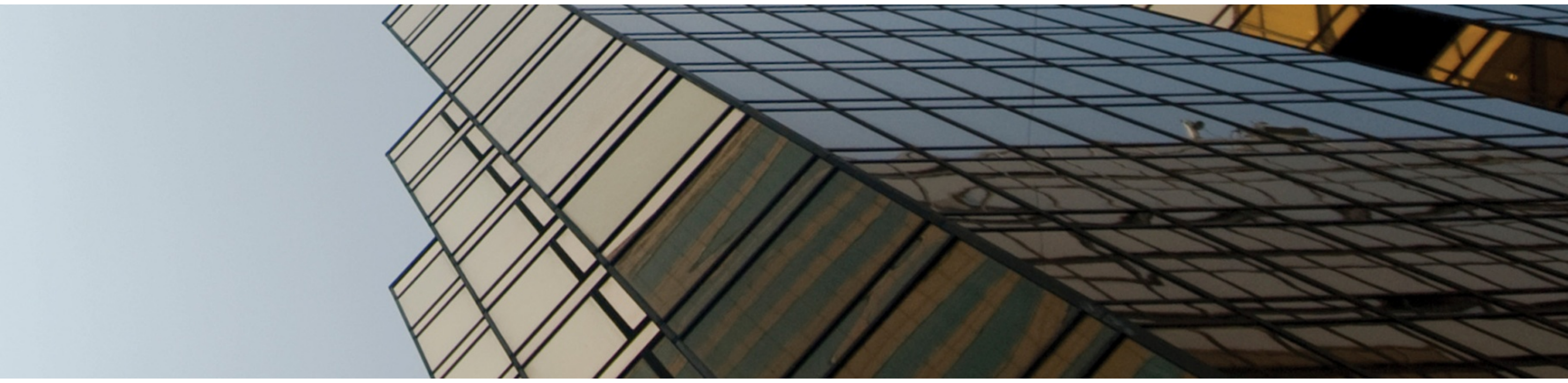

STUDY REPORT SR 297/1 (2014)

BEES PART 1: FINAL REPORT

BUILDING ENERGY END-USE STUDY

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EXECUTIVE SUMMARY

The BEES research has provided some key data resources for use in understanding energy and water use in non-residential buildings. As part of that work, it has, for the first time, provided data on the size and distribution of these buildings, identified construction and site placement.

A common thread to the BEES results is the issues that have been found in dealing with complex building types and uses. Unlike the houses explored in the Household Energy End-use Project (HEEP) research (Isaacs, et al., 2010a), non-residential buildings have a more complex range of building types, sizes and use patterns. The lack of a comprehensive database of buildings (dwellings and other residential buildings are surveyed by the quinquennial census) meant it was necessary to create an ad hoc sampling frame based on valuation records. As valuation records principally serve for legal and financial uses, converting them to building records added a further level of complexity.

What is clear from the BEES research is that non-residential buildings include large areas of floor space and consume significant amounts of energy. At the national level, they have the potential to play an important role in future greenhouse gas reduction programmes, while at the individual building level, there are important opportunities to improve building thermal, occupant use and economic performance.

Non-residential Buildings Energy Use

It is estimated that there are 41,154 ±1,286 (at the 95% confidence interval) BEES buildings in New Zealand, with a total floor area of 39.93 ±2.14 million m^2 (36.86 ±2.60 million square m^2 of which were BEES areas), giving an average area of approximately 970 m^2 per building. For comparison, there are approximately 1.5 million occupied dwellings in New Zealand with a total floor area of about 222 million m^2, giving an average floor area of about 160 m^2 per dwelling (including any internal garage).

The size distribution is extremely skewed, with a large number of smaller floor area buildings and a very small number of very large floor area buildings. In order for the BEES programme to obtain useful results, it was necessary to divide the total floor area into five approximately equal area groups (strata). In the smallest floor area stratum (S1), there are 27,609 buildings under 650 m^2, while the largest floor area stratum (S5) has 499 buildings over 9,000 m^2.

Table A: Estimate of Non-residential Building Size Strata.

Floor area strata	S1	S2	S3	S4	S5	Total*
Minimum floor area	5 m^2	650 m^2	1,500 m^2	3,500 m^2	9,000 m^2	
Maximum floor area	649 m^2	1,499 m^2	3,499 m^2	8,999 m^2		
Approximate number of buildings	27,609	8,007	3,544	1,496	499	**41,154**
Percentage of buildings	67%	19%	9%	4%	1%	**100%**
Total floor area (million m^2)	8.2	7.7	7.8	7.8	8.5	**39.9**
Percentage of floor	21%	19%	20%	19%	21%	**100%**
Average floor area (m^2)	298	955	2,198	5,187	17,014	**970**

**Note: rows may not add due to rounding.*

Table A provides analysis of the number of buildings per building size strata and the size boundaries of each building size stratum. This is the finalised analysis from the study and supersedes previous estimates. Although it was found that some buildings did not match their area calculated from combining the valuation records, for the purpose of analysis and to retain the links to the original valuation records, they are reported in the original building size strata.

Due to the many different types of uses, it was only possible to provide specific estimates for commercial office and commercial retail buildings. Table B provides a summary of total floor area, number of buildings and average floor area per building by building size strata for commercial office and commercial retail buildings. Although the overall BEES sample has approximately equal areas in each of the five building size strata, it should be noted that this does not hold for the detailed building use strata.

Table B: BEES Estimate of Count and Area of Commercial Office and Commercial Retail Buildings by Building Size Strata.

Building size strata	Commercial Office (CO)			Commercial Retail (CR)		
	Area Million (m²)	Count Number	Average (m²)	Area Million (m²)	Count Number	Average (m²)
S1: 0–649 m^2	1.31	4,022	326	4.31	15,300	282
S2: 650–1,499 m^2	1.35	1,404	962	2.52	2,668	945
S3: 1,500–3,499 m^2	1.75	790	2,215	2.32	1,035	2,242
S4: 3,500–8,999 m^2	1.85	339	5,457	1.71	339	5,044
S5: 9,000 m^2 +	2.34	137	17,080	2.04	111	18,378
Total	**8.61**	**6,692**	**1,287**	**12.91**	**19,453**	**664**

The results of the BEES analysis of building sizes raise some interesting questions. The BEES programme has confirmed historic research that total energy use is strongly related to floor area – in broad terms, larger buildings use more energy.

However, the research has also found that only a small number of buildings are very large (for example, the multi-storey office towers found in the central business districts). This group of buildings is numerically small and only represents about 20% of the floor area. The other 80% of floor area is found in buildings less than 9,000 m^2. Although the very large buildings will offer greater individual opportunities for promoting improved energy efficiency, the other buildings represent 80% of the floor area and hence energy use and are likely to require a different range of efficiency options.

Across all buildings, total electricity use was 6,370 ±1,100 GWh/yr or an electricity performance indicator ($EnPI_{elec}$) of 173 ±28 kWh/m².yr. Total gas use was 1,130 ±840 GWh/yr or a gas performance indicator ($EnPI_{gas}$) of 31 ±23 kWh/m².yr. Table C indicates the BEES sample showed an increasing $EnPI_{elec}$ with increasing floor area, with S1 at 143 kWh/m².yr to S5 at 223 kWh/m².yr. It is expected this increase is due to the increased level of services provided as building size increases. However, the pattern raises some interesting questions for future research.

Table C: $EnPI_{elec}$ by Building Size Strata and Building Use Strata.

Building size strata	$EnPI_{elec}$ (kWh/m².yr) Estimate	±95% confidence interval
S1: 0–649 m^2	143	57
S2: 650–1,499 m^2	153	53
S3: 1,500–3,499 m^2	154	65
S4: 3,500–8,999 m^2	201	73
S5: 9,000 m^2 +	223	66
Building use strata		
CO: Commercial Office	186	61
CR: Commercial Retail	176	45
Other BEES	158	36
Total	**173**	**28**

WebSearch

Detailed investigations were undertaken in approximately 3,000 buildings located around New Zealand. This WebSearch started with a weighted random sample and then made use of a range of web-based search, image and other tools including valuation records to match information on building size, orientation, construction and so on. This rich dataset has been used in developing the energy use estimates, but it has also provided some interesting data on the building stock.

It was found that about 50% of the buildings were one storey high and accounted for 32% of the floor area, and 27% were two storeys and represented 21% of the floor area. At the other end of the scale, 5% of buildings were 10 storeys or more and accounted for 20% of the floor area.

The WebSearch work also provided the base data for the development of an improved method to present data about urban environments through the use of 3D graphics in interactive city models.

Telephone Survey

The telephone survey obtained responses from 848 premises in 412 buildings. Only weak and often not statistically significant relationships were found between the premises' $EnPI_{elec}$ and the presence of air-conditioning, central heating, opening windows or double glazing.

Unlike houses, where a reasonably standard set of activities and energy uses occur, non-residential buildings have a wide and disparate range of uses. A domestic living room is a place where people gather, watch television, listen to music and play games with cards, computers or gaming consoles. In energy terms, going from one living room to another may make only small differences. The same is not necessarily the case in non-residential buildings where, for example, a shop's energy use may be driven by lighting or by cooking or refrigeration. In order to better explore the ranges of energy use, three premise use classifications were developed:

- Revised QV premise categories – based on the valuation use categories but applied at a premise level.
- Classification of premise activities (CPA) – based on the main activity occurring in the premise.
- Dominant appliance cluster (DAC) – based on the types of equipment used in the premise.

Each classification offered a way to explore the drivers of energy use and the services provided and could potentially provide a basis for future policy development as well as improved energy audit and efficiency guidance.

The link between energy consumption and the tenure of the premise or building was explored using the telephone survey. It was found that, of the 231 buildings with both telephone survey data and building energy estimates, over three-quarters (78%) were entirely occupied by tenants, 14% were owner occupied and 8% had both tenants and owners in occupation. No statistically significant correlation was found between the tenancy status and electricity use.

Modelling

Although computer modelling was originally included in the BEES research as a way to help explore the impact of future change, it soon became a tool to explore current buildings and opportunities for improved energy efficiency.

The earthquakes of 4 September 2010 and 22 February 2011 extensively damaged the Christchurch central city building stock and removed 11% of the BEES sample frame buildings. As a result, the Christchurch area was excluded from the BEES programme, but this disaster also created a unique opportunity to use data from elsewhere in BEES to assist in the redevelopment of Christchurch.

Measured data from the BEES targeted monitoring was used to create calibrated thermal simulation computer models and to explore the level of modelled detail required to optimise reliability. It was found that using detailed geometry can improve a building energy model's reliability by 5–15%, although using default heating, ventilating, air-conditioning (HVAC) values in the modelling was adequate, modelling correct ventilation rates was critical.

A wide range of options were explored for consideration in the Christchurch rebuild. It was found that savings from natural ventilation and daylight design (replacing electric light) can only be significant if the building form is kept narrow (17 metre maximum is suggested). Of considerable importance to the future energy use in non-residential buildings in the rebuilt Christchurch was the finding that an optimal combination of solar shading, insulation and free cooling can almost eliminate cooling energy consumption. Courtyards in conjunction with laneways (10 metre width) could deliver a significant reduction in energy (up to 47% per square metre less than the deep-plan baseline model) as they facilitate passive cooling and daylighting. Courtyards and laneways also open up the city centre, creating useful and pleasant outdoor spaces. It was also found that the planned façade step-backs were not effective in saving energy or making sunnier streets during the winter period. These results have been actively promoted for areas concerned with the rebuilding of Christchurch.

The modelling work has been actively involved in the joint Task 40 of the International Energy Agency (IEA) Solar Heating and Cooling and Annex 52 of the IEA Energy Conservation in Buildings and Community Systems Net-Zero Energy Building (Net ZEB) project. This has provided another unique opportunity for the New Zealand research to be expanded and critiqued at the international level, including developing training and exchanges for a number of students and researchers.

The New Zealand Building Stock Energy Consumption Dashboard has been created using the BEES data as input. In this model, 48 buildings were modelled across seven different climate zones to build up representative data for the dashboard. Users are able to select the data displayed on the different graphs and visualisation supports according to the size of the building. Then energy saving strategies can be selected and applied to the national model baseline.

Targeted Monitoring

Targeted monitoring was undertaken in 101 premises, with end-use electricity data available for 84 of these premises. This work provided, for the first time, data on the presence (or absence) of certain types of appliances and technologies. For example, plug loads and lighting were found in 100% of the premises, while identified circuit-wired space conditioning (i.e. not provided by plug-in appliances) was found in 74%, identified circuit-wired water heating in 64%, process energy use in 24%, non-domestic cooking in 21% and non-domestic refrigeration in 10% of premises. Loads in a catch-all Miscellaneous category were found in 61% of premises. Summary statistics of the electricity performance indicators were prepared for each of these end-use categories.

The three premise use classifications developed by the BEES programme were used to explore different patterns of end-uses across the wide range of premises. It was found that lighting is very important across most of the categories, especially in those premises with non-food retail activities. Commercial refrigeration dominates the electricity end-use in the Food Storage premises and to an extent in the Food Preparation & Cooking premises, where it is evident in a few of the premises. The Office and Multiple Use premises display the one-third rule, with approximately one-third of the energy going to lighting electricity, one-third to plug load electricity and one-third to space conditioning and other electricity, which is consistent across both the premise and building size groupings.

Detailed appliance analysis was possible based on the records for 100 premises. As part of the premises audit, a detailed inventory was created of the appliances. A list of 77 individual appliance types was developed, which, in turn, was compressed into 33 appliance groups that could then be compared to the 12 appliance groups recorded in the telephone survey.

Appliance counts per premise were converted into appliances per 1,000 m² both as an average across all premises (i.e. whether or not the appliance was present) and for just those premises with that specific appliance group. For example, appliances used to produce hot water (boiling water unit, jug, coffee maker and coffee machine) were found in 98% of premises with an average of 2.5 appliances per premise. Over all premises, 3.37 hot water appliances were found per 1,000 m², but in only the premises that had these appliances, the density was 3.4 per 1,000 m². However, residential style dishwashers were found in 34% of premises, with an average over all premises of 0.65 per 1,000 m² and an average of 1.19 per 1,000 m² in those premises that had this appliance. The lowest penetration was for automatic teller machines (ATMs), which were found in only 5% of premises, giving an average of 0.07 per 1,000 m² but an average of 0.69 per 1,000 m² in those premises that had this appliance.

The audits also provided information on the different types of lights found in non-residential premises. Fluorescent lamps were found in 98% of premises while compact fluorescent lamps (CFL) and halogen lamps were found in 58% of premises. Light-emitting diode (LED) lamps were found in only 2% of premises. Lamp types were generally found in combination, with up to six different lamp types being found in some premises. The most common lamp combination was of fluorescent, compact fluorescent and halogen lamps, but even this mixture was only found in 18% of premises. A total of 36 combinations of lamp types were found. Strong relationships were found between the lighting energy use and the premise floor area ($r^2 = 0.72$) and the total installed lighting capacity ($r^2 = 0.64$).

Detailed analysis was undertaken on the heating and cooling systems in 92 of the monitored premises in 81 buildings. Unsurprisingly, centralised HVAC systems were most common in the largest buildings in all but one of the S5 buildings. As building size reduced, the prevalent source of heating (and often cooling) was electric heat pumps. Only in the two smaller building size strata did simple electric resistance heaters as the primary source of heating exceed 30% of the sample.

One of the most interesting results was the distribution of supplemental electric heaters and fans, which was effectively independent of building size. In all building size strata, about half of the premises that were monitored contained some electric resistance heaters (either fixed or portable). Likewise, about half contained some portable electric fans. There was an average of 2.15 heating types used across all the premises, with a maximum of 2.29 heating types in the premises located in S5 buildings.

Temperatures and relative humidity were monitored in 330 locations in 100 premises in 83 buildings, illuminance in 305 locations in 99 premises in 82 buildings and carbon dioxide (CO_2) levels in 89 locations in 83 premises in 73 buildings. Detailed analysis was undertaken of the performance of the HVAC system in 11 premises. For the analysis, the different locations are divided into space groups (Administration, Shop and Other) and the time of year into seasons (winter, intermediate and summer), where intermediate is either spring or autumn.

In general terms, the summer and intermediate temperature distributions were similar for all three space groups, although the Administration space weekday daily average temperatures were higher than Shop and Other spaces. Nearly three-quarters of the Administration space group had temperatures controlled within ±1°C throughout the year, while locations with HVAC had smaller swings than those without HVAC both in summer and winter.

The air quality within the premises was measured by logging the concentration of CO_2 in the space. Locations with CO_2 concentrations less than about 600 ppm have air exchange rates much higher (300% or more) than required to maintain acceptable air quality. This can result in higher heating and cooling loads when the outdoor air is colder or hotter than indoor air. The mean weekday CO_2 concentrations were measured at less than 600 ppm in more than 88% of all locations in the winter season, reducing to 57% in the intermediate seasons, indicating they are probably over-ventilated. About 20% of the Administration space group in winter and 40% of the Administration space group in summer were also in this category, although the summer results may indicate greater use of outside air to maintain comfort conditions. At the other extreme, while no monitored locations averaged over 1,000 ppm during normal working hours, the average weekday maximum exceeded this level in 12% of all locations in winter and 15% in summer.

An acceptable level of illuminance to support clerical type activities, as would be expected in the Administration space group, is 320 lux – the recommended maintained illuminance for 'moderately difficult' visual tasks, including routine office tasks. About 50% of the Administration space group had recorded mean illumination lower than 320 lux, with 8% recording mean values less than 100 lux. Only the highest 30% of weekday measurements averaged above 500 lux.

About 55% of the Shop space group had recorded mean illuminance levels lower than 320 lux, with 12% below 100 lux. The highest illuminated 30% of the spaces measured during this study had mean daily illuminance over 500 lux, and about 10% had mean illuminance over 1,000 lux. Over 65% of the Other space group had mean illuminance levels lower than 320 lux, while 40% were below 100 lux. The top 30% had average illuminance measured over 600 lux. These were kitchens and workrooms but also a warehouse and a storeroom.

Over the 330 monitored locations, the average workday relative humidity range was 49–57%, while in the subset of Shop space group, the range was 46–57% and in the Administration space group, the range was 48–57%.

Full-year monitoring of temperature and humidity was undertaken in 33 locations in 30 buildings. This dataset provides the opportunity to examine the performance of these spaces over the full range of seasons. Carpet plots have been developed to provide ready visual access to the data to help in the identification of points of interest. On average, the locations in the Administration space group are 2.8°C warmer than the Shop space group, although this varies by the season. Only very limited seasonal analysis has been undertaken on this dataset, and it is likely to offer further research valuable new insights to the conditions inside New Zealand non-residential buildings on an hourly, daily and seasonal basis for workday, 24-hour and non-workday periods.

Occupant Surveys

The Building Use Studies post-occupancy evaluation (POE) tool was used in five premises that had also been subject to either a telephone survey or targeted monitoring or both.

The POE was found to provide valuable additional information about the premises, but it did not replace the environmental monitoring. While it appears that the POE can predict temperature distribution in a building and temperatures that are departing from the comfort range, it cannot definitively predict if they will be towards the upper or lower limits of comfort. A POE also cannot be used to predict measures of relative humidity, CO_2 and lighting. Quantitative measures of environmental conditions are important for the BEES research to compare with energy consumption data, which the POE cannot provide.

The POE provided a holistic assessment of building performance in relation to functionality and the happiness of occupants, while environmental monitoring is important for assessing the energy performance of a building. Functionality, occupant satisfaction and energy performance must all perform well if a building is to achieve sustainable success. Over the course of this report, it has become evident that using one method of analysis could lead to serious misjudgements of a building's overall performance. As with all analysis, care must be taken to account for external influences biasing results, but it is obvious that the POE tool used in tandem with environmental monitoring is very effective to optimise building performance.

Opportunities for Resource Optimisation

Detailed interviews were carried out with three different groups of building managers – facilities managers, property portfolio managers and property managers for green/social responsibility companies. The interviews revealed two quite different approaches, which have been labelled as building ownership for self-employment and non-residential buildings for investment.

The detailed interviews reinforce a persistent sense of underawareness and significant inertia on the part of building owners, owner-occupiers and property managers in relation to active management of energy and water use. This would suggest that improvements in resource consumption are most effectively achieved through building a resource-efficient non-residential stock. This presents a profound challenge to the building industry. How can resource efficiency be achieved while restraining the cost margins of designing and building resource-efficient non-residential buildings?

Associated with that problem is ensuring resource efficiency can be built into the numerous units of stock that are delivered into the smaller end of the market and are likely to be acquired and managed by owners with relatively few stock units. The problem with a focus on new-builds in the non-residential stock is of course its limited transformational impact. The small proportion of new-builds added to the existing non-residential stock on an annual basis is low.

This suggests the following:

- Technical solutions need to be devised to provide both cost-effective new-builds and cost-effective retrofit.
- Cost-effective and easily managed operational systems need to be developed and promoted.
- Considerable thought needs to be directed at prompting take-up for technologies, designs and materials as well as operational systems. In this context, transformation is going to require awareness building among building owners, property managers and tenants.
- Awareness building and take-up will need to be supported by credible and tailored value cases that take into account the different imperatives that these stakeholders bring.

In short, ensuring that New Zealand's non-residential buildings neither burn an energy or water hole in businesses' pockets nor consume more resource than New Zealand can sustain means recognising that not only are buildings different but that neither tenants nor building owners can be treated as homogeneous groups. Not all tenants are the same, nor do they have the same preoccupations. Building owners are also a diverse set of organisations and individuals.

Conclusion

The results of the BEES programme offer a new insight into the stock, operation and management of New Zealand's non-residential buildings. If one word could be used to describe the new knowledge from this research, it would be 'diverse':

- The stock is diverse in construction, size, location, ownership, management and use.
- The different uses are diverse both in economic activity and in the way energy is used.
- The management of both the buildings and the activities that take place within the building is diverse with a range of combinations of owners, managers and businesses.
- Energy use and performance are also diverse.

This diversity made BEES a much more complex research programme than was envisaged at its start in 2007. The non-residential building sector has more variability than could be safely imagined before the work commenced. This diversity has led to some unexpected results as well as constraining some of the desired research activities.

The lessons learned from this research will provide a strong base for future policy, energy management, standards, design tools and research around New Zealand's non-residential building stock. From the rich datasets that BEES has created, a wealth of knowledge and opportunities sits behind them that can be used to further explore energy and water use in relation to New Zealand's non-residential (office and retail) buildings.

Recommendations

1. A central database for storing all Building Warrant of Fitness detail would enable a better understanding of the New Zealand building stock as it would provide information on the building type, maximum occupancy, building age and information about the building services and maintenance requirements.
2. It is recommended to continue building upon the BEES database through NABERSNZ and any other data collection to support updating the New Zealand Building Code, when required. It is recognised through the BEES research that a greater appreciation of the diversity of the building stock could be reflected within the New Zealand Building Code.
3. A clear message found throughout the BEES research was the need to investigate by premise, as opposed to at a building level, in order to determine homogeneous groups, particularly in the Commercial Retail and Other BEES building use strata. It is recommended that future research will need to use premises as well as buildings in considering building energy use.
4. It is recommended that an agreed premise classification index be used for any future data collection and analysis. To make best use of the chosen classification, it would best be incorporated into the proposed central Building Warrant of Fitness database for non-residential buildings (refer Recommendation 1).
5. It is recommended that efficiency improvements in lighting technology (such as the advent of LED technologies) and its uptake continued to be monitored to ensure that standards incorporate appropriate in-use energy levels.
6. Further investigation should be undertaken on lighting performance levels, such as the extent to which energy reductions are possible due to the avoidance of lighting use through daylighting, automated lighting controls and better management of space.
7. The modelling work, along with a better understanding of the diversity of the building stock, suggests the requirements for energy efficiency in the New Zealand Building Code should be re-examined with regard to:
    - the requirements around form (for example, window-to-wall ratio)
    - whether different-sized buildings need different requirements.

8. The modelling section of NZS 4243:2007 *Energy efficiency – Large buildings* should be updated to incorporate the building templates and schedules developed through BEES.