The 'Mind the Gap' project: Investigating the difference, in performance, between design and the building 'in-use'

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Abstract. We have the ability to design and construct high performance buildings; and the knowledge and skills to operate them in an effective and efficient manner — so why does it not happen? The underpinning reasons for this gap in performance are generally unknown; there is a lot of speculation and hypothesis but little investigation and hard evidence. The 'Mind the Gap' project aims to collect evidence from typical exemplars of office buildings investigate the reasons for their performance and determine the underpinning causes. The first phase of the project will produce a methodology based on the learnings from five trial buildings and then rolled out in a second phase over a larger number of buildings. This paper presents some initial data and findings.

1 INTRODUCTION

The difference in performance between those predicted from the design and those found in actual operation are well documented [1,2]. The construction industry has in general been 'designing for compliance' using software with 'standardised driving conditions'; where standard conditions in terms of occupant behaviour and plant performance are assumed (see below). This is the start of the gap with real performance in-use; where the compliance software allows assets to be compared but the performance of the actual building in-use is not estimated properly. We know how to build good performance buildings, but the issue seems to be having the design intentions and predictions of performance feed through to performance in-use [3]. We can start to bridge this gap by 'baselining' the predicted performance of the building by using the Green Deal (GD) tool or Dynamic Simulation Models (DSMs) which allow the input of non-standard operating conditions, hours of operation and occupancy patterns, etc. By defining these aspects of the building 'in use', the predicted energy performance of the asset can be brought closer to the in-use reality [4]. This has been recognised by sustainability standards such as the BRE Environmental Assessment Method (BREEAM); the latest scheme to be updated BREEAM New UK Construction 2018 [5] has credits for using DSMs in the Energy Prediction and Post Occupancy Assessment Methodology [6]; the intention is to extend this to the UK BREEAM Refurbishment and Fit Out and the corresponding international schemes in the future. However, this only deals with the initial and smaller part of the poor performance issue but does 'baseline' the building. All of this has led to what has been termed the performance gap. In reality, this has two components (see Figure 1):

- The compliance gap; and
- Actual performance gap.

The overall gap has been estimated at between 200–450 per cent [7] of which the modellers estimate 50–70 per cent is the compliance gap [8] and can be solved with more realistic modelling, such as DSMs, mirroring the conditions in operation more closely as described earlier. However, the underpinning reasons for the second and larger actual performance gap are generally unknown. There is a lot of speculation and hypothesis but little investigation and hard evidence. The 'Mind the Gap' project is set-up to investigate this aspect in particular.

2 THE PERFORMANCE GAP

2.1 Why is this so important?

The management of real estate investments aims to maximise property value and return on investment (ROI) [9] via:

- Effective risk management;
- Efficient property management;
- Identification and implementation of valuable improvements.

A high-performing building generates maximum profit

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via:

- High and continuous rental income;
- Low operating and maintenance cost;
- Low depreciation.

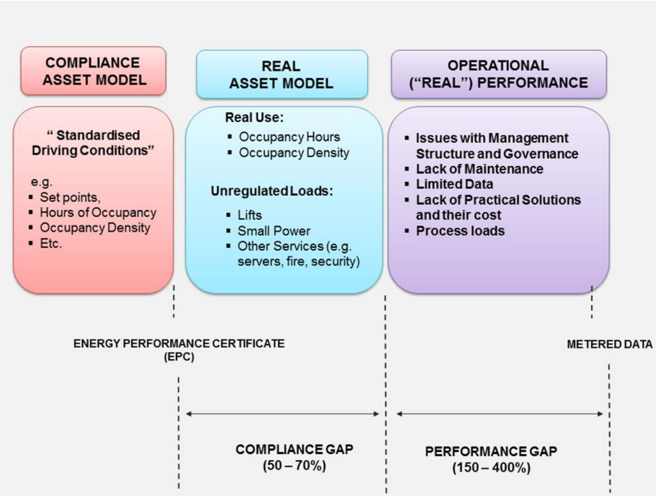

Fig. 1. The difference between design and the building 'in-use'

However, poor operational management also undermines the aims of asset management [1, 2] and leads to:

- Increased tenant complaints regarding comfort conditions and loss of reputation;
- Higher service charges;
- Longer void periods leading to a reduction of income;
- Lower and shorter rental values, as a consequence of high service charges and poor comfort conditions;
- Capital expenditure on heating, ventilation and air conditioning (HVAC) equipment failures, due to poor maintenance;
- Tenants wanting to renegotiate rent values based on comfort and maintenance issues.

On a pure cost basis, the operation energy or the energy used in using a building is up to 50 per cent of the operation costs or 40 per cent of the total cost of a building (see Figure 2).

Fig. 2. The life costs of a building

If this is inflated by a multiple of 2 to 4.5 [2] the cost to the end user is considerable. However, if the occupier is leasing these may just be passed onto them and they more not have much say in the management of the building.

The effect on the asset and its value is just as dramatic with:

- Deterioration of value;
- Service life of plant reduced;
- Fabric lifetime reduced;
- Costly remedial works to maintain value;
- In 'void' periods where there is likely to be still further deterioration through lack of use;
- Loss of reputation.

2.2 So why does the performance gap persist?

The following have been put forward by various parties as the underpinning reasons:

- Lack of knowledge
  - How assets and their components perform in practice;
  - What is buildable and functional;
  - How design strategies perform in practice;
- Poor communication and buy-in
  - The design intent gets lost
    - designers → constructors/installers → building managers
  - No feedback on actual performance
    - Building managers → constructors/designers → designers;
- Rarely any consequences
  - For designers, contractors and suppliers when actual energy consumption exceeds predictions;
  - The occupier ends up picking up the bill;
- The contractual model is wrong
  - Based on lowest cost rather than value for money;
  - Insufficient resources in place;
  - Authority not being devolved along with responsibility;
  - Roles and responsibilities unclearly defined and understood;
  - Management structure unable to act on this knowledge;
  - Skills sets lacking, and training needed;
  - Insufficient good quality data and not being captured properly;
  - Insufficient knowledge and expertise;
  - Unable to turn data into information;
  - None or inaccessible specialists in the supply chain.

2.3 Investigating the gap

The BRE has previously attempted to close the gap by using the GD tool to map Energy Performance Certificates (EPCs) onto Meter readings [4,10] although this approach has merit, the sliding energy management scale has little underpinning research to support the assumptions and no verification has been carried out to support these judgment calls by expert groups.

Anecdotal evidence from the asset management industry has indicated several possible reasons:

- Issues with the management structure and governance;
- Lack of maintenance due to resource and skills shortage;

- Limited data;
- Lack of practical solutions and their costs.

In fact, nobody knows the reasons why; which presents an opportunity for whoever finds the evidence for the underpinning causes and practical solutions to solve them.
This has been recognised by the construction industry and priorities that were fed back from the UKGBC Delivering Building Performance task group [1], the UK Innovate Building Performance project [2] and a BSRIA event on building efficiency [11] were:

- There was data on the performance gap but no systematic investigation of the reasons why and the magnitude of the issues — what was needed was a controlled study to investigate this; not attempting to link datasets;
- Design was not considered an issue, but operation and the associated issues seemed to be the cause, however there is only anecdotal evidence to support this. A study is needed to codify and quantify the causes of poor performance in use;
- The 'gap' seems to increase with time, again anecdotal evidence is available with no quantification of the underlying reasons; with a long-term study needed to identify, qualify and quantify any affect;
- Health and wellbeing is associated with this effect but, as before, there is not true quantification, model or tool; as a result, a monetary value cannot be assigned to the loss/gain of productivity leading to an incomplete business case. A desk study is needed to identify knowledge gaps followed by a field study producing data leading to a model/tool for quantification of productivity loss/gains.

A recent study on refurbishment has supported this view point in that a holistic people-centric renovation of a typical office building can lead to up to a 12% increase in productivity. At a European scale, that could be worth up to €500 billion [12].

The main barrier to providing systematics solutions is the lack of quality data from a large enough sample with full access to the building and their occupants — BRE and its partners have been presented with that opportunity.

We now have 'real-life' exemplars to investigate the actual causes of the performance gap and propose practical solutions.

2.4 The 'mind the gap' research project

This research project is in two stages: where the on-going first stage defines the methodology using five trial buildings to determine the correct data to collect and the right questions to ask; with a proposed second stage rolling this out over a larger number of buildings.

The objective of this project is:

1. Scope proposed buildings and choose suitable five trial buildings which are typical exemplars of office buildings for the purpose of collection and analysis of metered, asset and energy audit data (see Figure 3).
2. Using the results from the scoping phase, propose reasons for the performance gap; produce operational and asset recommendations; and model the benefits.
3. Based on the learning from these trial buildings produce a methodology that can be rolled out to a larger number of buildings.
4. Propose a second phase covering more office buildings, which covers the breath of the building stock in this sector and aims to produce a tested generic methodology for the office sector, which includes:
    a. Fully air-conditioned;
    b. Mechanical vented; and
    c. Naturally ventilated.

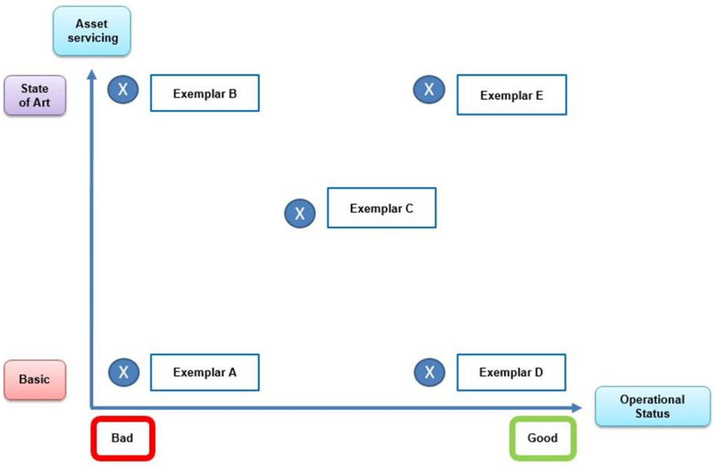

Fig. 2. The choice of exemplar buildings

2.5 The initial methodology

The initial methodology is laid out in the following steps:

1. To scope proposed buildings and choose suitable exemplars;
2. Hold an inception meeting for each of the buildings, along with targeted follow-up, to map the data and produce a data gap analysis. From this and consideration of the other research questions produce a full project action plan for the project;
3. The modelled data will be in the form of a NCT file from the interface to Simplified Energy Model (iSBEM) software [4] The NCT file will be checked to ensure it reflects the buildings current geometry, usage and servicing:
    a. The metered data will be in a half hourly form and transferred into a spreadsheet

   b. Operational data will be required and collected by a mini-audit including interviewing key members of the operational, facilities and maintenance staff (see Appendix 1);
4. Basic information about the population and lifts were sourced from the building operators. These inputs were used to run simulations using the generic Energy Model in the Elevate elevator simulation software [13]. Calibration of the model was based on measurements made as part of a research project with ThyssenKrupp [14]. The simulations were run applying a full day traffic demand template, reflecting the rise and fall of passenger demand during a typical day, and the impact this has on energy consumption. Out of hours and weekend energy consumption was assumed to reflect standby load only. Lifts of the same basic specification from different sources have dramatically different energy performance, thus the results are indicative only. There is insufficient measurement data in the public domain at this point to be able to give a range of expected results;
5. Determine any data gaps on completion of steps 1–4 for each building and proposed how they will be filled;
6. On the basis of the gap analysis above install and commission sub-metering if required on a building-by-building basis;
7. Collect additional data if required, especially with respect to energy management activities — this will include the use of 'energy matrices' [15];
8. Analyse the modelled data and input into the GD tool along with energy management, operational and bill data to join the asset and operational data up. Carry out a calculation of the lift energy usage.
9. Analyse the metered and produce energy profiles [15] for day/night, weekday/weekend and seasonal; look for high base consumption and any unusual usage patterns. Compare to the Real Estate Environmental Benchmark (REEB) - for energy [16] — these are produced by the Better Building Partnership (BBP):
   a. Based on the performance of buildings 'in-use';
   b. Publicly available operational benchmarks;
   c. Based on the annual consumption of BBP member's property portfolios;
   d. Based on a three-year rolling average;
   e. Updated each year;
   f. Office sample size for air-condition can be considered representative (185 assets);
   g. Limited sample (25 assets) for naturally ventilated offices
10. Carry out a targeted energy audit, in line with BS EN 16247 [17] and best practice [18] to:
   a. Investigate user behaviour;
   b. Investigate working practices including maintenance regimes;
   c. Examine high and unusual energy consumption patterns;
11. From consideration of the analysis of the asset and operations data, use the GD tool to run recommendations based on business case parameters and best practice [19].
12. The final methodology for the roll-out in the second phase will be based on the learnings from the trial buildings and aims to streamline the process with the aim of designing a second phase where this will be run out over a larger number of buildings to produce a statistically significant sample which covers office buildings with a full range of servicing and age.

2.6 People, roles and behaviours

The This builds on the initial methodology and takes into account issues such as communication, motivation and behaviours from the whole range of stakeholders who have influence on energy use in a building [20]. These will be different for different stakeholder groups, depending on roles and responsibilities within the organisational structure. As a result, it is essential to carry out a Stakeholder mapping exercise [21] which includes as many as the below as possible:

- Building owners;
- Landlords;
- Facilities/building manager;
- Other operational staff eg security, cleaners;
- Occupying organisation (Tenant);
- End users ie staff, visitors.

It is also essential to examine the organisational role breakdown for energy-saving behaviours. Firstly, the organisation owning or leasing the building will have an impact on its energy consumption, depending, for example, on occupancy patterns (for example, hours of operation needed for business requirements), which might greatly differ from the original design assumptions.

In addition, the organisation's approach to sustainability and the environment and the costs and benefits of action has an influence on the introduction and effectiveness of energy-saving interventions and campaigns.

In a leased building, the landlord will often be responsible for the common areas and will also need to work in partnership with tenant organisations in order to reduce energy use.

Facilities managers operating the building will also play an important role, for example, by avoiding unnecessary energy use through the use of building controls, changing thermostat settings or by installing low energy technological interventions.

The actual occupants and users of the building might be far down the chain of command and have little responsibility for the building and its operation and little interest in any savings that might ensue. Their main concern is having a comfortable working environment that supports their productivity and wellbeing.

Finally, in public access buildings, such as sports centres, retail stores or libraries, there are the customers who have little interest or ownership in the organisation apart from its role as a service provider.

2.6.1 Survey Methodology

The methodology will consist of an analysis of the organisational structure of the people responsible for day to day operation and management of the buildings and a questionnaire to ascertain the actual roles, responsibilities and behaviours and working practices in terms of energy management. This will enable us to identify factors and impacts that distinguish a well-managed building from one that is less well managed, and to produce operational and asset recommendations that will allow a methodology to be developed to roll out more extensively.

The Questionnaires will:

- Based on Energy Efficient Best Practice Programme Energy Management Matrices [15];
- Provide an overview of current energy management practices and priorities;
- Cover four key aspects:
    - Energy management;
    - Financial management;
    - Awareness and information;
    - Technical issues.

An additional section has been included covering communication and monitoring of the impact of the building on the occupants.

For each question, respondents are asked to select the statement from a list of five that best describes the situation in their building. The questionnaire form was designed using the Qualtrics Research Suite Platform, a software system that BRE uses to conduct online survey research.

Respondents will be emailed an electronic link that takes them straight through to the questionnaire form for easy response. The data will be kept confidential to the research team though will not be anonymous. However, no names or other identifiers of individuals will be included in any reports to the client.

The data will be analysed using SPSS statistical software. As the numbers are small we will use mainly descriptive statistics although we will also hope to carry out some comparative analysis between the buildings.

3 INITIAL RESULTS AND DISCUSSION

The initial results in terms of energy performance are given in Table 1. This table shows energy performance in terms of:

- The modelled asset usage including lift energy;
- The operational usage from metered data;
- The overall performance gap in terms of a percentage;

Observations from this initial data are:

- The performance gap was confirmed as real and in the range 208 to 490 per cent;
- The values observed were similar to that observed by previous studies which were between 200 and 450 per cent (see Figure 1);
- There was no relationship between the perceived operational status (see Figure 3) and that observed:
    - Exemplar E was perceived to have good operational status; has one of the best asset ratings (65 C) and the lowest metered usage. However, it has a performance gap of 276 per cent which is around the average of 288 per cent for the five buildings;
    - Exemplar C on the other hand was perceived to have averaged operational status; has the best asset rating (58 C); the highest metered usage; which results in the highest value for the performance gap at 490 per cent;
    - Exemplar B was perceived to have poor operational status; has the lowest asset rating (110 E); the lowest metered usage; which results in the lowest value for the performance gap at 151 per cent;

An asset rating was then modelled using data collected on site including hours of occupancy, HVAC set points and energy data. This was done in an attempt to granulate the performance gap into the contributions made by modelling for compliance and those due to poor operation.

The initial results indicated that the major effect was the contribution was by modelling for compliance and not operational issues. However, there were a pair of negative results which indicted the modelling of the "real" operational parameter was overestimating the energy usage. As a result, further auditing will be undertaken when the survey is undertaken to investigate the operation of the assets.

Table 1. Exemplar building energy performance

* After Data Entry of Occupancy, HVAC set points & Energy Data

	Exemplar	A	B	C	D	E
Metered data						
2017 unadjusted gas data KWh/yr.		1,098,666	1,062,816	95,184	212,242	4,176,555
Total 2017 electricity KWh/yr.		775,445	1,675,704	788,268	775,445	9,424,437
Total unadjusted usage KWh/yr.		1,874,111	2,738,520	883,452	987,687	13,600,992
Total unadjusted usage KWh/m²/yr.		**374**	**228**	**532**	**344**	**275**
Asset rating & iSBEM Version		67 C - 5.4.b	110 E - 5.4.b	58 C - 5.4.b	112 E - 5.4.b	65 C - 5.4.b
building environment		Air Conditioning	Air Conditioning	Air Conditioning	Air Conditioning	Air Conditioning
floor area (m²)		5515	12650	1675	2906	51608
Total KWh/m²/yr.		100.24	134.83	87.66	144.88	89.64
Lift energy KWh/m²/yr.		8.80	8.16	19.88	16.29	5.90
Total asset model KWh/m²/yr.		109.04	142.99	107.54	161.17	95.54
Performance gap (%)		**312**	**151**	**490**	**211**	**276**
Adjusted Asset rating* KWh/m²/yr.		294	246	413	381	227
Compliance Performance gap (%)		**269**	**172**	**384**	**236**	**237**
Operational Performance gap (%)		**43**	**-21**	**107**	**-25**	**39**

4 CONCLUSIONS

The initial data collection was difficult and time-consuming where the remaining data required for the first phase (see Appendix 1) is currently being collected or measured on-site. The current data collection and storage processes for these buildings are ineffective due to the lack of management and a dedicated resource.

The management structures for the five buildings are shown in Appendices 2 and 3. The issues with the first structure shown in Appendix 2 are that no-one is directly responsible for the building; there is no on-site presence or contact point; and the criss-crossing of communication routes where responsibilities and roles are unclear. The outcome is no focal point for the management and operation of the building, where all managerial actions are reactive.

The issues with the second structure are not so obvious but the building still has no better than an average performance gap. Therefore, more in-depth investigations are required, and these are part of the on-going research.

Currently, the team is investigating both the asset and operational features of the five exemplar buildings in more depth, in order to obtain more granularity in terms of key performance aspects/indicators and the underpinning reasons/drivers for the poor performance.

One thing is clear the management of data is a real issue both in terms of its existence, quantity, quality, and consistency. In the end if you cannot measure it you cannot manage it which leads into the next part of this projects' investigation.

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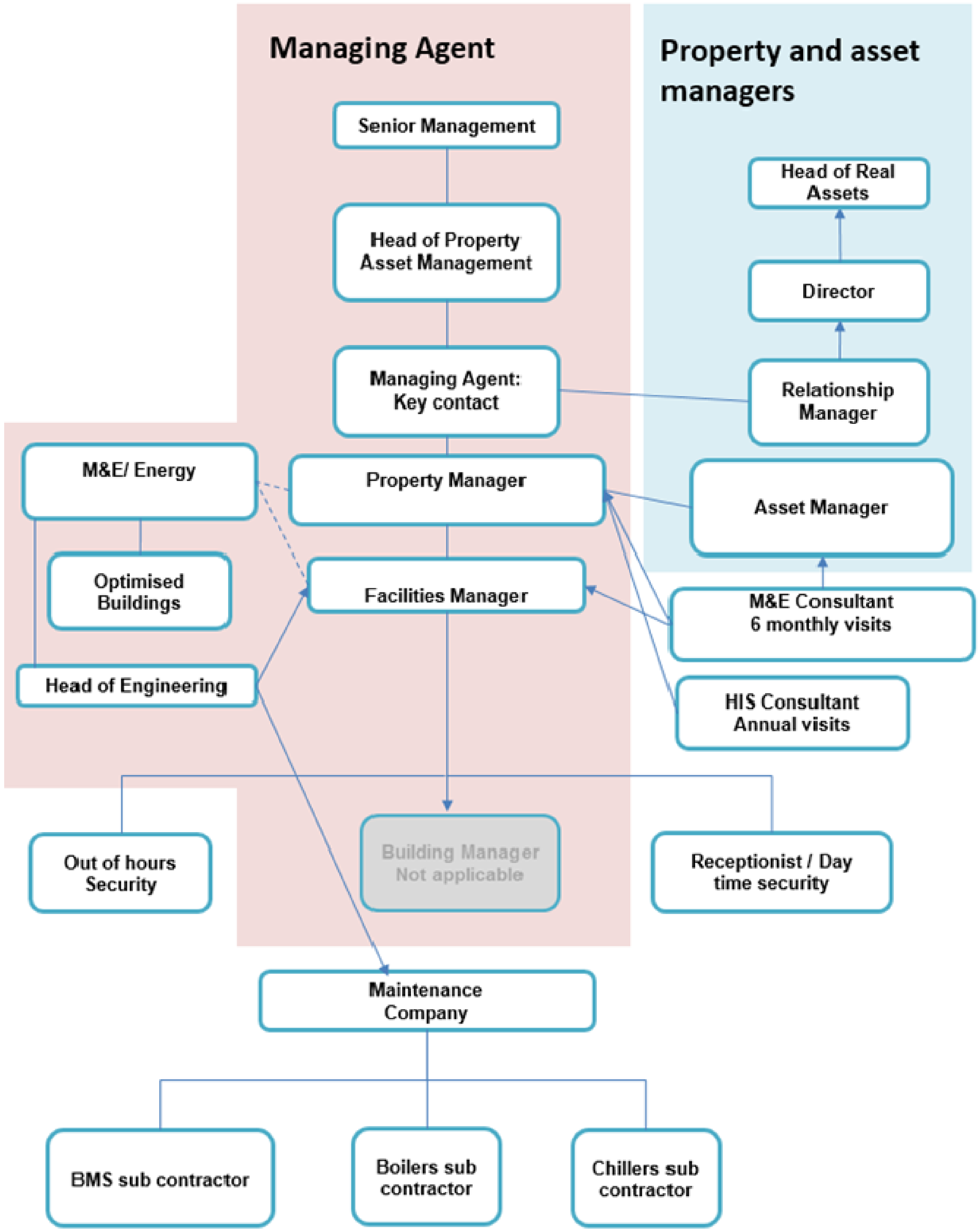
Appendix 1: Initial operational data

1. Occupancy hours and density for each property (P/M2)
2. Small Power Gains (W/M2)
3. HVAC Set Points (heating & cooling) (DegC)
4. Hot Water Usage (where known) (L/M2/Day)
5. Fresh Air Exchange rate (where applicable) (L/S/M2)
6. Lighting Lux Levels (Lux)
7. Lighting times (on/off including holidays & weekends) (Hour)
8. Display Lighting (W/M2)
9. There are 18 Management Questions (there will be more in the 3rd phase):
   a. Do you have a programme of regular inspection and remedial measures for air tightness?
   b. Do you have a programme of regular inspection and remedial measures for fixed shading?
   c. How are staff/users trained on how to use the systems within the building?
   d. Is managing energy part of somebody's job description?
   e. Are suitable qualified/trained staff running the system?
   f. Do you have a programme of monitoring & targeting your energy consumption?
   g. What level of understanding/training do staff/users have in relation to lighting?
   h. How Often are your luminaires cleaned?
   i. Do you know where your HVAC system controls are and how do you manage them?
   j. How are the operating times of your HVAC system managed?
   k. How does timing of your HVAC system respond to daily changes?
   l. Do you adjust your HVAC set point temperatures (heating and cooling) based on external weather conditions on an on-going basis?
   m. What levels of checking of your HVAC system does/will your energy manager carry out?
   n. How frequently is your HVAC plant serviced?
   o. How frequently do you/will you undertake air handling filter cleaning on your HVAC system?
   p. How frequently are the air handling components of your HVAC system cleaned/will be cleaned?
   q. Do you have comfort controls sub-divided within the zone and use/manage them on that basis?
   r. do you have lighting controls sub-divided within the zone and use/manage them on that basis?
10. MPAN & Electricity Meter Serial Numbers
11. months utility usage data for all fuel types (if estimated please indicate)

 https://doi.org/10.1051/e3sconf/201911104017

Appendix 2: Management structure for exemplars A to D



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Appendix 3: Management structure for exemplar E