I mentioned before, the nature of the applied occupancy-related models are often claimed to determine the reliability of building performance predictions. But what does such an assertion really mean, and how can we validate it? As I mentioned before, it would be rather incoherent to expect that simulation use cases in the design phase would lead to the specific long-term predictions of a specific building's energy use. Consequently, to evaluate the occupancy model deployed (whatever kind it may be), it would be not appropriate to conduct a kind of interval for interval comparison of "predicted" and actual values of performance indicators. Rather, in such a case, the long-term comparison of modelled and actual general patterns (overall statistical resemblance) of occupants' presence and behavior appears to be more appropriate.

Imagine, on the other hand, that an occupancy-related model is intended to be deployed in the context of a predictive building systems control scenario. Thereby, one is on the lookout for a model that provides, for relatively short time horizons (let us say 24 or 48 hours) the most reliable predictions of occupancy-related events in a specific building. In such a case, the aforementioned interval by interval comparison of predicted and actual events appears to be entirely coherent

3.4.5 Reflections

I do not imply that the above – rather brief – discussion of simulation deployment scenarios and the corresponding choice of proper occupancy-related representational methods is either exhaustive or definitive. Nonetheless, it does seem to suggest that different approaches to representation of occupancy-related processes in building performance simulation may be appropriate given different application scenarios and different types of queries. If consideration of the implications of variance in input assumptions is evidently critical to a specific performance inquiry, then properly developed and calibrated probabilistic models of occupancy presence and control actions would be necessary. On the other hand, when the objective of a simulation-based inquiry is to benchmark design proposals against applicable codes and standards or to parametrically compare design alternatives, consideration of random variations of boundary conditions and internal processes in simulation runs may be less critical – or, the intended objective of analysis could be achieved via means (such as the old-fashioned "factors of safety") that do not necessarily require the run-time execution of PR occupancy-related algorithms.

An analogous observation applies to the question of occupancy-related model evaluation. It seems to me that not only the choice of the model, but also the evaluation of how good it performs, requires the consideration of the use case and the nature of the simulation-supported queries. The way I see it, optimization of building designs does not require from a PR model to deliver faultless short-term predictions of actual occupancy processes. I suppose in this case the role of the PR model is to test – for more or less longer observational periods – the robustness of the projected design performance in the face of occupancy-related uncertainties. On the other hand, given an application scenario involving simulation-assisted predictive building systems control, the short-term predictive performance of the occupancy-related model is of critical importance. The choice of model evaluation criteria does need to consider the specifics of the simulation application case.

The sketchy discussion above obviously represents only a preliminary treatment of this matter. I suggest we need much more work and thinking toward a clear picture of the interdependence of simulation model usage and respective representations of occupancy-related phenomena.

4. Conclusion

To conclude:

- There are all kinds of good and important reasons to work toward better and more sophisticated methods of representing people’s presence and behaviour in building performance simulation applications. So the question is not if we need more advanced models. The question is how we get there.
- Simulation studies can support the understanding of a buildings' behaviour (its performance) given a number of assumptions. Treatment of the uncertainties associated with these assumptions – e.g., via uncertainty and sensitivity analyses – can be both useful and illuminating, but does not necessarily translate in provision of accurate "prediction" of the real future buildings' performance over the long run. Moreover, mapping the variance of input assumptions to the variance of simulation output is only then truly useful, when the variance of the former is empirically grounded.
- Whatever the underlying logic of an occupancy-related model (probabilistic or non-probabilistic), its reliability depends on the underlying observational data and the care with which such data has been collected and processed. Moreover, the application of a model to those kinds of cases that have not been statistically present in the model's underlying observational basis (i.e., other building types, construction, and system types, other locations and climates, other user populations, etc.) cannot be expected to yield reliable results.
- The choice of the modelling approaches and techniques, as well as the choice of model evaluation criteria are not independent of the intended purposes (application scenarios) of the building performance simulation studies. To identify one specific modelling technique and to suggest it to be applied to all stages, resolution levels, and queries in the building delivery process is reminiscent of the proverbial hammer looking everywhere for nails.

5. Acknowledgement

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