A Vision for Building Performance Simulation: a Position Paper Prepared on Behalf of the IBPSA Board

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Preamble

The IBPSA organisation (www.ibpsa.org) was inaugurated in the mid-80s to support the evolution of Building Performance Simulation (BPS) by providing forums for discussion of the issues relating to the development, testing and application of tools. Over the intervening years the organisation has evolved into a unique grouping of disciplines – architects, engineers of all types, computer scientists, facilities managers, policy-makers and academics – each bringing particular insights into the needs and prospects for a computational approach to building design and operation. Significantly, the organisation has the ability through its regional structure to act globally while responding to local need: at the present time the IBPSA network comprises 28 national affiliates, with additional affiliates in the process of formation. The work of IBPSA is pursued through national and international conferences, various publication activities (most notably this journal), and initiatives to support student development. Sub-committees are also established to address particular issues and one such committee, the *Futures Committee*, has been charged to elaborate a vision for BPS in order to encourage task-sharing developments and provide a benchmark against which progress can be measured.

This paper presents this vision, which has been contributed to and endorsed by the IBPSA Board and some members and may therefore be considered to represent the official view of the organisation. The purpose of the paper is threefold: 1) to elicit general feedback from those involved in the development or application of BPS in order to ensure that the vision statement is generally acceptable and complete[#]; 2) to stimulate a discussion on where and how IBPSA might resource specific developments; and 3) provide a community statement of intent that may be used by individuals and organisations as the context justification for specific project proposals.

Concept promotion

BPS is a technology of considerable potential that provides the ability to quantify and compare the competing cost and performance attributes of a proposed design in a realistic manner and at relatively low effort and cost. Indeed, it is perhaps the only way to explore operational robustness at the design stage and a growing number of practitioners will understand the maxim, 'if you can't simulate it, don't build it'. Moreover, during the operational phase, simulation provides a means to compare measured performance versus design intent, to test system for installation and operational faults, and to deduce effective control sequences.

Since its emergence in the 1970s as part of the personal computing revolution, BPS has matured slowly driven by academic enquiry and by commercial pressures in a regulations-driven industry. While the present generation of BPS tools have impressive capability, they remain a work in progress when viewed against the prospect of a truly powerful

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computational approach to design whereby arbitrarily complex models may be evolved on a task sharing basis, such models readily exchanged and understood by others, industry standard assessments automatically invoked, and seamless integration within the temporally evolving design process assured.

This position paper summarises the requirements of high integrity BPS and proffers contributions that could be made by IBPSA going forward. It is stressed that the topics considered relate to tool application functionality and support – problem definition, simulation coordination, results interpretation and the like – not to the theoretical basis of any tool. That said, the implication throughout is that the ultimate aim of BPS is the high integrity emulation of integrated building performance, with explicit modelling, however achieved, of what is observed in reality. The aim should not be the codification of discrete formulae and algorithms corresponding to weak problem abstractions as found in simplified design tools or tools intended to support building standards.

> *Proposition 0: IBPSA will promote globally the message that the purpose of simulation is to emulate overall performance of individual buildings and community energy grids in a manner that may be verified by observation.*

While BPS is a vital construction industry asset, for some time now (as distinct from periods in the past) it has suffered from intellectual drift with developments pursued in a non-collaborative manner and against no shared vision of a beneficial (and inspirational) end goal. This situation gives rise to unnecessary development repetition, and serves only to preserve an underdeveloped status quo. When viewed against the ultimate vision of a fully functional computational approach to design that embodies a high integrity emulation of building behaviour, the capabilities of present tools may be viewed as both partial and operationally inadequate.

From a global perspective, this unacceptable situation may best be addressed by creating a future vision for BPS that can unite the community and galvanise task-sharing developments, by identifying specific contributions that IBPSA can make over time, and by establishing a vital bridge between research and practice that reduces the time lag between tool evolution and commercial application.

> *Proposition 1: IBPSA will evolve, through researcher and practitioner consultation, a requirements specification for future BPS tool application functionality, use this to periodically agree where the state-of-the-art falls short, and foster specific developments that address deficiencies and may be shared by all.*

BPS presents formidable challenges relating to *problem representation*, support for *performance appraisal*, enabling *operational application*, and delivering *user education, training and accreditation*. The first challenge requires the detailed physical specification of site conditions & features, building form & fabric, plant & systems composition, occupant presence & behaviour, and control strategy & actions. It also (and this is problematic for practitioners) requires abstract supplementary information to enable configuration of the underlying mathematical models that dictate multi-variate behaviour. The second challenge requires the encapsulation of tools within an active design process in a manner that can accommodate myriad user requirements as driven by client and legislative expectations. Present developments in Building Information Modelling (BIM) represent only a partial overlap with the needs of BPS in both these regards. The third challenge requires tools to be developed in a manner that allows them to be integrated with building automation systems and periodically be updated over the lifespan of building systems. The last challenge requires the harmonisation of the (scant) teaching and learning materials available within higher education establishments and the development of industry-endorsed training materials for continuing professional development.

Proposition 2: IBPSA will develop a requirements specification for standard approaches to problem representation, performance appraisal and operational application; and support the elaboration of standard materials for education, training and user accreditation.

Problem representation

The detailed representation of a building will comprise the following data aspect models as required to support the stated simulation functionality with, where indicated, supplementary data being required to support the mathematical algorithms corresponding to particular assessment domains (power, energy, comfort, air quality, emissions, systems control, demand response/ management *etc*.). Complicating factors include the abstract nature of the supplementary data (e.g. spatial discretisation) and the need to support the representation of non-trivial domain interactions (e.g. the impact of solar irradiation on local air movement).

<u>Site data</u>

Data on surrounding objects, natural or otherwise, are required to support micro-climate assessments of local wind attenuation, heat island effects and solar distribution. It may be expected that such data will be more available in future due to the emergence of whole city models that will enable explicit boundary conditions assessment. In the absence of such models, recommendations need to be given on how best to adapt weather data to represent micro-climate effects.

Proposition 3: IBPSA will ensure that the content of emerging city models reflects the needs of BPS and foster the development of procedures for the selection of model boundary conditions that encapsulate micro-climate effects.

<u>Geometry data</u>

Data defining the non-orthogonal geometry of arbitrarily complex building forms, including the representation of material interpenetrations, façade features and internal contents are required by algorithms for heat, mass, light and sound transfers within and between buildings zones and constructions. While CAD systems have refined geometry representation capability, the need is to elaborate procedures for the definition of those additional aspects required by BPS (e.g. thermal bridges and movable façade features) and, where possible, to pre-construct standard representations for use in practice. Supplementary data defining surface and volume discretisation will be required by several domain models, most notably to support radiation flux computations relating to solar irradiation, natural/artificial lighting and infra-red flux exchange; and the movement of air, moisture and contaminants within spaces and constructions. While the discretisation resolution may vary between domains, the issue is largely the same in each case: the application of a structured grid to parts of the model geometry. The need is to standardise how grid parameters are defined and ensure compatibility with CAD-based approached to geometry definition.

Proposition 4: IBPSA will encourage the implementation within CAD tools of procedures for the definition of BPS-specific geometrical features and the imposition of static and adaptive spatial gridding schemes.

Construction data

Constructional definitions must be formulated in terms of hygro-thermal, optical and acoustic properties of materials that may, in general, be non-homogeneous, respond in an anisotropic manner, and exhibit time varying behaviour. Given the extensive data-sets already available and the sophistication of material testing laboratories, it should be possible to commence the collation of a harmonised dataset that covers a range of conditions that are likely to be encountered in practice. The key issues here are the inclusion of information on data provenance and the organisation of the data in a manner that reflects the inherent uncertainties derived from the testing, manufacture and construction processes.

Proposition 5: IBPSA will foster the development of a standard database of material properties, including related information on data source and application reliability.

Plant and systems data

Specifications of plant/ systems components and connections are required at sufficient resolution to enable dynamic simulation and building linkage. The opportunity here is to adhere to the same representation as applied to buildings – that is, explicit definition of geometry and material composition – but with data structures pre-defined at the component level. Supplementary data would then define aspects such as working fluid properties, required discretisation schemes and operational constraints (such as valve response time or operating limits) – and the topology of connected components as described below.

Proposition 6: IBPSA will encourage manufacturers to provide more fundamental descriptions of components and make these available within a standard library.

Network topologies data

These supplementary data will comprise 'node/ arc' representations of the distributed flows associated with air infiltration, ventilation/ hydraulic systems and electrical power supplies. While the component models that define network arcs (pumps, fans, conduits, electrical conductors *etc*.) will be included within the Proposition 6 library, the opportunity here is to offer users pre-constructed network topologies corresponding to a range of typical problems (single-sided, cross and displacement ventilation; building-integrated PV *etc*.), and to endorse rules to infer network topologies from appropriately-refined geometrical descriptions.

Proposition 7: IBPSA will support the development of a standard library of typical network topologies for fluid and electricity flow and endorse a method for their automatic generation from appropriately attributed geometrical descriptions.

Occupant data

Explicit representation of occupants should be possible in terms of their location, activity and behaviour to enable the insertion of 'agents' within simulations as a means to both model occupant interactions in response to individual preferences and, ultimately, to embed the means of judging performance acceptability within the simulation process itself (i.e. the acceptability of performance is decided by the occupant model, not by the tool user).

Proposition 8: IBPSA will foster discussion on how best to assemble a standard database of occupant models for use within simulations to change model parameters in response to individual and group judgements relating to evolving systems states.

Control data

Specification of control systems is required in terms of sensed and actuated states and the control algorithms that relate the two over time along with information defining the control purpose overall. The opportunity here is to standardise the approach to control system definition and to make available pre-constructed definitions corresponding to traditional and new control applications (e.g. heat pump regulation and demand manipulation within smart grids respectively).

Proposition 9: IBPSA will support the harmonisation of the vocabulary of control as used in BPS, the development of a standard definition procedure, and the creation of a library of control system template definitions corresponding to representative cases.

Overall data model

While data models relating to the above representations exist in various forms, they are either incomplete in terms of the range and/ or depth of aspects covered, or inadequate in that they are designed to accommodate the needs of simplified modelling approaches. Clearly, while a complete physical representation can service the needs of a spectrum of modelling approaches, reduced order descriptions often cannot service the needs of true BPS.

Proposition 10: IBPSA will support the elaboration of the overall data model required to undertake BPS when viewed as a multiple domain, non-linear, partly stochastic, always dynamic problem and encourage the progressive encapsulation of this data model within an open user interface tool using the specification emerging from the Proposition 2 activity.

Such a contribution should be viewed in the context of developments in BIM but with the focus on the problem representations and performance returns of BPS that has hitherto been excluded.

Performance appraisal

The impact of BPS can only follow from its encapsulation within the design process in a manner that respects the temporal nature of the activity and accommodates the disparate viewpoints of the various user types. The principal issues here include the user's ability to abstract a problem at the earlier stages of the design process, the availability of fit-for-purpose describing data for the problem parts, industry agreement on standard approaches to performance assessment, and the establishment of procedures to coordinate BPS use when embedded within a business. These issues are considered in turn.

Problem abstraction

One way to address the early design stage abstraction issue is to make available parameterised exemplar models that may be tailored to meet particular cases. In this way the user need only accept, decline or adjust model parts as opposed to conceiving and defining an abstract model in terms of unfamiliar modelling constructs. It may be anticipated that such models would be used to deepen the energy-related information content of future whole city models.

Proposition 11: IBPSA will foster the creation of a standard library of exemplar models and make these available in a format that may be readily modified to represent specific cases within BPS tools.

Data availability

Fit-for-purpose describing data may best be obtained by harmonising existing data-sets, by convincing material and component suppliers of the merits of the BPS approach, and by assisting suppliers to provide the required data in a standard format.

Proposition 12: IBPSA will support the development of exemplar materials that demonstrate the benefits of undertaking context-specific product appraisals and will assist suppliers in identifying the data required to enable this approach.

Standard performance assessment

Performance assessment requires the coordination of BPS tools in a manner that represents the operation of the building under anticipated conditions relating to extreme or typical events, seasonal or annual periods, or over its life cycle. A particular challenge is to develop performance criteria that can express the multi-variate, time-evolving performance of a building in a manner that captures real performance based on metrics acceptable to practitioners.

Proposition 13: IBPSA will develop and promote performance assessment procedures corresponding to principal appraisal requirements (control for minimum energy use, passive solar design features appraisal, low carbon operation, renewable energy systems integration etc.) along with a related set of assessment criteria that may be used to compare design alternatives.

Embedding BPS in practice

Realising the ultimate benefits of BPS will require changes to present work practices relating to topics such as problem representation, quality assurance, simulation processing, outcomes interpretation, feedback to design change, standard reporting, control system configuration, commissioning and operation. Such changes will more likely be accepted where suggested procedures have been well scrutinised and generally validated, and where the underlying business proposition has been clearly elaborated.

Proposition 14: IBPSA will elaborate, through developer and practitioner consultation, standard procedures for BPS use in practice along with cases studies of *observed business benefits in terms of quality/ cost and risk reduction when adopting novel systems and equipment.*

Education, training and user accreditation

There is an urgent need to harmonise the disparate educational information being used within degree programmes worldwide by providing a core resource pack on BPS and by assisting with the exchange of exemplar case study materials between regions. Further, there is a need to establish a procedure for the training and accreditation of BPS users to ensure best practice application of the technology.

Proposition 15: IBPSA will support the development of a core teaching and learning package for BPS, will establish a mechanism for the free exchange of tool- and problem-specific educational material, and will elaborate a generic approach to BPS user training and certification.

Operational support

BPS is the parameterised specification of design intent. The value of such tools can be increased if used during the operational phase of buildings to test the building fabric, mechanical plant and control system for correct operation relative to this intent. Moreover, BPS can assist in monitoring building (sub-)systems for measured versus expected performance, serve to reconcile such observed differences, be used to detect and diagnose faults and to guide operation in real-time.

Proposition 16: IBPSA will promote the use of BPS in building installation, commissioning and operational contexts in a manner that enables simulation-assisted information technology to be upgraded over the life span of the building systems.

Conclusions

This paper is an articulation of possible contributions to the harmonisation of BPS when, as might be reasonably expected, its progressive embedding in practice gives rise to accelerating user demands. Underlying the above propositions are many significant issues such as changes to company work practices, new user interface constructs and procedures, impartial tool screening, communicating the scientific culture, user support and accreditation, and process management within businesses. The contention here is that such issues can best be progressed by a community that shares a common vision and can be supported in its attempts to access the resource to pursue task-sharing developments. That is the only way to advance the science of building performance simulation in order to improve the design, construction, operation and maintenance of new and existing buildings worldwide.