A Review of Non-Domestic Energy Benchmarks and Benchmarking Methodologies

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Abstract

This paper, as part of the research remit of the UK Carbon Reduction in Buildings (CaRB) project, gives a review of a number of existing non-domestic building energy consumption benchmarks from both the UK and elsewhere. Although a range of benchmarking methodologies exists, including comparisons to statistical regressions or statistical distributions and comparison to a prototypical/model building, there are no clear guidelines on when and how to use them.

The paper presents reviews of the classification of building/occupant activity types, sources of data and its collection and analytical/quantification methodologies for a number of benchmarks. Through a discussion of the above, buildings practitioners should be enabled to make more informed and better quality choices in which benchmarking system to apply.

Introduction

The research presented in this paper is part of the major four-year research project Carbon Reduction in Buildings (CaRB), involving a consortium of five UK universities, investigating the associated carbon dioxide emissions from the UK domestic and non-domestic building stock. A key element of the project is the development of the CaRB Community non-domestic model. The aim of this is to allow yearly energy end-use modelling of the non-domestic building stock, at a Community level, where a Community can be anything from part of a city up to national level. The model thus must be capable of handling large numbers of non-domestic buildings, their diversity in both built form and activity and different levels of, in general, limited input data. In the worst case scenario, the only input data available would be building floor area, main activity and age. In general, the data initially available for buildings will be insufficient to allow energy calculations, therefore inference will be needed to generate the missing data; for example, the inference of construction properties based upon age and building type. A further stage is to infer likely HVAC plant configurations. The inference method is thus, if not more important than, then at least as important as, the first principle model used to predict the buildings' energy consumption. Existing benchmarks for non-domestic buildings represent a natural and logical source of information and data for developing the CaRB non-domestic community model inference engine.

Over the last couple of years, energy benchmarking in buildings has gained prominence with the adoption of the Energy Performance of Buildings Directive (EPBD) in 2002, more specifically implementation of the Directive through requirements for Operational Rating Certificates and Display Energy Certificates. However, long before EPBD, benchmarks were recognised as being important for comparing the operational energy efficiency of buildings and for influencing energy policy within building management. This paper gives a short review of a number of these benchmarking systems.

Review of benchmarks

The energy performance of a non-domestic building is frequently quantified by judging its performance against that of a sample of other similar buildings, usually through the application of a benchmark calculated from the sample. Alternatively, a prototypical building may be used as the benchmark. There are several basic types of benchmarking methods, of which the most common have been identified as:

1) Ranking systems [1]

2) Distribution models, using medians and percentiles [2]
3) Regression models [3]
4) Regression models using standard errors of a regression [4], or mean EUI (Energy Use Intensity), of the sample [5]
5) Prototypical models [6] [7]

These models usually take the form of an Energy Use Intensity (EUI), commonly kWh/m^2/year (kWh/sqft/year), MJ/m^2/year (Btu/sqft/year), or similar. The use of these units makes benchmarks easily understood by energy management professionals. Alternatively, a unit of kg CO_2/m^2/year may be used. Some benchmarks also give guidance on the percentage of energy which should be attributable to a particular end use.

This part of the paper presents the review of a number of benchmarking systems. Limitations of space have restricted the level of detailed description, but those aspects relevant to later discussion are presented.

UK Energy Efficiency Office Guides

At the end of the 1980s, the UK Energy Efficiency Office (EEO) produced a number of guides relating to the benchmarking of energy use in a range of non-domestic buildings [8]. Table 1 gives a summary of the end use percentages for a number of building use classifications, according to these guides. Essentially, these benchmarks use prototypical buildings, with adjustments made for the target building. The source of the data, upon which the benchmarks are based, is not given in the guides, but the level of disaggregation of the energy end uses, is quite detailed. The number of building uses covered is also quite broad. The assessment can be made for overall energy consumption or for the disaggregated end uses, making the benchmark suitable for identifying where a single end use consumes a disproportionately large amount of energy.

Table 1 is a simplification of the original documents, as there should be 28 notes attached to its content, indicating that there are a number of assumptions and restrictions affecting these building classifications and the energy end uses.

EEO benchmarks also include corrections for position of the building (sheltered, average, exposed), occupancy hours and degree day adjustment.

Table 1: End energy consumption, by percentage, according to EEO guides

Building classification	Space heating	Lighting	HWS	Other	Catering / Cooking	Ventilation	Manager's Accom'	Beer Cooling	Refrigeration	Date
Agency (high street)	67	19	4	10						1989
Bank (high street)	67	19	4	10						1989
Bingo Hall / Social Club	66	13	5		7	5		5		1990
Church	88	7		5						1990
Cinema	77	2	3	3		15				1990
Cold Store	8	10		***** [3]					82	1989
Court	84	8	5	2	1					1989
Factory	72	15	3	10						1989
Fast Food Outlet	3.5	1.5	24	1	70					1990
Health Centre	67	12	21							1991
Hospital (300 bed)	54 [4]	4.1	26.6	6.2	9.1	***** [4]				1991
Hotel (large)	50	9	11	12	18					1990
Libraries, Museums, Art Galleries	60	18		11		11				1990
Motorway Service Area	22	9	32		30	7				1990
Nursing Home (with pool)	46	7	20	27						1991
Office (natural ventilation)	60	20	8	12						1990
Office(with A/C)	48	16	6	1		29				1990
Prison	45	10	25	10	10					1989
Public House	38	12	18	5	11		6	10		1990
Restaurant	25	15	15		40	5				1990
Sports Centre (without pool)	75	11	3			11				1990
Supermarket	***** [1]	11	2	3	11	23 [1]			50	1990
Swimming Pool	***** [2]	9	3	33		55				1990
Transport Depot	80	6	4	8	2					1989
Warehouse	80	8	2	10						1989

Notes: [1] Heating and ventilation combined. [2] If not sub-metered. [3] See lighting. [4] Space heating and AC

UK Energy Consumption Guides

The Carbon Trust makes a number of benchmarking tools and publications available to the non-domestic sector. Among these are the Energy Consumption Guides (ECON Guides or ECGs) which provide benchmarks for a wide range of building occupancy types, or industrial activities. As well as paper documents, there are also online benchmarking tools [9].

As an example of the Guides, ECON19, for the assessment of the energy performance of office buildings, classifies office buildings into the following descriptive types:

1. Naturally ventilated cellular: A simple building, often (but not always) relatively small and sometimes in converted residential accommodation.
2. Naturally ventilated open-plan: Largely open-plan, but with some cellular offices and special areas. Typical size ranges from 500 m^2 to 4000 m^2.
3. Standard air-conditioned: Largely purpose-built and often speculatively developed. Typical size ranges from 2000 m^2 to 8000 m^2.
4. Air-conditioned, prestige: A national or regional head office, or technical or administrative centre. Typical size ranges from 4000 m^2 to 20 000 m^2. [10]

ECON19 may be used to benchmark energy consumption for nine or ten end uses, depending upon the above building classifications. These end uses are:

Heating and hot water	Cooling
Fans, pumps and controls	Humidification
Lighting	Office equipment
Catering, gas	Catering, electricity
Other electricity	Computer and communications rooms

Each of these end uses and the overall energy consumption are gauged as energy use indices (EUI). A factor may also be applied to each of the fossil fuel and electricity consumptions to give carbon dioxide emissions indices (CEI).

ECON19 divides the benchmarks into two categories:

1. **Typical.** Energy consumption patterns, which are consistent with median values of data collected in the mid-1990s for the Department of the Environment, Transport and the Regions (DETR) from a broad range of occupied office buildings.
2. **Good Practice.** Examples in which significantly lower energy consumption has been achieved using widely available and well-proven energy-efficient features and management practices. These examples fall within the lower quartile of the data collected.

The data upon which the benchmarks are based come from surveys of a range of office buildings in the 1990s, but that is the only information readily available on the source data. The method of application is a distributional model. However, there is evidence that the 'good practice' benchmarks have been derived from buildings in which a particular energy end use is significantly lower than the norm [10]. This means that the 'good practice' lighting may come from a building with extremely low lighting energy use, but that the 'good practice' space heating system may have been taken from a different building. As energy flows within buildings are intricately interconnected, reaching the level of energy consumption equating to 'good practice' for a whole building is difficult.

Due to its diverse building use classifications, another informative Guide is ECON75, for UK Ministry of Defence Estates [11]. For each of its eleven building use categories (see Table 2), there are varying levels of disaggregation of energy end uses, with the data provided in simple 'typical' energy use percentage tables. Of particular interest is the normalisation of space heating by degree days and the inclusion of a simple factor for exposure of the building to the weather. Twelve energy end uses are given as part of the benchmarking system (see Table 3), but not all of these apply to each building use category. For “specialist site facilities”, no energy end use percentages are given.

Table 2: ECON75 building use categories

Offices	Workshops	Hangars	Training & education facilities
Sports & recreation	Motor transport facilities	Catering Facilities	Specialist site facilities
Multi-occupancy accommodation	Sores/warehouses	Messes with integral accommodation	

Table 3: ECON75 energy end uses

Space heating	Water heating	Heating / hot water	Hot water / catering
Food storage, preparation and cooking	Cooling	Fans, pumps, controls	Lighting
Office equipment	Catering	General power	Other electricity use

Additionally, for some building use classes in ECON75, a factor is used to modify the energy consumption according to shift patterns; e.g. for workshops, the factor ranges from 1.00, for a 10 hour shift on five days per week, to 0.72 for continuous working. Temperature set points and degree days also form part of the ECON75 benchmarking process, thus increasing its accuracy and applicability.

CIBSE TM22 Energy Assessment and Reporting Method

TM22 is the Chartered Institute of Building Services Engineers’ (CIBSE) energy consumption assessment method for non-domestic buildings [8]. This method assesses on the basis of kWh / m^2 and other performance criteria, then compares the target building against established benchmarks from ECON19, for both kWh / m^2 and for $kgCO_2$ / m^2, using UK conversion factors for CO_2 emissions. The TM22 methodology covers the building use classifications shown in Table 4.

Table 4: CIBSE TM22 building types. [14]

Building general type	**Building sub-type**
Office	Naturally ventilated cellular Naturally ventilated open plan Air conditioned standard Air conditioned prestige
Hotel	Luxury, no AC or pool Luxury, with AC, no pool Luxury, with pool no AC Luxury, with AC and pool Business, no AC or pool Business, with AC, no pool Business, with pool, no AC Business, with AC and pool Smaller, no AC or pool Smaller, with AC, no pool Smaller, with pool, no AC Smaller, with AC and pool
Bank or Agency	Bank, gas heating, no cooling Bank, all electric, no cooling Agency, gas heating, no cooling Agency, all electric, no cooling Bank, gas heating, with cooling

	Bank, all electric, with cooling Agency, gas heating, with cooling Agency, all electric, with cooling
Mixed use industrial	Distribution and storage Light manufacturing Factory office General manufacturing Naturally ventilated cellular office Naturally ventilated open plan office Air conditioned standard office Air conditioned prestige office

One of three levels of appraisal methodology may be used, depending upon the available data.

1. *Option A*: Simple building assessment of a building of a single type with one or two energy supplies.
2. *Option B*: General building assessment of a building or site which can have zones of different types and non-standard occupancy and energy uses.
3. *Option C*: Systems assessment against benchmarks for the building systems.

Within the Option B assessment of TM22 the energy end use categories are:

Heating & hot water	Lighting	Office equipment
Ventilation & pumps	Cooling	Lifts & vertical transport
Controls	Humidification	Controls & telecoms
Local kitchens & vending		

"Special energy uses" are:

Dedicated computer room or suite	Catering kitchen and restaurant
Dealing rooms	Sports & leisure facilities
Covered car park	

Where a building is mixed use, the smaller, secondary use is entered as a separate area to the main area. Occupancy can be adjusted in Option B, as well. For each Option assessment type, the data is given a quality assurance (QA) rating to ensure that those reading the data are aware of its source. However, no methodology is specified for the survey process itself, though the procedure spreadsheets indicate the data required for a full plant survey.

When compared to the Energy Efficiency Office Guides' building classifications, the number of subclasses within TM22 has increased, thus making the benchmark more closely tailored to a specific building use/type.

Asia-Pacific Economic Cooperation (APEC) Energy Benchmark System

The Asia-Pacific Economic Cooperation (APEC) provides an example of a basic non-domestic building energy benchmarking system [15]. The building classification system is limited to offices, hotels, hospitals, paper mills, metals production and cement manufacture. Offices, hotels and hospitals are benchmarked in $GJ/m^2/yr$.

For hotels, the required data are:

1. A building number (previously assigned by the APEC member economy)
2. Location

3. Gross floor area
4. Number of workers (main shift only)
5. District steam or hot water (yes or no)
6. Energy source for space heating
7. Number of lodging rooms (optional)

Offices and hospitals are required to provide the same data as hotels, except for the numbers of workers and rooms. There is no disaggregation of energy end uses. Data may be submitted online, into a public access database, making the source data readily visible. However, there does not appear to be a validation procedure for the data submitted. As well as electricity consumption, figures may be entered for up to three other energy sources. The benchmarking process is achieved by comparing the test building's $GJ/m^2/yr$ value against those of other similar buildings in the database, using a number of charts, presented online.

US Energy Star®

Energy Star® is the assessment and benchmarking system made available by the U.S. Environmental Protection Agency and the U.S. Department of Energy [16]. Energy Star® covers many aspects of reducing energy consumption, but has a benchmarking tool which is specifically aimed at allowing the operators of non-domestic buildings to assess energy consumption.

Energy Star® uses data from the Commercial Buildings Energy Consumption Survey (CBECS) [17], which is carried out every 4 years, with the latest data being from 2003 and the next survey due to be carried out in 2008 [18]. The surveys are conducted, on behalf of the United States Energy Information Administration, to determine the end-uses of energy consumption in non-domestic buildings in nine major Census regions of the US. The survey data is publicly available to download from the CBECS website.

Overall, the sample sizes are large – in excess of 4,000 buildings in 2003 – with some (more complicated) buildings being subjected to an on-site survey. The basic survey is carried out over the telephone, but may include access to data on metered utilities. Note that the samples are cleaned before inclusion in the survey data. There is also data for degree days.

CBECS uses the following main building use classifications [18]:

Education	Food Sales	Food Service	Health Care
Lodging	Mercantile	Office Public	Assembly
Public Order & Safety	Religious Worship	Service	Other
Warehouse & Storage	Vacant		

These classes are subdivided into between two and twelve further sub-divisions, giving a total of 81 classifications. This is a workable number of classifications, even though it may aggregate some building uses into wider classifications than would be ideal. Surveys prior to 1999 did not use sub-divisions.

The survey collects sixty-five pieces of data in the following basic divisions:

1. Gross floor area
2. Use classes (14 main types)
3. Building age (8 bands)
4. Census regions, with subdivisions
5. Number of floors (5 categories)
6. Existence of internal transport systems (e.g. elevators)
7. Occupancy numbers (7 bands + vacant)
8. Occupancy hours (6 bands)
9. Number of establishments (subdivision of buildings)
10. Building envelope type – walls
11. Building envelope type – roofs

12. Modifications to building (yes / no)
13. Energy sources
14. Energy uses
15. Energy-using equipment
16. Treated floor areas

This data is put through a weighted least squares regression analysis, together with data filters, to produce an index of Source [Primary] Energy Use Intensity (EUI). The index of performance is from 1 to 100. To achieve Energy Star® status, a building must have a score of between 75 and 100. A score of 50 would indicate average performance for the building and its operational characteristics. Corrections are made for hours of occupancy, size of building etc.

Not all of the collected variables are included in the regression model, only those which explain *how* a building operates are included. In other words, factors which describe the physical operation, such as: floor area, hours per week, number of occupants, number of computers, cash registers, or number of refrigeration units, etc, [17]. Variables which explain *why* a building performs the way it does are not included because they do not describe a building's physical characteristics. These factors can be broken into two categories:

1. "Technology Factors – Factors that describe technologies that may contribute to overall performance are excluded because they are not physical constraints on the building operation. The type of lighting present (e.g. T-12 vs. T-8) is excluded from the analysis, because it is within control of the building owner/operator and does not define the building activity. Correct management and operation of a more efficient technology (e.g. T-8 lights) will result in lower energy consumption and a higher rating. By excluding technologies from the regression, buildings that install and properly manage efficient technologies should and will receive higher scores.
2. Market Conditions – Factors that may influence why a building performs the way it does such as energy prices. These factors do not define activity within a building and are external to a thermodynamic assessment." [17]

The most interesting aspect of Energy Star® is that it is based on the CBECS, for which the source data is readily available. The level of transparency about data gathering appears rare amongst non-domestic benchmarking methodologies – especially at this level of detail – and gives greater confidence in the validity of the benchmark's classifications and assessments. Additionally, the methodology of how the data are collected, by telephone, is also available [18].

Modelled Benchmarks

In order to avoid the problems of data collection and sample sizes associated with empirical benchmarks, it is possible to use an alternative model-based benchmark. Such benchmarks are usually associated with specific building activities and an example for laboratories is described in [6]. This method calculates the minimum energy consumption capable of allowing the building to perform its function. This is then compared to metered energy consumption for the target building. The process was tested on a number of laboratory buildings with some success, but the authors of [6] suggest that it could also be used for any building type. However, they also point out that some buildings with heavy consumers of energy may be adversely penalised. The example they give is for a laboratory with stringent air filtration requirements being compared to a less stringent standard building design.

The benchmark methodology has nine 'required inputs', such as plan areas of lab and non-lab spaces, location, electrical and fuel consumptions and time duration, which have no default values. Another twelve 'inputs with defaults', mainly concerning design parameters such as air-change rates and relative humidity, which may be overwritten with values that are known for the target building. From these inputs, the building's energy requirement can be calculated from first principles. The sources of the default values are given in [6], making these transparent.

The output metrics are the effectiveness of the electrical and fuel consumptions. These are given by the calculated energy consumption divided by the actual energy consumed for a given period. The efficiencies may then be compared to those of other buildings. However, the efficiency is for the specific building, so it is almost a self-contained benchmark and may be used to compare dissimilar buildings, but [6] indicates that accuracy of the model decreases in these circumstances and more research is needed.

Discussion

Some of the potential problems with energy benchmarks can be identified as:

1. Benchmark may be based upon small and unrepresentative samples
2. Normalisation may not be consistent across different methods
3. Source data is frequently not visible
4. Difficulties in establishing the assumptions used
5. Reliant on ‘snapshot’ data at time of surveys – both for the building and for the base dataset
6. Some models appear to ignore occupancy factors
7. Survey methodologies may lead to measurement of different characteristics
8. Inaccuracies in data collection

Jones et al [2] point out that the validity of statistical benchmarks, which use medians and percentiles, depends upon the use of samples which are sufficiently large, i.e. more than 100. Problems of accuracy may arise with inadequate amounts of accurate/detailed data on sufficient numbers of a wide range of non-domestic building types, or within the samples for classifications of buildings. The heterogeneity of non-domestic buildings indicates that these problems are likely to continue. It seems logical to assume that a reduction in building classifications would help increase the sample size for a given classification, without increasing the number of data and the time taken to collect them. This is relevant to the CaRB Community model as the availability of data is more important than extreme levels of detail.

An exception to the problem posed by small sample sizes is the prototypical, or model, building approach. One of the strengths of this method is that it does not require a dataset of existing buildings at the instigation of the benchmark model. However, the process is one of modelling, with an associated level of specific application to one building type and a need for accurate data inputs. The data upon which the prototypical building is based are primarily defined by local building regulations and design codes, so this could make the benchmark more useful to organisations which have a number of similar buildings in differing regulatory or climatic regions. Also, the design regulations and codes are in the public domain, thus making this aspect of the benchmarking process transparent.

To the questions above, we may add the role of assumptions and how they, too, may not be fully explained. One assumption may be that all building surveys and their data, upon which a benchmark is based, are of equal accuracy/value. TM22 partially avoids this assumption by including an element of quality assurance (QA), but this only applies to the source of the data gathered by the surveyor. Another consideration is that even where survey methodologies are identical, there is still considerable room for differences in the recorded data and/or survey output, as described for domestic energy surveys, by Chapman [19]. This variability of data quality could affect both the benchmarking process of a target building and the initial sample data collection, on which the benchmark is based.

It seems likely that some surveys will not represent a random sample of the building stock, thus affecting the distribution of energy performances within the sample. When data collection is not purely for the information of a benchmarking system, it is possible that there are other factors to be considered. Where surveys have been initiated by building managers who operate their buildings well, the energy consumption will probably be lower than average. In the Probe series of surveys [20] of a number of UK buildings, the buildings were mostly recently constructed, “…selected on the basis of their technical interest…” and “…only potentially well-performing buildings were long listed” [21]. If benchmarks were based upon these surveys there is a probability that the distribution of energy consumption would be skewed, compared to the full population of the building stock. Surveys, such as CBECS, upon which

Energy Star® is based, should avoid this problem as their sole purpose is to collect random samples, unlike the APEC system which relies on building operators contributing data themselves.

CBECS also has the advantage of having a scheduled update of its content (approximately) every four years. This schedule allows building operators to reassess their energy performance on a regular basis and for government to evaluate the overall performance of the building stock at state/regional and national levels. Because the base data for benchmarks, such as ECON19 are not accessible, this type of data suffers from being a 'snapshot' of similar buildings at the time of the design of the benchmark. Thus, updating the dataset – and hence the benchmark – becomes important. It may be that samples are updated, but this is not always obvious. This may also be the case with alterations to methodologies. Occupancy factors also suffer from this 'snapshot' problem, due to the possibility that occupancy factors change over time, even for the same building or premises. This may be significant, as some literature indicates that occupancy can be a variable of prime importance [4]. However, in [22], Bordass et al feel that occupancy is not a sound variable upon which to benchmark energy consumption.

Before data have been collected there is the question of the classification of building types and data analysis to be considered. The number of classification subdivisions appears to have increased over the years – e.g. EEO compared to TM22, or the development of CBECS/Energy Star® [18]. It seems that most benchmarks use dissimilar building classification systems and that there are many different methods of analysing and presenting the benchmark data. It may be that much of this diversity of methods is due to differences in the number of variables recorded and the volume of data collected. For these reasons, alone, it might be said that no two benchmarks can be directly comparable.

The range of sophistication of data inputs for benchmarks appears to vary, with the simplicity of the APEC system at one end of the spectrum, and the complication of the model described in [6], at the other. Because the data inputs/outputs, for APEC, are so limited, it is difficult to see how useful this benchmark tool would be to building operators. As a national level comparison tool, however, it may be of more value. Alternatively, it could be said that data can be submitted continuously, thus giving the APEC benchmark the potential to be permanently up-to-date. The problems of verifying the data are still present, though, together with extremely limited building use classifications.

The model building benchmark system presented in [6] could be adapted for other building types, but this would still require choices of new data inputs, which is likely to make it less user-friendly than other benchmarks. Although the benchmark can tell the building operator how efficiently energy is being used in their building, it does not compare it to other similar buildings directly, except where a sample of similar buildings have been assessed using the same methodology. This latter problem could make the benchmark of less value to building operators. Also, increasing complexity allows a greater probability of incorrect data input, or manipulation, as described in [19] [23].

Benchmarks, such as ECON75, are somewhere between the two extremes of data requirements. The benchmark includes sophistications such as occupancy factors and degree days. However, there are some un-stated assumptions which are apparently based upon hidden empirical data, for example, built form and heating plant, the details of which are not required (except for fuel type). Energy Star® provides a fair compromise of data transparency, usability and value to building operators. Although the CBECS data gathering has great strengths, it is only fully relevant to the United States, but CBECS does represent a workable methodology for others to consider when gathering non-domestic building stock data upon which to base benchmarks.

Conclusions

This paper has reviewed some existing benchmarks, datasets and methodologies for non-domestic buildings in both Europe and elsewhere. The benchmarks reviewed have varying degrees of complexity and comprehensiveness. The benchmarks with limited data inputs give outputs which are limited in their level of detail and applicability to specific building uses, whilst those with more comprehensive inputs may be so tailored to individual building types that they are also of limited value at the national scale.

Additionally, with increased data collection and inputting comes the danger of an increase in the number of errors.

It also seems that, whichever methodology is used, the quantity, quality and auditable source of a benchmark's base data are of importance. There appears to be a general lack of data transparency in a number of empirical benchmarks. The combination of these two situations makes a comparison of one building, using one benchmark, to a second building, using a different benchmark, problematic and of questionable value. A possible exception to this situation is a model-based benchmark, which can be applied to an individual building according to local design restrictions.

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