

# ON BUILDING PERFORMANCE SIMULATION IN A CHANGING ENVIRONMENT

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## ***Abstract***

*Computational simulation is one of the most powerful tools in our world today - it is used to simulate everything from war to economic growth. Modeling and simulation of building thermal performance using digital computers was first introduced in the 1970s, when it became clear that it is much cheaper to simulate than to build wrong buildings. Building performance simulation draws its underlying theories from many different disciplines. The theoretical challenges are bountiful when one recognizes that the physical state of a building is the result of the complex interaction of a very large set of physical components. Nevertheless, the ability to deal with the resulting complexity of scale and diversity of component interactions has gained building simulation a uniquely recognized role in the prediction, assessment and verification of building performance.*

*The building simulation discipline is continuously evolving and maturing and improvements are continuously taking place in model robustness and fidelity. As a result the discussion has shifted from the old agenda that focused on software features to a new agenda, which focuses on the effectiveness of building performance simulation in building life cycle processes, including quality assurance and multi-actor distributed tool developments. Of course this all takes place in a changing "environment" which includes global climate change, depletion of fossil fuel stocks, internationalization of the construction industry, increasing occupant demands for comfort, increasing awareness of relation between indoor environment and health, and increasing awareness of relation between indoor environment and productivity.*

*This paper presents several notes and remarks on the current state of building performance simulation and the role of the International Building Performance Simulation Association – IBPSA. Within this context, the paper also summarizes some of the research by the author's research group.*

*The main conclusions are that building performance simulation has the potential to deliver, direct or indirect, substantial benefits to many building stakeholders and to the environment; and that IBPSA and its regional organizations, such as a future IBPSA-Serbia, can/ should play a major role in promoting correct application and further development of this technology.*

**Keywords:** building, performance, simulation, IBPSA

## **1. On the current state**

In his editorial “Building performance simulation: the now and the not yet” Spitler (2006) states that “simulation of building thermal performance using digital computers has been an active area of investigation since the 1960s, with much of the early work (see eg Kusuda 1999) focusing on load calculations and energy analysis. Over time, the simulation domain has grown richer and more integrated, with available tools integrating simulation of heat and mass transfer in the building fabric, airflow in and through the building, daylighting, and a vast array of system types and components. At the same time, graphical user interfaces that facilitate use of these complex tools have become more and more powerful and more and more widely used.”

As stated earlier (Augenbroe and Hensen, 2004), over the past two decades the building simulation discipline has matured into a field that offers unique expertise, methods and tools for building performance evaluation. When used appropriately it has the potential to improve competitiveness, productivity, quality and efficiency in buildings and in the construction industry as well as facilitating future innovation and technological progress.

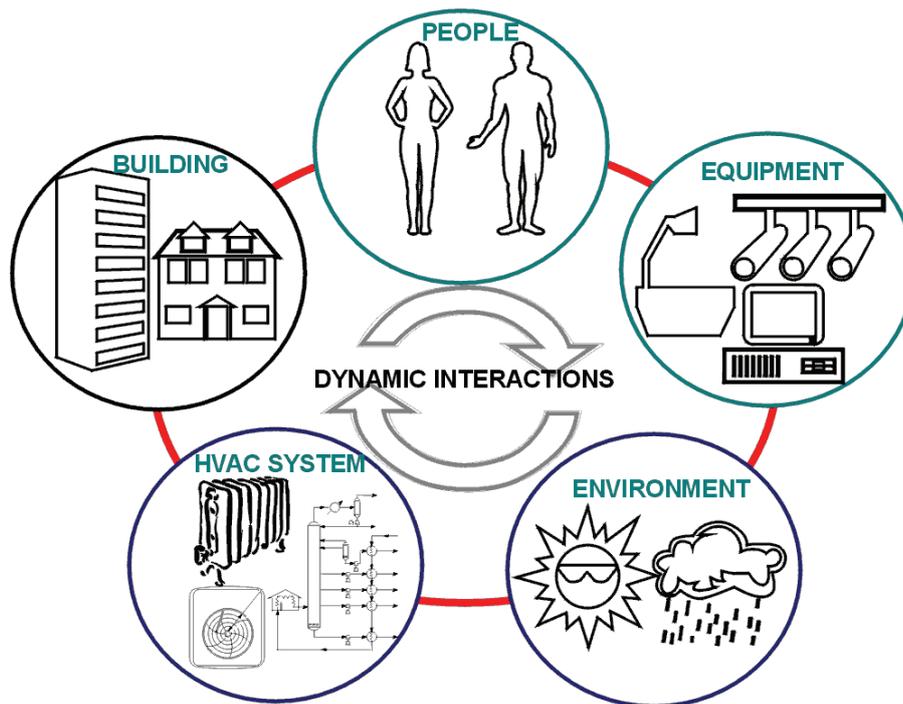


Figure 1. Dynamic interacting sub-systems in a building context.

Building performance simulation draws its underlying theories from diverse disciplines, mainly from physics, mathematics, material science, biophysics, human behavioral, environmental and computational sciences. The theoretical challenges are bountiful when one recognizes that the physical state of a building is the result of the complex interaction of a very large set of physical components (Figure 1). The integration of these interactions in one behavioral simulation poses major modeling and computational challenges. Its ability to deal with the resulting complexity of scale and diversity of component interactions has gained building simulation a uniquely recognized role in the prediction, assessment and verification of building performance.

This role is increasingly recognized in wide-scale promotional programs as well as in legislation around the world; examples are LEED (Leadership in Energy and Environmental Design) and EPAct (Energy Policy Act) in the USA, and EPBD (Energy Performance of Buildings Directive) in Europe. The development, evaluation, use in practice, and standardization, of the models and programs is therefore of growing importance. The building simulation discipline is continuously evolving and maturing and improvements are continuously taking place in model robustness and fidelity. As a result the discussion has shifted from the old agenda that focused on software features to a new agenda, which focuses on the effectiveness of building performance simulation in building life cycle processes, including the following.

## 2. On quality assurance

Although improvements in model robustness and fidelity are continuously taking place, quality assurance is – and will remain – a major issue. Quality assurance is most often discussed in the context of the software itself; i.e. in terms of verification, validation and calibration. A major international validation effort is the ongoing BESTEST initiative (e.g. Judkoff and Neymark 1995, Neymark et al. 2001), which has already found its first footholds in professional standards (e.g. the Standard Method of Test by the American Society of Heating, Refrigeration and Air-conditioning Engineers – ASHRAE – SMOT 140) as well as in national standards (e.g. the Energie Diagnose Referentie – EDR effort in The Netherlands). From that point of view it is surprising that there is still software on the market which does not satisfy the accuracy requirements according to the BESTEST and ASHRAE SMOT 140 procedure (Hensen and Radosevic 2004).

For building design, construction, operation, maintenance and management activities, there is an urgent need for the integration of "generally applicable" and "generally accepted" methods and tools, for various applications, each having various levels of complexity and/or various types of end-users. These user oriented aspects are very often underestimated in building performance simulation.

In terms of methods, for example, simulation is much more effective when used for predicting the relative performance of design alternatives, rather than when used to predict the absolute performance of a single design solution. In practice it is also often seen that high resolution modeling approaches (in particular computational

fluid dynamics (CFD) and ray tracing rendering methods are used for applications where a lower resolution method would be quite sufficient and much more efficient.

Another issue can be summarized as “Solving the right equations sufficiently accurate, as opposed to solving the wrong equations right”. In any type of model, the user is supposed to know which values to use for the model parameters. In addition, there are now many approaches where a user should also decide which (sub)model to use. This is specifically the case in open simulation environments (e.g. Matlab toolboxes) and in higher resolution approaches (think of wall functions and turbulence models in CFD, and the various models involved in ray tracing).

As argued before (e.g. Hensen 1991, 1993, Hensen and Clarke 2000) a first and paramount requirement for quality assurance is sufficient domain knowledge by the user. Apart from domain knowledge, it is also very important to make future engineers aware of the above quality assurance issues and to provide them with appropriate skills.

Part of this can be achieved in (higher) education. Another route might be by informing and training professionals. Here, IBPSA could play an important direct or indirect role.

### 3. On the impact for practical design

The uptake of building performance simulation in current building design projects is limited. Although there is a large number of building simulation tools available (e.g. DOE 2006), the actual application of these tools is mostly restricted to the final building design. It is mainly used for code compliance testing and for thermal load calculations in view of sizing of heating and air-conditioning systems.

Simulation tools are not used to support the generation of design alternatives, or to make informed choices between different design options, and they are neither used for building and / or system optimization (de Wilde, 2004).

In other words: it is mostly used for analysis (of a single solution) rather than (multiple variant) design optimization oriented. In an increasing number of cases this is complemented with high-resolution (light and airflow) modeling; probably often for communication purposes rather than physical necessity.

As indicated in Figure 2, this takes place only at the end of the design process, where most important decisions have been taken already. To illustrate this, consider the recent CIBSE (2005) publication which concluded that environment friendly building design strategies can be summarized in four simple methods.

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

The impact/ performance of the first three can only be predicted by simulation.

Another – more or less corresponding – design strategy is known as the Trias Energetica (2006). This is a relatively simple concept to achieve energy savings, reduce our dependence on fossil fuels, and save the environment. The 3 elements of Trias Energetica are:

1. *Reduce the demand for energy by avoiding waste and implementing energy-saving measures;*
2. *Use sustainable sources of energy instead of finite fossil fuels;*
3. *Produce- and use fossil energy as efficiently as possible.*

Again, the impact/ performance of the first element can only be predicted by simulation.

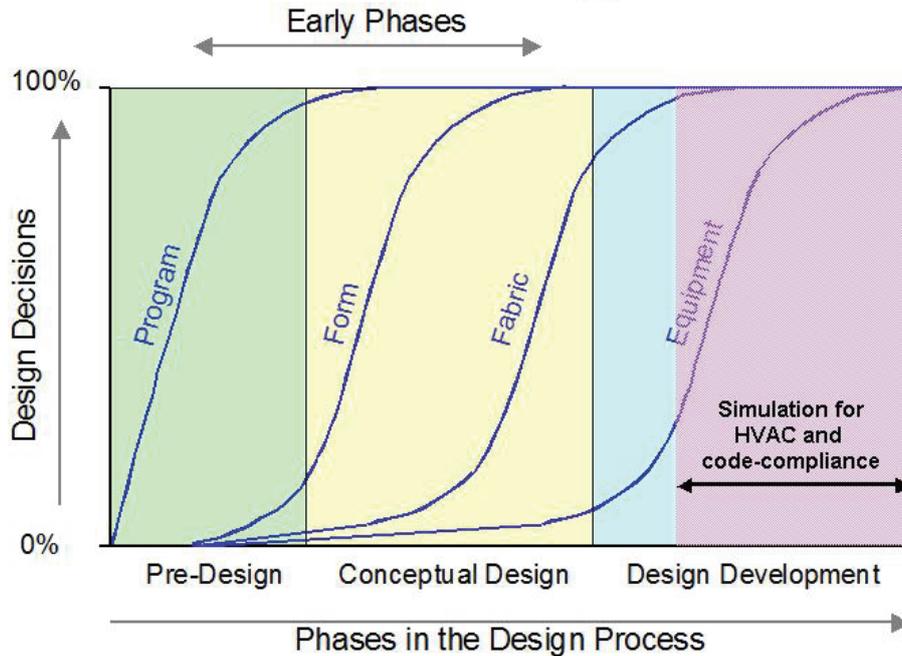


Figure 2 Design decisions during the design process

#### 4. On simulation tasks

Having stated the above, in current practice building performance simulation is mostly used for building envelope design (compliance testing); i.e. as part of architectural or environmental engineering. It is rarely used for mechanical design; for that more traditional methods are still commonly used.

Quoting Thomas (2006):

“Out of a typical large mechanical-electrical (M-E) design project consisting of 50,000 HVAC labor-hours, about 100 hours is spent on Energy analysis. Another 200 hours might be spent on Loads calculations over the course of the project. This is about the total extent of HVAC engineering design using computer programs today. The remaining 99.9% of computer use is for drafting, word processing and spreadsheets for organizing information. The same is true for electrical, lighting, plumbing and fire protection design.

The M-E design process is fragmented, equipment selection and scheduling is intermittent and the process consists of frequent revisions and continuous exchange of fragmented information between specialized architectural and engineering personnel. A-E design documents from schematic to construction are issued in 2-D whereas the new automated systems are in 3-D. The present organizational structure and specialized staff and tasks will not work well with these new advanced systems. There has to be a change in the A-E design culture.”

Of course there is a considerable amount of research into using simulation for post-design activities such as commissioning, operation and energy audit. The work by André et al. (2006) is a good example.

#### 5. On user expectations

Many tools start from the same level and are (to be) used in a similar manner. Many current tools could actually be labeled as legacy software having a monolithic structure, and are becoming increasingly hard to maintain. Use of these tools requires expert skills to run an analysis in a way that the right output is generated from which the desired performance data can be generated.

Many building performance simulation tools are not really used for design, probably because there is a mismatch between the anticipated user and the real user in terms of expectations, background knowledge, skills, and available resources.

Interviews with practitioners (e.g. Hopfe et al. 2006) confirmed this long-term suspected discrepancy between user expectations and simulation tool capabilities and features.

There is an increasing awareness in design practice as well as in the building simulation research community that there is no need for more of the same. However there is definitely a need for more effective and efficient design decision support applications.

In various fields, including building and system designers, people can be classified according to their innovativeness (Figure 3). In the above mentioned interviews, it was found that people can be innovator in one aspect (say use of simulation tools) while being “late majority” in another aspect (say in terms of design team integration). A typical requirement of an innovator would be that the tool is very flexible. A typical requirement/expectation by the “late majority” is that tools are very easy, intuitive to use. Obviously it will be very hard to create a single software which would satisfy all.

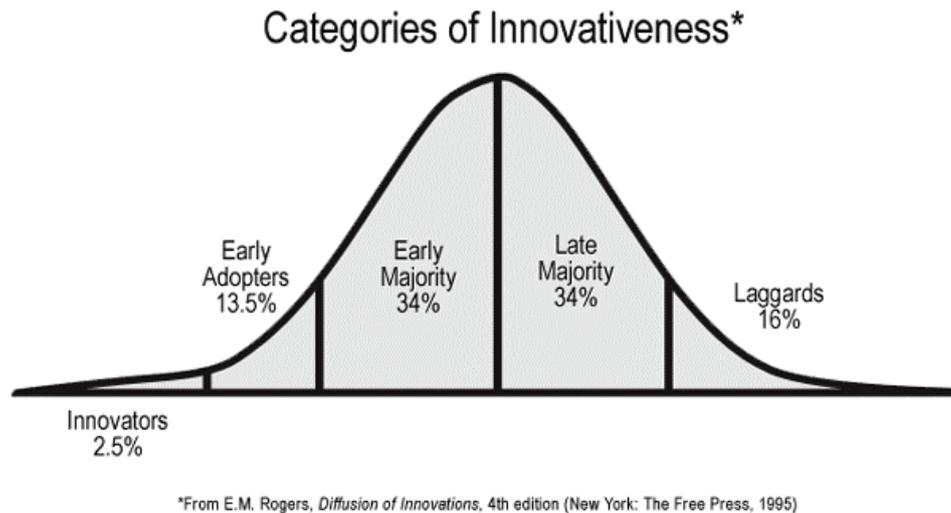


Figure 3 Categories of innovativeness

During the interviews mentioned above, many practitioners expressed the need to integrate design disciplines into the design process from the very early stages. One difficulty repeatedly encountered by engineers was the fact that the design stages are barely synchronized across disciplines as it is difficult for design disciplines to understand the impact of their design on the works of others. Another aspect identified was that not including specific design disciplines early enough in the design process might cause the design team to make uneducated decisions, risking sub-optimal solutions or additional design iterations.

## 6. On building simulation for early phase design

Although it is evident that the impact of design decisions is greatest in earlier design phases, building performance simulation is rarely used for this. Our current research in this area aims to improve the use and usefulness of building performance simulation during the (early phase) design of a building, by researching new, innovative, next generation building performance simulation models and applications that meet the needs of the architecture, engineering and construction (AEC) industry. This research focuses on providing tools for ‘avant-garde’ consultants who take a pro-active role in the building design process. The scope includes the domains of building physics, heating, ventilation, air-conditioning (HVAC) and thermal storage systems. The main objectives are to research and enable innovative application of building performance simulation for design support, in particular for:

- generation and selection of design alternatives during early phases in the design process, where decisions have to be made with limited resources and on the basis of limited knowledge but which will have a major impact and consequences during the remainder of the building life cycle;
- design optimization during the early and later phases of the design process.

In each case, the main questions to be addressed are:

- What are the prime analysis needs for this application of building performance simulation?
- What is the optimum model resolution level to address these analysis needs?

- How can models with this level of resolution be generated, expanded or reduced from existing models?
- What would be an appropriate performance assessment methodology for that phase given the background, objectives, needs and resources of the stakeholder(s) and practitioners in question?
- How to satisfy the simulation output requirements both in view of the designer and in view of other design team members including the client?

The projects have in common that they start with a literature review, analysis of state-of-the-art building performance simulation software, and in-depth interviews or short-term observation assignments with actual stakeholders, e.g. consulting engineers and contractors. The first results have been published recently (Hopfe et al. 2006) and are reflected in several of the above notes.

Both projects are using iterative rapid prototyping as the main research method. Existing industry strength software VA114 (VABI 1993) and h.e.n.k. (Itard 2003), has already been expanded with uncertainty and sensitivity analysis as a first step to provide more meaningful design information. The next step will be to incorporate multi-objective decision making; probably followed by optimization features. Subsequent prototypes will be developed, calibrated and tested on real world problems and with actual stakeholders and practitioners. Where necessary the developed models will be validated with results from experiments under controlled conditions in a laboratory setting. The main results are expected to include innovative simulation software, as well as appropriate building performance assessment methodologies and guidelines.

## 7. On distributed developments

A frequently encountered problem by engineers who would like to simulate the future behavior of building and system design alternatives is that certain performance aspects or specific building and system components are only represented in one simulation environment while other performance aspects or components are only available in other software. Previously (e.g. in Hensen 1991, 1993, 2000) it has been argued that in the area of system simulation there is enormous amount of work to be done. When compared to the building side, one could say that every single component is like a new type of building in itself. This – and the above indicated reasons for slow uptake of system simulation - implies that system modeling and simulation capabilities develop very slowly and take up an enormous amount of resources. Therefore, it has been suggested that sharing of developments by means of “open” simulation environments would be the best way forward.

Open simulation environments (the simulation laboratory metaphor) allow components, features and models to be provided by other stakeholders (producers, re-sellers, etc who could provide models as additional product documentation) as opposed to only by software developers and researchers. Open building performance simulation environments would also make it easier to consider different performance aspects (comfort, health, productivity, energy. etc.) at different levels of resolution in terms of time and space (region, town, district, building, construction element, etc); i.e. they enable multi-scale methods that can deal with large ranges of time and special scales and link various types of physics.

The four main strategies to enable sharing of distributed developments are as follows.

- Data and process model integration into a single executable.
- Data model interoperation.
- Process model interoperation.
- Data model and process integration by co-simulation of run-time coupled models

We are following the latter strategy in which executables representing sub-systems exchange information during run-time in order to co-simulate the overall system. The main advantage of this approach is that it supports coupling of various executables, including proprietary software of which the code is not accessible and open simulation environments such as Matlab and Simulink. For this reason, we feel that this run-time coupling approach – as schematically shown in Figure 4 - is currently the most promising direction for task-shared developments.

We are involved in three research projects in this area which focus on two-way coupling of building energy simulation with separate software packages for computational fluid dynamics software (Djunaedy 2005), control simulation (Yahiaoui et al. 2006), and system simulation (Trcka-Radosevic et al. 2006).

The main thrust of the work is to research and implement (options for) inter-process communication. This, in turn, should enable run-time coupling of simulation software and thus it should become possible to run two or more simulation programs in parallel where each program represents only that part of the building and systems which it is able to model. A typical application example is shown in Figure 5.

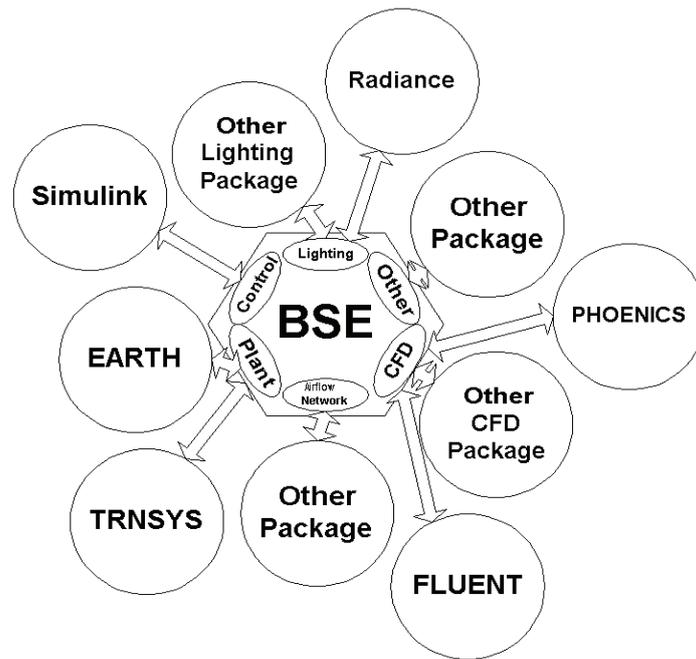


Figure 4. Schematic view of a distributed integrated building simulation environment based on an advanced multi-zone building simulation software run-time linked to external software packages

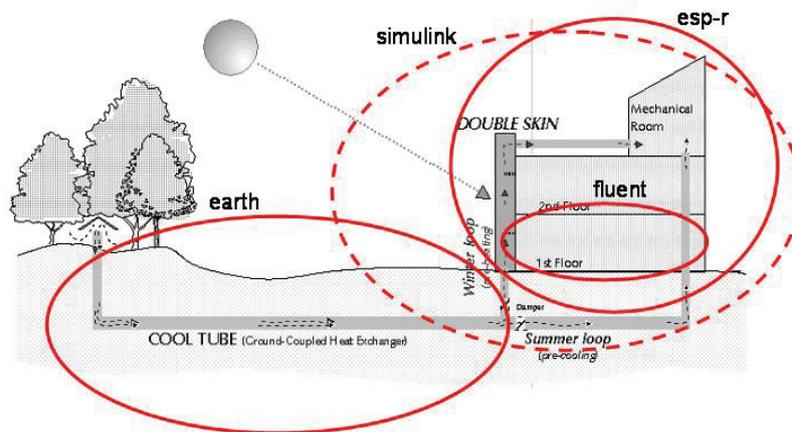


Figure 5. Schematic of an example super-low-energy building with a double-skin façade and a ground coupled heat exchanger for pre-heating or pre-cooling of fresh ventilation air. The overall configuration is simulated with run-time coupled models in Earth, Simulink, ESP-r and Fluent for the ground coupled heat-exchanger, the controls, the overall building and the air flow field in one of the thermal zones, resp.

The inter-process communication is being developed in a general sense. The results are implemented and tested in at least three different simulation environments, two of which are building domain specific (e.g. ESP-r and TRNSYS) and others are domain independent (MATLAB / Simulink and Fluent).

A key feature of the new functionality will be flexibility in terms of building systems definition from the user point of view; i.e. the user will no longer be restricted to system (and system component) options / features on offer in a particular tool, but, by combining simulation tools, will be able to model many more building and system combinations.

The extended design tools are being used / tested to assess and compare the performance of various innovative building and systems combinations such as, for example, earth coupled heat exchangers, combined heat and power, embedded renewable energy systems, etc. The research includes physical verification with experimental results and utilitarian verification by means of practical application in at least two realistic industry relevant design studies.

The research outcome is a prototype system and general knowledge regarding the coupling of building and system simulation software. Although the current work concerns run-time coupling of specific simulation environments, the coupling mechanisms and data-exchange protocols that will be developed, will ensure that the approach has general and wide applicability.

## **8. On IBPSA – [www.ibpsa.org](http://www.ibpsa.org) – a global network / community of practice**

The International Building Performance Simulation Association, IBPSA, was established now almost 20 years ago in 1986 as a non-profit society of building performance simulation researchers, developers and practitioners dedicated to improving the built environment.

IBPSA is in the lucky situation that it has many very active individuals amongst its several thousand members worldwide. The society is based on regional affiliate organizations (currently 16, with proposals being discussed in another 10 regions) around the world. It is managed by a central Board of Directors, consisting of officers, members at large, and a representative of each regional affiliate organization. Since quadrupled, so IBPSA is rapidly expanding.

To maintain its leading role in the promotion and development of building simulation technology, IBPSA provides a forum for researchers, developers and practitioners to review building model developments, facilitate evaluation, encourage the use of software programs, address standardization, accelerate integration and technology transfer. So that,:

- members all over the Globe find membership in IBPSA worthwhile and profitable in their area of interest;
- governments, industry, utilities and academic institutions look to IBPSA for guidance in determining policies, areas of research, and application development in building simulation;
- local chapters around the Globe benefit from the body of knowledge and experience available through IBPSA;
- IBPSA acts as a clearing house for publications on building simulation; members network with other members and societies through electronic means;
- IBPSA provides a framework for strategic alliances for information and cooperation in R&D and technology transfer.

IBPSA covers broad areas of building environmental and building services engineering. Typical topics include building physics (including heat, air and moisture flow, electric and day lighting, acoustics, smoke transport); heating, ventilation and air-conditioning systems; energy supply systems (including renewable energy systems, thermal storage systems, district heating and cooling, combined heating and power systems); human factors (including health, productivity, thermal comfort, visual comfort, acoustical comfort, indoor air quality); building services; and advancements and developments in modeling and simulation such as coupling with CAD, product modeling, software interoperability, user interface issues, validation and calibration techniques.

All these topics may be addressed at different levels of resolution (from microscopic to the urban scale), and for different stages in the building life cycle (from early sketch design, via detailed design to construction, commissioning, operation, control and maintenance) of new and existing buildings worldwide.

One of IBPSA's main activities is the organization of a series of bi-annual international conferences: Vancouver, Canada (1989), Nice, France (1991), Adelaide, Australia (1993), Madison, USA (1995), Prague, Czech Republic (1997), Kyoto, Japan (1999), Rio de Janeiro (2001), Eindhoven (2003), Montreal (2005), Beijing (2007) and Glasgow (2009).

IBPSA produces twice per year an international newsletter. IBPSA is well under way in establishing an international archival journal.

IBPSA has also recognized the difficulties surrounding the development of products and services that are appropriate to the day-to-day needs of its members. The underlying causes of these difficulties are twofold. Firstly, the geographical spread of IBPSA members is wide and gives rise to a requirement to cover disparate work practices, technologies and professional needs. Secondly, IBPSA's organizational structure is such that the coordination of activities at the local (regional) level is problematic. That is why IBPSA is organized in regional organizations which are making significant progress at the local level through seminar, workshop, publications, training and software development activities.

If it existed, “IBPSA – Serbia” could also play a role, similarly important as the other IBPSA affiliate organizations in their region.

## 9. In conclusion

Building performance simulation has the potential to deliver, direct or indirect, substantial benefits to many building stakeholders and to the environment.

It is the mission and role of IBPSA and its regional organizations to promote correct application and further development of building performance simulation.

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