The role of building operational emulation in realising a resilient built environment

Joe Clarke*

Energy Systems Research Unit, University of Strathclyde, Glasgow G1 1XJ, UK

*Corresponding author: joe@esru.strath.ac.uk

The role of building operational emulation in realising a resilient built environment

Abstract. Building performance simulation provides a means to assess the performance of a proposed design under dynamic operating conditions and in terms of performance criteria relating to wellbeing, environmental impact and energy use. While adoption of the technology has led to an improvement in design intent by supporting understanding and innovation, it has exacerbated the gap between this intent and the operational reality by encouraging more complex schemes that are proving to be less resilient. This paper describes the source of this resilience problem and outlines a proposed solution that is the subject of a current industry/ academic feasibility study in the UK.

Keywords: Building performance simulation; operational resilience testing; standardised performance assessment.

Problem statement

The drive towards a sustainable built environment raises challenges for construction-related practitioners. From an energy viewpoint, these challenges stem from the need to reduce energy consumption, integrate clean energy supplies and mitigate environmental impact, all while meeting expectations for human wellbeing and economic growth. The design of an energy efficient building or community is a formidable task because the physical processes underlying energy systems as deployed in the built environment are complex and coupled: stochastic weather, heat and mass transfer, radiation exchange, electrical power flow, distributed control action, occupant behaviour *etc*. All these factors are spatially and temporally varying. The problem is then confounded by competing objectives relating to issues such as user satisfaction, fuel poverty alleviation, air quality improvement, energy use reduction, emissions abatement, energy supply resilience, and legislative compliance; all pursued in the context of myriad policy agendas aimed at encouraging a clean energy transition through accelerated renewables deployment, the electrification of heating, or electric vehicle uptake. As a result of this sociotechnical complexity, is it any wonder that the gap between design intent and the operational reality is both persistent and growing (Menezes *et al* 2012, de Wilde 2014)?

Performance prediction

One way to reduce this gap is to simulate a proposed new design or refurbishment scheme (at whatever scale and stage in the design process) in order to ensure acceptable performance in terms of value propositions relating to service provision, energy use, system operability and environmental impact. This is done in accordance with the maxim that only the rigour of simulation at the design stage can deliver effective operation thereafter (Clarke and Hensen 2015). The legitimacy of the approach is perhaps best indicated by the growth in regional activity of the International Building Performance Simulation Association (www.ibpsa.org), an organisation that provides a forum for researchers, tool developers and tool users to review modelling methods, influence technical developments, identify standardisation needs, and share application best practice.

Paradoxically however, the simulation based approach to design can worsen the situation for two principal reasons. First, while the problem domain is known to be complex due to dynamic interactions, time variant describing parameters and the presence of stochastic influences, many simulation tools apply simplifications as a means to prioritise ease of use over representation accuracy. Second, tool application typically requires users to impose bespoke assumptions relating to system operation, weather conditions and the weightings applied to performance outcomes. From this viewpoint, simulation tools are being used as complex calculators to compute the performance of some obfuscated future scenario. This can result in proposals that appear to be well-founded but have little chance of delivering their promise when subjected to real world conditions. Consider this proposition: it is hubris to suggest that the future performance of a system as complex as the built environment can be predicted in any meaningful way with an ‘easy to use’ program.

Reality emulation

In order to realise the true potential of building performance simulation – as an emulator, not predictor, of future reality – it is helpful to change the application intent from performance prediction to operational resilience testing. Instead of requiring tool users to define the assessment conditions and subsequently analyse assessment outcomes, they would instead submit their proposal as an appropriately configured input model to a ‘resilience testing environment’ (*RTE*) resident on a cloud server (RTE 2018). The *RTE* would then automatically perform multiple annual simulations, with standardised perturbations imposed to represent events such as severe weather, equipment breakdown, tariff price change and the like. Outcomes over appropriate intervals (short, medium and long term) would then be evaluated against standardised expectations relating to performance aspects such as indoor environmental conditions, running cost and emissions. While the capabilities and features of an *RTE* would be the same for all users, it could be powered by any simulation ‘engine’ that is able to demonstrate an ability to represent the causal relationships underlying the particular resilience test to be applied. For example, to test the resilience of a community energy scheme, the causal relationships might commence with changing sky conditions, causing greater daylight penetration to indoor spaces, resulting in artificial light dimming, giving rise to a reduced electrical load, requiring the power flow from a local photovoltaic (PV) array to be exported, resulting in a power quality impact on the low voltage network, requiring an export refusal or tariff adjustment, and so on. Such a simulation would result in an entirely different outcome than one that merely determined the output power from the PV array for a given irradiance; and would lead naturally to a robust practical scheme. This implies the need for a high resolution input model that has relinquished reliance on simplifying prescriptions relating to weather, occupancy schedules, occupant behaviour, equipment efficiency, infiltration rates and the like in favour of explicit representations of these phenomenon that encapsulates realistic impacts. It also implies that the simulation engine embedded in the *RTE* (perhaps formed from several coordinating tools) be approved in terms of the representation of significant causal relationships in addition to algorithm validity as is done at present via procedures such as BESTEST (Judkoff and Neymark 1995). This may well result in a situation where specific simulation tools are approved for use with only a sub-set of the resilience tests supported by the *RTE* at any time and corresponding to different design scenarios and standards of performance.

Resilience test procedure

The procedure for accessing the *RTE* is envisaged as follows. A high definition model (*HDM*) is prepared at the required abstraction (early/detailed design stage) and scale (building, estate, district *etc*.) using suitable model definition tools (e.g. an application for 3D CAD). The *HDM* is introduced to the *RTE* via an open standard dashboard and the required resilience test(s) selected from an approved list. It may be expected that the *HDM* would become fully BIM compliant in future once the standard progresses to Level 3 and beyond, and that the list of resilience tests would grow as this descriptive capability matures. In any event, the resilience tests would:

- be *a priori* established for different target types (new low energy housing, housing refurbishment, high performance commercial buildings, community energy schemes, demand management/ response *etc*.) and increasing performance stringencies;

- impose target-specific perturbations corresponding to events such as adverse weather, equipment malfunction or tariff change to be applied appropriately but randomly over the proposal's anticipated lifetime;
- assess test-specific performance metrics relating to occupant satisfaction, facility management, legislative compliance *etc*.; and
- be approved by relevant professional bodies for the engineering and architecture domains.

After a *HDM* is introduced to the *RTE*, an automated calibration is undertaken to ensure that the outcomes are aligned with observations in the case of a refurbishment project, or with benchmarks corresponding to standard validation tests for new build cases. The calibrated model is then simulated over the multi-year lifetime of the proposal, the test-specific perturbations applied, and relevant performance metrics extracted corresponding to the evolving system state and test strictness: occurrences of thermal or visual discomfort, high CO_2 levels, excessive utility bills, problematic power quality, excessive local emissions *etc*. Such outputs would initially be treated by the *RTE* in a passive manner, merely flagging issues, until the related problem reaches a threshold where the *RTE* would suspend (but not terminate) the simulation process and request remedial action. On delivery of a revised input model that embodies a proposed remedy to the reported issues, the simulation process would recommence and continue until resilience is assured (i.e. the corn kernel stops popping). The final outcome would be a compliance certificate corresponding to the selected resilience test level. It is anticipated that the professional bodies would be the approvers of the content – perturbations and performance metrics/ criteria – of the resilience tests corresponding to different problem types and increasing stringencies.

The significant point is that the *RTE*-embedded simulator(s) would enact standard performance assessments for issues related to overall performance. Consider, for example, a test that assesses the risk of glare for standard viewing directions relative to the external facades within a commercial office. Here, the model perturbations might relate to changing sky conditions or the impact of loss of shading device control, while the performance metrics and target values might relate to the BS EN 12464-1 standard (BS 2011). Figure 1, shows one possible outcome indicating unacceptable luminance values (cd/m^2) corresponding to a critical viewing direction at a particular time.

Figure 1: Luminance distribution for a critical viewing direction.

The further (automated) processing of such outcomes might calculate the spatial variation in the Unified Glare Rating for comparison with the thresholds defined in the standard. Where deemed acceptable over time, this aspect of performance would pass the resilience test. Otherwise, the *RTE* user would be invited to accept a certificate at a lower test level or suggest a remedial action to recommence the suspended test.

Similar automated procedures can be introduced for other wellbeing aspects such as thermal comfort (Figure 2) and indoor air quality (Figure 3), as well as for energy utilisation, system control, embedded renewables, equipment operational efficiency, integrated energy storage, demand management, and the like.

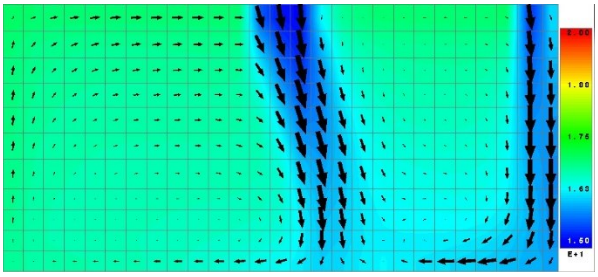

Figure 2: Operative temperature distribution for an office cross section.

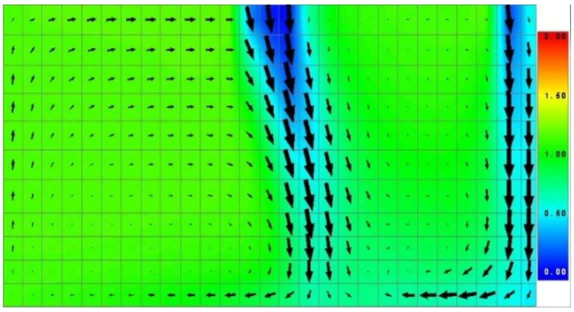

Figure 3: Mean age of air distribution for an office cross section.

Benefits of the approach

Such an emulation of reality has significant benefits. It relates to reality and not to an inappropriately simplified, partial representation. It does not require the simulation tool user to define performance assessments and interpret outcomes, thus standardising the assessment process and facilitating the inter-comparison of alternative proposals in terms of whether or not they passed the test. Such attributes leave the design team free to innovate, supported by a computational environment that assures acceptable performance under a range of conditions that are likely to be encountered in practice and in terms of a range of performance criteria that can be readily understood. The approach would also provide an approach to building regulation compliance that overcomes the constraints of the present rudimentary methods that fail to respect the thermodynamic integrity of contemporary and future energy systems.

It is stressed that models can still be configured against standard prescriptions to obtain outputs from simulation tools for legislative compliance purposes, to size system components for peak demand, or to obtain deeper performance insight, all as done at present.

Establishing resilience tests

To explore the approach, a prototype *RTE* has been created (RTE 2018) and a feasibility project enabled under the auspices of the Construction Scotland Innovation Centre (CSIC 2018). The intention is to establish industry groups, led by relevant professional bodies, to evolve the *RTE* concept by agreeing the resilience tests required for different application areas such as low energy housing, high performance commercial buildings and community energy schemes. Academic groups will support the initiative by evolving the *RTE* prototype and supporting its testing by industry organisations against realistic cases.

Given the potential major impact on all organisations engaged in energy system policy, design and operation, it is likely that the concept will attract grant funding from a number of sources, including research councils and innovation support organisations associated with the construction industry. It is also envisaged that a postgraduate forum be established to nurture a new generation of professionals familiar with energy system resilience testing through simulation. The concept gives rise to many research topics that could be pursued as relevant industry/ academic collaborations in future: the development of performance metrics that encapsulate best practice standards and legislative requirements; the development of perturbation events and combinations that constitute meaningful resilience tests for different cases; new mathematical models as required to represent adequately the intra- and inter-domain processes; the trialling of the *RTE* concept in practise, including formal studies into the efficacy of outcomes; and product development for operational robustness.

Conclusions

Explicit performance simulation provides powerful support for the creation of effective energy-related actions within the built environment. That said, the potential of the approach is being hampered by the lack of standards relating to the assessment of proposals in a manner that ensures resilience in operation and facilitates the ready comparison of alternative proposals.

This short paper has introduced the concept of a resilience testing environment that would automatically apply standardised resilience tests to proposals and provide a means to issue compliance certificates at increasing levels of resilience stringency. This is an emerging concept which, it is hoped, will bring benefit to design practitioners, policy makers, estate managers and researchers because it harmonises the use of performance simulation in practise as a means to explore dynamic behaviour over a proposal's lifetime in order to reduce the performance gap.

References

BS (2011) *BS EN 12464-1 Light and lighting. Lighting of work places,* London: British Standard Institute.

Clarke J A and Hensen J (2015). 'Integrated building performance simulation: Progress, prospects and requirements', *Building and Environment*, 91, ISSN: 0360-1323.

CSIC (2018). Construction Scotland Innovation Centre, *http://www.cs-ic.org/innovationcentre/*.

De Wilde P (2014). 'The gap between predicted and measured energy performance of buildings: A framework for investigation', *Automation in Construction*, 41, pp. 40-49.

Judkoff R and Neymark J (1995) ‘Building Energy Simulation Test (BESTEST) and Diagnostic Method’, *Final Report for International Energy Agency cooperation between Solar Heating and Cooling (Task 12B) and Energy Conservation in Buildings and Community Systems (Annex 21C)*, https://www.nrel.gov/docs/legosti/old/6231.pdf.

RTE (2018). Resilience Testing Environment prototype, ESRU, University of Strathclyde, *https://www.strath.ac.uk/research/energysystemsresearchunit/applications/rte/*.

Menezes C, Cripps A, Bouchlaghem D and Buswell R (2012). ‘Predicted vs. actual energy performance of non-domestic buildings: using post-occupancy evaluation data to reduce the performance gap’, *Applied Energy*, 97, pp. 355-364.