Understanding Energy Use in New Zealand's Non-Residential Buildings.

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Energy and Water demand in New Zealand's Non-Residential Buildings.

Understanding how energy and water resources are used in non-residential buildings is key to improving the energy and water efficiency of New Zealand's building stock. More efficient buildings will help to reduce greenhouse gas emissions and enhance business competitiveness. The Building Energy End-use Study (BEES) is establishing how energy and water resources are used in non-residential buildings and what factors drive this use.

Capturing the building, social and economic dynamics of energy and water consumption across the non-residential stock is by no means a trivial task. BEES has developed a sample frame and data collection methods to establish a representative sample of non-residential buildings and a multi-method approach that allows data from different sources to be triangulated.. Data on building structure, business activities and energy and water use have been collected. This has been achieved by compiling complementary data sets from broad surveying of buildings and businesses through to specific data collection and intensive detailed monitoring of individual premises. This paper provides an overview of the research methodology and key energy results from the project to date. It includes an understanding of the profile of the non-residential building stock, energy use baselines, determinants of resource use and an insight into the possible intervention points to improve resource use efficiency.

Keywords: Non-residential buildings; Energy efficiency; Energy end-use; Building characteristics.

1. Introduction

In New Zealand a significant amount of research on improving energy efficiency and the services it provides for housing has been completed, (Isaacs et al, 2010a), but information and research on non-residential buildings was minimal Once this was recognised, and funding and support made available from both government and the building industry, a

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research project was initiated. The project, the Building Energy End-use Study (BEES) aims to provide new knowledge on how energy and water resources are used in non-residential buildings in New Zealand and develop and understanding the factors that drive this use.

Through collection of measured data using surveys and monitoring the project objectives are to quantify and characterise the energy and water use in non-residential buildings and understand how energy is used in today's non-residential buildings. This will improve models of non-residential building energy use; provide design and operation guidance, and guidance to create more productive work environments. The research aims to provide a base for development of the New Zealand Building Code (NZBC), Standards and rating tools, along with Government policy development and implementation. It will also support the reduction of GHG emissions and adaptation to climate change.

To conduct this research, a range of skills and disciplines are necessary and a multi-disciplinary as well as cross-organisational, best-fit team of researchers has been assembled. This includes physical and social scientists, building energy and modelling experts and a statistician. This paper provides an overview of the BEES research and key results to date. It includes an understanding of the profile of the non-residential building stock, energy use baselines, determinants of resource use and an insight into the possible intervention points to improve resource use efficiency in these buildings.

There are several different definitions of non-residential buildings both internationally and within New Zealand so an early step of the research methodology was to develop a BEES definition of non-residential buildings. After investigating overseas approaches and definitions available within New Zealand it was decided the New Zeland Building Code definitions were the most appropriate. Therefore, buildings defined as Commercial and Communal Non-residential Assembly Care fell within the scope of the project (Isaacs et al, 2010b). This meant the key focus of the study would be on buildings where office and retail activities were conducted. This ensured that industrial and other buildings in sectors in which energy and water consumption was primarily attributable to the industrial processes housed in the building were excluded.

2. BEES Sample Frame

In New Zealand there is no database or regular census of non-residential buildings. Therefore to collect data from non-residential buildings other means of providing a sample frame was necessary. As a proxy the best available information available was the property valuation records. Selected valuation records were purchased from PropertyIQ and Auckland City Council (who had their own valuation department). These were in two key groups; valuation records that had category codes that were consistent with the BEES non-residential buildings definition; commercial buildings and two industrial categories (IW-warehouse and IS-service). The industrial categories were included because they had the potential to contain businesses that provided office or retail activity. This subset, defined as building records, provided the sample frame for the study (Isaacs et al, 2010b). It consists of over 50,000 building records.

The sample frame was stratified into 50 strata; a combination of floor, use and region groups. The floor area groups that divided the sample into quintiles based on estimated total floor area has been the dominant strata group used for data collection (see Table 1).

Table 1: Sample Frame Count by Floor Area.

Floor Area Group	**1**	**2**	**3**	**4**	**5**	**Total**
Minimum Floor Area	5m²	650m²	1,500m²	3,500m²	9,000m²	
Maximum Floor Area	649m²	1,499m²	3,499m²	8,999m²	111,000m²	
No of Building Records	33,781	10,081	4,288	1,825	564	**50,539**
% of Building Records	67%	20%	8%	4%	1%	**100%**
QV Total Floor Area (million m^2)	9.9	9.6	9.5	9.6	9.8	**48.3**
% floor area	20%	20%	20%	20%	20%	**100%**

From this framework a stratified sample of 3000 building records was randomly selected as the sample for analysis and data collection. The remaining building records in the sample frame were intended as replacements.

2.1 Survey and Data Collection

A range of data was required at several different levels to allow analysis to meet the project objectives. This included data and information on both the selected buildings and the businesses within the buildings. This was important because energy and water used within buildings is dependent on both the fabric and services (e.g. central heating) of the building but also the activities of the businesses within the building. Also, typically it is the businesses working within a building that pay for the energy and water use (whether directly or indirectly).

A business may work across multiple locations so the unit that links a business to a location is defined as a premise. This may be a single building or part of one building, i.e. where the business and building intersect.

The BEES programme has gathered data from via a range of methods:

- Web search using web-based search engines and the addresses provided from the building records provided a range of data including: building size and shape, estimated number of floors, number of buildings per building record, where possible business names and estimated floor plate areas.
- Data collection of business names, addresses and phone numbers within the BEES buildings were gathered from a range of other sources including: businesses directory data, street searching, internet based options (e.g. Google Street View) and organisations who supply business contact information.
- BEES Phone survey of premises was completed for the first 2000 building records from the sample. The survey provides information on the occupation of the premise

including the number of employees, hours of use, tenancy and ownership, appliance counts, operation of heating and cooling.

- Meter and water billing records for premises that provided consent. For every phone survey a request to access their billing data records for a two year period was requested. This required a formal signoff form the businesses to enable access to the data from the energy or water company.
- Detailed monitoring of a small group of premises. This provided physical data, typically over a two week period, on the energy use and end-uses within a premise, including lighting, plug loads and heating. Daylighting, temperatures and CO_2 measurements were also recorded.
- Detailed interviews for case studies. Detailed interviews or surveys were completed to better understand the complex relationship between, owners, property managers and tenants. Also a small set of building case studies to understand the user perceptions have been completed using the BUS method (Usable Buildings Trust, 2006).

The initial concept for the data collection was to have a cascading model so each level of greater detail would be a subset of the larger sample, starting with the web search of the randomly selected 3000 building records (Figure 1).

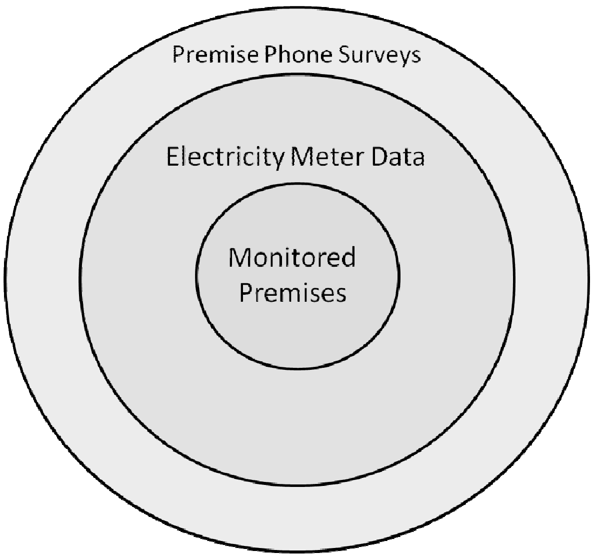

Figure 1: Data collection cascading model.

In reality the data collected has been more disparate. The diagram below shows the relationship of the data sets at a premise level. The result shows rather than a cascading sample there are areas that intersect. The reason for this has been twofold:

- Very few premises were prepared to carry out all three components, especially where the level of 'sign off' increased. In particular, the two step process required from completing the phone survey to signing a consent form for the meter data.
- Having two parallel research streams (surveying and detailed monitoring) meant that a few of the detailed monitored premises when requested at a later date to complete a phone survey opted not to proceed.

Premise Data	Total
Phone Survey	840
Meter Data	402
Monitored	101

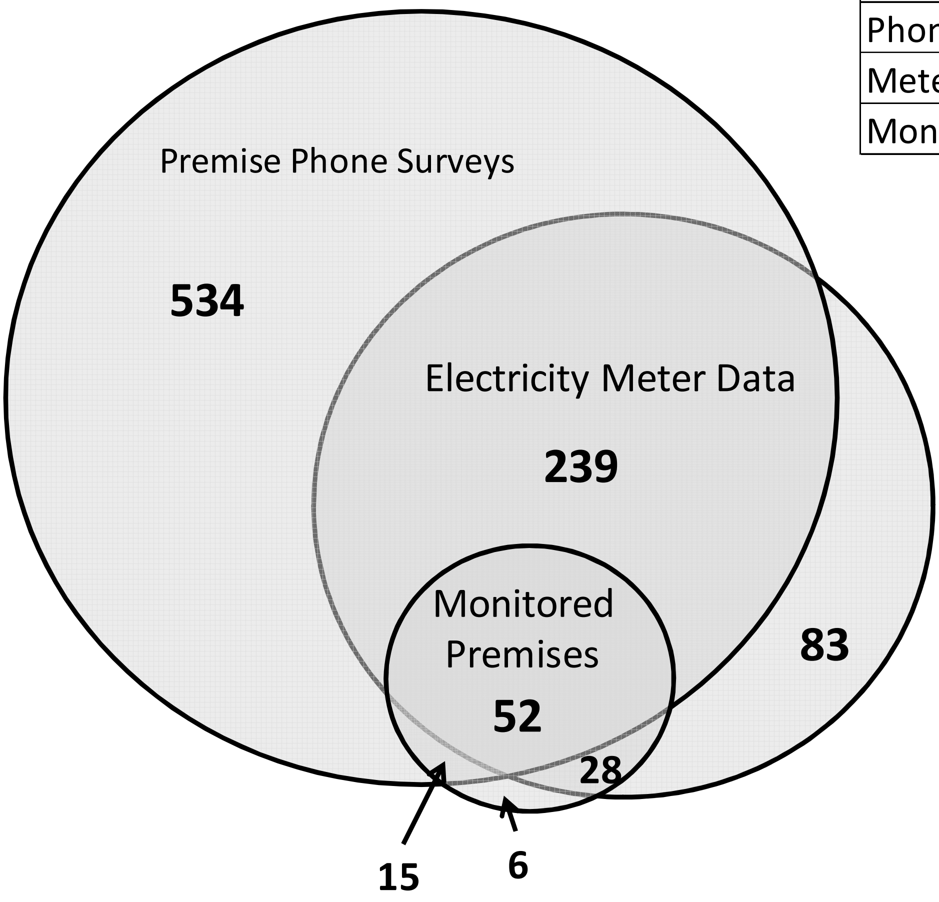

Figure 2: Data collection numbers from Premises (n=957).

However, the multiple option approach to data collection has provided rich datasets that can be interrogated and cross linked in numerous ways. These allow analysis of relationships between the physical buildings and their characteristics, the building activities, building owners and its users, and the services provided. All of these have an impact on the energy and/or water use and the potential to improve efficiency of use.

3. Results

The BEES data allows analysis to better understand the physical nature of the building stock and through modelling the identification of opportunities to improve both energy and water use at a broad level and energy end-use at a detailed level. Through the survey and interviews the energy efficiency opportunities can also be identified for the different groups of people involved in managing and using non-residential buildings. For each of these a significant amount of analysis is being undertaken to meet the programmes objectives. The following provides some of the key results and knowledge to date.

3.1 Building Characteristics

An unexpected outcome of the research has been the ability and necessity to use the data to develop a good understanding of the overall non-residential building stock.

Table 2 provides an estimate of the number of non-residential buildings in NZ. It suggests there are approximately 33,000 non-residential buildings in New Zealand, a combination of office, retail and mixed use. The reduction in from the sample frame is because when assessed in detail, approximately 20,000 did not fit the BEES non-residential building criteria. Non-residential buildings have a total floor area of about 31,000 million square metres. There are estimated to be about 400 buildings in the largest floor area strata (over 9,000m²) when assuming one building per building record. However at the other end of the scale there are approximately 23,000 buildings with a floor area less than 650m^2 (Isaacs, 2011).

Table 2: Non-residential buildings by size

	Building Floor Area					**Total**
Minimum Floor Area	5m²	650m²	1,500m²	3,500m²	9,000m²	
Maximum Floor Area	649m²	1,499m²	3,499m²	8,999m²	111,000m²	
Approx. No. of 'Buildings' % of Buildings	22,915 70%	5963 18%	2617 8%	1072 4%	398 1%	32,965 **100%**
Total Floor Area (million m²) % floor	6.9 22%	5.8 19%	5.8 19%	5.7 18%	7.0 22%	31.0 **100%**
Average floor area (m²)	300	967	2200	5270	17,530	**940**

The data can also be analysed to provide estimates of the number of storeys per building and hence explore the relative importance of low rise versus high rise buildings. Table 3 provides a breakdown of the web search sample by number of storeys per building for BEES eligible with floor area data. It shows 50% of this representative sample is single storey, although this group is only 32% of the floor area. Approximately 10% are 6 storeys or more although percentage of the floor area is double that at 20% of the sample.

Table 3: Web-search Analysis by Number of Storeys per Building

Number of Storeys	No of Buildings	% of Buildings	Total Floor Area	% of Floor Area
1	1071	50.5%	2955	32.4%
2	578	27.2%	1944	21.3%
3	115	5.4%	577	6.3%
4	95	4.5%	644	7.1%
5	44	2.1%	267	2.9%
6	37	1.7%	284	3.1%
7	34	1.6%	245	2.7%
8	21	1.0%	195	2.1%
9	20	0.9%	156	1.7%
10+	107	5.0%	1841	20.2%
Total	**2122**	**100%**	**9108**	**100%**

Both Table 2 and Table 3 show the skewed nature of this building stock, with the majority of the buildings being small single storey buildings and very few large multi-storey buildings, with the average floor area across this building stock is only 940m^2.

While the web search provides data on the current use of most of the buildings, comparison of the original building use (as reported in the valuation) and the current use proves to be interesting. For example a building coded as "Industrial Warehouse" in the original valuation record, may have moved to "Retail" use. Table 4 shows that by count 11% of the industrial service categorised building records and 5% of the industrial warehouse building records have changed their use and now used predominantly for either retail or office activities. Future analysis will be completed to determine and code the current use of the buildings in the IS and IW buildings.

Table 4: Building Record count by size and use category –

Use Group	Building Record (Count) Floor Area Size					Total	%
Minimum Floor Area	5m²	650m²	1,500m²	3,500m²	9,000m²		
Maximum Floor Area	649m²	1,499m²	3,499m²	8,999m²	111,000m²		
Office Total	3709	997	547	314	131	5698	17%
Retail Total	12,806	2365	716	224	113	16,224	49%
Mixed Total	3446	1318	646	338	98	5846	18%
IS Total	2444	839	328	84	14	3709	11%
IW Total	510	444	379	113	42	1488	5%
Grand Total	22,915	5963	2616	1073	398	32,965	100%
%	70%	18%	8%	3%	1%	100%	

Operational characteristics can be added to the physical information in the web search and valuation data through the use of phone survey data, which is currently available for of 791 premises. For example, the phone survey asked about the use of mechanical ventilation, air-conditioning and passive options (Saville-Smith & Fraser, 2012). Results from the premise survey showed a strong, and possibly not surprising trend, that the larger the building the more likely it will be air-conditioned, as shown in Table 5. Based on the total building stock and using these percentages Table 5 also provides a national estimate of the number of air-conditioned buildings by floor area strata.

Table 5: Estimate on number of air-conditioned buildings in New Zealand based on premise survey.

Premise survey (n=791)	**Building Size (total floor area m^2)**				
Minimum Floor Area	5m²	650m²	1,500m²	3,500m²	9,000m²
Maximum Floor Area	649m²	1,499m²	3,499m²	8,999m²	111,000m²
Percentage air-conditioned (% of premises)	34.4%	48%	55%	70.7%	76.6%
Estimated number of buildings air-conditioned	7883	2862	1439	758	305
Estimated total number of buildings in this building size	22,915	5963	2617	1072	398

The ability to open windows shows the opposite pattern and can be assumed to represent the passively ventilated non-residential building stock. Only about one-fifth (21.6 percent) of premises in very large buildings have windows that open, compared to 72.1 percent of premises in buildings less than 650m^2.

Overall, approximately 40% of the BEES building stock is estimated to have air-conditioning. This was reported from the premise surveys, so it is possible that some of these buildings use a split system single unit heat pump for individual room or premise air-conditioning and heating (using similar plant as would be found in a residential house), rather than a central HVAC (heating ventilating and air conditioning) system. The detailed monitoring found this to be the case, where in the first 77 buildings monitored from Strata 1-4, the most common type of heating/cooling system was by heat pumps (Camilleri & Babylon, 2011).

Future analysis of the building envelope data will provide new understanding of passive design opportunities, but the premise survey has already revealed that double glazing has a low penetration rate with similar proportions of premises (about 12% irrespective of floor area) reporting the presence of double glazing.

Collectively, the BEES analysis is developing a picture of New Zealand's non-residential building stock. It shows the diversity of the physical nature and activities within the buildings. The most dominant collective group is small retail shops (less than 650m^2) with an estimated 12,806 buildings, or approximately 39% of the total stock. The next largest group is small office buildings (under 650 m^2) at 11%. These results are suggesting that there will need to be tailored energy efficiency strategies to meet the different building types and uses. Perhaps most importantly it is suggesting that while the largest opportunities by building count may be in the very large buildings, there is a sizeable amount of floor area in the small buildings, albeit in a very much larger number of these buildings.

3.2 Who Managers the Buildings?

The energy and water efficiency of any building not only depends on the physical nature (building envelope and services) and the activities carried out within, but also on how the building is operated and managed. The management/owner/tenant relationships have an impact on the energy efficiency opportunities, so understanding these relationships are an important aspect to the characteristics of this non-residential building stock.

The analysis of phone survey premise data highlights smaller buildings are managed and used differently from larger buildings. This is shown in Figure 3. The recipients were asked who managed the building they occupied. For buildings less than 650m2, less than 20% response reported a building manager but most concerning was that approximately 40% said there was no one managing the building. At the other end of the scale for those premises in buildings over 9000m2 approximately 50% had appointed building managers.

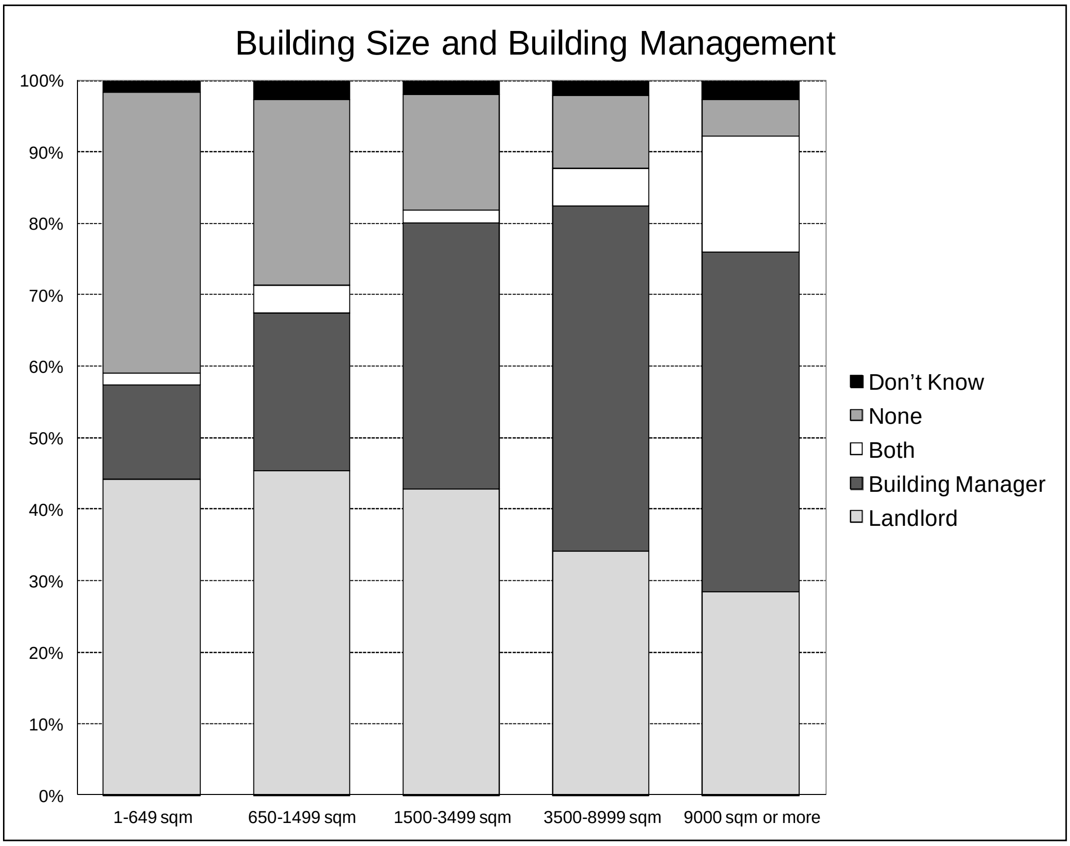

Figure 3: Reported building management in BEES surveyed premises.

Analysis revealed that building size when cross referenced with building ownership, use and occupancy generated different market segments.

The combined building characteristics presented above gives an indication of huge variation in this building stock, in not only the physical nature, but also resource uses and management. Therefore it is important not to develop broad brush initiatives to improve either energy or water efficiency that attempt to cover the all non-residential buildings.

Instead targeted initiatives that are carefully matched to segments defined by particular combinations of owner, occupant and building type are likely to be more successful.

3.3 Understanding End-uses

Detailed monitoring of premises provides an in-depth understanding of energy end-use which can be related to the services provided by energy use and the activities within the building. The BEES project has monitored premises in over 126 buildings to provide time of use energy and environmental data. Where possible, metered revenue data for at least a 12 month period was also obtained. Analysis of the meter data to date has shown that these randomly-selected buildings within the BEES sample have a much wider distribution of energy use intensity (energy use per square metre, EUI), with some much lower and some much higher, than previously measured. What is interesting to note is the very low and very high EUI are all from buildings occupied by retail business (Bishop and Isaacs, 2012).

Through interrogating the monitored data it is possible to understand what is driving the energy use within a premise. An example is shown below of a premise with a very high EUI.

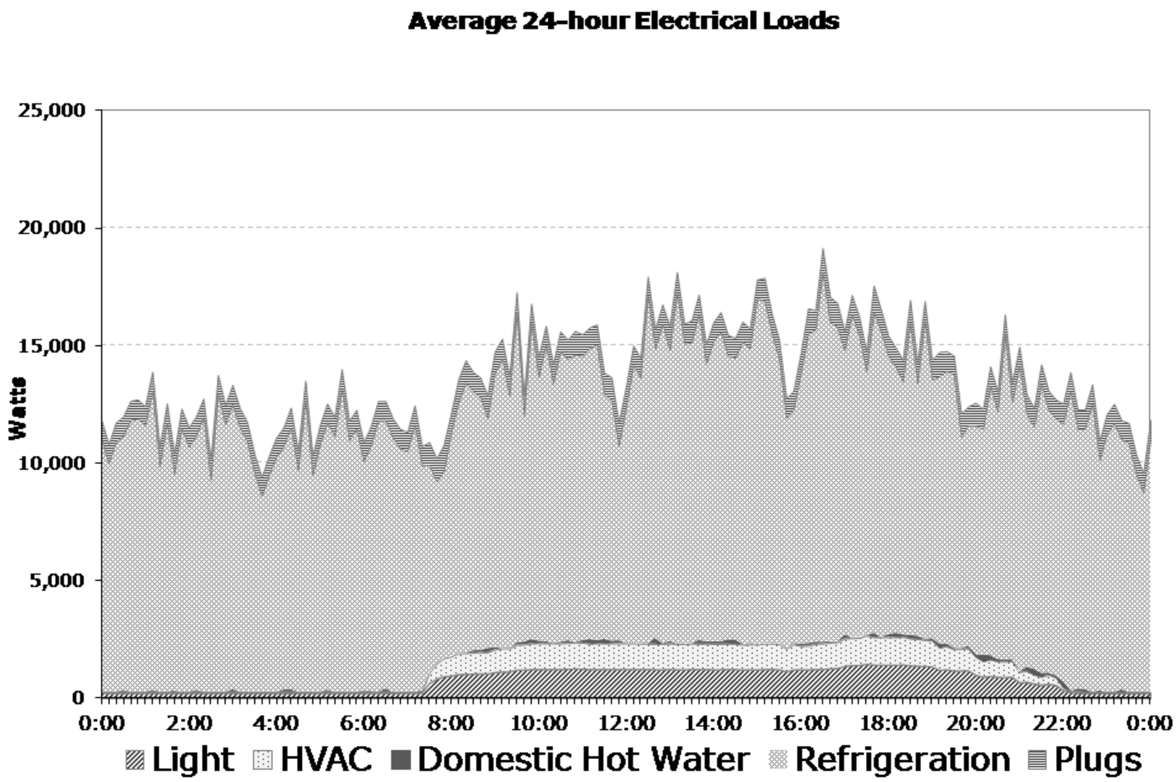

Figure 4: 24hr electrical profile from detailed monitoring – Liquor store

Figure 4 shows the average weekday electrical load for a small (298m^2) retail liquor store. The EUI for this premise was high at 401 kWh/m^2 which is outside the historical typical range of 100 - 300 kWh/m^2. From the detailed monitoring it was possible to determine the reason for the high load was the refrigeration, which not only is very high but also not cycling and running on full 24hours a day. Both the lighting and HVAC indicate hours of use from just before 8:00 in the morning to 8:00 at night. Observation from the revenue data shows the energy use is not temperature dependant which implies the refrigeration systems are unlikely to be operating efficiently.

Analysis and observations of a further five premises with anomalously high EUIs, of which all were retail buildings, found high EUI were invariably associated with food handling (cooking and/or refrigeration), so it was their high process loads which caused the high energy use. Several of them had refrigeration systems that were operating for long hours with poor control and poorly insulated storage areas.

It is only through the end-use monitoring that nuances of energy use within non-residential buildings can be fully understood, especially given the heterogeneous nature of this stock. The detailed monitoring also provides base data to improve building energy modelling inputs and scenarios explicit to New Zealand.

4. Insights and Learnings to date

This paper provides an overview of the BEES research and an insight into the analysis to date. An understanding of the size of the non-residential building stock in terms of size, construction and form has been developed along with a breakdown of retail and office activities. Further analysis into mixed use buildings, which is those that have both retail and office or other uses, and changes over time, will be completed as part of the project.

An understanding of the variation in EUI's much greater than previously recognised has been observed through monitoring and revenue data with a six-fold increase from the very low EUI's to the high EUI's. These outliers all have retail activities whilst office buildings have a smaller range, typically within the expected 100 – 300 kWh/m2. Already the monitored data has improved our knowledge of the energy end-uses, and in particular identified refrigeration in food processing and retail outlets as offering opportunities for significant cost (and energy) savings. The research will continue to investigate and explain large variations and the key energy uses for the different types of buildings.

The importance of the management and ownership structure of New Zealand's non-residential buildings has been identified in relation to building size and the survey data suggests opportunities for improved energy efficiency need to be shaped accordingly. Large buildings are more likely to be managed by professional property, building or facility managers; and small buildings are either unmanaged or managed by owner-occupiers, tenants or landlords with little awareness or interest in resource efficiency.

Analysis of the finalised data sets, along with building energy modelling will enable benchmarks and indices developed for energy tools and policy development, leading to more efficient non-residential buildings in New Zealand.

5. Acknowledgements

The authors would like to thank the BEES research team members for their contribution to the research. BEES is a joint project involving BRANZ Ltd; the Centre for Research, Evaluation and Social Assessment (CRESA); Energy Solutions Ltd; Centre for Building Performance Research (CBPR) at Victoria University of Wellington; and John Jowett, consulting technician.

Thanks to the funders and supporters of the research. BEES is funded by BRANZ Ltd. through the Building Research Levy and the Ministry of Business, Innovation and Employment through its Building and Housing group and its Science and Innovation group, and the Energy Efficiency and Conservation Authority (EECA).

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