Hensen, J. L. M. 2012, "Evaluation through computational building performance simulation," in *Enhancing Building Performance* , S. Mallory-Hill, W. F. E. Preiser, & C. G. Watson, eds., Wiley-Blackwell, Oxford, pp. 223-233

19.1 INTRODUCTION

Providing adequate building designs for current and future use is perhaps more challenging now than it has ever been. Not only do new building designs need to fulfill all operational requirements of the users, they also need to be aware and take account of a variety of dynamic processes surrounding the design situation. Among the most important of these processes are: depletion of fossil fuel stocks; changing market prices for fuel sources; global climate change; growing occupant needs and comfort expectations; increasing flexibility of organizations; growing realization that indoor environment correlates with the health and wellbeing of the occupants, and consequently, with their productivity. The complexity involved in simultaneously managing these processes requires an integrated approach to building design. Providing robust building and system solutions capable of living up to future demands is not realistic without the thoughtful integration of the requirements of indoor actors and activities, the effects of the ambient environment, and the state of the art practices from the fields of building construction and building services.

19.2 BACKGROUND

The immediate need to produce sustainable buildings and technologies is now well understood by the vast majority of, if not all, stakeholders in the fields of design and construction. Indeed, this need is reflected in the stringent 20-20-20 initiative set out by the European Union, which dictates that by 2020, we must achieve a 20% reduction of energy consumption, a 20% reduction of CO_2, and a 20% introduction of renewable energy in relation to 1999 figures. Of course, the European Union is not the only party to recognize the need to achieve significant reductions in energy use. Many countries from around the globe have published guidelines, which in some cases are even stricter than those of the EU initiatives. Despite their strictness, these initiatives and guidelines must be viewed as nothing more than an intermediate step towards more ambitious future guidelines discussed, for example, in the work of Lund and Mathiesen (2009).

To reach the ambitious sustainability targets mentioned, net energy producing buildings or sites must be developed. Realizing this development requires models and tools capable of assimilating interoperating domains, including transport networks and energy grids of a sufficient scale. This development is necessary to achieve the global optimization of energy production and consumption in the built environment. Importantly, any attempt to develop a greener and more sustainable built environment must take account of trends in the current building stock. At present, in Europe the annual construction activity for new buildings only accounts for about 1 % of the total heated area in broad terms. This means that a change in energy performance for new buildings will take more than 100 years before all existing buildings have been replaced. Therefore it is crucial to look on energy upgrading of the existing buildings stock, as the largest energy saving potential lies there (see, e.g. (Petersdorff et.al 2006) and (Jensen et al. 2009)).

Aside from the energy related requirements set out in guidelines, the growing awareness of building user needs requires significant improvements to indoor environment quality. Within the status quo it is common practice for building designs to aim for the minimum standards for environmental parameters such as temperature, air quality, lighting and acoustical levels. These minimum standards are largely meant to avoid dissatisfaction and complaints. Future buildings, however, must aim to provide the optimum indoor environment to realize the core function of the building, whether it is to stimulate, heal or relax the users of the building. Only then can one talk of truly high performance buildings (Green 2009).

19.3 BUILDING PERFORMANCE SIMULATION

Nowadays, computational modeling (i.e. creating a computer based representation of a real system) and simulation (i.e. using a model to predict (future) behaviour of a real system) is one of the most powerful and widely used analysis techniques, with applications ranging from games to economic growth to engineering problems. It is very important to recognize that (1) simulation does not provide solutions or answers – its main purpose is to increase understanding, and (2) most of the time it is difficult to ensure the quality of simulation results.

As elaborated in Hensen and Lamberts (2011) 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. Computational building performance simulation has been actively researched and applied since the 1960's. While the early work mainly focused on (cooling) load calculations, in later years this was expanded with heat and mass transfer in the building fabric, airflow in and through the building, daylighting, and a vast array of heating, ventilation and air-conditioning system types and components. During the same time, the development of more powerful and user-friendly interfaces resulted in much wider use of building performance simulation. Nevertheless, many theoretical and practical challenges still need to be overcome before the full potential of building performance modeling and simulation can be realized.

The proliferation of activities and publications of the International Building Performance Simulation Association (IBPSA - www.ibpsa.org) provides ample evidence that the discipline of building simulation is continually evolving and maturing. The fidelity and robustness of simulation models has improved significantly, and is set to continue. Whereas in the early days of simulation the main agenda focused on software features, the discussion has moved in recent decades to the effectiveness of building performance simulation in building life cycle processes.

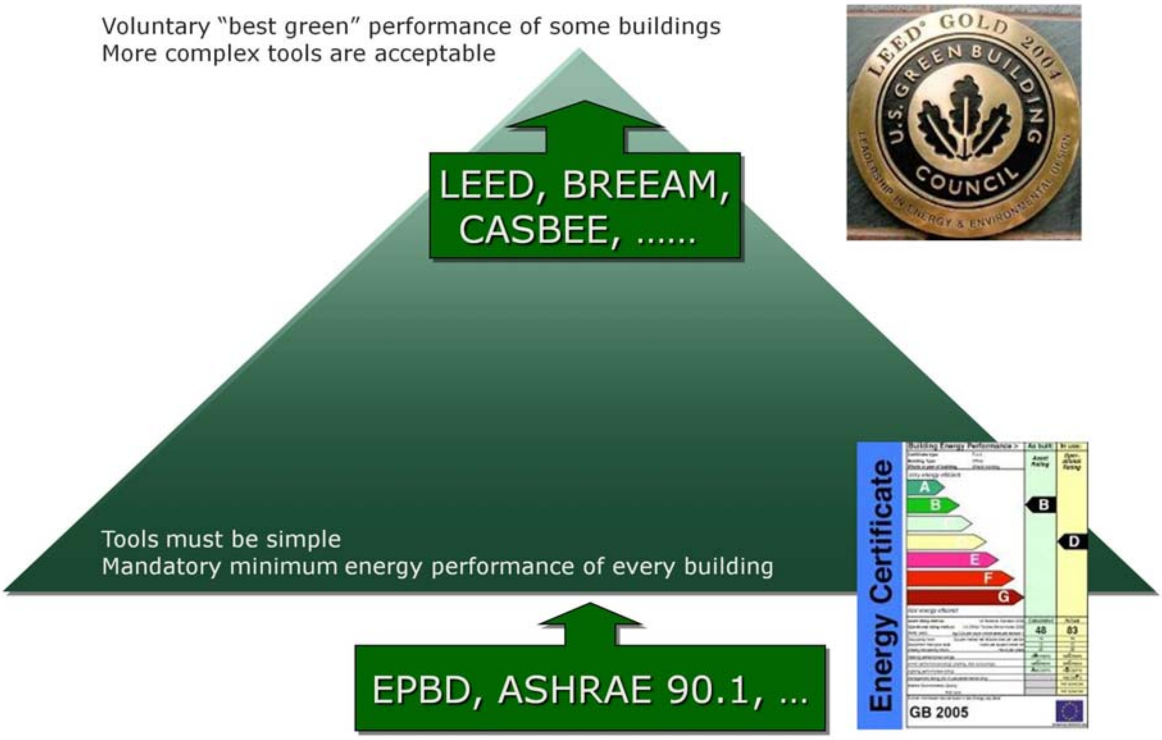


Figure 19.1: Position of building performance simulation in the context of green building design guidance

At present, there is a growing acceptance that modeling and simulation can have an important role to play in the development of new, green buildings (see Figure 19.1). A great deal of work is currently being undertaken on the development, evaluation, use in practice, and standardization of a wide range of models and programs for various uses. Some of the most noteworthy developments include the green building rating systems that are gaining international importance, such as LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method), the incentive programs such as the US EPAct (Energy Policy Act) and also legislation such as the European EPBD (Energy Performance of Buildings Directive).

19.4 STATE OF THE ART

One of the most efficient and economical ways to manage building design innovations is to predict and analyze future behavior in advance in order to prevent unpleasant future surprises, rather than to have to go to the trouble and expense of fixing problems afterwards. Despite this observation, within building design practice there is at present a surprisingly low uptake of building performance simulation. The majority of current tools (see, e.g. (DOE 2010) and (Crawley et al. 2008) and applications focus on the final phases in building design (see Figure 19.2), whereas there is a huge potential during each of the six phases of the process model for BPE (see Chapter 1, A process model for building performance evaluation). For further discussion of computational building performance simulation potential throughout the building life-cycle see (Hensen and Lamberts 2011).

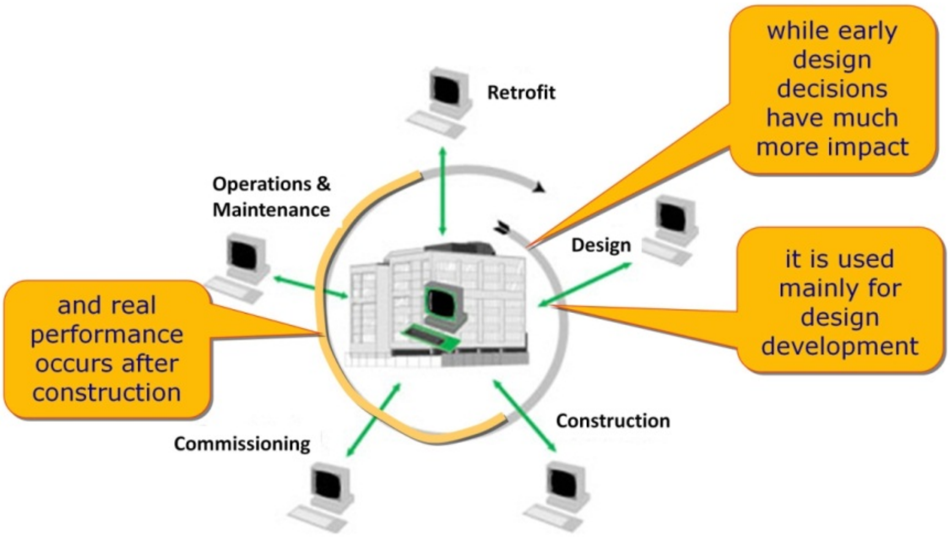


Figure 19.2: Current application of computational simulation in the building life-cycle.

Nowadays, aside from the low adoption rate, building performance simulation is still generally restricted to a relatively small number of tasks: the design of building envelopes; the prediction of the risk of overheating during the summer, as shown in Figure 19.3, and/or the calculation of maximum cooling loads in relation to equipment size (see Figure 19.4 and 19.5 as examples).

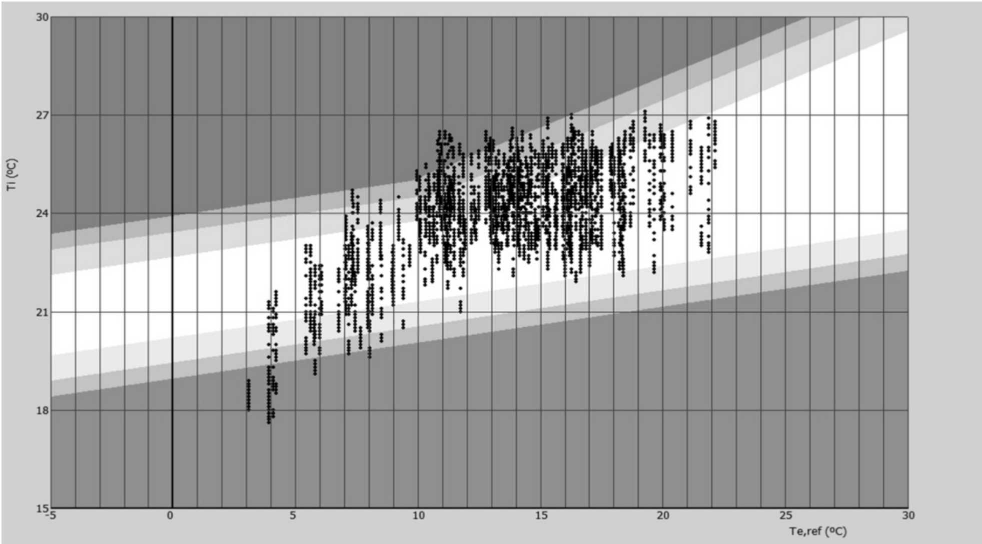
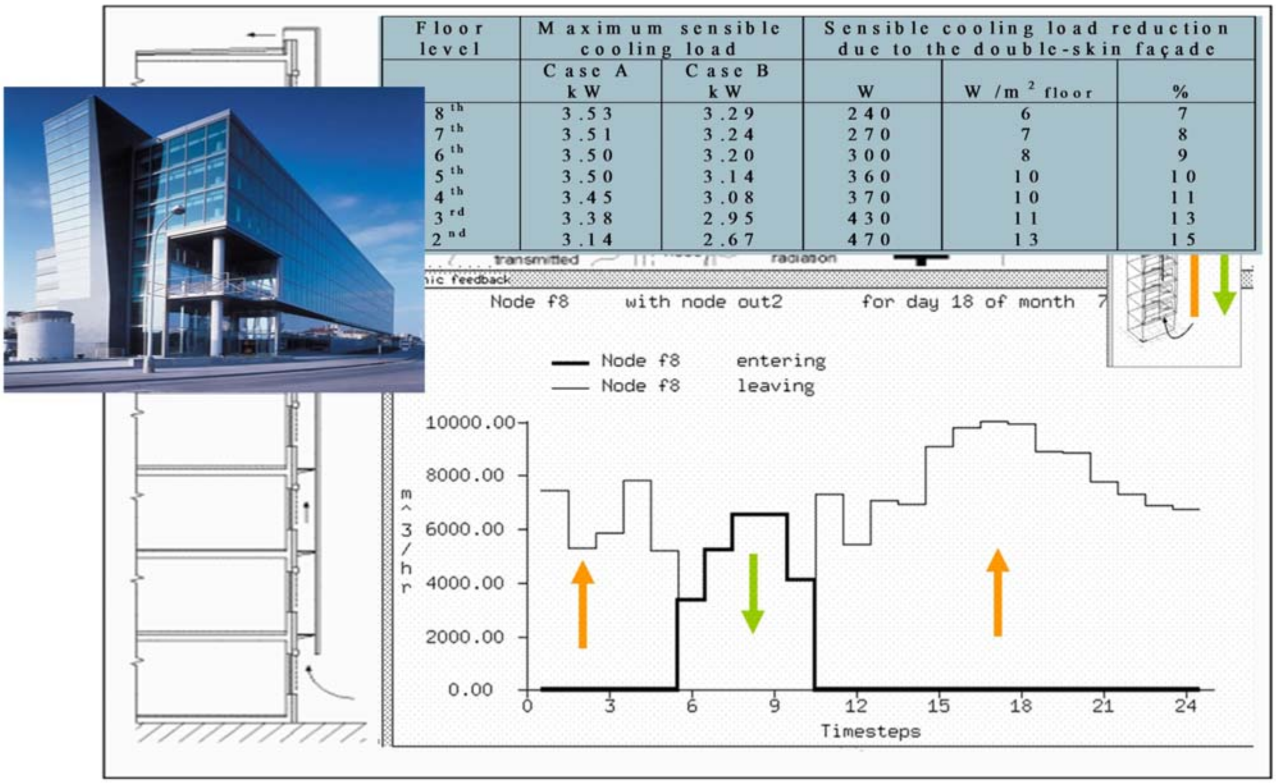


Figure 19.3: Predicted hourly indoor temperature and adaptive thermal comfort bands as a function of reference outdoor temperature



Floor level	Maximum sensible cooling load		Sensible cooling load reduction due to the double-skin façade		
	Case A kW	Case B kW	W	W/m² floor	%
8th	3.53	3.29	240	6	7
7th	3.51	3.24	270	7	8
6th	3.50	3.20	300	8	9
5th	3.50	3.14	360	10	10
4th	3.45	3.08	370	10	11
3rd	3.38	2.95	430	11	13
2nd	3.14	2.67	470	13	15

Figure 19.4: Airflow and cooling load simulation results for an office building with naturally ventilated double-skin façade

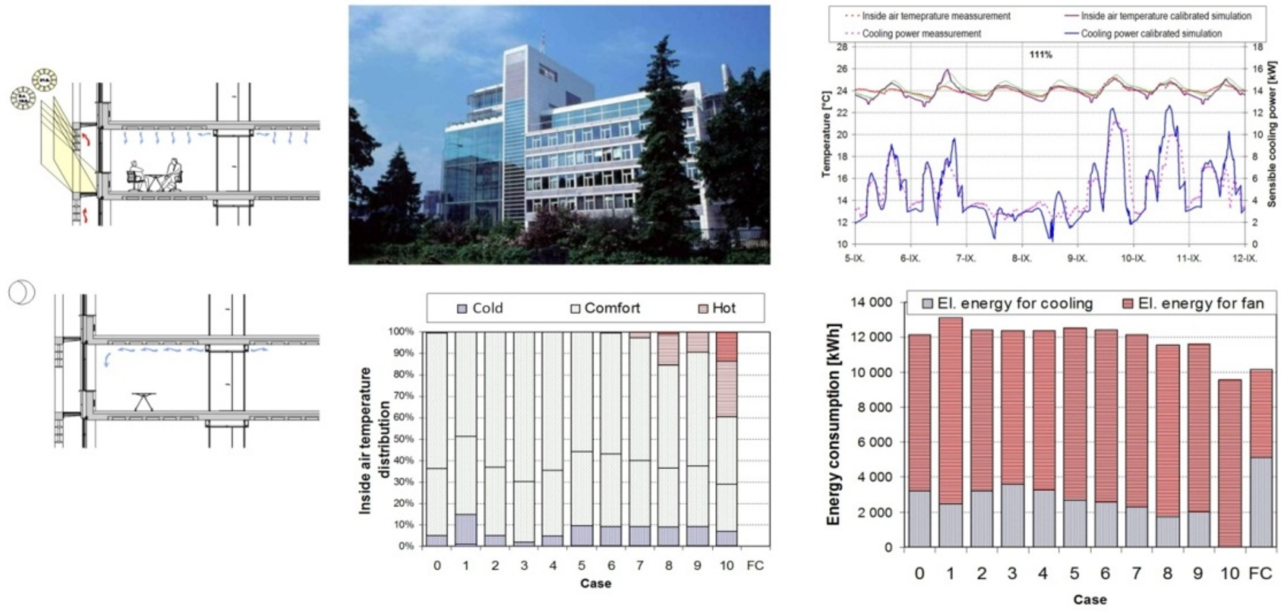


Figure 19.5: Thermal comfort, cooling load and energy simulation results for a low-energy office building

However, design decisions related to building program, form and fabric are made early in the design process and potentially have much more impact than those made towards the end of the design. Thus, building simulation should be used much earlier in the design process, and its use must be extended to include uncertainty, sensitivity and robustness analysis, as well as (multiple variant and multi-objective) design optimization.

As well as research in design process applications, there is increasing interest in both practice and research in the use of simulation for post-construction activities as commissioning, operation and management. At present, adoption in these areas is still quite slow, but is expected to increase in pace dramatically over the next decade or so. The two key drivers for this expected increase 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.

19.5 QUALITY ASSURANCE OF SIMULATION BASED DECISIONS

Quality assurance of simulation results is of paramount importance. Obviously, this is reliant on the physical correctness of the model. It is important to keep in mind, however, that in the majority of academic fields it is not possible to validate a model and its results, but only to increase the level of confidence that is placed in them (Robinson 1999). A great amount of effort within the international building performance simulation domain is put into increasing the confidence of simulation results. Leading work in this area includes the ongoing BESTEST initiative (e.g. Judkoff and Neymark, 1995; Neymark et al., 2001) the results of which have found their way into professional standards such as the building simulation related standard method of test (ASHRAE 2004).

As far as practical applications go, simulation has proved much more effective in predicting the relative performance of design alternatives, than in predicting absolute performance for a single design solution. It is interesting to note that confidence levels for simulation results still are not routinely reported. This is noteworthy, because it has long been known that uncertainties in occupant behavior can lead to significant differences in, for example, real and predicted energy consumption of low-energy buildings. Figure 19.6 shows the variability in 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, compared to measured values for the 1984-1986 heating seasons (Hensen 1987).

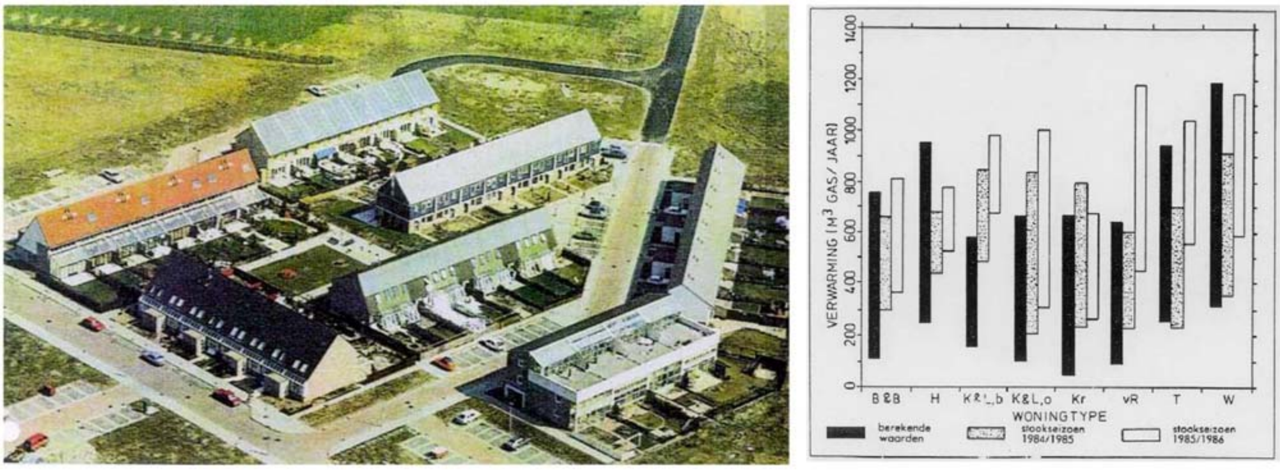


Figure 19.6 Occupancy related variability in predicted (black bars) and measured (grey bars) gas use for space heating in eight different types of Dutch low-energy houses

In building performance modeling one should consider Occam's Razor or Einstein's principle that implies that a model should be as simple as possible but not simpler. Thus, as Robinson (2008) points out:

"All simulation models are simplifications of reality…. The issue in conceptual modeling 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."

A common observation in practice, however, is that complex high resolution modeling approaches (such as computational fluid dynamics (CFD)) are applied, when in fact a lower resolution method would be more efficient and more than adequate for the job at hand. This situation may well arise from the common misconception that the uncertainty of the results can be decreased simply by increasing the model complexity. As Trcka and Hensen (2010) concluded, the potential error in the simulation result increases with deviation from the optimum to either higher or lower complexity.

There is an important implication here: The same physical artifact (e.g., a building, a façade or an HVAC component) requires different modeling approaches, depending on the objective of the simulation. An elaboration of this point for building airflow related performance studies can be found in (Hensen 2004).

The main point to be drawn from the above discussion is that the most fundamental requirement for quality assurance is sufficient domain knowledge on behalf of the user. Nevertheless, one should remember the important distinction made by Becker and Parker (2009), that being a subject matter expert in something is rather different than being able to describe that thing so it can be simulated, or actually being capable of implementing and testing the simulation.

Much can still be learned from modeling and simulation work from other domains. This is particularly true with respect to methodological aspects. For example, Banks and Gibson (1997) from the field of electrical engineering, concluded that it is better not to simulate when:

1. The problem can be solved using "common sense analysis“
2. The problem can be solved analytically (using a closed form)
3. It's easier to change or perform direct experiments on the real thing
4. The cost of the simulation exceeds possible savings
5. There aren't proper resources available for the project
6. There isn't enough time for the model results to be useful
7. There are no data – not even estimates
8. The model can't be verified or validated
9. Project expectations can't be met
10. System behavior is too complex, or can't be defined.

Like any other skill, simulation needs to be learned. To become an adept simulator, one must first acquire sufficient domain knowledge, before acquiring knowledge and skills relating to assumptions, limitations and principles of modeling and simulation. Determining when (not) to use simulation will only be possible once this knowledge has been successfully combined.

In the context of quality control by simulation users it is very encouraging 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 an individual’s 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 an individual’s competence to model new and existing buildings and systems with their full range of physics.

19.6 CONCLUSION

Building performance simulation has the potential to deliver substantial benefits to building stakeholders and to the environment, both directly and indirectly. However, there are still many challenges facing the building simulation community for the future. These challenges can be categorized in two main areas:

- The provision of better design support: issues here 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); construction process modeling, etc.

- Provision of support for building operation and management: issues here include accurate in-use energy consumption prediction; whole building (total energy) performance analysis; model predictive (supervisory multi-input multi-output control)

For discussion of many, but not all, of these issues the reader is referred to (Hensen and Lamberts 2011).

19.7 BIBLIOGRAPHY

ASHRAE (2004) ‘Standard method of test for the evaluation of building energy analysis computer programs’, American Society of Heating, Refrigerating and Air-Conditioning Engineers, ASHRAE SMOT 140.

Banks, J. and Gibson, R.R. (1997) ‘Don't simulate when: ten rules for determining when simulation is not appropriate’, *IIE Solutions,* September 1997, Institute of Industrial Engineers, IIE Solutions.

Becker K. and Parker, J.R. (2009) ’A simulation primer’, in Gibson, D. and Baek, Y. (eds), *Digital simulations for improving education: learning through artificial teaching environments*, Hershey, PA: IGI Global.

CIBSE (2005) ‘Climate change and the indoor environment: impacts and adaptation’, Chartered Institute of Building Services Engineers, publication M36, London, UK.

Crawley, D.B., Hand, J.W., Kummert, M. and Griffith, B.T. (2008) ‘Contrasting the capabilities of building energy performance simulation programs’, *Building and Environment* 43(4): 661-673.

DOE (2010) ‘Building Energy Software Tools Directory’, Online. Available at: http://apps1.eere.energy.gov/buildings/tools_directory/ (accessed 15.2.2010).

Green, H.L. (2009) ‘High-performance buildings’, *Innovations: Technology, Governance, Globalization* 4(4): 235-239.

Hensen, J.L.M. (1987) ‘Energieproeftuin: resultaten na twee stookseizoenen’, *Bouw* 42(3): 38-41

Hensen, J.L.M. (2004) ‘Integrated building airflow simulation’, in Malkawi, A. and Augenbroe, G. (eds) *Advanced Building Simulation*, New York: Spon Press, pp: 87-118.

Hensen, J.L.M. and Lamberts, R. (eds) (2011) *Building Performance fSimulation for Design and Operation*, London: Spon Press.

Jensen, O.M., Wittchen, K.B.. and Thomsen, K.E. (2009) ’Towards very low energy buildings – Energy saving and CO2 emission reduction by changing European building regulations to very low energy standards’, Danish Building Research Institute, Aalborg, report SBI 2009:03.

Lain, M., Bartak, M., Drkal, F., and Hensen, J. (2005) ‘Computer simulation and measurements of a building with top-cooling’, in *Proceedings of the 9th International IBPSA Conference*, Montreal, Canada. pp: 579-586.

Linden, A.C. van der, Boerstra, A.C., Raue, A.K., Kurvers, S.R. and de Dear, R.J. (2006) ‘Adaptive temperature limits: A new guideline in The Netherlands: A new approach for the assessment of building performance with respect to thermal indoor climate’, *Energy and Buildings* 38(1): 8-17.

Lund, H. and Mathiesen, B.V. (2009) ’Energy system analysis of 100% renewable energy systems—The case of Denmark in years 2030 and 2050’, *Energy* 34(5): 524-531.

Petersdorff, C., Boermans, T. and Harnisch, J. (2006) ‘Mitigation of CO2 emissions from the EU-15 building stock. Beyond the EU directive on the energy performance of buildings’, *Environmental Science and Pollution Research* 13(5): 350-358.

Robinson, S. (2008) ‘Conceptual modelling for simulation Part I: definition and requirements’, *Journal of the Operational Research Society*. 59(3): 278 -290.

Robinson, S. (1999) ‘Simulation verification, validation and confidence: a tutorial’, *Transactions of the Society for Computer Simulation International* 16(2): 63-69.

Trcka, M. and Hensen, J.L.M. (2010) ’Overview of HVAC system simulation’, *Automation in Construction* 19(2): 93-99.

BIO-SKETCH

Jan Hensen is full professor in computational building performance simulation in the Department of Architecture, Building and Planning, Eindhoven University of Technology. His research and teaching focus on computational modeling and simulation for performance based design and

operation of buildings while considering energy, indoor environment, building physics, building services and building integrated (renewable) energy systems.

He is the immediate past-president of the International Building Performance Simulation Association (IBPSA), Fellow of the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) and has received several scientific and practice awards. He has authored or co-authored over 200 papers and more than 100 reports. He is on the editorial boards of Building and Environment, Energy and Buildings, International Journal of Low-carbon Technologies and is the founding co-editor of the Journal of Building Performance Simulation.