View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by LJMU Research Online

LJMU Research Online

Brady, LJ and Abdellatif, M

Assessment of Energy Consumption in Existing Buildings

http://researchonline.ljmu.ac.uk/id/eprint/6583/

Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Brady, LJ and Abdellatif, M (2017) Assessment of Energy Consumption in Existing Buildings. Energy and Buildings, 149. pp. 142-150. ISSN 0378-7788

LJMU has developed **LJMU Research Online** for users to access the research output of the University more effectively. Copyright © and Moral Rights for the papers on this site are retained by the individual authors and/or other copyright owners. Users may download and/or print one copy of any article(s) in LJMU Research Online to facilitate their private study or for non-commercial research. You may not engage in further distribution of the material or use it for any profit-making activities or any commercial gain.

The version presented here may differ from the published version or from the version of the record. Please see the repository URL above for details on accessing the published version and note that access may require a subscription.

For more information please contact researchonline@ljmu.ac.uk

http://researchonline.ljmu.ac.uk/

Assessment of Energy Consumption in Existing Buildings

Abstract

There has been general recognition within the construction industry that there is a discrepancy between the amount of energy that buildings actually use and what designers considered that they should use. This phenomenon is termed “The Performance Gap” and is normally associated with new buildings. However, existing and older buildings contribute a greater amount of operational carbon. In response to the Performance Gap, CIBSE have developed the TM54 process which is aimed at improving energy estimates at design stage. This paper considers how the TM54 process can also be used to develop energy management procedures for existing buildings. The paper describes an exercise carried out for a university workshop building in which design energy use has been compared with the actual building energy use and standard benchmarks. Moreover, a sensitivity assessment has been carried out using different scenarios based on operation hours of building/ equipment, boiler efficiency and impact of climate change. The analysis of these results showed high uncertainty in estimates of energy consumption. If carbon challenges are to be met then improved energy management techniques will require a more systematic approach so that facilities managers can identify energy streams and pinpoint problems, particularly where they have assumed responsibility for existing buildings which often have a legacy of poorly metered fuel consumption.

Keyword: Benchmarks, DSM, Energy consumption, TM54, uncertainties

1. Introduction

The energy used in buildings in the UK is significant. Non-domestic buildings account for approximately 35% of UK greenhouse emissions (Gummer et al., 2013). The scale of these emissions represents a considerable amount of energy use which has consequent associated national costs. It is therefore a matter of concern that, in many cases construction professionals do not presently have the data or tools to accurately predict at design stage, how much energy a building will use. The gap between predicted and actual building energy use has come to be known as “the performance gap”. The factors which contribute to this gap range from briefing and design issues through to problems relating to installation, commissioning and data feedback.

The skills, knowledge and improved management systems needed to eliminate the performance gap can enable construction professionals to hand over buildings which will, not only perform as they were designed, but they can also set the conditions for the building users to operate and maintain building so that they can be managed to provide optimum performance. The “Soft-Landings” initiative (Bunn and Way, 2014) encourages construction teams to provide an after-care service which can deal with some of the post-occupancy problems which may not have been apparent at building handover stage. However, eventually the operation and management of the occupied building will become the responsibility of facilities managers.

The life cycle energy used by a building during its operational phase is between 80% and 90% of its total life cycle energy (Churcher, 2013). Therefore management of energy use during this period can have a critical influence on building carbon emissions. The process of managing energy in buildings can vary in complexity from simply ensuring that utility bills are accurate to operating a system which monitors and controls the various energy using services. CIBSE (Warburton et al., 2009) recommend that monitoring and targeting of energy use can control energy use by "monitoring consumption and comparing it against historical data and benchmarks". CIBSE publish benchmarks for a range of building types and are easily accessible, whereas valid historical data requires to have been compiled and catalogued.

In response to the problem of the performance gap, CIBSE have developed TM54 (Cheshire et al., 2013a) which is a technical manual which provides guidance for the estimation of building operational use at design stage. The TM54 method recognises the value of dynamic software, which can simulate heating and cooling loads. It also proposes the use of more long hand type methods for the assessment of those loads which can be heavily influenced by occupant behaviour. It is recommended that energy assessors determine how and when buildings will be operated. This may be achieved by a combination of access to logged data and from interviews with building users.

Two approaches to the application of the TM54 process can be seen in how it has been used for forecasting energy use for a new air ambulance operational base (Rankin, 2015) and how British Land (Webster, 2015) have made use of the process for evaluating operational energy use in completed buildings. In the case of East Anglian Air Ambulance, it was considered that the improved confidence in energy modelling enabled the client to make informed decisions as the design progressed and avoided the "natural" tendency for designers to be over-optimistic. Nevertheless, it was still necessary to explore different scenarios with a range of forecasts which will need to be compared to actual performance data when it becomes available. For the British Land project, the energy performance of a recently completed building in the City of London was examined. In this case the TM54 process was applied using actual occupancy data. It was found that TM 54 provided "robust performance benchmarks and targets, as well as feedback to design teams on the impact of their design". But, this examination also recognised that, in order for modelling to be meaningful, it needed to be “revisited through the design process and into the operational phase of the building”.

The importance and relevance of energy use within university buildings has been recognised by initiatives such as Carbon Buzz, Display Energy Certification and other statutory requirements. With regard to educational buildings, not only does this raised awareness enhance the motivation of researchers, but it also has practical implications for estate and business managers. The aims of reducing emissions and associated fuel costs require an appreciation educational building energy use in order that solutions can be developed. Fahi and Srinivasan (2015) have explored how modelling/simulation and statistics could be applied to identify the characteristics of particular buildings in order to evaluate building performance and the effectiveness of energy saving measures. Although this report concluded that energy and financial savings were feasible, it differs from the TM54 process in that more of the analysis was based on dynamic modelling. Another approach in analysing building energy was the basis of an examination by Soares et al (2015) whereby an audit of electricity, gas and water usage at was combined with a web-based survey aimed at “engaging the entire academic community “in order top also investigate behaviour patterns. Behaviour effects on energy use are also part of the TM54 process, though the methods for its assessment suggest that audited data is combined with face-to- face stakeholder interviews. Also Laurence, (2015); Robinson et al., (2015); Blight and Coley, (2013); Menezes et al., (2012); Bordass et al., (2001) were used CIBSETM54 for assessing energy prediction and the performance gap, in order to raise important questions about decisions made at the design stages that impact on energy performance over a building’s lifespan.

Although the TM54 document has been prepared for use by designers, this paper considers how the methods set out in TM54 can assist in the energy management of operational buildings for situations where no valid historical information is available, or where data exists but is simply annual gas and electricity totals. The reasoning behind this approach is that the TM54 method identifies energy use and allocates it against the various energy streams for buildings. The paper also considered different scenarios to address the uncertainties as a result of building operation and global warming and system efficiently. This paper showed that whilst energy estimates were judged to be improved, it was still considered necessary for engineers to apply judgement and to use these forecasts as a reliable basis on which to improve designs. Where it can be said that the TM54 process clearly adds value to the current case study in identifying energy streams and thereby contributing to an enhanced system of energy accounting.

2. Case Study

An energy survey using the TM54 process was carried out for a university block which comprises engineering workshops and office/study areas. The single storey portal frame structure is located within a campus area and comprises 4 workshops with an adjacent two storey office/study area. The workshops houses specialist equipment for particular student investigations. There are also, within this facility, typical engineering workshop machine tools including lathes, milling machines, power saws and pillar drills. The office/study area locates most of the office equipment –PC's, printers, photocopiers, though PC's are also available in the workshop areas. There are no canteen facilities, although a small kitchen space within the office area includes a sink, toaster, microwave and kettle. The building is illuminated by fluorescent lighting and internal environmental conditions are maintained by unit heaters in the workshops with some radiators in office areas. The electrical installation includes small power for socket outlet circuits and some laboratory equipment. There is also three phase power available for larger machine tools and test equipment. The office area is air-conditioned by split system units which also have a heat pump capacity.

3. Methodology

Investigating the energy use for this workshop involved four processes:

- Survey, This involved compiling a schedule of electrical and mechanical equipment, and (importantly) obtaining on times of occupation and equipment usage (survey information in appendix A, B)
- TM54 assessment
- Dynamic simulation modelling of building heating and cooling characteristics
  Long hand calculations for all equipment including operational schedules. This is where site survey information on usage times is critical
- Comparison with historic energy bills
- Comparison with bench mark data (actually part of TM54 assessment)
- Sensitivity analysis to address the uncertainty with the energy consumption

3.1 Survey

A visual survey was carried out to observe building layout, condition of the building structure, servicing strategy and size and location of power-using equipment (Appendix A, B). It was also necessary to establish the floor areas. For an energy survey it is important that the building floor areas used in the calculations reflect the areas of the building for which energy is expended by the building services plant.

Additionally, within the survey informal interviews were held with building users in order to assess hours of building occupancy and frequency of equipment use. This information is required for the estimation of electrical energy use by equipment which operates according to user demand rather responding to weather or time schedules. This data is also an important input into the DSM for which it can help to make load and scheduling templates as realistic as possible, as well as enabling the software to factor equipment heat gains into environmental analysis of internal conditions. Unlike the complicated, dynamic nature of heat transfer between fabric and space, energy use associated with occupant behaviour would be a relatively straightforward calculation, if user behavioural characteristics were less difficult to quantify. With regard to small power, Menezes et al (2014) have developed models which can be used to estimate small power usage. The techniques developed by Menezes recognise the limitations of simple benchmarks and incorporate behavioural aspects and the variable power inputs of different types of office equipment. The TM54 process incorporates this approach. However, the levels of occupancy and hours of equipment operation can have a significant effect and, if this data has not been automatically logged, then the knowledge and experience of building users must be explored. Energy used to charge mobile devices is another unmonitored area, which perhaps warrants some further research. In this context, however occupant interviews inferred that its effect on overall energy use for these facilities would be negligible.

Laboratory equipment energy use estimates are also dependent user behaviour. In this particular situation, some of the equipment is old and much of the equipment is more of a “one-of” nature than a mass produced product so no bench marks exist. This is further complicated because, in the recent past academic operational factors took priority over any need to monitor or measure energy use. An estimation of energy use for this equipment has required an investigation into individual item power specifications combined with operational hours of use information. Power requirements are accessible from machine nameplates etc. but time periods are dependent on the judgement and memory of laboratory staff.

The energy workshops are considered to be public buildings and, as such require a Display Energy Certificate (DEC), which for this size of building must be renewed annually. DEC’s are based on annual energy use and therefore provide a historical record of energy use. Though this is very useful, the DEC’s only record annual electrical and fossil fuel totals. These are not broken into sub-headings so although they can indicate general overall trends they are less helpful in pin-pointing specific energy using areas.

3.2TM54 assessment

The TM54 process involves the application of dynamic simulation software (DSM) combined with longhand/spreadsheet assessments of the loads which are more affected by occupant behaviour. The logic behind this approach is that the mathematical power behind a DSM is appropriate for the dynamic and constantly changing building heating and cooling loads, whereas other loads are more accurately assessed by examination of how they are used. In this case, for example the laboratory machine tools do not use power in response to weather or temperature but their operational energy tends be more associated with usage.

Figure 1 summarises the methodology for evaluating energy use, including a summary of the activities required at each step.

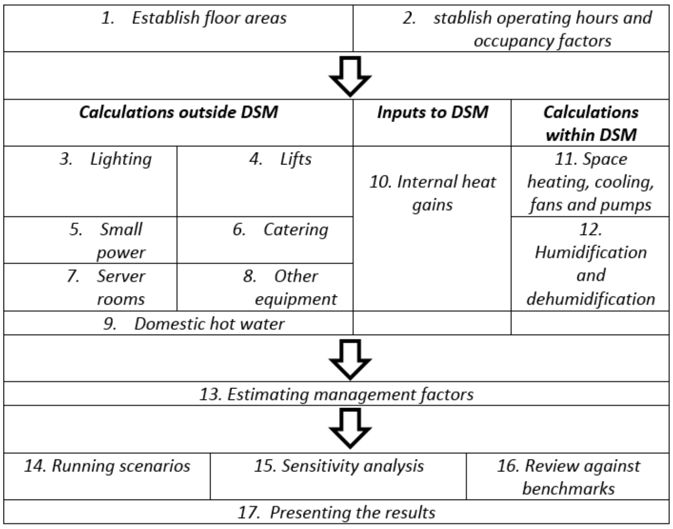

Figure 1: Methodology for evaluating energy used in the design using TM54 estimate (Cheshire et al., 2013)

Calculation outside the DSM:

Step 1: Establishing Floor Areas:

Treated floor area is used as the basis for the energy calculations in this methodology. The logic of this approach is that it includes only the areas of the building that are serviced by plant and equipment. Treated floor area for the case study has been taken as 95% of total gross area as recommended by CIBSE Guide F (2012) that gives a total Treated floor are of 1594.19m^2.

Step 2: Estimating Operating Hours and Occupancy Factors

All the information regarding hours of plant & equipment operation has been directly collected from the Facilities Management Team, through structured interviews. The building opens 12 hours a day between 7am-7pm with different occupancy levels and plant operation periods (see Appendix A).

Step 3: Evaluating Interior lighting energy. The following equation applies to the calculation of annual load.

Annual energy use (KW.h/year) = energy use for illumination (w_1)+ parasitic energy (w_p) (1)

$$W_1=\sum\{(P_n X F_c) X (t_d X F_0 X F_d)+(t_n X F_O)\}/1000 \quad (2)$$

$$W_p=\sum(W_{PC}+W_{em}) \quad (3)$$

Where:

P_n = Total Installed Power in the Room (W)

F_c = Constant Illuminance Factor (taken 1 as no constant Illuminance control)

F_o = Occupancy Dependency Factor (taken 0.9 automatic control>60% of connected load)

F_d = Daylight Dependency Factor (taken as 0.9 photocell dimming with daylight sensing)

t_d = Daylight time usage hours (h) (8 hrs @ 5 days a week over 48 weeks)

W_{pc} = Parasitic Control Annual Energy Consumption (5KW.h/m^2)

W_{em} = Parasitic Emergency Annual Energy Consumption (1kW.h/m^2)

Step 4: Evaluating energy use for Lift

There is only one lift in the building. This has been installed for disabled persons' access. It is not used frequently. Annual energy use is obtained from the method quoted in CIBSE Guide D which originated from BS ISO/DIS 25745-1 (BSI, 2012).

$$E_L=(SPt_h/4)+E_{standby} \quad (4)$$

Where:

E_L is the energy used by a single lift in one year (KW.h)

S is the number of starts made per year

P is the rating of the drive motor (kW)

t_h is the time to travel between the main entrance floor and the highest served floor from the instant the door has closed until the instant it starts to open (hrs)

$E_{standby}$ is the standby energy used by a single lift in one year (KW.h)

Step 5: Evaluating energy use for small power. This includes office equipment and other small power requirements for catering (microwave, toaster, kettle, coffee/vend, hand-drier and refrigerator).

Modern small power equipment operates at working power and "sleep" condition. Annual energy use is determined from an assessment of power conditions and operating time.

$$\begin{aligned}&Annual\ energy\ consumption\ (KW.h)=\\&number\ of\ working\ stations\ X\begin{pmatrix}average\ power\ consumption\ during\ operation\ X\ annual\\hours\ of\ operation\end{pmatrix}+\\&\big(sleep\ mode\ consumption\ X\ (8760-hours\ of\ operation)\big)\end{aligned} \quad (5)$$

Details of power consumption and hours of operation for the equipment are presented in Appendix.

Step 6: This building does not have catering facilities other than items listed under small power in step 5.

Step 7: Energy used by server rooms is determined from the product of power and operational time;

$$\begin{aligned}&Annual\ energy\ consumption\ (KW.h)\\&= number\ of\ rooms\ X\ rated\ power\ demand\ X\ ratio\ of\ rated\ to\ operational\ power\ demand\\&\quad X\ hours\ of\ operation\end{aligned} \tag{6}$$

Step 8: Other equipment for this installation includes the machinery and equipment used in the workshops and laboratories. For this building some of the equipment is unique and may be considered to be non-typical for educational applications. The product of power and operational hours is used but specific operating periods are related to research and experimental use which has been difficult to quantify (equipment details: appendix A)

Step 9: Annual energy use to provide domestic hot water is found from the product of annual mass flow of water use and energy required to raise its temperature from 5^0C (cold feed water) to 65^0C (storage temperature). Annual domestic hot water usage has been obtained from CIBSE Guide G.

$$\begin{aligned}&Mass\ of\ water\ (Kg) =\\&daily\ water\ \ consumption\ per\ person\ \left(\frac{l}{person}\right) X\ density\ of\ water\ \left(\frac{Kg}{l}\right) X\ number\ of\ occuppied\ days\end{aligned} \tag{7}$$

$$\begin{aligned}&Annual\ energy\ consumption\ (KW.h/year) =\\&mass\ of\ water\ (Kg) Xtemprature\ diffrence\ (K) X\ specific\ heat\ capicity\ of\ water\ \left(\frac{KJ}{Kg}.K\right)/3600\end{aligned} \tag{8}$$

3.3 Dynamic simulation modelling (DSM)

DSM has been used to estimate the energy use for space heating, cooling fans and pumps using National Calculation Methodology templates replaced with bespoke profiles for individual plant, equipment, operating hours, lighting, small power etc.

The DSM that has been carried in this study using Integrated Environmental Solutions, Virtual Environment (IES-VE) software. IES-VE has been used by many studies in building information modelling and energy analysis eg. Stundon et al., (2015); Workie, (2015). Azhar et al. (2009) conducted an evaluation study in which they compared the capabilities, advantages, and disadvantages of three Building Energy Management (BEM) tools (Ecotect, Green Building Studio, and IES VE). They concluded that IES VE was the strongest of the three BEM tools based on its range of analysis options. Stadel et al. (2011) showed how certain BIM platforms (e.g., Revit) can be used in connection with IES VE for performing lifecycle analysis in order to estimate the environmental impact (in terms of lifecycle energy consumption and greenhouse gas emissions) of building materials from the cradle to grave phases.

The main data required for thermal model are geometry of the building (Figure 2), construction dimensions, thermal, and solar shading information. The latter includes location and weather data of the studied site. Once a geometrical model had been created in the IES VE, the next step is to apply properties to the model that specify the materials that are used in the construction, the sources of internal heat gains, and the methods by which rooms are heated, cooled, and ventilated.

Construction data including materials and fabric heights, lengths and widths are entered into the software as templates which automatically calculates the data necessary for determining dynamic heat losses and gains to the space. Simultaneously, the templates also include internal heat gain data which is combined with solar gain loads which are determined from geometric and building orientation information. Construction information enables the software to factor the damping influence of the fabric into the dynamic effect of solar gains. Heat losses, gains, space temperatures, annual loads and other factors are available from the software outputs.

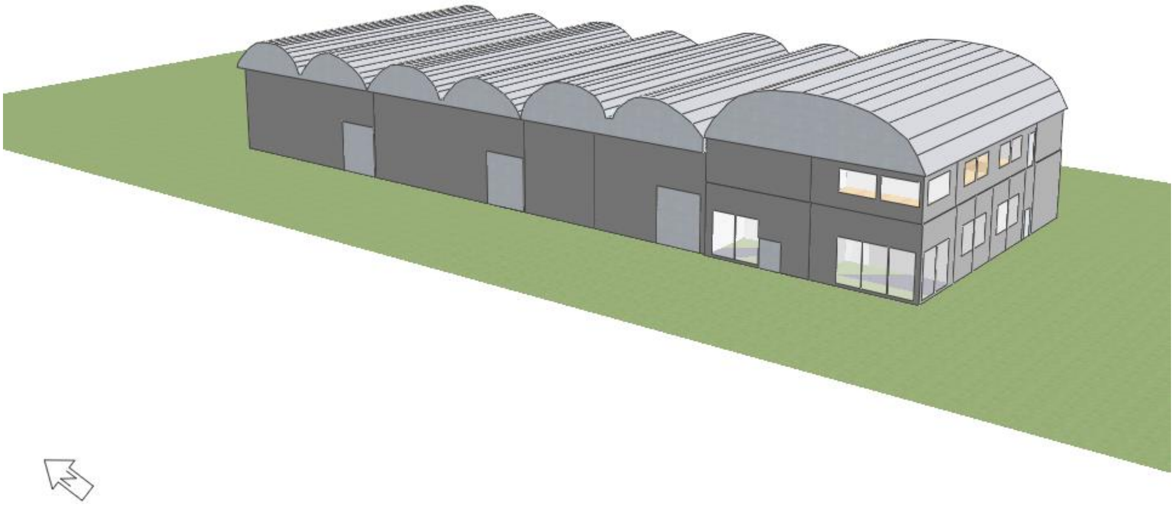

Figure 2: IES-VE model

It should be noted that dynamic simulation modelling, despite its powerful mathematical capability is considered to have some inherent simplifications are identified in CIBSE manual TM54 (Cheshire et al., 2013b):

- Simplified approach for the heat flow through the ground floor slab with an assumed ground temperature
- Assumption that U values are static, when they are actually dynamic and change with temperature and other climatic conditions
- The use of standard weather sets based on historic weather data, which will be different from the conditions in any given year that the building is operating.

The use of dynamic simulation modelling (DSM), like all design methods relies on accurate data upon which to determine outputs. Capable designers should be sufficiently competent to input reasonably representative design values for temperature, insulation, air change rates, internal heat gains etc. They should be experienced enough appreciate the levels of accuracy this kind of input data will generate, knowing that actual designs need to be practical given that actual building services engineering systems will not be operating under laboratory conditions.

However, DSM's also require input data regarding occupancy, hours of operation and schedules for particular usage of office machinery. For current case study although plant operational times are programmed into the building management system, controls can bring plant on line during non-occupancy periods. This occurs where outside temperature conditions could create frost damage internally, or else to reduce the energy needed to bring internal conditions to comfort levels during morning start-up. This facility has been incorporated into the simulation model. The operating temperature for different zones in the case study has been presented in Appendix B and overnight temperature is maintained at lower temperature of 10^0C and if the room temperature dropped below this the heating will operate.

These factors can have significant effects on calculated annual loadings, particularly if excessive margins are applied. Despite its critical nature, unlike some other forms of data, this information is not easily available from databases or design guides. To obtain an understanding of how, when, and for how long the building and associated plant will operate, designers need to interrogate clients, building users and their agents. This is not a straightforward task. For new buildings there is an element of predicting the future. Although for existing buildings occupants and facilities managers can be helpful, it is unlikely that compiling historical data on building use has had a high priority. Ideally this kind of could be logged automatically by means of a building management system.

4. Results& Discussions

The initial result of TM54 estimate for different energy uses is presented in Table1. The effect of energy use by other equipment is, in this case significant but may not be typical and other equipment of the Lab and workshop, small power and lighting consumes significant amount of energy while other uses showed relatively low consumption.

Table 1: Annual Energy Use Estimate (TM 54)

Service	Fossil (kWh)	Electricity (kWh)	Total (kWh)
Lighting		28,650.19	
Lifts		144.35	
Small power		45,796.83	
Server rooms		17,607.60	
Domestic hot water	7,761.60		
Other equipment		236, 934.81	
Space heating	350,630.2		
Space cooling		3352.9	
Fans, pumps, controls and auxiliary		4358.8	
	358,391.80	335,409.88	629, 520.6

4.1 Display Energy Certificates and Benchmarks

Comparing the initial TM54 energy estimates with the annual mechanical and electrical energy use (reported in Display Energy Certificates) indicates a gap in both cases between the estimate and the energy use recorded on DEC's **(**Figure 3),

- Electrical energy use rang between + 274% to +175% of estimated value
- Gas energy use range between +214% to +147% of estimated value

Min et al (2016) note that the phrase "performance gap" is normally applied to the difference between design and actual energy use for new buildings and that that it is unclear how this phenomenon is described for existing buildings but suggest that "FM gap" may be a more appropriate term.

Recorded electricity use shows a reduction in the period since DEC's were introduced. However, gas usage has not demonstrated a definite trend either way but varies from year to year. Further investigation into these figures revealed that energy for this building has not been individually metered. The workshops are located within a campus set-up and space-heating, primary heating for domestic hot water and electrical energy are generated centrally. Low pressure hot water is generated in a boiler house some distance from the workshop and electrical energy is obtained from the campus high voltage ring main. For both energy sources metering occurs upstream and therefore figures for annual energy use (DEC's) in the workshop must therefore be calculated or inferred. The Carbon Trust (2012) consider that "insufficient means of measuring and managing" energy in operational buildings is one of the reasons why building performance falls short of design intent. However the Carbon Trust also identifies other likely causes. These include poor commissioning and the inability of facilities managers to operate the building optimally. There is a logical relationship between inadequate commissioning at handover and limitations to what facilities managers can achieve post occupation.

Perhaps the major finding from investigating electrical and gas use at the engineering workshops was that monitoring of where and how much energy is used for this building has historically had a low priority in this organisation. This is illustrated by the metering strategy, or lack of it. But it should not be forgotten that the primary function of this facility is to contribute to student education and research. It is important that this is primary organisational function is recognised because this is the driving force that identifies the major responsibilities of the teaching and support staff, including the facilities managers. This management strategy may be related to why the energy supplies to this building are not metered, though it is more likely that those responsible for managing energy presently were not involved at the design stage for this building. Given the prevalence of existing buildings over new, many FM's must cope with a legacy of problems that were created when designer and constructors operated in an era when there was much less awareness of environmental issues and statutory regulations set lower standards for energy performance.

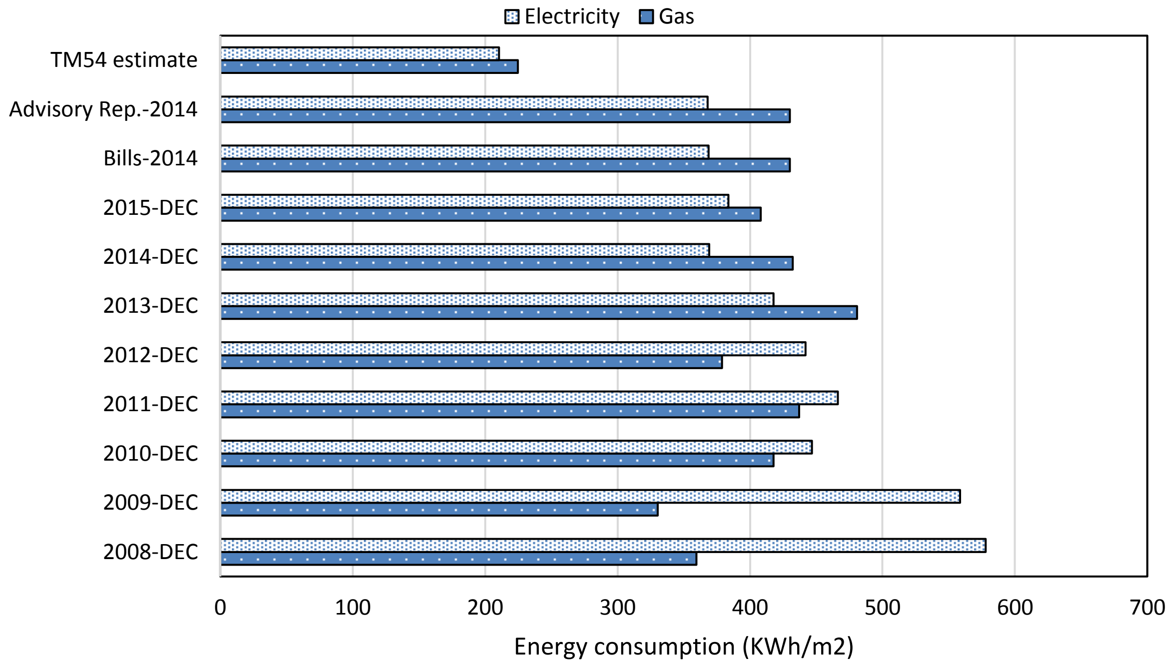

Figure 3: Annual energy consumption data from DEC's

However, if TM54 values are compared with published benchmarks, the situation is somewhat different. The graph below (Figure 4) illustrates how the TM54 estimate compares with benchmarks from three CIBSE publications.

In all three cases, the TM54 figure exceeds the benchmark figure. The TM54 estimate is based on more specific building and occupancy information in comparison to the benchmark data which must use, by definition, typical values. Although this process should benefit from this more closely related data, incorrect information about occupancy levels and equipment operation schedules can have substantial effects on both software and long-hand calculations.

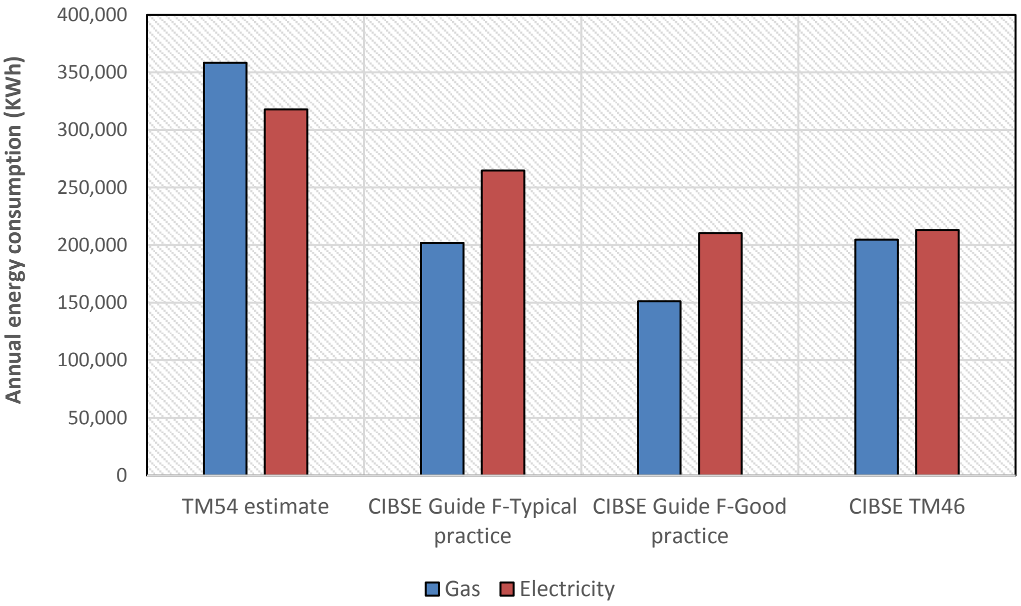

Figure 4: Annual energy consumption in the building compared to standards benchmarks, CIBSE TM 46 (Field et al., 2008) and CIBSE Guide F (Wright et al., 2013)

4.2 Sensitivity analysis

In order to provide some context in which to frame the energy estimate uncertainties related to the case study different possible scenarios have been considered. These uncertainties have been assessed individually based on:

a. Change in operational hours and impact on total energy consumption (Figure 5)

b. Change in operational hours for the lift, small power, machinery and building working hours (Figure 6)

c. A one hour shutdown during the daytime for heating, cooling, small power and machinery (Figure, 6)

d. Application of weather data based on predicted climate change effects. (Figure, 6)

e. Boiler efficiency (Figure, 6)

If the results of the calculations (before scenarios are applied) are considered to be optimistic, then it is informative to examine the results from a low end scenario. Similarly, where the case study figure is pessimistic, a high end scenario offers perspective. For the case study, high-end and low-end scenarios were calculated by manipulating the variables listed in the previous paragraph.

Figure 5 illustrates the effect of different building operational hours on gas and electricity use. A low end scenario would reduce the consumption by only 2% and 47% for gas and electricity while the higher estimate sees energy consumption by increase by 3% and 24%. The impact of varying operational hours on the range of different energy uses within the building is also illustrated in terms of high and low scenarios in Figure 6.

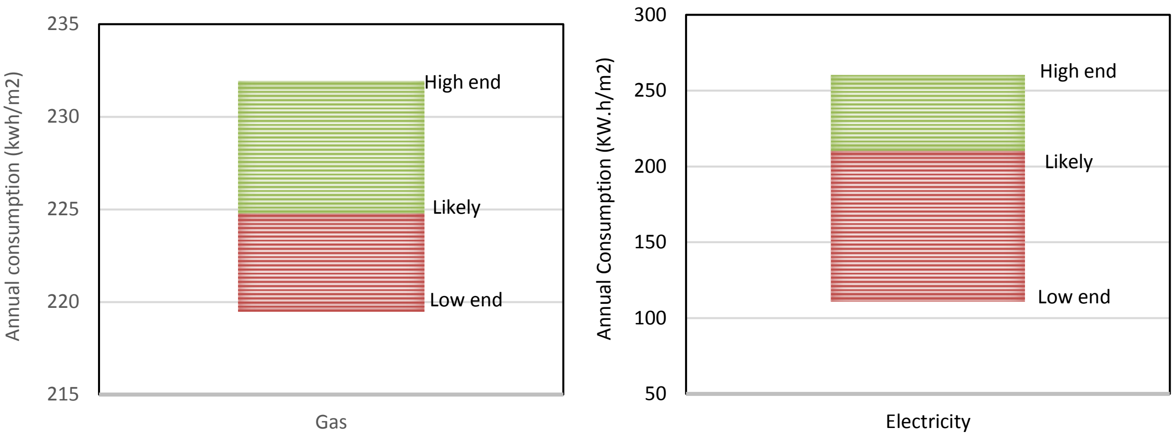

Figure 5: TM54 estimate for Gas and electricity due to change in the operation hours

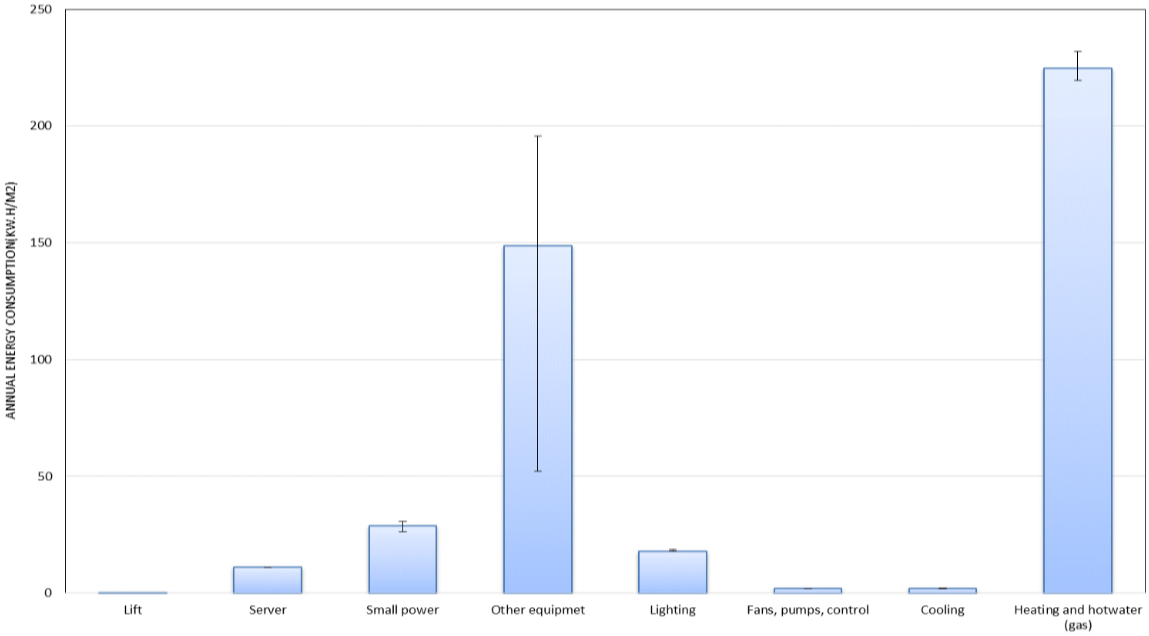

Figure 6: Impact of change in building operation hours on different consumptions using TM54 (error bar shows high end, low end)

A sensitivity analysis for the case study building is graphically demonstrated in Figure 7. This chart shows the varying proportions of building energy streams under different scenarios. It can be seen from the diagram that some of the proposed parameters have significant effects on calculated energy use. For example a 4% change in boiler efficiency make a very small difference in overall energy use (only 4% reduction), whereas reducing the operating hours (during day time) by one hour per day provides an 10% reduction. The relationship between the varied operational factors and their effect on energy use suggests some guidance in comparing future energy use predictions. These are:

- The importance of reviewing the assumptions with the prospective operators
- The importance of only presenting the results alongside the assumptions that used to generate the results.
- The value of carrying out an evaluation of estimated energy use in order to identify where to focus attention

Furthermore, the potential impact of weather conditions on the estimate can be tested. For the case study building the DMS was run with CIBSE future weather data (UKP02) scenarios for 2020 High Greenhouse emissions scenarios (CIBSE, 2009) in order to explore how increase temperatures will affect energy use. For the case study, there was 8% reduction in the heating energy use and 6% increase in cooling energy use.

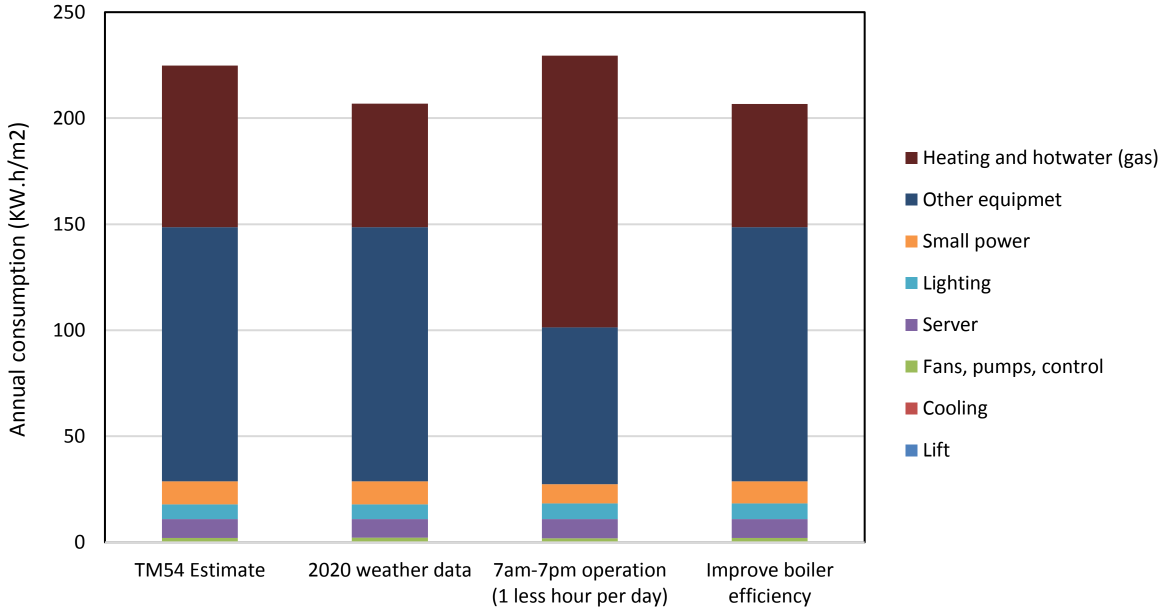

Figure 7: Comparison between different operation conditions in the building using TM54

5. Conclusions

An ideal method for managing energy in buildings would begin at feasibility stage and would be a critical element in planning for design, installation and operation. Metering and logging would feature heavily and data quality parameters would be focussed on ensuring that the information gathered was accurate, up to date, representative and of practical value. This method would be incorporated into a management system in which data was assessed which, where necessary initiated appropriate action. For a great many buildings, particularly older constructions this is not the case and facilities managers must determine and infer energy performance from imperfect information.

This paper has considered how the energy performance of an existing building could be analysed using the typical data sources which are available to facilities managers. These data sources tend to be utility meter readings, DEC's, and a schedule of operational hours. In this case the meter readings, and consequently the DEC's, must have been based on estimates since neither electricity nor gas for this building was directly metered. The paper recognises the difficulties facing many facilities managers who carry operational energy responsibility for design decisions they had no part in, and whose day-to-day priorities often place energy considerations below other business requirements. In this scenario, the availability of utility bills etc. tend to be a blunt instruments in that they do not provide sufficiently specific information.

The TM54 process has been developed by CIBSE as a design method which can help to eliminate or reduce the gaps between actual and predicted building energy use. This paper proposes that by applying the TM54 process to an existing building improved operational energy management can be achieved. For the case study building energy estimates were compared with utility bill information and benchmarks. These comparisons have exposed discrepancies which indicate that the present level of data is not satisfactorily accurate. However, energy use has been broken down under individual areas of use which means that instead of judging building performance against overall annual gas and electricity totals, energy can be monitored more specifically. It is not proposed that this technique can be developed in one session, but that its application over several heating and cooling seasons can enable initial approximations to be fine-tuned. By monitoring the energy used by lights, small power, lifts, heating etc. targets can be produced which, when compared with actual energy use will indicate how that particular energy stream is performing. It can also signal where faults have developed and when servicing is required.

By linking a design method to a system of post occupancy energy analysis, this paper sets out a strategy for developing an effective energy management system which may be particularly useful for existing buildings in which metering and measurement apparatus is not present. The case study building featured in the report is an extreme example of this kind of situation in that neither gas nor electricity supplies were metered. It is unlikely that the suggested strategy will yield immediate benefits but if it is applied over a suitable period valid and results can be obtained.

References

Azhar, S.; Brown, J.; Farooqui, R. 2009 BIM-Based Sustainability Analysis: An Evaluation of Building Performance Analysis Software. In Proceedings of the 45th ASC Annual Conference, Gainesville, FL, USA, 1–4 April 2009.

Blight TS and Coley DA. 2013 Sensitivity analysis of the effect of occupant behaviour on the energy consumption of passive house dwellings. Energy and Buildings 66: 183–192.

Bordass, B., Leaman, A and Ruyssevelt, P. 2001 Assessing building performance in use 5: conclusions and implications. Building Research & Information 29(2): 144–157.

BUNN, R. & WAY, M. 2014. The Soft Landings Framework [Online]. Usable Buildings Trust. Available: https://www.bsria.co.uk/services/design/soft-landings/ [Accessed 12th July 2016].

CHESHIRE, D., MENEZES, A. C., BACON, M., CRIPPS, A., FULBRIGHT, X., GRAHAM, B., HOLDING, A., MCLAUGHLIN, M. & WILSON, J. 2013a *Evaluating operational energy performance of buildings at the design stage,* London, CIBSE.

CHESHIRE, D. M., MENEZES, A. C., BACON, M., CRIPPS, A., FULBRIGHT, X., GRAHAM, S., HOLDING, A., MCLAUGHLIN, M. & WILSON, J. 2013b. *Evaluating operational performance of buildings at design stage,* London, CIBSE.

CHURCHER, D. 2013 Life Cycle Assessment : an introduction, Bracknell, BSRIA.

Fathi, S., Srinivasan, R.S. 2015 ANALYSIS OF ENERGY PERFORMANCE OF UNIVERSITY CAMPUS BUILDINGS USING STATISTICAL AND ENERGY MODELING APPROACHES. Proceedings of the 2015 Winter Simulation Conference

FIELD, J., BORDASS, W., BRUHNS, H., COHEN, R., DELORME, L., DAVIES, H., IRVING, S., JONES, P., LILLICRAP, C. & MARTIN, P. 2008. Energy Benchmarks TM 46, London, CIBSE.

GUMMER, J., CHATER, N., FANKHAUSER, S., HOSKINS, B., JOHNSON, P., KING, J., KREBS, J., LEQUERE, C. & SKEA, J. 2013 Meeting Carbon Budgets. Progress report to parliament 2013. London: Committe on Climate Change.

Laurence, R. 2015 Design for Flexiliobilty in Low Cabon office.In: the 7th international Confrence on Sustainable Devolpment in Building and Engineering.27-29 Juluy, University of Reading, Uinversity of Cambriadge and Chongqing University. ISBN 978-0-9931207.01

MENEZES, A. C., CRIPPS, A., BUSWELL, R. A., WRIGHT, J. & BOUCHLAGHEM, D. 2014 Estimating the energy consumption and power demand of small power equipment in office buildings. *Energy and Buildings,* 75**,** 199-209.

Menezes, AC., 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: 355–364.

MIN, Z., MORGENSTERN, P. & MARJANOVIC-HALBURD, L. 2016 Facilities management added value in closing the energy performance gap. International Journal of Sustainable Built Environment, 5, 197-209.

Rankin, P., 2015 Predicting the energy use of the Cambridge base for the East Anglian Air Ambulance. CIBSE Journal, *CIBSE Journal***,** 20-24

Robinson, J.F., Taylor, P.G., Foxon, T.J. 2015 Performance gap analysis case study of a non-domestic building Engineering Sustainability. Volume 169 Issue ES1. Robinson, Foxon and Taylor.

SOARES, N., PEREIRA, L. D., FERREIRA, J., CONCEIÇÃO, P. & SILVA, P. P. D. 2015. Energy efficiency of higher education buildings: a case study. International Journal of Sustainability in Higher Education, 16, 669-691.

Stadel, A.; Eboli, J.; Ryberg, A.; Mitchell, J.; Spatari, S. 2011 Intelligent sustainable design: integration of carbon accounting and building information modeling. J. Prof. Iss. Eng. Ed. Pr. 2011, 137, 51– 54.

Stundon, D., Spillane, J., Lim, J. P. B., Tansey, P., & Tracey, M. (2015). Building Information Modelling Energy Performance Assessment on Domestic Dwellings: A Comparative Study. In A. B. Raidén, & E. Aboagye-Nimo (Eds.), Proceedings for 31stAnnual ARCOM Conference (pp. 671-679). ARCOM.

TRUST, C. 2012 Closing the gap:lessons learned on realising the potential of low carbon building design. Available: **https://www.carbontrust.com/home/** [Accessed 7th February 2017].

WARBURTON, P., ARMSTRONG, J., ARNOLD, D., CRISP, V., GLENNY, T., HARROLD, M., HODGSON, T., KNIGHT, R., MCDERMOTT, P. & TUOHY, P. 2009. *Building Control Systems,* Londob, CIBSE.

WEBSTER, M. 2015 Delivering an energy efficient design - TM54 modelling. *British Land sustainability articles* [Online]. Available: **http://www.britishland.com/sustainability/blogs/articles/2015/delivering-on-energy-efficient-design-tm54-modelling**.

Workie, M.D .2015 Thermal Mass Modelling in Whole Building Simulation Tool, For Model Predictive Control of Peak Demand Limiting and Peak Load Shifting. Phd Thesis, University of Strathclyde.

WRIGHT, B., LILLICRAP, C., CHESHIRE, D., TREANOR, J., LINDEY, M., COTTON, M., MCDONALD, N., LYNES, P. & JONES, P. 2013 *CIBSE Guide F* [Online]. UK Green Building Council. Available: **http://www.ukgbc.org/resources/additional/pinpointing-discussion-cibse-guide-f** [Accessed].

Appendix A: Building operation hours and total power for different equipment and services for the actual estimate

	Operation time	Total Power (Watt)
Light	8 hrs daylight time usage and 4hrs non- daylight time usage)@ 48 weeks* 5days	7889
Small power:		
Computers	8hrs@ 48 weeks* 5days with sleep mode hrs	150 for number of 37
Screens	8hrs@ 48 weeks* 5days with sleep mode hrs	45 for a number of 37
Printer	3hrs@ 48 weeks* 5days with sleep mode hrs	320
Photocopier	3hrs@ 48 weeks* 5days with sleep mode hrs	1100
Scanner	3hrs@ 48 weeks* 5days with sleep mode hrs	1100
Coffee/vend	3hrs@ 48 weeks* 5days with sleep mode hrs	120 for a number of 2
Fridge	24 hrs@ 48 weeks* 5days with sleep mode hrs	350 a number of 2
Microwave	3hrs@ 48 weeks* 5days with sleep mode hrs	800 a number of 2
Other Equipment		
Fume Cupboards	3hrs@ 48 weeks* 5days	1500
Workshop 1 machineries	3hrs@ 48 weeks* 5days	64325.56
Workshop 2,3	3hrs@ 48 weeks* 5days	94927.04
Lab1	3 hrs@ 48 weeks* 5days	49961.6
Lab2	3 hrs@ 48 weeks* 5days	54957.76
Special teach	3 hrs@ 48 weeks* 5days	61827.48
Toaster	2 hrs@ 48 weeks* 5days	1.5
Kettle	3.5 hrs@ 48 weeks* 5days	1.5
Hand dryer-Toilets	3.5 hrs@ 48 weeks* 5days	1.5
Server Rooms	3 servers for 365 days@24hrs	1000
Lift	6 times per month@ 48 weeks* 5days	344
Hot water	8 litres per person for 63 occupants @48 weeks* 5days	-
Space heating	7pm-7pm (Oct-April)	-
Space cooling	7pm-7pm (June-August)	**-**
Occupancy	63 person distributed at different density	

Appendix B:

Location	**Operative Temperature**
Circulation area	20^0C
Food preparation area	20^0C
Workshops	19^0C
Labs	19^0C
Offices	20^0C
Toilets	20^0C