THE ABGR VALIDATION PROTOCOL FOR COMPUTER SIMULATIONS

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ABSTRACT

The Australian Building Greenhouse Rating (ABGR) scheme is a performance-based rating for office buildings. While it was originally designed for existing buildings, its success in that sector has led to its rapid adoption as a performance standard for new buildings.

As a result of this application, there has been an upsurge in the use of simulation as a predictor of absolute performance. The problems inherent in such absolute predictions led to the creation of the ABGR Validation Protocol for Computer Simulations.

This paper describes the background and content of the Protocol, and highlights issues and lessons learnt from its development and application.

INTRODUCTION

There has been a great deal of emphasis on the technical improvement and validation for computer simulation models over recent years, which have in turn created many improvements in the validity of commonly used models (Judkoff and Neymark 1995). However, there continue to be issues associated with the way models are used by designers and consultants to validate design decisions.

In Australia, a variety of circumstances have combined to create considerable interest in the use of simulations as absolute predictors of commercial building performance. Irrespective of whether this is advisable in the minds of the simulation development community, it is a natural consequence of greater interest in the use of simulation and in the achievement of genuine in-practice energy efficiency.

In this paper, the details of a quality assurance protocol for computer simulations are described. This protocol has been developed as a means of improving the quality of simulations and the quality of understanding as to the weaknesses of the simulation as a predictor of absolute performance.

THE AUSTRALIAN BUILDING GREENHOUSE RATING SCHEME

The Australian Building Greenhouse Rating Scheme (ABGR) is a performance based rating scheme for the energy/greenhouse efficiency of office buildings. The scheme is based purely on performance, as determined by actual energy use in operation per unit net lettable area, corrected for hours of use, internal load density and climate. (Bannister et al. 2004, Bannister 2005)

ABGR is based on the position of a building within the statistical population of building performance. A rating of between one and five stars is awarded dependent on the relative position of the building in the population: one star means approximately 80% of the population is more efficient, 2.5 stars is approximately the population median, and 4 stars represents the top 10% of the market. Five stars is generally set at a level that is not achievable without major innovation, and as such is derived from theoretical considerations rather than statistics.

ABGR has three different types of rating, which reflect the various methods of dividing landlord and tenant responsibility for energy use in Australian office buildings. The ratings are:

- Base building rating: This is based on the energy use of the air-conditioning system, lifts, common area lighting and other landlord-controlled services provided to the tenant. In many Australian offices, the energy costs of these services are grossed into the rent so that the efficiency risk and opportunity lies with the landlord.
- Tenancy rating. This is based on the energy use of the tenant lights and office equipment. Again, this is commonly subject to its own metering and billing in Australian offices.
- Whole building rating. This is based on the energy use of the entire building, i.e. all the energy in the base building plus all the tenancy energy.

ABGR rating thresholds are set such that the threshold for any given whole building rating is equal to the sum of the thresholds of the tenancy and base building ratings. Ratings are linear (against a

$kgCO_2/m^2$ per annum scale), in that for each individual rating type the distance between stars is constant across the scale.

The scheme, which has been operating since 1999 in the Australian State of New South Wales, and throughout the rest of Australia since 2000, has a high level of acceptance amongst the industry. This is evidenced by its use by major property portfolios as an internal benchmarking measure and its use as a diagnostic tool by energy managers.

ABGR was designed for existing buildings, and has a high level of use in this sector. One of the key functions of the scheme is to provide an easily determined and reliable market signal by which the issues of energy efficiency can be brokered in tenant-landlord interactions.

However, its success in the existing building market inevitably has led to a market demand for its application in new buildings: tenants who have become interested in sourcing high efficiency existing buildings inevitably have an interest in achieving exemplary efficiency in new buildings (Bannister 2004a).

Furthermore, in Australia, there have historically been no national energy efficiency requirements for commercial sector buildings. ABGR was quickly identified as a potential methodology by which this gap could be filled. This has resulted in numerous municipalities adopting a minimum ABGR rating as a criterion for development approval. Furthermore, state governments have been rapidly adopting ABGR as a benchmark requirement for new buildings, with this requirement sometimes being linked to penalties for non-performance once the building is operation.

While the process of specifying a benchmark level of performance is comparatively simple, it bypasses the question of how such a level of performance is demonstrated at the design stage, before the building is built.

This issue is further complicated by the fact that the level of requirement has typically been set at 4.5 stars. To date, this rating has been achieved by only one fully-conditioned building in the temperate zones of Australia. Thus design teams are faced with the dual difficulty of working with the uncertainty of a performance based target, and the challenge of being asked to build to a level of performance for which there are essentially no precedents.

DEMONSTRATING PERFORMANCE FOR NEW BUIDLINGS

The performance of a building is a consequence of a range of factors of which the underlying design is only one (albeit major) influence. Other factors include:

- HVAC control function. The detailed control functionality and control commissioning can have a major influence of building performance. The detail of control is generally left to the controls contractor in Australian office building projects.
- Build quality. Anyone who is actually involved in building construction will be well familiar with the wide range of as built deviations from design, both those intended by designers and those occurring in error, that can occur in practice that may have an influence on building energy efficiency.
- Commissioning. Australia has generally poor commissioning practices and this can have a major impact on building performance.
- Operability and maintainability. If a building is not designed to make maintenance and operation viable within normal commercial constraints, the building operation will fall short of expectation. Problems in this area can include poor documentation, inherently unstable control, inclusion of high maintenance plant items and the location of plant such that it is difficult to access.
- Operation. The best design, well built, and fully commissioned, may perform poorly if it is badly operated or maintained.

This is a far wider brief than most designers are used to – or indeed capable of – addressing. Australian design engineers generally lack a detailed understanding of HVAC control and have little or no experience in the operation of buildings, and so have difficulty assessing or even recognizing issues of operability or maintainability.

Many of the issues raised above are relatively “soft” in nature. They carry few absolutes and certainties. As a consequence some parts of the design community have endeavored to claim that these are not “their problem”. However, in a market driven situation where clients are demanding in-practice performance, a designer’s decision to disown these issues is effectively a decision to opt out of the market.

The ABGR team, in response to these issues, has created a two-component process to assist designers and developers with understanding the issues around the achievement of a performance rating in practice. The components of this process are:

- Independent Energy Efficiency Design Review. This review is conducted by one of a panel of accredited reviewers who have extensive experience in existing buildings. The review focuses on the identification of potential risks and opportunities in design. The risk areas cover items that are known to often cause problems in operating buildings. An example of this would be the identification that hot water reheats are difficult to maintain and are a frequent source of energy waste in operating buildings. The opportunities cover items where the design could be improved technically, such as by selecting a better chiller or more efficient motors.

- Computer Simulation. For buildings aiming to achieve 4.5 stars or higher in the base building or whole building ratings, the process requires the use of a computer simulation to demonstrate that the proposed level of performance is theoretically achievable.

The Independent Energy Efficiency Design Review is generally considered to be the more important item by the ABGR team, for reasons discussed below. The two components above are integrated into a voluntary "Commitment Agreement" signed between the Department of Energy Utilities and Sustainability and the developer. This agreement has a third requirement that the building is subject to a performance rating after one year of occupancy.

It is noted that, in the context of the processes being focused on risk management, neither process is considered to be a pass/fail exercise; they are presented to the developer to assist them in understanding the risks associated with the project relative to the achievement of the proposed performance target.

PROBLEMS WITH SIMULATION

Much as though the ABGR team may consider the Independent Energy Efficiency Design Review to be the senior component of the design evaluation, it was clear from an early stage in the process that design teams, and indeed the development and regulatory community at large, place a very high level of faith in simulation as an arbiter of potential performance. A substantial number of projects have proceeded on the basis of the simulation report alone, with little or no consideration given by the developers or regulators to the advice of the Independent Review. This perhaps reflects the appeal to the uneducated user of certainty and "science" associated with the use of computers; it also reflects the expansion of computer simulation, through enhanced interfaces and ease-of-use, into a wide range of individuals who are not necessarily equipped to critically evaluate their own work (Donn 1999).

There appear to be few other markets in which simulation is being used as an unqualified predictor of actual performance. ASHRAE 90.1 for instance specifically notes that an energy cost budget does not necessarily reflect actual energy use (ASHRAE, 2001). This is similar to many other regulatory applications where the simulation methodology is based around comparison of a design simulation against a nominal code compliant simulation (e.g. Seattle 2004, Standards New Zealand 1996). In a design context, simulations are generally used to compare design scenarios. Where simulation requires reconciliation with reality, some form of calibration process is recognized as being necessary (e.g. FEMP 2000) – which of course is not possible for an unbuilt building.

Such precautionary approaches are supported by empirical studies. A recent study (New Buildings Institute 2003) found poor correlation between the theoretical and achieved performance of buildings across a large US data set. A smaller scale study by the author (Bannister 2004b) in relation to Australian buildings confirmed this finding for local conditions. In both cases, it was noted that the simulations represent an upper asymptote for achievable performance, which can potentially be achieved if sufficient focus is placed on "tuning up" the building to optimum performance. However such focus is generally not present in average building projects, causing actual performance to fall short of potential.

Perhaps the most demonstrative evidence of a disconnect between simulation and reality, however, is the simple fact that most good quality simulations of large office buildings in temperate Australia show a simulated performance equivalent to 4.5 stars or, often, far better, and there is yet only one verified 4.5 star building in practice. Indeed, average performance for delivered new buildings has historically been largely undifferentiated from the existing building stock, at around 2.5 stars.

THE VALIDATION PROTOCOL: PHILOSPHICAL AND PRACTICAL UNDERPINNINGS

While the broader causes of disagreement between simulation models and actual performance are open to debate, inspection of simulation reports submitted in support of projects clearly identified common inadequacies in the quality of the work. Common issues included:

- Incomplete modeling of the building, in some cases avoiding representation of key features of the building and in others failing to represent end uses that are not simulated but nonetheless for part of total building energy use, such as lifts.
- Unrealistic schedules. It was common to receive simulations showing lights, equipment and occupancy all changing from zero to 100% at 8am and back to zero at 6pm. In the context that the simulation is endeavoring to predict performance in reality, this is clearly unrealistic.

- Lack of reporting. Probably the most troubling feature of many simulations was the lack of detail in reporting. This made it impossible to review or interpret the detail of results. This would cover both the inputs, which were often glossed over, and the outputs, which would often be presented as a single figure without breakdown.
- Inappropriate use of simulation models. In some cases, simulation models were used to represent systems that they are not actually capable of representing. Thus a fan coil system would be used to represent a variable volume refrigerant system. While such problems are sometimes unavoidable, the simulators would rarely declare the existence of the approximation.

In the light of these problems, it was clear that some form of process was required to encourage better practice, more realistic modeling and better reporting. This would then facilitate an understanding of the validity of the results among both expert and non-expert readers of the reports.

This builds into a broader philosophy that simulation is one part of a risk management process. The developer, who may have a legal commitment to a performance target, needs to understand what the simulation result really means, rather than be misled into a feeling of complacency by a good simulation result. This is particularly important given the disparity between the number of buildings that simulate at 4.5 stars and above as opposed to the number of buildings actually performing at that level.

Off-Axis Scenarios and Risk Management

The application of a risk management approach to the use of simulation also leads to a new approach to the use of simulation – being the use of simulation to assess the impact of operational risks. This in many ways is a natural extension of the conventional approach of simulating design scenarios. However the focus, rather than being the assessment of design features, is the assessment of the impact of design, construction or operational failures upon performance.

This is encapsulated within the Protocol through the requirement for the use of "off-axis" scenarios. These are scenarios where the building is subject to operational and control failures – in so far as they can be modeled – to identify the robustness of the base case result to common failure mores. Thus for instance, a variable air volume design might be subject to a scenario that looks at an increased minimum air flow rate, tighter control deadbands, poorer supply air temperature control and restricted economy cycle operation.

The use of off-axis scenarios recognizes the reality that real buildings are imperfect but that simulation models generally represent them as being perfect. By representing common failure modes, one can assess whether these failure modes are important to the chances of the building achieving the desired performance targets. Examples of the application of such scenarios include:

- A building that was rating 4.4 stars in the base case, and was under pressure to achieve 4.5 stars. This was tested on a simple off-axis scenario that demonstrated that the building was highly exposed to control failures in the VAV system – the off-axis scenario rated at 2 stars. As a consequence the focus of design development moved from achieving 4.5 stars to avoiding the achievement of 2 stars.
- A building that simulated robustly at 4.5 stars in both the base case and off-axis scenario but showed major temperature control failures in the off-axis scenario. As a result, it was recommended that the controls system design be revised and management processes put in place to ensure that the key failure modes are prevented from occurring.

Comparison with Similar Standards

The Validation Protocol is to some extent similar to a number of existing standards. For instance, the ASHRAE 90.1 Energy Budget Cost Method (ASHRAE 2001) similarly provides requirements on reporting and standardized schedules but, like many comparable standards, is based on a comparison approach rather than absolute figures. Similar precedents exist for specific jurisdictions (e.g. Seattle 2004, Standards New Zealand 1996).

The Validation Protocol differs from these precedents in that it has simulation of actual performance as its primary target. This leads to an emphasis on risk declaration, assessment and management rather than compliance. It is as such a largely informative standard, although in some applications it has a compliance role.

THE VALIDATION PROTOCOL: CONTENT

The following subsections describe the key components of the Protocol. For further detail, readers are directed to the Protocol document itself.

Overall Approach

The protocol is focused on the following key outcomes:

- Documentation of simulation input parameters, assumptions and approximations at a level that enables easy and quick review by expert and non-expert reviewers;
- Directing the simulator towards the use of more realistic input assumptions that reflect actual building operation;

- Documentation of simulation outputs and outcomes in a manner that facilitates critical review by expert reviewers and forces some validation of simulation viability by the simulator;
- Directing the simulator towards the inclusion of all relevant end-uses (up to 50% of the energy use of some buildings lies in items that have not been explicitly modeled as part of the simulation);
- Identification of factors that might cause the simulation to relate poorly to reality both because imperfections in the simulations and in the delivery of the building relative to simulation;
- Encouragement of a realistic interpretation of simulation result in the light of the known limitations of the model, the outcomes of the off-axis scenarios and the available empirical evidence for performance of similar buildings.

The Protocol also includes provision for use in a more conventional theoretical performance calculation using the default inputs. This provision is used by the Green Building Council of Australia's GreenStar Office Design Tool.

Advisory and Default Information

The protocol provides a range of advisory and default information including:

- Identification of the correct use of the Protocol for ABGR Commitment Agreements and for use in the Green Building Council of Australia's GreenStar Office Design ESD rating tool.
- Guidelines for the establishment of key input parameters
- Default schedules for lighting, occupancy and equipment operation, based on realistic loads. In particular, it is noted that the default overnight tenant equipment schedule is 50% of daytime peak.
- Default figures for occupant and tenant equipment density, based on real loads.
- Guidelines for how input parameters can be correctly converted to inputs for the ABGR rating.

Guidelines for Simulation Input Parameters

The simulator is required to brief their client on the limitations of applicability of their model, both in terms of the inherent limitations of the package and the limitations of the representation by the simulator of the particular building. This is to be summarized in the simulators report in the form of an input data validation table that discusses the treatment of key items of the simulation, including:

- Climate data,
- Building form including the representation of the building overall, any short cuts taken, external shade, glazing, insulation, car parks, floor area
- Lighting, including lighting power density, hours of operation and controls
- Equipment including density and hours of operation;
- Occupant density and scheduling,
- HVAC including system type(s), hours of operation, plant details, zoning and control
- Energy systems coverage, identifying any non-simulated features, any exclusions from the rating assessment and any estimates and their rationale;
- Metering Requirements, identifying any metering that would be required to be able to duplicate the coverage of the energy estimate in the simulators report.

Simulation Results

The simulator is required to:

- Provide, as a minimum, one base case scenario plus one off-axis scenario dealing with a minimum of four potential risk factors.
- Define each scenario relative to the base case described in the simulation input parameters section, and clearly identify what differs between the scenario and the base case
- Present an operational summary that identifies:
    - Presence of systems failing to meet peak demand or maintain temperature conditions. In particular a quantitative identification of occupied hours outside control range and of the number of hours that the HVAC plant fails to meet system loads is required.
    - Presence of issues or problems identified by the simulation, such as primary plant staging or sizing, building envelope performance improvements or other HVAC design issues.
- Energy end use breakdown covering all energy end uses in the building (both simulated and estimated) broken into the following categories:
    - Lighting (separately listing: tenancy, common area, car park, exterior)
    - Tenancy equipment
    - Lifts and escalators
    - Domestic hot water
    - Miscellaneous non-tenant loads
    - Space heating
    - Space cooling
    - Heat rejection
    - HVAC fans (occupied areas)
    - Ventilation fans (toilets, plant rooms)
    - Car park fans
    - Tenant condenser water loop energy
    - Tenant supplementary air-conditioning energy
- Floor area calculation, identifying gross floor area, net lettable area and a brief description of spaces for each floor as modeled; total net lettable area of the building as modeled and total net lettable area of the building in reality

- Figures used as inputs for the ABGR rating calculation (post code, rated floor area, hours of use, number of computers, energy use by fuel type).

Interpretation of Results

The simulator is required to:

- Nominate the proposed performance level in MJ/m² and in terms of the ABGR rating
- Identify the nearest star and half star boundaries in the ABGR thresholds, so that some idea of the robustness of the performance level can be determined
- Identify which scenarios are used to derive the proposed performance level
- Identify any caveats on the proposed performance level
- Provide a table of identified risks that could impact upon the performance of the building relative to the simulated level of performance, and provide brief strategies for the management of these risks
- Provide a short disclaimer identifying that computer simulation is not a complete representation of building performance and does not provide an adequate basis for any form of guarantee or warrantee of performance in operation.

Compliance Checklist

The simulation report has to include a compliance checklist to identify that all the key requirements of the Protocol have been complied with.

THE PROTOCOL IN PRACTICE

The Protocol has found widespread application within the Australian market and has also been adopted as the compliance standard for simulations used in the Green Building Council of Australia's GreenStar Office Design ESD rating tool.

While the Protocol definitely has created an improvement in the quality of simulation work and reporting, the level of compliance with the Protocol is variable, at least partly because there is no real method for its enforcement. The inclusion of the Compliance Checklist in the Protocol was introduced to create a concrete item that could be identified as a point of non-compliance where necessary.

Although there is no more than anecdotal data available at present, there is some evidence that the use of the Protocol in conjunction with a process for managing design and construction risks is producing better efficiency outcomes and reduced gaps between actual performance and simulated performance. However, it has not necessarily prevented designers from claiming high performance levels that appear *a priori* to be unlikely to be achieved. This partly reflects the continuing difficulty in getting designers to apply sufficiently aggressive failure scenarios in the off-axis analyses. It is expected that more significant impacts may occur once there are sufficient case studies of new buildings showing successes and failures against claimed performance targets. An emerging factor in this area is that far greater emphasis is being placed on the reconciliation of simulation results with actual performance in a number of high profile Australian projects. The Validation Protocol facilitates this increased emphasis by providing better documentation of the original simulation prediction.

It has been interesting to note that there remain some pockets of resistance to the Protocol, mainly amongst designers who have a strong ideological commitment to simulation as the sole arbiter of performance. These individuals reject the validity of the approach and argue that the simulation is correct and that the potential problems that might arise downstream are caused by third parties not doing their job correctly. It is the opinion of this author at least that this type of approach risks the credibility of the entire simulation industry.

It has also been interesting to note that when the Protocol was circulated to a number of key individuals in the international simulation development community, there was a significant failure to understand the purpose of the Protocol. In particular the was clearly some difficulty understanding the importance and differentiation of the processes proposed in the Protocol relative to the simulation engine validation work being conducted under BESTEST (Judkoff and Neymark 1995). At a trivial level this perhaps reflects confusion over the use of the word "Validation" which clearly has different meaning in different contexts. At a broader level it perhaps indicates the existence of a degree of disconnection between the simulation development community and the users of simulation in the market place. If simulation is to achieve true integration into design, there must be an excellent integration of the potential of simulation tools with the understanding and abilities of the users. This is perhaps an area that is lacking in simulation development at present, at least in Australia.

A final observation that relates to the particular interests of this author is that the Protocol process quickly demonstrated the inadequacy of simulation packages to represent air-conditioning controls in the level of detail that is necessary to replicate actual control routines in real buildings. This probably reflects the design focus of the use of simulation in the past 20 years. As people become more interested in assessing actual performance with simulation tools, it will become more important to enable simulation tools to represent and analyze absolute performance in detail. HVAC controls represent an absolutely critical component of this process.

CONCLUSIONS

The Australian Building Greenhouse Rating Scheme is a performance based rating for office buildings. While it was originally designed for existing buildings, its success in that sector has led to its rapid adoption as a performance standard for new buildings.

The application of a performance standard to new design in Australia has immediately created a demand for the use of simulation to produce a reliable and useful prediction of absolute performance. However, evidence does not support the existence of a general relationship between simulated performance and absolute performance. The reasons for this vary but include a wide range of factors that either cannot be or are not well represented in most simulation models.

The ABGR Validation Protocol for Computer simulations was produced as a means of assisting users of simulation to produce better quality and more useful interpretations of simulated absolute building performance. The Protocol provides useful information on the input parameters for the simulation and provides comprehensive reporting guidelines to enable users of the simulation report to understand the meaning and reliability of the simulation results in detail.

The Protocol has achieved widespread use in Australia. The need for its existence demonstrates the existence of a knowledge gap in the understanding of the correct use and interpretation of simulations. It may also represent the existence of a gap between what simulation developers think simulations are for and what simulation users are doing with simulation. Furthermore, the use of the Protocol demonstrates the inadequacy of most simulation packages in the assessment of absolute performance, particularly with respect to air-conditioning controls.

It has been contested that simulation developers must act to close the gap between how they think simulation tools should be used and how they are being used. The Protocol is designed as one step in this bridging process.

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