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Characterising space use and electricity consumption in non-domestic buildings

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Abstract

Non-domestic buildings account for approximately 20% of UK carbon dioxide emissions and reducing these is a government policy commitment. Bottom-up modelling of the energy consumption of large numbers of non-domestic buildings is problematic due to the heterogeneity of the stock. Detailed energy surveys are time-consuming and costly and access to detailed energy consumption data is limited. Energy meters record when and how much energy is used, but generally not what is consuming the energy or where in the building, thus limiting understanding of intervention scenarios.

This paper presents analyses of detailed building energy surveys. Premises have been divided into individual rooms, in which room use, area and electricity-consuming equipment were recorded.

For a range of premises activity types, typical combinations of room uses and their proportion of total floor area, together with their electricity consumption per square metre, are identified. Patterns are also sought in the further breakdown of electricity consumption, by end use. These outputs will be matched to space uses within UK Valuation Office Agency datasets, to better inform energy models using these data.

Keywords: non-domestic buildings, energy, space use, internal gains,

Introduction

There is currently increased interest in reducing carbon emissions from United Kingdom non-domestic buildings. With approximately 20% of UK carbon dioxide emissions resulting from the operation of non-domestic buildings, UK government has begun targeting this sector with increasingly stringent Building Regulations and methods of measuring as-built and operational performance, such as Energy Performance Certificates and Display Energy Certificates. Although these initiatives are likely to improve the performance of buildings – particularly new buildings – detailed knowledge of the non-domestic building stock is still limited.

In the English House Condition Survey a sample of approximately 16,000 dwellings in the UK domestic stock is surveyed each year, creating a longitudinal record of change in the domestic stock. There is no equivalent survey carried out for the non-domestic stock. In addition to a general lack of building survey data, the non-domestic stock is also more heterogeneous than the domestic stock, due to the number of combinations of size, age, built form and activity. This heterogeneity poses problems when attempting to estimate the energy consumption of multiple buildings, as it is not normally economically viable to carry out detailed surveys of tens, hundreds, or thousands of buildings. Modelling energy consumption with sophisticated and detailed building simulation models is not currently feasible for the non-domestic building stock.

The energy consumption of a building is subject to change – independent of the weather – as the building changes physically, or the activity within it changes. In Brand (1994, page 13), a model of change in buildings is proposed, which states that the structure of a building can usually only be changed due to demolition, whilst the external fabric might change every 30 – 50 years. The electrical and water services etc are more short-lived and may change at 15 year intervals. The use of space, within a building, may change every few years, or perhaps months, depending upon the economic climate, change of business activity, or even fashion in interior design. The equipment in the building spaces can change by the day, hour, or minute; for example a laptop computer might be moved from one room to another.

Brand's model suggests that understanding the use of space and equipment could prove to be useful when modelling the electricity consumption of buildings. This paper examines the use of space and equipment, in non-domestic buildings, as a means of estimating electricity consumption, and hence internal gains, independent of built form or building fabric.

The most comprehensive source of information about activities in the non-domestic building stock, in England and Wales, is the Valuation Office Agency (VOA). The only available and sufficiently-large source of information on building services, space use and equipment, is the set of building energy surveys carried out by the Resources Research Unit of Sheffield Hallam University (SHU).

It is the aim of this research to enable the mapping of annual electricity consumption per unit floor area (energy intensity), from the analyses of the SHU survey data, onto VOA data. This will enable the development of profiles of electrical loads for lighting and appliances, and thus electricity-based internal gains, which can be applied to VOA data. This confluence of data can then be used by a non-domestic energy model to estimate internal gains from premises type and floor area.

The Sheffield Hallam University Building Energy Surveys

Between 1991 and 2000, the Resources Research Unit of Sheffield Hallam University (SHU) carried out detailed internal energy surveys of 712 non-domestic premises, on behalf of DEFRA, to inform DEFRA where energy was used in the UK non-domestic stock (Mortimer et al., 2000). Sixty percent of these surveys were carried out in 1993/1994 and were initially based on a subset of the previous Four Towns surveys by the Open University (OU) – external surveys of 3350

addresses (Brown et al., 2000). Later, the SHU surveys moved outside of these constraints, so that more buildings of particular activity types could be included.

The published output from the SHU surveys improved the understanding of energy-consuming equipment in the non-domestic stock, but this paper specifically seeks to improve understanding of non-thermal comfort-related electricity consumption of individual room types. This research may also help explain how activity is the main determinant of energy consumption in non-domestic buildings, as asserted by Mortimer (2009).

Although many more details were recorded per premises in the SHU surveys, for this research the main data are:

- Premises activity: 56 types (Valuation Office Primary Description Codes)
- Total premises occupied area (m²)
- Room uses: 63 classifications across 11,919 rooms
- Room areas (m²)
- Energy-consuming equipment in each room: 372 descriptions/codes (63,000 records)
- Premises' hours of occupancy
- Metered energy consumption for at least one year, taken from billing records

In the early days of the SHU project, surveyors were not required to record room floor areas, thus these are missing for some premises. (Mortimer, 2009) states that great attention was paid to the recording of equipment, and the data are therefore assumed to be fundamentally correct. This, together with their breadth of premises activities and recording of room uses, renders the SHU data extremely valuable.

In addition to the details above, the end use of the energy, used in equipment, was also identified and aligned to one of the classifications listed in Table 1, below.

Table 1: Classes of energy end use.

Heating	Small Power	Light	Domestic Hot Water
Computer	Computer Accessories	Process	Catering
HVAC Controls	Lifts	Fans	Pumps
Cooling	Telecoms	Other	Unknown

The power ratings of equipment were either taken from the name plates of the equipment itself, or assumed following detailed desk research. To estimate the consumption for each piece of equipment, equation [1] was used.

$$W * L * O * U = \text{energy consumption per item of equipment per year as kWh/yr} \quad [1]$$

Where:

- W = Power of item (Watts) (recorded/inferred data)
- L = Load factor for item (inferred data)
- O = Premises occupation hours/year (reported data)
- U = Utilisation factor for item (reported/inferred data)

The sum of the output of these calculations was then compared to the billed energy consumption for the premises. An initial consumption figure to within 20% of the billed energy consumption was not uncommon (Mortimer, 2009). Where discrepancies did occur, the surveyor would generally adjust the utilisation factor, as this was usually a reported, or judgement, figure and most open to latitude in interpretation. Recorded data, such as energy meter readings are less open to interpretation than are reported data, such as hours of occupancy. Further description of the methods used to estimate energy consumption and the general methodology of the SHU surveys can be found in (Mortimer et al., 2000).

Valuation Office Agency Data

The Valuation Office Agency (VOA), of England and Wales, is entrusted by the UK government to survey and value premises for real estate taxation purposes. The valuation surveys take into consideration factors such as floor area, access, geographical location, premises activity, presence of air conditioning and suchlike. Although not designed with energy surveys in mind, some valuable information can be extracted from the VOA data, for use in energy consumption modelling. There are two key levels of information: the Rating List and Line Entries which appear to inform the Rating List.

The Rating List contains a record for most premises in England and Wales. Major exceptions are some properties owned by the Crown (e.g. Ministry of Defence Estates), places of worship and agricultural premises and land.

The VOA also holds details of Line Entries. Although the VOA does not normally release all of the details, it is possible to gather information on premises' overall activity (Primary Description) and total floor area. Additionally, where premises are subdivided, floor areas and activities are available for such subdivisions. There is some degree of standardisation of the descriptions of the subdivisions – from here on simply termed “Line Entries” – in the form of 56 Accommodation Use Codes (AUCs). These AUCs are not for application to all premises types, and are not adhered to rigidly, but are useful in categorising the space described by the Line Entry. The number of Line Entries does not necessarily increase with premises' floor area; for example, some large retail premises can have a single Line Entry of very limited descriptive value. Also, some Line Entries have multiple descriptions, for example, “office, kitchen, store.” These multi-descriptions will require separation from single-description Line Entries, as the proportions of space use within the multi-description Line Entries cannot be defined in the same manner as single descriptions.

For the purposes of this research the Rating List and Line Entries for the City of Leicester have been made available, under the auspices of the Measuring, Mapping, Modelling and Management (4M) project. Hereon, these datasets will be referred to as the Leicester Rating List (LRL) and the Leicester Line Entries (LLE).

Cleaning the SHU Data

To ensure the greatest confidence in the data analyses, it was decided to check the SHU survey data for obvious problems. Dealing with problems in the SHU and VOA datasets independently, before attempting to map the SHU onto the VOA, follows general guidance on data cleaning, given in Rahm and Do (2000).

The first exercise gauged the completeness of the surveys, in terms of the floor areas recorded per premises. The Occupied Area, usually taken either from the Open University Four Towns surveys, or VOA data, was compared to the sum of the recorded room areas, for each premises, and expressed as a percentage. For each Primary Description (PD) activity type, these values were averaged and any premises of that PD with a percentage of area completion less than one standard deviation below the mean, was excluded from further analysis. This method formalises the criteria for acceptance/rejection of incomplete data, whilst retaining premises for which a reasonable proportion of the floor area was recorded, without reducing the limited sample too much. However, the method can reduce sample sizes severely, where the threshold is very high – say 90% – and the sample size very small.

Once suitable premises were identified, each PD category was analysed to give the proportion of floor area used by different room types. During this process, the data were subject to a second filtering process, which highlighted premises with room use percentages more than five standard deviations away from the mean. This flagged obvious errors which could have an excessive effect on the total values – the required data output – without reducing the sample size excessively. When premises' room use proportions were found to be outside the stated limits, the SHU database was interrogated further and the error corrected, or the entire premises excluded from further analyses. The filtering process was then reapplied and further adjustments made. The more usual three standard deviation filter was not employed, as this would have depleted the sample sizes beyond reasonable use.

When analysing the data to ascertain average electricity consumption per square metre of room, a similar repetition of a five standard deviation filter was applied. Again, this highlighted rooms with exceptionally high energy consumption and reasons for this were sought in further investigations of the data. Frequently, the error lay in unfeasibly large amounts of equipment in relation to the floor area of the room; for example 80 five-foot fluorescent tubes in a 12.7m² office room. As this part of the research only required reliable data for each room, rather than for the whole premises, mostly only individual rooms were excluded from further analyses.

Application of the flag system, or the author's familiarity with the data, resulted in the alteration of a small number of room use codes. Also, rarely, as a means of simplification, single instances of room uses (within a PD) were amalgamated with less-rare room types but only where this was judged not to mask the energy consuming characteristics of the room and the premises.

Cleaning the VOA Data

The Leicester Rating List (LRL) and the Leicester Line Entries (LLE) were also examined with the aim of ensuring usability in this research context. The LRL, due to its more limited number of data fields, did not require significant cleaning. However, it does contain many mismatches of PD Code and Primary Description text record, which might be problematic in later stages of the research.

The LLE dataset is complicated by the existence of multiple records for some Line Entries, due to the inclusion of historical valuations. Cleaning this dataset to gather the most recent valuations and hence the assumed to be most up-to-date data, was carried out; however, this indicated a number of apparent mismatches of valuation dates between the LRL and the LLE. As the LLE appears to contain more premises than the LRL, it has been decided to use the former, in preference to the LRL, subject to clarification by the Valuation Office Agency.

Analysis of the SHU Data

For this research, the three main characteristics required from the SHU data are: space use within premises of a given Primary Description (PD) activity class; average electrical energy intensity (kWh/m²/yr) per room use – both per PD and across all premises activity types; and distribution of electricity end use per room use.

Analyses of 16 Primary Descriptions are underway, with analyses of only office premises and retail premises presented here. The threshold for the degree of completeness of the recorded floor areas (as described above) was 78% for offices and 80% for retail. These values may seem quite low, but these are Gross Internal Areas and thus take no account of internal walls, rebates in walls, chimney breasts, support columns and so forth. Also, in view of the scarcity of these types of datasets, thresholds could not be set so high that the sample size would become unusable. For example, from an initial sample of 165 office premises, only 80 passed the initial area filter threshold. For retail, 97 of 223 passed. This reduction in the samples can partly be attributed to the non-collection of room floor areas in the early SHU surveys. Sample sizes were subsequently subject to change, as analyses progressed.

Space Use and Energy Consumption in Office Premises

Figure 1 shows the total distribution of room use within the SHU office premises sample, indicating what the distribution of space use will be, across the office building stock, assuming the SHU sample is representative.

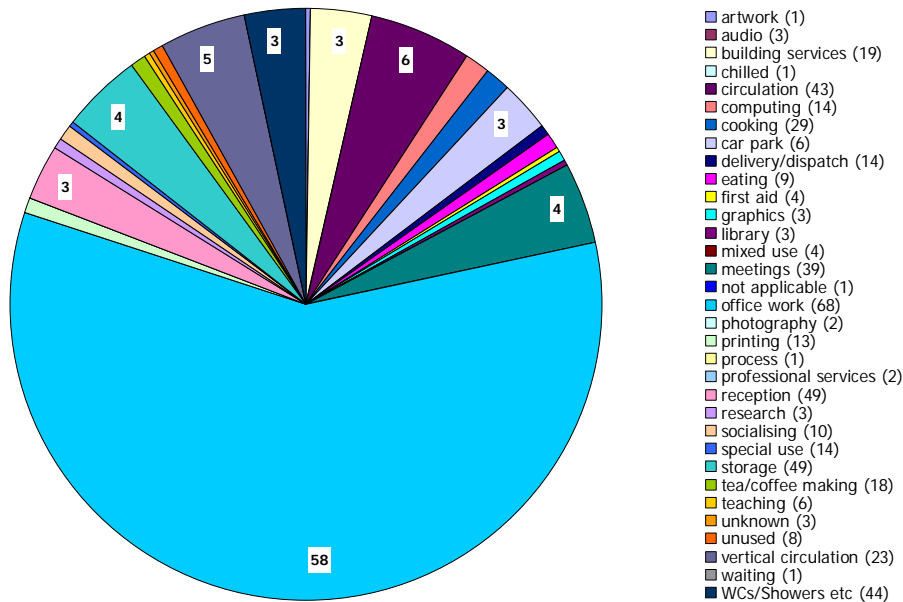


Figure 1: Use of space in office premises. Sample size, 70 premises. (Numbers in brackets indicate the number of premises with that room use type)

Figure 1 also indicates that although “office” premises may be described as being “offices”, their use of space is more complex than the term “office premises” would indicate. In this sample there are 33 different uses of space, and within the UK stock there might be an even greater variety. In this sample, some office premises contain no office space, as the SHU room use classification system allows them to be described more specifically; for example, as “graphics”. Note that values below 3% are not indicated numerically, but are still represented by segments of pie. Overall, the floor area is predominantly “office work” (59%), with “reception”, “storage”, “circulation” and “meetings” rooms combined accounting for a further 20%.

Figure 2, below, indicates the spread of the proportions of room use areas. The distribution of the data is shown by the distances between the 5 data point types: larger distances indicate wider distributions. There is considerable diversity in the percentage of total recorded room floor area used for “office work, but some room uses are much less diverse; for example, “circulation”, “computing” and “WCs/Showers etc.” Where the count of premises is high, and the distribution of values is narrow, Figure 3 suggests that the area of a room use is strongly related to the total floor area. The 70 premises presented in Figures 1 and 2 ranged in size from 33m² to 6170m².

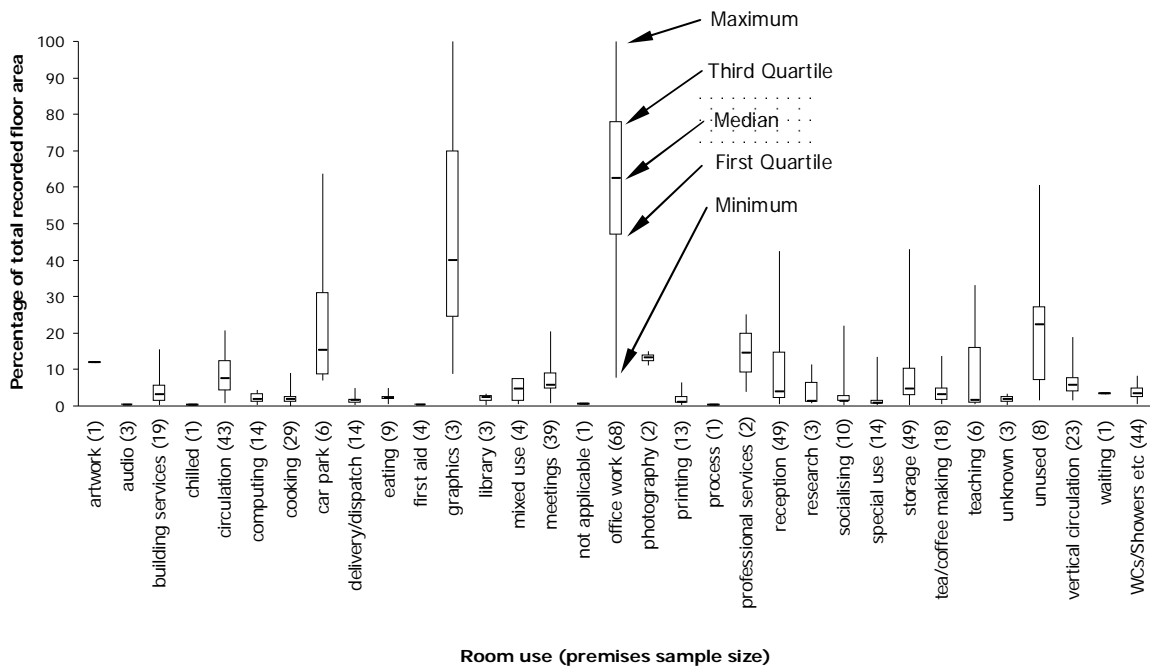


Figure 2: Space use in office premises. Quartile distribution and median values. Sample size, 70 premises. (Numbers in brackets indicate the number of premises with that room use type)

Figure 3, below, shows the distribution of values for the energy intensity of the different room uses, found in the office premises sample. Again, the numbers in brackets alongside the room use, on the x axis, indicate the number of premises with that room type.

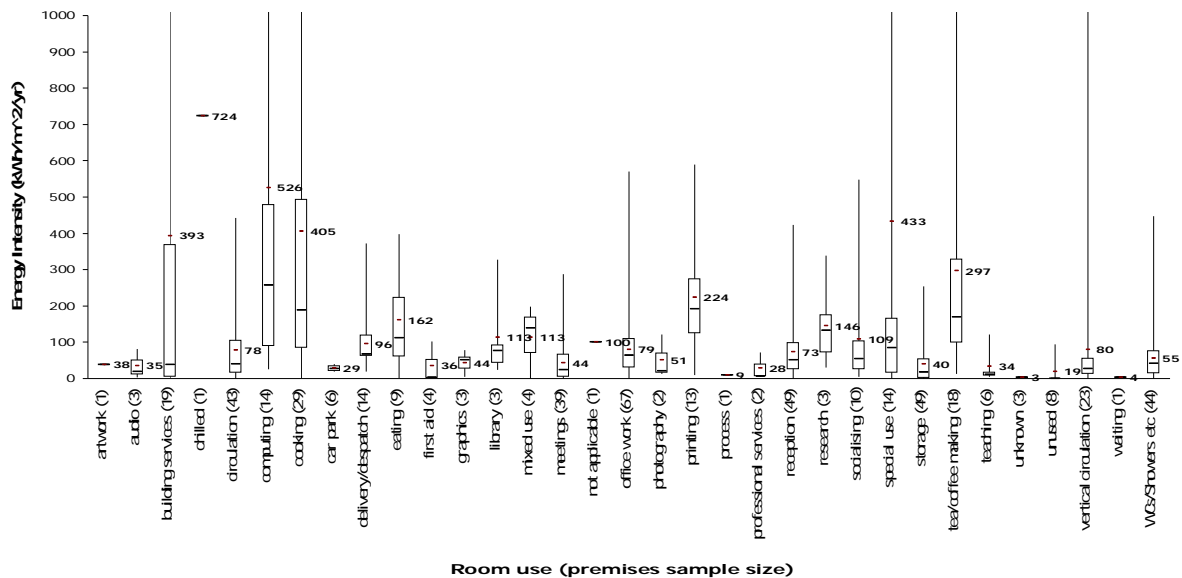


Figure 3: Energy intensity of room uses in office premises. Quartile distribution, median and mean values. Sample size, 69 premises.

In Figure 3, the sample size has shrunk to 69 premises as a result of the data filtering process previously described. The numbers on the plot area of the chart are the mean values of

Space Use and Energy Consumption in Retail Premises

Figure 5 shows the total distribution of space use for the PD Commercial Shops, i.e. all retail outlets, in the SHU sample. Note that values below 2% are not indicated numerically, but are still represented by segments of pie.

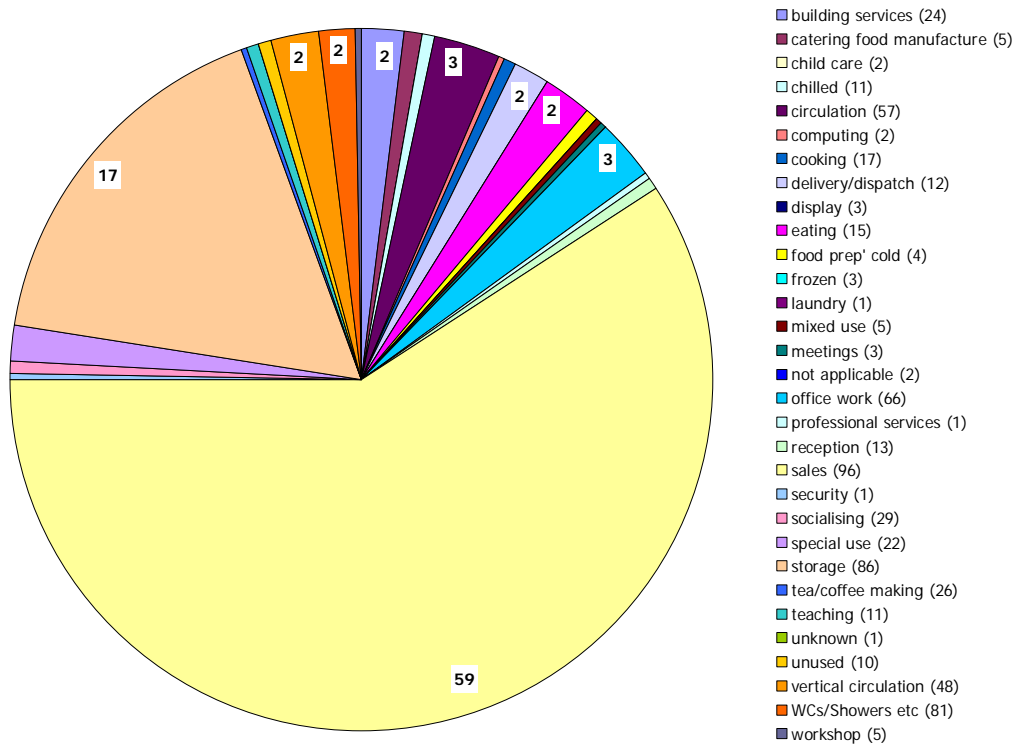


Figure 5: Use of space in retail premises. Sample size, 97 premises. (Numbers in brackets indicate the number of premises with that room use type)

The premises range in size from 33m² to 5160m², with a range of activities including a supermarket, baker's shop, photographic outlet, and butcher's shop represented. As one might expect, the majority of floor area is devoted to "sales", but the total of 55% might not be as much as one would expect. The other key uses are "storage" (20%), "office" (5%), "circulation" (3%) and "vertical circulation" (3%). So, in the same way that office premises are not just offices, so retail premises are not simply sales spaces.

Figure 6, below, shows the distribution of data for the percentage of total recorded floor area attributable to each room use, in the SHU retail premises. The data indicate that there is quite a wide distribution of space devoted to "sales", but that the distribution is also quite normal; though some premises have as little as 10% of their floor space classified as "sales". As with office premises, the spread of data for "WCs/showers etc", is very narrow, but circulation spaces appear to be more varied.

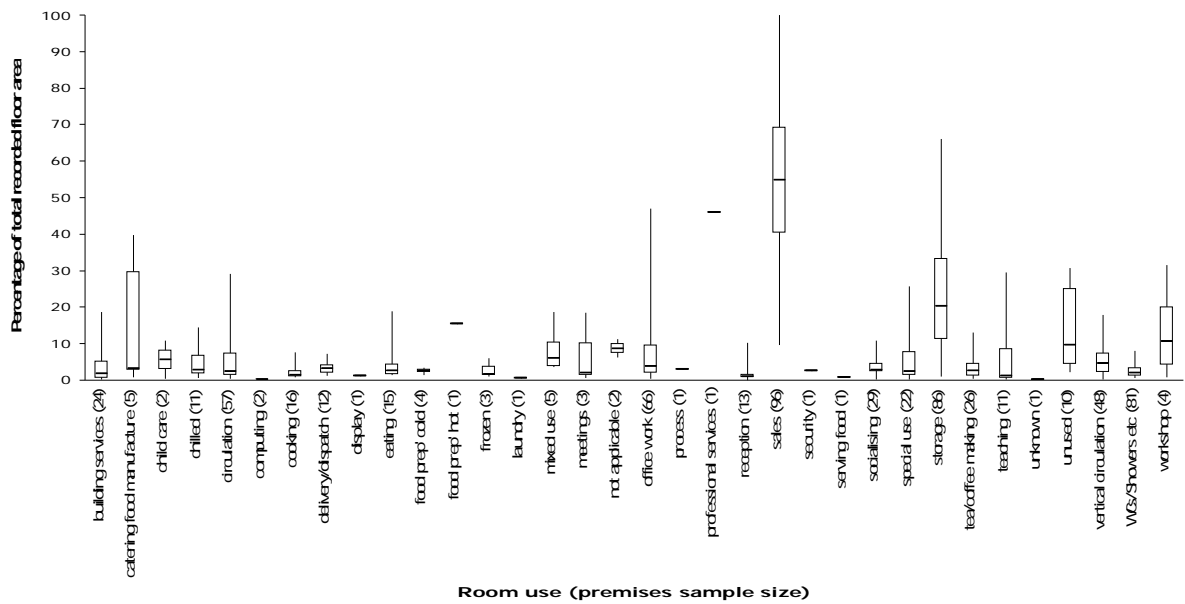


Figure 6: Space use in retail premises. Quartile distribution and median values. Sample size, 97 premises. (Numbers in brackets indicate the number of premises with that room use type)

Figure 7 shows the distribution of electrical energy intensity for each room use, together with its mean. The y axis is truncated at 5000kWh/m²/yr, for clarity. The maximum value for “building services” rooms is 20600kWh/m²/yr, with “catering food manufacture” at 7100kWh/m²/yr and “chilled” at 5900kWh/m²/yr. The variation in energy intensities is very wide when taken across all room uses, but the spread of intensity for each room use is still fairly narrow. This can be seen more clearly in Figure 8, where the y axis has been truncated at 1000kWh/m²/yr, as for office premises (Figure 3), above.

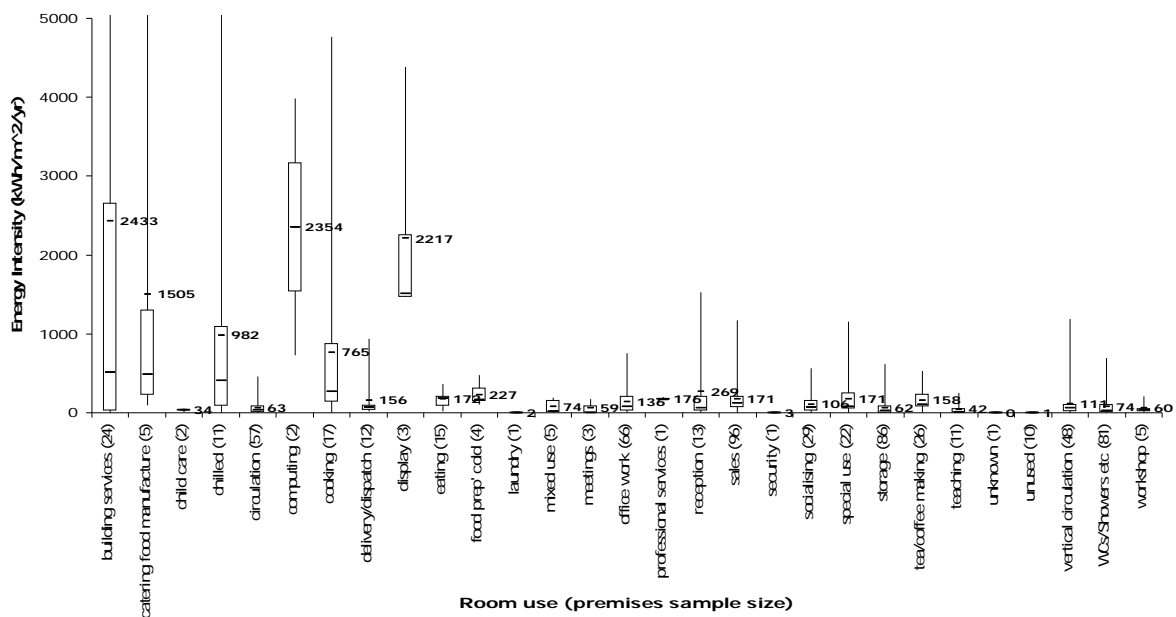


Figure 7: Energy intensity of room uses in retail premises. Quartile distribution, median and mean values. Sample size, 97 premises.

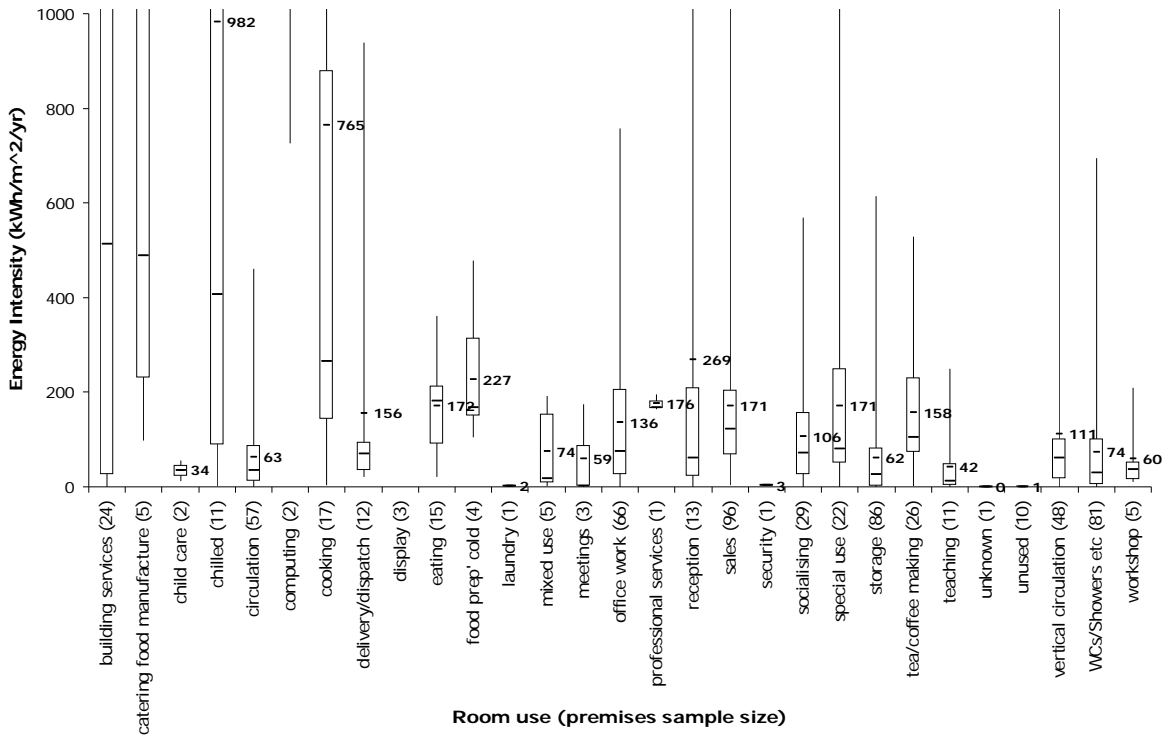


Figure 8: Energy intensity of room uses in retail premises. Quartile distribution, median and mean values. Sample size, 97 premises. y axis truncated at 1000.

Figure 9 shows the distribution of electricity consumption in retail rooms; as with offices (Figure 4), lighting plays a significant role in many room types. Catering is also now prominent, as is small power in some room types.

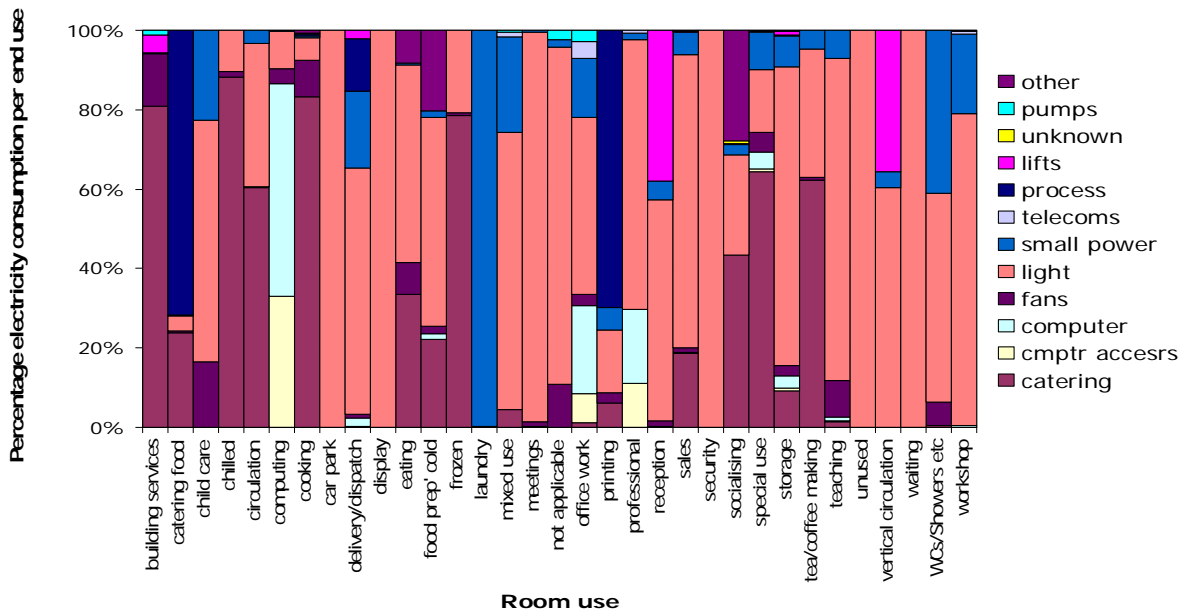


Figure 9: End uses of electricity, per room use, in retail premises. Sample size, 97 premises.

Computing is far less prominent than in office premises, but Figure 8 shows that mean electricity consumption for “computing” rooms is substantially higher than that for computing rooms in office premises and Figure 7 shows that the proportion of floor area and likelihood of occurrence are both small. It should also be noted that, due to the age of the SHU data, current use of computers is likely to be more widespread now and that this will probably affect energy intensities in “office work” and “sales” areas. “Computing” rooms might also be more common, too.

Discussion

Familiarisation with the SHU data has formed a significant and vital part of this research. Understanding the motivation and methodology behind the surveys has helped in forming the analysis procedures and interpreting the outputs. The identification of erroneous data using informed judgement has proved challenging, but has highlighted the problems of dealing with predominantly reported data, rather than recorded data. Some errors were found in recorded data, such as room areas and/or numbers of pieces of equipment and these were generally easier to identify.

The existence of multi-description VOA Line Entries poses a problem when attempting to map the SHU room uses onto Line Entries. The SHU-based room area profiles provide the means to deal with these problematic multi-descriptions. It is proposed that where Line Entries have multi-descriptions, the entire premises should be amalgamated into a single floor area figure and that this is subdivided according to the average room area profile for the appropriate Primary Description Code. Once the SHU room uses have been mapped onto the VOA Accommodation Use Codes, this should be fairly straightforward. This method could also be used to deal with those (generally) large premises that have only a single Line Entry description, but would be expected to be more complex than a single description would indicate. These problematic Line Entries are where the value of the overall room use profiles is greatest.

Initial observations of the Leicester Line Entries indicate that 68% of the floor area can be matched to the defined Accommodation Use Codes (ACUs). Also, the author has carried out a “by-eye” non-systemised matching of the SHU room uses to the Leicester Line Entries description. When the Leicester Line Entry descriptions are ranked according to their summed floor area, the top 100 account for 82% of the total non-domestic floor area listed. Matching these top 100 to the SHU room uses does not appear problematic, thus estimating the internal gains of more than 80% of Leicester’s non-domestic floor area seems feasible, though a coded, systematic approach may alter the degree of SHU/VOA matching.

For some room uses, the distribution of electricity energy intensity is fairly restricted (see Figures 3, 7 and 8). When matched to the VOA Line Entry Accommodation Use Codes, these intensities should provide a robust means of estimating the internal gains of the Line Entries of premises. This level of inference has not previously been achieved for VOA data and should lead to a better understanding of why premises activity has greater influence on energy consumption than physical building characteristics, as asserted by Mortimer (2009). Some work on updating the power ratings and frequency of occurrence of some equipment (e.g. computers and updated lighting systems) could be beneficial. But, this updating procedure should not come from design

guidance, as this could negate a key benefit of using the empirical data from the SHU surveys of real, in-use, premises.

In summary, the combination of proportional total room areas, and the described method of estimating end use consumption, indicates the potential to go beyond what is generally achieved with metered energy consumption data, enhancing knowledge of where to target energy conservation/efficiency measures in premises. The estimation of internal gains, based upon empirical data, could also benefit. Combining the SHU electricity consumption profiles and Valuation Office Line Entry data is ripe for application to a multi-premises/multi-building energy consumption model.

Future Work

This research is a work-in-progress. The following activities have been identified as work needed to expand and make greatest use of the foundations outlined above.

- Systemise the matching of the SHU room uses to the VOA Accommodation Use Codes and other Line Entry descriptions within Leicester VOA Line Entries
- Create a look-up database of internal gains for energy models based upon VOA data.
- After the alignment of the SHU/VOA, analyse the Leicester VOA Line Entries in the same way as the SHU has been analysed, to ascertain whether there are patterns of space use. Compare any emergent patterns with the SHU room use profiles.
- Source information to update SHU equipment power rating specifications. Produce an update for the SHU energy intensity profiles.

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