AN ANALYSIS OF RESULTS VARIABILITY IN ENERGY PERFORMANCE COMPLIANCE VERIFICATION TOOLS

Rokia Raslan[1], Michael Davies[1], and Nick Doylend[2]
[1]CBES, Bartlett School of Graduate Studies, UCL, London, England
[2]PHA Consult, London, England

ABSTRACT

To address the functional complexities and volumetric variability found in the UK non-domestic building stock (Pérez-Lombard et al, 2008, Bruhns, 2008), the methodology for demonstrating compliance with energy performance criteria outlined in Approved Document Part L2A (ADL2A) allows the use of a variety of accredited simulation tools.

This paper reports on the interim results of an inter-model comparative study that aims to investigate potential variability in results generated by the range of accredited tools available at the time of writing.

An overview of the applicability limitations of the tools is presented, key issues associated with results variability, including possible implications concerning the credibility of the methodology and recommendations to address the current shortcomings are highlighted.

INTRODUCTION

In transposing Article 3 of the Directive on Energy Performance of Buildings (Official Journal of the European Communities, 2002), the Building and Approved Inspectors (Amendment) Regulations 2006 (England and Wales) (DCLG, 2006) defines the "National Calculation Methodology" (NCM) as the single simulation-based calculation route to verifying compliance with energy performance criteria specified in Approved Document Part L (Conservation of Fuel and Power).

Approved Document Part L differentiates between building types (classifying them as either domestic or non-domestic and new or existing) and defines a separate approach to implementing the NCM for each category (DCLG, 2008). Figure 1 illustrates the NCM procedure for the new non-domestic sector (ADL2A-New Buildings other than Dwellings) which entails simulating the actual building (ACT), creating an equivalent notional building (NOT) then quantifying the energy performance of each according to a CO_2 emissions factor. Two benchmarks-the Building Emissions Rate (BER) and Target Emissions Rate (TER)-are then generated and compared to determine a "pass" or "fail" result based on the relative performance of the proposed building.

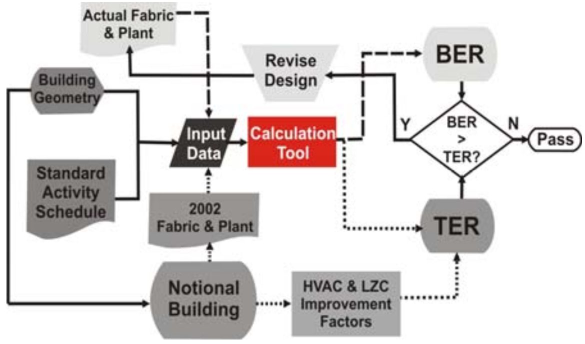


Figure 1 The NCM process for the non-domestic sector (Jaggs, 2007)

OVERVIEW OF ACCREDITED TOOLS

The Simple Building Energy Model (SBEM) was developed as the default tool for implementing the NCM for the new non-domestic sector (BRE, 2005). However, this tool uses a labour intensive non-graphical user interface (iSBEM) for data input and its calculation engine is limited in its ability to model complex HVAC systems and strategies.

To address the need for software that is more suited to the functional complexities and volumetric variability found within the non-domestic stock (e.g. Pérez-Lombard et al, 2008, Bruhns, 2008), the use of accredited third-party software that offers additional modelling and design support capabilities was permitted.

The two main tools classes defined within this category (Figure 2) are SBEM Front-end Interfaces (FI-SBEM) and Dynamic Simulation Modelling software (DSM) (DCLG, 2008a). The main features of each of the three tool classes are summarized in Table 1.

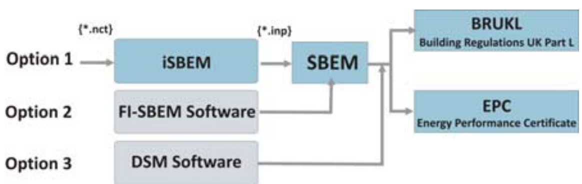


Figure 2 Relationship Between Software Options

Table 1
Main Features of Tool Options

Class	Input Method/Data	Calculation Methodology	Outputs
SBEM	Non-graphical, Microsoft Access based input forms. Data includes geometry, thermal properties of constructions, HVAC parameters and renewable systems. Contains some default values such as HVAC efficiencies.	Monthly average calculation based on the Dutch methodology NEN 2916:1998 (Energy Performance of Non-Residential Buildings).	-BRUKL/SBEM outputs -Data reflection reports -EPC Certificates
FI-SBEM	A front-end graphical interface is used for building geometry input. While data such as HVAC & renewable systems generally conforms to the iSBEM format, some details may vary due to individual tool capabilities & available databases.	The tool interfaces with the SBEM calculation engine, relying on the same algorithms to implement a monthly average calculation method.	-BRUKL/SBEM outputs -Data reflection reports -EPC Certificates
DSM	3D CAD front-end modules allow building geometry to be input &/or imported from CAD packages, 3D BIM & other software. Includes more detailed input options /extensive databases for materials & systems.	A detailed dynamic hourly or sub-hourly calculation using each tools own algorithms	-BRUKL/SBEM outputs -Data reflection reports -EPC Certificates -Load calculations, energy performance analysis results

Results Variability in Building Energy Simulation

Previous research (Judkoff & Neymark, 2006, Neymark & Judkoff, 2002) has indicated that for the majority of advanced energy simulation tools, the significant range of disagreement in their respective methods for calculating basic building physics has resulted in significant predictive differences between their results (Rittelmann & Ahmed, 1985, Judkoff & Neymark, 1995a, 1995b).

For ADL2A accredited tools, prescribed validation tests require that test model results must be either in exact agreement with (FI-SBEMSs) or within stringent margins (DSMs) of reference results. DSMs are also subject to additional testing according to procedures defined in the technical document TM-33:2006 (CIBSE, 2006) to ensure that their calculation algorithms are technically robust.

Despite these validation and accreditation measures, results from a wide-scale industry survey assessing the applicability of ADL2A found that in the majority of cases where multiple tools were used, respondents reported differences and frequent inconsistencies in results (Raslan & Davies, 2006, 2008). Consequently, this has raised the issue of results validity and, ultimately confidence in the credibility of the compliance methodology.

COMPARATIVE ANALYSIS OF TOOLS

In an aim to investigate the extent of variability of results produced by ADL2A accredited software, a comparative study of the tools was undertaken.

Study Methodology

Software testing can be conducted through a variety of approaches which differ according to the objective required from the test and the scope it covers (Witte, et al 2001). In general, comparative testing involves assessing a tool by comparing results of either multiple runs of the same tool or results of runs from multiple tools and is primarily used for diagnostic and validation purposes.

For this study, testing was implemented through an inter-model comparative methodology which has been commonly used in validation procedures such as ASHRAE Standard 140 (ANSI/ASHRAE, 2007) and BESTEST (Judkoff & Neymark, 2006). While this methodology provides a more flexible approach than either analytical or empirical testing, it does not provide an *absolute* standard. However, if adequate measures are adopted to ensure the statistical validity of results, findings can be considered representative of the general case.

Variant Models

Previous research (Carey, 2007) suggests that in the case of a high number of potential variables, the use of a simple standard model is preferred. For this analysis, three simplified physical building variants outlined in the UKGBC report "Report on carbon reductions in new non-domestic buildings" (UKGBC, 2007) that represent the main typologies found in the UK non-domestic stock were used.

Modelling Assumptions and Input Data

Key thermal and physical properties (Figure 3) of the variants were determined in accordance with the following factors:

Source modelling data: Building geometry, constructions and renewable energy strategies reflected input data outlined in the UKGBC report.

Software capability: HVAC systems described in the UKGBC report were substituted with alternatives that reflect current technologies used in similar building types and can be modelled by all tools included in the study.

Regulatory compliance: HVAC and DHW systems assumptions followed requirements outlined in "Non-Domestic Heating, Cooling and Ventilation Compliance Guide" (DCLG, 2006).

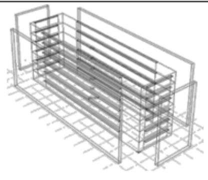
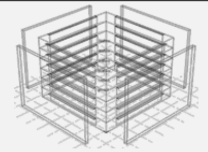
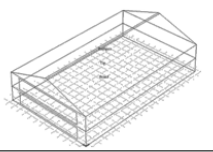
	DESCRIPTION	FUNCTION	MODEL	CONSTRUCTIONS			SYSTEMS AND RENEWABLES	
				Element	Type	U-Value	System	Description
1	Shallow plan sidelit	Office		Walls	Cavity Wall E&W 2006 Full Fill	0.27	HVAC System	Chilled Beams/Displacement Ventilation
				Ground	Solid Ground Floor E&W 2006	0.22	DHW	Dedicated Hot Water Boiler
				Floors	Office-E&W 2006 Solid Floor	0.22	Lighting	T5 Fluorescent
				Ceiling	Office-E&W 2006 Solid Ceiling	0.22	PVs	350 c-Si-Monocrystalline- Flat
				Roof	Flat Roof-E&W 2006 Concrete Deck	0.16	Wind Turbine	10 1.5kW Turbines
				Glazing	Triple glazed argon filled-low-e	1.529	CHP	Yes
2	Deep plan high rise	Office		Walls	Cavity Wall E&W 2006 Full Fill	0.27	HVAC System	Chilled Beams/ Displacement Ventilation
				Ground	Solid Ground Floor E&W 2006	0.22	DHW	Dedicated Hot Water Boiler
				Floors	Office-E&W 2006 Solid Floor	0.22	Lighting	LED Lighting
				Ceilings	Office-E&W 2006 Solid Ceiling	0.22	PVs	350 c-Si-Monocrystalline-Flat
				Roof	Flat Roof-E&W 2006 Concrete Deck	0.16	Wind Turbine	10 1.5kW Turbines
				Glazing	Triple glazed argon filled-low-e	1.529	CHP	Yes
3	Sheds	Retail		Walls	Light Steel Framing 75mm polyurethan	0.27	HVAC System	Active Chilled Beams
				Ground	Solid Ground Floor E&W 2006	0.22	DHW	Same as HVAC
				Floors	Retail-E&W 2006 Suspended Floor	0.22	Lighting	Fluorescent/Halogen lighting
				Ceilings	Retail-E&W 2006 Suspended Ceiling	0.22	PVs	300 c-Si-Monocrystalline-30^{o} South
				Roof	Pitched roof coated metal	0.13	Wind Turbine	12 1.5kW Turbines
				Glazing	Triple glazed argon filled-low-e	1.529	CHP	Yes

Figure 3 Study Model Variants and Modelling Assumptions

Study scope and limitations

For the preliminary stage of the study, 6 out of a possible 12 accredited tools, representing all available tool options at the time of writing (April 2009) were analysed (Table 2). Since the two DSMs each employ their own algorithms, both were included at this stage in an attempt to incorporate results from all accredited calculation methodologies.

Table 2
Tested Software Tools

SOFTWARE	VERSION	TOOL CLASS	CALCULATION ENGINE
iSBEM	3.3b	FI-SBEM (Default Tool)	SBEM
Carbon Checker	1.3.1	FI-SBEM	SBEM
Cymap 2008	Build 90	FI-SBEM	SBEM
Design Builder	1.8.1	FI-SBEM	SBEM
Design Database	24.21	FI-SBEM	SBEM
Graphical-ISBEM	14.0	FI-SBEM	SBEM
Pro EP Cert	24.21	FI-SBEM	SBEM
Quick EP Cert	24.21	FI-SBEM	SBEM
SBEM Lifespan	1.0	FI-SBEM	SBEM
Space Manager	2.59	FI-SBEM	SBEM
VE Virtual	5.9	FI-SBEM/DSM	SBEM/Apache
TAS Building	9.1.1	DSM	Tas Engine

Key ▢ Included in study
▢ Not included in study

Implementation of the exercise

To eliminate possible variation arising from differences in the modelling capability of different users (Guyon et al. 1997), all exercises were implemented by a single modeller with relevant engineering qualifications (BSc. /MSc.) and more than 3 years experience in the use of energy performance software. The modeller was not yet registered under any of the available schemes but had received formal training in the use of several accredited tools, including that undertaken by candidates for the BRE Competent Persons Scheme.

The use of external software was only permitted when necessary and limited to the following instances:

- AutoCAD to produce DXF plans for required for the TAS 3D modelling module.
- PVSYST v4.33 to define PV system properties for the Tas PV Macro.

RESULTS ANALYSIS

For the purposes of the reporting of the results of this study, tools were each assigned a random designation (A to G). The m ain compliance document (BRUKL) for each variant was produced, from which the following key data was analyzed:

Calculated CO_2 emissions

Table 3 summarizes the predicted CO_2 emissions benchmarks used for the demonstration of compliance with Criterion 1 of ADL2A. The results generally show:

-A lack of consistency in providing a pass/fail outcome for the same building.

-A considerable variation between the predicted emissions, where DSMs (Tools F-G) produced much lower predicted emissions rates for all benchmarks.

Since SBEM is not a design tool, the results cannot be considered as absolute figures for actual building CO_2 emissions and are therefore not directly comparable. However, the relationship between the BER, TER and NOT produced by each of the tools can be compared and expressed as the percentage improvement of the BER on each of the other two benchmarks.

The BER improvement percentage indicators are significant since they provide a measure of the expected improvement attainable with the adoption of an energy efficient approach to designing the building envelope and systems and an indication of the improvement on the minimum legislative requirement.

According to the calculation methodology:

When: BER<=TER → Compliance
Where: TER= NOT x (1- IMP) x (1- LZC)

*Improvement factor (IMP) and Low Zero Carbon benchmark (LZC) are constant for each variant.

Hence, the relationship between these benchmarks can be described as follows:

- For a compliant building, the percentage improvement of the BER on the NOT should always be a positive value.
- For a compliant building, the percentage improvement of the BER on the TER should be either zero or a positive value.
- For all cases, the difference between the percentage improvement of the BER on the NOT and TER respectively should always be constant.

The results not only show a considerable variability in the value of the benchmarks, but also inconsistency in the previously mentioned relationship between them.

Specific issues concerning each variant include: **Variant 1:** The building passes for all but one tool (Tool F). However, while the results show a general similarity in the generated NOT and TER within tool classes, the BER varies considerably throughout. The percentage improvement of the BER over these benchmarks therefore also varies considerably, most significantly within the FI-SBEM tool class where it is approximately 15-27%.
Variant 2: The building passes for all tools. With the exception of Tool D, results reflected the expected large decrease between the TER and BER associated with the introduction of energy efficient LED lighting in an office-type building. However, a considerable variation in the quantification the lighting improvement was observed and was more evident in the case of iSBEM and FI-SBEMs (ranging between 48% to 75%) than in DSMs (approximately 30%).
Variant 3: The building fails in 2 cases, and of all test variants, the percentage difference between TER and BER was most varied. It should be noted that in the modelling exercise, some FI-SBEMs had difficulty in recognising the pitched roof element and its thermal properties.

Table 3
Criterion 1: Predicted CO_2 emissions calculations

Variant 1 : Shallow Plan Office Building							
Tool	Class	Emmisions (kgCO$_2$/m^2.annum)				BER Improvement %	
		Notional	TER	BER	Pass/Fail	Notional	TER
A	FI-SBEM	75.3	54.2	53.9	Pass	28%	1%
B	FI-SBEM	72.9	52.5	28.6	Pass	61%	46%
C	FI-SBEM	89.3	64.3	50	Pass	44%	22%
D	FI-SBEM	89.4	64.4	61.1	Pass	32%	5%
E	FI-SBEM	89.5	64.5	34.4	Pass	62%	47%
F	DSM	43.6	31.4	32.6	Fail	25%	-4%
G	DSM	52.2	37.6	33.7	Pass	35%	10%
Variant 2 : Deep Plan Office Building							
Tool	Class	Emmisions (kgCO$_2$/m^2.annum)				BER Improvement %	
		Notional	TER	BER	Pass/Fail	Notional	TER
A	FI-SBEM	74.6	53.7	13.2	Pass	82%	75%
B	FI-SBEM	75.2	54.1	24.7	Pass	67%	54%
C	FI-SBEM	86.9	62.6	22	Pass	75%	65%
D	FI-SBEM	98.7	71.1	62.2	Pass	37%	13%
E	FI-SBEM	87.4	62.9	32.7	Pass	63%	48%
F	DSM	53.1	38.2	26.1	Pass	51%	32%
G	DSM	38.8	27.9	19.5	Pass	50%	30%
Variant 3 : Retail							
Tool	Class	Emmisions (kgCO2/m2.annum)				BER Improvement %	
		Notional	TER	BER	Pass/Fail	Notional	TER
A	FI-SBEM	170.5	122.7	111.7	Pass	34%	9%
B	FI-SBEM	108.1	77.9	80.0	Fail	26%	-3%
C	FI-SBEM	157.6	113.5	74.2	Pass	53%	35%
D	FI-SBEM	106.6	76.7	84.2	Fail	21%	-10%
E	FI-SBEM	150.5	108.4	58.9	Pass	61%	46%
F	DSM	93.3	67.2	52.8	Pass	43%	21%
G	DSM	77.2	55.7	39.4	Pass	49%	29%

HVAC systems performance

Figure 4 illustrates the estimated annual energy consumption (kWh/m^2) for both the notional and actual building. As one of the parameters used to gauge HVAC systems performance in the BRUKL document, this comprises the annual heating, cooling and auxiliary energy consumption and is calculated according to factors such as HVAC system type, system efficiencies in addition to inherent building characteristics including use, geometry and fabric.

Since HVAC systems specification was consistent for each variant, the calculated energy consumption figures of the notional building were expected to be similar for all tools. Some variation was expected in the actual building due to factors such as input method variation (e.g. forms, macros, wizards), the increased degree of complexity available for describing HVAC systems and different calculation methods employed in DSMs.

However, the generated results show an unexpected variation within tool classes for the notional building and a more significant than expected variation for the actual building. There were several anomalies in calculations produced by Tool D. DSMs (Tools F-G) appeared to produce lower figures for both the actual and notional buildings than other tools.

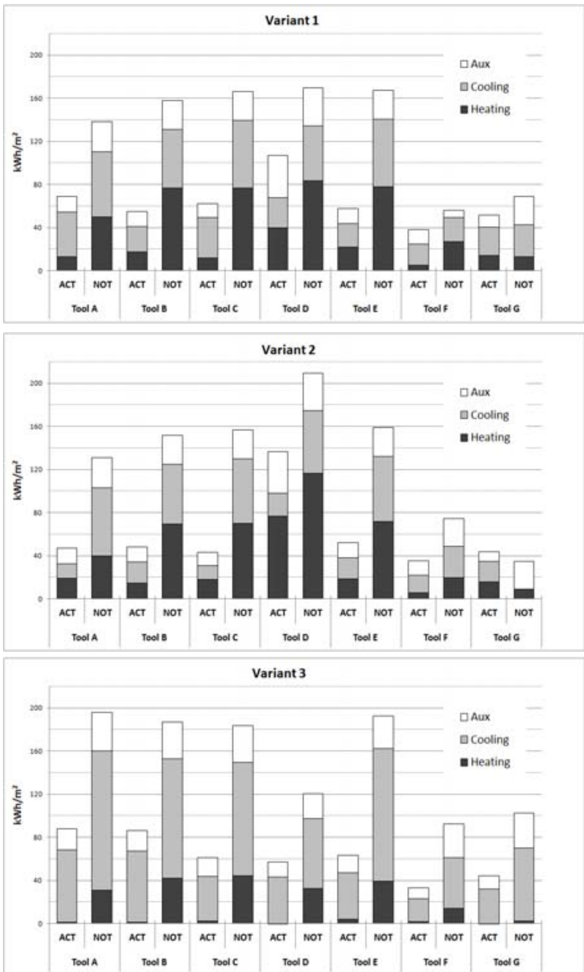


Figure 4 Calculated annual energy consumption

DISCUSSION AND CONCLUSIONS

The findings of the study, which encompass both issues experienced throughout the implementation of modelling exercises and the analysis of the modelling results, highlight several important concerns. Since the study uses model variants that represent the main typologies found in the UK non-domestic sector and includes software representing all tool categories, it can be assumed that the following findings hold a degree of statistical representation and can therefore be applied to a large portion of cases covered by ADL2A compliance process. The main conclusions that can be drawn from this work includes:

Limitiations in the scope of applicability of accredited tools:

It has been previously established (Bartholomew et al, 1997) that traditional steady state calculations, are not adequate for innovative designs such as those incorporating natural or mixed mode ventilation or other passive features.

In the context of this study, only the 2 DSMs were able to model the relatively complex HVAC systems and Tri-Gen CHP applications originally described in the UKGBC report. As a result, these were altered to suit the simulation capabilities of all tools included in the study. Similar limitations were also experienced with modelling the lighting and DHW systems.

Futher constraints experienced with physical models not examined in this study but outlined in the NCM modelling guide (DCLG, 2008a) include:

- Night ventilation strategies and ventilation with enhanced thermal coupling to structure
- Demand-controlled ventilation
- Automatic blind control
- Variable speed pumping
- Light transfer between highly glazed internal spaces such as atria or lightwells

While the NCM modelling guide regards these limitations as being “not insurmountable”, in practice unless iSBEM or FI-SBEMs substitute the current SBEM steady-state calculation methodology with one that employs a dynamic simulation modelling approach, the increase in the time and effort associated with attempting to represent the effect of these systems may discourage modellers from attempting to do so and instead resort to the introduction of more easily simulated fabric improvements or renewable strategies.

Additionally, whereas currently accredited DSMs are capable of modelling more complex HVAC systems, ans strategies their upatke may be limited by factors such as high software costs (e.g. A single annual user license is in excess of £1000) and the extensive training required to aquire the degree of profeciency required for their use.

The implications of the previous circumstances might in effect discourage or limit the introduction of complex energy efficient systems, due to the presumption that their effect will not be adeqautely represented in the compliance document.

Consequently, due to the technological limitations of accredited tools, it the can therefore be concluded that resultant effect of the current approach of demostrating regulatory compliance has in many ways opposed, or hindered one of the main objectives of the EPBD.

A lack of input data standardisation

In order to provide consistency of application, standard measurement conventions must be used for all accredited tools (DCLG, 2008a). However, in many cases, this standardisation does not seem to apply to measurement units. In these instances, the use of referenced calculation and conversion procedures may lead to possible errors and inconsistencies that may undermine the validity of the resulting input data.

Examples where differences in units required conversion or calculation include:

- *Thermal properties of constructions:* The use of the elemental internal heat capacity measure (κm value-kJ/m^2K) in SBEM and FI-SBEMs provides a simplified means for SBEM to approximate thermal mass of building elements. DSMs do not use this method and employ a more accurate numerical solution to account for it. In addition, the κm value is not a readily available as an industry standard technical specification of building constructions and must therefore be calculated on an individual basis when required by each modeller referencing additional guidance (DCLG, 2008c).
- *Infiltration rate:* The use of either the air changes per hour (ach) or m3/m^2/hr@50pa convention should be adopted for all tools as the single measurement unit for infiltation/air permeability.

Variability between tool results and industry confidence in building energy simulation:

While the results from the accredited tools cannot be directly compared as absolute figures for actual building CO_2 emissions, the large degree of variability between the BER and TER produced by each of the tools and the lack of consistency between tools in providing a pass/fail result for the same building raises the issue of the credibility of this methodology as a method of demonstrating compliance.

Variations between different tool groups can be assumed a product of factors such as:

- Calculation methodology (steady state monthly average vs. hourly detailed)
- Thermal modelling algorithms (SBEM algorithms vs. Tas/IES Apache algorithms)
- Additional capabilities of DSMs which allow the integration of solar shading calculations

However, causes of the variations within tool groups are less obvious and can be assumed to be a product of either tool error or possible user error in data input.

Furthermore, since all of the tools are also accredited for producing the non-domestic EPC (energy performance certificate), a similar variability will be highly likely and the associated implications regarding the credibility and standing of the ratings system will also be an issue.

RECOMMENDATIONS

Although the benefit of compliance testing with a clear pass-failure criteria eliminates any possible inconsistency on the part of local authorities in interpreting and enforcing Building Regulations requirements (DCLG, 2008d), the current methodology means that enforcing compliance will not necessairly guarantee the same extent of improvement in the energy performance of the actual (real) building or that it will comply with energy performance standards.

To improve the current approach, the following strategies are suggested:

- *Extending the applicability of FI-SBEMS:*

  As a tool class, FI-SBEMs have seen the largest increase in number in the past year. Due to their relative low cost, they provide an opportunity to increase the use of compliance checking at the earliest design stages and have increasingly been integrated within various multi-function suites such as facilities management software.

  However, as previously discussed, the technical scope of FI-SBEMs in terms of their applicability to more complex building systems remains limited by the SBEM calculation engine. Future strategies should aim to extended these capabilities to allow them to model more complex ventilation strategies, HVAC systems and energy effcient lighting systems through the integration of a calculation engine that employs a dynamic simulation modelling approach.

  There are currently several public domain DSMs such as EnergyPlus (US-DoE, 2008) that could be used for this purpose without incurring a significant increase in software costs. However, as illustrated by the results generated by the DSM tools included in this study, the possibility of variations arising from the different calculation alogorithms will be an issue that should be addressed through more rigourous accreditation procdeures as will be discussed.

- *The development of more rigorous accreditation procedures:*

  Since the scope for introducing further requirements for pre-completion testing is currently limited (DCLG 2008d) the NCM is likely to continue as the standard for energy compliance demonstration. It is therefore of significant importance to investigate variations between the results produced by the accredited tools to detrmine possible causes and eliminate factors that could potentially affect their validity.

  The current accreditation procedure aims to ensure that the calculations are technically robust, however these tests vary considerably between DSMs and FI-SBEMs and currently do not seem rigorous enough to ensure tools use consistent modelling approaches. For the DSMs in particular, the testing procedures employed require that they be carried out using simplified steady state assumptions whereas in practice, these tools are used with their default algorithms.

  Therefore, the introduction of more consistent and rigourous testing procedures for all tool classes in addition to addressing the issue of maintaining the consistency of the algorithms used in the testing procedure and in practice for DSMs should be addressed (Strachan et al, 2006) Further procedures that ensure that procedural guidance is followed not only in terms of the calculation and reporting processes, but also in terms of a consistent modelling approach should be also be considered.

- *The need for measures to increase the validity and consistency of results:*

  A number of additional measures that can be considered for implementation, include a policy that aims to increase the standardisation of units and the revision of problematic input requirements (such as the κm value) to ensure the consistency and quality of input data.

  In addition to the validation testing carried out in the accreditation procedure, previous work (Strachan et al, 2006) has shown that it is possible to embed validation tests within the tools themselves to enable the frequent assesment of tools and ensure that the results they produce continue to be within specified tolerance bands required for compliance with regulations.

  Finally, the provision of additional guidance regarding typical projected CO_2 emissions or energy consumption values for various building/HVAC combination types will also help to provide a comparative benchmark to confirm the validity of the generated results for proposed designs.

FURTHER WORK

The work presented in this paper presents the interim results of the first phase of a two-tier study investigating the suitability of accredited software tools for the purposes defined in ADL2A. Further work will aim to expand this study to incorporate the entire range of tools accredited for the purposes of implementing the NCM in England and Wales. Additionally, a second phase involving the implementation of a single-model sensitivity analysis to determine the effect of changes in key input variables on generated results for each of the tools will also be included.

AKNOWLEDGEMENTS

This work was made possible through the assistance of Professor Andrew Peacock (Heriot-Watt University), Harry Bruhns (University College London) and with the support of Dr Andy Tindale (DesignBuilder Software Ltd), Integrated Environmental Solutions and Pythagoras International Ltd.

REFERENCES

ANSI/ASHRAE. 2007. Standard 140-2007. Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

Bruhns HR. 2008. Identifying determinants of energy use in the UK nondomestic stock: Proceedings of The 5th International Conference on Improving Energy Efficiency in Commercial Buildings. Frankfurt: IEECB'08.

Bartholomew D, Hand J, Irving S, Lomas K, McElroy L, Parand F, Robinson D & Strachan P. 1997. An Application Manual for Building Energy and Environmental Modelling' Building Simulation '97, Prague, Vol2, pp387-393, Sept 1997.

Building Research Establishment. 2005. Simplified Building Energy Model. Part L is changing - are you ready? (Online:www.bre.co.uk/energy rating/page.jsp?id=694

Carey P. 2007. Comparisons of results from a case study investigation: Part L Criterion 1 where are we now? IBPSA-England Symposium 'Building simulation in the southwest' University of Plymouth, Sherwell Centre, 16 November 2007

Chartered Institute of Building Services Engineers. 2006. CIBSE TM33: Standard tests for the assessment of building services design software. UK: Charted Institution of Building Services Engineers.

Department for Communities and Local Government. 2006. The Building and Approved Inspectors (Amendment) Regulations 2006 Statutory

Instrument 2006 No. 652. UK: Crown Copyright.

Department for Communities and Local Government. 2008a. National Calculation Methodology (NCM) modelling guide (for buildings other than dwellings in England and Wales) (Online: http://www.communities.gov.uk/publications/planningandbuilding/ncmmodellingguide).

Department for Communities and Local Government. 2008b. Building Energy Calculation Software Approval Scheme (Online: http://ukreg-accreditation.org/Index.html).

Department for Communities and Local Government. 2008c. A User Guide to iSBEM (iSBEM version 3.3.b) Available Online : http://www.ncm. bre.co.uk /download2.jsp

Department for Communities and Local Government. 2008d. Performance Testing of Buildings. (Online: http://www.communities.gov.uk/documents/planningandbuilding/pdf/performancetesting.pdfl).

Gard Analytics. 2008. Available Online http://www.gard.com/index.htm. Retrieved: 20-01-2008

Guyon G. 1997. The role of the user in results obtained from simulation software program, in proc. BS'97 The International Building Simulation Conference, Prague, 1997

Jaggs, M. 2007. Designing and Complying with Part L and the EPBD. Presentation at Interbuild – BRE Low Carbon Buildings. Birmingham October 2007.

Judkoff, R & Neymark J. 2006. Model Validation and Testing: The Methodological Foundation of ASHRAE Standard 140 Presented at the ASHRAE 2006 Annual Meeting Quebec City, Canada June 24–29, 2006

Judkoff, R. & J. Neymark. 1995a. *International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method*. NREL/TP-472-6231. Golden, CO: National Renewable Energy Laboratory.

Judkoff, R. & J. Neymark. 1995b. *Home Energy Rating System Building Energy Simulation Test (HERS BESTEST)*. NREL/TP-472-7332. Golden, CO: National Renewable Energy Laboratory.

Neymark J. & Judkoff, R. 2002. Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST) Volume 1: Cases E100–E200. International Energy Agency

Official Journal of the European Communities.2002. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. Belgium.

Pérez-Lombard L, Ortiz J, Pout C. 2008. A review on buildings energy consumption information. Energy and Buildings; 40:394–398.

Raslan, R & Davies M. 2008. An Analysis of Industry Capability for the Implementation of a Simulation-Based Compliance Approach for the UK Building Regulations 2006. Building Services Engineering Research & Technology (In review).

Raslan, R & Davies M. 2006. The implementation of a simulation-based compliance methodology for the UK Building Regulations 2006: An industry survey. Proceedings of the European Modelling Symposium 2006. UK Simulation Society & the Graduate School, UCL.

Rittelmann, P. Richard, S. Faruq Admed. 1985. Design Tool Survey. May 1985. IEA SHC Task 8 Passive & Hybrid Solar Low Energy Buildings, Subtask C Design Methods. Washington, DC: U. S. Department of Energy.

Strachan, P,Kokogiannakis,G,Macdonald,I & Beausoleil-Morrison, I. 2006.Integrated comparative validation tests as an aid for building simulation tool users and developers. ASHRAE Transactions, V112(2), pp395-408.

Witte, MJ, Henninger, RH & Glazer, J. 2001. Testing and Validation of a New Building Energy Simulation Program - Seventh International IBPSA Conference Rio De Janeiro, Brazil August 13-15, 2001

UK Green Building Council. 2007.Report on carbon reductions in new non-domestic buildings. DCLG.

US Department of Energy. 2008. Building Technologies Program. Available online at: http://apps1.eere.energy.gov/buildings/energyplus/getting.cfm