

Building Performance Simulation for Sustainable Buildings

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SUMMARY

This paper^{*} aims to provide a general view of the background and current state of building performance simulation, which has the potential to deliver, directly or indirectly, substantial benefits to building stakeholders and to the environment. However the building simulation community faces many challenges for the future. Several challenges relate to the need to provide better design support. Issues include early phase design support, multi-scale approaches (from construction detail to district level), uncertainty and sensitivity analysis, robustness analysis (employing use and environmental change scenarios), optimization under uncertainty, inverse approach (to address “how to” instead of being able to answer “what if” questions), multi-physics (particularly inclusion of electrical power flow modeling), and integration in the construction process (using building information modeling (BIM), process modeling, etc). Another group of challenges relates to the need to provide support for building operation and management. The issues include accurate in-use energy consumption prediction and model predictive control.

INTRODUCTION

In terms of sustainable building design and operation we are living in exponential times. The challenges for researchers, practitioners and other building stakeholders are bountiful when one recognizes the dynamic processes around us such as global climate change, depletion of fossil fuel stocks, increasing flexibility of organizations, growing occupant needs and comfort expectations, increasing awareness of relation between indoor environment and wellbeing/health, and increasing awareness of relation between indoor environment and productivity. This asks for an integrated approach of the subsystems shown in Figure 1 in order to achieve at robust building and system solutions which will be able to withstand future demands.

Nations all over the world have agenda's similar to – or even more demanding than - the European Union's 20-20-20 initiative (relative to 1999, by 2020 20% reduction of energy consumption, 20% reduction of CO₂, and 20% introduction of renewable energy). The goals for 2050 are much more demanding as discussed in, e.g., [1]. Achieving these ambitious sustainability targets requires the development of net energy producing buildings or sites. For this we need models and tools which allow the consideration of interoperating domains such as transportation and large scale energy grids. Only then can the global optimization of energy production and consumption in the built environment be achieved.

^{*} This paper is largely based on the Introduction chapter of Building Performance Simulation for Design and Operation, J Hensen and R Lamberts (Eds), Taylor & Francis, Oxford, 2011

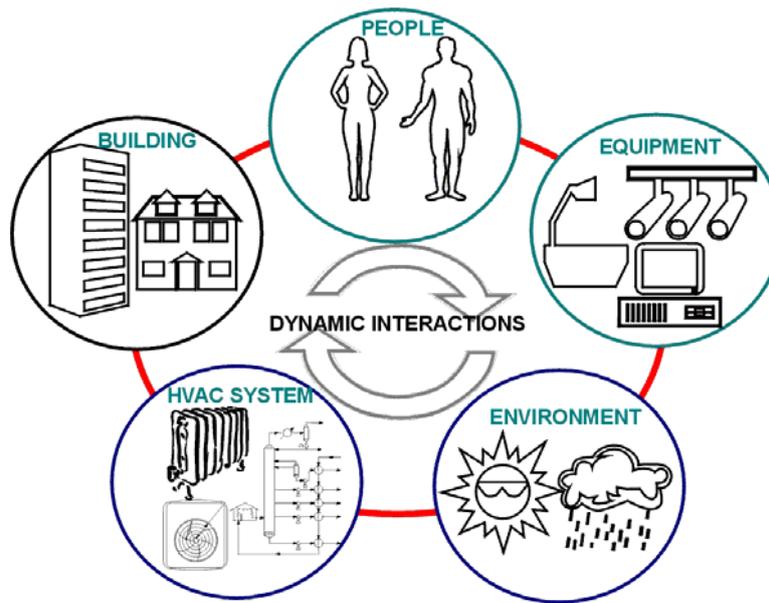


Figure 1. Dynamic interactions of (continuously changing) sub-systems in a building context.

In addition to these higher sustainability requirements, future buildings should also deliver considerable improvements to indoor environment quality. Rather than the current practice of merely complying with minimum standards for environmental parameters such as temperature, air quality, lighting and acoustical levels, future buildings should provide a positive indoor environment that is stimulating, healing or relaxing, depending on the function. This will then result in truly high performance buildings [2].

At present, however, the focus - even in high performance buildings - is still very much on reducing energy demand. Given the relatively low volume of new building projects (in Europe only about 10% per year of the total building stock), it is evident that in order to reach the sustainability targets in time, a huge amount of work is needed in terms of refurbishment of existing buildings (see, e.g. [3]). So - both new and refurbishment - future projects face huge challenges that seem too complex for traditional design tools and approaches.

BUILDING PERFORMANCE SIMULATION

Computational simulation is one of the most powerful analysis/analytic tools in our world today - it is used to simulate everything from games to economic growth to engineering problems. Both the power and the complexity of building performance modeling and simulation arise from its use of many underlying theories from diverse disciplines, mainly from physics, mathematics, material science, biophysics, human behavioral, environmental and computational sciences.

Like many other technological developments, building performance simulation also experienced a so-called hype cycle [4], as shown in Figure 2. The "recognition" took place in the early 1970s, with the peak of inflated expectations in the 1980s, followed by the trough of disillusionment. It seems fair to state that building performance simulation in general has been on an upward slope of productivity for almost two decades now.

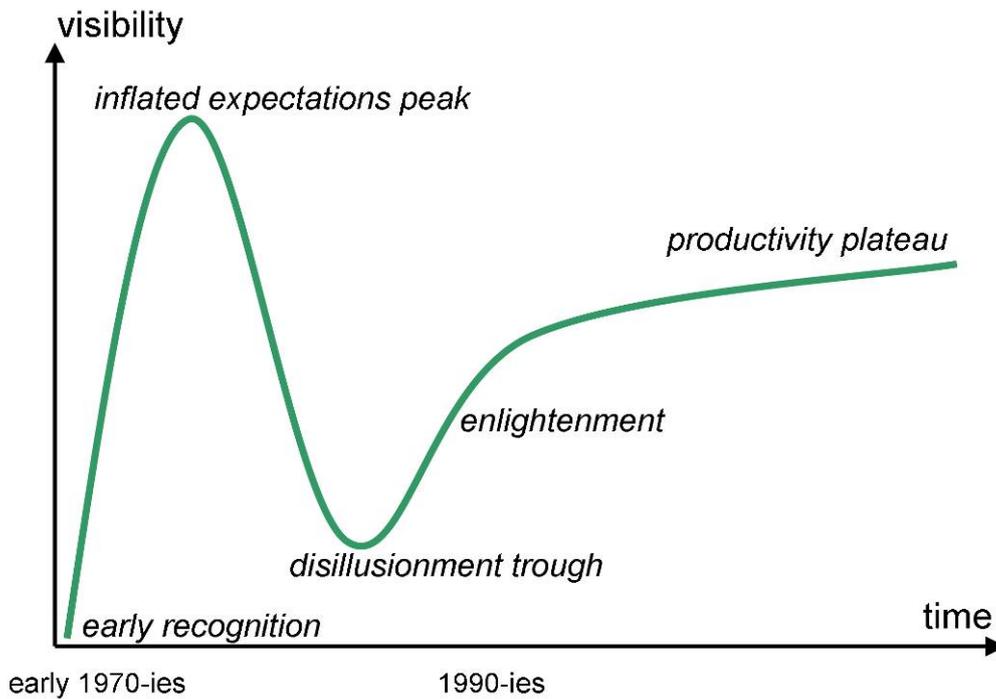


Figure 2. Hype cycle of building performance simulation technology

In this context, the important role of the International Building Performance Simulation Association (IBPSA - www.ibpsa.org) should be acknowledged, since one of its most important goals is to increase awareness of building performance simulation while avoiding both inflated expectations and disillusionment.

The building simulation discipline is continuously evolving and maturing and improvements are continually being made to model robustness and fidelity. As a result much of the discussion has shifted from the old agenda focusing on software features, to a new agenda that focuses on the effectiveness of building performance simulation in building life cycle processes.

The development, evaluation, use in practice, and standardization, of the models and programs is therefore of growing importance. This is evidenced in, for example, green building rating systems currently being promoted around the world, such as LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method), in incentive programs such as the US EPC Act (Energy Policy Act) and also in legislation such as the European EPBD (Energy Performance of Buildings Directive).

CURRENT USE IN PRACTICE

It is widely recognized that predicting and analyzing future behavior in advance is far more efficient and economical than fixing problems arising from occupant behavior when the building is in the use phase. Nevertheless, the uptake of building performance simulation in current building design practice is surprisingly limited. The actual application is generally restricted to the final phases in building design as indicated in Figure 3.

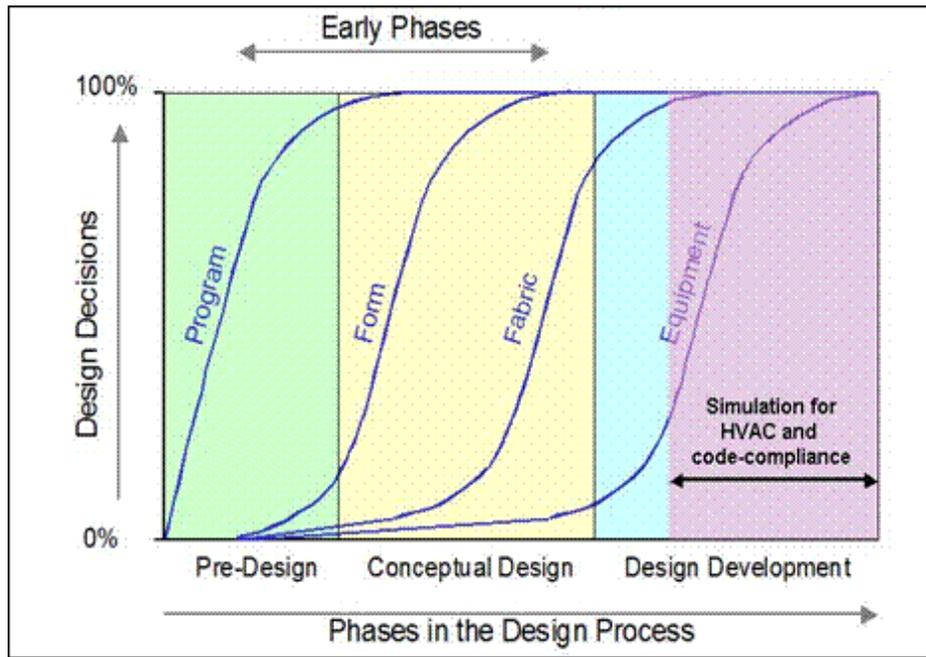


Figure 3. Current use of performance simulation in practical building design. [5]

At present, in addition to its relatively low adoption, the use of building performance simulation is largely restricted to a few key areas such as building envelope design; to predict risk of overheating during the summer (Figure 4 as example) and/or to calculate maximum cooling loads in view of equipment sizing (Figure 5 as example).

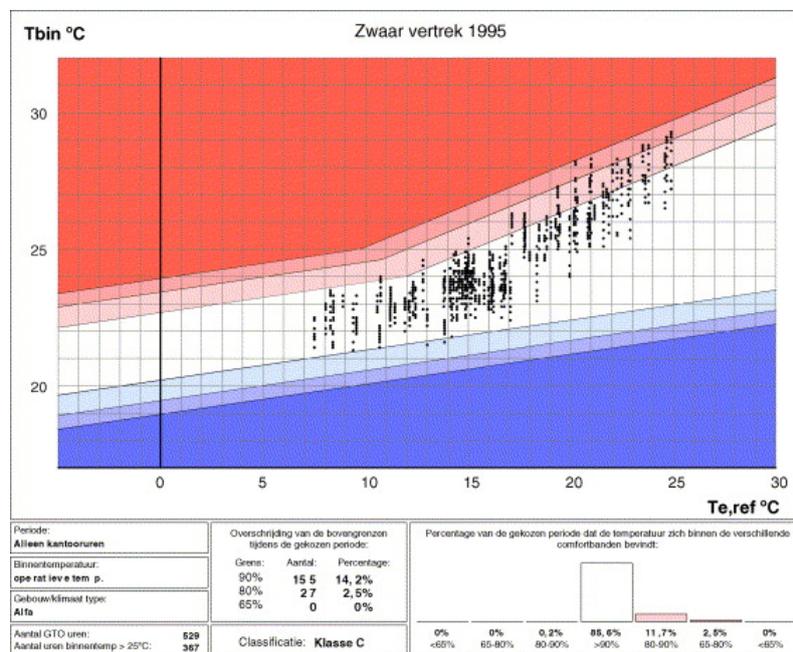


Figure 4. Output visualization of adaptive thermal comfort predictions for a medium-heavy office building in The Netherlands during the period from May to end September 1995 [6] (Linden *et al.* 2006)

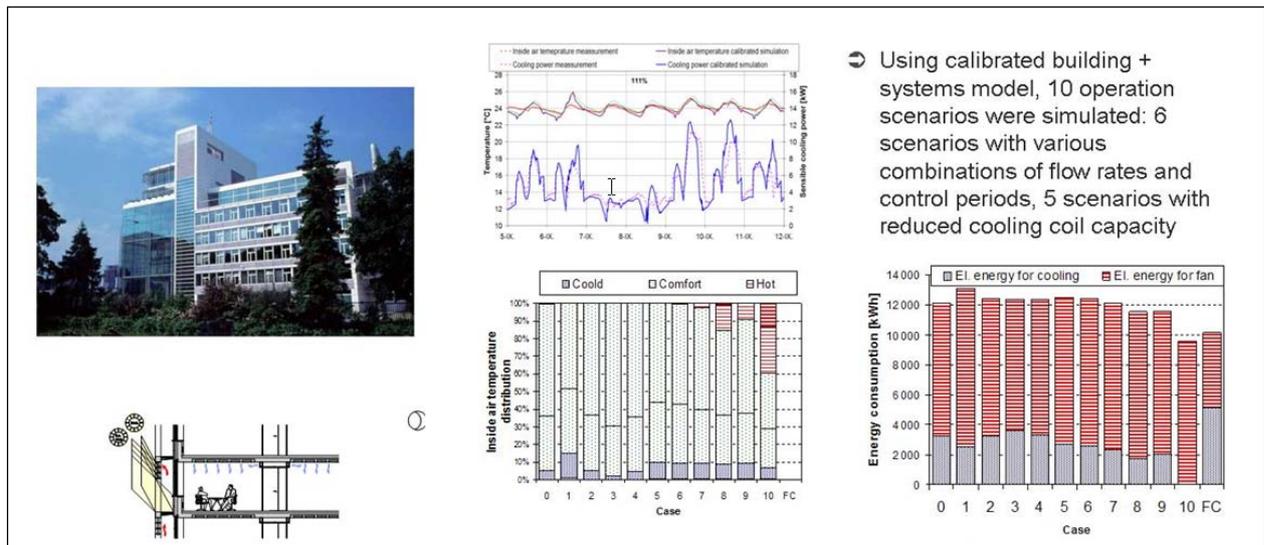


Figure 5. Sample comfort, cooling load and energy simulation results for a low-energy office in Prague where 10 different system operational scenarios have been compared [7]

Although Figure 5 is from a study where simulation was used for mechanical engineering design, in reality these sorts of studies are rare. It is still much more common to see traditional design approaches being used for this.

To recap/summarize, in current practice building performance simulation is largely restricted to the analysis of a single design solution. The potential impact of building simulation would be greatly enhanced if its use was extended to (multiple variant) design optimization and included much earlier in the design process. To illustrate this point, consider the CIBSE [8] design strategy for environment friendly and future proof building design, which can be summarized in the following sequential steps:

1. Switch off – relating to internal and external thermal loads
2. Spread out – use thermal mass
3. Blow away – apply (natural) ventilation when possible
4. Cool when necessary – do not hesitate to include some extra (mechanical) cooling in order to be prepared for future climate change

The effects of the three first approaches depend mainly on design decisions related to building program, form and fabric, and can only be predicted by simulation.

Moving beyond the design phases, there exists a considerable and rapidly increasing interest - in practice and research - in the use of simulation for post-construction activities such as commissioning, operation and management. The uptake in current practice is still very limited, but it is expected that the next decade will see a strong growth in application of building performance simulation for such activities. The two main reasons for this are (1) the current (considerable) discrepancy between predicted and actual energy consumption in buildings, and (2) the emergence of new business models driven by whole life time building (energy) performance.

QUALITY ASSURANCE OF SIMULATION BASED DECISIONS

Quality assurance is a very important and ongoing issue. The quality of simulation results depends, of course, on the physical correctness of the model. Although [9] is not related to building simulation, the conclusion that it is not possible to validate a model and its results, but only to increase the level of confidence that is placed in them, seems to be equally true for our domain. The ongoing BESTEST initiative represents a major international effort within the building domain to increase the confidence of simulation results. Its progress is reflected in its first footholds in professional standards such as the American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard Method of Test 140.

It is worth noting that it is still common practice not to report confidence levels for simulation results. This is interesting because it is well known that, for example, real and predicted energy consumption of low-energy buildings is extremely dependent on uncertainties in occupant behavior; as illustrated in Figure 6.

User and use related aspects are very often under-appreciated in building performance simulation. In terms of application, for example, simulation is much more effective when used to predict the relative performance of design alternatives, than when used to predict the absolute performance of a single design solution.

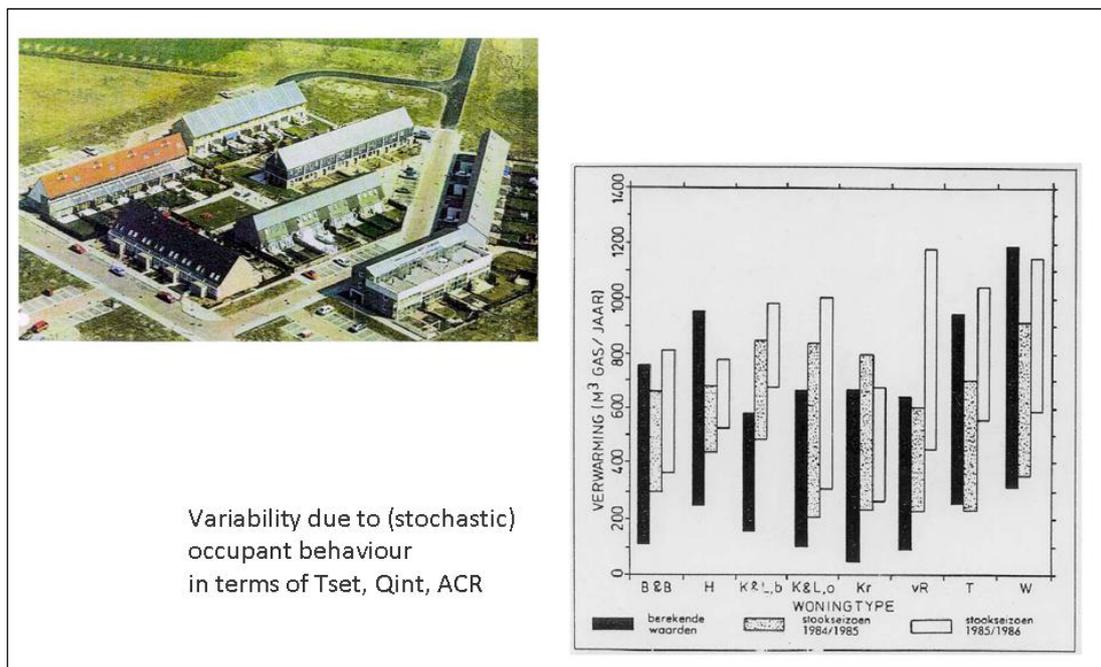


Figure 6. Variability in real and predicted gas use for space heating in eight different types of Dutch low-energy houses due to uncertainties in occupant behavior in terms of heating set-point, casual gains and infiltration rates.[10]

In practice it can also be commonly observed that complex high resolution modeling approaches (such as computational fluid dynamics (CFD)) are used for applications where a lower resolution method would be quite sufficient and much more efficient. There is also a wide-spread misconception that increasing the model complexity will decrease the uncertainty of the results. As indicated in Figure 7, in reality, deviation from the optimum to either lower or higher complexity increases the potential error in the simulation results.

The above discussion is an element of conceptual modeling, i.e. the process of abstracting a model of a real or proposed system. [11] states that

“All simulation models are simplifications of reality.... The issue in conceptual modelling is to abstract an appropriate simplification of reality..... The overarching requirement is the need to avoid the development of an overly complex model. In general, the aim should be: to keep the model as simple as possible to meet the objectives of the simulation study.”

The implication of this is that for the same physical artifact (e.g. a building, a façade or an HVAC component) a different modeling approach is to be preferred depending on the objective of the simulation. [12] elaborates on this for building services related performance studies.

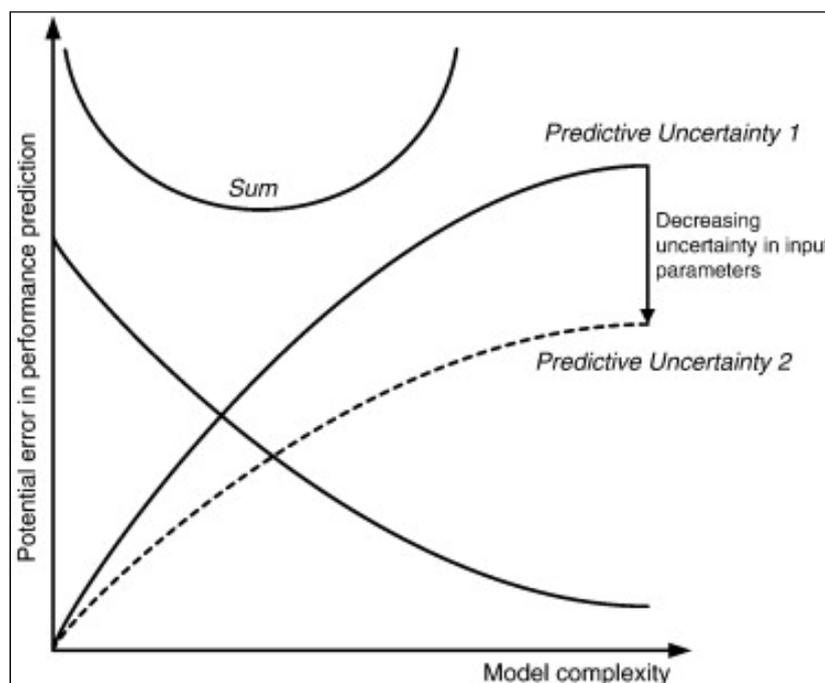


Figure 7 Potential errors in performance prediction vs. model complexity/ level of detail [12]

DISCUSSION

(Future) simulators should note that simulation is a skill that needs to be learned. The first step is to acquire sufficient domain knowledge, and then skills and knowledge relating to principles, assumptions and limitations of modeling and simulation. Only with this combined knowledge it will be possible to determine when and when not, to use simulation.

In the context of user aspects of quality control it is very good to see that professional organizations such as ASHRAE and the Illuminating Engineering Society of North America (IESNA) are collaborating with IBPSA to develop an Energy Modeling Professional certification program. The purpose of this certification is to certify individuals' ability to evaluate, choose, use, calibrate, and interpret the results of energy modeling software when applied to building and systems energy performance and economics and to certify individuals' competence to model new and existing buildings and systems with their full range of physics.

ACKNOWLEDGEMENT

This paper is largely based on the Introduction chapter of [13]. This multi-author book aims to provide a comprehensive and in-depth overview of various aspects of building performance modeling and simulation, such as the role of simulation in design, outdoor and indoor boundary conditions, thermal modeling, airflow modeling, thermal comfort, acoustics, daylight, moisture, HVAC systems, micro-cogeneration systems, building simulation in operational optimization and in building automation, urban level modeling and simulation, building simulation for policy support, and finally a view on future building system modeling and simulation.

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