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THOUGHTS ON THE SELECTION OF THE APPROPRIATE SIMULATION MODELS IN BUILDING PERFORMANCE ASSESSMENT

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Abstract. Building performance simulation serves the derivation of the relevant building performance indicators (e.g., energy use, indoor-environmental conditions) given the assumptions of certain model input parameters (i.e., description of the building, boundary conditions, occupants' presence and behaviour). Simulation can be employed for multiple purposes, including but not limited to building design support, building systems configuration, and code compliance demonstration. It has been suggested that the level of detail and resolution of simulation models must match their deployment purpose. However, there is arguably a lack of definitive guidelines for the purpose-dependent selection of appropriate simulation models. To address this challenge, the present contribution suggests that the attributes of a simulation model in general, and the type of the adopted occupant model in particular, must correspond to the specifics of the building performance indicator under investigation. To make progress in this area, a typological classification of building performance indicators is proposed along three salient dimensions, namely the indicators' topical domain (e.g., energy use, thermal comfort, noise control), their spatial attributes, and their temporal attributes. Following a detailed analysis, the paper presents a high-level approach to derive the basic requirements concerning occupant models as a categorical function of the simulation purpose.

Keywords: Building performance, simulation purpose, model selection.

1. About building performance simulation

Computational models can assist the explanation and prediction of diverse entities and processes in various areas. As such, a carefully constructed and validated computational model of an entity or a process can be used as its virtual (digital) twin. At their core, computational models embody algorithms that use provided input data to derive the values of designated output variables. In case of building performance simulations, model input parameters typically include information on buildings' physical properties (construction, fabric, systems) as well as external boundary conditions (climate, weather) and internal processes (e.g., occupants' presence and activities). The output of the simulation process includes the values of the variables that capture buildings' performance. These variables, or performance indicators, may be related to different domains. They may address, for instance, buildings' energy use, or their indoor-environmental performance (thermal, visual, acoustic, air quality). Note that a number of such performance indicators pertain either directly to occupants' needs or can be affected by occupants' actions [1, 2]. Hence, building performance simulation frequently requires reliable models of occupants' presence in buildings and their interactions with buildings' control systems (e.g., heating, cooling, ventilation, lighting).

As described above, the building performance simulation process generated data relevant for assessment, evaluation, and comparison (e.g., through ranking) purposes. The generated data typically constitute values of the relevant building performance indicators (BPIs). In practice, these values are compared with target values that may be specified as per requirements in codes and standards or otherwise included in relevant contractual documents. Building designers, operators, and other pertinent stakeholders can use the simulation process and tools to pursue various queries. Two common forms of queries are as follows. The first form, which we may label as direct, looks for the values of performance indicators for a given set of input assumptions. The second, indirect, form looks for those constellations of input variable values that would yield a specific – desired – output. Options to address this latter kind of queries include, for instance, iterative simulation runs, parametric studies, and optimization tools.

2. Application purposes of building performance simulation

The discussion hitherto suggests to view building performance simulation as a process by which values of

Attribute	Description
Topical	The relevant field of performance query (e.g., energy performance, daylight availability, thermal comfort, noise control)
Spatial	The physical extent of the simulated object (e.g., workstation, single office, meeting room, whole building, urban district)
Temporal	Specific time stamp(s) or time interval(s) for which the value of the BPI is computed (e.g., temperature at a specific time, monthly or annual energy use)

Table 1. Schematic presentation of the key attributes of BPIs (see also [3]).

BPIs can be derived based on available or assumed input information on buildings' geometry, construction, systems, occupants, and context. The main concern of the present paper is the role of occupants in building performance simulation. However, performance simulation studies may be conducted for very different reasons or purposes [4–6]. Common instances of these purposes are as follows:

- Analysis of the behavior of building elements/components (e.g., numeric thermal bridge simulation).
- Whole building design support (e.g., examination of the performance implications of decisions regarding building geometry, fabric, envelope, etc.).
- Design and configuration support of building systems for indoor-environmental control (e.g., heating, cooling, ventilation, illumination).
- Support of optimal building operation (for instance, via model-predictive control methods).
- Performance assessment at the urban level (concerning, for instance, the patterns of air flow and migration of pollutants).
- Compliance assessment with building standards and codes, as well as benchmarking vis-à-vis building quality certification systems.
- Generation of content (e.g., for project competitions, promotion of new building projects, educational material).

Given the diversity of performance-related queries, it has been reasonably argued that the choice of a proper simulation model must consider the purpose of the inquiry. As mentioned before, the simulation process typically results in BPI values. Hence, we can simply suggest that the selection of a simulation model (as well as the embedded occupant model) should take the specifics of the relevant BPI into account. In other words, the simulation model must fit the purpose of simulation, and the embedded occupant model must fit the simulation model. To put it in more succinct terms, the simulation query implies an appropriate BPI, the BPI an appropriate simulation model, and the simulation model an appropriate occupant model.

3. Toward a building performance indicator typology

The above observations provide a conceptual basis for the discussion of the selection process of a suitable simulation model for a given purpose. However, we must attempt to explore the practical implications of these observations. To this end, it may be useful to arrive at a basic typology or classification of BPIs. Detailed ontologies of building performance data and BPIs have been proposed and discussed in previous publications [7–11]. For the purposes of the present discourse, we need to consider only three BPI dimensions or attributes (see Table 1).

4. About the resolution level of building performance indicator values

Given the previous discussion, we can now turn our attention to the question of the appropriate level of resolution as applied to BPIs. Given vast computational resources, one would be tempted to suggest that we should obtain BPI values at a very high level of resolution level regarding time and space. After all, values of a BPI such as energy use that are derived on a minute-by-minute and on a room-by-room basis could be easily aggregated to hourly, daily, monthly, or annual values for individual rooms, different floors, or whole buildings. Note that the reverse process is rather non-trivial: If initial BPI values are computed for longer time intervals or at the whole building level, they cannot be disaggregated in a straight-forward manner into values of higher temporal or spatial resolution.

These observations must be interpreted carefully, lest a misunderstanding ensues. The problem of fitting simulation models to specific queries cannot be solved by conducting simulations always at the highest possible level of spatial and temporal resolution. The premise of such an approach is that highly detailed simulation results could be adapted, via averaging and aggregation operations, to fit the needed resolution level of target BPIs. But there are both practical and conceptual problems with this approach. The reliable application of high-resolution simulation models is computationally expensive and requires considerable expertise. There is also the much-discussed problem of scarcity of detailed and exact input information particularly at the early stages of building design process. Hence, in an early design stage scenario, a high-resolution simulation model would require large amounts of detailed yet uncertain data. In other words, it can be argued that the added value of higher resolution is questionable, if it comes with higher uncertainty. This implies that high-resolution simulation models are not necessarily more suitable for all tasks, neither do they automatically yield more accurate results. Specific tasks require simulation models with the appropriate resolution, which does not always mean the highest possible resolution.

To approach this question in more concrete terms, consider the relationship between the temporal structure of the simulation algorithm on the one side, and the type of the modelled physical process on the other side. For instance, when modelling thermal processes in buildings, we need to properly consider phenomena pertaining to thermal inertia, thermal lag, and thermal storage. The nature of these phenomena mandates transient simulation, which in turn requires minimum temporal resolution levels of the applied numeric solutions. This requirement is perhaps of lesser relevance in case of visual and acoustic simulation. These observations explain why it has not been possible to come up with fast and easy rules for matching simulation models to the nature of performance queries. They also underline the essential role of users' knowledge, expertise, and experience in conducting reliable simulation studies. Nonetheless, our discussion so far does suggest the possibility of sketching certain general approaches toward the systematic and appropriate identification of the adequate simulation models for a given task, including the consideration of information requirements regarding the deployed occupant models. To this end, however, we must first reflect upon the available options with regard to the representation of the patterns of occupants' presence and behaviour in buildings.

5. About models of occupants

Occupant models and their integration in simulation models can be discussed from different viewpoints [4, 12, 13]. For the purposes of the present contribution, we can direct our attention to the thermal performance simulation domain as a case in point. Consider the kinds of information that must be embedded in occupant models. Generally speaking, occupant models suitable for thermal simulation are expected to entail information on occupants' attributes including their location in the building, their activity, and the thermal resistance of their clothing. Occupant models must also capture occupants' passive and active effects on buildings [1]. Passive effects denote occupant-induced introduction of sensible and latent heat as well as various emissions (CO_2, water vapour, etc.). Active effects concern the interactions of occupants with buildings' various indoor-environmental control devices and systems, including, for example, windows, blinds, luminaires, and fans.

It is conceivable that we could classify the presence and behaviour models of occupants in buildings in a manner that corresponds to the dimensions of BPIs (domain, temporal attribute, spatial attribute). As such, we can assign the passive and active effects of occupants to specific performance domains. Occupants' activity rates, for instance, are relevant to the thermal simulation domain. Their clothing's sound absorption is, on the other hand, relevant to the performance domain of room acoustics. The spatial attribute is likewise relevant to occupant models. For instance, we can represent occupants in terms of a group (e.g., all occupants in a building, in a floor, in a room). Occupants can be also individually assigned to specific locations such as workstation or a single-occupancy office. As far as the temporal attribute of occupants' presence in buildings is concerned, intervals of various duration may be selected. Similarly, occupants' control-related actions may be assumed to ensue within such intervals. Alternatively, if the simulation runs are event-driven, occupants' actions can be mapped to specific instances in time and marked with a time stamp. A further relevant aspect in constructing occupant models is the approach chosen to represent occupants' locations and their actions. These can be expressed either in terms of recurrent (fix) patterns, or in a probabilistic manner. As such, stochastic instances of occupant models may be, in certain cases, more adequate than conventional schedules and diversity profiles.

We can thus conclude that occupant models can be broadly classified with regard to their location in a conceptual multi-dimensional space (relevant domain, spatial attribute, temporal attribute). Consider, for instance, the thermal simulation domain. At one end of the spectrum, a simple simulation model may be single-zone spatially and annual (or monthly) temporally. In this case, occupants are representationally reduced, through fix daily schedules, to their contribution to the internal gains (which is typically added to gains associated with equipment and lighting) and the fresh air volume flow they require. At the other end of the spectrum, simulation tools and processes that involve agent-based modelling, would represent each occupant individually. In this case, the occupants' influence on the resulting high-resolution values of the relevant BPIs (energy use, indoor environment) is modelled probabilistically and dynamically.

6. High-level directions for the selection of occupant models in building performance simulation

It may be rather difficult to arrive at strict rules for the query-driven selection of simulation models (and entailed occupant models). However, the previous discussion provides the basis for the formulation of some general directions in the matter. To this end, consider three topical areas, namely

(1.) the code compliance use case,

(2.) the temporal dimension of the BPIs, and

(3.) the potential of probabilistic modelling.

6.1. Code compliance

The relevant BPIs are commonly predefined when the use case is the examination of building projects in view of their compliance with applicable codes and standards. Frequently, even the computational tools that can be applied are specified a priori. Furthermore, in the code compliance use case, the obtained values of BPIs are generally expected to be, at least in principle, reproducible by independent parties. What does this mean for the selection of the model used to represent the occupants? For one thing, the occupant model's resolution should preferably match the deployed computational model. For instance, in case the pertinent standard requires the values of an aggregate BPI, the application of neither a high-resolution simulation model nor a high-resolution occupant model would be critical. Examples of aggregate BPIs would be monthly values of buildings' estimated heating or cooling loads.

It may be useful here to reflect on a "historical" circumstance. In a number of instances, simplified methods for code-based assessment of building performance were thought as substitutes of previously applied prescriptive codes. A case in point is standard-based documentation of the thermal quality of buildings' construction (fabric, envelope). Such procedures did not per se consider occupants and their role in the buildings' performance. In the course of a paradigmatic shift from prescriptive codes to performance-based ones, the computational prediction of the energy demand of buildings was suggested to supplement – if not replace – prescriptive mandates regarding, for instance, the maximum thermal transmittance values of the components of the buildings' envelope such as windows and walls. In other words, the inclusion of information on occupants was not necessarily meant to address the sensitivity of the buildings' thermal performance in view of occupant behavior. As such, it could be argued that the inclusion of normalized occupant-related information in calculations was part of a procedure to document the influence of other factors (especially the physical quality of the building fabric) on the thermal performance of buildings. The application of simplified occupant models in thermal performance assessment procedures can be of course questioned. However, the reasoning behind the initial adaptation of simplified occupant representations in code-based calculations must be understood, lest the criticism would miss the point entirely.

6.2. The temporal dimension

When deciding what simulation and occupant models to choose, one must pay attention to the temporal dimension of the pertinent BPIs. We mentioned already the relative slow characteristics of the thermal behavior of buildings (particularly with regard to thermal conduction) and its distinction from visual and acoustic processes. Thermal performance simulation must specifically consider the thermal inertia and lag effects. Hence, the selected simulation models and respective numeric methods must be capable of representing transient phenomena. Whereas hourly thermal simulations appear to represent the standard in basic simulations of the energy use of (and the thermal conditions in) buildings, finer resolutions levels (e.g., sub-hourly intervals, event-driven simulation procedures) could be preferable, especially in those cases that involve regular human interaction with control devices such as windows, blinds, and luminaires.

6.3. Probabilistic modeling

It has been suggested, falsely, that occupant models should be stochastic, because occupants "behave stochastically". What would be more reasonable to suggest is that the overall patterns of the presence and behavior of occupant populations in buildings can be realistically reproduced using probabilistic formalisms. Consequently, it could be appropriate to use, in specific use cases, probabilistic modeling methods [1, 5]. However, these methods obviously do not generate single values for BPIs, but rather result in distributions. This has been suggested to be useful: Stochastic models can theoretically deal with the inherent uncertainties of processes and events attributable to building occupants. But one needs to be careful, as unvalidated or insufficiently validated probabilistic models could perhaps generate patterns that morphologically resemble actual occupant behavior processes, but would be entirely different than actually monitored behavioral data. The empirical foundation of a stochastic model needs to be relevant to and representative of the specific object of the simulation (a rarely feasible option in the building design phase), otherwise the resulting simulation data would not be reliable. If carefully conceived and deployed, there is still considerable potential in the application of stochastic modeling techniques in building performance simulation. However, in typical building design use cases, it could be more useful to address the matter of uncertainty in performance simulation via sensitivity analysis [14, 15]. Thus, one could explore the implications of variance in model input data without suggesting that the simulation results more accurately predict the future performance of a design.

6.4. A summarized view

The previous discussion can be broadly summarized in terms of the following matrix (see Table 2). Thereby, desirable features of occupant models are listed as

Simulation purpose	Spatial resolution	Temporal resolution	Probabilistic modeling
Compliance with codes	L/M	L/M	NA
Building design/retrofit support	M/H	M/H	L
Building systems design support	M/H	H	M
Building operation support	H	H	H

Table 2. Fitting spatial and temporal resolution levels of occupant models as well as their suitability for inclusion of probabilistic features as a function of the simulation application use case (L: low; M: medium; H: high).

a function of the simulation use case (i.e., demonstration of compliance with codes, building design and retrofit support, building systems design support, and building operation support). The desirable features of occupant models are specified for spatial and temporal resolution levels, as well as the models' suitability for inclusion of probabilistic features [3]. Here, the categories of spatial resolution are labelled low (applicable, for instance, in case of building floors and whole buildings), medium (applicable to rooms), and high (relevant, for instance, to individual workstations). Similarly, the categories of temporal resolution are labelled as low (for instance, monthly or annual), medium (hourly intervals), and high (sub-hourly intervals, event-driven simulation). The suitability of adopting stochastic occupant models in the building performance simulation process is characterized, qualitatively, in terms of the attributes non-applicable (NA), low, medium, and high.

7. Concluding remark

The discussion in the previous chapter in general, and the entailed summary matrix in particular (Table 2) are of course not suggested to represent a clear-cut recipe for the purpose-dependent selection of occupant models in building performance simulation applications. Composing such a recipe would not be a trivial matter: Building design and operation processes are highly complex and dynamic. They depend on a host of typological constraints, local circumstances, climatic conditions, economic parameters, and cultural factors. The objective of this contribution was rather to provide a bird-eye view of the relevant considerations with regard to identification of the simulation approaches and tools that would be fitting to the nature of specific performance queries. We are arguably not in a position to automate this matching process between models and queries. But obtaining a better understanding of the nature of this process could support the responsible experts in their choice of proper simulation models in general and occupant models in particular.

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