Building simulation: state-of-the-art and the role of IBPSA

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Abstract

This paper outlines the current state-of-the-art in integrated building simulation. The ESP-r system is used as an example where integrated simulation is a core philosophy behind the development. The current state and future developments are illustrated with examples. The importance of the interoperability is discussed in the area of airflow, multi-dimensional conduction, lighting, CFD, and power flow modelling. It is argued that for building simulation to penetrate the profession in the near future, there is a need for appropriate training and professional technology transfer initiatives.

It is in the latter area where IBPSA International[*] and its growing number of regional affiliates - such as the future IBPSA NL or IBPSA Benelux - seek to play a major role.

Background

Currently many buildings are constructed or remodeled without consideration of energy conserving strategies that could, in many cases, be incorporated in a cost-effective manner. For example, it is estimated that nearly 80% of new commercial buildings constructed each year in the United States are of 2,000 square meter or less in size. These buildings, as well as most single- and multi- family residential buildings, are generally designed and constructed by builders or design-build contractors, without the benefit of computerized building energy analyses and equipment sizing.

To provide substantial improvements in energy consumption and comfort levels, there is a need to treat buildings, with their individual subsystems, as complete optimized entities, not as the sum of a number of separately designed and separately optimized components. Computerized tools are needed to characterize and assess proposed new equipment and system integration ideas, and to aid in the identification of such ideas.

Although a number of sophisticated computer programs have been developed in recent years these are typically used by researchers, engineers concerned with very large building projects and for code compliance (usually translated to simpler computer or worksheet form). It is paradoxical that although architectural practices for larger firms have moved to computer design programs for the physical elements of buildings and building systems (piping, ductwork, etc.) there has been little effort by the design community to learn and apply energy analysis as a standard part of the design process. This is generally left to “specialists” at HVAC consulting firms after the building has been defined.

Since there are real opportunities to affect the building energy use through tradeoffs in building siting, orientation, spatial definition and envelope configuration, waiting until these have been completed, and perhaps even the HVAC and other systems are defined, can result in missed opportunities for energy savings.

Although most practitioners will be aware of the emerging building simulation technologies, few as yet are able to claim expertise in its application. This situation is poised to change with the advent of:

- performance based standards;
- societies dedicated to the effective deployment of simulation - such as IBPSA;
- appropriate training and continuing education;
- and the growth in small-to-medium sized practices offering simulation-based services.

One thing is clear: as the technology becomes more widely applied, the demands on simulation programs will grow. While this is welcome, in that demand fuels development, it is also problematic because the underlying issues are highly complex. Although contemporary programs are able to deliver an impressive

[*] IBPSA: International Building Performance Simulation Association - http://www.ibpsa.org

array of performance assessments, there are many barriers to their routine application in practice (Clarke 1995), not least the complete absence of a standard building product model and any means to manage inter-program transactions. To elaborate on the current state-of-the-art, the following sections summarize the capabilities of one modelling system, ESP-r.

ESP-r system - an example of state-of-the-art

The ESP-r system (Clarke 1985) has been the subject of sustained developments since 1974. The aim, now as always, has been to permit an emulation of building performance in a manner that a) corresponds to the reality, b) supports early-through-detailed design stage application and c) enables integrated performance assessments in which no single issue is unduly prominent. ESP-r is available under research (cost-free) and commercial (low cost) license from the University of Strathclyde. In both cases source code is made available.

ESP-r comprises a central Project Manager (PM) around which is arranged support databases, a simulator, performance assessment tools and a variety of third party applications for CAD, visualisation, report generation, etc. (Figure 1). The PM's function is to co-ordinate problem definition and give/receive the data model to/from the support applications. Most importantly, the PM supports an incremental evolution of designs as required by the nature of the design process.

The typical starting point for a new project is to scrutinise and make ready the support databases. These include hygro-thermal and optical properties for construction elements and composites, typical occupancy profiles, pressure coefficient sets for use in problems involving air flow modelling, plant components for use in HVAC systems modelling, mould species data for use with predicted local surface conditions to assess the risk of mould growth, and climate collections representing different locations and severities. ESP-r offers database management for use in cases where new product information is to be appended.

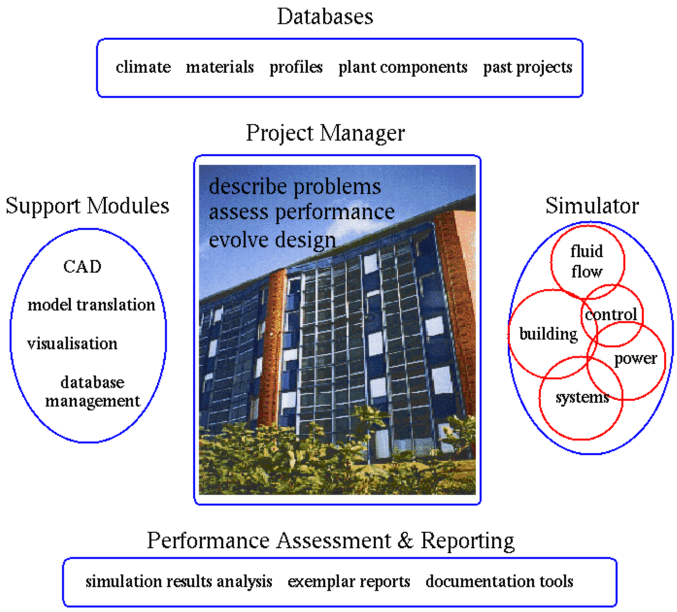

Figure 1 Architecture of ESP-r showing the central Project Manager and its support tools.

Although the procedure for problem definition is largely a matter of personal preference, it is not uncommon to commence the process with the specification of a building's geometry using a CAD tool. ESP-r is compatible with the AutoCad (Autodesk 1989) and XZIP (Stearn 1993) systems, either of which can be used to create a building representation of arbitrary complexity (Figure 2 - left).

After importing this building geometry to the PM, constructional and operational attribution is achieved by selecting products (e.g. wall constructions) and entities (e.g. occupancy profiles) from the support databases and associating these with the surfaces and spaces comprising the problem. It is at this stage that the simulation novice will appreciate the importance of a well-conceived problem abstraction, which achieves an adequate resolution while minimising the number of entities requiring attribution.

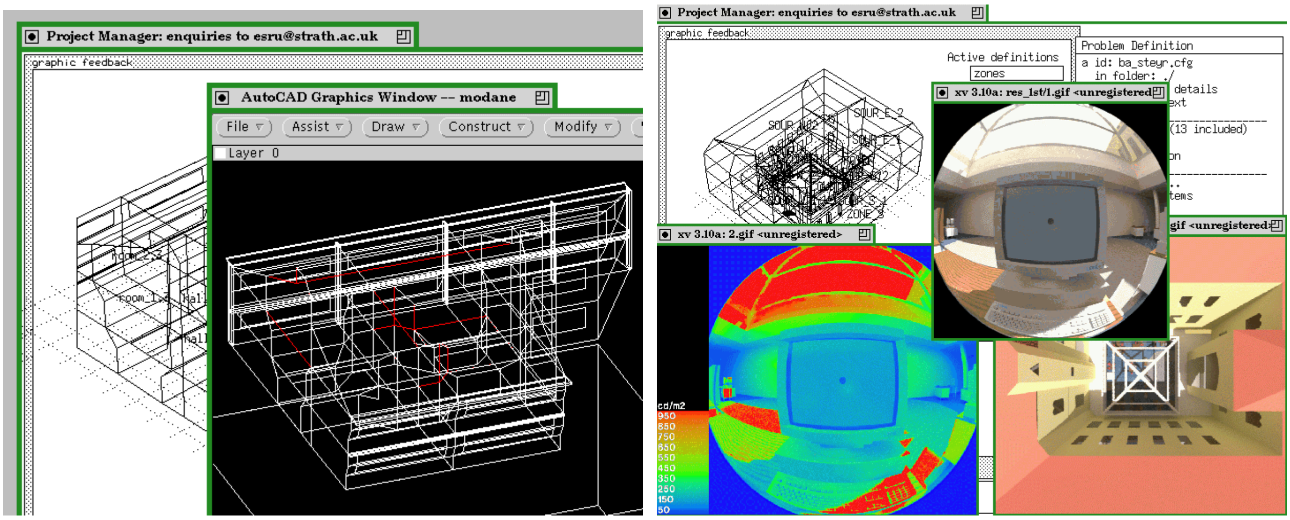

Figure 2 Defining problem geometry using AutoCad (left) and using RADIANCE to quantify luminance for a visual comfort/impact assessment or illuminance as input to a lighting controller (right).

The PM provides coloured, textured physically correct images via the RADIANCE system (Ward 1993) and wire-frame photomontages via the VIEWER system (Parkins 1977), automatically generating the required input models and driving these two applications (Figure 2 - right).

As required, component networks are now defined representing HVAC systems (Hensen 1991, Aasem 1993, Chow 1995), distributed fluid flow (for the building-side air or plant-side working fluids) (Clarke and Hensen 1990, Hensen 1991) and electrical power circuits (Kelly 1996). These networks are then associated with the building model so that the essential dynamic interactions are preserved.

Control system definitions can now proceed depending on the appraisal objectives. Within ESP-r this involves the establishment of several closed or open loops, each one comprising a sensor (to measure some simulation parameter at each time-step), an actuator (to deliver the control signal) and a regulation law (to relate the sensed condition to the actuated state). Typically, these loops are used to regulate plant components, to associate these components with building zones, to manage building-side components such as blinds, and to co-ordinate flow components (e.g. window opening) in response to environmental conditions. Control loops can also be used to change portions of a problem with time (e.g. substitute alternative constructions) or impose replacement parameters (e.g. heat transfer coefficients).

For specialist applications, the resolution of parts of the problem can be selectively increased, for example:

- ESP-r's default one-dimensional gridding scheme representing wall conduction can be enhanced to a two- or three-dimensional scheme to better represent a complex geometrical feature or thermal bridge (Nakhi 1995).
- A one-, two- or three-dimensional grid can be imposed on a selected space to enable a thermally coupled computational fluid dynamics (CFD) simulation (Negrao 1995, Clarke et al 1995).
- Special behaviour can be associated with a material, e.g. electrical power production via crystalline or amorphous silicon photovoltaic cells (Clarke et al 1996).
- Models can be associated with material hygro-thermal properties to define their moisture and/ or temperature dependence in support of explicit moisture flow simulation and mould growth studies (Anderson et al 1996).

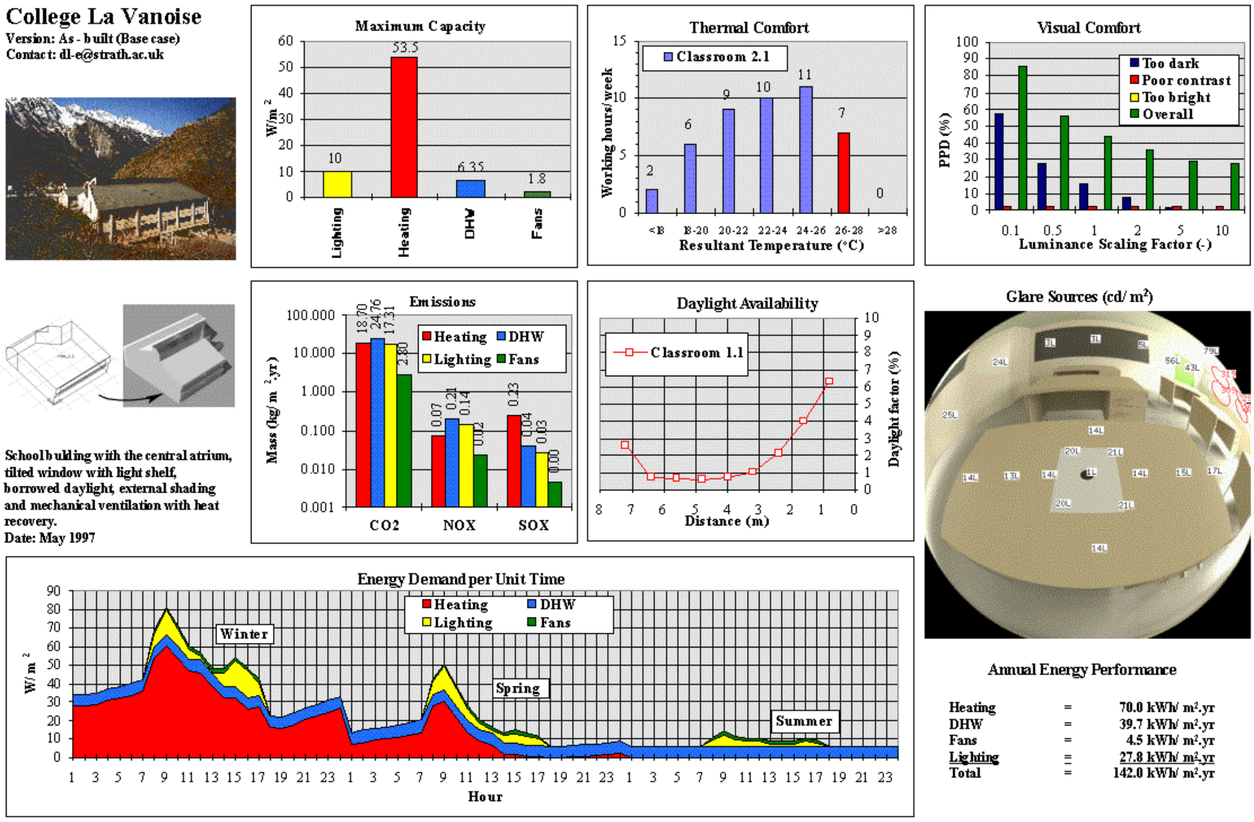

Figure 3 An integrated performance summary giving details on seasonal fuel use, environmental emissions, and thermal/ visual comfort.

The PM requires that a record be kept of the problem composition and to this end is able to store and manipulate text and images which document the problem and any special technical features. It is also possible to associate an integrated performance summary with this record (Figure 3) so that the design and its performance can be assessed without having to commission further simulations.

The problem - from a single space with simple control and prescribed ventilation, to an entire building with systems, distributed control and enhanced resolutions - can be passed to the ESP-r simulator where, in discretised form, the underlying conservation equations are numerically integrated at successive time intervals over some period of time. For problems involving daylight utilisation, the simulator can invoke the RADIANCE system in direct coupling or daylight coefficient mode (Clarke and Janak 1998) to quantify the time varying internal illuminance distribution for input (via a sensor) to an artificial lighting control loop. Simulations, after some minutes or hours, result in time-series of "state information" (temperature, pressure, etc.) for each discrete region.

ESP-r's results analysis modules are used to view the simulation results and undertake a variety of performance appraisals: changes to the model parameters can then follow depending on these appraisals. While the range of analyses are essentially unrestricted, interrelating the different performance indicators (Figure 3), and translating these indicators to design changes, is problematic because of the lack of performance standards and the rudimentary level of simulation scholarship and training.

The PM also offers model management whereby past designs are stored as fully attributed 3D models. Several exemplar sets are included with ESP-r to assist with application training (Hand and Hensen 1995). These sets range from simple problems demonstrating basic model construction, through real scale designs, to systems involving special components such as photovoltaic cells, advanced glazing or displacement ventilation. Several notable European buildings are also available as on-line exemplars.

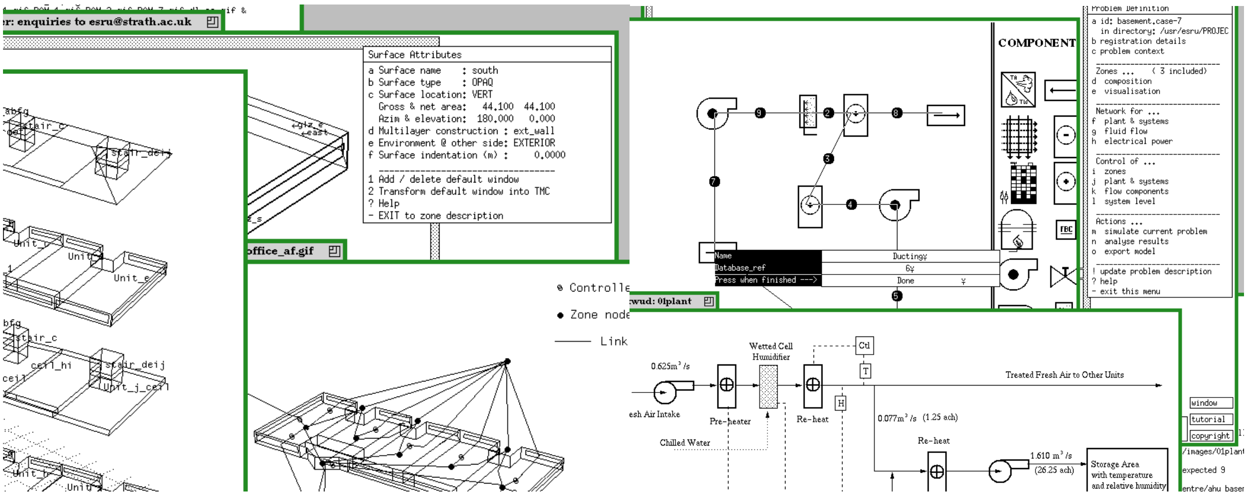

Figure 4 Defining an air flow network (left) and defining a plant system (right).

Some typical exemplars include:

- An office block with natural ventilation represented as a multi-zone system with an air flow network superimposed (Figure 4 - left). Typical application: summertime temperature estimation against postulated occupant interactions and weather severities.
- An air handling plant with temperature and humidity modulation serving spaces requiring critical environmental control (Figure 4 - right). Typical application: component sizing, alternative layout appraisal and control system tuning.
- A house with enhanced resolution around a thermal bridge and explicit construction moisture flow. Typical application: estimation of condensation and mould growth risk (Figure 5 - left), with appraisals of the potential of various retrofits to alleviate problems.
- A large factory space with radiant heating and a CFD domain grid. Typical application: assessment of spatial temperature distribution to achieve workplace comfort at minimum energy consumption (Figure 5 - right).
- An office with photovoltaic facade and electrical network. Typical application: appraisal of facade power generation and heat recovery potential, and a comparison of autonomous utilisation versus grid connection.
- A school employing daylight utilisation and artificial lighting control. Typical application: assessment of the electrical power reduction potential and checking that any reduction is not being achieved at the expense of other performance parameters such as thermal and visual comfort and heating fuel consumption.

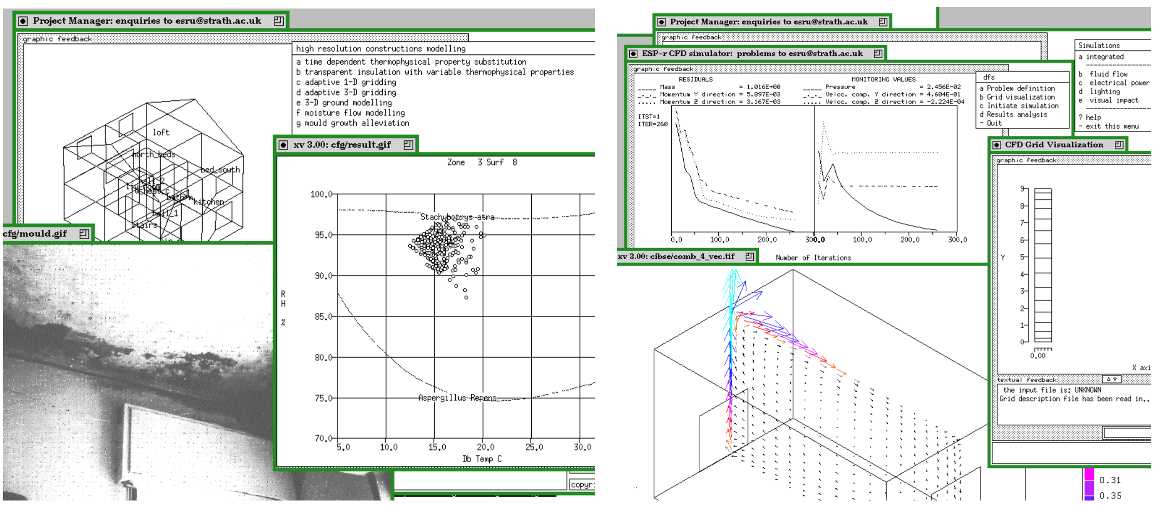

Figure 5 Predicting mould growth (left) and undertaking an integrated CFD analysis (right).

Before simulation programs can be routinely applied in practice, there are four main issues, which must be addressed.

- Firstly, since all design assumptions are subject to uncertainty, programs must be able to operate on the basis of uncertainty bands applied (automatically) to their input and output data. Such a facility is currently under development for ESP-r (Macdonald 1996) so that performance risk may be assessed on the basis of prediction ranges resulting from uncertainty considerations applied to the input (design) parameters.
- Secondly, validation testing procedures must be agreed and routinely applied as the modelling systems evolve in response to user requirements.
- Thirdly, program interoperability must be enabled so those design support environments evolve in response to inter-disciplinary design needs. This was the goal of the EC's COMBINE project (Augenbroe 1992) in which a prototype Intelligent, Integrated Building Design System was developed (Clarke et al 1995).
- Finally, a means is required to place program development on a task-sharing basis in order to ensure the integrity and extensibility of future systems. This was the objective of the EPSRC funded Energy Kernel System (Clarke et al 1992), which sought to eliminate the inefficient theoretical and software de-coupling of current programs.

IBPSA and its role in technology transfer

Let us divert for a moment from the specifics of a software system such as ESP-r and take a broader perspective in terms of building energy simulation in general. We have argued in this paper the importance of this technology and how it will benefit in an economical and environmental context.
However many people in the field are not yet aware of this. For alleviating this problem and thus for moving this technology into the everyday working practice of engineers and architects several initiatives and approaches take place, in the context of the International Building Performance Simulation Association (IBPSA).

IBPSA is a non-profit making organization that was first incorporated in January 1987. The Association’s principal mission is to promote and advance the practice of building performance simulation in order to improve the energy and environmental performance of new and existing buildings worldwide.

IBPSA seeks to achieve its goals through the establishment of a range of products and services aimed at informing and equipping those who are involved in the construction industry and who seek to utilize computer-based tools to good effect. To this end, the **IBPSA Strategic Plan** identifies nine specific areas that encompass the organization’s activities. These are:

1. Strategic Alliances with professional organization such as the engineering and architectural societies. The intention is to engender a better understanding of the profession’s requirements and the technology’s potential.

2. International Conference Series to periodically collate and preserve those developments that comprise the current state-of-the-art.

3. Technical Development Program aimed at influencing the direction the technology of building simulation might take at any given point in time.

4. Educational Initiatives concerned with the teaching of building simulation in the higher education institutions and in the context of continuing professional development.

5. Harmonization Activities in an attempt to regularize the application of the different modeling systems through the definition of standard methods for performance assessment and the provision of standard support data.

6. Member Recruitment aimed at extending the IBPSA products and services to those practitioners who can most benefit from the new technology.

7. Products and Services devised in response to the profession’s evolving needs.

8. Technology Transfer concerned with the delivery of training in all aspects of computer-based performance assessment at all stages of the building life cycle.

9. Regional Development to subject the foregoing activities to appropriate regional influences and enable their effective delivery.

Today's meeting is concerned with regional development in order to more effectively address local needs and create a mechanism for an international exchange of know-how and best practices.

Rationale

IBPSA has achieved significant success at the international level - largely through its biannual conference program (Vancouver '89, Nice '91, Adelaide '93, Wisconsin '95, Prague '97, Kyoto '99, and –probably – Rio de Janeiro '01), its web based services and worldwide electronic mailing facility. 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. At the same time like-minded, but regional, organizations are making significant progress at the local level through their seminar, workshop, publications, training and software development activities.

If the construction industry were to be well supported in its attempts to harness effectively the emerging IT and simulation technologies then the establishment of regionally based support organizations was essential. Equally essential was the creation of a structure by which these organizations could affiliate in order to disseminate their know-how and promote their local best practice. Only in this way could the benefits of the new technology be understood and future standardization enabled. It was with the view of a network of autonomous regional organizations that IBPSA has turned to regionalization and is encouraging existing or newly formed groups to become IBPSA affiliates, as was done earlier by IBPSA Australasia, IBPSA Canada, IBPSA Czech Republic, IBPSA France, IBPSA Ireland, IBPSA Slovakia, IBPSA UK / BEPAC, and IBPSA USA. Regional affiliates currently being established are IBPSA Greece, IBPSA Japan, and **IBPSA Netherlands** (or **IBPSA Benelux**?).
More information on the structure and operation of an IBPSA affiliate organization can be found in the Appendix.

What IBPSA Netherlands/ Benelux could do

- Providing information in terms of simulation options, capability, applicability and quality issues to a wide spectrum of potential users and beneficiaries.
- Establish strategic alliances with, for example, ISSO, TNO, VABI, ECN, NOVEM, TVVL, VNI, VNA, SBR, etc.
- Providing a forum/ platform for simulation software users and developers to exchange/ discuss/ agree local standard operating conditions, local weather data, local standard building descriptions, etc.
- Provision of a web site with public and members-only activities and services.
- Promotion of quality assurance in the application of building simulation.
- Promotion of accreditation of building simulation software products.
- Stimulate appropriate training and (continuing) education.
- Production and distribution of an electronic newsletter.
- Representation of the region in IBPSA International.
- Organization of seminars, mini-symposia, etc.
- ………………

Acknowledgements

The ESP-r system has evolved to to its present form over 20 years. Throughout this period many individuals have made substantial contributions. In particular, we would like to acknowledge the contributions of some of our ESRU colleagues: Jon Hand, Milan Janak, Nick Kelly, Iain Macdonald, John McQueen, Abdul Nakhi, Cezar Negrao and Paul Strachan. Our hope is that the many other contributors, too numerous to mention, will be content with collective thanks.

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Appendix: IBPSA Affiliate Structure and Operation

Under the existing structure, IBPSA affiliates are financially and administratively independent. In practice, this means that they raise and deploy their funds as long as these funds are under the control of elected officers and are used in pursuit of aims and objectives that are consistent with those of IBPSA. IBPSA-International concentrates its resources on issues such as inter-region communication, international conferences and product standardization. In this way IBPSA complements and empowers the regional affiliates in their attempts to inform and support their members in the context of local design issues and concerns. The entire IBPSA network is represented by a 15-member Board comprised of an executive and regionally elected officers.

The following guidelines have been devised to assist with the establishment and operation of an IBPSA regional affiliate.

1. Organizers of a new regional affiliate should prepare a brief proposal for the IBPSA Board of Directors. This should outline the proposed name, geographic territory, organizational structure and goals and objectives (if different from those included in the IBPSA charter statement). Affiliation depends only on the organization having a purpose and mission consistent with those of IBPSA. The Affiliate and IBPSA then enters into a specific agreement by defining their working relationship based on regional considerations prevalent at the time.
2. Regional affiliates may be named **"IBPSA <region>"** or they may use any other appropriate name. Their letterhead and other publicity material should indicate that they are "an affiliate of IBPSA".
3. For regions with limited financial resources, IBPSA can provide a limited amount of **matching start-up funds** (see below) to aid the initial set-up of the affiliated organization. A case for support should be submitted to the IBPSA Secretary for consideration by the Board.
4. The financial structure of a regional affiliate is independent from IBPSA. This means that affiliates will retain all member dues or other funds raised by their activities.
5. IBPSA will provide affiliates with a list of operational guidelines, contact information for persons available to assist the local organizer and electronic images of the IBPSA logo.
6. The regional affiliate will provide membership data to IBPSA for use in mailing IBPSA materials.
7. Members of the regional affiliates will automatically be full members of IBPSA. Any given individual or organization will pay dues directly to IBPSA only if there is no regional affiliateoperating in their area.
8. IBPSA will make newsletters and other IBPSA materials available to all members of the regional affiliates either in printed form or in downloadable electronic format from the IBPSA web page. This will be at no cost or at a nominal cost depending on the circumstances. Other services may be provided by IBPSA to the regional affiliates for a fee.

Start-up Proposal Guidelines:

It has been the IBPSA Board's policy to grant start-up funds to regions that are in need of matching funds to get the organization officially registered and/or to purchase initial office support equipment. The proposal should be submitted to the IBPSA board and should contain the following elements:

1. Name of Affiliate: i.e., **IBPSA-<region>.**
2. Geographic territory covered.
3. Organizational structure – The IBPSA Charter is founded on a set of board- and member-approved by-laws. Each Affiliate's organizational structure is therefore expected to adhere to the same or similar principles of operation.
4. Officers -- i.e., Specify the officers that will be constitute the board (e.g., Chairperson, secretary, treasurer, etc. – see IBPSA by-laws)
5. List of goals and objectives – Must be consistent with the mission statement and objectives of the IBPSA Charter.
6. Minutes of the first organizational meeting, indicating organizational business transacted.
7. List of initial members and their affiliations (can be those attending the first meeting).
8. Proposed activities of the affiliate.
9. Proposed amount of annual membership dues.
10. Breakdown of costs associated with set-up of the Affiliate organization.
11. Amount of matching funds provided by the Affiliate.
12. Amount of the requested support from IBPSA. [†]

[†] * Please note that IBPSA's policy is to provide start-up funds with the expectation that the Affiliate will return the granted amount once the region reaches financial stability. The Affiliate is therefore asked to return the funds on a voluntary basis, so other regions can be assisted in the same fashion.