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# BUSINESS SUCCESS THROUGH PROCESS BASED APPLICATION OF SIMULATION

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## ABSTRACT

Progressive design practices are increasingly cognisant of the potential of building energy simulation to assist the delivery of energy efficient, sustainable buildings. However, the success of any building performance assessment hinges on the capabilities of the tool; the collective competences of the team formed to apply it; and, crucially, the existence of an in-house framework within which simulation can be applied with confidence (McElroy and Clarke 1999). There is also a need for the professions to set up mechanisms that facilitate dialogue with vendors in order to influence tool capabilities. And on the related issues of building an in-house competency and a framework for application, the two core issues facing the professions are:

- a need for the development of in-house procedures for management of simulation; and
- quality assurance of the related models and appraisal results.

Fundamental to the success or otherwise of the application of simulation in design practice is not the existence of such procedures, but the rigour with which these are developed, monitored and applied.

## KEYWORDS

Simulation in practice, knowledge transfer, quality assurance, quicker, cheaper, better.

## INTRODUCTION

For a number of years IBPSA Scotland has contended that simulation-based design can yield results, quicker, cheaper and better than conventional methods. Despite the fact that the construction industry is traditionally conservative with regard to risk taking, considerable success has been achieved over the last seven years in terms of transferring simulation capabilities into design practice. However, it should be stressed that this success has required considerable fortitude on the part of the businesses involved. Such progress is due in part to the partnering and mentoring scheme offered through the project, and in part to the 'buy-in' of company directors and design staff who acknowledge the need for the development and rigorous application of a procedure for use of simulation in practice, backed up by checks and balances in the form of quality assurance systems and benchmarking – not to mention determination to succeed. Failures are few, and relate in the main, to lack of time investment, inadequate 'buy-in' at all levels within the company, and a perception of simulation as an 'add-on' rather than an interal part of the design process. The high level of capital investment required is less of an issue than might be expected.

This paper explores and analyses successes and failures in transferring these technologies into mainstream design and contracting businesses. In particular, it describes an eight step quality assurance focused process in detail, identifying three key steps between stages in the procedure that make the difference between success and failure. Where appropriate, case study material, drawn from completed projects, is introduced to elaborate the benefits of simulation as seen from the viewpoints of the practitioners involved.

## QUALITY ASSURANCE

Experience indicates that the greatest threats to the use of modelling in design practice centre on:

- timescales required to develop the necessary skills;
- lack of trust in the accuracy of models;
- credibility and risk of misinterpretation of results;
- the impacts of uncertainties;
- risks associated with user error: and, most importantly:
- the lack of support available to develop the necessary skills.

The viability of adopting computer-based assessment as a mainstream design activity within a commercial environment is therefore dependent on developing appropriate working practices and Quality Assurance procedures that facilitate monitoring and documentation of the modelling work to a level that will instil confidence in users (and recipients of recommendations extracted from simulation outputs) without hampering design progress. Within this framework, co-operation between developers, practitioners, consultants and staff is critical to ensuring that modelling objectives are not compromised by the mechanistic application of procedures.

It is essential that the Quality Assurance [QA)] system adopted covers all possible procedures, decisions, assumptions and data sources employed, with a degree of documentation that is adaptable and appropriate to the scale and type of the project. The primary concern within industry is in ensuring that QA procedures do not impede the simulation/ design process, e.g. due to delays experienced while waiting for simulation results.

New tool users can be disheartened by systems that do not adequately support model creation, documentation, archiving and retrieval. There is a risk that such systems will 'trap' or conceal errors, and unless identified first time around, this can result in the perpetuation of model inaccuracies. Hand (1999) recommends that these issues be addressed by developing a procedure that is encapsulated within an overall quality assurance procedure, but this is a complex task, (Parand and Bloomfield 1991, and Chapman 1991).

IBPSA Scotland aims to assist businesses to evolve such a procedure by building upon the good practice established previously by the Energy Design Advice Scheme [EDAS], (ETSU 1998a and 1998b) and CIBSE (1998). The procedure has 8 stages:

1. project initiation;
2. identification of objectives;
3. mapping of objectives to simulation tasks;
4. identification of uncertainty & risks;
5. development of procedures and maintaining an audit trail;
6. translating simulation outcomes to design evolution;
7. client reporting;
8. model archiving and 'sign-off' procedure.

This procedure was introduced in previous papers written in conjunction with IBPSA Scotland member companies (McElroy & Clarke 1999, McElroy, et al, 2003, Hobbs et al 2003). However, over the last four years, the procedure has been developed and tested in practice and is elaborated below. The following sub-sections explain how these stages are implemented in practice with IBPSA Scotland support:

**Project Initiation**

Project Initiation includes the definition of the project's scope, the selection of the most appropriate software applications and the establishment of the in-house project team. At this stage IBPSA Scotland will assign a specialist staff ember to oversee and support the process in order that the simulation program does not burden the process.

**Identification of objectives**

At this stage the technical objectives are defined and responsibilities agreed between the organisations involved. At this juncture, IBPSA Scotland's role is to facilitate access to any new simulation packages, to ensure that misapplication does not arise from unfamiliarity and to determine any barriers to routine tool use. In this last respect, IBPSA Scotland staff document the approach taken, the tools used, the outcomes attained and the perceptions of the project team, before, during and after the process.

**Mapping of objectives to simulation tasks**

Because modelling specialists are not building designers, and building designers are not (yet) proficient modellers, the mapping of design questions to modelling intent is a non-trivial activity.

For those with little simulation experience, initiating simulation projects and identifying objectives are non-trivial issues. As most building designers are not proficient modellers there can be a tendency to rush the initial stages in an eagerness to obtain a working simulation model. In addition, the preparation of a simulation model is time-limited, in order to accommodate real-time design process constraints.

Many subsequent model construction, simulation and output quality issues stem from the fact that there is no available clear guidance as to the important features of a building model (Donn, 1999). For example, no hierarchy is given as to what issues or zones require the greatest (or least) level of detail. This lack of guidance can lead to the modeller spending unnecessary time building zones with surplus or inadequate levels of detail. IBPSA Scotland will ensure that ensure that the mapping of design questions to modelling strategy are fully considered and that a level of understanding of critical and non-critical issues is reached. In this way it is ensured that good practice will evolve over time.

**Identification of uncertanties and risks**

In the context of innovative design, it is the risk element that must be tested if the boundaries of best practice are to be pushed forward. Only when a parameter's uncertainty is known, can the associated risk be determined (Macdonald et al 1999). Perceived uncertainties and risks are documented and discussed as part of the prcess in order to build up a level of understanding of where the greatest risks and uncertainties lie, and which are of greatest potential significance.

### Simulation procedures and maintaining audit trail

While vendors may be confident about the validity of the results produced by their program, there is as yet, no mechanism whereby this confidence can be passed to a user. Experience to date has shown that engineers frequently request simulation without any real consideration as to the nature of the problem, or indeed, what the simulation is expected to prove or disprove. By deveoping mechanisms that force such requests to be better considered with respect to purpose, it is envisaged that simulation users will become better able to direct their time efficiently and effectively.

IBPSA Scotland is also working with the industry to raise the level of awareness about the relationship between actual and predicted perfomance predictions with a view to establishing procedures for simple model calibration and to develop a checklist approach to model/ result archiving.

### Translating simulation outcomes to design evolution

Simulation allows designers to perceive the future reality at the design stage. And the outputs from simulation can thereforehave have a significant impact on the design of a building. Unfortunately, the mapping of time series performance data to decisions on design hypothesis modification is a non-trivial process. Consequently, there is a need at some stage in every simulation process for an expert/ adviser to assist with the interpretation of simulation results. Even in the case of simulations conducted by experts this step is necessary as modellers, closely involved in model creation often find it difficult to detach themselves from the process, and thus their judgment can be biased. Similarly, non-experts, without the benefit of an expert/ adviser can find it difficult to know how best to make use of results. There is no 'quick-fix' solution to this problem, however, IBPSA Scotland seeks to raise the level of debate on this issue through its wider activities through seminars and workshops, and sees team working and partnership as key to successful outcomes.

### Client reporting

The development of a standardised reporting procedure is seen as an essential prerequisite for practitioners. As discussed in the previous section, assuming users are able to understand the performance impacts of intended design actions, it is important to develop appropriate methods for translating outcomes to a format suitable for all design team members to digest (McElroy et al 2003).

By creating company specific, standardised reports, it is envisaged that the whole dsign team will develop a better understanding of the process thus instiling confidence to question simulation results.

### Model archiving and sign-off procedure.

Good practice simulation dictates that project models be archived for possible future use. The decision on which model to archive will depend on its perceived value within the project. IBPSA Scotland is assisting member companies to explore how this might be done in a manner that supports inter-organisation use.

In respect of providing assistance with the development of specuific in-house QA procedures for tool use in practice, IBPSA Scotland is now acting as a think-tank and repository for sharing of experiences, while working in-house with companies to help them to build systems and to gain from the experience of others who have already travelled the same path.

## MODELLING PROCEDURES

The underlying reasons for adopting QA procedures are fundamental to good design practice. Essentially, the purpose is to:

- instil confidence in clients that the work is undertaken to a consistency high standard;
- estimate the time and cost of consultancy and ensure the achievement of these targets;
- improve coordination between members of the building simulation team;
- ensure that the simulation work is addressing the needs of the client, ensure the simulations are accurate, introduce consistency into the implementation of simulations;
- enable new work to capitalise on previous projects;
- enable previously archived projects to be resurrected and understood.

The creation, testing and proving of a computer model is often the most time consuming part of the process, and the time and resources dedicated to this early stage must be balanced with the level of detail within the model itself. (CIBSE 1998a).

However, an appropriate level of detail in documenting the model is also essential for providing clarity in respect of what assumptions have been made and why, in order to allow the model to be re-visted at a later date if necessary.

A key problem that has been highlighted amongst users in industry, is the ability to maintain an audit trail once simulations progress beyond the base case model. When the simulation process begins in earnest, and numerous new design scenarios are being tested, the information stored can become outdated unless a rigorous audit trail is maintained. Typical issues that this would affect are changes to:

- air change rates;
- glazing types and areas, opening schedules;
- occupancy, equipment, lighting heat gains;

- heating and cooling controls;
- infiltration, ventilation levels;
- supply air temps; and
- lighting controls.

New and experience users alike find it an onerous task to track all of the changes made to the original model as it evolves. Indeed, it is often the case that once the base case model is created and archived, rather than working through a logical course of simulations there is a temptation to try to change too many variables at once rather than tracking changes individually and recording results as the design is developed. (McElroy et al 2003), highlighted the fact someone must be responsible for the overall simulation strategy. Whether or not this person is directly involved in the simulation process may be irrelevant, what is important is that someone is responsible for the primary strategic decisions regarding simulation scenarios and are able to direct the simulation user so that the objectives of the simulation remain clear.

Accordingly, project notes should be continually updated during the evolution of the model and the building design. The aim is to ensure that post-completion, a model could be resurrected by someone not involved in creating and testing the original model. This may seem obvious, but is difficult to manage in practice – usually due to timescale pressures that result in model changes without documentation, or in a failure to record a key step in the process. In the development of such procedures, consideration should therefore be given to the following items (CIBSE 1998b):

- documentation of the methodology and procedures used to generate and evolve the model;
- detailing of assumptions built into the model;
- ensuring that logical naming conventions are used within databases, model and zone descriptions, environmental control systems, etc., in the event that the model may be re-visited by another designer;
- use of clear directory and file naming conventions to clarify projects with multiple iterations/ parametric variations;
- documented procedures for integrating changes, (e.g. in composition or operational characteristics);
- sign-off, 'pack-up' and archiving procedures.

The time required to extract and understand modelling outputs and results in terms of design performance predictions should not be underestimated. Insufficient time invested in analysis can contribute to misinterpretation of results and a failure to spot errors. It is recommended that businesses embarking on a simulation-based design approach develop and invoke a series of customised checks, supplemented by critical professional judgement, e.g.:

- are results as expected, plausible?
- do changes in model give expected change in predictions?
- is the magnitude of annual energy consumption similar to that derived from a steady state calculation or best practice guides, such as ECON 19 for Office Buildings (Carbon Trust).
- how do results compare with similar projects?

These procedures are summarised below in Table 1.

| Step | Typical decision |
|---|---|
| Identify issues to be addressed and simulation objectives. Translate to modelling approach, and agree required output format and key indices required to judge performance – Client, Design Team, IBPSA staff. | Is project a 'one off' assessment? Is it a parametric or an interactive exploration? Are explicit assessments of issues such as external shading and natural ventilation required – will these require dynamic analysis or are approximations adequate? |
| Abstract the essence of the design and develop model at a level of detail appropriate to the focus of the study. | Is it necessary to describe the whols design or is a portion of the building representative enough to allow results to be scaled up? How much geometric detail is required? |
| Organise problem files and documentation and proceed with simulations – this reduces the risk of not archiving at the end of the process. | Which databases are appropriate and do modifications need to be made for this project? Are there regular patterns of occupancy and equipment use? What naming conventions are appropriate for file recovery purposes in future? |
| Run initial simulation and calibrate model to instil confidence in all parties. | Are predicted internal temperatures as expected? Examine impact of heat gains and losses in terms of time lags to test fabric assumptions. |
| After simulating, results must be interpreted, perfor-mance assessed, reports written and presented to the client. | Can the tool's native reporting facilities be used or should results be passed to an external package for statistical analysis? |

*Table 1: Modelling Procedures*

## CASE STUDIES

## 1. ATKINS GLOBAL

A recent series of interactions between IBPSA Scotland and Atkins Global (Atkins) explores many of the issues raised above. Atkins had a history of 'buying-in' assessment services, but the company had come to the conclusion that this approach was less efficient than had been originally expected. This was identified as being due to an increased burden on staff time in terms of the need to analyses and digest the assessment reports. In addition, the company had concluded that this 'out-sourcing' approach offered few options for adding value to the deliverables, or time for revisiting issues with alternative proposals. A key issue was the fact that there was little or no opportunity to learn from such a detached approach.

As a consequence of reaching this conclusion, a long -term plan to build an in-house simulation capability was developed by the Glasgow office with continuous input from IBPSA Scotland. This required commitment to:

- up-front mid-level management buy-in;
- commitment to freeing of resources for staff training;
- mentoring of their working practices; and
- critical support for delivering useful information within design teams.

During the period of 'up-skilling', the project leader worked to change the ethos within the company towards valuing the deliverables of the team.

The need for such commitment may seem obvious, however, in the past, for many companies embarking on this path, lack of management buy-in, lack of objectives/ direction and lack of effort to carve a niche for such new activity has resulted in companies giving up, and returning to traditional methods.

Due to the existence of the IBPSA Scotland support facility the company overcame the barriers associated with timescales required to develop the necessary skills: from lack of trust in the accuracy of models to risk of misinterpretation of results, and is well on the way to developing skills to deal with the impacts of uncertainties and the risks associated with user error.

## 2. CROWN HOUSE TECHNOLOGIES

Another such project involved the building of in-house simulation assessment capabilities for Crown House Technologies Ltd (Crown House), a design and build contractor, specialising in health care facilities. The aim in this case was to support fine-tuning of the design of environmental control systems. In particular, this company's designers held the belief that they could deliver designs that would maintain patient comfort while at the same time reducing environmental system complexity and initial costs, but they were fighting against the *'....but, this-is-how-we-always-do-it...'*, view of their sub-contractors. IBPSA Scotland assisted the engineering staff to compare and contrast the performance of alternative designs and, furthermore helped them to demonstrate that there was no negative impact on comfort for patients as a result of adopting alternative approaches. In the process, the staff involved gained confidence in use of the simulation tool employed. The project involved the development of 'virtual wards' and the modelling processes demonstrated not only the response that the engineering staff had expected, but also gave them the enhancement of an ability to fine-tune the model and/ or to review related performance issues interactively. This provided them with indicators of the work-flow/ timescale issues that they could expect once staff were proficient in use of the tools.

In this case, the focused support of IBPSA Scotland led to design ideas that could be applied generically in typical patient rooms, resulting in considerable savings in initial costs and on long-term maintenance. Bearing in mind the fact that this is a contracting company that is used to operating within tight timescales, it would have been understandable if they had decided that they could not make available the time resources required to acquire the skills necessary to develop an in-house simulation capability. It would also have been easy to opt to contract-out the work, having taken the initial steps necessary to understand the process. However, having realised the benefits, the company seized the opportunity, and with the support of management and IBPSA Scotland throughout the process the staff were afforded the time to develop skills to a high enough level to take them beyond some of the key barriers: the timescales required to develop the necessary skills; lack of trust in the accuracy of models and risk of misinterpretation of results.

## 3. ENCONSULT

Another example in recent times involved the integration of advanced modelling into Enconstult (Enconsult), a small but ambitious environmental engineering company. The first stage involved the company agreeing to send two design staff members to attend training courses on the simulation packages initially identified as best meeting the company's needs. Following this, the company sent senior managers on a similar training course in order that they could appreciate the potential of the technology and so that they could better support less experienced staff through the application of their engineering knowledge to the simulation outputs: e.g. to help test the plausibility of results and whether or not changes in the model give the expected changes in predictions. This was run in parallel with the delivery of project specific support, both in-house and on the premises of IBPSA Scotland.

This company specialises in environmental solutions that minimise use of traditional mechanical systems and which focus on a 'whole building' approach. The use of simulation within the practice has therefore focused on projects where strategies such as natural ventilation and daylighting work hand-in-hand with the building form and fabric. Simulation is seen as essential in developing the design on these projects, representing the only available means of analysis that allows the practice to meet client needs and deliver leading edge design solutions.

Although the complexities of a full thermal simulation may not be considered necessary by some, the ultimate intention in this case is to integrate the use of simulation in order that it can be offered as a primary design tool to every client. The appropriateness of this will depend on project type and time constraints, and the company recognises that this route will not always be applicable.

The company has identified the following as being of critical importance, to ensure that simulation does not adversely affect either the design process or the economics adversely:

- in order to avoid being side-tracked by the power of the simulation tool, the objectives of the exercise must be clearly defined, and parameters agreed;
- novice users must accept their limitations and allow expertise to develop. In this case, support was provided by experienced senior managers and by IPBSA Scotland;
- quality assurance procedures ensure that the novice modeller can build confidence to ensure that the building performance is analysed according to appropriate criteria;
- ongoing support is essential to ensure a successful deployment and associated staff training ensures that development of skills continues.

The experience of this small practice acknowledges the need for appropriate training and subsequent support in deploying simulation. It also recognises that if support is available, results in which the team can be confident can be obtained quicker and better than by using traditional methods, thus saving the company money through reduced design development. The skills attained will allow the practice to offer clients access to leading edge technology to analyse innovative designs effectively.

The practice is now free to explore things it could only guess at before, but for other small practices offers the following cautionary note:

The main cost in making this commitment is not hardware or software, but staff training time. For a small practice, the initial start-up cost in terms of staff time is considerable. The company set out to develop its business with skills based on adopting free software, customised to suit its needs. However, it was soon discovered that for this company, the time involved in this approach outweighed the perceived cost benefits. In the end they invested in a proprietary commercial tool, despite the considerable up-front investment - equivalent to a young engineer’s salary for a year, based on capital outlay, formal training and time lost in moving from the old to the new methods. Without support, the cost could double.

## MODEL BENCHMARKING

Designers are often reluctant to use simulation in cases where they have no concept of what outcome to expect. Benchmarks provide a means to judge the integrated performance of a building against others in the same class. They also allow users to scrutinise the impacts of new program releases. Supported use of modelling in practice allows the IBPSA Scotland network to build a repository of models of specific building designs that typify certain ranges, and this is generating model performance data, normalised by floor area, weather, etc. It is envisaged that feedback from this can be used to develop integrated performance benchmarks based on application of theory to live projects. This is based on the range of criteria that would typically be used to characterise building performance: energy efficiency, comfort, air quality, environmental impact, renewable energy utilisation, etc.

These benchmarks provide a mechanism to compare the integrated performance of a building with others of a similar type of thermal characteristic within the same type (Carbon Trust (a)).

## ADVANCING THE UPTAKE OF SIMULATION WITHIN PROFESSIONS

The computational approach as advocated by IBPSA Scotland addresses the integration of the computational skills required to quantify building environmental performance. However, it does not address the paucity of feedback on the actual performance of these buildings in use.

Sust. (2005) is a Scottish Executive funded project, devised by The Lighthouse (Lighthouse 1999), to be consistent with its approach to sustainable development (Scottish Executive 2002 and 2005). Sust. supports the delivery of a sustainable built environment and assists those designing and commissioning buildings in delivery of buildings that meet the expectations of all involved.

Sust. works alongside recognised experts and organisations in various built environment related fields to support the development of tools, techniques and guidance, to assist all building stakeholders to make the necessary changes to their approaches and work practices - in effect to mainstream sustainable development - and provides additional financial support in the form of project funding and grants towards new technologies and the equipment necessary to monitor the effectiveness of systems comparing the accuracy of predictions against reality, post construction. Sust. is working with IBPSA Scotland in order to maximise the potential impact at the implementation stage of a project and to improve opportunities for working more closely with the professions, by providing them with greater access to early stage design tools, in order to improve their understanding of sustainable design issues and the implications and issues associated with delivering this in the real world.

It is envisaged that through such collaboration, it will be possible to build a greater appreciation of the opportunities that simulation can offer, while making designers aware of the limitations and the risks associated with new technologies.

Support for all of this activity is available through such guides as the CIBSE's Technical Memorandum TM 33: Tests for Software Verification and Accreditation (CIBSE 2006), and Applications Manual AM 11 (CIBSE 1998), which describes a series of standard tests for commercial software calculation tools as well as working procedures and simulation methodologies. The aim is to verify that such tools produce results consistent with good practice and are consistent with the methods in the CIBSE Guides (CIBSE).

## THE IMPACT OF LEGISLATION

After many years of trying to encourage designers to adopt a computational approach to design, with little measurable impact, we are now being forced down this route by new environmental legislation. This has both positive and negative implications for the construction industry worldwide.

There is concern that in many cases this is being implemented without adequate consulation with the industry and without a full understanding of the implicationsfor businesses. In Europe for example, we are experiencing difficulties due to the fact that neither the industry nor the available tools are particularly ready to meet the challenge. Given that the simulation industry in the UK is fairly mature, it is recognised that while some practices clearly benefit from simulation-derived information, others get 'answers' that mean little in terms of delivery. Thus, the technology can be as much a hinderance as an asset in the delivery of a more sustainable environment. And, while the new legislation is, on the one hand seriously challenging those practitioners who currently do not use building performance modelling software, on the other, designers using modelling are increasingly delivering a building as part of a 'process' rather than as a 'product', thus encouraging wider adoption of the technology. Notwithsanding this, one of the biggest concerns at the moment is the gulf between theory and practice.

## REAL BUILDING BENCHMARKS

In the UK, using the Simplified Building Energy Model (BRE, 2005) which is being developed by the Building Research Establishment [BRE], designers will be required to test their 'Actual' building against a 'Notional' and 'Target' building, in terms of meeting Building Regulation performance targets based on theoretical building usage patterns. This tool is available as a stand alone or, increasingly, as a plug-in to the main commercial packages in the UK. It is not a substitute for simulation and is purely seen as a Building Regulation compliance checker, and therefore it merely provides a comparison with the 'Target'. There is a real need to compare thoery with practice and to build up a set of real benchmarks for real buildings, and for these to inform the development of legislation.

In some countries in Europe, legislation is already being drawn up that will require ongoing monitoring after a period of occupation, to monitor energy performance and to compare this with the predicted figures in order to highlight and address any issues that this might reveal. There is also scope within this exercise to expose patterns in terms of recurring themes, issues and margins of error between theory and practice. However, as currently there is no obligation to do this in the UK, while the regulations will require theoretical integrated energy performance criteria to be set, this will not (necessarily) be tested in practice.

In our view, if governments are serious about reducing the global environmental impact of buildings, they must commit to two things:

- investment in training of those that are responsible for the implementation of the legislation (on the basis that poorly understood 'input' results in meaningless 'output') and
- imposition of a requirement to monitor performance in order to improve quality assurance in the use of building energy performance assessment tools in practice, and to improve the accuracy of the tools by measuring actual building performance – thus providing better building benchmarks in the long run.

## CONCLUSIONS

Over the last 20 years, we have witnessed a steady growth in demand for 'business friendly' simulation tools, suitable for integration into the design process. The challenges to the building design professions of moving simulation from an academic to a business environment are now recognised and accepted by industry and consequently, industry has gradually begun to accept that in order to accommodate the new technology, design procedures will have to evolve accordingly. Moreover, to facilitate effective, risk free use in practice, bespoke in-house QA and modelling procedures will have to be developed. The requirement to integrate simulation will continue to grow in the light of new regulations, most notably in Europe with the EPBD, (EU 2003), which will require analysis of renewable and alternative energy sources for new buildings and major refurbishments.

With the assistance of IBPSA Scotland and through initiatives such as Sust. and others described in this paper, and supported by the kind of guides and Technical Memoranda produced recently by CIBSE, innovative engineering practitioners have already demonstrated that over the course of the design process, effective use of early stage information allows better designs to be produced at lower cost and in a shorter timescale.

The next goal is to continue to facilitate delivery of more sustainable buildings by improving understanding of what this means in a language appropriate to different audiences. The aim is to engender a need for performance quantification in practices without the capabilities to adopt the tools in-house.

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