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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

40 teams to provide an after-care service which can deal with some of the post-occupancy
41 problems which may not have been apparent at building handover stage. However, eventually
42 the operation and management of the occupied building will become the responsibility of
43 facilities managers.

44
45 The life cycle energy used by a building during its operational phase is between 80% and 90%
46 of its total life cycle energy (Churcher, 2013). Therefore management of energy use during
47 this period can have a critical influence on building carbon emissions. The process of
48 managing energy in buildings can vary in complexity from simply ensuring that utility bills are
49 accurate to operating a system which monitors and controls the various energy using services.
50 CIBSE (Warburton et al., 2009) recommend that monitoring and targeting of energy use can
51 control energy use by “monitoring consumption and comparing it against historical data and
52 benchmarks”. CIBSE publish benchmarks for a range of building types and are easily
53 accessible, whereas valid historical data requires to have been compiled and catalogued.

54
55 In response to the problem of the performance gap, CIBSE have developed TM54 (Cheshire
56 et al., 2013a) which is a technical manual which provides guidance for the estimation of
57 building operational use at design stage. The TM54 method recognises the value of dynamic
58 software, which can simulate heating and cooling loads. It also proposes the use of more long
59 hand type methods for the assessment of those loads which can be heavily influenced by
60 occupant behaviour. It is recommended that energy assessors determine how and when
61 buildings will be operated. This may be achieved by a combination of access to logged data
62 and from interviews with building users.

63
64 Two approaches to the application of the TM54 process can be seen in how it has been used
65 for forecasting energy use for a new air ambulance operational base (Rankin, 2015) and how
66 British Land (Webster, 2015) have made use of the process for evaluating operational energy
67 use in completed buildings. In the case of East Anglian Air Ambulance, it was considered that
68 the improved confidence in energy modelling enabled the client to make informed decisions
69 as the design progressed and avoided the “natural” tendency for designers to be over-
70 optimistic. Nevertheless, it was still necessary to explore different scenarios with a range of
71 forecasts which will need to be compared to actual performance data when it becomes
72 available. For the British Land project, the energy performance of a recently completed
73 building in the City of London was examined. In this case the TM54 process was applied using
74 actual occupancy data. It was found that TM 54 provided “robust performance benchmarks
75 and targets, as well as feedback to design teams on the impact of their design”. But, this

76 examination also recognised that, in order for modelling to be meaningful, it needed to be
77 “revisited through the design process and into the operational phase of the building”.

78
79 The importance and relevance of energy use within university buildings has been recognised
80 by initiatives such as Carbon Buzz, Display Energy Certification and other statutory
81 requirements. With regard to educational buildings, not only does this raised awareness
82 enhance the motivation of researchers, but it also has practical implications for estate and
83 business managers. The aims of reducing emissions and associated fuel costs require an
84 appreciation educational building energy use in order that solutions can be developed. Fahi
85 and Srinivasan (2015) have explored how modelling/simulation and statistics could be applied
86 to identify the characteristics of particular buildings in order to evaluate building performance
87 and the effectiveness of energy saving measures. Although this report concluded that energy
88 and financial savings were feasible, it differs from the TM54 process in that more of the
89 analysis was based on dynamic modelling. Another approach in analysing building energy
90 was the basis of an examination by Soares et al (2015) whereby an audit of electricity, gas
91 and water usage at was combined with a web-based survey aimed at “engaging the entire
92 academic community “in order top also investigate behaviour patterns. Behaviour effects on
93 energy use are also part of the TM54 process, though the methods for its assessment suggest
94 that audited data is combined with face-to- face stakeholder interviews. Also Laurence, (2015);
95 Robinson et al., (2015); Blight and Coley, (2013); Menezes et al., (2012); Bordass et al.,
96 (2001) were used CIBSETM54 for assessing energy prediction and the performance gap, in
97 order to raise important questions about decisions made at the design stages that impact on
98 energy performance over a building’s lifespan.

99
100 Although the TM54 document has been prepared for use by designers, this paper considers
101 how the methods set out in TM54 can assist in the energy management of operational
102 buildings for situations where no valid historical information is available, or where data exists
103 but is simply annual gas and electricity totals. The reasoning behind this approach is that the
104 TM54 method identifies energy use and allocates it against the various energy streams for
105 buildings. The paper also considered different scenarios to address the uncertainties as a
106 result of building operation and global warming and system efficiently. This paper showed that
107 whilst energy estimates were judged to be improved, it was still considered necessary for
108 engineers to apply judgement and to use these forecasts as a reliable basis on which to
109 improve designs. Where it can be said that the TM54 process clearly adds value to the current
110 case study in identifying energy streams and thereby contributing to an enhanced system of
111 energy accounting.

112
113

114 **2. Case Study**

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

129
130 **3. Methodology**

131
132 Investigating the energy use for this workshop involved four processes:

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

143
144 **3.1 Survey**

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

150

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

170
171 Laboratory equipment energy use estimates are also dependent user behaviour. In this
172 particular situation, some of the equipment is old and much of the equipment is more of a
173 “one-of” nature than a mass produced product so no bench marks exist. This is further
174 complicated because, in the recent past academic operational factors took priority over any
175 need to monitor or measure energy use. An estimation of energy use for this equipment has
176 required an investigation into individual item power specifications combined with operational
177 hours of use information. Power requirements are accessible from machine nameplates etc.
178 but time periods are dependent on the judgement and memory of laboratory staff.

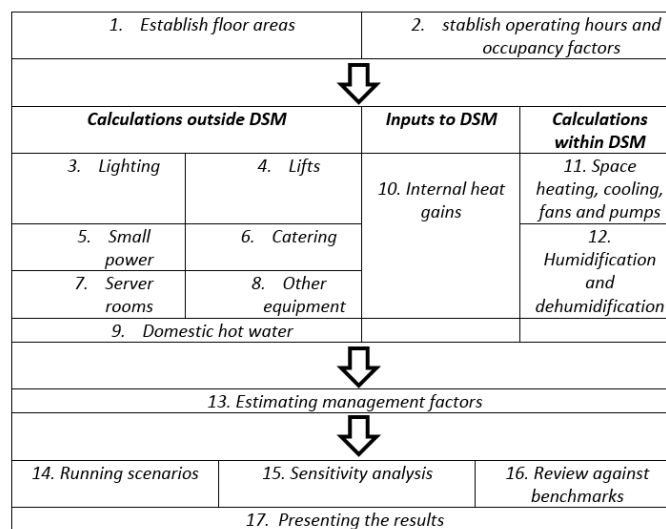
179
180 The energy workshops are considered to be public buildings and, as such require a Display
181 Energy Certificate (DEC), which for this size of building must be renewed annually. DEC’s are
182 based on annual energy use and therefore provide a historical record of energy use. Though
183 this is very useful, the DEC’s only record annual electrical and fossil fuel totals. These are not
184 broken into sub-headings so although they can indicate general overall trends they are less
185 helpful in pin-pointing specific energy using areas.

186
187

188 **3.2TM54 assessment**

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

196 Figure 1 summarises the methodology for evaluating energy use, including a summary of the
 197 activities required at each step.
 198



199
 200 **Figure 1:** Methodology for evaluating energy used in the design using TM54 estimate (Cheshire et al.,
 201 2013)
 202
 203

204 **Calculation outside the DSM:**

205 **Step 1:** Establishing Floor Areas:

206 Treated floor area is used as the basis for the energy calculations in this methodology. The
 207 logic of this approach is that it includes only the areas of the building that are serviced by plant
 208 and equipment. Treated floor area for the case study has been taken as 95% of total gross
 209 area as recommended by CIBSE Guide F (2012) that gives a total Treated floor are of
 210 1594.19m².

211
 212 **Step 2:** Estimating Operating Hours and Occupancy Factors

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

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

219
 220 Annual energy use (KW.h/year) = energy use for illumination (w_l) + parasitic energy (w_p) (1)

$$221 W_1 = \sum \{ (P_n \times F_c) \times (t_d \times F_o \times F_d) + (t_n \times F_o) \} / 1000 \quad (2)$$

$$222 W_p = \sum (W_{PC} + W_{em}) \quad (3)$$

223 Where:

224 P_n = Total Installed Power in the Room (W)

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

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

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

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

229 W_{pc} = Parasitic Control Annual Energy Consumption (5KW.h/m²)

230 W_{em} = Parasitic Emergency Annual Energy Consumption (1kW.h/m²)

231
 232

233 **Step 4:** Evaluating energy use for Lift

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

$$237 E_L = (SPt_h/4) + E_{standby} \quad (4)$$

238 Where:

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

240 S is the number of starts made per year

241 P is the rating of the drive motor (kW)

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

244 $E_{standby}$ is the standby energy used by a single lift in one year (KW.h)

245

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

249

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

252 Annual energy consumption (KW.h) =

$$253 \text{ number of working stations } \times \left(\frac{\text{average power consumption during operation} \times \text{annual}}{\text{hours of operation}} \right) +$$

$$254 (\text{sleep mode consumption} \times (8760 - \text{hours of operation})) \quad (5)$$

255
256 Details of power consumption and hours of operation for the equipment are presented in
257 Appendix.

258
259 **Step 6:** This building does not have catering facilities other than items listed under small power
260 in step 5.

261
262 **Step 7:** Energy used by server rooms is determined from the product of power and operational
263 time;

$$\begin{aligned} 264 \quad & \text{Annual energy consumption (KW.h)} \\ 265 \quad & = \text{number of rooms} \times \text{rated power demand} \times \text{ratio of rated to operational power demand} \\ 266 \quad & \times \text{hours of operation} \end{aligned} \quad (6)$$

267
268 **Step 8:** Other equipment for this installation includes the machinery and equipment used in
269 the workshops and laboratories. For this building some of the equipment is unique and may
270 be considered to be non-typical for educational applications. The product of power and
271 operational hours is used but specific operating periods are related to research and
272 experimental use which has been difficult to quantify (equipment details: appendix A)

273
274
275 **Step 9:** Annual energy use to provide domestic hot water is found from the product of annual
276 mass flow of water use and energy required to raise its temperature from 5⁰C (cold feed water)
277 to 65⁰C (storage temperature). Annual domestic hot water usage has been obtained from
278 CIBSE Guide G.

$$\begin{aligned} 279 \quad & \text{Mass of water (Kg) =} \\ 280 \quad & \text{daily water consumption per person} \left(\frac{l}{\text{person}} \right) \times \text{density of water} \left(\frac{\text{Kg}}{l} \right) \times \text{number of occupied days} \quad (7) \\ 281 \quad & \\ 282 \quad & \text{Annual energy consumption (KW.h/year) =} \\ 283 \quad & \text{mass of water (Kg)} \times \text{temperature difference (K)} \times \text{specific heat capacity of water} \left(\frac{\text{KJ}}{\text{Kg}} \cdot \text{K} \right) / 3600 \quad (8) \end{aligned}$$

285 286 **3.3 Dynamic simulation modelling (DSM)**

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

290
291 The DSM that has been carried in this study using Integrated Environmental Solutions, Virtual
292 Environment (IES-VE) software. IES-VE has been used by many studies in building
293 information modelling and energy analysis eg. Stundon et al., (2015); Workie, (2015). Azhar
294 et al. (2009) conducted an evaluation study in which they compared the capabilities,
295 advantages, and disadvantages of three Building Energy Management (BEM) tools (Ecotect,
296 Green Building Studio, and IES VE). They concluded that IES VE was the strongest of the

297 three BEM tools based on its range of analysis options. Stadel et al. (2011) showed how
298 certain BIM platforms (e.g., Revit) can be used in connection with IES VE for performing
299 lifecycle analysis in order to estimate the environmental impact (in terms of lifecycle energy
300 consumption and greenhouse gas emissions) of building materials from the cradle to grave
301 phases.

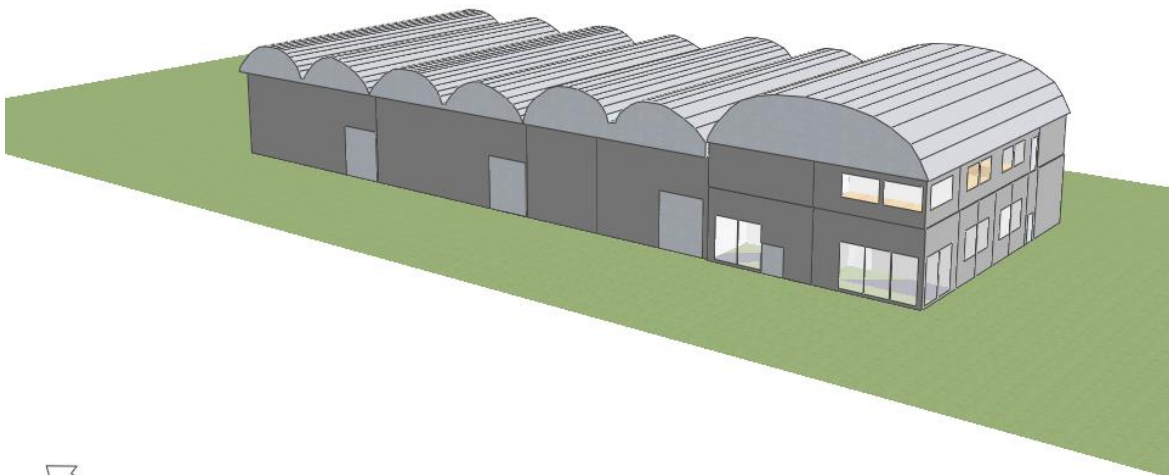
302

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

309

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

318



319

320

Figure 2: IES-VE model

321

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

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

331
332 The use of dynamic simulation modelling (DSM), like all design methods relies on accurate
333 data upon which to determine outputs. Capable designers should be sufficiently competent to
334 input reasonably representative design values for temperature, insulation, air change rates,
335 internal heat gains etc. They should be experienced enough appreciate the levels of accuracy
336 this kind of input data will generate, knowing that actual designs need to be practical given
337 that actual building services engineering systems will not be operating under laboratory
338 conditions.

339
340 However, DSM's also require input data regarding occupancy, hours of operation and
341 schedules for particular usage of office machinery. For current case study although plant
342 operational times are programmed into the building management system, controls can bring
343 plant on line during non-occupancy periods. This occurs where outside temperature conditions
344 could create frost damage internally, or else to reduce the energy needed to bring internal
345 conditions to comfort levels during morning start-up. This facility has been incorporated into
346 the simulation model. The operating temperature for different zones in the case study has
347 been presented in Appendix B and overnight temperature is maintained at lower temperature
348 of 10°C and if the room temperature dropped below this the heating will operate.

349
350 These factors can have significant effects on calculated annual loadings, particularly if
351 excessive margins are applied. Despite its critical nature, unlike some other forms of data, this
352 information is not easily available from databases or design guides. To obtain an
353 understanding of how, when, and for how long the building and associated plant will operate,
354 designers need to interrogate clients, building users and their agents. This is not a
355 straightforward task. For new buildings there is an element of predicting the future. Although
356 for existing buildings occupants and facilities managers can be helpful, it is unlikely that
357 compiling historical data on building use has had a high priority. Ideally this kind of could be
358 logged automatically by means of a building management system.

359 360 **4. Results& Discussions**

361 The initial result of TM54 estimate for different energy uses is presented in Table1. The effect
362 of energy use by other equipment is, in this case significant but may not be typical and other

363 equipment of the Lab and workshop, small power and lighting consumes significant amount
 364 of energy while other uses showed relatively low consumption.

365

366 **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

367

368 **4.1 Display Energy Certificates and Benchmarks**

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

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

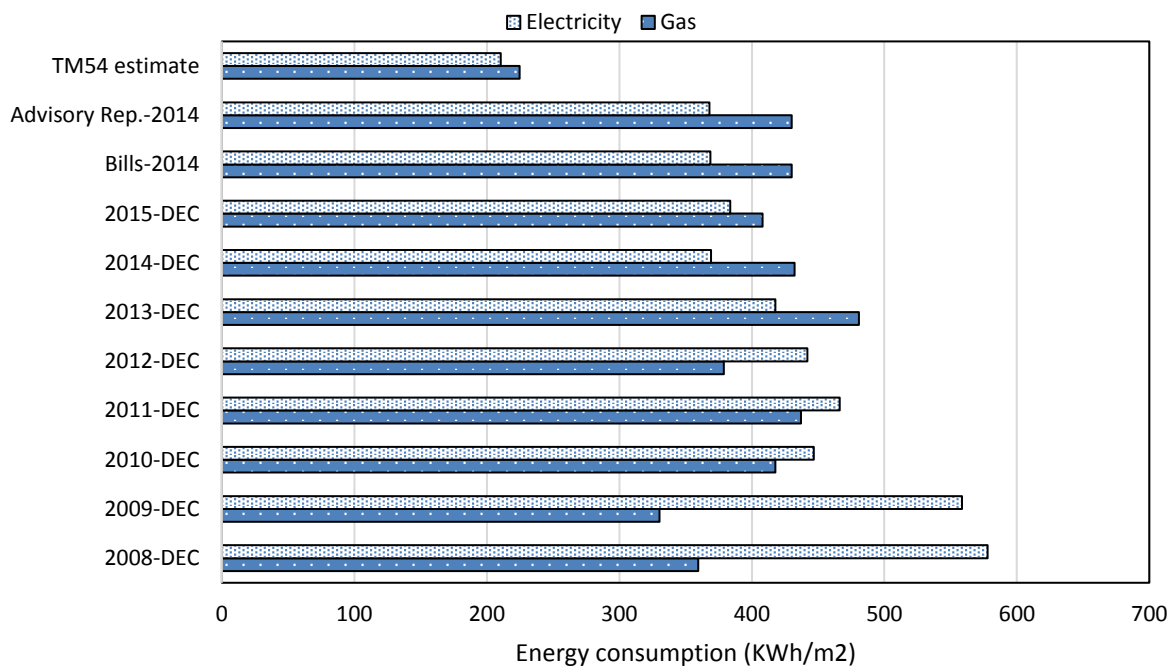
374 Min et al (2016) note that the phrase “performance gap” is normally applied to the difference
 375 between design and actual energy use for new buildings and that that it is unclear how this
 376 phenomenon is described for existing buildings but suggest that “FM gap” may be a more
 377 appropriate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

378

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

392 commissioning at handover and limitations to what facilities managers can achieve post
393 occupation.

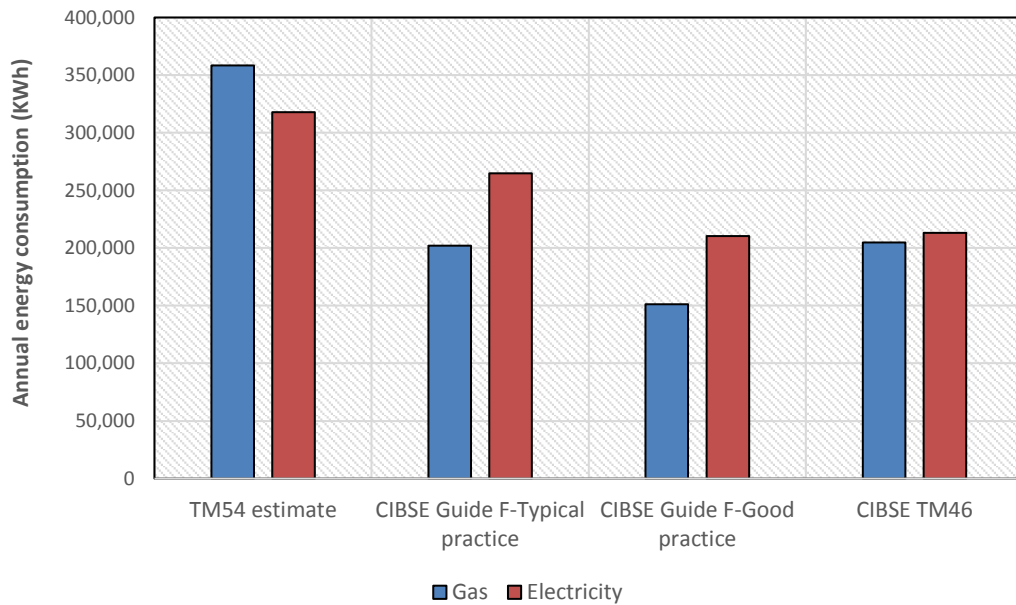
394
395 Perhaps the major finding from investigating electrical and gas use at the engineering
396 workshops was that monitoring of where and how much energy is used for this building has
397 historically had a low priority in this organisation. This is illustrated by the metering strategy,
398 or lack of it. But it should not be forgotten that the primary function of this facility is to contribute
399 to student education and research. It is important that this is primary organisational function is
400 recognised because this is the driving force that identifies the major responsibilities of the
401 teaching and support staff, including the facilities managers. This management strategy may
402 be related to why the energy supplies to this building are not metered, though it is more likely
403 that those responsible for managing energy presently were not involved at the design stage
404 for this building. Given the prevalence of existing buildings over new, many FM's must cope
405 with a legacy of problems that were created when designer and constructors operated in an
406 era when there was much less awareness of environmental issues and statutory regulations
407 set lower standards for energy performance.



408
409 **Figure 3:** Annual energy consumption data from DEC's
410

411
412 However, if TM54 values are compared with published benchmarks, the situation is somewhat
413 different. The graph below (Figure 4) illustrates how the TM54 estimate compares with
414 benchmarks from three CIBSE publications.
415

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



421 **Figure 4:** Annual energy consumption in the building compared to standards benchmarks, CIBSE TM
 422 46 (Field et al., 2008) and CIBSE Guide F (Wright et al., 2013)
 423

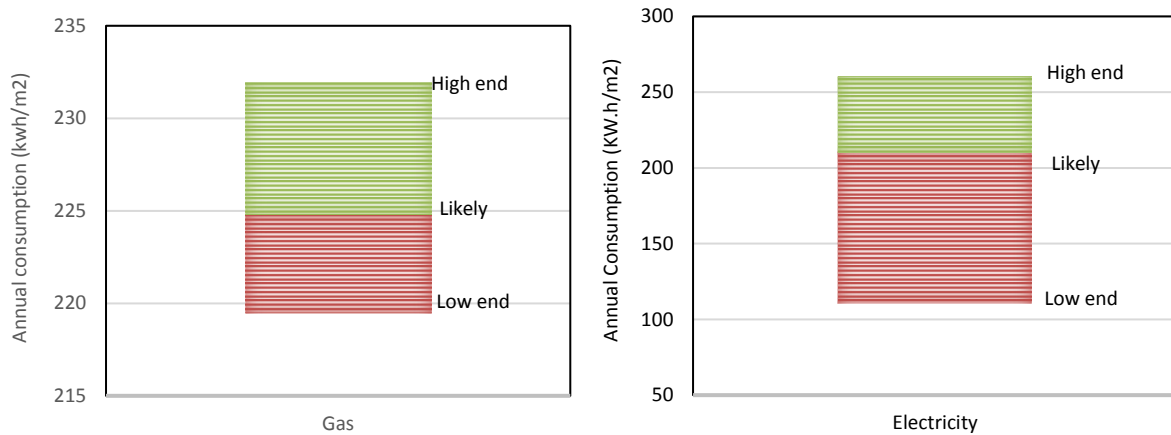
424
 425 **4.2 Sensitivity analysis**

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

- 429 a. Change in operational hours and impact on total energy consumption (Figure 5)
- 430 b. Change in operational hours for the lift, small power, machinery and building working hours
 431 (Figure 6)
- 432 c. A one hour shutdown during the daytime for heating, cooling, small power and machinery
 433 (Figure, 6)
- 434 d. Application of weather data based on predicted climate change effects. (Figure, 6)
- 435 e. Boiler efficiency (Figure, 6)

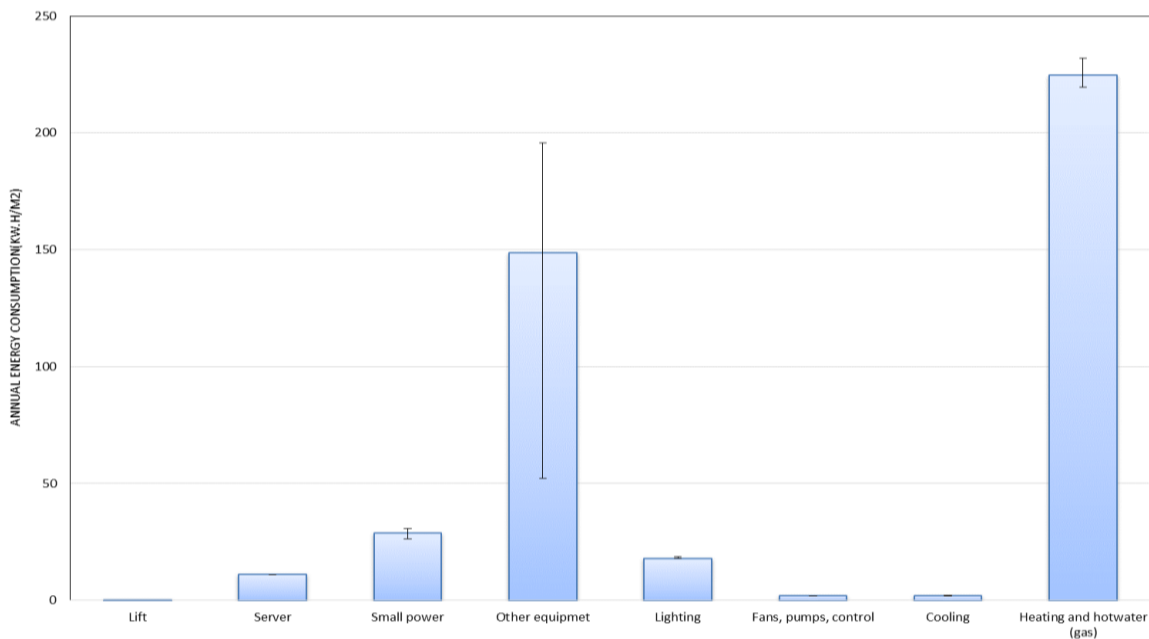
436
 437 If the results of the calculations (before scenarios are applied) are considered to be optimistic,
 438 then it is informative to examine the results from a low end scenario. Similarly, where the case
 439 study figure is pessimistic, a high end scenario offers perspective. For the case study, high-
 440 end and low-end scenarios were calculated by manipulating the variables listed in the previous
 441 paragraph.

442 Figure 5 illustrates the effect of different building operational hours on gas and electricity use.
 443 A low end scenario would reduce the consumption by only 2% and 47% for gas and electricity
 444 while the higher estimate sees energy consumption by increase by 3% and 24%. The impact
 445 of varying operational hours on the range of different energy uses within the building is also
 446 illustrated in terms of high and low scenarios in Figure 6.
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Figure 5: TM54 estimate for Gas and electricity due to change in the operation hours



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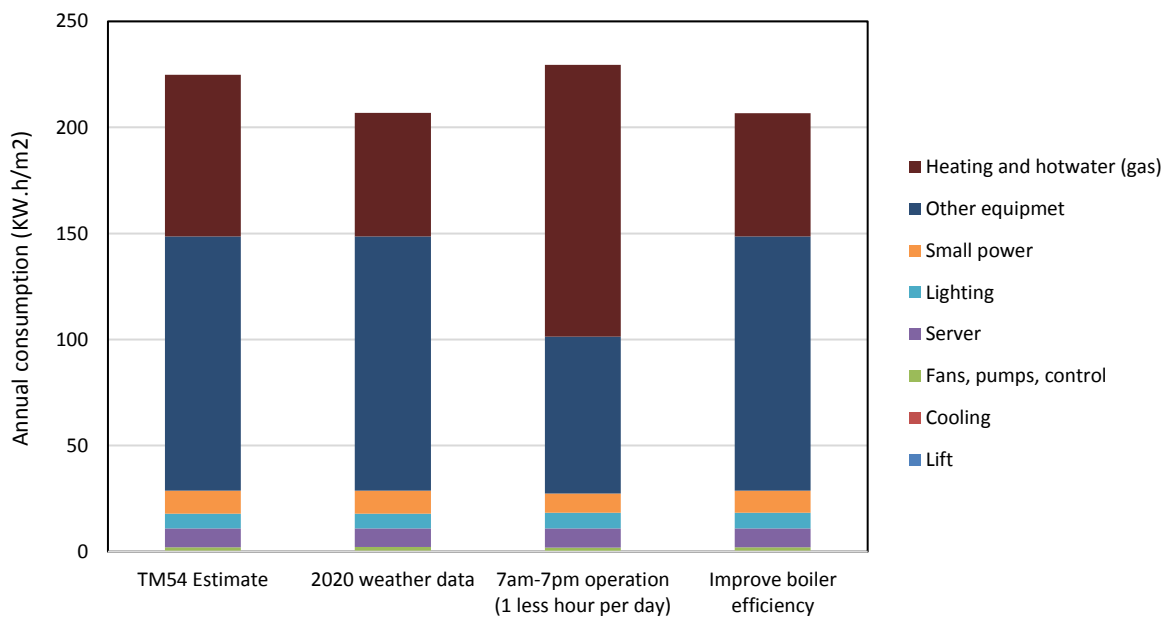
Figure 6: Impact of change in building operation hours on different consumptions using TM54 (error bar shows high end, low end)

455 A sensitivity analysis for the case study building is graphically demonstrated in Figure 7. This
 456 chart shows the varying proportions of building energy streams under different scenarios.
 457 It can be seen from the diagram that some of the proposed parameters have significant effects
 458 on calculated energy use. For example a 4% change in boiler efficiency make a very small
 459 difference in overall energy use (only 4% reduction), whereas reducing the operating hours

460 (during day time) by one hour per day provides an 10% reduction. The relationship between
 461 the varied operational factors and their effect on energy use suggests some guidance in
 462 comparing future energy use predictions. These are:

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

468
 469 Furthermore, the potential impact of weather conditions on the estimate can be tested. For the
 470 case study building the DMS was run with CIBSE future weather data (UKP02) scenarios for
 471 2020 High Greenhouse emissions scenarios (CIBSE, 2009) in order to explore how increase
 472 temperatures will affect energy use. For the case study, there was 8% reduction in the heating
 473 energy use and 6% increase in cooling energy use.
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 476 **Figure 7:** Comparison between different operation conditions in the building using TM54

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 478 **5. Conclusions**

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 481 An ideal method for managing energy in buildings would begin at feasibility stage and would
 482 be a critical element in planning for design, installation and operation. Metering and logging
 483 would feature heavily and data quality parameters would be focussed on ensuring that the
 484 information gathered was accurate, up to date, representative and of practical value. This
 485 method would be incorporated into a management system in which data was assessed which,
 486 where necessary initiated appropriate action. For a great many buildings, particularly older

487 constructions this is not the case and facilities managers must determine and infer energy
488 performance from imperfect information.

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

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

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

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612 **Appendix A:** Building operation hours and total power for different equipment and services for the
 613 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	

614
 615 **Appendix B:**

Location	Operative Temperature
Circulation area	20°C
Food preparation area	20°C
Workshops	19°C
Labs	19°C
Offices	20°C
Toilets	20°C

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