The Building Energy End-use Study (BEES): Study Design and Early Findings

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Abstract

The Building Energy End-use Study (BEES) is a large, multi-year study of the energy use in commercial buildings in New Zealand. The study design is described, including the methods used to overcome some of the major difficulties faced in covering the diverse range of non-residential building types and sizes. Analysis of the building stock characteristics from information derived from public sources including valuation data, Google Earth and Streetview is given. The study aims to develop a complete understanding of the energy use in non-residential buildings that can be used to assist in the development of benchmarks and information for improved building operation for building occupants and managers, and in policy and planning.

Keywords: energy efficiency, commercial buildings, building stock

1. Review

The commercial sector spends over $NZ 900 million/year on energy, accounting in 2008 for 11% of New Zealand's energy and 23% of electricity use (MED, 2009). The sector was responsible directly for 3% of energy Greenhouse Gas (GHG) emissions in 2008 (MED, 2009). In 2008 the sector consumed 22% of total electricity use, making it indirectly responsible for 5% of energy GHG emissions. Thus the sector is directly and indirectly responsible for 8% of national energy GHG emissions. It is important for both macro-economic and environmental management to know where the cost-effective opportunities for energy efficiency and conservation exist.

There is a pressing need to understand where and how energy is used, to help reduce GHG emissions and improve efficiency. To this end, several large scale studies internationally of energy in non-domestic buildings have been undertaken:

1. Commercial Buildings Energy Consumption Survey (CBECS, USA)
2. Commercial and Institutional Building Energy Use Survey (CIBEUS, Canada)
3. Non-Domestic Building Stock (NDBS, UK)
4. Carbon Reduction in Buildings (CaRB, UK)
5. California Commercial End-Use Survey (CEUS, USA)

CBECS is the longest running program, established in 1979 to cover the entire USA and repeated on an approximately four year cycle ever since (EIA, 2009a). The scope and coverage are extensive, encompassing all "commercial" buildings, defined as any building that has at least 50% of the floor area neither residential, manufacturing/industrial, nor agricultural (EIA, 2009b). Therefore there is great diversity in the type and usage of the buildings, and great diversity in energy use and energy intensity. This necessitates a large sample (approximately 5,000 buildings) with sophisticated sampling and analysis procedures to ensure that statistically reliable estimates of energy use and other parameters can be derived for the population as a whole, and sub-populations by building type, building use, geographic region etc. Although participation in the interview is voluntary, a high response rate is achieved, which was 82% for the 2003 survey. Data is collected using Computer Assisted Personal Interviewing (CAPI), where trained field staff conduct the interview on-site with a knowledgeable interviewee. Energy was not directly monitored, but revenue meter data was obtained either from the participants or directly from the energy suppliers[1]. Since energy consumption is only collected at a high level (e.g. building total by fuel) the amount used by various end-uses is not explicitly known but is generated by statistical analysis.

[1] CBECS comes under the EIA's mandatory data collection authority.

CIBEUS was carried out by Statistics Canada, mainly "to collect energy intensity information for the commercial and institutional buildings in Canada for the reference year 2000" (NRC, 2003). This information was used (in part) to assess Canada's greenhouse gas emissions reduction commitments. CIBEUS was very similar in scale and scope to CBECS, and shared some common definitions and methodologies.

CEUS was a program of comparable scale to CBECS, however conducted only in the State of California for the California Energy Commission (CEC) for the specific purposes of electricity and gas end-use forecasting and energy efficiency market assessment activities (CEC, 2006). Thus the study design was different, although the issues around the sample boundary, sampling, and statistical analysis are similar. In California, many commercial buildings had interval revenue meter data (15-60 minute intervals), and the CEC has a statutory right to access that data. In addition, during the planning stage of the project aggregated electricity data for all commercial buildings in California was obtained supporting enabling a thorough evaluation of the sampling methods. A stratified sample with strata of: energy utility area; building type; size; and climate zone was adopted to both improve the statistical accuracy or estimates and to better match the intended use of the data.

As CEUS required a much greater level of detail than CBECS delivered, different information was collected, extending down to detailed end-use equipment stock and characteristics and the detailed building layout. The information was collected during on-site visits by a trained auditor, so relied more on the expertise of the auditor than the knowledge of the occupants. The data permitted energy models to be created and tuned to match the interval meter billing records By analysis of the load characteristics for the various end-uses in each building, an estimate of the load profile and energy consumption for the different end-uses generated.

End-uses were not directly monitored, though in some cases (~500) time of use meters were installed on dedicated equipment to assist in the modelling end-use disaggregation process. CEUS remains the most detailed large scale study of commercial building energy use.

The NDBS project in the United Kingdom ran from 1991 to 2001, and was designed to support government policy-making for carbon dioxide emissions (Steadman and Bruhn, 2000). Policy making had found that the lack of information on the non-residential stock was a major problem, so one of the main outcomes of the project was a national database of non-residential buildings. More detailed street surveys were also carried out on four central city locations.

The CaRB project started in 2004, built on the methodological foundations of NDBS, extending coverage to all buildings with the long term goal to create a socio-technical model of energy use in U.K. building at scales ranging from national to community level (CaRB, 2009).

In New Zealand a series of field surveys were used to determine energy use in the commercial sector in several major cities: Auckland (Beca Carter Hollings et al., 1979), Wellington (Baird, Donn and Pool, 1983) and Christchurch (R. W. Morris & Associates, 1985), however, unlike CBECS the NZERDC surveys did not achieve nationwide coverage, and the process was not repeated. Subsequent research extended to performance monitoring of end-uses in three large commercial buildings in Wellington (Baird and Pool, 1985).

Each of these projects has had to overcome common methodological difficulties including:

1. Defining what is a "building" or the sample unit
2. Defining the population of buildings
3. Sampling the hugely diverse population efficiently
4. Compiling a list of buildings and occupants to recruit
5. Obtaining accurate and reliable energy data
6. The wide range of energy uses and intensities
7. The wide diversity of the types and levels of service provided

These common difficulties create major issues in sampling and analysis, some of which can be addressed by an appropriate sample scheme (e.g. sample stratified by building floor area, building type, and location) and by sampling a sufficiently large number of buildings.

Only Baird and Pool (1985) directly monitored energy consumption at the end-use level. The end-use estimates for these other studies have been inferred by other methods (e.g. modelling, statistical analysis, time-of-use monitoring, surveys or extrapolations from other research)

2. The building energy end-use study (BEES)

The key objectives of the Building Energy End-use Study (BEES) are to gain an understanding of how and where energy and water is used in non-residential buildings, what level of service is provided and how the efficiency of use can be improved. BEES commenced in late 2008.

Eight key research questions have been identified for this research on the non-residential buildings sector:

1. What is the aggregate energy & water use?
2. What is the average energy and water use per unit area per year?
3. What characterises the largest energy and water using buildings?
4. What is the average energy use per unit area for different building use categories?
5. What are the distributions of energy and water use?
6. What are the determinants of water & energy use patterns?
7. Where are the critical intervention points to improve resource use efficiency?
8. What are the likely future changes as the building stock type and distribution change?

To answer these questions, three complementary data collection methods have been designed and piloted, and are being rolled out in 2010:

1. Aggregate survey: A telephone survey of businesses owners to collect occupant, construction, location, energy and water data for a target of at least 500 buildings.

2. Targeted survey: Detailed monitoring of energy end-use and environmental data for a target of 300 buildings.
3. Case studies: Highly detailed case studies designed to explore the operation of specific buildings, for a target of 5 studies per year.

The data collection is supported and supplemented by: an annotated bibliography of New Zealand and international literature prepared; a systematic review; modelling of all surveyed buildings.

3. BEES sample frame

The sample frame defines the population of buildings which will be studied, which must be specified and sampled appropriately. Even at this most basic level there are difficulties to overcome:

1) Defining what a "building" is
2) Finding an efficient sampling strategy
3) Compiling a list of all valid buildings of interest
4) Finding contacts for businesses in the buildings

There is no commonly accepted definition of a non-residential "building". Non-residential buildings often share common walls and sometimes services, and may have common access arrangements. Sometimes existing buildings are modified and joined to other buildings to create a 'new' building. Buildings could therefore be separated by the architectural boundary (discrete physical structures), the services boundary, or the ownership boundary.

CBECS and CIBEUS used a very similar definition, basically "a structure totally enclosed by walls that extend from the foundation to the roof…" [EIA (2009c); NRC (2003), pg 494)]. NDBS and CaRB used the same definition, basically "…a 'building' encloses space which is accessible and usable for some human activity. …" (Bruhns, Steadman, Herring et al., 2000).

3.1 Information sources

Information on the building stock was gathered from a wide range of sources including:

1. Property valuation data
2. Aerial photos
3. Google Streetview images
4. Internet search of directories and business websites
5. Business directories
6. Brief site visits, to confirm and expand this information

These sources were used initially to get as much information on the buildings in the sample frame as possible, before surveying the buildings or occupants. The intention was to reduce the overall cost for the project and thereby enable a larger sample of buildings and occupants than could have been achieved if site visits were used. This process has turned out to be more difficult than anticipated for various reasons, including incomplete coverage of directories and internet information sources, difficulties identifying the correct land parcel and/or building, and occupant information being out-of-date due to the turn-over of business and buildings.

3.2 Valuation information

Although there is a New Zealand national database of valuations of legal titles[2] (representing land, buildings, parts of buildings, and other structures) used for local government 'rating' purposes[3], this was not in a suitable form for a sample frame. Valuation records are categorised by the principal use of the land at the time a valuation was undertaken. In some cases there may be a number of uses, and a 'multiple use' category is applied. In some cases the use may have changed over time but not yet been changed in the valuation record. A valuation record may include one or more buildings, parts of buildings, or other structures.

BEES purchased a copy of all the valuation records for commercial, industrial service and warehouse and "other" (includes educational, health, and community) categories - a total of 92,555 valuation records. Some buildings have multiple legal titles for different parts (e.g. floors or units) and although these were aggregated to form a parent "building record", without physically inspecting the actual site it is not possible to be 100% certain that this process represents an actual 'building'. This is a similar process to that in used in the NBDS and CaRB, where "hereditaments" (a legal title very similar to that use in New Zealand) were grouped to form a "building". The valuation records were grouped into parent records representing (usually) a single building or campus, yielding 75,400 building records, and various checks and data cleaning performed.

The total floor area for 'Commercial', 'Industrial Service', 'Industrial Warehouse', and the selected 'Other' categories is approximately 75 million m², in these 75,400 valuations (Table 2). The commercial category is the largest with 36 million m² in some 40,000 valuations. The three largest commercial sub-categories are 'Commercial-Retail', 'Commercial-Multiple/Other' and 'Commercial-Office', and their combined floor area is 27 million m², which is 75% of the total 'Commercial' floor area (Table 3). In the 'Other' category, the 'Educational' sub-category has 45% of the total floor area, far larger than any other sub-category.

Using this analysis, and guided by the aims of the study, the decision was made to restrict the main BEES study to the Commercial subcategories: Office, Retail, Mixed, Service Station[4],

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[2] Held by Property IQ - www.propertyiq.co.nz

[3] Rates are local property taxes levied by local and regional councils to provide various services.

[4] A gas or petrol station, nowadays usually also includes a convenience store.

Motor[5], Liquor, and Tourist. These categories seem to best represent those where retail or office activities predominantly occur. The Commercial subcategories of accommodation, rest home, and car park are therefore excluded. 'Educational' and 'Health' categories have been separated out for a sub-study.

After the records in non-BEES categories are removed, it is estimated that in New Zealand there are 50,540 BEES non-residential buildings, with a total of 48.3 million m² total floor area.

3.3 Sampling strategy

These building records were used to investigation efficient options for sampling. Taking a simple random sample of 1,000 building records with equal probability, and assuming energy use was related to the proxy variable of property value, would give an estimated standard error in average total energy consumption of ±17%. In contrast, a stratified random sample of 1,000 buildings with 5 size strata each representing 20% of the total floor area (Table 1) would give a standard error of ±3%. This is caused by the highly skewed distribution of total floor area (see **Error! Reference source not found.**): by count, 87% of all non-residential buildings are under 1,500 m² in floor area, but the remaining 13% by count represent 60% of the floor area. This type of skewed distribution was also observed to occur in the USA in CIBECS and CEUS, and in the UK in the NBDS and CaRB studies, and presumably also applies to other countries. It is expected that other studies of non-residential building energy use in general will have to deal with these kind of sampling issues. Section 4 has more detailed information on the distribution of floor area.

Table 1. Floor area strata used for the BEES sample

Floor area group	*Strata 1*	*Strata 2*	*Strata 3*	*Strata 4*	*Strata 5*	*Total*
Minimum Floor Area	*5 m²*	*650 m²*	*1,500 m²*	*3,500 m²*	*9,000 m²*	
Approx. No. of 'Buildings'	*33,781*	*10,081*	*4,288*	*1,825*	*564*	*50,539*
% of Buildings	*67%*	*20%*	*8%*	*4%*	*1%*	*100%*
Total floor area (million m²)	***9.9***	***9.6***	***9.5***	***9.6***	***9.8***	***48.3***
% floor	*20%*	*20%*	*20%*	*20%*	*20%*	*100%*

3.4 Compiling list of businesses

Implementing the survey design is still not a straightforward process, due to the difficulties of then compiling a list of building and occupants to recruit. There is no near-complete list of building owners or occupants, a problem found and resolved in different ways in other

[5] Motor vehicle sales. Motor vehicle servicing is excluded, and is usually found in the Industrial Service valuation category.

countries. The list of building owners attached to the valuation data is not complete, and many of the owners are trusts or other legal entities which are difficult to contact. Business directories are also not complete, achieving perhaps 50-70% coverage, with some types of businesses unlikely to be listed in general directories.

Statistics New Zealand[6] does hold a list of "enterprises", which are all businesses with GST returns (a value added tax of 12.5%) exceeding $30,000 per annum. This is also incomplete as smaller businesses are excluded, and in addition an "enterprise" can be a business spread across a number of different sites (including fishing boats), so does not always correspond to the BEES sample unit of a "building record". In the absence of a comprehensive directory of businesses, the available business directory was used, supplemented by business names found in Google Streetview or web search, and then followed up with a site inspection to confirm the information, and record any additional businesses.

For BEES, the business level sample unit is called a *premises*, which is a single business operating in all or part of a building record. There can be one or more premises in a building record. Before a phone survey can even commence collecting data, it is necessary to identify all premises and obtain their contact details. Using Google StreetView, the on-line 'Yellow Pages', a web search and purchasing address data from a commercial supplier, a total of 7,682 premises were identified in the 3,043 building records selected for possible recruitment into the study, on average 2.5 premises per building record.

Site visits were then undertaken for the first 800 of these building records to check the information, and search for any additional premises in preparation for the telephone survey. This process yielded a total of 2,568 premises, (3.2 per building record), however 6% of the building records were vacant or not found, and 24% of the premises were not found, leaving 1,943 premises. Of these 1,557 were eligible for the BEES study and had phone numbers. This clearly illustrates how difficult it can be to find a list of survey candidates.

3.5 Websearch

An internet websearch was used to compile information on ~2,400 valuations. The main internet tools used were Google Earth and Google Streetview, which together enabled aerial and street level images to be found, and characteristics of the building inferred, such as the number of floors, floor area, construction materials, glazing etc. Google Sketchup was used to create building models, ready for analysis in the thermal model EnergyPlus, with the information on the building included.

The data collection phase of the websearch was completed in December 2009, and analysis and modelling is continuing.

4. Building stock floor area distribution

The distribution of floor area is highly skewed, as the count of buildings is dominated by small to medium sized buildings, but the floor area is dominated by comparatively few very large buildings. For the Commercial categories, only about 2% of buildings have floor areas larger than 10,000 m², but together they have 20% of the total floor area *Figure 1*. This pattern is seen for all valuation categories, and is particularly pronounced for hospitals and educational buildings, as there are some very large regional hospitals and university campuses. Such a highly skewed distribution creates problems in sampling and estimation.

Table 2. Estimates of total floor area and valuation count – separate and parent records.

Category	*Total Floor Area (m²)*	*Count of 'separate' and 'parent' Valuations with floor area*
Commercial-Accommodation	*3,532,580*	*3,880*
Commercial-Cinema/Hall	*255,530*	*150*
Commercial-Elderly	*2,086,630*	*930*
Commercial-Liquor	*902,150*	*1,080*
Commercial-Motor	*829,130*	*1,490*
Commercial-Multiple/Other	*8,608,160*	*7,020*
Commercial-Office	*7,618,290*	*6,670*
Commercial-Parking	*450,360*	*490*
Commercial-Retail	*10,534,160*	*16,560*
Commercial-Service Station	*571,640*	*1,270*
Commercial-Tourist	*264,170*	*310*
Commercial-Vacant	*58,020*	*220*
Industrial-Service	*8,495,630*	*9,990*
Industrial-Warehouse	*10,328,930*	*6,820*
Other-Assembly Halls	*949,830*	*2,390*
Other-Educational	*8,450,260*	*4,300*
Other-Health/Medical	*2,582,210*	*1,180*
Other-Maori Sites	*431,560*	*800*
Other-Multiple/Other	*3,466,460*	*2,950*
Other-Passive Reserve	*446,600*	*970*
Other-Religious	*1,810,070*	*3,470*
Other-Sporting	*2,063,920*	*2,320*
Other-Utilities	*42,810*	*20*
Other-Vacant	*169,610*	*120*
Total 'Commercial'	***35,710,820***	***40,070***
Total 'Industrial'	***18,824,560***	***16,810***
Total 'Other'	***20,413,330***	***18,520***
Total 'Commercial+Other'	***56,124,150***	***58,590***
Total	***74,948,710***	***75,400***

[6] www.statistics.govt.nz

Table 3. Average floor area by valuation category – ‘Commercial’ only

Category	*Average Floor Area (m²)*	*Count*	*Percentage of floor area*
Commercial-Accommodation	*910*	*3,882*	*10*
Commercial-Cinema/Hall	*1,681*	*152*	*1*
Commercial-Elderly	*2,249*	*928*	*6*
Commercial-Liquor	*834*	*1,082*	*3*
Commercial-Motor	*558*	*1,486*	*2*
Commercial-Multiple/Other	*1,226*	*7,024*	*24*
Commercial-Office	*1,142*	*6,673*	*21*
Commercial-Parking	*923*	*488*	*1*
Commercial-Retail	*636*	*16,559*	*30*
Commercial-Service Station	*449*	*1,273*	*2*
Commercial-Tourist	*855*	*309*	*1*
Commercial-Vacant	*264*	*220*	*0*
All	***891***	***40,076***	***100***

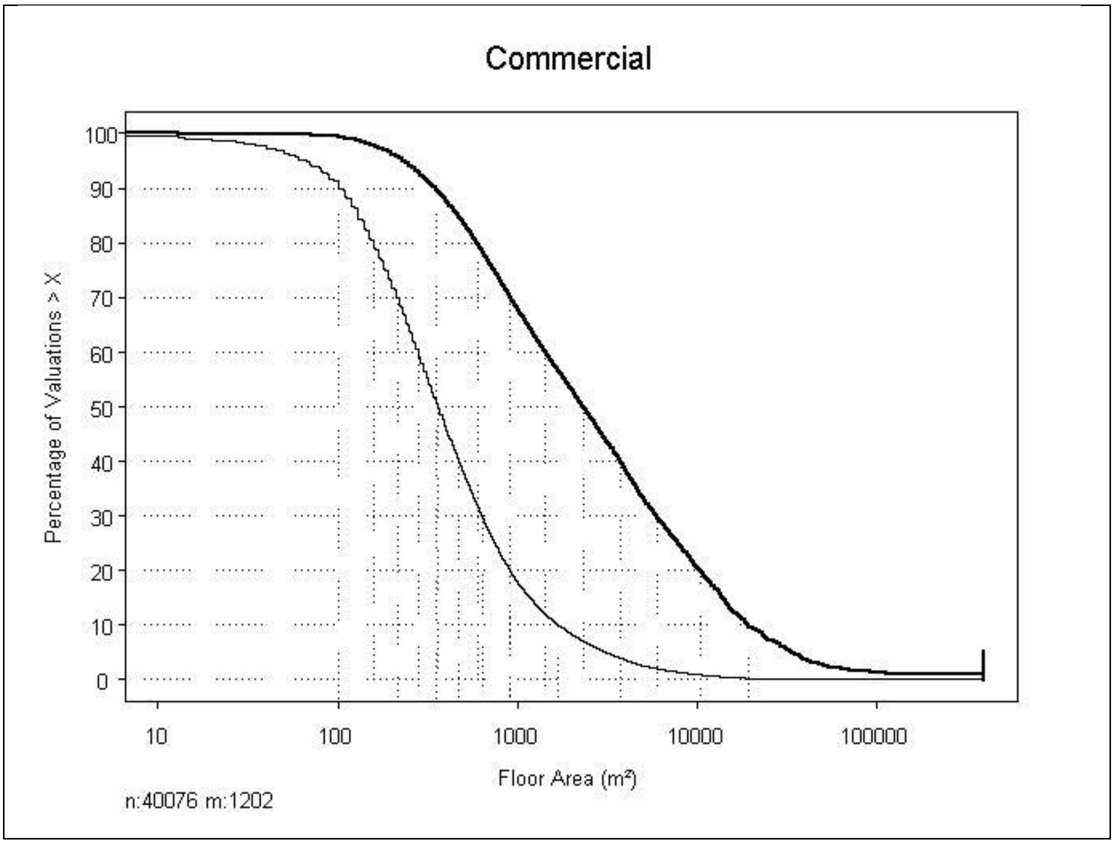

Figure 1. Cumulative percentiles for Commercial valuation categories.
Thin line is cumulative count, thick line is cumulative floor area

5. Energy and environmental data

Energy data for studies of this type is usually sourced from utility billing records, or from interval data (e.g. 30 minutes) from utility interval metering or the building Energy Management System (EMS). Utilising billing records always sounds as if it will be a cheap and easy process, however it does take a lot of time and effort to obtain and process the data. To quote from Beca Carter Hollings et al. (1979):

> "It is often suggested by energy researchers and other interested parties contemplating energy studies that 'energy consumption information can be obtained from supply authorities'. … Any future researcher contemplating a broad multi-fuel type investigation should be prepared for a pot-pourri of classification and accounting systems, as well as considerable variation in accessibility of data."

Energy billing records for BEES premises will be obtained to give a longer time series of data than could be monitored, including revenue records from prior to the commencement of the BEES work. In the 30 years since the Beca Carter Hollings et al. (1979) study was completed this process has become easier as accounts and records are fully computerised but more complex in many other way:

1. The energy market reforms of the 1990s have led to a multitude of energy (electricity and gas) retailers, each with their own systems and requirements
2. Agreeing and trialling information exchange processes
3. Matching account signatory to all matching account and meter IDs
4. Importing, reformatting, and processing data

If the utility suppliers were active participants in the project, or commissioning agents, this process would be much easier as working relationships would already be in place.

Obtaining energy end-use and environmental information (e.g. electricity, gas, temperature, humidity, light) requires a different approach, as these are not usually monitoring in a building unless it has a comprehensive EMS.

For BEES, electricity end-uses are monitored directly at electrical distribution boards around the building using proprietary equipment. The recent commercialisation of Rogowski coils for measuring current has enabled much smaller current clamps than conventional magnetic current transformers. After trials of several systems, the Multivois system was selected, supplied by the French company OmegaWatt (www.omegawatt.fr). This system uses a DIN rail mounted "concentrator" (data logger) which connects to up to nine modules, each with 6 Rogowski coil sensors. The logger and sensors are very small and easy to fit on distribution boards, are accurate (typically ±2%), and cover a very wide power range. The planned monitoring would not be practicable with any other available system due to space restrictions, safety concerns, and likely power interruptions.

Environmental data is collected at several points in each premises using battery powered temperature, humidity, and lux loggers, with carbon dioxide levels monitored by a separate logger at a single point.

6. Conclusions

Planning and piloting of monitoring for the Building Energy End-use Study (BEES) has been largely completed and the full study is underway in 2010. To get to this point some major obstacles have had to be overcome to deal with the huge diversity in building types, size, services, use, and energy consumption - issues that will be common to any similar study. Survey methods for collecting information on buildings and their occupants have been trialled. Methods for monitoring energy end-uses and environmental conditions have been tested and trialled and are being used to monitor buildings. Together these methods should give an unprecedented understanding of how energy is used in buildings, and provide many future opportunities for optimising energy and resource use.

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