THE MANAGEMENT AND CONTROL OF ENERGY AT THE DESIGN STAGE OF BUILDINGS

Laurie Brady[1] and Rachael Hanmer-Dwight

[1] *School of Built Environment, Liverpool John Moores University, Byrom Street, Liverpool, L3 3AF, UK*

[2] *Liverpool John Moores University, 70 Mount Pleasant, Liverpool, L3 5UA, UK*

An essential element of a sustainable building is the amount of operational energy that will be needed to power the engineering services which provide buildings with safe, healthy, comfortable and secure environments. The environmental impact and financial costs associated with energy running costs are factors which are increasingly recognised for their importance. The paper considers the accuracy and usefulness of energy bench-marking and discusses its application in the management of the design of sustainable buildings. Within this context, the design of building services plant is an iterative process in which design decisions become progressively more accurate. At the stage when project objectives and sustainability aspirations are not fully defined designers may use benchmarks data for preliminary energy target setting. There are several types of bench-marking systems available for predicting building energy use. Typically, benchmarks are provided in which annual energy use is allocated in terms of annual KWh/square metre of building floor area for various building types. CIBSE has developed a Technical Manual which provides more sophisticated guidance on evaluating energy performance. This investigation used TM54 and TM46 to compare predictive energy consumption against actual energy bills for an existing large educational building in Liverpool. The research consisted of seven individual applied studies, which together produced a comparative range of estimates. Subsequent review of the work indicated some imperfections; however, the TM54 method was found to produce greater accuracy for energy consumption prediction which remains an important and necessary component of sustainable design.

Keywords: benchmarking, carbon-buzz, performance gap, TM54

INTRODUCTION

The RIBA plan of work (RIBA, 2013) sets out, in a logical sequence, the stages involved in taking a building project from an identification of the need for a building project through to its handover to the client and its operational phase. The RIBA plan is not only useful for project planning, but it also illustrates the iterative nature of project design and the interdependent nature of the relationships between the project stakeholders.

After the business case for a project has been established, the next stages involve a consideration of “sustainability aspirations” and “development of project objectives”. This is where the professional team begin to transform a client’s requirements into practical, achievable packages of work and where budget, quality and time constraints

[1] l.j.brady@ljmu.ac.uk

Brady, L and Hanmer-Dwight, R (2016) The Management and Control of Energy at the Design Stage of Buildings. *In*: P W Chan and C J Neilson (Eds.) *Proceedings of the 32nd Annual ARCOM Conference,* 5-7 September 2016, Manchester, UK, Association of Researchers in Construction Management, Vol 2, 1171-1180.

become clearer. Developing these work packages can identify a necessity for decisions which may have both technical and financial implications. The effect of these implications may create modifications to the project brief.

Within this development phase, when both design decisions and project brief may be somewhat fluid, building services engineers may be invited to predict future energy use. This is an essential element in design management, not only because this information enables the design team to allocate the areas and volumes that will be required to install and operate engineering plant and services, but it is also an early indicator of potential building energy performance. Space planning for building services is often negotiated with other disciplines. Portman (2014) refers to this process as “a battle for distribution space”. This has traditionally been the role of building services consultants.

The reliability of predictive building energy data has grown in importance, particularly since a performance gap between design and actual energy use has been recognised. Research at Plymouth University (de Wilde, 2014) considers that bridging of this performance gap is crucial “if the design and engineering stage is to provide serious input to the delivery of buildings that meet their (quantified) ambitions”.

Predictive building energy data

Predicting energy consumption

Appreciating how a building will perform in energy terms can have implications for the assessment of lifecycle costs and consequent project financial viability. Estimated building energy performance will indicate subsequent financial implications, both in terms of utility costing, and service/maintenance planning. If planned financial budgets are severely limited, then predicting and minimising energy may become the driving factor in design. This can affect decisions on building orientation, types of façade and servicing strategies. If in turn the Strategic Definition of a project has included a vision on how users will engage with the building, then this vision may be compromised and require adjustment depending on whether the technical design decisions (if based on energy consumption) can support this. Additionally, where energy targets are set, it may become an index of project success or failure. In fact, studies by Sun *et al*., (2016) in the USA have recognised a “performance risk” factor which may actually constrain growth in the development of energy efficient buildings.

Assessing the energy efficiency of a building must start by quantifying the energy used by that building which can then be compared to some agreed benchmark or criteria/threshold. An energy consumption benchmark may be derived by how an organisation contextualises its energy use and energy planning. Subsequently, a benchmark may be derived from:

- forward planning for utility expenditure
- operating within a scope 1 and 2 emissions reduction framework
- performance management as prescribed under the Directive on the Energy Performance of Buildings 2002/91/EC
- performance criteria in building environmental and energy assessments

Organisations with large property portfolios may have developed statistical energy use data which can be applied to new projects. Of course this would have meant that strategic energy metering had been carried out and that management had devoted sufficient resources so that historical data was actually recovered and catalogued. Straightforward consumption records can be useful but sophisticated energy metering can produce valuable comparative data. However, in the recent past energy costs have carried less significance for business organisations than other running expenses such as salaries and property.

In any case, ability to predict energy with historic metering information may be limited if the data has failed to capture the consumption breakdown of the separate building services. This fails to support consumption comparisons on a service by service basis, and thus may risk the reliability of subsequent predictions. In this event, benchmarking tools still represent a valid process for predicting energy consumption of proposed building services.

Predicting building energy use and target-setting for the many organisations without their own statistical data is carried out by accessing published bench-mark information, energy modelling using software, or a combination of both.

Benchmarks
There are many energy assessment schemes available. Various countries have produced their own schemes. Wang (2012) categorized them under the following headings based on their target applications:

- Environmental Assessment Schemes
- Building Energy Certification
- Whole-Building Benchmarking Tools
- Hierarchical Assessment and Diagnosis tools

The UK environmental assessment scheme (BREEAM) sets criteria for energy which is related to the calculations set out in Part L of the UK Building Regulations. Important as this process is, these calculations are designed to demonstrate compliance with legislation and are not intended to be predictions of energy use (Cheshire, 2015).

The Chartered Institute of Building Services Engineers publish energy bench-mark information in two documents: “Energy Benchmarks, TM46” (Field, 2008), and “Energy Efficiency in Buildings, CIBSE Guide F”. TM46 describes the building energy benchmarks which are used in association with Display Energy Certificates. The TM46 tool is used to quantify estimated usage in a building and thus provide a ‘typical’ energy consumption benchmark. This can be compared with the building’s actual metered energy use. This comparison of energy performance is shown on the Display Certificate on a colour coded rating scale, its purpose being to raise public awareness of energy use in building.

Although, TM46 benchmarks are commonly used for predictive purposes, Display Energy Certificate data should be determined using approved software by registered consultants (Chadderton, 2013). TM46 sets out annual energy benchmarks in term of KWh/m2 (kg of CO2 emissions/m2) of floor area. Benchmarks are included for 29 types of building and TM46 includes correction factors for occupancy and weather, as well as a method for separating out high energy using processes which would otherwise undermine a typical comparison.

Guide F provides benchmark data in a similar format to TM46. Guide F differs from TM46 in that some greater detail is provided such as differentiating between “typical” and “good practice” values. The Green Building Council (2013) expressed a concern regarding the age of Guide F data and noted that some of the benchmarks had been updated through TM46. In the same document by the Green Building Council it was noted that "CIBSE Guide TM54 is intended to form the missing link between design stage estimates."

Carbon Buzz
Carbon Buzz (CIBSE, 2016) is a database platform which has been set up in a joint venture by RIBA and CIBSE in response to a realization that many buildings use more energy than was predicted at design stage. This phenomenon is termed the "Performance Gap" and this quantifies the amount of actual energy use by a building in comparison to its design figure. The Carbon Buzz website states that "on average buildings consume between 1.5 and 2.5 times predicted values".

Carbon Buzz is a freely accessible site in which participants can enter building energy case studies or simply browse. Case studies may be anonymous. The available data enables users to compare their own building energy performance against similar categories.

Dynamic simulation modelling
The energy used in buildings is influenced by the dynamic nature of the effects of convection, conduction, radiation between building fabrics, furniture, occupants and equipment, as well as by constantly changing weather conditions. In the past this level of interaction has been reduced to steady state, or semi-transient calculations for design calculations which, though simplified, could still require many long-winded calculations where loadings and plant sizing were based on worst case scenarios. Heating plant was sized for the lowest winter temperature and cooling plant for the highest summer gain.

The power of software has led to the development of computer models which can cope with sophisticated heat transfer and storage calculations which would have been impossible to complete by hand and should therefore produce more accurate results, if provided with reliable input data. Some of the major modelling packages available include: Energy Plus, TAS Building Designer and IES. The characteristics of these systems (Jankovic, 2012) tend to hinge on the how users interface with the software and the ease with which simulations can be run. Though the mathematical power available has proved to be invaluable, it has become apparent that some software systems do not account for actual operating circumstances.

TM54 and the performance gap

TM54
One of the responses to the Performance Gap question has been the publication of CIBSE Technical Manual TM54, "Evaluating operational energy performance of buildings at the design stage" (Cheshire, 2013). One of the aims of this document is "to provide a methodology that engineers can use to undertake better-informed calculations of energy use in operation".

The two main causes for the performance gap cited in TM54 are that design calculations do not account for all building energy uses, and that site practice does not always result in designs being built as intended. In the context of site practice Davies includes commissioning and operation of buildings. Site practice is outside the scope of TM54.

The methodology employed by TM54 recognises some of the "inherent simplifications" contained in dynamic simulation software and therefore also includes some long-hand calculations. Figure 1 (below) summarises the TM54 methodology.

Comparing TM46 and TM54 estimates with energy bills for an existing building
An exercise in the application of TM54 and TM46 energy assessment methods was carried out for an educational building in Liverpool with the aim to examine the value of CIBSE-developed energy prediction tools. The purpose of comparing the outcome of both tools was twofold. First, while TM54 is a newer tool, both enjoy prevalent use in the construction industry and are therefore both relevant to an exploration of how well they serve energy prediction purposes. Second, any comparable differences between the TM46 and TM54 studies could demonstrate what degree of progress has been made in predicting energy more accurately and in reducing the performance gap, as per the rationale behind development of TM54. A group of seven building service engineers each prepared energy estimates for the project. The group included mechanical and electrical engineers from a mixture of consultancy or contractor backgrounds. Each engineer had professional occupational responsibilities of at least an intermediate level but had not previously used either of these systems.

University Estates managers provided record drawings and arranged for site surveys, though these were mainly basic visual inspections.

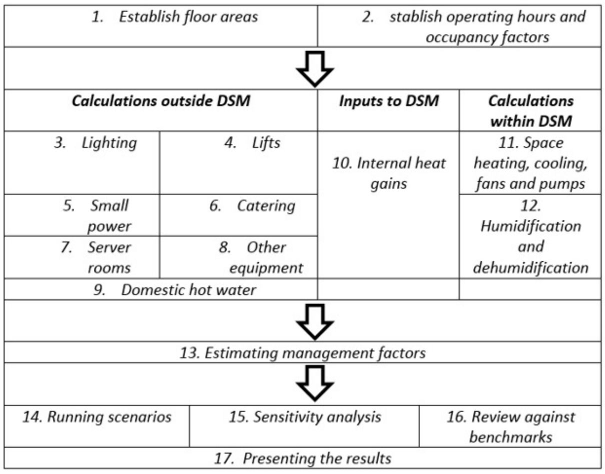

Figure 1: TM54 methodology

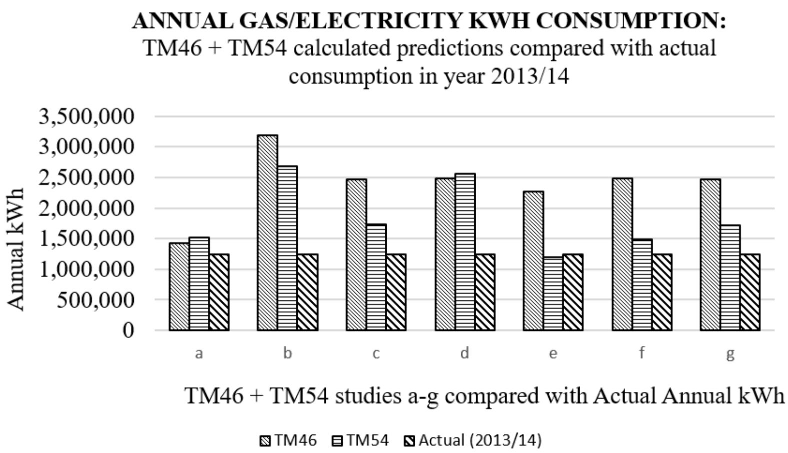

Figure 2: TM54, TM46 and annual energy use

Between the predictive studies (see Figure 2 above) TM46 and TM54, the overall percentage differences between each study and the actual consumption show that TM54 was more reliable in its predictions. Whilst both over-estimated, the median percentage difference between TM54 and actual consumption was +38%, whilst the respective median percentage difference between TM46 and actual consumption was considerably greater at +99%.

Additionally, if those studies which give rise to a prediction in excess of 200% of the actual consumption are removed (if treated as anomalies), this strengthens the reliability of TM54 over TM46 further still: TM46 median actually remains as +99%, whilst the TM54 median reduces from +38% to +22%. Both indicate a consistent over-estimation, but TM54 is nonetheless producing a more accurate prediction than TM46.

When observing the breakdown within the TM54 studies, the tool appears to work better for some services over others (see Table 1). ‘Dehumidifying’ calculations represented the tightest figures across the seven studies; conversely, ‘Lighting’ and ‘Server Room’ calculations encountered the greatest variation of the specified services. ‘Other’ services calculations represented the largest variance of all and highlights a potential challenge in the use of energy prediction models:

Table 1: Variance in the TM54 studies' predictions, by building service

Building Service	Coefficient of variance (%)
Dehumidifying	12
Domestic hot water	20
Space heating	21
Lifts	22
Small power	34
Server rooms	46
Lighting	58
Other	125

All estimates (TM46 and TM54) predict higher than actual energy use. The average TM46 estimate was almost double the actual energy use (193%), whilst the average TM54 figure was 1.48 times the actual energy use value. Though there are discrepancies between actual and predicted energy use, the exercise simulated a typical early design stage situation in which not all decisions have been finalized, and therefore it would be expected that figures would be approximate. The access and data given to the engineers carrying out this work was limited. This was due partly to the workload of facilities managers whose priorities are arranged around operational matters, and also the time pressures on the engineers preparing the estimates. All factors which would be familiar to working engineers and managers.

That TM54 energy predictions were all high in this case, would infer that accuracy can be improved by familiarity with the technique and a more intimate knowledge of building occupancy and operation. The process is straightforward and logical, particularly when compared with other prediction models, many of which rely completely on software with varying levels of complexity. An example of this approach is demonstrated by Brohus *et al*., (2012).

Since the level of accuracy for TM54 is linked to knowledge of building use, approximate predictions must be expected and will need to be fine-tuned as information is firmed. Improved support for designers during the design process is welcomed to ensure that the best decisions can be made with regards building services; however, it is worthwhile considering that the areas of variance are typically those which experience a greater user engagement and, thereby, energy impact. Increased awareness of this may encourage greater support not only for the design process but also for the user interface and engagement upon occupancy. The decision in the early design stages to employ a tool like BSRIA's Soft Landings may lend itself to better-manage the behaviour element of building energy control. This may improve accuracy of prospective energy predictions.

The validity and role of energy prediction techniques for the management of construction projects

How worthwhile is the process of predicting energy use? Using a cost control analogy, it is normal practice for quantity surveyors to commence with approximate estimates which are refined as project information is firmed. The availability of pricing data used by quantity surveyors has been available for long enough for it to become sophisticated. For example, on-line cost data is regularly updated and characterised to reflect such elements as location, construction type, market conditions, and more. This is not quite yet the case for building energy data, though initiatives like Carbon Buzz are compiling actual energy-use data. Research by Robinson and Mumovic (2014) found that although many consultants often collect information about their buildings, fear of liability restricted wider access.

A recent research exercise by Innovate UK (Palmer *et al*., 2016) looked at 50 "leading edge" buildings and found that the average carbon emission rate was 3.8 times higher than that used to show compliance with building regulations; a figure greater than the multiplier quoted by Carbon Buzz. Although the predicted loads which fall under UK building regulations compliance do not account for unregulated loads[*], the report does consider that meeting UK carbon reduction targets will be "an unattainable goal, unless there is a revolution in how the country constructs and operates buildings".

Evidence suggests that buildings use too much energy post-occupancy. This is dramatically demonstrated if compared to predicted energy use, yet energy benchmarks can vary. Although building services are the largest energy users in building lifecycle terms (Churcher, 2013), building services designers specify systems and plant in response to the loads imposed on a building. Those building loads result from the way architects and other construction professional meet client requirements. If this process is considered in reverse, then much of a building's energy load can be reduced by intelligent architectural and structural design. In other words, the key to achieving a low energy building is a combination of active and passive design. This idea is not new and can be recognised in slogans such as "fabric first" or in the carbon hierarchy concept, however it does suggest that its application requires a multi-disciplinary management approach.

From a practical standpoint, the usefulness of energy predictions include:

- Contributions to initial assessment of project viability

---

[*] UK Building Regulation (Part L) calculations refer to regulated loads only. Unregulated loads include small power or "plug loads", lifts etc.

- Early feasibility assessments of the effects of building orientation
- Feasibility guidance on project servicing strategy
- Determination of plant spaces and volume requirements

Whilst these inputs are valid, project managers must recognise the implications for collaborative management strategies (Pittard and Sell, 2016). An awareness of the "chicken and egg" nature of building design is vital.

It is difficult to reconcile actual and estimated values against the various headings in TM54 because meters often record gas or electricity use for whole buildings. It should be noted that Part L of the building regulations now calls for more strategic metering arrangements. However, there are some factors which can be considered to be significant:

- Dynamic Simulation Modelling – software systems can be complicated with large learning curves
- Surveys – although access to the building was available for examination of plant and systems, information on occupancy and operational matters was sparse
- University facilities managers' major role is to maintain buildings at a safe and operational level, leaving little time for deep examination of system performance

This particular university building includes laboratories, postgraduate research offices, educational administrative offices as well as teaching spaces. This combination of room usage demands lower student occupancies

CONCLUSIONS

This paper suggests that the process of predicting building energy use contributes to several construction management functions. In terms of design management, predicting energy use is an iterative process in which accuracy is increased as design moves from concept to developed design. To be successful this process should inter-relate and develop in step with the other design disciplines. An appreciation of the energy implications of architectural and structural design decisions can improve overall building design. However, this will only be practical if each party accepts the sketch-type nature of early proposals. Reviewing and re-working ideas may increase workloads and this may need to be reflected in fees.

Predicting energy use enables designers to allocate space for plant. Research by Wan and Kumaraswamy (2012) concluded that poor co-ordination in building services projects is a "critical production shortcoming", and that the process of space conflict resolution during installations may result in demolition, replacement or rework. BIM is seen as offering a solution to co-ordination issues. However, Godden and Mansell-Thomas (2016) provide a reality check in their examination of digital techniques for construction. Their work identifies that, presently, major disconnect exists between the "shared data environment" of designers and site reliance on "red pens and photocopiers".

Though accurate sizing and co-ordination are vital components of low energy design, early energy predictions also enable construction managers to take the first steps in tackling performance gaps and developing a project energy control plan. This paper compares the concept of energy control plans with cost control plans. Quantity surveyors are now embracing the idea of in-use costs. Operational energy represents the greatest portion of life-cycle energy costs.

Managing the energy the use of buildings has been likened to cost management. The sophistication of the data available to quantity surveyors has been recognised. In comparison, the energy prediction exercise described in this paper identifies some imperfections in the use of energy benchmark data. All of the predictions exceeded actual energy use and, within this, small power and lighting resulted in the most generous estimates. Estimates of occupancy and user behaviour are major causes of approximation error for both longhand and dynamic simulation elements of predictions. This may be partly resolved when accurate details of occupancy numbers and periods become clear, though lack of clarity can typify early sketch scheme situations. The TM54 methodology recommends sensitive analysis of results.

Another contributor to approximation error is proficiency in the application of dynamic simulation software. All of the estimators who carried out the energy predictions are working engineers and are competent software users. However, dynamic simulation packages can require specialist training and often require to be accessed frequently in order for users to maintain competence levels, particularly as these systems are regularly updated. This has management implications for construction organisations in which it may be necessary to find the right blend of computer-literate graduates and experienced professionals.

Clearly, though energy consumption predictions at the building design stage will often include approximations, the exercise is nonetheless a critical element in sustainable design and will improve as the quality and management of feedback data research gains in its sophistication.

REFERENCES

Brohus, H, Frier, C, Heiselberg, P and Haghighat, F (2012) Quantification of uncertainty in predicting building energy consumption: A stochastic approach. *Energy and Buildings*, **55**, 127-140.

Chadderton, D (2013) *Building Services Engineering*. Abingdon, Oxon: Routledge.

Cheshire, D (2015) The problems with design stage estimates of energy use of buildings and how this can be improved by using the methodology set out in CIBSE TM54. *Journal of Building Survey, Appraisal & Valuation*, **4**(2), 150.

Cheshire, D and Menezes, A C (2013) *Evaluating operational energy performance of buildings at design stage TM 54*, CIBSE. Suffolk: Lavenham Press.

Churcher, D (2013) *Life Cycle Assessment: An introduction*. Bracknell, BSRIA.

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

Field, J E A (2008) *CIBSE TM 46 Energy Benchmarks*. London: CIBSE.

Godden, E and Thomas, L M.- (2016) *Digital Masterbuilders: Modernising Communication Between Designers And Constructors*. CIBSE Technical Symposium, Heriot-Watt University Edinburgh, 14-15 April 2016. Edinburgh: CIBSE.

Palmer, J, Terry, N and Armitage, P (2106) *Building Performance Evaluation Programme: Findings from Non-Domestic Projects*. Available from https://connect.innovateuk.org/home [Accessed 9th March 2016].

Pittard, S and Sell, P (2016) *BIM and Quantity Surveying*. Abingdon, Oxon: Routledge.

Portman, J (2014) *Building Services Design Management*. Oxford, John Wiley and Sons.

RIBA (2013) *RIBA Plan of Work, 2013*. London: Royal Institute of British Architects. Available from http://www.ribaplanofwork.com/ [Accessed 15th February 2016]

Roberston, C and Mumovic, D (2014) Building performance in the context of industry pressures. *International Journal of Energy Sector Management*, 8(4), 527-543.

Sun, S, Kensek, K, Noble, D and Schiler, M (2016) A method of probabilistic risk assessment for energy performance and cost using building energy simulation. *Energy and Buildings*, **110**(1), 1-12.

Wan, S K M and Kumaraswamy, M M (2012) Improving building services coordination at the pre-installation stage. *Engineering, Construction and Architectural Management*, **19**(3), 235-252.

Wang, S, Yan, C and Xiao, F 2012 Quantitative energy performance assessment methods for existing buildings. *Energy and Buildings*, **55**, 873-888.

Wright, B, Lillicrap, C, Cheshire, D, Treanor, J, Lindey, M, Cotton, M, Mcdonald, N, Lynes, P and Jones, P (2013) *CIBSE Guide F*. UK: Green Building Council. Available from http://www.ukgbc.org/resources/additional/pinpointing-discussion-cibse-guide-f.