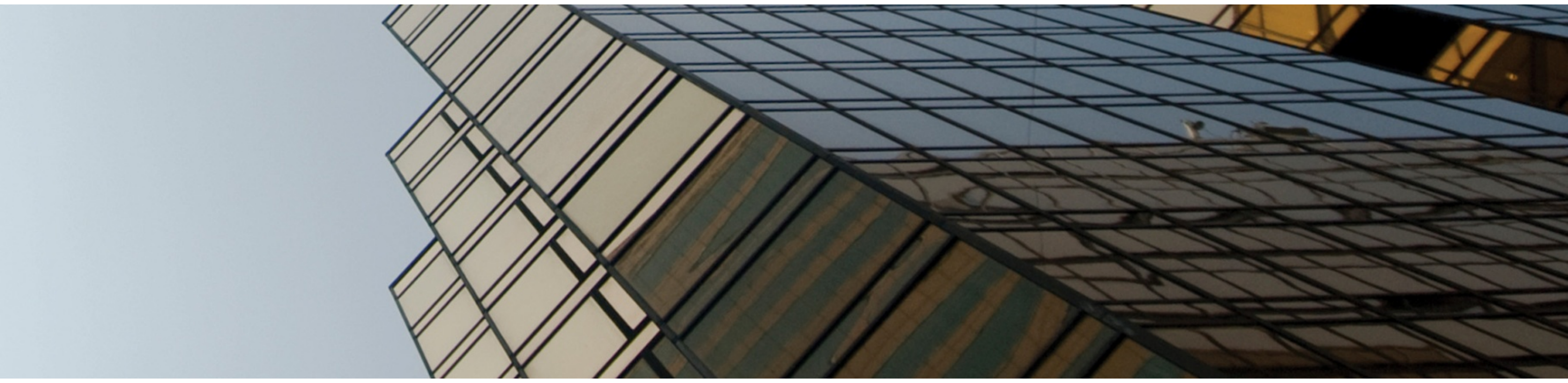

STUDY REPORT SR 297/1 (2014)

BEES PART 1: FINAL REPORT

BUILDING ENERGY END-USE STUDY

Lynda Amitrano [Ed], Nigel Isaacs, Kay Saville-Smith, Michael Donn, Michael Camilleri, Andrew Pollard, Michael Babylon, Rob Bishop, Johannes Roberti, Lisa Burrough, Peony Au, Lee Bint, John Jowett, Alex Hills and Shaan Cory

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EECA Energy Efficiency and Conservation Authority Te Tari Tiaki Pūngao

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BUILDING ENERGY END-USE STUDY (BEES) PART 1: FINAL REPORT

BRANZ Study Report SR 297/1 (2014)

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Reference

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PREFACE

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 reduce greenhouse gas emissions and enhance business competitiveness. The Building Energy End-use Study (BEES) has taken the first step towards this by establishing where and how energy and water resources are used in non-residential buildings and what factors drive the use of these resources.

The BEES research started in 2007 and ran for 6 years, gathering information on energy and water use through carrying out surveys and monitoring of non-residential buildings. By analysing the information, it has been possible to answer key research questions about resource use in buildings including baseline estimates on the number of buildings, total energy use in New Zealand, average energy and water use intensity and water consumption amounts for the Auckland region.

Characteristics of buildings and their most energy-intensive uses have been identified as well as the different distributions of energy at an end-use level for different building activities. Determinants of energy-use patterns have been investigated and the strength of these relationships determined, where possible. This new knowledge has been used to discuss critical intervention points to improve resource efficiency and possible future changes for New Zealand's non-residential buildings.

Understanding the importance and interaction of users, owners and those who service non-residential buildings has also been an important component of the study.

For BEES, non-residential buildings have been defined using categories in the New Zealand Building Code, but in general terms, the study looked at commercial office and retail buildings. These vary from small corner store dairies to large multi-storey office buildings. Earlier reports, conference papers and articles on the BEES research are available from the BRANZ website (www.branz.co.nz/BEES).

The study had two main methods of data collection – a high-level survey of buildings and businesses and intensive detailed monitoring of individual premises.

The high-level survey initially involved collecting data about a large number of buildings. From this large sample, a smaller survey of businesses within buildings was carried out using a telephone survey, and records of energy and water use were collected with data on floor areas. The information has enabled a picture to be created of the total and average energy and water use in non-residential buildings, the intensity of this use and resources used by different categories of building use.

The targeted monitoring of individual premises involved energy and indoor environmental monitoring, occupant questionnaires and a number of audits, including appliance, lighting, building systems, hot water, water and equipment.

Examination of future changes has been based on extensive computer modelling. This includes creating a dashboard that is based on the estimated number of non-residential buildings in New Zealand. It has been built up using 48 building models across seven different climate zones.

This report is divided into two parts. Part 1 provides an overview of the research with key results, discussion and conclusions. Part 2 is a series of appendices that provide detail on the methodologies used to obtain the results and information created through this research.

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 m²	650 m²	1,500 m²	3,500 m²	9,000 m²	
Maximum floor area	649 m²	1,499 m²	3,499 m²	8,999 m²		
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 m²)	8.2	7.7	7.8	7.8	8.5	**39.9**
Percentage of floor	21%	19%	20%	19%	21%	**100%**
Average floor area (m²)	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 m²	1.31	4,022	326	4.31	15,300	282
S2: 650–1,499 m²	1.35	1,404	962	2.52	2,668	945
S3: 1,500–3,499 m²	1.75	790	2,215	2.32	1,035	2,242
S4: 3,500–8,999 m²	1.85	339	5,457	1.71	339	5,044
S5: 9,000 m² +	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 m². 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 m²	143	57
S2: 650–1,499 m²	153	53
S3: 1,500–3,499 m²	154	65
S4: 3,500–8,999 m²	201	73
S5: 9,000 m² +	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.

CONTENTS

FIGURES

TABLES

ORGANISATIONS

ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
BRANZ	Building Research Association of New Zealand
CBPR	Centre for Building Performance Research, School of Architecture, Victoria University of Wellington
CERA	Christchurch Earthquake Recovery Authority
CRESA	Centre for Research Evaluation and Social Assessment
EECA	Energy Efficiency and Conservation Authority
IEA	International Energy Agency
NIWA	National Institute of Water and Atmospheric Research, a New Zealand Crown Research Institute
QV	Quotable Value Ltd
VUW	Victoria University of Wellington
WIW	WhoIsWhere

CLASSIFICATION GLOSSARY

BEES sample frame

A list of non-residential building records selected from both QV and Auckland City Council property codes was retrieved and developed into the building use strata.

Code	Description
CL	Liquor outlets including taverns.
CM	Motor vehicle sales or service.
CO	Office type use.
CR	Retail use.
CS	Service station.
CT	Tourist type attractions as well as other amenities with an emphasis on leisure activities of non-sporting type.
CV	Vacant land or with low value of improvements that, when developed, is likely to have commercial use.
CX	Other commercial uses or where there are multiple uses.

Building size strata

This applies to the building floor area as identified in the BEES sample frame. Note that this may differ from the observed floor area of a particular building. The building size strata each cover approximately 20% of the BEES cumulative floor area.

Code	Description
S1	5–649 m^2
S2	650–1,499 m^2
S3	1,500–3,499 m^2
S4	3,500–8,999 m^2
S5	9,000 m^2 +

Building use strata

The building use strata were assigned to building records from the underlying valuation records.

Code	Description
CO	Commercial Office
CR	Commercial Retail
CX	Commercial Other
IS	Industrial Service
IW	Industrial Warehouse

These may or may not be the type of activities in the building as information is taken from valuation assessments of a particular building and not from characteristics of the building within it.

Business activity sector — BAS

Industry sector based on the Australia New Zealand Standard Industrial Classification (Statistics New Zealand, 1996). This is assigned to a business. This classification can be assigned to a premise, but the BAS does not indicate the type of activities undertaken within the premise.

Revised QV premise categories		Premises are coded according to their assumed core activities, derived from BAS information, which was collected through the telephone survey. This was created within BEES and proposes a refinement of the QV classification system to better align with energy use.

Code	Description
Food & Drink	Building activity sector of Accommodation, Cafés and Restaurants
Office	Clerical, administrative and office work
Retail	Retail excluding Food & Drink
Other	Residual category
Service	Services personal, community, recreation and cultural, education
Wholesale Trade	Wholesale trade

These categories relate to the premises within a building as opposed to the building as a whole. There is likely to be a range of these revised QV premise categories within each building.

Dominant appliance cluster	DAC	The dominant appliance clusters were developed using the appliance, business activity sector and occupant information recorded during the telephone surveys. The DAC was generated by identifying the equipment types that could be expected to be critical for the delivery of premise services. This uses four categories.

Code	Category Description
Cooking & Refrigeration	Must have one or more cooktops AND refrigerators. May have either dishwasher or microwave. Dishwasher and microwave without other cooking and refrigeration appliances NOT enough. In general, it would be expected that low ratio of computers to staff and relatively few other appliances. Corroborating data shows the production of food processed for on or off-premise consumption is core activity.
Refrigeration	One or more refrigerators. May have cooktop/oven, dishwasher or microwave, but evidence needed to suggest that these are directed to the occupants' personal use and not part of the food processed for on or off-premise consumption as a core activity or an activity that is reliant on refrigeration. Low numbers of office appliances can be expected and a limited range of those appliances.
ICT	Information, computing and communication technology. ICTs have a computer ratio of >0.65 to occupants, and these are supported by an array of other office equipment (printers, servers, etc.). Cooking and refrigeration may be present, but business information suggests that these are for occupants' personal use, not part of the production of service provided by the business.
Other	Residual category.

Classification of premise activities | CPA | The classification of premise activities is a rules-based assignment based on the premise's operational activity, assumed key energy uses and the BAS. This has eight categories.

Code	Activity	Activity description	Key energy uses
OFF	Office	General office activities with designated workstations and sedentary work.	Office equipment, lighting, space conditioning.
MIX	Multiple	Multiple premise activities.	Unable to be separated.
GEN	General Retail	Retail premade products ready for sale (no processing).	Focused/display lighting, space conditioning.
BOX	Big Box Retail	As per GEN but more warehouse base.	Flood lighting.
HOT	Food Preparation & Cooking	Typically heats, cooks or bakes food.	Cooking, lighting.
ICE	Food Storage	Typically stores food without any major HOT activities.	Refrigeration, lighting.
CSV	Commercial Service	Generally provides commercial services.	Process, lighting, space conditioning.
ISV	Industrial Service	Garage/warehouse type service, intensive processing/manufacturing.	Process, lighting.

The CPA provides a finer level of detail on the different premise activities and is used to explore the drivers of energy end-use.

BEES TERMINOLOGY

Aggregate data	Data collected from sample buildings used to estimate the size and sources of New Zealand's BEES non-residential building stock.
Baseline building energy model	Baseline building energy model representing commonly used urban and building parameters identified through BEES.
BEES building	A BEES building meets the programme eligibility criteria by having at least one premise operating within the building envelope that is BEES eligible. BEES buildings have been recruited by reference to valuation records and other information sources that allow eligibility to be defined. Some valuation records are associated with more than one building, and a BEES building may also be the site of other premises that do not meet the BEES eligibility criteria. These premises have not been included in the data collection activities associated with BEES premises.
BEES eligibility	Eligible BEES uses are spaces within buildings that are used for office and publicly accessible retail ventures. Spaces used for office or retail activities that primarily support the operation of the building for a non-BEES use do not qualify the building to be included in the study (for example, warehouse storeperson's office or a small cafeteria in a factory). A building that has the majority of the floor area (over 75%) occupied by non-BEES uses should not be included in the study.
BEES participant building	A BEES building that has participated in the BEES programme through the telephone survey, revenue data consent, targeted monitoring or a combination of these.
BEES sample frame	A list generated from processing selected Auckland City Council valuation records and QV valuation records.
Building	A structure totally enclosed by walls that extend from the foundation to the roof that is intended for human access. Structures such as water, radio and television towers were excluded from the survey as were partially open structures, such as lumber yards; enclosed structures that people usually do not enter or are not buildings, such as pumping stations, cooling towers, oil tanks, statues or monuments; dilapidated or incomplete buildings missing a roof or a wall; parking buildings.
Building record	The building record was created by BEES by using the parent and child relationships in the valuation records. The building record may include none (if no building has yet been built), one or multiple real buildings.

Built form		As identified in WebSearch using Steadman et al. (2000) models. Examples of codes include:

Code	Description
CD04	Daylit (sidelit) cellular strip with open-plan space, 1–4 storeys
CD05	Daylit (sidelit) cellular strip with open-plan space, 5+ storeys
CS	Cellular strip geometry
CS4	Daylit (sidelit) cellular strip, 1–4 storeys
CS5	Daylit (sidelit) cellular strip, 5+ storeys
CT1	Toplit, cellular, single storey
HA	Artificially lit hall
HD	Daylit hall, either sidelit or toplit or both
OA	Artificially lit open-plan multi-storey space
OC1	Open-plan continuous single-storey space
OD4	Daylit (sidelit) open-plan strip, 1–4 storeys
OD5	Daylit (sidelit) open-plan strip, 5+ storeys
OG	Open-plan car parking or trucking deck
OP5	Large open-plan geometry
OS	Open-plan space in a single shed
SR	Single-room forms
SSR	String of single-room forms

Central services		Services provided by the landlord for all tenants of the building such as HVAC, common area lighting, exterior or security lighting, shared restrooms, etc. Relates to common areas (A_{ZC}).
Commercial building		Applies to a building in which a natural resource, goods, services or money are either developed, sold, exchanged or stored, for example, an amusement park, auction room, bank, car park, catering facility, coffee bar, computer centre, fire station, funeral parlour, hairdresser, library, office (commercial or government), police station, post office, public laundry, radio station, restaurant, service station, shop, showroom, storage facility, television station or transport terminal (Department of Building and Housing, 2011).
Common area	A_{ZC}	The floor area within a building that is used for central services. This was measured from floor plans as any area that could not be attached to an individual premise or lettable space and includes lift lobbies, HVAC and plant areas and any passage ways/hallways. Measured in square metres (m^2).
Cross tenancy		Where multiple businesses share non-common area spaces and/or equipment. This make separation of electricity/gas billing for each business impractical. (It is likely one electricity and/or gas meter covers the floor space.)
Gross area	A_{ZG}	In BEES, the term 'gross area' is the total building floor area calculated by multiplying the floor plate(s) area(s) by the number of storeys. Measured as square metres (m^2). This definition differs from that used in the property sector.
Industrial building		Applies to a building where people use material and physical effort to extract or convert natural resources, produce goods or energy from natural or converted resource, repair goods or store goods (ensuing form the industrial process, for example, an agricultural building, agricultural processing facility, aircraft hangar, factory, power station, sewage treatment works, warehouse or utility (New Zealand Building Code Handbook 3rd Edition, 2010). Industrial uses are excluded from BEES.
Ineligible area	A_{ZZ}	Spaces that are outside the scope of BEES, such as car parks, residential and some educational, industrial and warehouse spaces.

Net area	A_{ZN}	For the purpose of BEES, the net area is the gross area of the building less any void areas such as atria, elevator or stair shafts or other voids. Measured as square metres (m^2).
Non-participating area	A_{ZA}	The floor area within a BEES building taken up by a non-participating organisation that is BEES eligible. Measured as square metres (m^2).
Non-participating premises		Organisations that are not within the participating sample but are eligible under the BEES eligibility criteria.
Organisation		Includes for-profit and not-for-profit organisations, central or local government agencies that may have a premise participating in BEES.
Participating premises		The organisations or businesses participating in BEES, including those in the telephone survey, targeted monitoring and those that have provided revenue data. Data on these are available at the premise level. A single business may have multiple premises, many of which will not be participating in the BEES research.
Premise(s)		A premise corresponds to a specific business occupying any amount of floor area, located within a building. The premise is the intersection of an organisation and a building. Within BEES, the word 'premise' is used for the singular form to allow 'premises' to be used as the plural form.
Quotable Value property identifier	QPID	A primary key to identify a particular building record from the BEES sample frame as well as providing linkage to the underlying QV records.
QV record		The valuation record relating to an entry in the BEES sample frame.
Strata		One of 50 strata used to generate the BEES sample: - Five building size strata (S1, S2, S3, S4, S5) - Five building use strata (CO, CR, CX, IS, IW) - Two geographical strata (Auckland, rest of New Zealand)
Targeted monitoring		A project portion of BEES concerned with monitoring electricity and environmental conditions (temperatures, relative humidity, CO_2 and illuminance) at a premise and an end-use level for 2–4 weeks and some further gas and water meter readings.
Telephone survey		The collective data from the BEES telephone surveys and interviews of the participating organisations.
Unoccupied premises		Vacant premises at the time of surveying. They are assumed to use no energy (outside of that provided for central services). However, for aggregation purposes, they are assumed to be consuming 100 kWh/m^2.yr.

Valuation record	The valuation record has been obtained from QV for BEES sampling. The valuation record is used for the purpose of local government rating. Under the Rating Valuations Act 1998, a value is placed on each rating unit, which is generally represented by a Certificate of Title. This can be for an estate fee simple (for example, a piece of land) or for a stratum estate (for example, part of a piece of land or building). The valuation record is based on the land and the improvements. In general, the largest part of the improvements is one or more buildings. Each valuation record is allocated to a property category at some point in the valuation cycle. This allocation is based on the rules provided by LINZ, but their application may (or may not) be uniform across all valuers across time or at any given time. Where there is more than one property use, the mixed category is used. It is not known from the QV valuation record when this property category was allocated nor whether it is current. Where improvements are clearly a building, the QV allocates a code to each valuation record to indicate whether the record is a parent (i.e. the overall building) or a child (i.e. part of a building). Where the child is the same as the parent, the whole building is covered by one Certificate of Title. This may (or may not) be uniformly applied by all valuers across time or at any given time. In summary, each valuation record represents a whole or part of a piece of land. As far as can be determined, those selected for the BEES sample frame represent whole or part of an actual building.
WebSearch	Spreadsheet formulated of built characteristics form the first 3,043 entries in the sample frame. Where additional buildings were seen on the site, additional entries were made.

TECHNICAL GLOSSARY

Cramer's V		A measure of association between two nominal variables. This will be given as a value between 0 and +1, where the closer to +1 the stronger the association will be. It is based on Pearson's chi-squared statistic.
Daylight autonomy	DA	Percentage of time per year that a building is occupied when target illuminance can be maintained by daylight alone.
Daylight factor	DF	The ratio – on cloudy days only – of indoor illuminance, using only daylight as the light source, to outdoor illuminance.
Energy		Energy use as the total collection of all fuels (electricity, gas, solid fuel, diesel, coal and other). It should never refer to just electricity, unless that is the only fuel equating to the total energy in that instance.
Energy revenue data		Revenue meter readings that are provided by the energy provider.
Energy performance indicator	EnPI	A term for benchmarking the comparative energy use of buildings, the EnPI is generated by dividing the annual energy use (from individual or combined energy sources) by a normalising value. In most cases, this is the floor area of the space. An EnPI can be used for comparing individual energy end-uses (such as plug loads, refrigeration or heating, for example) as well as total energy use. The energy use intensity if specified by fuel type: - $EnPI_{total}$ is for energy from all fuel sources. - $EnPI_{elec}$ is for energy from electricity only. - $EnPI_{gas}$ is for energy from gas only. - $EnPI_{e+g}$ is for energy from electricity and gas only. Measured in kilowatt hours per square metre per year ($kWh/m^2.yr$).
Envelope		The building's external fabric, which separates the outdoor environment from the internal building spaces.
Façade step-back		Where a façade is stepped back away from the vertical boundary of the building to reduce its visual mass and potentially allow more sunlight into the adjacent street.
Heat pump		Refers to an air source heat pump.
Heating, ventilation, air-conditioning	HVAC	A generic term for the plant and system that provides heating, cooling or air-conditioning to a given space or building.
Household Energy End-use Project	HEEP	The Household Energy End-use Project was a study undertaken by BRANZ. For more information, please refer to (Isaacs, et al., 2010a).
Information, computing and communications technology	ICT	A generic term for the equipment used for information, computing and communications technology.
Kendall's tau-c		A statistic used to measure the association between two measured quantities. It is a non-parametric hypothesis test for statistical dependence base on the tau coefficient.

Net lettable area	NLA	The Resource Management Act (Ministry for the Environment, 2013) defines this to be the sum of the area of the floors of a building measured from the exterior faces of the exterior walls or from the centre lines of walls separating two uses within a building and excludes all common areas such as hallways, elevators, voids and unused pats of buildings. Measured in square metres (m^2).
Net-zero energy building	Net ZEB	A building that is very energy efficient and offsets the residual energy consumption with renewable energy generation.
New Zealand Building Code	NZBC	The performance specification for buildings of various types attached to New Zealand's building statute.
Non-residential		The New Zealand Building Code Handbook 3rd Edition (Department of Building and Housing, 2011) identifies non-residential building stock categories, which includes Communal Non-residential. This applies to a building or use being a meeting place for people where care and service is provided by people other than the principal users. The two types of non-residential buildings given are: - commercial buildings - industrial buildings.
Probability value	*p*-value	Probability of the outcome occurring by chance, or the probability of obtaining a test statistic at least as extreme as the one that was actually observed.
Parts per million	ppm	A measure of concentration of the volume of one gas in another. In the context of this report, it refers to the concentration of carbon dioxide (CO_2) in air. CO_2 levels measured at Baring Head, Wellington, average about 390 ppm. In other places, this varies by location and time of day (Ministry for the Environment, 2007).
Passive		Relating to or being of a heating, cooling, ventilating or lighting system that uses no external mechanical power.
Peak load		The peak measured load of the energy assessed as contributing to an end-use.
Post-occupancy evaluation	POE	A method of assessing a building's operational performance by various means, often including extensive building user surveys. Developed by Building Use Studies.
Plug load		The energy load placed on a building by the operation of equipment such as computers, printers, portable heater, etc. Typically, it is equipment that plugs in as opposed to equipment that is permanently or fixed wired.
Resistance value	R	Measure of thermal resistance of a material. Measured as metres squared Kelvin per watt (m^2K/W).
Thermal comfort band		Temperature range in which humans have been found to be most comfortable.
Urban canyon		Physical gap in an urban environment created by a street cutting through dense blocks of structures (between buildings).
Visible sky angle	VSA	Degree of unobstructed sky visible from the middle of the window in the subject space. Angle is from the bottom of eave/overhang at the window to the top of the building opposite the window.
Water revenue data		Revenue metre readings that are provided by the water service provider.
Working plane		Typical office desk height (700 mm above finished floor level).

1. INTRODUCTION

For the first time in New Zealand we can estimate on the basis of systematic evidence how much energy and water non-residential buildings are using. For example, the Building Energy End-use Study (BEES) research estimated that 6,370 GWh/yr of electricity is consumed by New Zealand's non-residential office and retail buildings every year. That constitutes around 16% of New Zealand's electricity consumption.

These non-residential buildings, the businesses that occupy them and the owners that invest in them represent enormous opportunities to improve energy efficiency across New Zealand. Designing or building better means New Zealand could reduce the energy demand per new building by 40%, achieved through designing to eliminate cooling and maximising daylight. The BEES research also shows that businesses can make very real savings by ensuring building systems and plant such as air-conditioning systems (heating and cooling) are properly sized, managed and maintained. Perhaps even more importantly, building users have real opportunities to manage their own consumption of energy. Office equipment, refrigeration and cooking are all big consumers of energy and, therefore, business dollars.

Improving energy efficiency in New Zealand's some 41,154 commercial office and commercial retail buildings is not straightforward. BEES found that New Zealand non-residential building types are diverse, and even within a single building, there is often a variety of uses. Businesses undertaking administrative or service work may share a building with a café and a shoe shop. Those businesses have different dominant appliance clusters. For administrative and service businesses, the critical equipment tends be information, computing and communications technology (ICT). For a café, the critical equipment tends to be focused around heating food and cool storage, while a shoe shop energy use may be focused on lighting.

Even within those different sorts of businesses, there is considerable diversity. For instance, offices, cafés, supermarkets and other shops vary significantly in floor size, staff numbers and the quantity of equipment they pack into their available space. Building owners are also diverse in their commercial goals in relation to their buildings. In addition to the issues of diversity, there are also challenges arising from the way in which energy is supplied to building users and the leasing arrangements between users and building owners, which can disincentivise both parties from committing to energy efficiency.

This report presents the findings of the BEES research along with background information on the programme itself and some case studies. It provides key metrics around the energy consumption and end-uses in New Zealand's non-residential buildings. It explores the patterns and determinants of energy consumption with reference to the buildings themselves, the businesses that occupy those buildings and their energy end-use characteristics. It looks at the relationship between buildings, their owners and the businesses that occupy non-residential buildings. Finally, it reflects on the implications of the BEES findings for improving the energy efficiency in the non-residential building stock. In doing so, it comments on New Zealand's current approach to energy consumption and management and identifies opportunities to do better through segmented targeting, awareness promotion and management tool development.

1.1 Background

When BEES commenced in 2007, the research team had recently completed the Household Energy End-use Project (HEEP) (Isaacs, et al., 2010a). This had provided, for the first time, detailed data on how, why, when and where energy was used in residential houses, allowing a clear understanding of energy use and the services it provided in this sector. No similar data was available for non-residential buildings. The BEES research was intended to develop an understanding of the population of non-residential buildings in New Zealand.

It is tempting to liken the BEES programme to a non-residential version of HEEP. However, the programme structure and method of BEES must be significantly different to that implemented in HEEP.

HEEP was effectively a two-component programme. One component involved the household energy monitoring and surveying followed by analysis of that data. The other component involved the development of the housing energy stock model, which, while based on the HEEP findings, was directed to forecasting changes in aggregate demand.

That approach was not adequate for BEES. Not only was BEES concerned with both energy and water use, but the non-residential sector's buildings and use patterns are significantly more diverse than those found in the residential sector. Consequently, the programme structure of BEES was developed in such a way as to:

- deal robustly with both the diversity of building uses and the diversity of building users
- generate the information that will assist stakeholders to improve the resource performance of non-residential buildings.

Internationally, the need for the BEES type of study was clearly stated by the International Energy Agency (IEA) in its report *Energy Efficiency Policy Recommendations 2008 in Support of the G8 Plan of Action* prepared for the leaders of the G8 group of countries (France, the USA, the UK, Russia, Germany, Japan, Italy and Canada). In the recommendations dealing with buildings, it states:

> *2.3 Existing Buildings*
>
> *Governments should systematically collect information on energy efficiency in existing buildings and on barriers to energy efficiency.*

1.2 Scope

BEES used the New Zealand Building Code definitions for determining the non-residential stock.

The New Zealand Building Code clause A1 defines five non-residential building stock categories: communal non-residential, commercial buildings, industrial buildings, outbuildings and ancillary buildings (Department of Building and Housing, 2011). However given BEES is about energy and water use affected by the building, industrial buildings (where processes dominate the overall consumption), outbuildings and ancillary buildings were immediately excluded.

Communal non-residential is divided into two further categories: assembly service and assembly care. Assembly service buildings have a huge diversity and typically will only be used occasionally (for example, church or clubroom), hence not making it suitable for the research. Due to the distinct nature of assembly care buildings (schools, hospitals, universities, etc.), these could not be included in the surveys and monitoring. Instead, a separate desktop study was completed on schools and hospitals and reported on in the BEES Year 3 Study Report (Isaacs, et al., 2010b). This meant that the BEES study focused on commercial buildings as defined by the New Zealand Building Code.

The sample frame is based on valuation records obtained from PropertyIQ (or Quotable Value Ltd) and the Auckland City Council valuation department. As the valuation records relate to a legal title, it has been necessary to group them into building records. There may be more than one building in a building record, so the values below were first estimates. The sampling frame was divided into 50 strata based on valuation data:

> **5 building size strata** – based on the estimated total floor area by building record. Table 1 provides the non-residential building size strata and the approximate number of buildings and their floor area.
>
> **5 building use strata** – Commercial Office (CO), Commercial Retail (CR), Commercial Other (CX), Industrial Service (IS), Industrial Warehouse (IW), based on the use category of the valuation parent record. As not all building records with these uses are eligible for inclusion in BEES, further selection activities had to be undertaken.
>
> **2 geographic group strata** (Auckland, rest of New Zealand) – the Auckland group is defined by the area covered by the Auckland Regional Council in 2009. Approximately 22% of the building records and 33% of the floor area are in the Auckland region.

Dividing into floor area strata is necessary to vary the sampling rates from size group to size group. The grouping was done to give approximately equal total floor areas for all five building size strata groups. This approach increases the statistical precision of the survey. More detailed information on the development of the sample frame is given in Appendix B.

Table 1: Initial Building Size Strata (Isaacs, et al., 2009).

Floor area strata	S1	S2	S3	S4	S5	Total
Minimum floor area	5 m²	650 m²	1,500 m²	3,500 m²	9,000 m²	
Approximate number of building records	33,781	10,081	4,288	1,825	564	**50,539**
Percentage of building records	67%	20%	8%	4%	1%	**100%**
Total floor area (million m²)	9.9	9.6	9.5	9.6	9.8	**48.3**
Percentage of floor area	20%	20%	20%	20%	20%	100%

It was soon found that the uses reported in the valuation records were not necessarily found currently in the actual building. Methods were developed to ensure that buildings selected for investigation were in fact within the designed sample frame.

1.3 Objectives

The BEES programme was concerned with understanding energy and water use in New Zealand's non-residential buildings. It was designed to assist both private and public sector agencies and organisations by providing new knowledge and better understanding of the relative importance of building design, use and function; quantity and types of energy and water end-uses; and opportunities for targeted management to optimise energy and water use through building design and construction, building management and occupant behaviours. Table 2 provides a summary of the key research questions driving BEES and their alignment with policy, management and practice issues.

Table 2. Alignment of BEES Key Research Questions and Policy, Management and Practice.

Key research questions	Contribution to policy, management and practice
1. What is the aggregate energy/water consumption of non-residential sector buildings? 2. What is the average kWh/m².yr? 3. What categories of non-residential buildings appear to contribute most to the aggregate energy/water consumption of the commercial sector buildings?	• Highlight importance of commercial buildings in context of New Zealand energy/water use. • Allow policy sector to consider potential of intervention in relation to quantum of resource use. • Provide crude indication of possible intervention targets.
4. What is the average kWh/m².yr of each selected non-residential building use strata? 5. What are the uses to which energy/water are directed? 6. What are the determinants of those patterns of use: a. Building structure and form b. Function c. Other attributes, for example: • climate • ownership • multi-use • occupancy • city/town position • building age	• Allow policy sector to consider potential of intervention in relation to quantum of resource use. • Indicate possible intervention targets and the variables important in developing interventions. • Establish extent of variation in resource use and determinants. • Provide crude indicator of the types of intervention that might be critical ranging from education/information, incentives and disincentives, regulation.
7. What are the critical intervention points to improve non-residential building resource efficiency: • Building envelope and amenities • Building management • Occupant behaviour	• Establish the range of interventions programmes and regulatory requirements for building stock efficiency improvements.
8. What is the likely change in energy and resource demand from the non-residential sector buildings into the future as stock type and distribution changes?	• Provide forecasts of resource efficiency as building stock changes in quantum and type. • Identify risks and opportunities for managing resource consumption in the commercial sector.

The BEES research components are fourfold and set out along with the primary research methods in Table 3.

Table 3. Research Components, Method and Research Question Alignment.

Research component	Method	Key questions
Aggregate resource use patterns (energy and water)	Valuation data extraction and analysis. WebSearch data and analysis. Premise telephone surveys, revenue meter data.	1–3
Determinants of resource use (energy and water)	End-use monitoring in subset of buildings. Interviewing and surveying.	4–6
Managing and improving resource efficiency	Case studies, feasibility studies and topic analysis.	1–7
	In-depth interviews and analysis. Review of international practice.	
Future demand and potential	Modelling and simulation. Interim topic reports.	8

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 (for example, central heating) of the building but also on 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.

1.4 Methods

The BEES programme has gathered and analysed data using a range of methods:

- Valuation data was purchased from PropertyIQ, which was used to construct the BEES sampling frame, provided supporting information for WebSearch and provided linkages to other BEES data sources.
- WebSearch used web-based search engines and the addresses provided from the building records and 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. This was undertaken on the first 3,043 building records.
- Data collection of business names, addresses and phone numbers within the BEES buildings was undertaken from a range of other sources including businesses directory data, street searching, internet-based options (for example, Google Street View) and organisations that supply business contact information.
- A telephone survey of premises was completed for the first 2,000 building records from the sample frame. The telephone survey provides information on the occupation of the premise including the number of employees, hours of use, tenancy and ownership, appliance counts and operation of heating and cooling. There were 848 participants in the telephone survey.
- Energy water revenue records were collected for premises that provided formal consent. As a part of the telephone survey, a request was made to access their billing data records for a 2-year period. This required a formal signoff form from the businesses to enable researchers to access the data from their energy and/or water company. However, not all 392 premises with energy and/or water revenue data will have a telephone survey.
- Targeted monitoring was undertaken on a small group of 101 premises. This provided physical data, typically over a 2–4 week period, on the energy use and end-uses within a premise, including lighting, plug loads and heating. Illuminance, temperature, relative humidity and CO_2 measurements were also recorded. In a number of cases, monitoring of temperature and relative humidity was undertaken in a premise for a full year.
- Detailed interviews or surveys were completed to better understand the complex relationship between, owners, property managers and tenants. Also, a small set (four) of building case

studies to understand the user perceptions have been completed using the POE method (Usable Buildings Trust, 2006).

Data was collected at a low level. Individual businesses and organisations (premises) provided a key level of data collection, such as telephone survey, revenue data and targeted monitoring. This data can be used consistently within BEES by aggregating up to a building level.

Figure 1 summarises the number of premises for which the different datasets have been obtained. For example, while electricity revenue data has been obtained for a total of 392 premises, this includes 234 premises that have also only been phone surveyed, 31 that have only been targeted monitored and 55 that have also been telephone surveyed and targeted monitored.

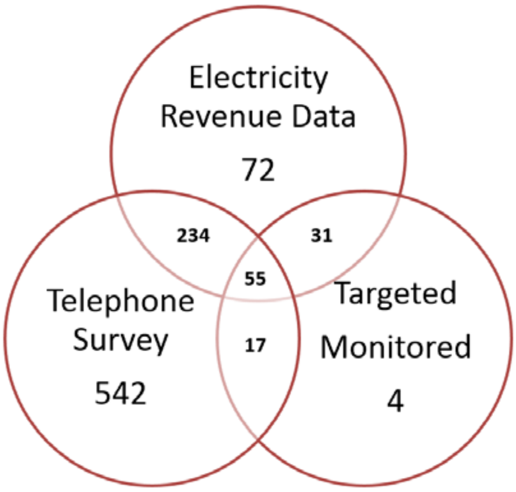


Figure 1: Premise Data Availability.

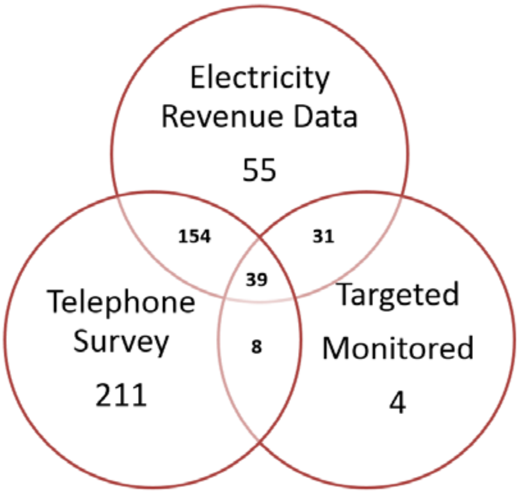


Figure 2: Buildings with Premise Data Availability.

Figure 2 shows the same information as Figure 1; however, this is for the buildings containing the participating premises.

1.5 Report Structure

The report consists of 13 sections. A separate report, *Building Energy End-use Study (BEES) Part 2: Appendices, SR 297/2* consists of Appendices that provide further detail on a range of topics that support this main report:

Section 1 Introduction – provides a brief overview to the BEES research, including the key research questions, scope, objectives and methods.

Section 2 Non-residential Building Energy Use – provides the key results from the BEES research, including aggregate energy consumption and energy use by floor area.

Section 3 Building Characteristics – uses WebSearch to assess the construction, form and materiality of the subset of buildings relating to WebSearch only.

Section 4 Energy Use Patterns – explores some of the drivers of energy use, including building systems and user activities. It introduces a number of new approaches to the classification and categorisation of premises' energy uses.

Section 5 Modelling – provides the results of modelling carried out using actual BEES data to calibrate thermal simulation models. It provides new knowledge to assist in the wider use of thermal simulation models.

Section 6 Energy End-uses – uses the results from the on-site targeted monitoring to analyse the different ways different types of activities use energy and the services they obtain.

Section 7 Key End-uses – sets out details on the range of energy end-uses found in the targeted monitoring for appliances, lighting and HVAC. Detailed performance data is provided for a number of selected premises that have been targeted monitored.

Section 8 Environmental Services – provides a preliminary analysis of targeted monitored data for temperature, relative humidity, illuminance and CO_2. It provides some typical 24-hour profiles for each of these. It also reports on 32 locations that have been monitored for temperature and relative humidity for over 1 year.

Section 9 Post-occupancy Evaluation (POE) – provides the results from the POE survey used to assess the building environment of five targeted monitored premises. It aimed to establish the correlation, if any, between occupant-reported satisfaction and environmental performance.

Section 10 The Take-up Challenge – uses the results of discussions with building owners, designers, managers and tenants to examine the New Zealand challenges to greater take-up of energy and water efficiency opportunities.

Section 11 BEES Water Use – uses the results from an examination of data from Watercare Services Ltd (Auckland's supplier of potable water) to explore drivers of water use in non-residential buildings. As only a small number of premises that participated in the BEES research were able to provide their water use data, this provided a major opportunity to make use of a non-BEES data source to examine this issue.

Section 12 Conclusions – brings together the results of the research to provide guidance for opportunities to improve resource utilisation in New Zealand's non-residential buildings and identify future opportunities for other analysis of the wealth of data collected by the BEES research.

Section 13 Recommendations – summarises the key recommendations from BEES and a number of further recommendations for future work efforts and policy development.

References – provides the sources used in this report as well as a complete listing of the BEES research outputs.

Building Energy End-use Study (BEES) Part 2: Appendices, SR 297/2 contains the following Appendices.

A: Survey Methodology and Results – provides the summary of the three social surveys taken to collect data about buildings, their use and management.

B: BEES Sample Frame Development – describes the development of the BEES sampling frame.

C: Total BEES Area and Energy Consumption Estimation – describes the data collection methods and how the data was used to develop estimates of aggregate energy use and energy density.

D: Extrapolation from Premise to Building – documents the process on how the revenue data was applied to determine whole-building estimates of energy use.

E: Targeted Monitoring – describes the targeted monitoring process for the 101 monitored buildings from the energy end-use data to the different audits that were conducted.

F: Lighting Power Density – sets out the lighting power density tables for the 101 monitored premises with lighting audit information separated into premise activity categories.

G: Lessons – How to Monitor HVAC Loads – sets out the lessons learned during BEES monitoring and the keys aspects of monitoring for understanding HVAC energy use.

H: Observations from 'Outliers' Report – provides a brief summary of selected very high and very low energy use density premises.

I: POE Case Studies – sets out the case studies for the five premises (seven levels) that had a POE survey conducted.

J: Modelling – provides the modelling process and input parameters for the different simulations done in BEES.

K: New Zealand Dashboard – sets out the steps taken to develop energy estimates of New Zealand non-residential building stock resulting from the use of a visualised energy database.

2. NON-RESIDENTIAL BUILDING ENERGY USE

This section provides the key results from the BEES research at an overall building level. It establishes where energy is used in the non-residential sector. This includes:

- estimates of the non-residential building stock numbers and floor areas, with further breakdowns by building use strata and building size strata
- analysis to determine the aggregate energy consumption and energy use by floor area
- specific analysis for office electricity use by building size strata
- analysis on the height (number of storeys) against the size (gross floor area) of the buildings.

In the estimated 41,154 BEES buildings, the dominant fuel type was electricity with a much smaller proportion of gas and other fuel types. For the analysis in this section, a breakdown of the building use strata (Commercial Office, Commercial Retail and Other BEES) and the five building size strata of the BEES sample frame was developed.

The $EnPI_{elec}$ appears to increase as the building size strata increase. This is also apparent when filtering the sample frame to just Commercial Office buildings. However, when the sample frame was separated into the individual building use strata, this increase with each building size stratum was less prominent, with the average $EnPI_{elec}$ ranging from 150 kWh/m^2.yr to 190 kWh/m^2.yr.

One and two-storey buildings make up more than three-quarters (approximately 50% and 27%, respectively) of the BEES sample frame with over half the total floor area. The average building floor area was 970 m^2.

The BEES programme was prompted by a broader recognition internationally that, while considerable attention has been given to energy efficiency in industrial and residential buildings, relatively little has been given to non-residential buildings.

Understanding how energy is used in non-residential buildings is key to improving the energy efficiency of New Zealand's building stock. Over the last decade, commentators in the United States and elsewhere have argued that commercial buildings may be important in energy efficiency targeting for three reasons:

- Commercial buildings are still a sizeable energy consumer within the building sector. In Europe, it is estimated that commercial buildings on average account for over a third of building stock energy consumption (Perez-Lombard, et al., 2008).
- There is evidence to suggest that, while the transport, industrial and residential sectors all saw energy efficiency improvements in the last three decades of the 20th century, this was not evident in the commercial sector.
- Even where commercial buildings constitute a minority of the energy consumed by buildings when compared with the residential sector, on the basis of floor area, the residential sector is a significantly smaller consumer of energy than non-residential buildings (U.S. Department of Energy, 2008).

This study has taken the first step for New Zealand towards establishing how energy is used in this sector and what factors drive energy use in these buildings. This section presents the BEES findings on the number and floor area of New Zealand's non-residential buildings, their energy consumption nationally and average consumption by floor area. It also comments on the relative consumption of New Zealand's residential buildings and its non-residential buildings.

2.1 Estimated Number of Buildings and Aggregate Floor Area

A breakdown of the types and sizes of buildings has been taken from the BEES sample frame that used information from building valuation records. The five building size strata were developed from dividing the building records into quintiles by total floor area. The building record types were coded with a simplified form of valuation property record categories as shown in Table 4. The building records selected for BEES investigation, in addition to being allocated one of these codes, were also tested for BEES eligibility.

Table 4: Valuation Record Codes and Description and Building Use Strata Codes Used in BEES.

Valuation record		Building use strata	
Code	**Description**	**Code**	**Description**
CO	Office-type use	CO	Commercial Office
CR	Retailing use	CR	Commercial Retail
CL	Liquor outlets including taverns etc.		
CM	Motor vehicle sales, service etc.		
CS	Service stations		
CT	Tourist-type attractions and non-sporting amenities		
CV	Vacant land when developed will have a commercial use		
CX	Other commercial uses or where there are multiple uses	CX	Commercial Other
IS	Service industrial, direct interface with the general public	IS	Industrial Service
IW	Warehousing with or without associated retailing	IW	Industrial Warehouse

Building use strata other than Commercial Office (CO) and Commercial Retail (CR) have been aggregated into Other BEES. These buildings will be of a mixed use or have a BEES use but were originally coded Commercial Other (CX), Industrial Service (IS) or Industrial Warehouse (IW). For further information on the valuation record building use categorisation, see BEES Year 1 & 2 Study Report (Isaacs, et al., 2009).

Table 5 shows the final estimates, with 95% confidence intervals and coefficient of variation of the estimates, for the total number of BEES buildings in New Zealand. There are an estimated 41,154 BEES buildings that have a total floor area of 39.93 million m^2, of which 36.86 million m^2 are for BEES uses.

Table 5. Estimated Number and Floor Area of BEES Buildings.

	Estimate	95% confidence interval	Coefficient of variation
Number of BEES buildings	41,154	±1,286	1.6%
BEES area excluding common areas (m^2)	35,050,000	±2,600,000	3.7%
Common areas (m^2)	1,810,000	±370,000	10.1%
Total BEES area (m^2)	36,860,000	±2,700,000	3.5%

Non-residential buildings are frequently assumed to be large buildings, however BEES has found almost 70% of buildings are less than 650 m^2. These small buildings together make up only 21% of the aggregated floor area of all BEES non-residential buildings. Table 6 provides a breakdown of the total number of estimated buildings by building size strata and building use strata with 95% confidence limits. This is also provided graphically in Figure 3.

Table 6: Numbers of BEES Buildings by Building Size Strata and Building Use Strata.

Building size strata	Commercial Office (CO)		Commercial Retail (CR)		Other BEES		Total	
	Number	95% confidence limits	Number	95% confidence limits	Number	95% confidence limits	Number	95% confidence limits
S1: 0–649 m^2	4,022	477	15,300	825	8,287	909	27,609	1,317
S2: 650–1,499 m^2	1,404	321	2,668	385	3,936	577	8,007	764
S3: 1,500–3,499 m^2	790	201	1,035	201	1,719	251	3,544	379
S4: 3,500–8,999 m^2	339	49	339	61	817	149	1,496	168
S5: 9,000 m^2 +	137	19	111	18	250	111	499	114
Total	**6,692**	**378**	**19,453**	**749**	**15,009**	**974**	**41,154**	**1,286**

Table 7 gives the national estimate of floor area for BEES buildings by building size strata and building use strata.

Table 7: Floor Area of BEES Buildings by Building Size Strata and Building Use Strata.

Building size strata	Commercial Office (CO)		Commercial Retail (CR)		Other BEES		TOTAL	
	Area (10^6 m^2)	95% confidence limits	Area (10^6 m^2)	95% confidence limits	Area (10^6 m^2)	95% confidence limits	Area (10^6 m^2)	95% confidence limits
S1: 0–649 m^2	1.31	0.23	4.31	0.37	2.61	0.33	8.23	0.55
S2: 650–1,499 m^2	1.35	0.30	2.52	0.36	3.79	0.55	7.65	0.72
S3: 1,500–3,499 m^2	1.75	0.41	2.32	0.51	3.72	0.59	7.79	0.88
S4: 3,500–8,999 m^2	1.85	0.26	1.71	0.27	4.19	0.69	7.76	0.78
S5: 9,000 m^2 +	2.34	0.38	2.04	0.22	4.1	1.69	8.49	1.74
Total	**8.61**	**0.62**	**12.91**	**0.66**	**18.42**	**1.93**	**39.93**	**2.14**

The average floor area by building size strata and building use strata is given in Table 8. The average floor area was calculated by dividing the total floor area by the number of buildings in that building size and building use stratum.

Table 8: Average Floor Area by Building Type.

Building size strata	Commercial Office (CO)	Commercial Retail (CR)	Other BEES	TOTAL
	Average area (m^2)	Average area (m^2)	Average area (m^2)	Average area (m^2)
S1: 0–649 m^2	326	282	315	298
S2: 650–1,499 m^2	962	945	963	955
S3: 1,500–3,499 m^2	2,215	2,242	2,164	2,198
S4: 3,500–8,999 m^2	5,457	5,044	5,129	5,187
S5: 9,000 m^2 +	17,080	18,378	16,400	17,014
Total	1,287	664	1,227	970

Table 9 gives the percentage by floor area and count for building use strata and building size strata. As noted previously, the BEES sample was developed to have approximately equal floor area in each building size stratum. The right-most columns in Table 9 show that this has been achieved for the building size strata for the total floor area, with each stratum having 19–21% of the total floor area. As expected, the count shows the skewed pattern, with a very large percentage in the smallest building size stratum (67% of buildings) and a very small percentage in the largest building size stratum (1%).

It was not expected that this approximately equal floor area distribution would hold for the different building use strata, and this is shown from the Commercial Office, Commercial Retail and Other BEES building use strata in Table 9. The basic patterns remain with respect to count, with a high percentage in the smallest building size stratum and a lower percentage in the largest building size stratum, but the floor areas do not have approximately equal weighting in each of the building size strata.

Table 9: Percentages by Building Size Strata and Building Use Strata.

Percentage of area or count	Commercial Office (CO)		Commercial Retail (CR)		Other BEES		Total	
	Area	Count	Area	Count	Area	Count	Area	Count
S1: 0–649 m^2	15%	60%	33%	79%	14%	55%	21%	67%
S2: 650–1,499 m^2	16%	21%	20%	14%	21%	26%	19%	19%
S3: 1,500–3,499 m^2	20%	12%	18%	5%	20%	11%	20%	9%
S4: 3,500–8,999 m^2	21%	5%	13%	2%	23%	5%	19%	4%
S5: 9,000 m^2 +	27%	2%	16%	1%	22%	2%	21%	1%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

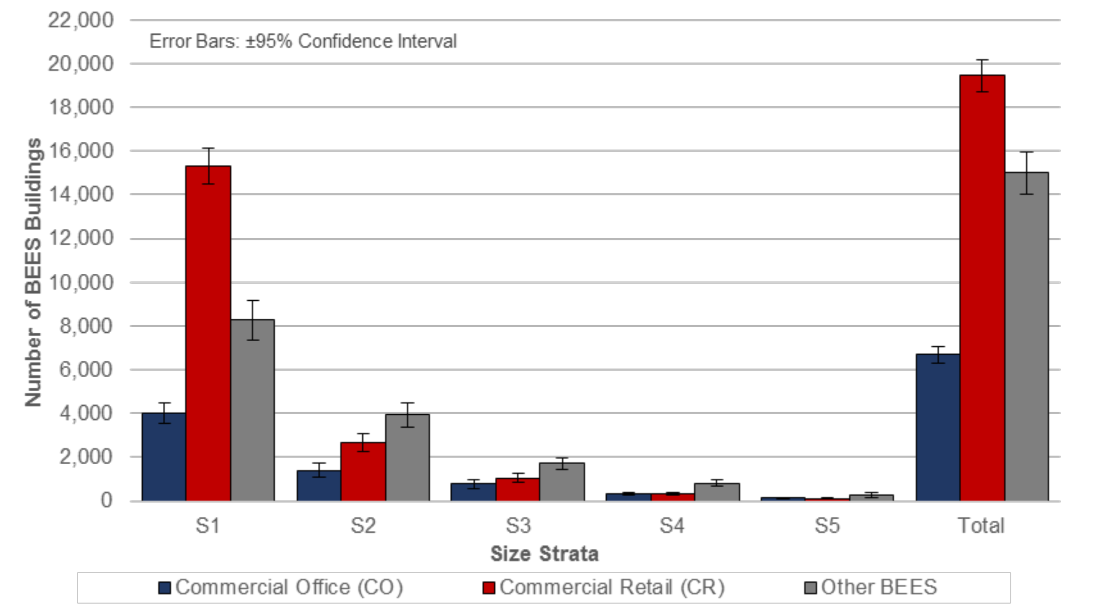


Figure 3: Estimated Number of BEES Buildings by Building Size Strata and Building Use Strata.

Figure 3 shows the dominance, by count, of Commercial Retail buildings in the smallest building size stratum, whilst in the larger building size strata, Other BEES buildings are the most prevalent building use strata. At a total stock level, there is a comparatively smaller number of Commercial Office buildings (16%) compared to Commercial Retail buildings (47%), which is the largest valuation category group, and Other BEES buildings (37%), refer Figure 4. However, due to many Commercial Retail buildings being in the smaller building size strata, its floor area percentage is considerably less at 32% (Figure 5). The largest category by floor area is Other BEES at 46%, whilst Commercial Office is still the smallest at 22% by floor area.

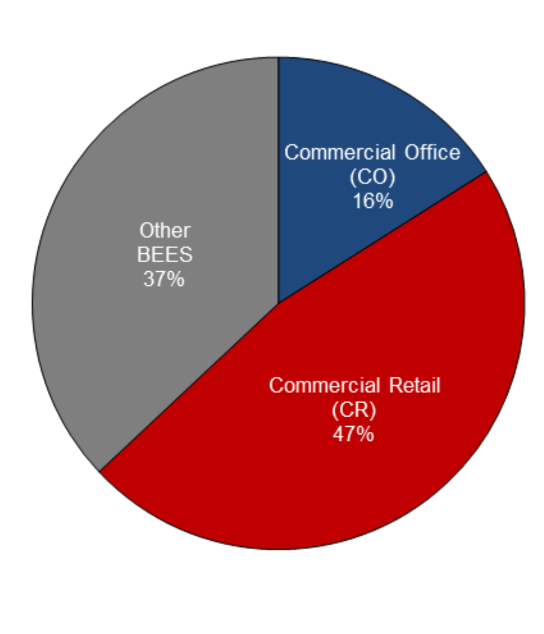


Figure 4: Estimated Number of BEES Buildings by Building Use Strata.

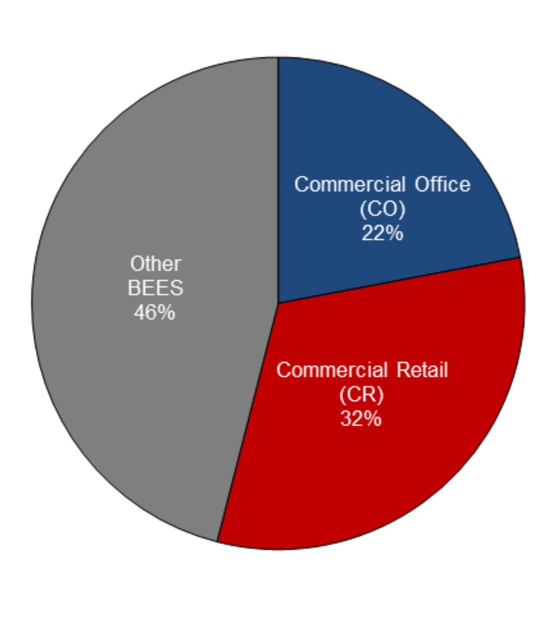


Figure 5: Estimated BEES Floor Area by Building Use Strata.

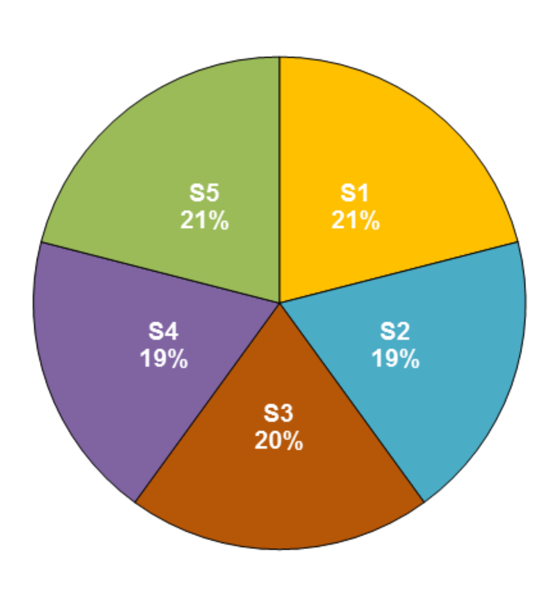


Figure 6: Estimated Number of BEES Buildings by Building Size Strata.

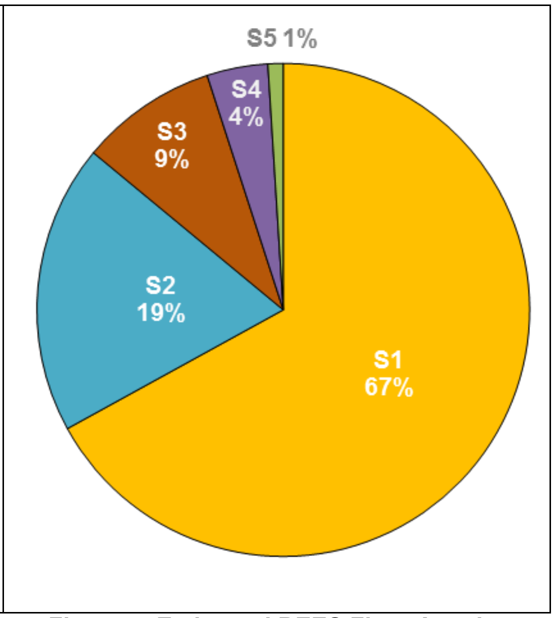


Figure 7: Estimated BEES Floor Area by Building Size Strata.

Given there are significantly more smaller buildings than larger buildings, the BEES sample frame was set up so there were five equal size groups (quintiles) based on the floor areas in the valuation records. Figure 6 shows that the final estimated floor area proportions closely match the original sample frame estimates. The difference between Figure 6 and Figure 7 highlights the difference between the estimated number of BEES non-residential buildings and the estimated floor area of each building size stratum.

2.2 Aggregate Energy Consumption

To determine the overall consumption of the Commercial Office and Commercial Retail building stock, a basic estimation technique was used. To estimate the number of buildings and gross floor areas, BEES building records in the sample frame (from the WebSearch database) were used. To extrapolate by stratum, the energy use, estimates of building energy use built up from the telephone surveys and revenue data at a premise level were used and applied to the sample frame. This resulted in two sets of estimates: one where the extrapolation was done using numbers of records shown in Table 5 and one where the extrapolation was done using gross floor areas (see Appendix C).

Within the estimated 41,154 buildings, an estimated 7,500 GWh/yr of energy (electricity and gas) is used (Table 10).

By far the dominant fuel is electricity (6,370 GWh/yr). Due to the much smaller use of gas and hence the data collected being limited, the coefficient of variation for gas use is much higher. The amount of revenue data collected for coal, wood, oil and renewables was either very limited or non-existent, and so estimates could not be provided for these fuel types. This matches with supply-side information (Ministry of Economic Development, 2012) where the main fuel types are gas and electricity with very little other fuels being used by buildings in this sector.

Table 10: Estimated Aggregate Energy Consumption for BEES Areas.

Fuel types	Consumption estimate (GWh/yr)	95% confidence interval	Coefficient of variation
Electricity	6,370	±1,100	8.6%
Gas	1,130	± 840	37.2%
Electricity and gas	7,500	±1,410	9.4%

2.3 Energy Consumption by Floor Area and Building Use

The energy performance indicator (EnPI) is calculated as the energy consumption per square metre. An EnPI is typically used to benchmark and assess the performance of the overall stock and as a comparison of individual buildings, premises and end-uses. The overall EnPI for the BEES sample has been broken down into fuel types in Table 11. It shows that, for this very complex and diverse set of buildings, the average energy use per square metre is estimated to be 203 kWh/m^2.yr.

Table 11. Estimated BEES Building Energy Consumption by Floor Area for BEES Areas.

Fuel type		Estimate (kWh/m^2.yr)	95% confidence interval	Coefficient of variation
Electricity	$EnPI_{elec}$	173	±28	7.8%
Gas	$EnPI_{gas}$	31	±23	36.6%
Electricity and gas	$EnPI_{e+g}$	203	±35	8.6%

Figure 8 and Figure 9 provide the breakdown for electricity use ($EnPI_{elec}$) by both the building size strata and building use strata. It shows an increase in $EnPI_{elec}$ as the building size increases. Less prominent is the difference in average $EnPI_{elec}$ of the building use strata, with a range from 150 kWh/m^2.yr to 190 kWh/m^2.yr, with Commercial Office buildings (CO) having the highest and Other BEES buildings having the lowest $EnPI_{elec}$.

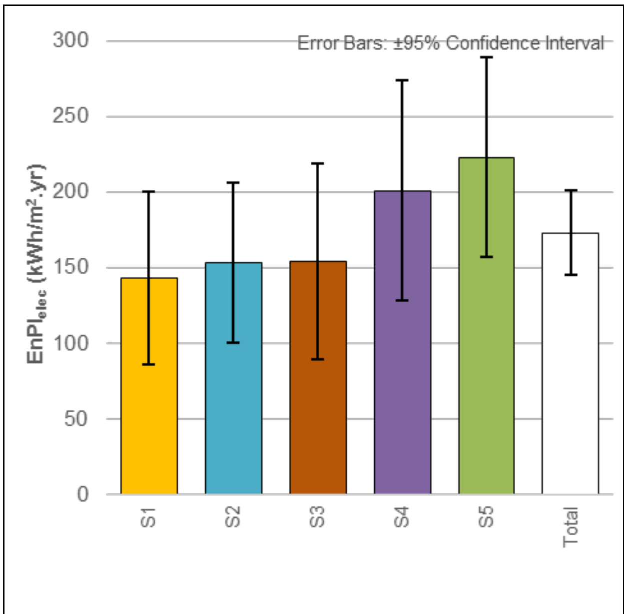


Figure 8: Estimated $EnPI_{elec}$ Floor Area by Building Size Strata.

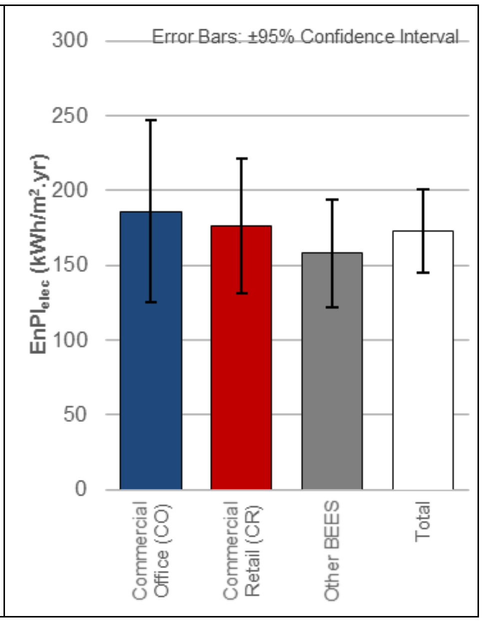


Figure 9: Estimated $EnPI_{elec}$ Floor Area by Building Use Strata.

Refer to Appendix C for further tables and information.

2.4 Commercial Office (CO) Buildings

It is desirable to consider how building size affects particular types of buildings. Unfortunately, as more factors are considered, the number of cases being compared can become small. In this section, energy use of buildings in the Commercial Office (CO) building use strata will be examined in relationship to their building size strata. Figure 10 gives the electricity use ($EnPI_{elec}$) of Commercial Office (CO) buildings only on the vertical axis with the building size strata for those buildings on the horizontal axis. Individual building records are shown as a circle with a small displacement in the horizontal position to better discriminate similar values. The solid red lines indicate the mean $EnPI_{elec}$, while the green line indicates the median $EnPI_{elec}$ for the building records within each building size stratum. The mean and median

$EnPI_{elec}$ for each building size stratum along with the mean and median $EnPI_{gas}$ and $EnPI_{e+g}$ is tabulated in Table 12.

The divergence between the mean and the median $EnPI_{elec}$ is evident in building size S3 and S5, where the mean $EnPI_{elec}$ has been increased by the presence of a high outlier value within each of these building size strata. For one of these buildings, the occupancy schedule was different due to having a 24-hour service centre. It is likely there will be similar reasons for the second outlier.

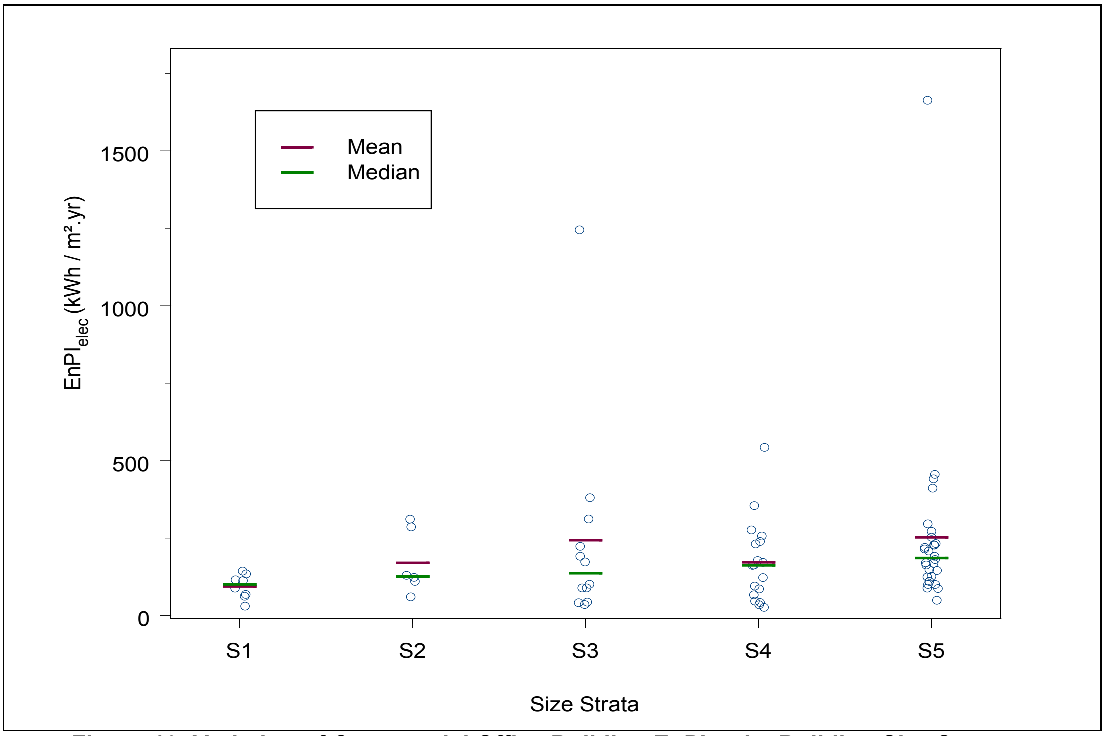


Figure 10: Variation of Commercial Office Building $EnPI_{elec}$ by Building Size Stratum.

This illustrates an important difference between the mean and the median in the smaller datasets. Average (mean) values are affected by outliers while typical (median) are less so. Care must be taken to not equate average and typical within small datasets.

Table 12: Commercial Office Building Mean and Median EnPI by Building Size Stratum.

	S1	S2	S3	S4	S5
Count	8	6	12	18	28
Mean $EnPI_{elec}$ (kWh/m^2.yr)	94.3	170.0	243.6	171.9	252.7
Mean $EnPI_{gas}$ (kWh/m^2.yr)	0	0	0	42.8	53.8
Mean $EnPI_{e+g}$ (kWh/m^2.yr)	94.3	170.0	243.6	183.8	260.4
Median $EnPI_{elec}$ (kWh/m^2.yr)	100.8	126.3	136.8	162.2	185.9
Median $EnPI_{gas}$ (kWh/m^2.yr)	0	0	0	22.6	45.6
Median $EnPI_{e+g}$ (kWh/m^2.yr)	100.8	126.3	136.8	163.3	195.5

Due to the smaller sample numbers and larger variation in other building use strata types, it is not useful to provide means or medians for these other categories. Applying weighting factors and regrouping the data may be required if further exploration is required.

3. BUILDING CHARACTERISTICS

This section uses WebSearch to understand the buildings and some of their built characteristics in more detail. WebSearch was based on the use of Building Warrant of Fitness documents, Google Street View and aerial and street photographs or through web-based search engines to assign a material, construction or form based on a set of criteria or guidelines for each example. Therefore, the following discussion on building characteristics is indicative only due to individual judgement limitations and the sample only being representative of the number of buildings reported.

It should be noted that, where the characteristics in specific cases were complex or difficult to assign to a variable, it was classed as unidentified. The discussion below will only report on those buildings where characteristics were able to be identified and assigned to a specific category. Typically, between 10% and 30% of the buildings were unable to be assigned within each characteristic grouping.

3.1 Built Form

Analysis of the WebSearch data suggested that more than half of the non-residential buildings described in valuation records as Commercial Office (CO), Commercial Retail (CR) or Commercial Other (CX) are only one storey in height. A further 24% are buildings with two storeys. Together, these one and two-storey buildings make up more than three-quarters of the building stock and include over half of the total estimated floor area.

Based on the WebSearch data, the estimated average building floor area was a modest 970 m^2 across the entire non-residential building stock in New Zealand.

Table 13: WebSearch Analysis by Number of Storeys per Building.

Number of storeys	Number of buildings	Percentage of buildings	Total floor area (m^2)	Percentage of floor area
1	1,734	58%	5,264,989	41%
2	733	24%	2,727,616	21%
3	131	4%	684,021	5%
4	100	3%	673,393	5%
5	49	2%	322,258	3%
6	41	1%	310,845	2%
7	38	1%	287,342	2%
8	25	1%	250,795	2%
9	23	1%	186,441	1%
10+	125	4%	2,113,126	16%
Total	**2,999**	**100%**	**12,820,825**	**100%**

There is considerable diversity in building form. Analysis of the valuation record data for the period 1970–2008 suggested that almost two-thirds (65%) of building records by count have a footprint in excess of 300 m^2 but are under three storeys tall. Only a tiny proportion (0.1% of building records) have small footprints of less than 300 m^2 but have a vertical presence with three storeys or more. Only 6% of building records are associated with footprints in excess of 300 m^2 with three storeys or more. These tall, large buildings are generally Commercial Office (CO) buildings, which are frequently referred to as office blocks and are much less prevalent than the small footprint, low buildings. The latter constitute well over a quarter (29%) of building records.

However, the built form of the buildings also differed by whether access to daylight existed or if it was artificially lit and whether it was a cellular strip, hall or single-room form based on template geometries (Steadman, et al., 2000).

Below are two graphs showing the proportion of buildings containing each built form, by building size strata on the left (Figure 11) and building use strata on the right (Figure 12).

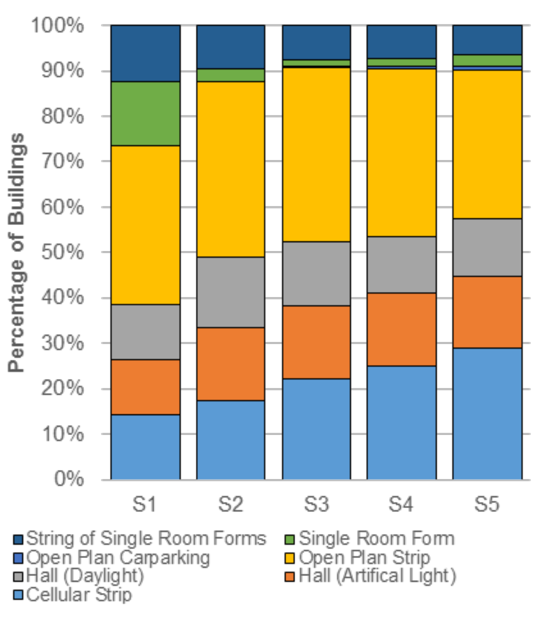


Figure 11: Built Form by Building Size Strata (*n* = 2,788).

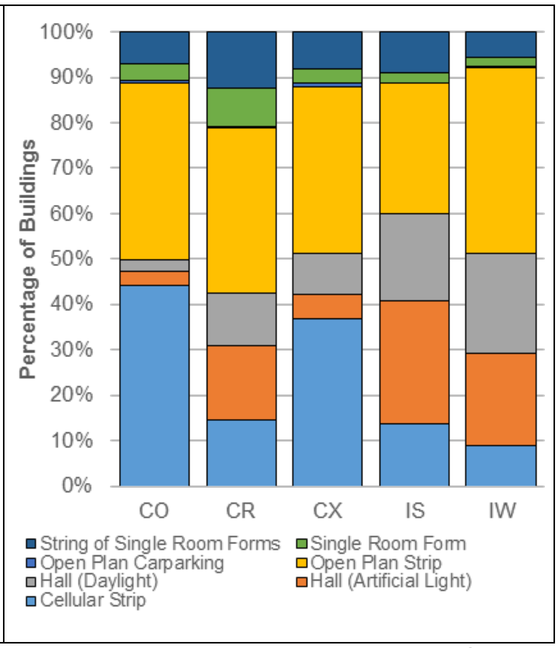


Figure 12: Built Form by Building Use Strata (*n* = 2,788).

From the two figures above, the open-plan strip appears to the most common built form with approximately 30% of all buildings. Other than the cellular strip built form, there appears to be very little of anything else.

3.2 Materiality

No real patterns or trends exist when considering building materiality from the WebSearch sample. Below are some key examples of this, where the wall construction materials, building fabric and window framing systems are discussed.

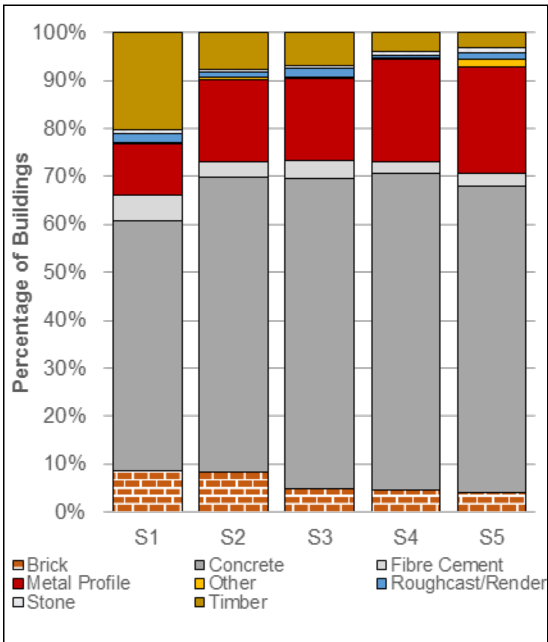


Figure 13: Wall Construction Materials by Building Size Strata (*n* = 2,803).

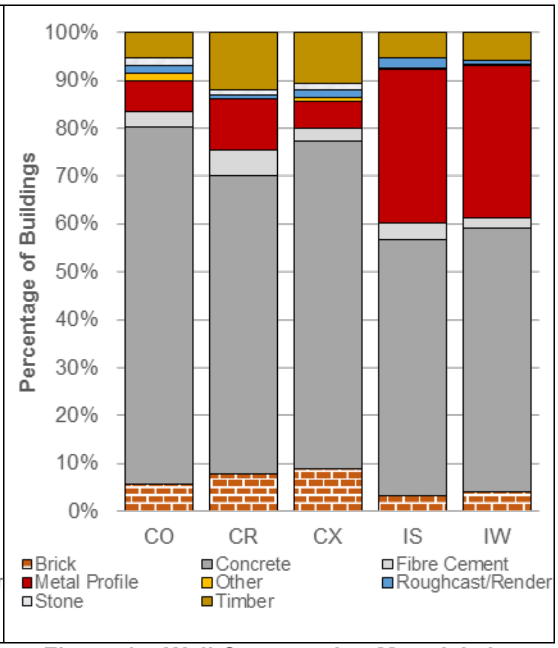


Figure 14: Wall Construction Materials by Building Use Strata (*n* = 2,803).

Concrete appears to the be most common (>60%) type of wall construction material used across most building size strata and building use strata, with the exception of Industrial Service (IS) and Industrial Warehouse (IW) buildings, where there would be more stand-alone shed-type structures expected.

There is very little stone, roughcast/render, fibre cement and other wall construction materials within this sample of buildings.

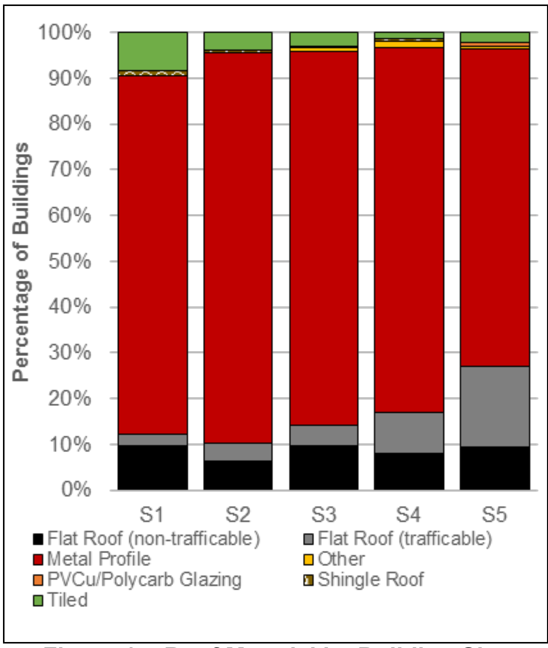


Figure 15: Roof Material by Building Size Strata (*n* = 2,948).

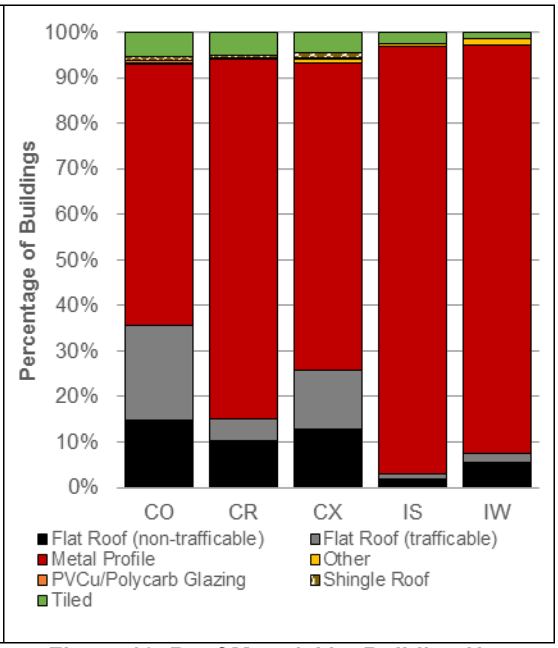


Figure 16: Roof Material by Building Use Strata (*n* = 2,948).

By and large, the dominant roof material appears to be metal profile (~80%) across all building size strata and building use strata, with very little other roof materials present.

The larger-sized buildings and Commercial Office (CO) and Commercial Other (CX) buildings appear to have more flat roof constructions. This would generally coincide with a small footprint to building height ratio.

Due to the inability to determine the glazing type without accessing the building, questioning the occupants/management or accessing the building drawings and specifications, only the window framing system is reported on here.

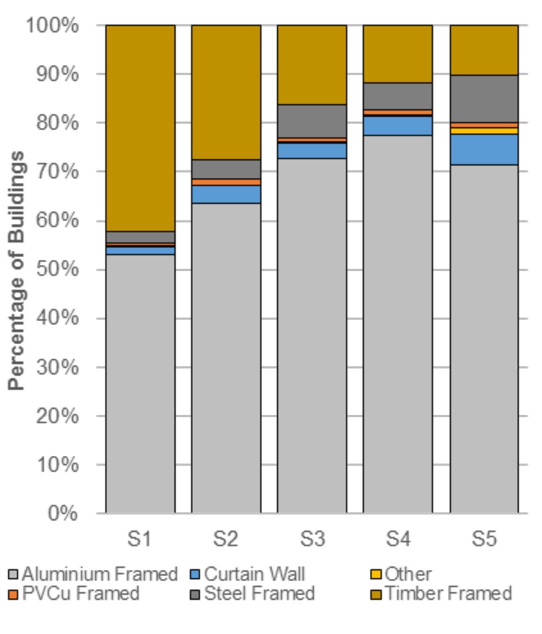


Figure 17: Window Framing System by Building Size Strata (*n* = 2,533).

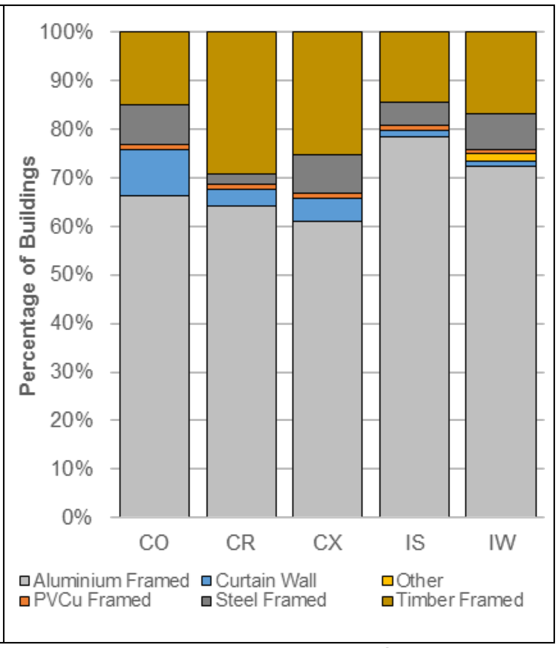


Figure 18: Window Framing System by Building Use Strata (*n* = 2,533).

The above figures give the impression that aluminium framing (~70%) is the most common window framing system, followed by timber framing (~20%).

In Figure 17 above, curtain walling appears to increase in presence with building size. In Figure 18, the Commercial Office (CO) buildings appear to have most curtain walling present. However, curtain walling only appears in less than 5% of all buildings assessed.

3.3 Building Age

Building age was determined largely by reading the Building Warrant of Fitness documents, which are typically on public display within the ground floor lobby of a commercial building. The below graph shows the majority of buildings were constructed in the 1980s.

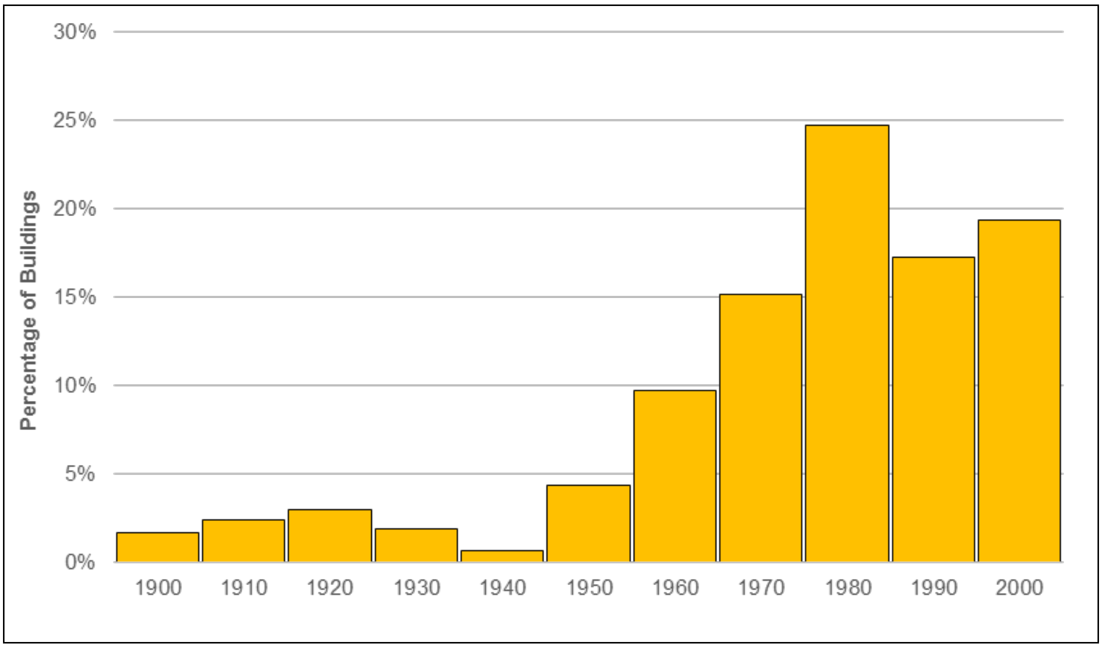


Figure 19: Building Age (*n* = 2,402).

4. ENERGY USE PATTERNS

This section is concerned with the diversity of energy consumption that emerges when some of the physical attributes of buildings are considered, including their different sizes and the energy-using systems. Due to the nature of the data collected, these analyses are primarily focused on electricity use.

It is also concerned with the way in which energy consumption varies according to the type and activity of premises located within a building, the core business operations and the clusters of appliances that are associated with these premise activities and operations. Statistical analysis is provided for the numerous relationships between building use strata, premises and energy or electricity use, along with other factors such as occupancy and visitors.

Two measures are commonly used in this analysis:

- Energy consumption – either annual (kWh/yr) or average daily (kWh/day).
- Energy performance indicator (EnPI) (kWh/m^2.yr).

Four alternative categorisations were developed in this section, as the building use strata do not often differentiate important differences between activities. Two of these categorisations are business activity sector (BAS) and dominant appliance cluster (DAC). A relationship between the premise categorisation and the electricity was determined. The findings were:

- a moderately strong association between the BAS and the annual consumption of electricity by premise (Cramer's V 0.305, *p*-value 0.001)
- a statistically significant association between BAS and $EnPI_{elec}$, but this is considerably weak (Cramer's V 0.276, *p*-value 0.045)
- a statistically significant association between the DAC and electricity consumption but weak in terms of annual premise electricity consumption (Cramer's V 0.153, *p*-value 0.036)
- a moderately strong association between DAC and $EnPI_{elec}$ (Cramer's V 0.249, *p*-value 0.000).

Using DAC, premises with Refrigeration and Cooking & Refrigeration as the dominant appliances tend to have a higher $EnPI_{elec}$, with most premises demonstrating ICT clusters. Associations between premise activities and total electricity consumption as well as $EnPI_{elec}$ suggest that the type and range of premise DAC within a building will impact on the building's consumption of electricity and $EnPI_{elec}$.

There is a statistical association between the number of employees at a premise level and the annual electricity consumption. The more employees in the premise, the higher the energy consumption is likely to be.

4.1 Building Systems

BEES provided a number of datasets through which the impact of building systems on electricity use can be explored. The telephone survey of premises combined with the electricity revenue data allows the implications on electricity consumption to be explored and the reported presence of:

- air-conditioning
- central heating
- double glazing
- opening windows.

The limited data available on other forms of energy (gas, oil, coal, etc.) meant the analysis has focused on electricity only.

There is also data available through the targeted monitoring of premises (see sections 6 and 7) that further explores the importance of these aspects of buildings and their building systems on energy consumption. In the context of the premise data, there is (Table 14):

- a weak statistically significant and systematic relationship between the reported presence of centralised air-conditioning in a building and the energy performance indicator ($EnPI_{elec}$) for electricity by the premises within those buildings (Figure 20)
- a statistically significant relationship between the $EnPI_{elec}$ and whether it is reported that staff can open and close windows in a building (refer Appendix A)
- a very weak statistically significant association between premise $EnPI_{elec}$ and the reported type of glazing system (single or double glazed)
- no statistically significant association, however, between the $EnPI_{elec}$ of a premise and whether central heating is reported in a building.

The statistical significance has been tested using Cramer's V where the closer the value is to 1, the more significant the relationship.

Table 14: Significance Tests between Building System and Premise $EnPI_{elec}$.

Reported building system	Cramer's V	*p*-value
Air-conditioning and $EnPI_{elec}$	0.185	0.011
Central heating and $EnPI_{elec}$	0.120	0.331
Opening windows and $EnPI_{elec}$	0.284	0.000
Double glazing and $EnPI_{elec}$	0.154	0.047

Each of these relationships can be represented graphically with column charts where the data is divided into quartiles to show the distributions. It is important to recognise that differences between the columns do not necessarily mean there is statistical significant difference. However, they are useful to show the distribution differences.

Figure 20, as an example, shows two sets of data – the percentage (and in brackets the number) of premises in buildings with central air-conditioning and those without. It shows that a greater proportion of premises from non-central air-conditioned buildings are in lowest quartile $EnPI_{elec}$. At the other end of the scale, the third and fourth (upper) quartiles are over-represented by premises in air-conditioned buildings. Figure 20 shows this distribution by count for the number of buildings, which also shows that, in this sample, more buildings had air-conditioning than did not. The other cases are explored in Appendix A.

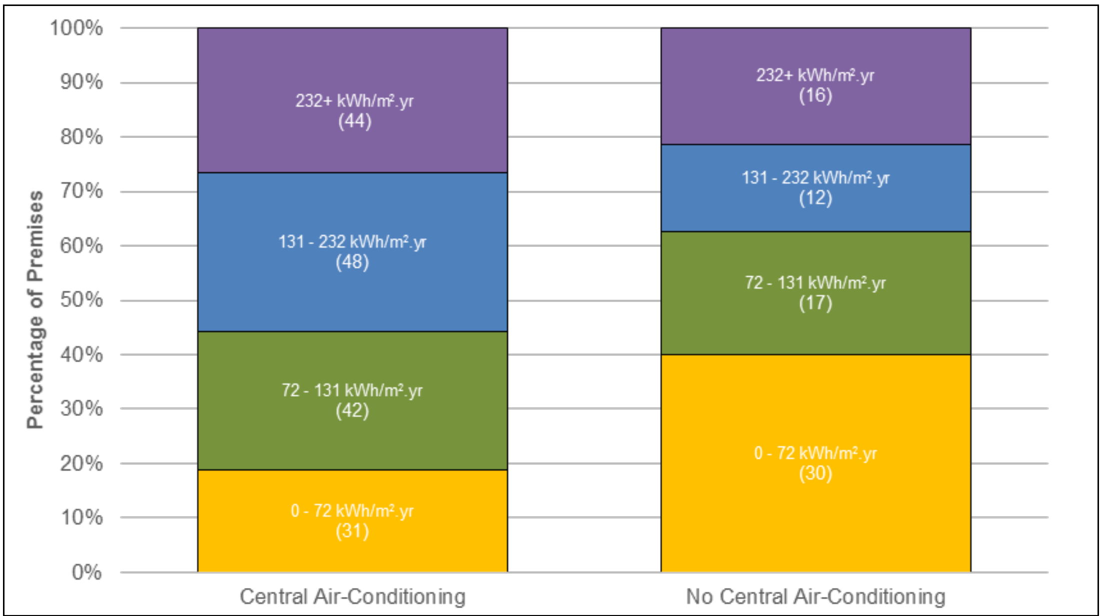


Figure 20 $EnPI_{elec}$ and the Presence of Centralised Air-conditioning.

4.2 Energy Consumption and User Activities

One of the fundamental, albeit often unspoken, assumptions about the sort of buildings that fall within the scope of BEES is that buildings cluster together users involved in similar activities. BEES, however, shows that eligible premises demonstrate considerable diversity in their activities.

This section:

- sets out data related to premise electricity consumption and the associations between electricity consumption and premise activities
- explores the extent to which the different premise activities impact on overall consumption of electricity on a building basis.

Conceptualising user activities – what a premise within a building delivers as its core business – is peculiarly difficult. Quotable Value (QV) uses categorisations such as Commercial Office, Commercial Retail, Industrial Service and Industrial Warehouse (refer Table 4). These are very crude categorisations and often obscure important differences between activities. This is particularly evident in retail, where the fish and chip shop or restaurant can, for instance, become included in the same category as a department store or shoe shop.

An alternative – the business activity sector (BAS) classification promulgated for public statistics by Statistics New Zealand – has the advantage of some opportunity for specificity. For instance, BAS does differentiate some activities around retail (café, restaurants, etc.) that would otherwise be obscured. However, as its nomenclature indicates, it is a measure of sectorial association. As such, it also can obscure important differences and similarities around activity. For instance, the core work and processes used in a business associated with the financial sector may be equally used in a business associated with the construction sector.

To tease out the relationship between electricity consumption and user activities, three other categorisation methods have been developed:

- A revised version of the existing QV categories to separate out what appears to be an important distinction in the Retail category between those retail buildings that have premises involving processed food sales and drink (Table 15).

Table 15: Revised QV Premise Categories.

Code	Category	Description
CO	Office	Clerical, administrative and office work
CR	Retail	Retail excluding Food & Drink
Ser	Services	Services personal, community, recreation and cultural, education
Food & Drink	Retail Processed Food and Drink	Building activity sector of Accommodation, Cafés & Restaurants
WST	Wholesale Trade	Wholesale trade
Other	Manufacturing and Other Activities	Residual category

- The classification of premise activities (CPA) (Table 16) was completed for all premises that were surveyed. However, analysis using this categorisation has only been completed for the monitored premises (section 6). This categorisation identified the main activity occurring within the premise starting with the BAS and refined from further detailed research on each premise.

Table 16: Classification of Premise Activities (CPA).

Code	Activity	Activity description	Key energy uses
OFF	Office	General office activities with designated work stations and sedentary work	Office equipment, light and space conditioning energy
MIX	Multiple	Multiple premise activities	Unable to determine assumed key energy use
GEN	General Retail	Retail premade products ready for sale (no processing)	Focused/display lighting and space conditioning energy
BOX	Big Box Retail	As per General Retail but more warehouse base	Flood lighting energy
HOT	Food Preparation & Cooking	Heats, cooks or bakes food	Cooking and light energy
ICE	Food Storage	Stores food without any major food preparation cooking activities	Refrigeration and light energy
CSV	Commercial Service	Generally provides commercial services	Process, light and space conditioning energy
ISV	Industrial Service	Garage/warehouse type service, intensive processing/manufacturing	Process and light energy

- The final categorisation variable used to explore the relationship between electricity consumption and user activities is the dominant appliance cluster (DAC). The DAC is generated by identifying the equipment types that could be expected to be critical for the delivery of services to each premise. The DAC consists of the four categories set out in Table 17.

Table 17: Description of Dominant Appliance Cluster (DAC).

Description	Core activity	Required appliances	Other appliances	Other comments
Cooking & Refrigeration	Production of processed food	One or more cooktops and refrigerators	May have dishwasher or microwave	Low ratio computers to staff
Refrigeration	Holding chilled or frozen foods	One or more refrigeration or freezer units	Dishwasher or microwave for personal use	Low ratio computers to staff
ICT (Information, computing and communication technology)	Office	Computers/employee >0.65	Cooking and refrigeration for personal use	
Other	Residual	No dominant set of appliances		

Figure 21 shows the relationship between the BAS (rows) and DAC (coloured segments) categorisation methods. Also interesting is the wide range of BAS categories that businesses within BEES participant buildings fall into, including some unexpected categories such as Electricity, Gas & Water and Construction. There is a statistically significant relationship between BAS and DAC (Cramer's V 0.563, *p*-value 0.000).

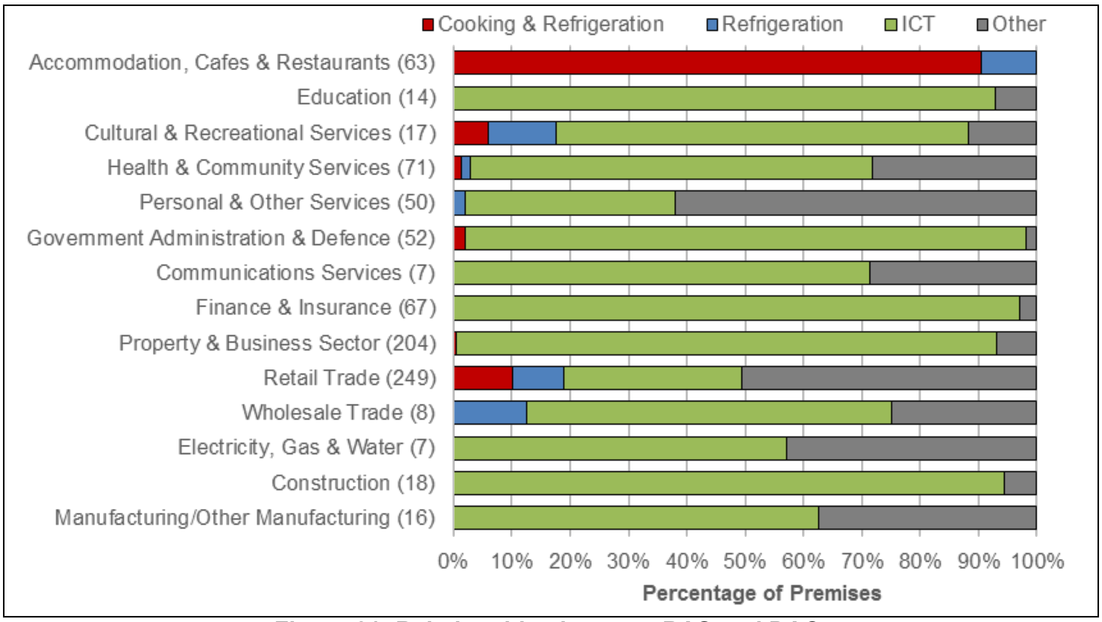


Figure 21: Relationships between BAS and DAC.

Figure 21 highlights Cooking & Refrigeration as well as Refrigeration DAC in premises within the BAS classification of Accommodation, Cafés and Restaurants, but premises operating in other sectors also have those types of appliance clusters, albeit in the minority, including Cultural & Recreational Services, Health & Community Services and Retail Trade. There is a similar pattern of relationship between the revised QV premise categorisation and DAC (Cramer's V 0.545, *p*-value 0.000) which is shown Figure 22.

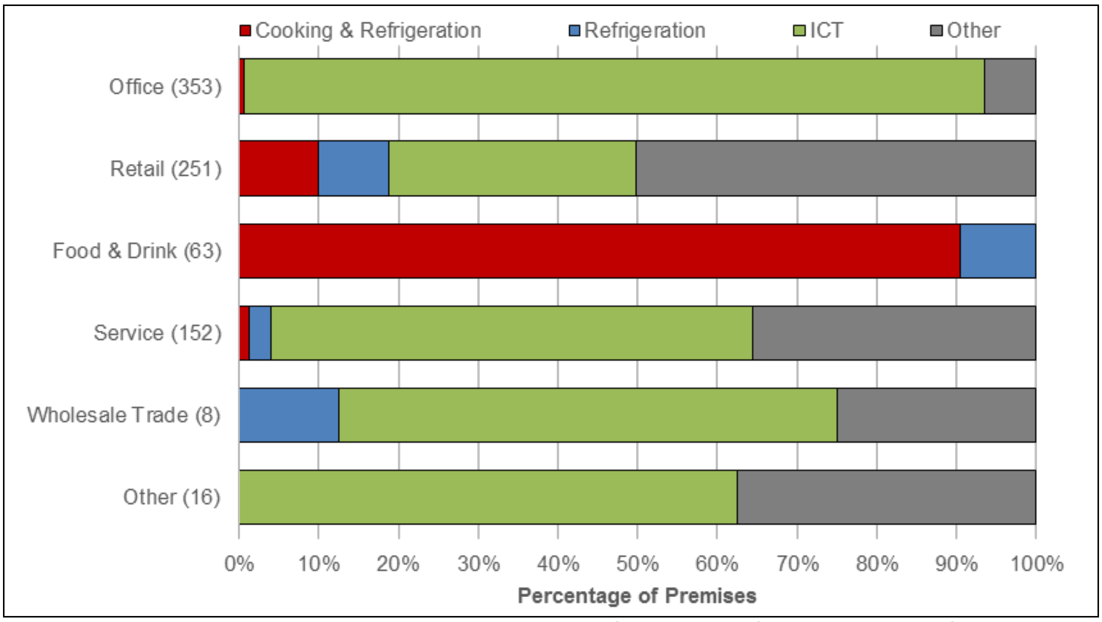


Figure 22: Relationship between Revised QV Premise Category and DAC.

4.2.1 Activities and Premise Electricity Consumption

This section uses information from the BAS and DAC to understand if there are any relationships or patterns between the business activities and electricity consumption.

There is a moderately strong association between the BAS and the annual consumption of electricity by a premise (Cramer's V 0.305, *p*-value 0.001). There does remain a statistically significant association between BAS and $EnPI_{elec}$, but this is considerably weaker (Cramer's V 0.276, *p*-value 0.045). Figure 23 shows the distribution of $EnPI_{elec}$ in quartiles across the BAS categories. It shows that all premises in the

Transport BAS category are in the lowest $EnPI_{elec}$ quartile whilst 70% of premises in the Accommodation, Cafés & Restaurants BAS category are in the upper quartile $EnPI_{elec}$ range.

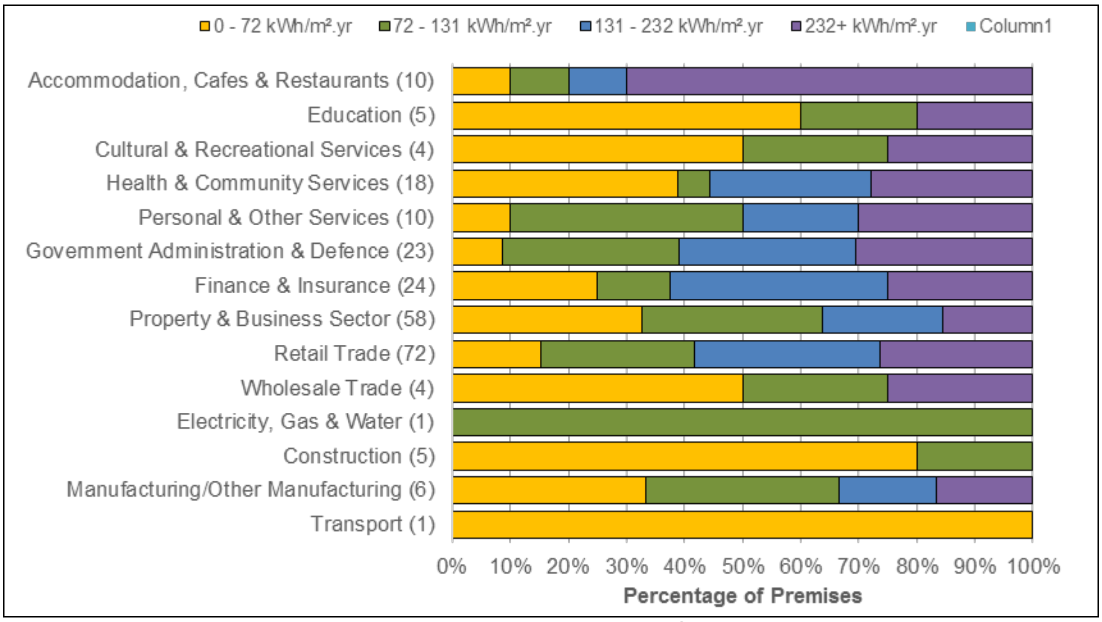


Figure 23: Relationship between BAS and $EnPI_{elec}$.

The relationship between the DAC and electricity consumption also has a statistically significant association. However, that association is weak in terms of annual premise electricity consumption (Cramer's V 0.153, *p*-value 0.036) but moderately associated with $EnPI_{elec}$ (Cramer's V 0.249, *p*-value 0.000). The $EnPI_{elec}$ quartiles and distribution by count are shown in Figure 24.

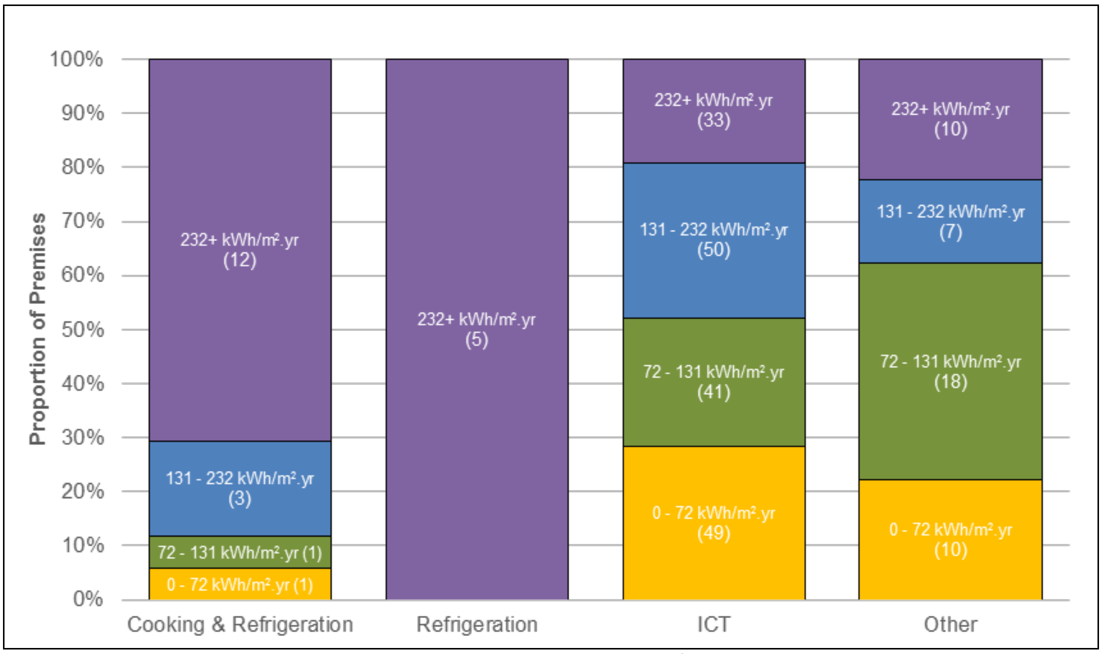


Figure 24: Relationship between DAC and $EnPI_{elec}$.

Premises whose dominant appliances are clustered around Refrigeration and Cooking & Refrigeration tend to be more prevalent among higher $EnPI_{elec}$ quartiles compared to lower $EnPI_{elec}$ quartiles. ICT-dominant premises are most prevalent in the BEES premises, but premises with these uses are spread across the $EnPI_{elec}$ quartiles.

There is significant variation in the average $EnPI_{elec}$ when categorising using DAC compared to the other methods. The average $EnPI_{elec}$ for premises by DAC vary between 169 kWh/m^2.yr and 638 kWh/m^2.yr

(Table 18). The average $EnPI_{elec}$ for premises by the revised QV premise categorisation vary between 124 kWh/m^2.yr and 296 kWh/m^2.yr (Table 19). The average $EnPI_{elec}$ for premises by BAS vary between 29 kWh/m^2.yr and 379 kWh/m^2.yr (Table 20). This shows how the use of appliances within premise activities can have a large impact on their $EnPI_{elec}$. This is discussed in more detail in section 6. There was only one premise in each of the Transport and Electricity, Gas & Water BAS categories. Therefore, they have been removed due to confidentiality reasons.

Table 18: Premise Mean and Median Electricity Consumption by DAC.

Dominant appliance cluster (DAC)		**$EnPI_{elec}$** (kWh/m^2.yr)	**Average daily electricity** (kWh/day)	**Annual electricity** (kWh/yr)
Cooking & Refrigeration	Mean	638	490	178,848
	Median	395	172	62,929
Refrigeration	Mean	430	1,762	643,459
	Median	428	237	86,451
ICT	Mean	189	447	163,421
	Median	126	126	46,019
Other	Mean	169	2,295	838,164
	Median	115	71	25,766

Table 19: Premise Mean and Median Electricity Consumption by Revised QV Premise Category.

Revised QV premise categories		**$EnPI_{elec}$** (kWh/m^2.yr)	**Average daily electricity** (kWh/day)	**Annual electricity** (kWh/yr)
Office	Mean	207	589	215,209
	Median	115	127	46,405
Retail	Mean	257	381	139,156
	Median	146	149	54,329
Food & Drink	Mean	296	266	97,159
	Median	273	120	44,009
Services	Mean	196	300	109,413
	Median	66	111	40,436
Wholesale Trade	Mean	190	2,778	1,014,616
	Median	123	81	29,670
Other	Mean	124	111	40,692
	Median	110	81	29,595

Table 20: Premises Mean and Median Electricity Consumption by BAS.

Business activity sector (BAS)		$EnPI_{elec}$ ($kWh/m^2.yr$)	Average daily electricity (kWh/day)	Annual electricity (kWh/yr)
Finance & Insurance	Mean	379	632	230,849
	Median	157	149	54,349
Accommodation, Cafés & Restaurants	Mean	296	266	97,159
	Median	273	120	44,009
Government Administration & Defence	Mean	267	1,606	586,619
	Median	172	632	230,768
Retail Trade	Mean	257	369	134,870
	Median	145	148	53,919
Cultural & Recreational Services	Mean	217	24,628	8,995,358
	Median	86	122	44,482
Health & Community Services	Mean	199	87	31,663
	Median	148	67	24,537
Wholesale Trade	Mean	196	300	109,413
	Median	66	111	40,436
Personal & Other Services	Mean	188	205	74,809
	Median	131	83	30,451
Education	Mean	137	132	48,267
	Median	71	40	14,765
Property & Business Sector	Mean	131	188	68,523
	Median	99	114	41,586
Manufacturing/Other Manufacturing	Mean	124	111	40,692
	Median	110	81	29,595
Construction	Mean	53	30	11,082
	Median	52	19	6,795

4.2.2 Buildings, Occupying Premises and Electricity Consumption

Associations between premise activities and total electricity consumption as well as $EnPI_{elec}$ suggest that the cluster of premises within a building may impact on the building's consumption of electricity and $EnPI_{elec}$.

BEES data allows only a limited exploration of this because data was not collected from a representative sample of premises within each building but rather from a representative sample of buildings. While 848 premises participated in the telephone survey, energy revenue data and telephone survey data in combination, available for this analysis, was from premises within 231 separate buildings. Those buildings are the basis for the analysis presented in this subsection and in section 4.3.

To explore the relationship between collective premise activities within buildings, all 231 buildings in this dataset have been defined according to the prevailing dominant appliance cluster (DAC) of the premises located within them.

The majority of buildings had BEES premises located within them with similar appliance clusters (Figure 25). A little less than 15% had a mix of DACs among the premises within the buildings. These were categorised as:

- mixed with **either** Cooking & Refrigeration and/or Refrigeration present along with the ICT and/or Other DAC
- mixed with **neither** Cooking & Refrigeration and/or Refrigeration present along with the ICT and/or Other DAC.

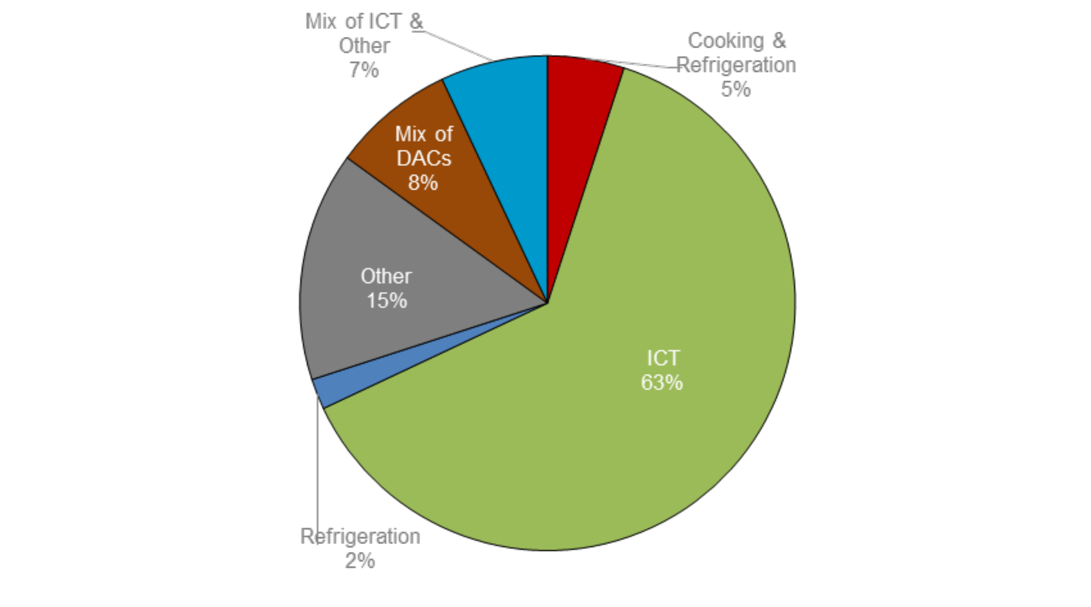


Figure 25. Buildings with BEES Premises by DAC.

Both the revised QV premise categorisation and the DAC of buildings with telephone survey and electricity revenue data show a significant but weak association with the estimated annual electricity consumption and $EnPI_{elec}$ of the building. Of the two variables, the revised QV premise categorisation has a weaker association than the DAC of occupying premises in relation to annual energy consumption. DAC and revised QV premise categorisation have very similar strength associations with $EnPI_{elec}$. The significance tests for each are set out in Table 21.

Table 21: Significance Tests on Building DAC and Revised QV Premise Categorisation Association with Annual Electricity Consumption and $EnPI_{elec}$.

Test	Cramer's V	*p*-value
Revised QV premise categorisation and building annual electricity consumption	0.182	0.029
DAC and building annual electricity consumption	0.205	0.016
Revised QV premise categorisation and building EnPI	0.234	0.000
DAC and building EnPI	0.230	0.001

4.3 Buildings, Premises, Employees and Visitors

There is a statistical association between the number of employees at a premise level and the annual electricity consumption (Figure 26). The more employees, the more electricity is likely to be consumed. This is less pronounced when the $EnPI_{elec}$ is measured, although the latter remains statistically significant (Figure 27). This is also likely to be due to the size of the building, that is, the larger the building, the more people and more energy.

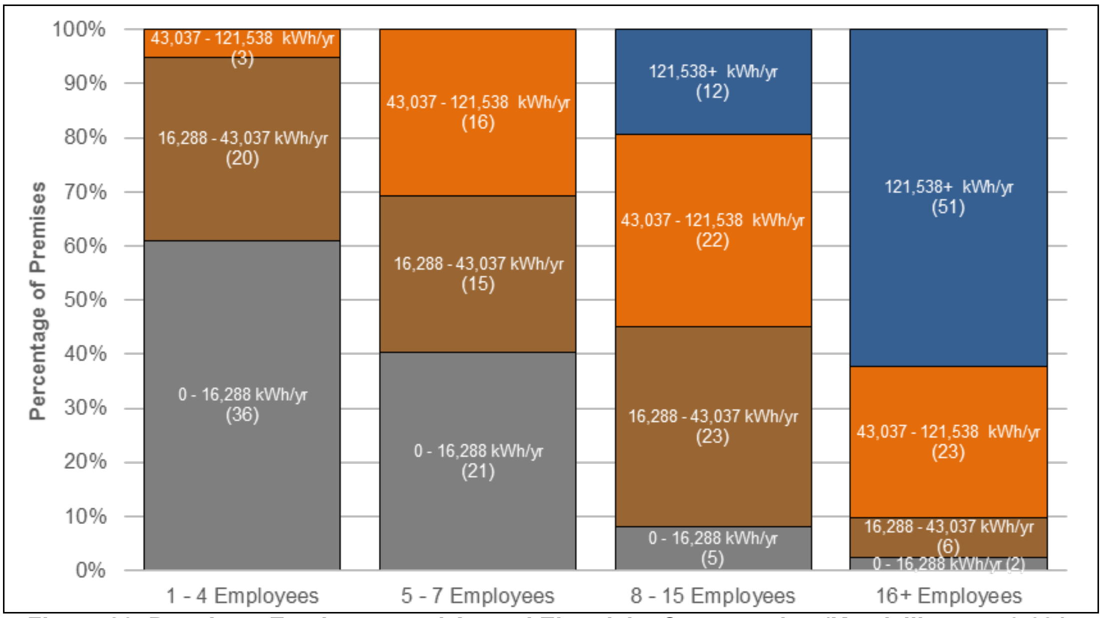


Figure 26: Premises, Employees and Annual Electricity Consumption (Kendall's tau-c 0.631, *p*-value 0.000).

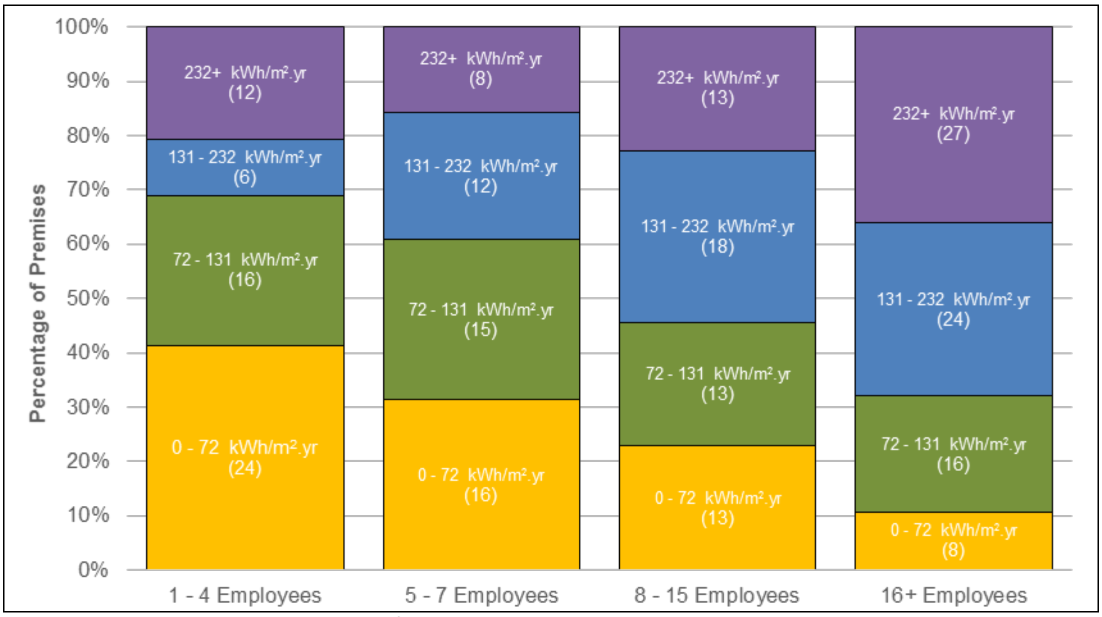


Figure 27: $EnPI_{elec}$ by Number of Employees (Premise Level) (Kendall's tau-c 0.249, *p*-value 0.000).

The less pronounced association between employees and $EnPI_{elec}$ may reflect the tendency of high electricity dominant appliance clusters being under-represented among premises with larger staff numbers compared to those with a dominant appliance cluster of ICT (Figure 28). However, while the association between employees and DAC is statistically significant, the relationship is very weak (Cramer's V 0.105, *p*-value 0.001).

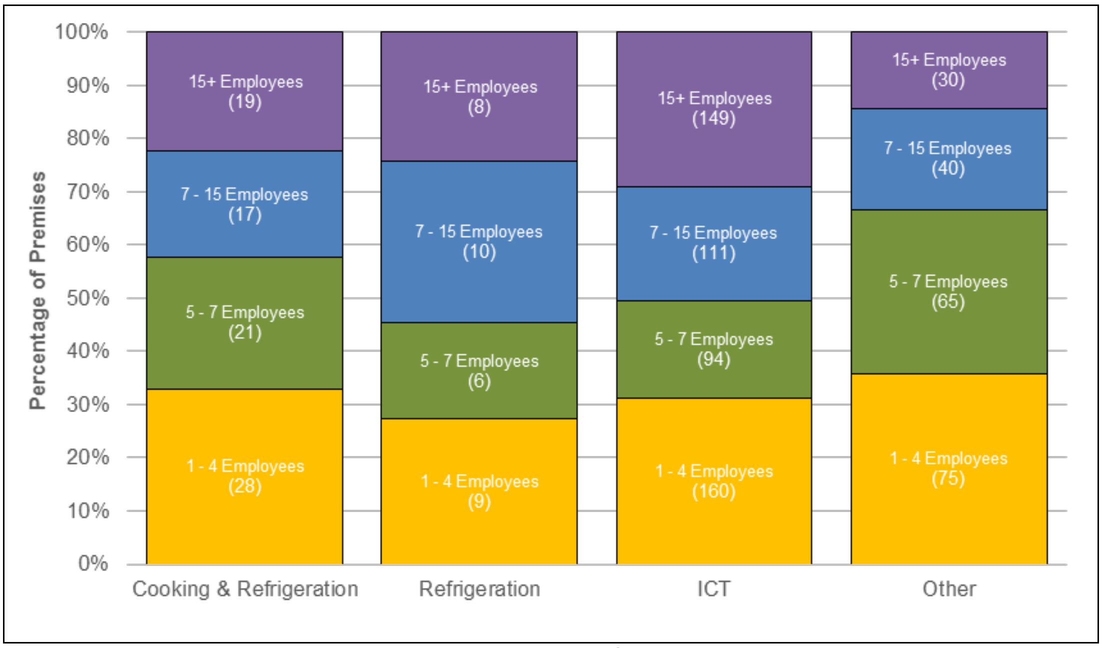


Figure 28: Employees by DAC (Premise Level).

There is a strong and statistically significant association between the estimated electricity consumption of buildings over a year as well as the $EnPI_{elec}$ and the number of employees on site in BEES premises within the building. This data must be treated with some caution. In some buildings, the total numbers of employees will exceed those in BEES participant premises.

Nevertheless, knowing employee numbers in these BEES premises provides a moderately strong association with the ability to predict total annual electricity consumption improved by almost 39%. Typically, the more employees in BEES premises within a building, the higher the consumption of electricity annually by that building. This, of course, is consistent with the relationship between gross building size and electricity consumption. It is also consistent with the tendency for larger buildings to have larger aggregates of employees associated with BEES participating premises (Figure 29). Knowing the gross size of a building provides an improvement in prediction numbers of employees in BEES participant premises of over 47%.

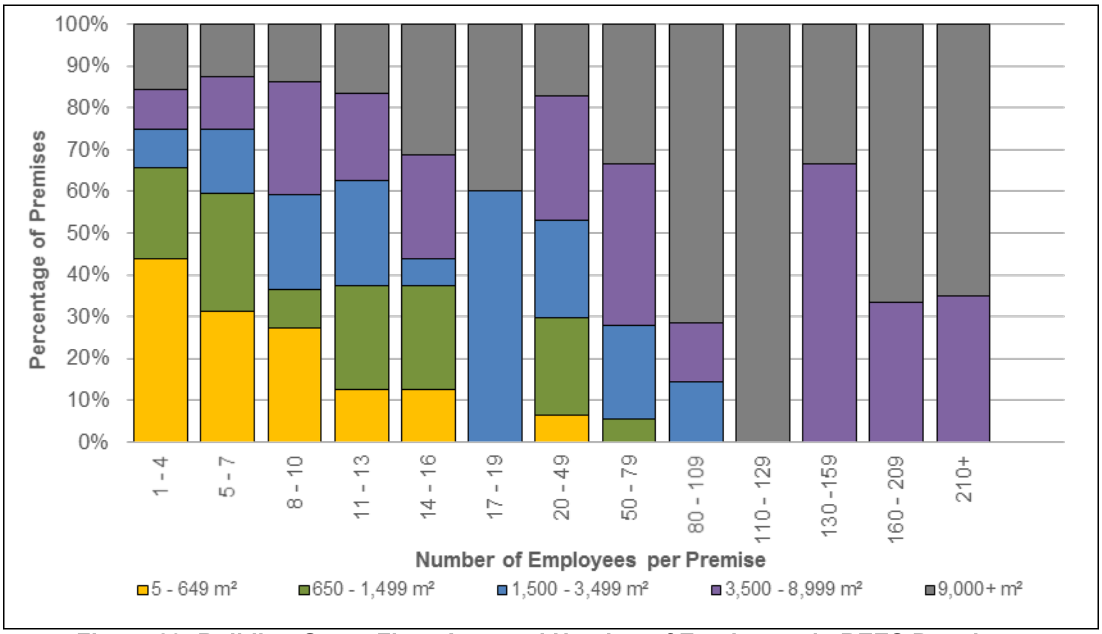


Figure 29: Building Gross Floor Area and Number of Employees in BEES Premises.

The association between number of employees and building electricity consumption reflecting to a considerable extent sheer building size is evident when considering $EnPI_{elec}$. The association between building $EnPI_{elec}$ and the number of employees in premises is more muted. The size effect is removed by $EnPI_{elec}$ being measured on a square metre basis. Knowing employee numbers in BEES premises improves the ability to predict building $EnPI_{elec}$ by less than 20%.

Further analysis could consider the relationships between floor area, total electricity use and $EnPI_{elec}$ by DAC. This would provide some consistency across the different types of energy uses.

The number of visitors or clients typically visiting a premise is statistically significantly associated with the electricity consumption of premises and the $EnPI_{elec}$ of premises. Knowing visitor/client numbers provides between 18% and 22% improvement in predicting these forms of electricity consumption. In that respect, it is a moderate association between the clients/visitors and energy consumption.

4.4 Energy Consumption, Premise and Building Tenure

Of the 231 buildings with telephone survey data and estimated energy consumption for the building, over three-quarters are entirely occupied by tenants. A minority are occupied by owner-occupiers only, while a smaller proportion again are occupied by both the building owner and tenants (Figure 30). There is no statistically significant relationship between the tenancy status of premises and their $EnPI_{elec}$ (Cramer's V 0.127, *p*-value 0.253) or annual electricity consumption (Cramer's V 0.096, *p*-value 0.583). The tenure status of buildings as a whole has no statistically significant association with either building annual electricity consumption (Cramer's V 0.000, *p*-value 0.000) or building $EnPI_{elec}$ (Cramer's V 0.000, *p*-value 0.000).

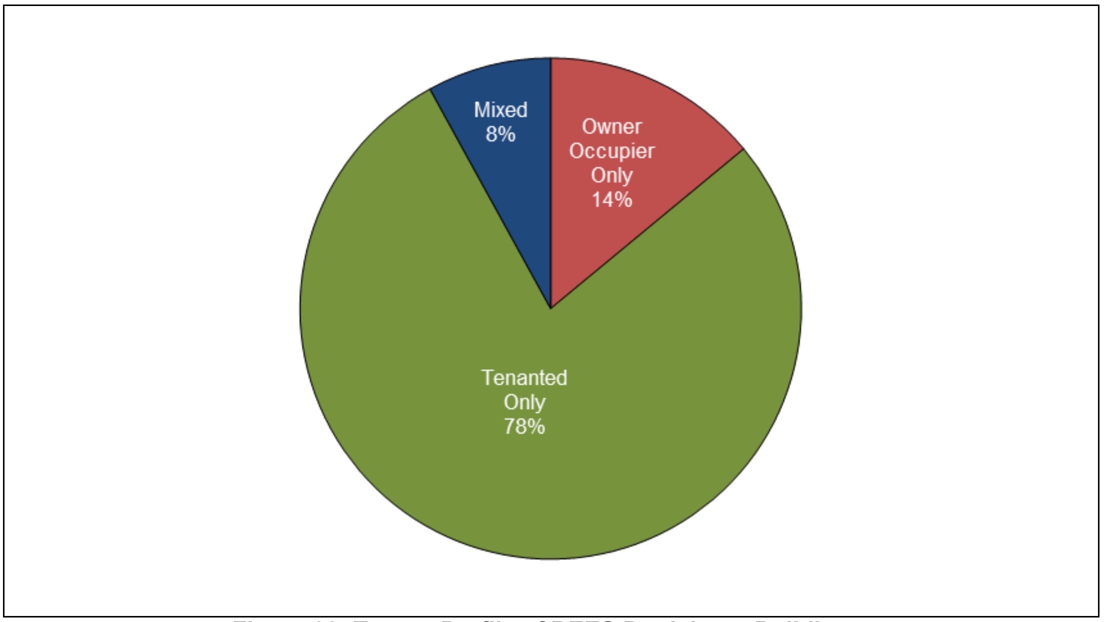


Figure 30: Tenure Profile of BEES Participant Buildings.

5. MODELLING

This section provides the results of energy and thermal simulation modelling, which was carried out using targeted monitored data to calibrate these models. It provides new knowledge to assist in the wider use of thermal simulation models:

- Savings from natural ventilation and daylight design (replacing electric light) can only be significant if the building form is kept narrow (<17 m).
- An optimal combination of solar shading, insulation and free cooling can almost eliminate cooling energy consumption for Christchurch commercial buildings.
- Courtyards in conjunction with laneways (of 10 m 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.
- Opening up the city centre with courtyards and laneways also creates useful outdoor spaces.
- Planned façade step-backs are not effective in saving energy or making sunnier streets during the winter period.

The key principle learned is that the roof, walls and glazing are important elements to insulate, especially when considering that glazing has no requirements under the New Zealand Building Code.

There were two motivations for the modelling aspect of the BEES research. The first motivation arose from the desire to examine how the project might contribute knowledge of commercial building energy performance to the Christchurch rebuild. The Christchurch earthquakes of September 2010 and February 2011 have resulted in 80–90% of the central city being demolished (OPUS, 2011). As the focus of BEES draws statistically relevant energy performance data about New Zealand commercial buildings through studying existing buildings, Christchurch had to be left out of the survey portion of the study. This study was undertaken based on models drawn up for the statistical analysis of the BEES survey data. It therefore became a first application of the potential of this modelling approach to explore how simulation-based design studies might be performed on the remaining BEES dataset.

The second motivation arose from a desire to examine how modelling might examine new-build design options in general, particularly for Christchurch. Through the Share an Idea scheme set up to address the rebuild, the people of Christchurch indicated a strong sentiment for a highly sustainable exemplar city (Christchurch City Council, 2011b). The Christchurch City Council and contributors developed the draft Central City Plan to direct the rebuild of the city centre. On 18 April 2012, Canterbury Earthquake Recovery Authority (CERA) Minister Gerry Brownlee gave the Christchurch City Council approval to proceed with the Central City Plan (Christchurch City Council, 2012).

The Central City Plan reflects the general desire of the people of Christchurch to move in a green direction. Features such as height limits and courtyards are proposed to increase accessibility to natural commodities within an otherwise energy-intensive urban environment. Included in this plan was an outline of urban form features (i.e. building height limits, façade step-backs, laneways and courtyards) that were envisioned to increase daylight into the city and create porosity for movement and pockets of community. However, opposition exists to the concept of surrendering profitable privately owned land area to public courtyards and laneways. Some remain unconvinced that the benefit these urban restrictions will provide justifies the loss in productive space (Christchurch City Council, 2011a).

Urban building form features of the Central City Plan are investigated for their effect on passive performance – the intrinsic performance of the buildings themselves, reducing their reliance on installation of energy-efficient equipment such as boilers and chillers or energy supply services such as photovoltaic electricity generation. This passive performance is evaluated by calculating the energy required to meet thermal and lighting comfort standards in a range of standard offices.

Refer to BEES Study Report 277/5 (Gates, et al., 2012) for more information on the methodologies applied in the modelling processes. It should be noted that, although this section is largely focused on a Christchurch geographic climate, the learnings can be applied to the rest of New Zealand.

5.1 Building Design Optimisation

Figure 31 displays a non-residential building highlighting (in orange) the central core zone that is too far from the windows to be naturally lit and/or naturally ventilated. Figure 32 displays a non-residential building with the same floor area but restricts all zones to be within 7 m of the building perimeter, so there is no central core.

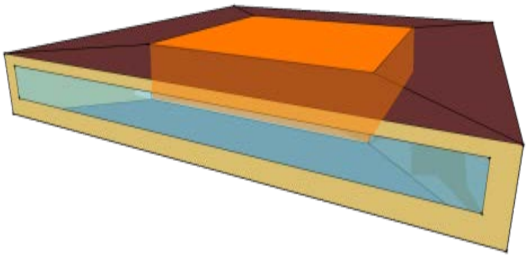


Figure 31: Non-residential Building showing Central Core Zone.

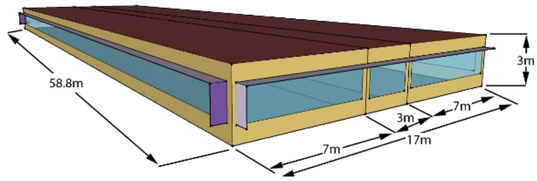


Figure 32: Non-residential Building with all Zones <7 m of the Building Perimeter.

Fundamental to significantly lowering energy use in these buildings is the use of passive design principles, identification of natural ventilation (free cooling) and daylight design (replacing electric light). The modelling and subsequent analysis showed savings from these two design principles can only be significant if the building form is kept narrow, as these savings are only feasible in rooms near (≤7 m) the outside walls of a building as shown in Figure 32. Fewer savings are possible in buildings with a deep plan and thus a core zone due to the lack of access to natural daylight and air. An optimal combination of solar shading, insulation and free cooling can almost eliminate cooling energy consumption.

The passive design techniques (or solutions) were split into three groups: cooling strategies, heating strategies and daylight strategies. The strategies refer to which building energy-related challenge a specific solution is trying to deal with.

Table 22: Passive Design Techniques.

Strategy	Passive design techniques
Cooling	**Natural ventilation** uses wind and air properties without the need for active mechanical systems. Natural ventilation can be achieved using two major effects: pressure difference (caused by wind) and natural buoyancy (difference between warm and cool air and dry and humid air, also known as stack ventilation).
	Solar shading reduces the building's cooling loads by preventing sun radiation from penetrating the building by shading windows. Shading devices can be either applied to the building externally (overhangs, louvres and side fins), internally or between double glazing or double-skin façades.
	Night cooling evacuates the energy stored during the day by the building's thermal mass therefore reducing the demand for cooling.
	Ground cooling pre-conditions (pre-cools) the supply air for mechanical ventilation to reduce the energy required for space conditioning.
Heating	**Thermal mass** is the ability to store and release heat energy.
	Solar heat gain uses the building's orientation, the window orientation and the glazing selection in order to let the maximum sunlight penetrate the building. This is only possible through thermal mass and can be achieved through two principal strategies: direct passive gain (thermal mass absorbing excessive heat gains in periods where the sun is directly entering the space) and indirect gain (thermal mass separates the collector from the conditioned space).
Daylight	**Skylights** installed on the roof can only bring daylight to the floor below. In order to prevent too much daylight or hot spots of light, they need to be shielded through the use of diffuse glazing, blinds or other materials.
	Windows, when properly oriented (north in the southern hemisphere), bring daylight into the rooms. They can also bring a lot of heat energy inside, so they may need to be coupled with shading devices.
	Tubular daylight systems are tubes installed on the roof that bring sunlight into the rooms. At the top end of the tube, a lens collects the natural light, which is then transported into the room through the tube (using reflection).
	Light shelves reflect the sunlight onto the ceiling and bounce it deep into the room and are a solution for glare issues.

5.1.1 Christchurch Energy-lowering Reference Buildings

A Christchurch baseline scenario model for a 1,000 m^2 single-storey commercial building in Christchurch was created to represent what would currently be built to meet the New Zealand Building Code. The base scenario model was used to optimise the building parameters to lower the annual energy consumption; however, the building also had some design changes applied to determine the degree to which they would lower the energy use.

The key results for each parameter showed the following:

- Solar shading to different depths depending on the orientation was necessary to prevent unwanted solar gains. The most shading is needed on the east façade with the overhang being 2.5 m, the east fin being 0.125 m.
- The window-to-wall ratio stays at 50%, which is the maximum allowed by the New Zealand Building Code prescriptive method of compliance. However, the window did move up each façade vertically above centre by 200 mm to allow for better daylight penetration into the rear of the perimeter spaces.
- The roof, wall and glazing insulation increased well above the recommended New Zealand Building Code values, with all three insulation results possibly not reaching optimal (minimum energy use) levels. However, they did reach the maximum optimisation value allowed set through the modelling process. It is important to realise that a cost-benefit analysis was not part of this analysis.

Figure 33 displays the energy end-use breakdown of the EnPI for three scenarios. The coloured bars are the results for the perimeter zones and the red lines the results for the core zone. The blue bars represent the energy end-use consumption for the base scenario, the red bars represent the scenario with natural ventilation and electric light controls installed and the green bars represent the fully optimised solution set scenario (with optimum solar shading, insulation, window-to-wall ratio etc.).

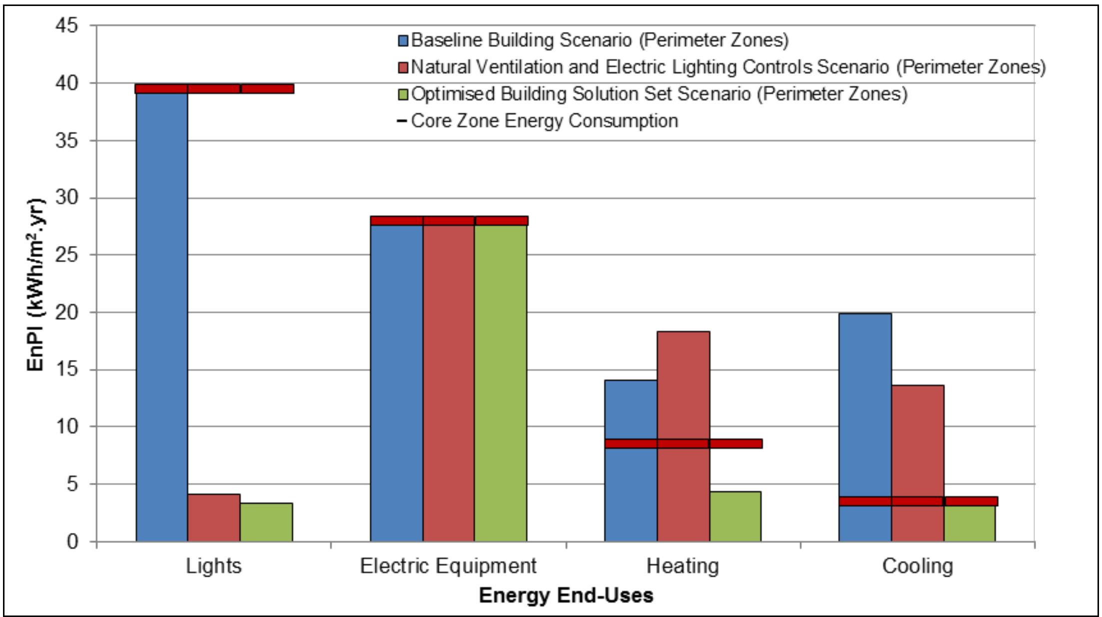


Figure 33: Christchurch Building Scenario Energy End-use Breakdown.

Figure 34 displays the energy end-use savings for the two energy-lowering building scenarios for the perimeter zone only. Energy savings achieved by each scenario are represented by the two coloured bars, with the red for the natural ventilation and electric light controls scenario and the green for the fully optimised solution set scenario.

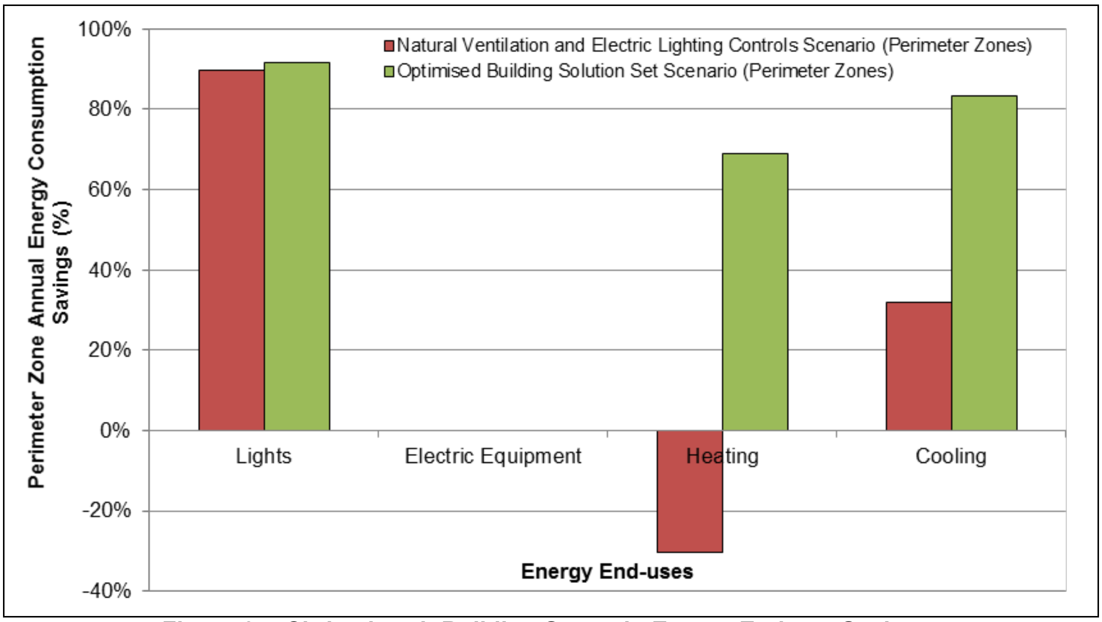


Figure 34: Christchurch Building Scenario Energy End-use Savings.

As can be seen in Figure 34, the large energy savings are achieved in the cooling, heating and lighting building energy end-uses. The reductions in the cooling and lighting energy consumption are achieved with just the natural ventilation and electric light controls. These savings are mostly attained in the cooling and heating energy end-uses.

In the base scenario, the four perimeter zones consume more energy than the core zone (Figure 33). However, this radically changes when the energy-lowering design changes are implemented. In the base scenario, the perimeter zones consume 21.9 kWh/m^2.yr more energy than the core zone. In the natural ventilation and electric light controls scenario, the perimeter zones use 15.5 kWh/m^2.yr less than the core zone. In the fully optimised solution set scenario, the perimeter zones use 40.4 kWh/m^2.yr less than the core zone.

Figure 35 displays the building's total annual energy consumption in the columns and percentage of annual energy savings in the large dots for the three building design scenarios introduced above as well as a fourth building scenario. The fourth building scenario is the fully optimised solution set design in a shallow floor plan. This means all 1,000 m^2 of floor area is contained in a building that acts entirely like a perimeter zone.

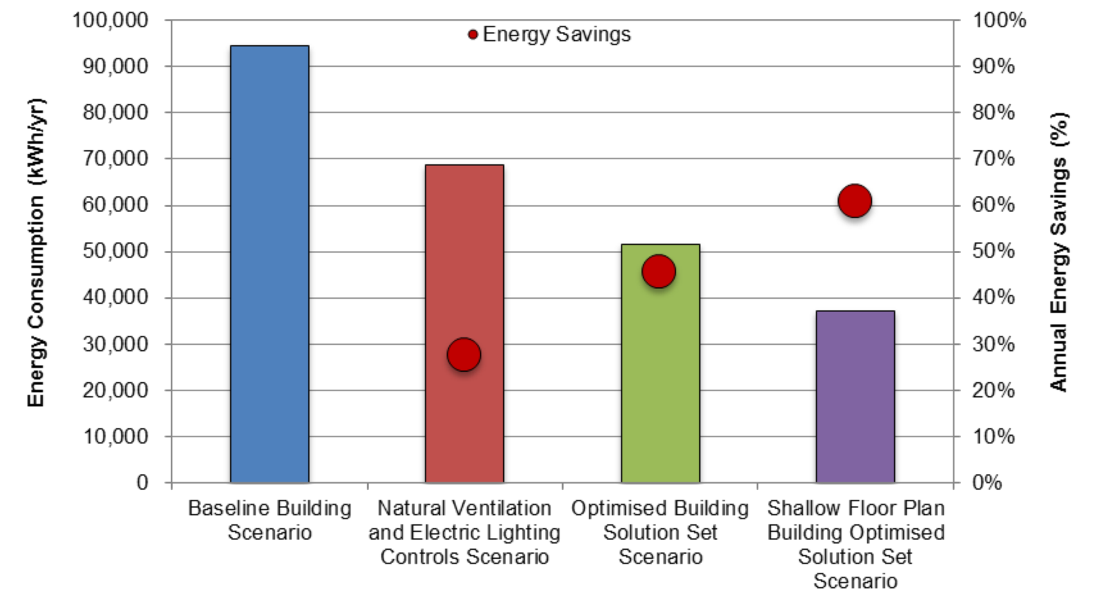


Figure 35: Christchurch Building Scenario Annual Energy Consumption Results.

As can be seen in Figure 35, each stage reduces the energy consumption dramatically. In the building scenario implementing natural ventilation and electric light controls, the annual energy consumption is reduced by 27%. With the fully optimised solution set implemented, the energy is reduced a further 18% to reach total energy savings of 46% when compared to the base scenario. By just using a shallow floor plan, the annual energy consumption can be reduced by another 15% to reach total energy savings of 61% when compared to the base scenario. Therefore, optimising just the building layout and envelope can reduce the energy consumption by approximately 60%.

5.1.2 Christchurch Design Principles and Guidelines

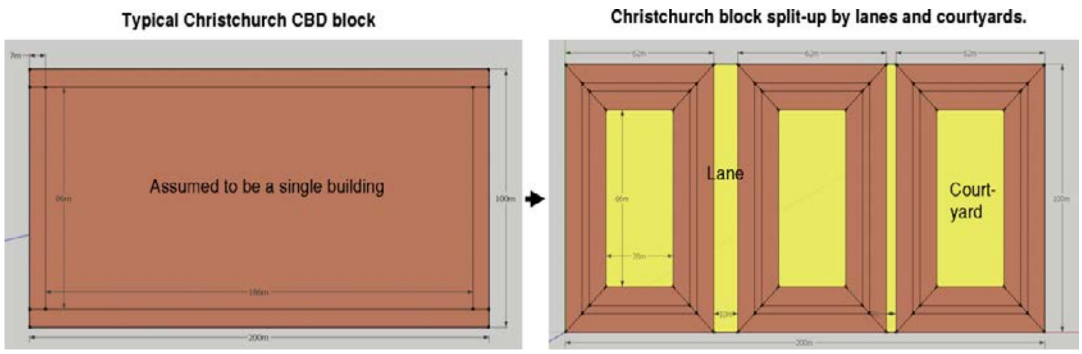
Having a fully optimised solution set implemented in new Christchurch commercial buildings could reduce the annual energy consumption by as much as 46% when compared to the standard built to Code. Furthermore, by using a shallow floor plan, the annual energy consumption can be reduced by a further 15% to reach total energy savings of 61% when compared to the standard built to Code. Therefore, optimising the building layout and envelope can reduce the energy consumption by approximately 60%.

Five design principles were established in the work presented in the above sections:

1. Using natural ventilation/free cooling and daylight design is crucial to lowering energy. This principle also indicated that the savings could be large if the building form is kept narrow as the perimeter savings would be more prominent without an internal building core zone.
2. With the combination of optimal solar shading, insulation and free cooling, the cooling energy consumption can almost be eliminated.
3. Commercial buildings need to be insulated well, especially the roof and glazing.
4. The window-to-wall ratio does not need to be bigger than the maximum New Zealand Building Code value of 50% but should definitely not be smaller.
5. The last principle is that the windows need to be situated high on the façade to allow for good daylight penetration.

5.2 Christchurch Urban Form and Energy

The goal of the urban form ideas from the Christchurch Central City Plan was that buildings and city streets would gain greater solar and fresh air access through breaking up city blocks with laneways, alleyways and courtyards. This had the potential benefit of creating buildings that could effectively use natural lighting, heating, cooling and ventilation and therefore provide a passively comfortable environment. The specific Central City Plan testing parameters can be found in Appendix J.



Largely internal building space. In reality, may be comprised of many individual buildings. Shows total net lettable area if all the city block was developed intensely.

Open outdoor space; sun, fresh air; public/private; lost net lettable area.

Indoor spaces adjacent to light, sun and fresh air; remaining net lettable area in individual buildings grouped around the courtyards.

Figure 36: Plan View of City Block with the Central City Plan Urban Form Changes Implemented.

5.2.1 Benchmarks of Passive Performance

Comparative modelling was carried out to measure effectiveness of the Central City Plan passive urban form features. Therefore, a baseline model was established for comparison against the stated passive urban form features proposed in the Central City Plan. Both models consist of identical foundation parameters (i.e. block and street dimensions, materiality, testing methods, measurable outputs). The Central City Plan features included step-backs, laneways and courtyards. For the geometry and methodology used for the modelling and testing of the Christchurch Central City Plan, refer to Appendix J.

The following table describes the indexes used in this study to measure building performance.

Table 23: Benchmarks of Passive Performance.

Factor	Benchmark	Unit	Description
Daylight autonomy		%	Measures illuminance levels across a space over the full occupied year. It shows where in the space daylight is plentiful and where it may be lacking. Daylight autonomy can be set to a required minimum illuminance of 320 lux (Standards New Zealand, 2006) and will demonstrate which areas of that space are sufficiently lit and for what percentage of the year. In essence, daylight autonomy illustrates what percentage of the year artificial light can be turned off in that space.
Passive thermal	18–25	°C	Thermal conditions are measured across the occupied year (weekdays 8:00 am to 5:00 pm). A comfort band is used in these analyses to determine comfort in test cells. The more time spent within the prescribed comfort zone without active heating or cooling, the better the passive thermal performance.
Natural ventilation			Natural ventilation is not simulated in detail in this study. Instead, a rule of thumb is used where 90% of the artificial cooling requirements in Christchurch can be subtracted from the simulated figure due to the use of natural ventilation (Cory, et al., 2012a).
Total energy consumption		EnPI	Energy consumption is measured for each zone for the whole building and EnPI. Total building energy is useful for knowing the urban form changes' overall effects on the building. Square metre energy rates are useful for comparison against the loss of net lettable area associated with implementing these urban form changes.
Sunlight to street	4,380	Hours	Total sunlight hours counts the time each point of an analysis grid spends in direct sunlight over a full year. It focuses on direct solar beam referred to as sunlight and does not take into consideration diffused (reflected) light referred to as daylight. Total sunlight hours are measured between 7:00 am and 7:00 pm. The resulting values are between 0 hours (no time spent in sun) and 4,380 hours (maximum possible sunlight hours). The closer the figure is to 4,380 hours, the sunnier that point (or grid average) is.

5.2.2 Step-backs

The aim of step-backs is to allow more daylight into the north and south-facing perimeter zones by stepping back the façade on the top two storeys as shown in Figure 37.

5.2.2.1 Daylight Autonomy

The step-back urban form change influences daylight in the north and south-facing perimeter zones only. Therefore, daylight autonomy for test cells on the ground levels and levels four and seven on both north and south perimeter zones were conducted. Daylight autonomy is given in terms of range, which covers the lowest point of daylight performance in the cell to the highest, and average daylight autonomy, which indicates percentage of the year that artificial lighting can be turned off in that cell.

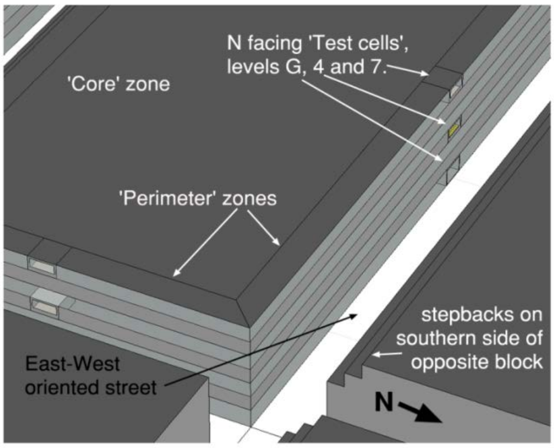


Figure 37: Perimeter and Core Zones in Southern Façade Step-back.

A clear improvement in daylight autonomy across most cells was achieved when step-backs were included into the design. This was expected on the north-facing perimeter but not to such an extent on the south. The area most improved was the mid-level zone on the northern façade, which was expected. This scenario also best represents likely circumstances of commercial offices.

Figure 38 and Figure 39 offer a visual representation of maps of daylight autonomy in this northern mid-level zone. Here, daylight autonomy patterns can be seen at each specific point in the test cell. Yellow squares represent areas of high daylight autonomy (80–100% of year sufficiently lit), whereas red represents less effective daylighting (40–60% of year sufficiently lit). An evident improvement can be seen by the increase of yellow squares in Figure 39. This improvement can be measured as an 11% increase (average daylight autonomy of 69% up to 80%) in daylight autonomy in this space. This means artificial lighting could be completely turned off for an extra 11% of the working year (approximately 5 weeks).

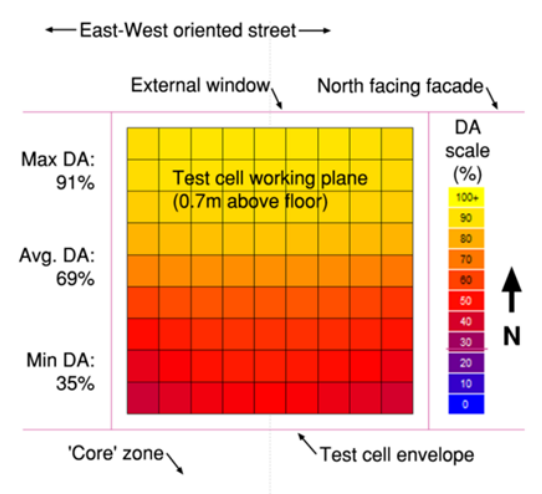


Figure 38: Baseline Daylight Autonomy.

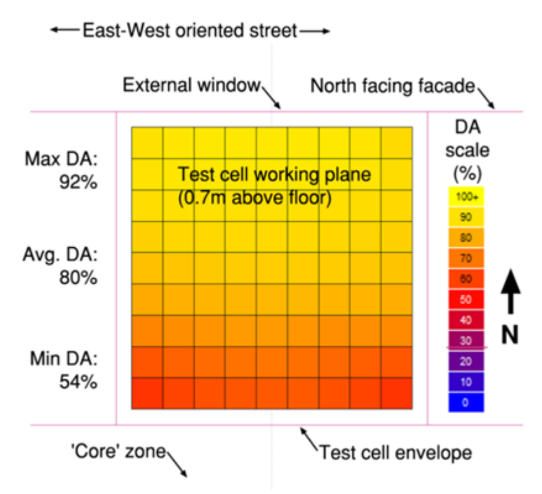


Figure 39: Step-back Daylight Autonomy.

5.2.2.2 Thermal Comfort

Increasing daylight to building spaces also contributes to increased temperatures. Typically, the extra solar penetration into the urban canyon improves thermal conditions (for most levels), making northern perimeter zones passively warmer than they were in the baseline model. There is potential for areas to overheat, so additional cooling would be required.

5.2.2.3 Total Energy Consumption

The results shows the electric lighting energy saved would be offset by the amount of artificial cooling and heating required to maintain thermal comfort. Another important consideration in determining the overall influence of the step-backs on energy consumption over the entire building is the relationship between core and perimeter zones. As this urban form change only affects the northern perimeter zones, core zone energy consumption will remain the same.

The results of the modelling showed an overall reduction of 1,400 kWh/yr for the entire building from the use of step-backs, which is negligible (<0.001%). Despite being conceived based on logical theory, testing of the step-backs demonstrated they in fact do not deliver any significant improvement to the city's performance, at least not in terms of energy consumption.

5.2.2.4 Total Sunlight Hours

Another factor that the step-backs influence is sunlight to the street. Figure 40 and Figure 41 demonstrate how stepping back the façade on just the top (sixth and seventh) floors can make a considerable difference to the amount of sunlight that reaches the street. This factor is important for pedestrian comfort and was requested by the people of Christchurch. The total sunlight hour maps below for east/west-oriented streets show that an additional 236 hours (30%) of direct sunlight can be realised through step-backs over the year (out of a possible 4,380 total sunlight hours). Most of this improvement would be during summer months as the angle of the winter sun would not reach the ground level over a seven-storey building in winter.

North/south-oriented streets experienced an improvement of 6% (738 up to 778 hours) all of which occurred at the northernmost edge of the analysis grid, meaning changes were very localised and largely unhelpful.

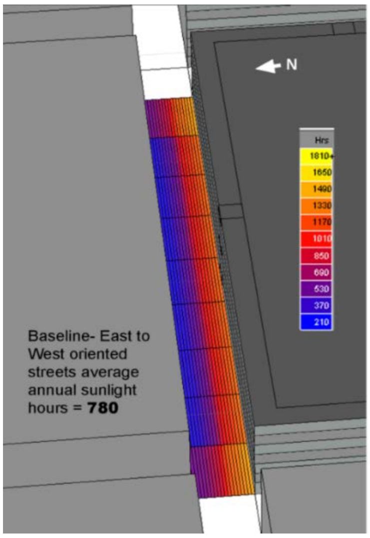


Figure 40: Total Baseline Sunlight Hours.

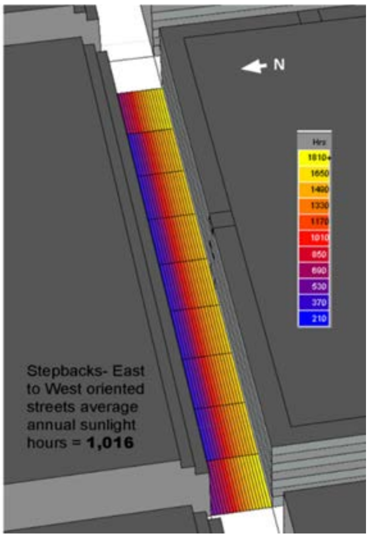


Figure 41: Total Sunlight Hours with Step-backs.

The analysis looked at buildings that were four storeys as well as the proposed maximum seven -storey limit. The step-backs of levels three and four on a four-storey building do have an effect across the whole year, though this change is still more obvious during the summer months. Comparing the fourth-storey and the seventh-storey results, the common sense notion that the lower city would have sunnier streets in winter is true.

5.2.3 Laneways and Alleyways

The second urban design option was to break up city block with laneways or alleyways. Modelling was carried out on two options– a 4 m wide laneway and a 10 m wide laneway.

5.2.3.1 Daylight Autonomy

Daylight analyses were carried out at mid-height east-facing perimeter zones. This location was selected as it gave an average situation overview of the daylight down each of the 4 m wide and 10 m wide north/south laneways. East and west-oriented cells perform equally. Figure 42 display the level of daylight autonomy that could be expected in each of the laneways.

At 4 m wide, the modelling showed the laneway delivers very poor daylight to adjacent internal spaces, averaging only 9%, with the majority of the space not reaching adequate illuminance levels at all during the year. Therefore, the 4 m wide laneway proved ineffective for daylighting. The 10 m wide laneway, however, provides considerably more daylight and deeper into the space. Here, almost half of the space (44%) is sufficiently lit to 320 lux throughout the year. Although still low, this test cell demonstrates that a 10 m wide laneway can provide useful daylight to adjacent spaces.

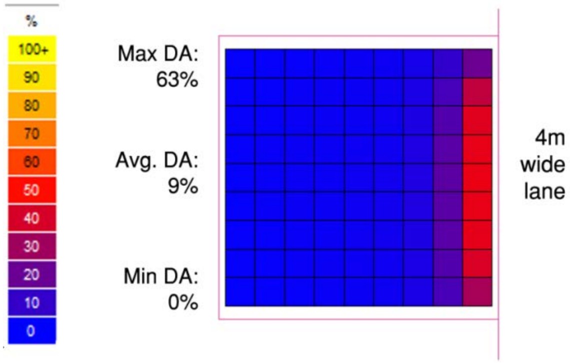


Figure 42: Daylight Autonomy Model with 4 m Laneway Adjacent.

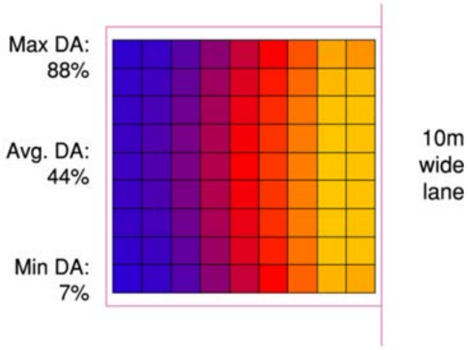


Figure 43: Daylight Autonomy Model with 10 m Laneway Adjacent.

5.2.3.2 Total Daylight Hours

Aligned with daylighting within buildings is the sunlight to ground level in the laneways. The 4 m laneway is dark with an average of only 93 hours of direct sunlight per year. The 10 m wide laneway allows better sunlight with an average of 348 sunlight hours per year (out of 4,380 possible sunlight hours).

5.2.3.3 Thermal Comfort

At the fourth level, this zone benefits from thermal buffer zones above and below, stabilising temperatures and minimising heat loss. Additionally, as the narrow urban canyons created by the laneways provide little avenue for direct sunlight onto these façades, solar gains are limited. This means both 4 m and 10 m wide laneways would result in passively comfortable spaces in adjoining perimeter zones for around 80% and 93% of the year respectively.

5.2.3.4 Total Energy Consumption

Figure 44 illustrates how, with natural ventilation and intelligent artificial lighting (providing only enough light to supplement natural daylight to the required illuminance level), energy consumption can be reduced. Here, zones adjacent to 4 m wide laneways benefit mainly from natural ventilation, but the 10 m wide laneway model benefits from daylighting as well. Compared to the baseline EnPI of 76 kWh/m^2.yr, the 4 m wide laneway reduces to 67 kWh/m^2.yr (12% reduction) and the 10m wide modelled to 63 kWh/m^2.yr (17% reduction).

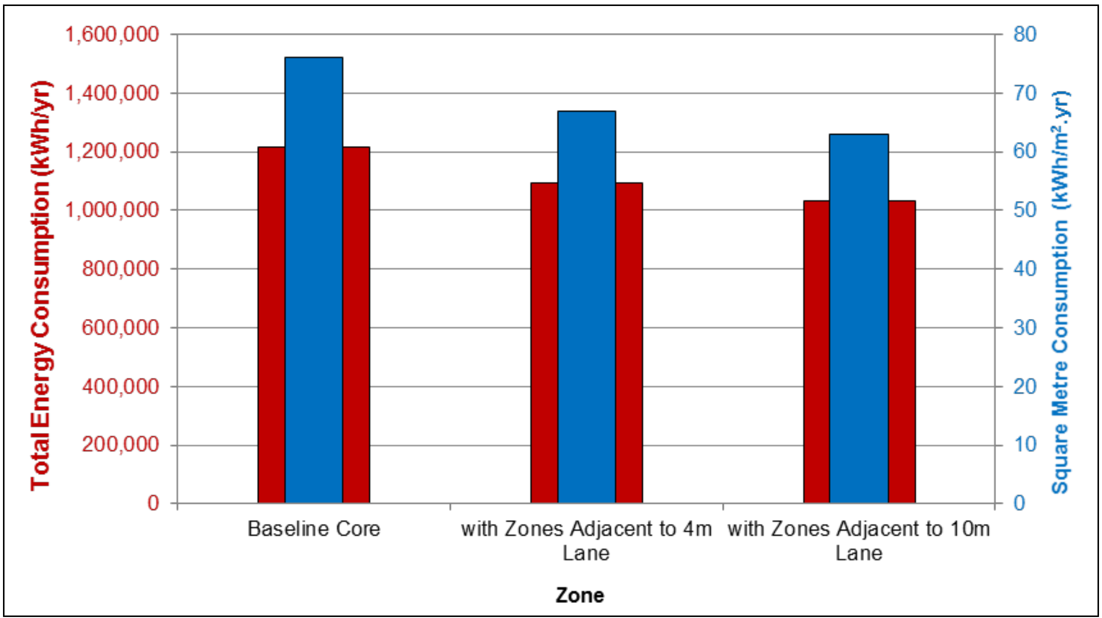


Figure 44: Baseline 4 m Laneway and 10 m Laneway Comparison of Overall Energy Consumption.

5.2.4 Internal Courtyard

Courtyards create pockets of life and activity within an urban environment, which can be designed to offer unique emotive qualities. For buildings, they provide daylight to all building spaces and the opportunity to use passive cooling.

5.2.4.1 Daylight Autonomy

As with the laneways, the effects of courtyards were assessed on the fourth level. Test cells were situated on each internal façade facing the courtyard to represent the new internal perimeter zones created by the courtyard's insertion. Figure 45 displays daylight autonomy results for each of the north, south and east/west (considered equal) facing cells.

As is evident just by looking at the colour rendering of these maps, all four cells experience very high daylight autonomy. In fact, the lowest reading at any one point across all cells is 54%, meaning that all artificial lighting can be turned completely off for over half of the occupied year.

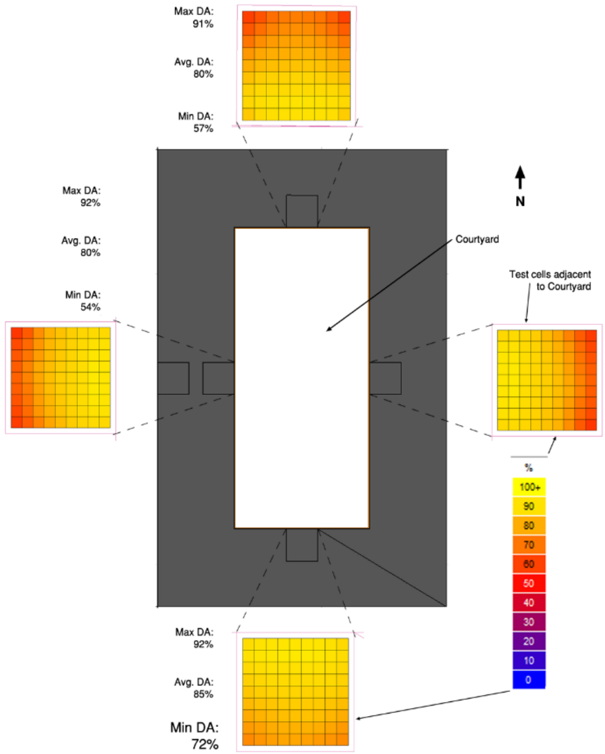


Figure 45: Daylight Autonomy Mapping of Level 4 Perimeter Zones facing Courtyards.

Even more impressive, average daylight autonomy across all four cells is over 80%, meaning the majority of each cell's floor area is sufficiently lit for over 80% of the occupied year. Such daylight autonomy performances are very high and can effectuate significant energy savings through reduced artificial lighting needs. Levels above this fourth level will experience equally or even more beneficial daylighting conditions, but levels closer to ground will not benefit so prosperously.

5.2.4.2 Thermal Comfort

Passive temperatures reflect the high level of solar access to level four perimeter zones seen in the daylight analysis. Figure 46 portrays mostly comfortable temperatures in all courtyard-adjoining zones but with definite overheating problems. The north-facing cell, modelled here without any shading, is not surprisingly the hottest, with almost half of the occupied year experiencing temperatures above 25°C. This would readily be controlled with appropriate shading and the natural ventilation that the courtyard makes feasible. East and west-oriented cells are more often comfortable at only 30% overheated, and south-facing cells manage to exceed comfortable temperatures for 19% of the occupied year, demonstrating that the heat gains from people and equipment inside the building are a significant contributor to the temperatures experienced indoors.

Baseline core passive temperatures were included in the graph to demonstrate a comparison between central core temperatures and new inner perimeter zone temperatures. This shows that the baseline core actually performs particularly well in terms of thermal comfort when compared to courtyard-facing cells, especially the north-oriented cell. However, the issue with the core zone is that 20% overheating must be cooled by purely artificial measures, whereas perimeter zones (even the north-facing zone) require little to no artificial cooling provided they have access to natural ventilation.

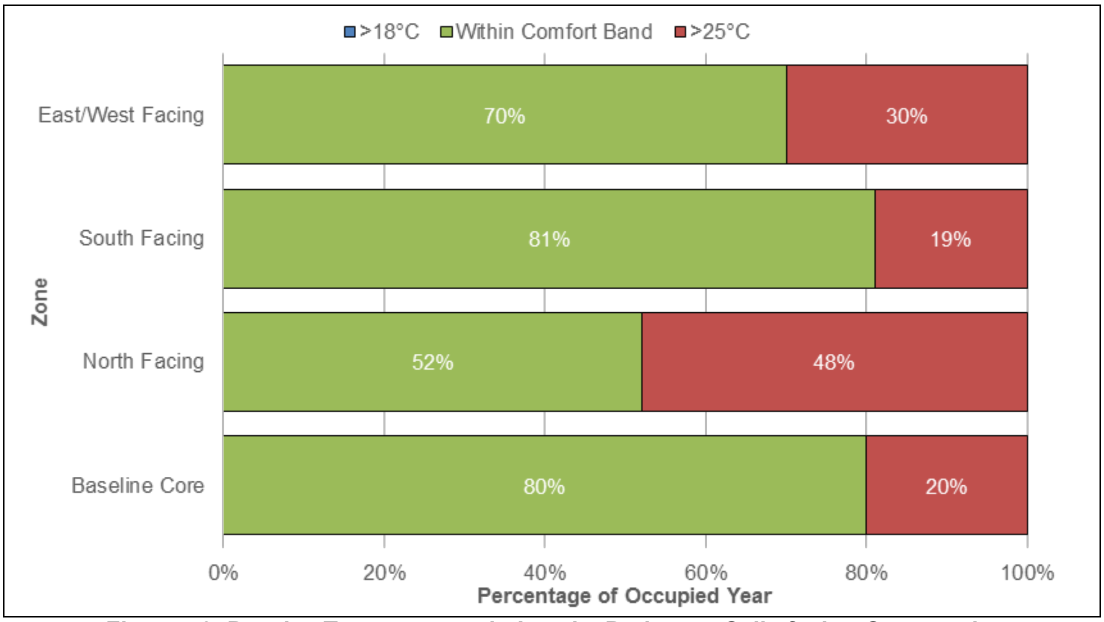


Figure 46: Passive Temperatures in Level 4 Perimeter Cells facing Courtyards.

5.2.4.3 Total Energy Consumption

The EnPI for each courtyard-facing cell in Figure 47 illustrates the benefits of designing using natural ventilation. Although the north-facing zone was passively the hottest of the four presented scenarios, it was also the least energy intensive. Due to natural ventilation reducing cooling requirements by up to 90% and ample daylight, the north-facing perimeter zone EnPI was reduced to 20 kWh/m^2.yr (from 76 kWh/m^2.yr baseline core). South and east/west-facing cells were nearly as efficient at 25 and 33 kWh/m^2.yr respectively.

The basic principle is to ensure narrow plans to allow through flow of air for ventilation and access to daylight.

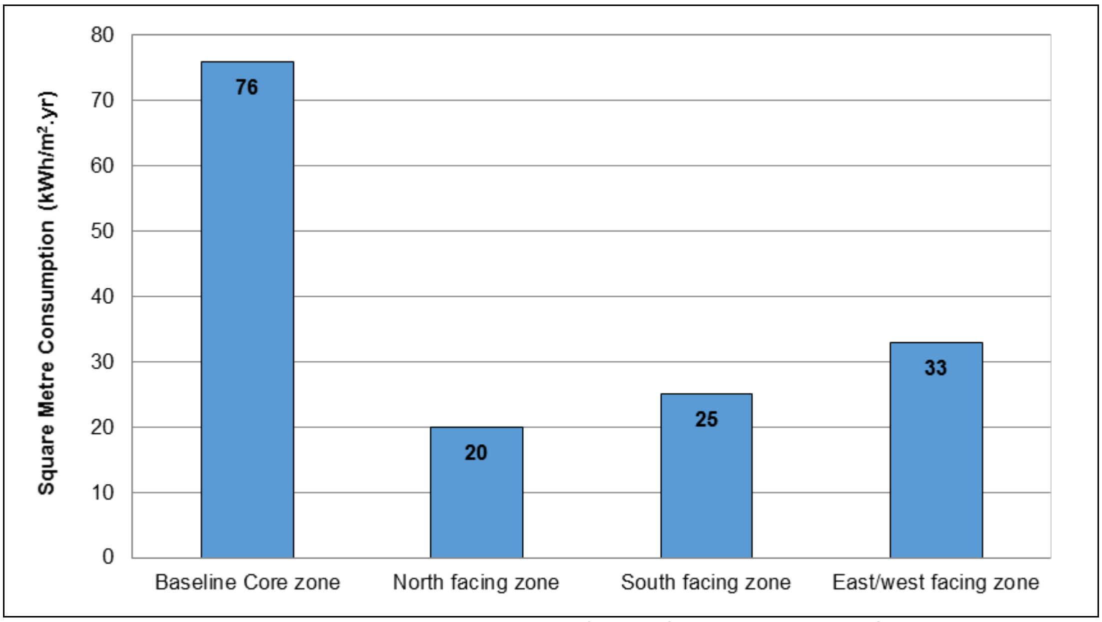


Figure 47: Level 4 Internal Perimeter Zones facing Courtyard Energy Comparison.

5.2.4.4 Total Daylight Hours

Total sunlight hours at ground level in the courtyard are not as high in the main east/west running streets but are on par with north/south running streets. Due to the 29 m high building surrounding the courtyard, direct sunlight struggles to penetrate to that depth. Figure 48 illustrates how the area immediately south of the northern perimeter building is predominantly under shade, achieving only about 200 hours of sunlight per annum (in summer months). Sunlight manages to penetrate further to the south of the courtyard for longer periods of the year but only during midday hours. Across the entire courtyard area, the average total sunlight is only 570 hours per year.

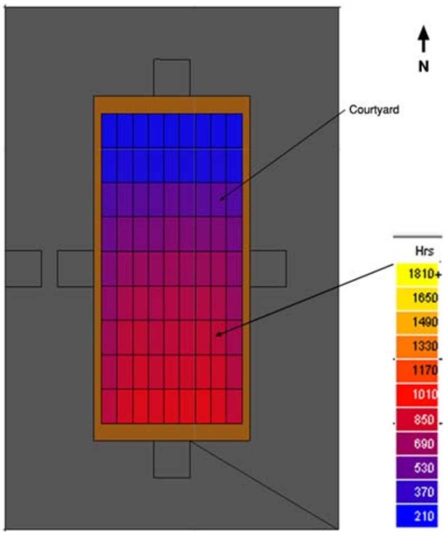


Figure 48: Total Sunlight Hours for Ground Level (of Seven Storeys) in Courtyard.

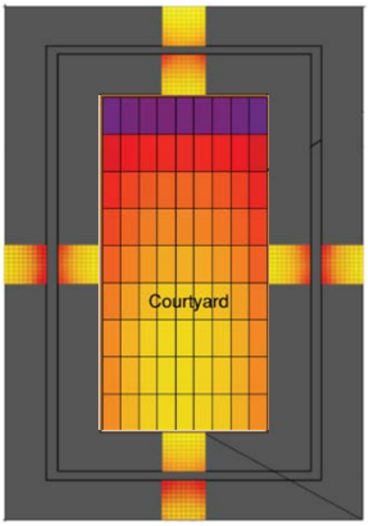


Figure 49: Total Sunlight Hours for Ground Level (of Four Storeys) in Courtyard.

The effect of four storey (17 m) instead of seven storey (29 m) buildings can readily be understood from Figure 49. It shows on the same light scale as Figure 48 the daylight in rooms and the solar access to the courtyard. Whilst the picture may show a best scenario and therefore an exaggeration of reality, there is clearly more sun in a courtyard formed by shorter buildings.

5.2.5 Summary

The results from the modelling have shown a range of effects resulting from urban form features proposed by the Central City Plan. All three features – step-backs, laneways and courtyards – have been shown to improve daylighting and reduce energy consumption requirements in a standardised central city block/building.

Figure 50 presents the overall effectiveness of each Central City Plan form feature against the baseline passive performance. This graph clearly shows the benefit courtyards, and laneways to an extent, have on passive performance.

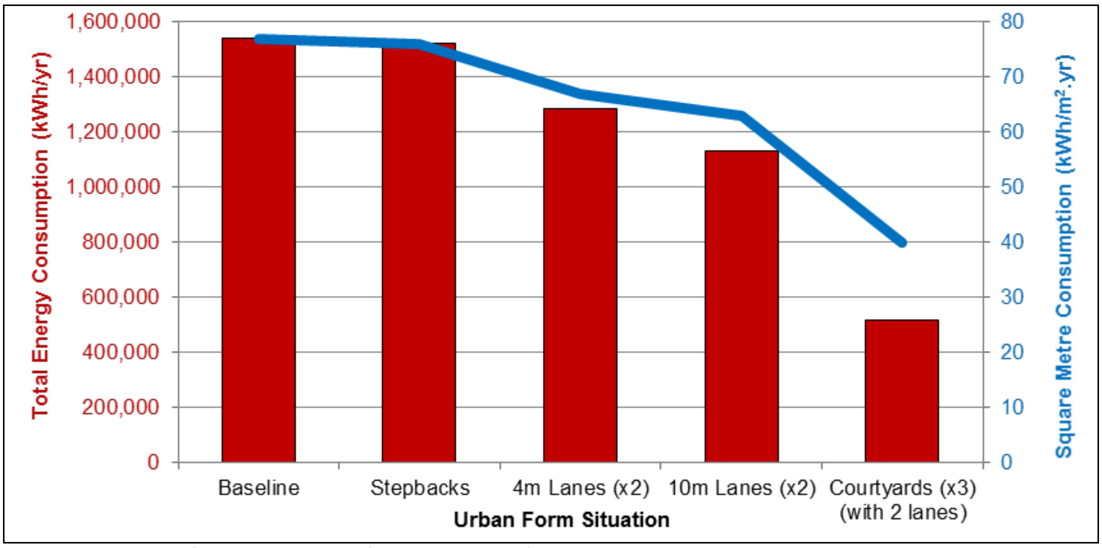


Figure 50: Overall Energy Consumption for each Urban Form against Baseline Model.

Figure 50 is also useful in gauging what influence the lost net lettable area had on energy consumption. As was reported, step-backs effectuate negligible improvement. Laneways had a bigger effect, but the most significant changes were seen through the insertion of courtyards. By breaking the large 200 x 100 m blocks/buildings into three sections with laneways, each sub-block/building containing an internal courtyard saw a substantial reduction in energy consumption. From the 1.54 million kWh/yr baseline model down to 519,000 kWh/yr, this combination of form changes implements a reduction of roughly two-thirds (66%).

Originally, each square metre of floor area consumed 76 kWh/m^2.yr. This could be minimised to just 40 kWh/m^2.yr using laneways and courtyards. This is a reduction of almost one-half (48%). The amount of floor area or net lettable area lost to achieve these energy consumption reductions was 35% (20,000 m^2 down to 13,056 m^2) or roughly one-third. If, by employing laneways and courtyards, the energy used could be reduced by roughly one-half, yet only one-third of net lettable area is lost, the rate of savings outweighs the rate of losses in terms of energy consumption per square metre.

Based on these findings, it is clear that employing more open urban forms such as courtyards in conjunction with laneways (and the seven-storey building height limit) would be highly beneficial to passive performance of Christchurch central city. For further detail on these modelling analyses, please refer to the relevant BEES Study Reports (Cory, et al., 2012a; Gates, et al., 2012; Creswell-Wells, et al., 2012).

6. ENERGY END-USES

This section uses the results from the targeted monitored premises to analyse the various ways different types of activities influence energy use and the services they obtain. In total, 101 premises were fitted with targeted monitoring equipment. Appliance and lighting audits were undertaken simultaneously, resulting in 100 appliance audits and 101 lighting audits. However, only 84 of the monitored premises had useful data available for end-use analysis.

All of the targeted monitored premises had lighting and plug load circuits, with around three-quarters having space conditioning circuits. Using the classifications developed in BEES, the end-use patterns for different activities, building use and building and premise size can be examined. The findings are as follows:

- Using the revised QV premise categories, the lighting $EnPI_{elec}$ is similar across all categories except the Retail premises, which demonstrate a higher $EnPI_{elec}$
- Using the DAC, the refrigeration end-use is mostly in the Refrigeration cluster, while the lighting end-use is consistent through all clusters. Premises with ICT clusters generally followed the one-third rule.
- Using the CPA categorisation, there is a large difference in overall electricity consumption and the proportion of refrigeration load in the Food Storage category.
- Using the building use strata, most of the refrigeration end-use appears in premises within Commercial Retail buildings, while premises within Commercial Office buildings followed the one-third rule.
- Using the building size strata, the smaller and larger strata appear to be using less total electricity by square metre, most likely because the refrigeration end-use is not dominant in these strata. However, it was found that the building size strata was an inadequate method for understanding energy consumption patterns.

Further analysis using the CPA shows that the lighting end-use group is predominant across most activities, especially in premises that are non-food based. Commercial refrigeration dominates the electricity end-uses in the Food Storage premises and in some Food Preparation & Cooking premises. The Office and Multiple Use premises display the one-third rule – one-third plug load electricity, one-third lighting electricity and one-third space conditioning and other electricity.

BEES provided a unique opportunity to explore the uses for which energy, particularly electricity, is used through the data collected by on-site targeted monitoring. The main reason for conducting the targeted monitoring was to collect information on energy end-uses and environmental data, which could only be obtained through monitoring.

The targeted monitoring was the most intensive data collection process used in BEES, with both energy and environmental monitoring taking place in the premises for a 2–4 week period. Occupant questionnaires and audits (including appliance, lighting, building, hot water, HVAC system and other energy sources) were also undertaken. The BEES targeted monitoring methodology is summarised in Appendix E.

The following analysis treats these premises as a set. There are some premises that have distinct differences from the larger set of premises and buildings recruited through the sample frame.

6.1 Targeted Monitored Premises

Data from 84 of the targeted monitored premises, located within 71 buildings across 68 building records, had electricity consumption separated into end-uses. These premises had a wide spread across the sample building use strata and building size strata, as shown in Table 24.

Table 24: Targeted Monitored Premises with End-uses Available.

Building use strata	Premise count	Building size strata	Premise count
Commercial Office (CO)	33	**S1**	18
Commercial Retail (CR)	27	**S2**	18
Commercial Other (CX)	16	**S3**	24
Industrial Services (IS)	4	**S4**	13
Industrial Warehouse (IW)	4	**S5**	11
Total	**84**	**Total**	**84**

The breakdown into end-uses was achieved by selecting separate circuits from the various distribution boards within each of the premises. It was found that, as different premises are wired in different ways, only a broad categorisation of end-uses is possible. For further detail on the monitoring at a circuit level, see Appendix E.

An overview of the end-use breakdown is shown in Table 25. The plug load end-use includes some mixed-use circuits, which may include such equipment as portable electric heaters, refrigeration and cooking units. Had this equipment been on a separate circuit, it would have been assigned to another end-use group.

Table 25: End-use Groupings and Example Components.

End-use	Example components	Description/rule
Lighting	Lights	Lighting.
Plug load	Plug loads, appliance groups	Anything that plugs into a power socket or is part of a combined fixed-wired circuit. This includes some appliances that would have been assigned to another category had they been able to be isolated. Examples of this would be plug-in refrigeration and portable electric heaters not on dedicated circuits.
Water heating	Water heating	Fixed hot water units, for example, instant hot water, hot water cylinders.
Space conditioning	HVAC, air-conditioning, air-handling unit, heat pump, heating, boiler, air-curtain, reheat	Anything used to intentionally/directly alter the thermal environment of a space. Systems may or may not be ducted
Cooking	Cooking, stove, bakery oven, oven, pie warmer	Anything used to transform food through heat.
Refrigeration	Refrigeration board total, refrigeration, chiller, fridge, food cabinet	Any commercial refrigerator or chiller that is separately hard wired. Plug-in refrigerators/chillers will be in the plug load group.
Misc.	PABX, server room, garage, central services, lift, UPS, ATM, timer, other	Residual category.
Process	Screen printing dryer, x-ray, fan, mechanical, tools, compressor, industrial, pump	Anything process or industrial oriented.

Only 10% of the targeted monitored premises had dedicated refrigeration circuits present (see Figure 51) while cooking circuits were present in twice as many premises. Around one-quarter of the premises had specialised processes present, which seems high given that only 5% of the premises were identified as Industrial Service (see Table 24). All of the monitored premises had lighting and plug load circuits, with around three-quarters having circuits for space conditioning. Water heating (64%) and miscellaneous (51%) circuits where found in more than half of the premises.

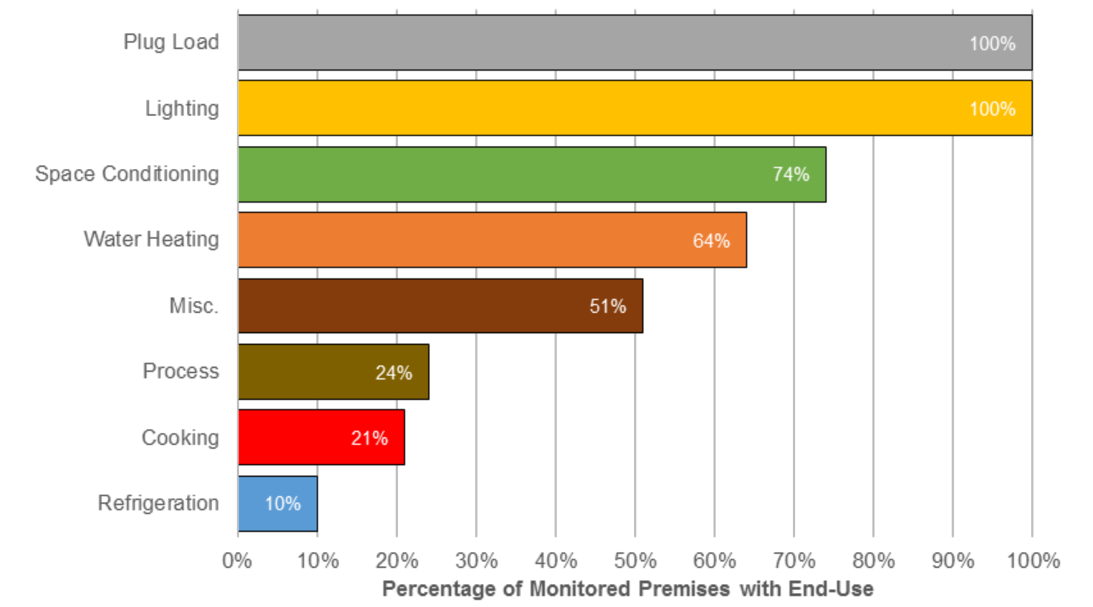


Figure 51: Presence of End-use Groupings within Premises.

The EnPI$_{elec}$ by end-uses for each premise is shown in Figure 52. Each premise is shown as a single circle. A random 'jitter' has been added to the horizontal position of each point so that overlapping points can be better distinguished. The end-uses are arranged in decreasing mean EnPI$_{elec}$ for each end-use, which are shown by a horizontal red line. The median for each end-use is consistently less than the mean and is shown with a green line. The lighting and plug load end-uses have higher average EnPI$_{elec}$ than the other end-uses, while the EnPI$_{elec}$ for the remaining end-uses tend to reduce as the proportion of premises with that end-use reduces.

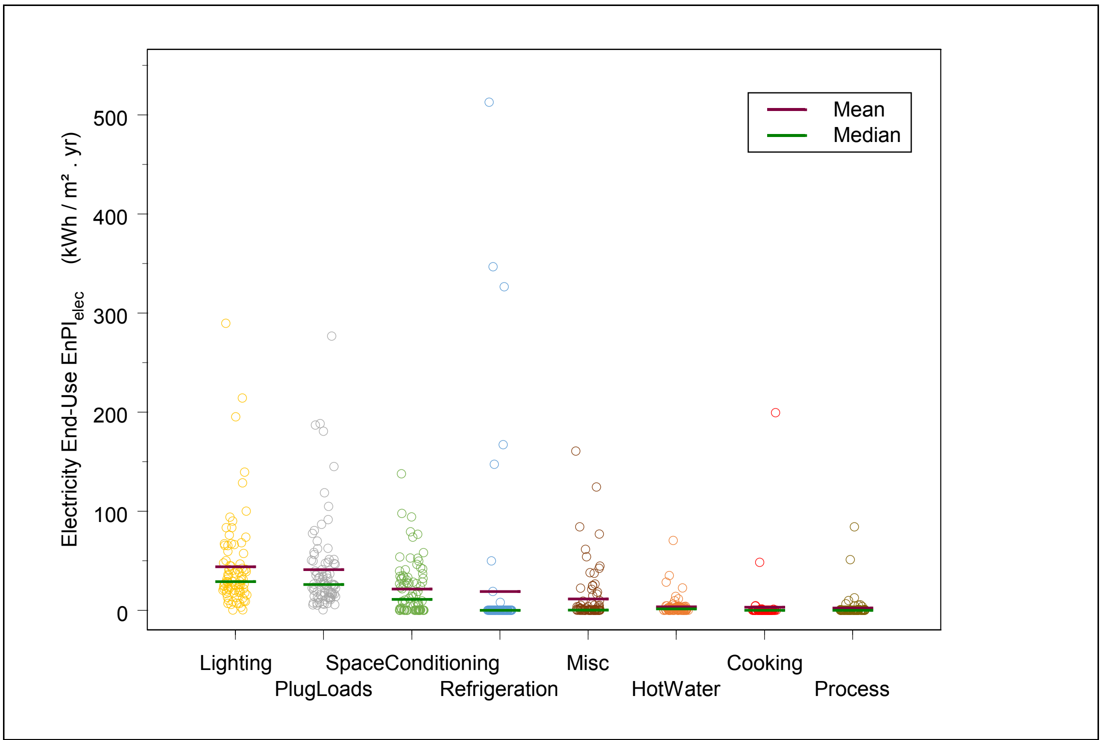


Figure 52: Dot-plot of End-uses by Premise.

The high number of zeros for the end-uses that are not usually present, such as the refrigeration and the miscellaneous end-uses, strongly affects the mean EnPI$_{elec}$ for those groups. Table 26 gives some summary statistics where only end-uses that are present are considered. The refrigeration end-use, when present, can be seen to be very large in comparison to the other end-uses.

Table 26: Summary Statistics for the End-use Groups when Present.

End-use	Count	EnPI$_{elec}$ (kWh/m^2.yr)						
		Minimum	Lower quartile	Median	Mean	Upper quartile	Maximum	Standard deviation
Lighting	84	0.13	19.7	28.9	43.8	48.2	289.5	46.3
Plug load	84	0.25	14.8	26.0	40.9	47.5	276.6	46.8
Space conditioning	62	0.09	8.0	26.7	28.9	38.7	137.6	27.3
Refrigeration	8	7.91	42.0	157.1	197.0	331.4	512.8	181.8
Miscellaneous	43	0.01	1.6	5.0	22.3	25.6	160.5	34.5
Water heating	54	0.11	1.5	2.5	5.5	3.8	70.3	11.1
Cooking	18	0.01	0.1	0.1	14.5	1.2	199.3	47.5
Process	20	0.00	0.1	0.8	9.2	5.6	84.1	20.9

The large differences between the mean and median for the end-uses suggest the distribution of the end-uses may be skewed. Histograms of the non-zero EnPI$_{elec}$ for each of the end-uses are given in Figure 53 and show that this is indeed true. The distributions had a long tail to the right indicating that many end-uses have values far in excess of typical (median) or average (mean) usage.

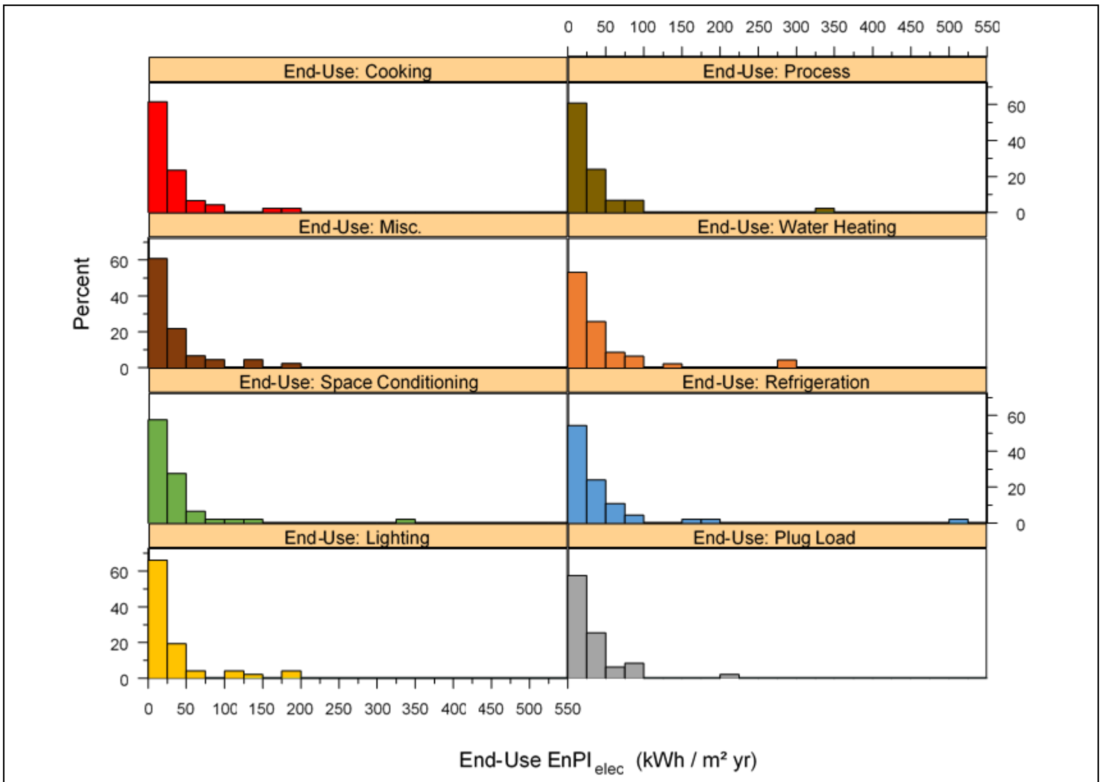


Figure 53: Non-zero EnPI$_{elec}$ by End-use Group.

6.2 Understanding Patterns of End-use

Early New Zealand research into energy use in non-residential buildings suggested that the end-use energy profile was equally split between space conditioning, lighting and computing appliances (Baird & Newsam, 1986). BEES both confirms the importance of that trio of end-uses and also found that, in many premises and consequently in many buildings, different end-use patterns exist.

In order to understand the reasons for different end-use patterns, it is important to assess the different activities, building types and building and premise sizes. As a range of different categories/strata have already been used throughout BEES, the figures below provide a comparison of the monitored electricity by end-use against some of those categorisations. The left figure in each pair provides an EnPI$_{elec}$

comparison, while the right figure gives the proportions of electricity consumption for each end-use. The numeric values at the top of each EnPI$_{elec}$ column represent the number of targeted monitored premises falling into that grouping. In a number of cases, this is a very small number.

These categories or strata have been allocated based on available data, The business activity sector (BAS) is taken from Statistics New Zealand but does not necessarily match the actual activities being carried out in that specific premise. The dominant appliance cluster (DAC), revised QV premise categories and classification of premise activities (CPA) have been developed from the BEES work. Refer to section 4 for more detailed information on categorisations.

Figure 54 and Figure 55 allocate each premise to one of six revised QV premise categories. Figure 54, on the left, gives the breakdown by EnPI$_{elec}$, and Figure 55, on the right, gives the breakdown by proportion of the premise's total electricity consumption.

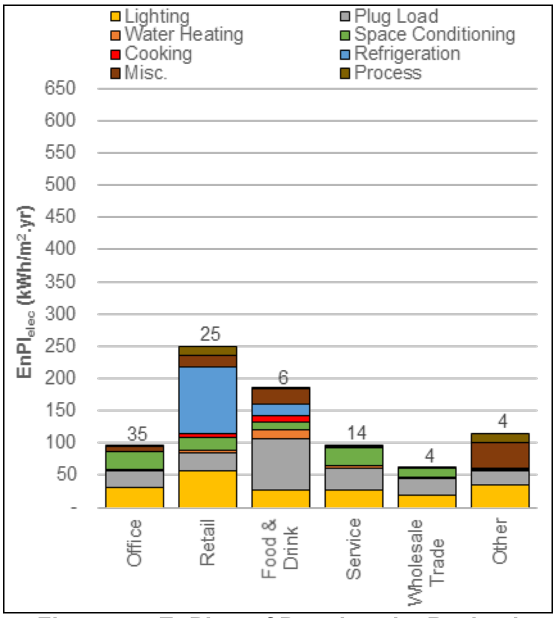


Figure 54: EnPI$_{elec}$ of Premises by Revised QV Premise Categories.

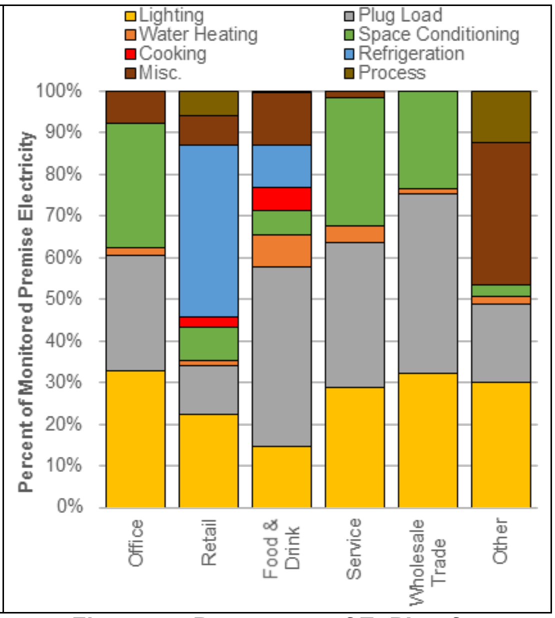


Figure 55: Percentage of EnPI$_{elec}$ for Premises by Revised QV Premise Categories.

The absolute lighting EnPI$_{elec}$ is very similar across all but the Retail premises, which is higher by intensity but lower in proportion of total EnPI$_{elec}$ although not as low as the Food & Drink category.

Next the DAC are considered. These were also derived from the telephone survey information but are based on groupings of different appliance types (see section 4.2). The rules-based assignment of appliance clusters was then applied to the non-telephone surveyed but targeted monitored premises where appliance audits existed. Figure 56 and Figure 57 show the monitored end-use breakdowns against the DAC.

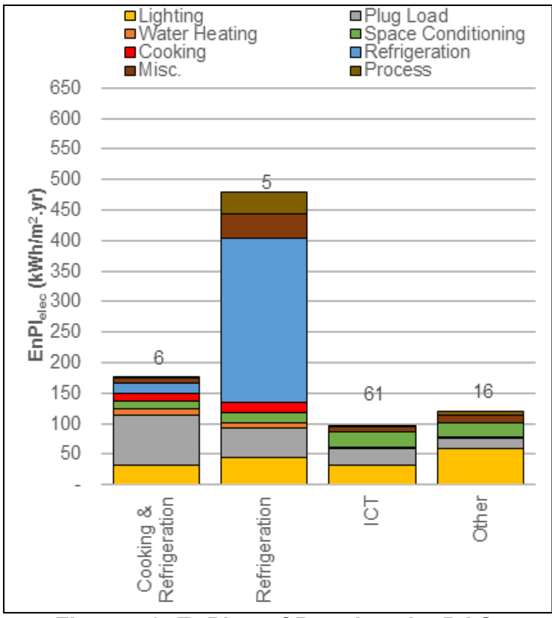


Figure 56: EnPI$_{elec}$ of Premises by DAC.

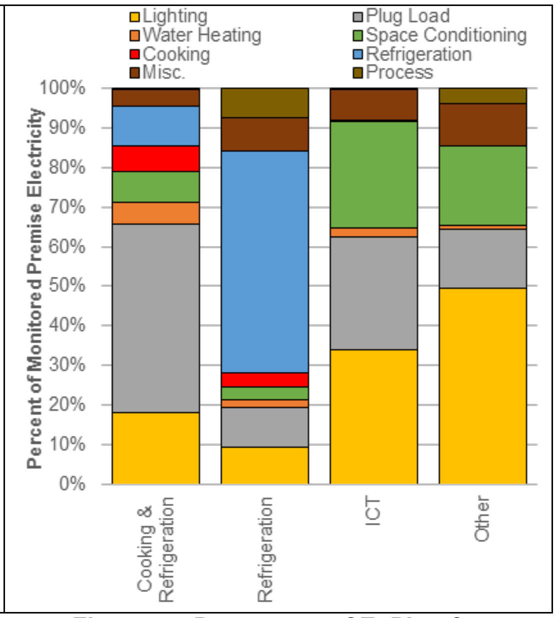


Figure 57: Percentage of EnPI$_{elec}$ for Premises by DAC.

The DAC groupings demonstrate that the Refrigeration cluster contains most of the refrigeration loads, with the remaining in the Cooking & Refrigeration cluster. Lighting EnPI$_{elec}$ appears to be fairly consistent across all categories; however, it is more highly spread when considering the total proportions. The ICT cluster appears to show the approximate one-third rule.

Figure 58 and Figure 59 below use the classification of premise activities (CPA).

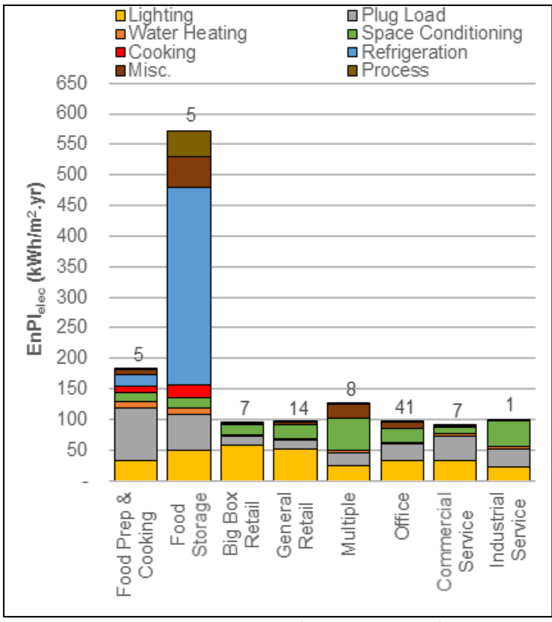


Figure 58: EnPI$_{elec}$ of Premises' CPA.

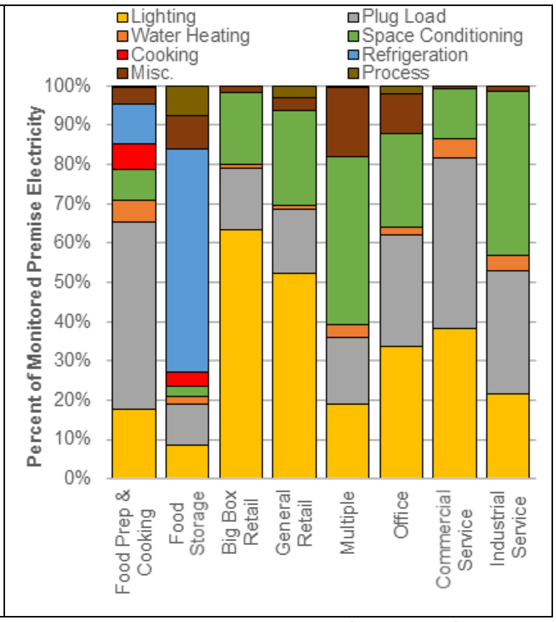


Figure 59: Percentage of EnPI$_{elec}$ for Premises by CPA.

Of interest in Figure 58 and Figure 59 is the large difference in overall electricity consumption and the proportion of refrigeration load in the Food Storage category compared to the other CPA. The Food Preparation & Cooking category also has a noticeable refrigeration EnPI$_{elec}$.

As there was only one premise monitored in the Industrial Service category in the CPA classification, it has been transferred to the Multiple Use category for the following analyses.

Using the CPA, the next charts separate out the food-based activities (Food Preparation & Cooking and Food Storage) from the remaining non-food activities (Big Box Retail, General Retail, Multiple Use, Office and Commercial Service). The premise floor area thirds used in Figure 60 and Figure 61 were determined using all premises within the participation sample.

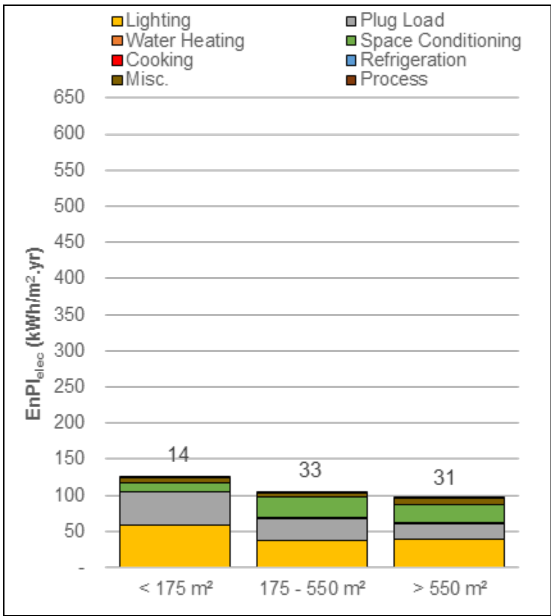


Figure 60: $EnPI_{elec}$ of Non-food-based Premises by Premise Floor Area.

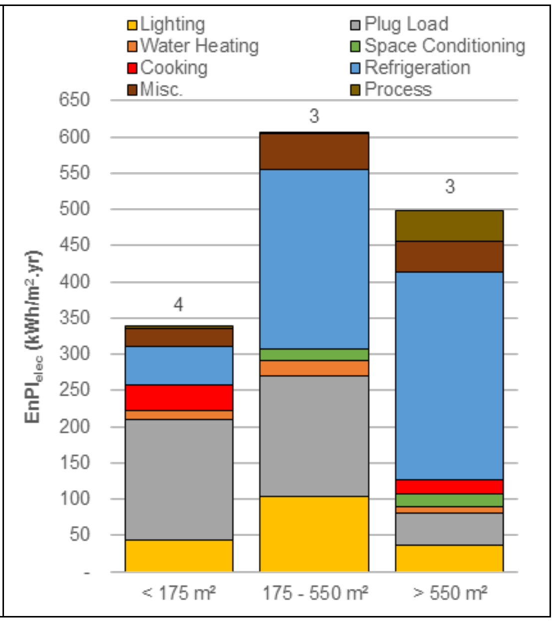


Figure 61: $EnPI_{elec}$ Food-based Premises by Premise Floor Area.

The difference between Figure 60 and Figure 61 is primarily the increased overall $EnPI_{elec}$ for the food-based premises across all premise size ranges, while the presence of space conditioning is much lower in the food-based premises than the non-food-based categories. It can also be seen that, within the non-food-based categories, the smallest premises by floor area had the larger $EnPI_{elec}$ and larger proportion of plug loads in contrast to the other categories.

The next figures still only use the premise electricity data but are shown using a number of building groupings, some of which have been used previously in BEES.

Figure 62 and Figure 63 divide the premises by building use strata (refer Table 4).

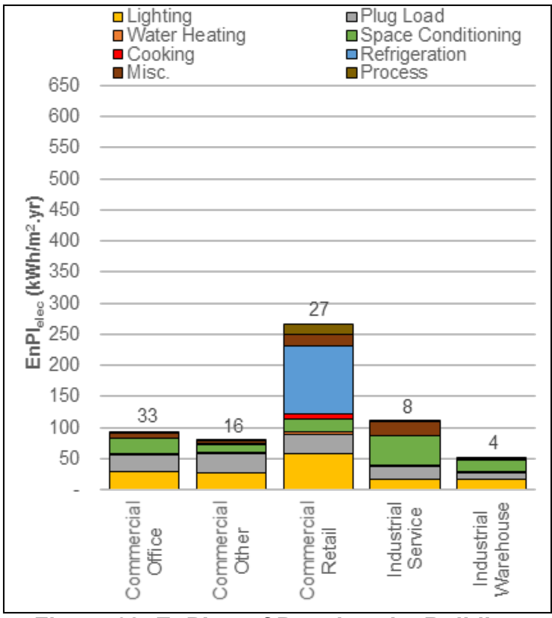


Figure 62: $EnPI_{elec}$ of Premises by Building Use Strata.

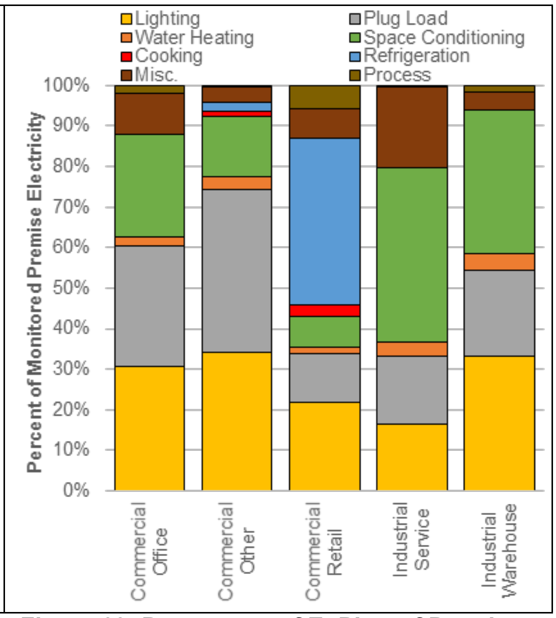


Figure 63: Percentage of $EnPI_{elec}$ of Premises by Building Use Strata.

The majority of the refrigeration loads are within the premises within Commercial Retail buildings, with a very small amount also appearing in premises within Commercial Other buildings. Again, the premises within the Commercial Office category seem to follow the one-third rule.

Figure 64 and Figure 65 are based on the building size strata established within the BEES sample frame.

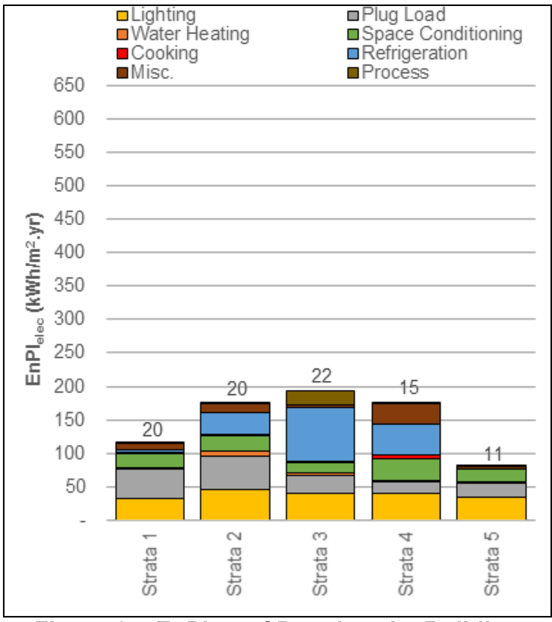


Figure 64: $EnPI_{elec}$ of Premises by Building Size Strata.

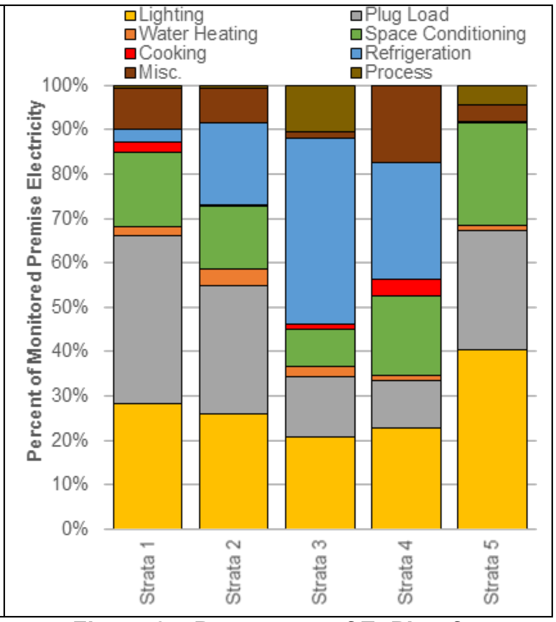


Figure 65: Percentage of $EnPI_{elec}$ for Premises by Building Size Strata.

Figure 64 and Figure 65 show a wide spread of premise activities and/or end-uses across all building size strata. The smaller and larger building size strata appear to be using less total electricity per unit area, primarily due to the absence of refrigeration, which indicates that the bigger building size strata are less likely to contain Food Preparation & Cooking or Food Storage premise activities. It is clear that the building size strata are inadequate as a basis for understanding energy consumption – information is also required on the activities being carried out within the premises and/or building.

Figure 66 shows the $EnPI_{elec}$ for the non-food-based premises (Big Box Retail, General Retail, Multiple Use, Office and Commercial Service), and Figure 67 shows the $EnPI_{elec}$ for the food premises (Food Preparation & Cooking and Food Storage), grouped by building floor area. Note that, in Figure 60 and Figure 61, this was grouped by premise floor area. The building floor area differs from building size strata by the fact that the building floor area is the measured building floor area as opposed to the sampled size from the building record information (which in turn was based on the valuation record). Note that there are no Food Preparation & Cooking/Food Storage premises in the over 4,948 m² buildings.

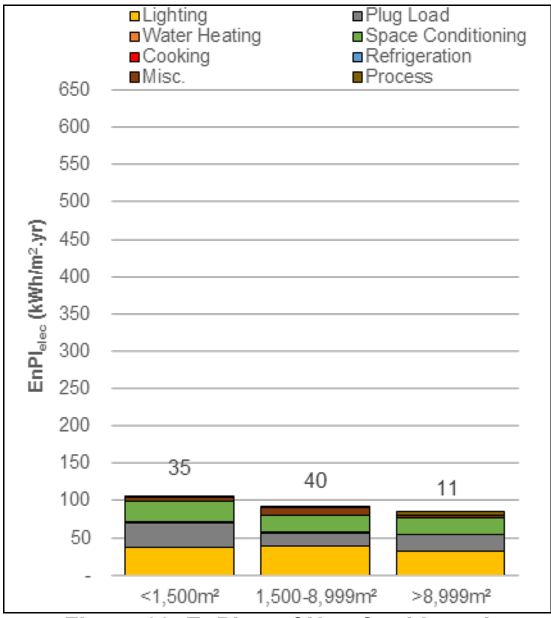


Figure 66: $EnPI_{elec}$ of Non-food-based Premises by Building Floor Area.

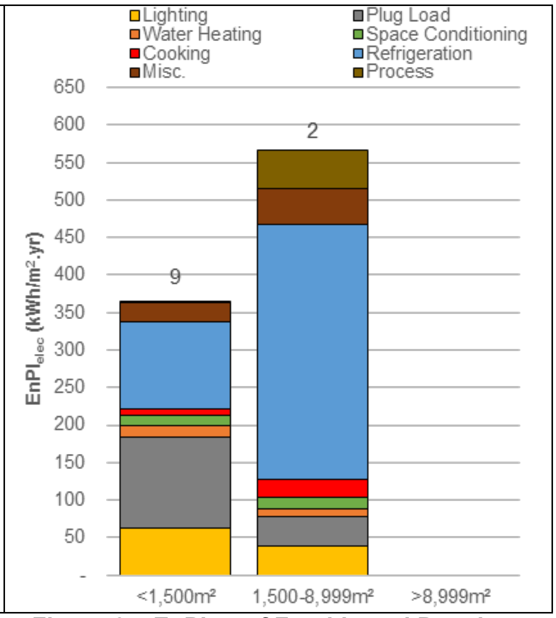


Figure 67: $EnPI_{elec}$ of Food-based Premises by Building Floor Area.

The Food Preparation & Cooking and Food Storage premises in the middle group are larger supermarkets. Lighting $EnPI_{elec}$ is much lower for the food-based premises than the non-food-based premises. The $EnPI_{elec}$ across the non-food-based building floor area groupings are very consistent, ranging from an average of 91.5 kWh/m².yr in the middle building size grouping to an average of 115.5 kWh/m².yr in the smallest building floor area grouping, while the largest building floor area grouping uses 100.6 kWh/m².yr.

The above set of 14 charts show that the one-third rule is appropriate in non-food-based premises, except those with a very small premise floor area. However, in the Food Preparation & Cooking and Food Storage premises, the presence of refrigeration and cooking end-uses significantly impacts on the overall electricity usage per square metre, demonstrating the need for these two categories to be considered independently for patterns of electricity and/or individual end-use consumption.

The different premise activity classifications demonstrate that analysis based solely on floor area is not as useful as classifications that discriminate electricity end-uses and activities, such as the CPA. Therefore, CPA has been applied throughout the following end-uses analysis.

Figure 68 and Figure 69 are a series of grouped pie charts showing the breakdowns of the grouped end-uses by premise and building floor area, respectively, against the premise activity as a proportion of $EnPI_{elec}$ for each targeted monitored premise. The numbers above each pie chart give the number of premises from which the data has been taken. In some cases, the number of monitored premises is too small to provide a detailed pie chart breakdown of energy uses.

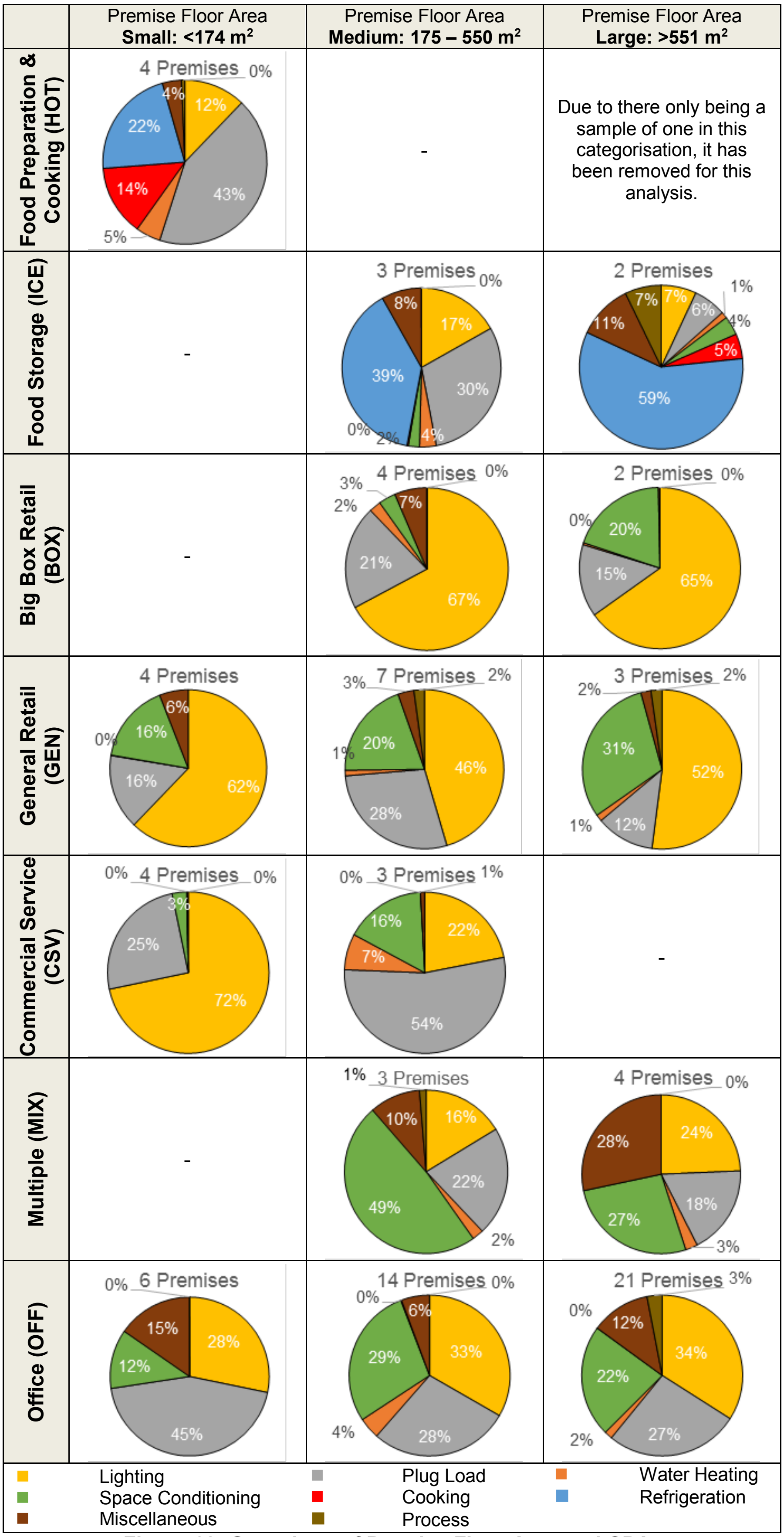


Figure 68: Groupings of Premise Floor Area and CPA.

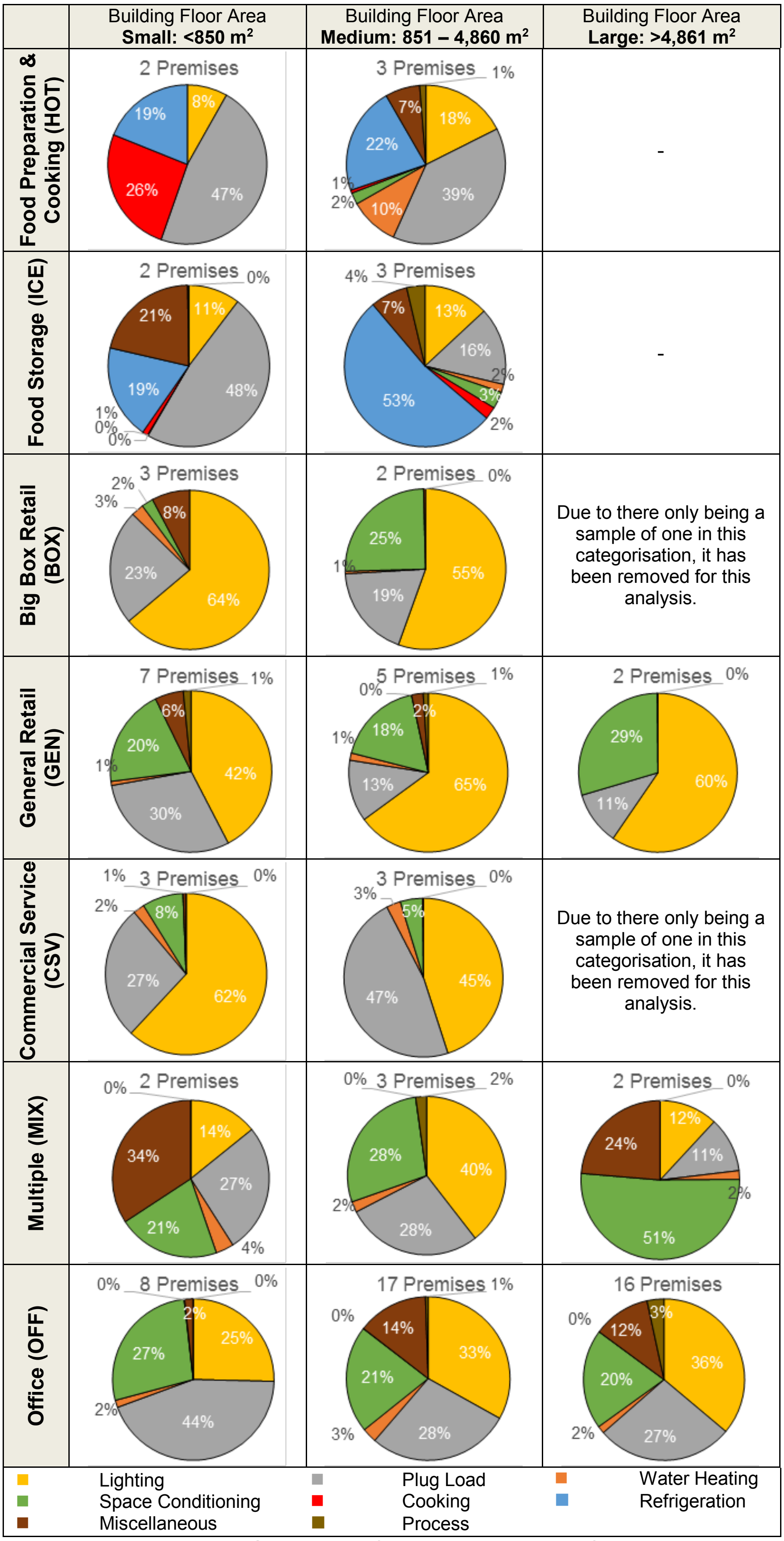


Figure 69: Groupings of Building Floor Area CPA.

Overall, the Food Preparation & Cooking and Food Storage premises appear to have a high proportion of plug loads as opposed to cooking end-uses. This may be due to the number of cooking end-uses that are not circuit wired (i.e. temporarily plugged in through a wall socket) and therefore will be included in the plug load end-use group. The plug loads in the Big Box Retail and General Retail premises do not appear to be large and generally would only include a small number of components. The Commercial Service, Multiple Use and Office premises appear to have a much higher plug load presence, all having it account for approximately one-third of the electricity use.

The lighting load appears to be very important in the General Retail, Big Box Retail and Commercial Service premises, which display a higher proportion of lighting by $EnPI_{elec}$. Within the Food Preparation & Cooking and Food Storage premises, lighting seems somewhat unimportant as a focal point for improving resource efficiency. In the remaining Office and Multiple Use premises, lighting appears to be approximately one-third of the monitored electricity consumption.

Premise level space conditioning appears to be the most prevalent in the Office and Multiple Use premises and a smaller portion in the General Retail premises, and the $EnPI_{elec}$ does not necessarily increase with premise or building floor area. Based on the monitoring results, space conditioning is largely absent from the Food Preparation & Cooking and Food Storage premises. A possible reason for this may be that a portion of the space conditioning end-use was included on the refrigeration circuits.

Two of the monitored Food Storage premises are supermarkets, displaying very intense refrigeration use, and fall within the large or medium building size. Refrigeration does not appear in any other CPA, other than in Food Preparation & Cooking premises. Cooking end-use is also a distinguishing factor in these categories, which only appears in the Food Preparation & Cooking and Food Storage premises. It is noted that refrigeration and cooking end-uses may be present in most premises but are only used for employees' personal use as opposed to business operational purposes.

The miscellaneous and process end-uses are quite widely spread over all classifications and groupings, while water heating is generally very consistent across all groupings but is very small in contrast to the other end-uses. However, this may be due to some buildings' reticulation systems having central water heating plant, which may not necessarily be picked up within the premise level monitoring and walkthrough audits.

It is able to be concluded that lighting is very important across most activities, especially those premises with non-food retail activities. 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 approximate one-third rule previously discussed, with one-third lighting electricity, one-third plug load electricity and one-third space conditioning and other electricity, which is consistent across both the premise and building size groupings as shown in both Figure 68 and Figure 69.

7. KEY END-USES

Three end-uses have been identified as having notably and consistently higher electricity performance indicators ($EnPI_{elec}$) and proportions. These are plug loads (whereby only the appliances will be assessed), lighting and space conditioning. This section details the range of energy end-uses found in the on-site targeted monitoring for these three end-uses. Detailed performance data is provided for a number of selected premises that have had targeted monitoring undertaken.

Analysis of end-use data has allowed appliance, lighting and space conditioning electricity use to be quantified for the various appliances in the monitored premises. The analysis provides a better understanding of the opportunities to improve electricity efficiency. Energy auditing and building energy modelling are two areas where this type of information can be immediately applied.

Across the 100 monitored premises that had an appliance audit done, the three appliance grouping that appears in at least 90% of the audited premises were hot water, computer and heating and cooling. Some premises relied heavily on office equipment with high penetrations of desktop and laptop computers, printers and copiers and other computer-related equipment. Most audited premises had limited kitchen facilities for staff use.

Through the 101 monitored premises that had a lighting audit, fluorescent lamps were the dominant lamp type, being found within 98% of all audited premises, with an average of 227 lamps per premise. However, fluorescent lamps were generally not the only lamp type found in each premise. In some General Retail and Office premises, up to six different lamp types were recorded.

Central HVAC systems were most prevalent in the larger-sized premises. However, as the premise size decreased, the prevalent source of heating and cooling became electric heat pumps. Only in premises within S1 and S2 buildings were simple electric resistance heaters the primary source of heating.

Electricity was the main source of heating, regardless of premise size. Gas (whether fixed or portable heaters) was only used in S1 to S3 buildings (only in 17% of these premises). The maximum number of heating types was five (central HVAC, fixed electric, portable electric, portable electric fans and portable gas heaters). This was found in a premise within an S2 building in a small rural town. Although the proportion of premises with only one heating type was similar across all five strata, the number of heating types increased as the building size strata increased. It was found that, in some premises that had a central HVAC system, there was still a wide range of supplementary heaters present.

7.1 Plug Loads

Plug loads on average, range between 21% and 56% of the total estimated annual electricity use, based on end-use monitoring across the classification of premise activities (CPA). It is notably higher in the Food Preparation & Cooking and Commercial Service premises and much lower in the General Retail and Multiple Use premises.

The appliance assessment uses data from appliance audits on 100 premises (refer to Figure 1). The audit involved taking an inventory of all appliance stock on the site visit walkthrough. For a subsample of these appliances, high-resolution electricity consumption data was recorded over a 2–4 week monitoring period. These individually monitored appliances were randomly selected from the initial auditing process. For further information on the monitoring methods, see Appendix E.

7.1.1 Appliance Inventory

Through the appliance audit process, a list of 77 individual appliance types was developed, recording everything plugged in as an individual appliance. This excluded ducted HVAC, large circuit-wired end-uses (for example, refrigeration), domestic hot water, lighting and other central services.

These appliance types were then assembled into 33 appliance groups for further analysis. The appliance groups were then compared with the 12 equipment count responses from the telephone survey, as shown in Table 27 and Figure 70.

Table 27: Appliance Types and Appliance Groupings.

Telephone survey (12 components)	Appliance group (33 groups)	Appliance type (77 appliances)
Computer	Computer	Desktop computer, laptop computer, mini-computer, mainframe computer, iMac, docking station
	Monitor	CRT monitor, LCD monitor
Printer	Printer	Desktop printer
Server	Server	Server
Photocopier	Copier	Desktop copier, floor copier, large production copier
Stand-alone fax	Fax	Fax machine
Projector	Projector	Projector
Whiteboard	Whiteboard	Electric whiteboard
Cooktop or oven	Cooking	Oven, hob, range, grill, range hood, deep fryer
Microwave	Microwave	Microwave
Refrigerator	Residential refrigeration	Residential fridge, residential fridge/freezer
	Commercial refrigeration	Residential type freezer, commercial refrigeration, commercial refrigeration, commercial freezer, walk-in fridge or freezer
Water cooler	Water cooler	Water cooler
Dishwasher	Residential dishwasher	Residential dishwasher
	Commercial dishwasher	Commercial dishwasher
(Not specifically asked)	Security system	Security system
	UPS	UPS
	Computer networking	Ethernet/wireless/router, telephone system
	Stereo	Stereo/radio, PA sound system
	Television	Small TV, large TV, DVD, VCR or similar, video game
	Payment	Checkout conveyor, cash register, EFTPOS
	Vending	Non-refrigeration vending, refrigerated vending
	ATM	ATM
	Miscellaneous retail	Advertising display, digital photo console
	Heating and cooling	Portable electric heater, dehumidifier, heat pump/air-conditioner, fan, fixed electric heater
	Food handling	Cold food handling, food warmer
	Hot water	Boiling water unit, jug, coffee maker, coffee machine
	Small kitchen appliance	Toaster, sandwich press, etc.
	Vacuum cleaner	Vacuum cleaner
	Laundry	Residential washing machine, commercial washing machine, residential dryer, commercial dryer
	Hand dryer	Hand dryer
	Power tools	Powered hand tools, powered tools
	Miscellaneous appliance	Charger/power adapter, large equipment, miscellaneous small appliance, miscellaneous large appliance

The appliance audit information from targeted monitoring may differ slightly from the telephone survey information. The telephone survey asked about the whole premise in which the subject business occupied, while if the targeted monitoring premise occupied multiple floors, then one or two floors that would be considered to be representative of the whole premise were surveyed

Figure 70 gives the recorded differences between the appliance audit information and the telephone survey appliance densities, as a percentage. The blue, positive bars indicate that the appliance audit information had a higher stock count than the telephone survey, while the red, negative bars indicate that the telephone survey had a higher stock count than the appliance audit information.

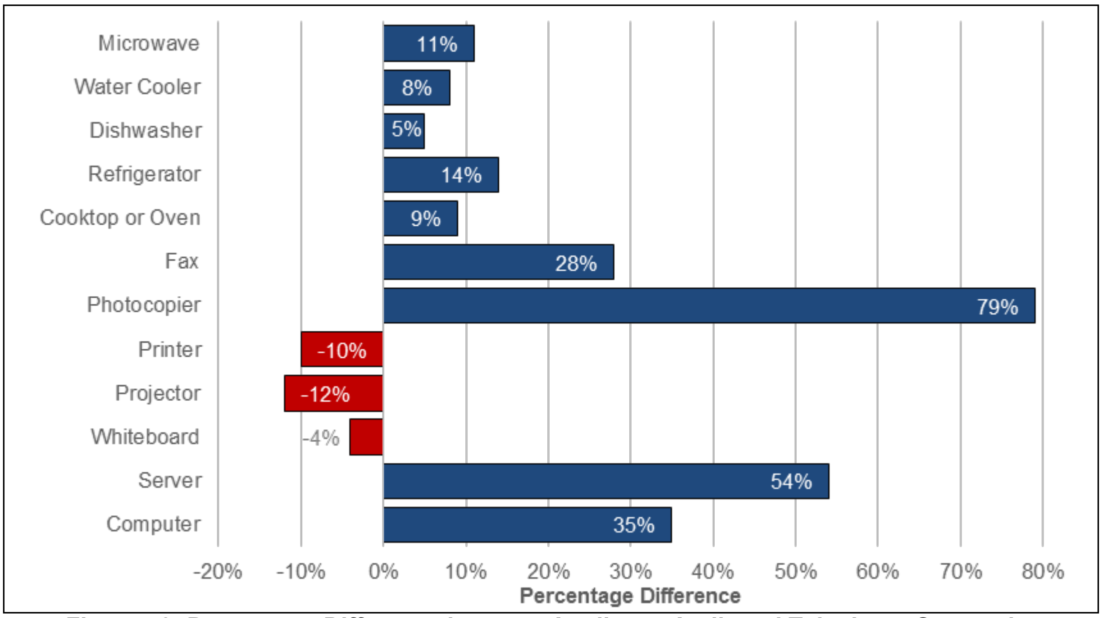


Figure 70: Percentage Difference between Appliance Audit and Telephone Survey, by Appliance Density.

Figure 70 above demonstrates a wide variation between the appliance groups from the appliance audit information and the appliance count responses from the telephone survey. For example, the appliance audit information reported 35% more computers than the telephone survey information did on average.

It should be noted here that, while the telephone survey asked for the count of printers, photocopiers and fax machines individually, in the modern office, it can be expected that many of these will be multi-function devices that are able to undertake all three tasks from the one machine, which, in the appliance audit, have been counted as being in the desktop printer or copier grouping.

Even given these possible differences, Figure 70 demonstrates that, while useful, the participant-reported information was not necessarily always accurate.

For stock and energy modelling, the appliance penetration, average count and density, or count per 1,000 m^2, were the primary parameters of interest, as given in Table 28:

- Penetration was defined as the percentage of premises that have a given appliance.
- Average count by premise was defined as the average number of a given appliance for those premises that have that appliance.
- Density, or average count per 1,000 m^2, was defined as the average number of a given appliance per 1,000 m^2 of aggregate floor area (not calculated per premise).
- Density, or average count per 1,000 m^2 appliance present, was defined as the average number of given appliance per 1,000 m^2 of the premise floor area where the appliance was present (not calculated per premise).

The penetration, average count and density, or count per 1,000 m^2, of appliances was estimated at a premise level and not a building level, as in most cases, there were several premises in a building with different activities, such as a restaurant and an office.

Table 28: Appliance Group Penetration.

	Number of appliances per premise								Penetration	Average count by premise	Average count per 1,000 m^2	
Appliance group	1	2	3	4	5	6–10	11–20	21+			All premises	Appliance present
Hot water	34	25	16	15	3	5	-	-	98%	2.5	3.37	3.40
Miscellaneous appliance	8	9	11	7	2	13	24	19	93%	13.8	17.5	18.8
Computer	10	9	5	6	3	13	14	32	92%	26.0	33.3	33.6
Heating and cooling	11	8	8	7	8	20	17	11	90%	9.9	12.4	12.7
Residential refrigeration	47	16	14	5	3	3	-	-	88%	2.0	2.44	2.56
Microwave	56	16	9	-	4	2	-	-	87%	1.7	2.06	2.19
Stereo	38	22	10	7	2	7	-	-	86%	2.3	2.79	3.26
Computer networking	38	27	5	1	4	1	-	3	79%	3.7	4.03	4.98
Copier	26	14	12	6	4	10	5	1	78%	3.8	4.14	4.49
Monitor	6	4	3	4	4	12	18	25	76%	26.8	28.3	31.3
Small kitchen appliance	19	18	15	4	5	9	2	-	72%	3.3	3.29	3.91
Printer	16	9	8	7	4	12	4	1	61%	4.5	3.84	6.14
Television	20	8	13	8	2	4	5	1	61%	4.1	3.41	4.35
Vacuum cleaner	42	8	4	3	-	2	-	-	59%	1.6	1.32	2.56
Security system	50	4	1	-	-	-	1	-	56%	1.3	1.02	1.84
Fax	44	6	4	-	-	1	-	-	55%	1.4	1.03	1.74
Payment	22	11	5	7	1	4	1	4	55%	4.4	3.33	6.45
Water cooler	35	12	2	-	1	1	-	-	51%	1.5	1.06	1.42
Server	29	11	2	2	1	3	-	1	49%	2.9	1.98	3.20
Cooking	19	8	4	2	1	7	1	-	42%	2.8	1.63	3.23
Residential dishwasher	24	8	1	1	-	-	-	-	34%	1.4	0.65	1.19
Commercial refrigeration	7	6	1	1	3	7	3	1	29%	6.8	2.76	7.79
UPS	23	2	1	2	1	-	-	-	29%	1.5	0.60	1.13
Power tool	10	5	1	2	-	5	5	-	28%	4.7	1.84	5.01
Projector	12	8	2	-	1	-	-	-	23%	1.7	0.54	1.37
Vending	13	4	2	-	1	2	-	-	22%	2.2	0.67	1.76
Whiteboard	8	4	3	2	-	4	-	-	21%	3.0	0.89	2.37
Miscellaneous retail	7	4	3	3	-	1	-	-	18%	2.4	0.60	3.55
Commercial dishwasher	13	3	-	-	-	-	-	-	16%	1.2	0.26	1.03
Food handling	8	2	1	-	-	2	1	1	15%	5.7	1.20	7.07
Hand dryer	2	3	2	4	-	2	-	-	13%	3.2	0.58	2.45
Laundry	3	3	-	3	1	-	-	-	10%	2.6	0.36	3.29
ATM	5	-	-	-	-	-	-	-	5%	1.0	0.07	0.69

Note: - = 0

Figure 71 displays the penetration of appliances across premises. Across almost all of the targeted monitored premises, three appliance groupings were present at least 90% of the time – hot water, computer and heating and cooling. The miscellaneous appliance group covers a large range of appliances and cannot be considered a true category (refer to Table 27 for the different appliance types that fit under this category).

The heating and cooling group appears in 90% of the monitored premises – in some cases as the primary means of heating and cooling – but is also found in premises with ducted HVAC systems. Fans and portable heaters could be viewed as personal comfort appliances and might be used either if there was no other heating or cooling system or if the main heating and/or cooling system was inadequate. Anecdotally, the presence of fans or portable heaters in a fully space conditioned building could be an indicator of comfort issues for some occupants – they were often found in rooms where the occupants informally expressed their dissatisfaction to the BEES team during the audits (refer to section 7.3).

The more operation-specific appliances, such as commercial dishwashers or food handling equipment, were less likely to have a high penetration rate. However, if separated into premise activity, these penetration rates can differ quite dramatically. Please refer to Appendix E for more detail on these breakdowns by activity.

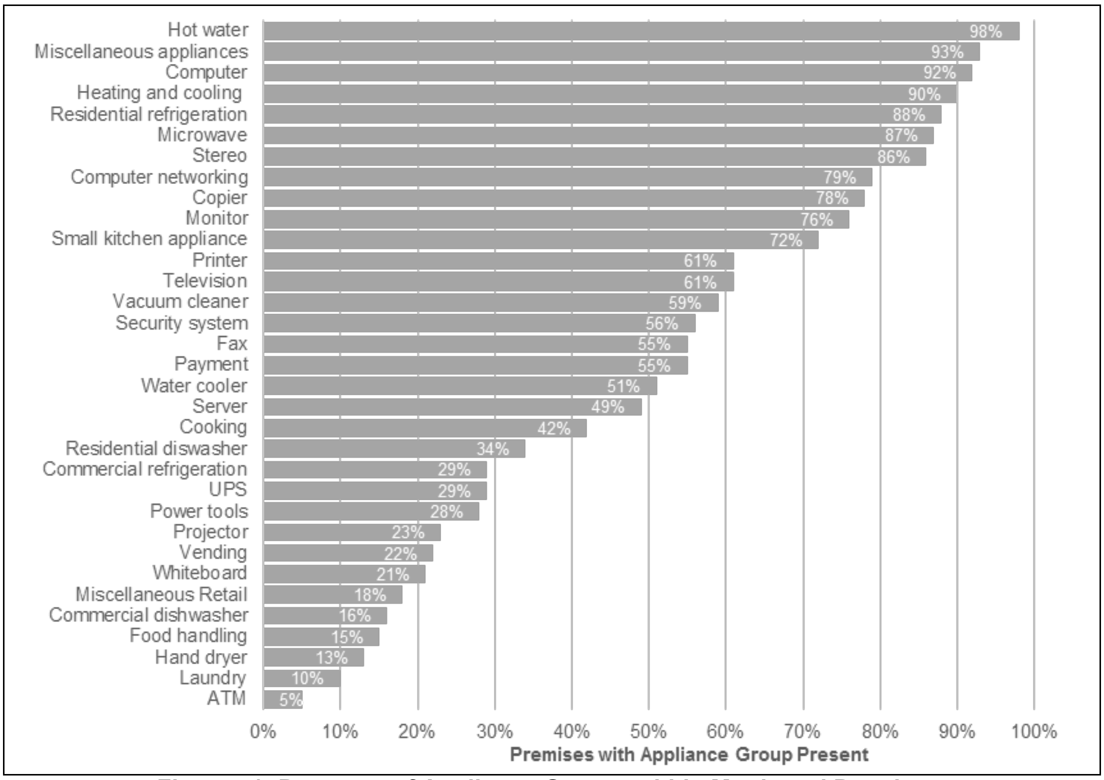


Figure 71: Presence of Appliance Groups within Monitored Premises.

7.1.2 Appliance Types

The appliance auditing resulted in a total of 77 appliance types, as listed in Table 27. Some businesses relied heavily on office equipment with a high penetration of desktop computers (85%) and/or laptops (52%), desktop printers (61%) and/or copiers (78%) and other computer-related equipment.

Most premises had limited kitchen facilities for staff use, typically with a residential refrigerator (88%), microwave (87%), electric jug (65%) and/or boiling water unit (64%). Some premises had kitchen appliances such as a coffee maker (24%), toaster and kitchen range.

Within the heating and cooling appliance group, heat pumps (either a single or multiple split-system air-conditioner) had the second highest penetration at 61%, using an average of 4.7 heat pumps per premise, followed by portable electric heaters at 55%. (Note that ducted HVAC systems were not included in this table.) Fixed electric heaters had a low presence (16%) and appeared to be in the process of being replaced by heat pumps, whereby many of the older distribution boards still had labelling for fixed electric heaters, complete with timers and control gear. Often these circuits were used for newly installed heat pumps, with timers and control bypassed. Fans were the most common, with a penetration of 63%.

The targeted monitoring collected energy data from over 220 individual appliances for the 2–4 week monitoring period. Figure 72 shows a dot-plot of the annual electricity use for 31 different types of monitored appliances. The vertical scale was broken at 2,500 kWh/yr to show the detail of the majority of appliance while still including the four commercial refrigerator units that were using in excess of 3,000 kWh/yr.

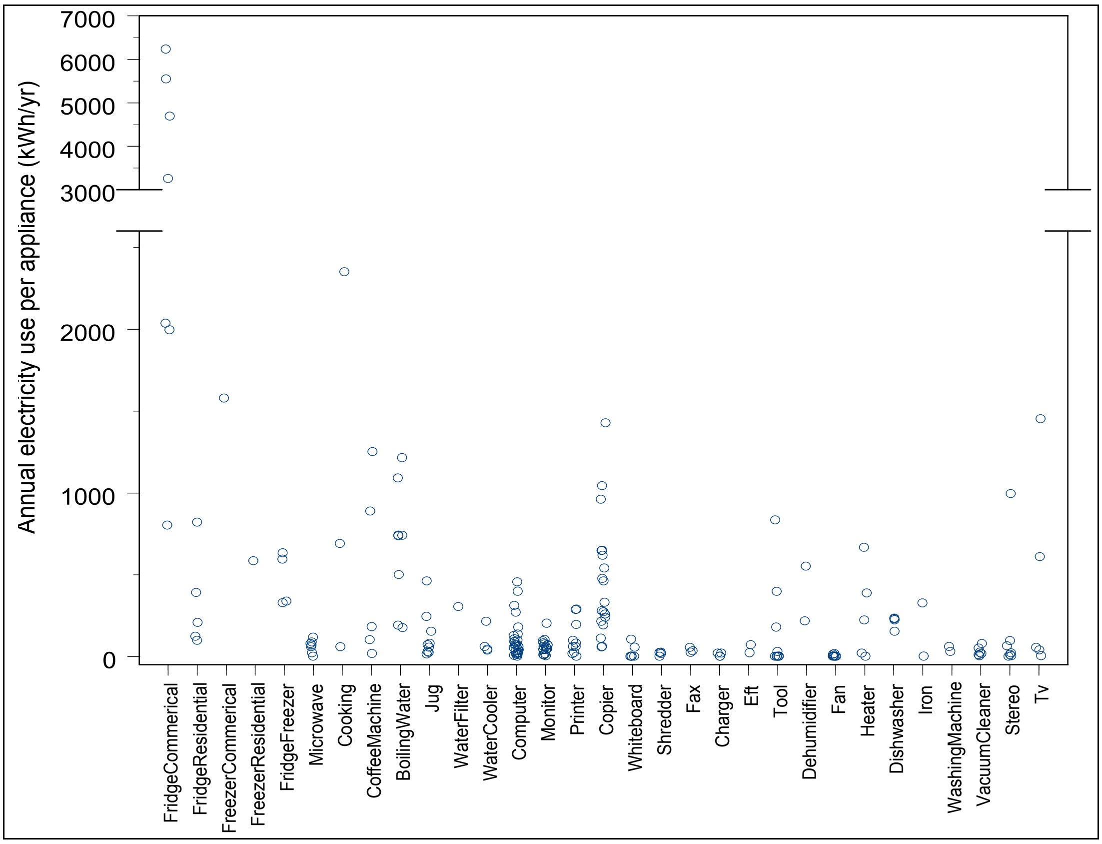


Figure 72: Estimated Annual Electricity Use per Monitored Appliance, by Appliance Type.

While many appliance types only had a few individual appliances recorded, some had multiple appliances recorded. In particular, within the office equipment (computer, copier, monitor and printer), many appliances were recorded. The distribution of the appliance types, like the distribution of the end-uses, shows a skewed distribution with many values higher than the median. The range from highest to lowest energy use for an appliance group can be high but is perhaps more influenced by a very low value as to a very large value (for example, the difference in electricity usage for the stereo for the highest to lowest is over 50,000 times). The copiers appear to be well spread, but the high value of the lowest electricity use of copier means the range for copiers is 25 times less than the range for printers, which span a range from highest to lowest energy use of over 4,500 times.

7.2 Lighting

Lighting as an end-use ranges between 10% and 55% of the total estimated annual electricity across the eight premise activity groupings. Lighting is especially higher in General Retail and Big Box Retail premises and much lower in the Food Preparation & Cooking and Food Storage premises, as demonstrated in the pie charts in Figure 68 and Figure 69.

Lighting audits were undertaken on 101 premises. The lighting audits involved a walkthrough audit taking an inventory of all installed and operable lamps and luminaires. Information was also collected on the installed capacity for each of the lamps and luminaires. As well as the physical lighting information, interior illuminance levels were also monitored for a 2–4 week period.

7.2.1 Lamp Inventory

The lamps were divided into nine lamp types as listed in Table 29, which also gives the penetration or presence of differing lamp types. Table 29 shows the dominance of fluorescent (F) lamp types, with 98% of all audited premises containing this lamp type, with an average of 227 fluorescent (F) lamps per premise. Compact fluorescent lamp (CFL) types were also found in 59% of the premises, with an average count of 30 lamps per premise.

Table 29: Estimation of Lamp Stock per Premise.

Lamp type		Premises with lamp type	Penetration	Percent of total count	Average count	Average count per 1,000 m^2	
						All premises	Lamp type present
F	Fluorescent	99	98%	30%	227	308	310
CFL	Compact fluorescent	60	59%	18%	30	24.6	36.4
H	Halogen	59	58%	18%	49	39.8	53.5
I	Incandescent	52	51%	16%	6	4.23	8.93
IR	Incandescent reflector	24	24%	7%	12	3.96	18.0
MH	Metal halide	14	14%	4%	28	5.37	20.4
O	Other	13	13%	4%	15	2.79	15.1
IP	Incandescent PAR	4	4%	1%	12	0.41	5.74
LED	Light-emitting diode	2	2%	1%	27	0.74	17.1

However, fluorescent (F) lamp types were generally not the only lamp type found in each premise. They were typically found in combinations with one or more other lamp types. Figure 73 shows the number of different lamp types by premise activity. In some General Retail and Office premises, up to six different lamp types were recorded during the walkthrough lighting audits.

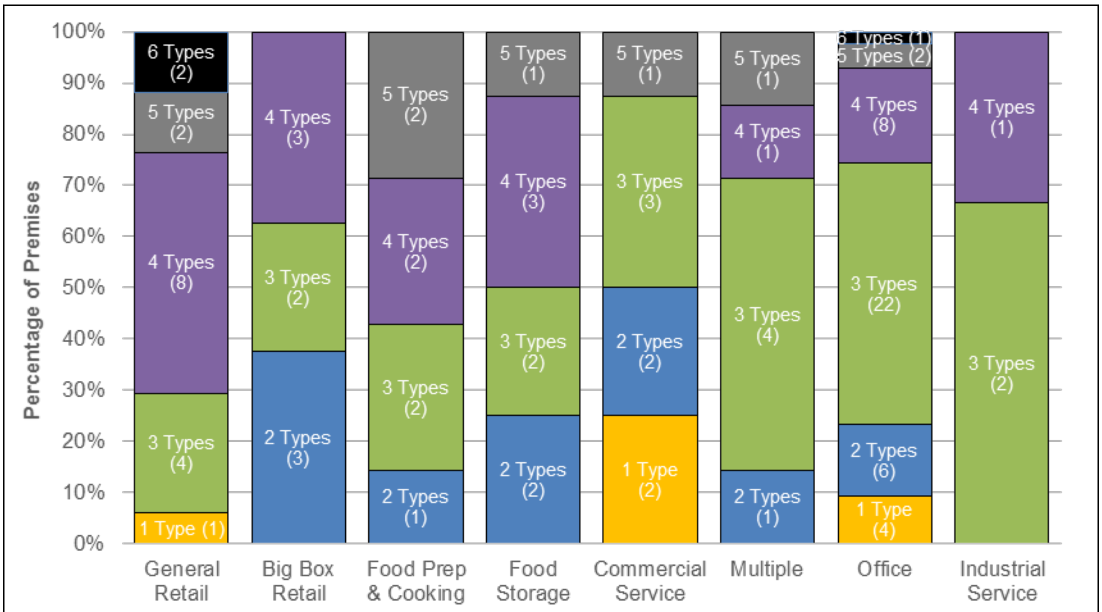


Figure 73: Number of Lamp Types, by CPA.

Taking these numbers, Figure 74 is a column chart showing the various lamp type combinations found in the lighting audits.

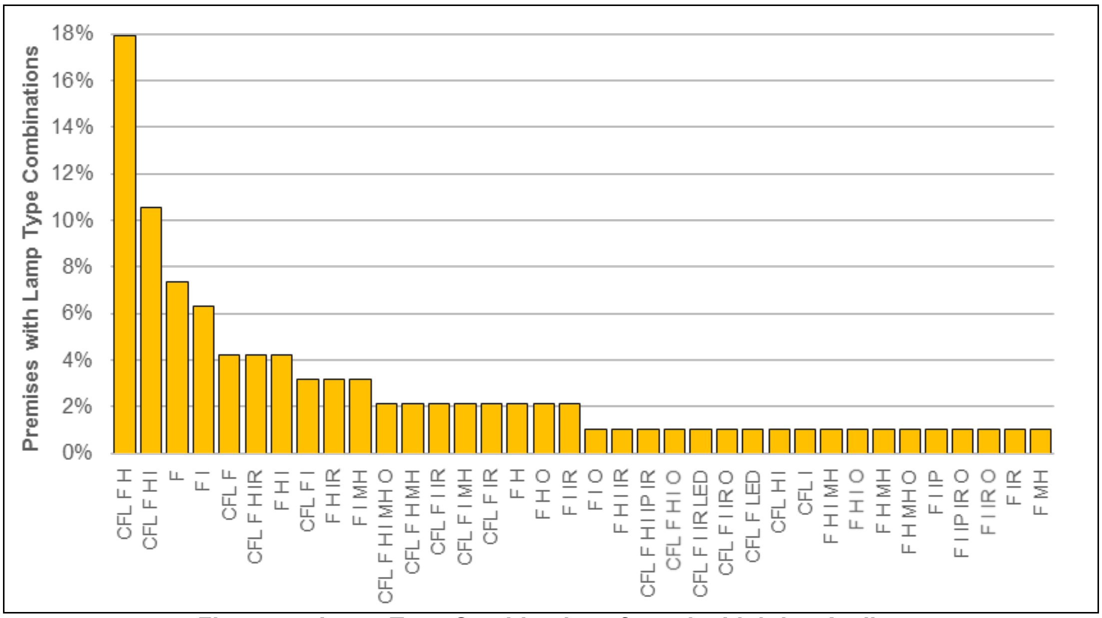


Figure 74: Lamp Type Combinations from the Lighting Audits.

Lamp types
F: Fluorescent
CFL: Compact fluorescent
H: Halogen
I: Incandescent
IR: Incandescent reflector
MH: Metal halide
O: Other
IP: Incandescent PAR
LED: Light-emitting diode

This shows that almost one-fifth of the monitored premises had a combination of compact fluorescent (CFL), fluorescent (F) and halogen (H) lamp types. Due to there being so many combinations and the variety of the lamp types within each combination, it is difficult to distinguish common lamp type clusters.

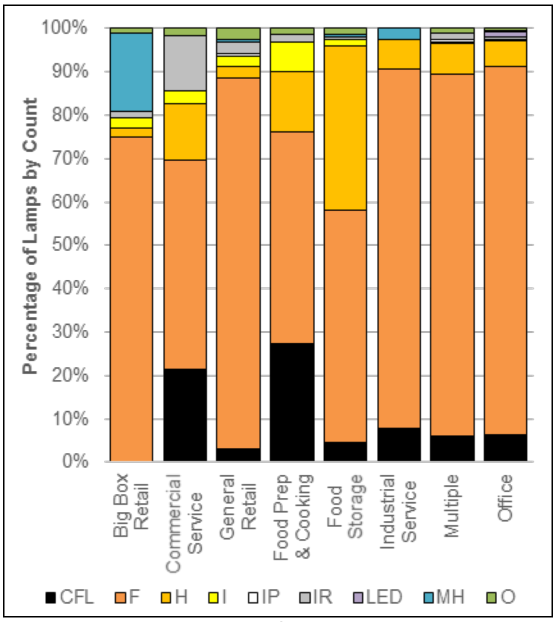


Figure 75: Number of Lamps by Type and Premise Activity.

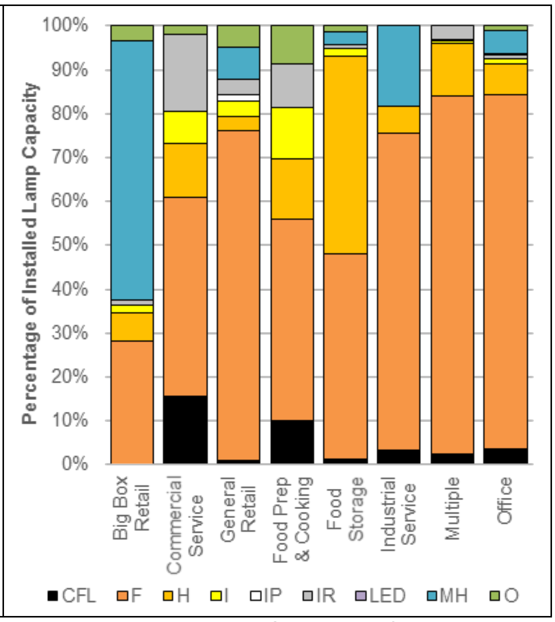


Figure 76: Installed Capacity of Lamps by Type and Premise Activity.

Figure 75 and Figure 76 show that, by and large, that fluorescent (F) lamp types are dominant, both by count and by installed capacity, across all premise activities. What is interesting is the contrast between the count and the installed capacity in the Big Box Retail and Industrial Service premises, with the metal halide (MH) lamp type demonstrating a more significant or increased electricity impact and the compact fluorescent (CFL) lamp type having a less significant or reduced electricity impact. Most other CPA groupings appear to be more similar to one another.

7.2.2 Lighting Electricity Use

The drivers of lighting energy use are complicated. The best single predictor from an exploratory analysis of such factors as premise floor area, installed lighting capacity, illuminance and average hours of use was the floor area, producing a correlation coefficient of r = 0.85.

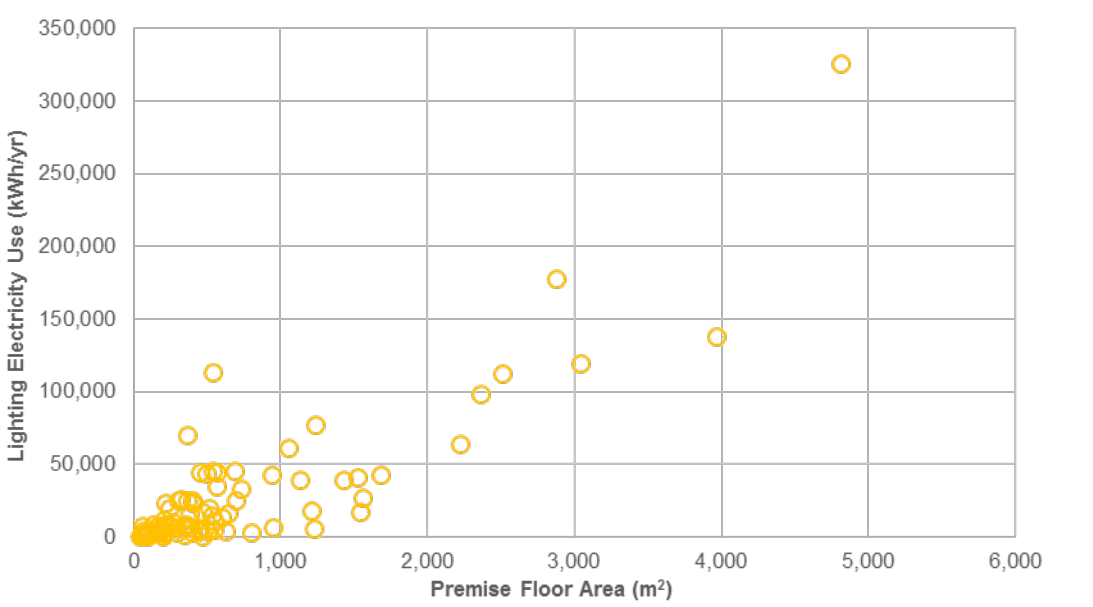


Figure 77: Annual Electricity Lighting Use and Size of the Premise.

To explore the relationship between lighting electricity use and other factors, data from the targeted energy monitoring (estimated annual lighting electrical use as well as the estimated hours of use per day), the targeted environmental monitoring (average illuminance levels during the weekdays from 10:00 am to 4:00 pm) and the lighting audit (installed lighting capacity in watts) were examined. Appendix F gives scatter plots of each of these variables against one another in the squares above the diagonal.

The strongest relationships involving the lighting energy use are between the premise floor area (r = 0.85) and the total installed capacity of the lighting (r = 0.80). Including both of these variables in a linear model increases the multiple r^2 for the model from 0.74 for just the floor area to 0.76 for both the floor area and total capacity. This very small increase in predictive value shows that little is added when the lighting capacity is considered. It can be seen in Figure 77 that the total installed lighting capacity is strongly correlated with the floor area suggesting that much of the correlation of lighting energy use with lighting capacity is due to the fact that lighting capacity itself is correlated to premise floor area.

Furthermore, the lighting $EnPI_{elec}$ and the lighting power density (W/m²) were less correlated with one another (r = 0.32) than the correlation between the total lighting electricity use and the lighting capacity (r = 0.85).

Additional exploratory analysis was undertaken on the relationship between the types of activity undertaken within the premise (using the CPA); however, no strong insights were identified. There remain many areas of non-residential lighting energy use to examine, and the BEES data is expected to be important to further explore these areas.

7.3 HVAC/Central Services

The theory of heating, cooling and ventilation in buildings is thought to be well understood by designers, engineers, building scientists, thermal modellers and policy-makers. However, in New Zealand, the assumption that buildings have sufficient heating and/or cooling capacity to maintain their occupants at comfortable temperatures is not always justified. The central services assessment from the targeted monitoring provides an insight into the performance of HVAC systems in New Zealand's non-residential buildings.

Figure 78 shows the proportion of premises monitored by year. The top number is the year and the bottom is the percentage of the total number of premises monitored. It can be seen the majority of premises (59%) were monitored during the 2010 calendar year.

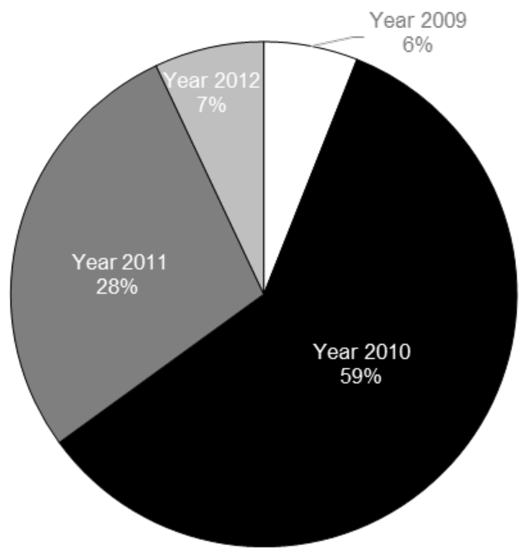


Figure 78: Calendar Years in which Premises were Monitored.

The following analysis reports on 92 of the monitored premises in 81 buildings. Unsurprisingly, centralised HVAC systems were most common in the largest buildings, with all but one of the S5 (9,000+ m²) buildings using this. As building size reduced, the prevalent source of heating (and often cooling) was electric heat pumps, down to the smallest buildings. Only in the two smaller strata did simple electric resistance heaters as the primary source of heating exceed 30% of the sample.

One of the most interesting results is 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.

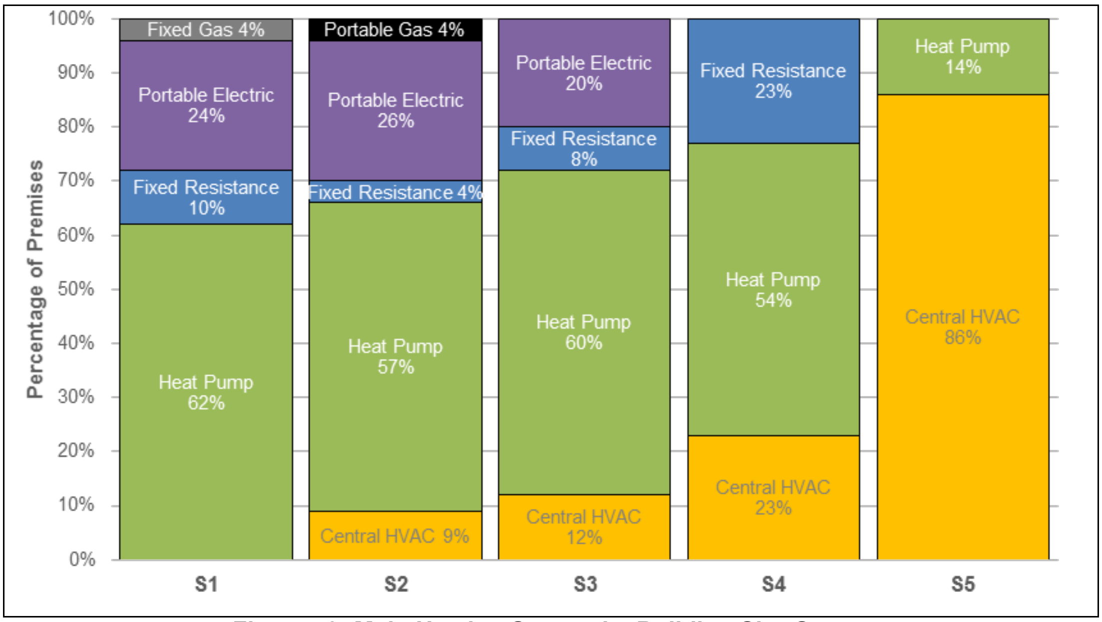


Figure 79: Main Heating System by Building Size Strata.

Figure 79 shows the main heating system used in the monitored premises by building size strata. Three premises (one in each of building size S1, S2 and S3) had no reported heating system. It can be seen that the premises in the largest building size stratum have more central systems, but not all. At the other end of the scale, in premises in smaller buildings, heat pumps are the main heating system, with electric resistance heating found in building size S1 to S4. Two-thirds (10 out of 15) of the buildings with an HVAC system had electricity as the primary heating fuel, 20% (three buildings) had gas while 13% (two buildings) used solid fuel. By far the majority (92%) of premises, across all building size strata, use electricity as their main heating fuel.

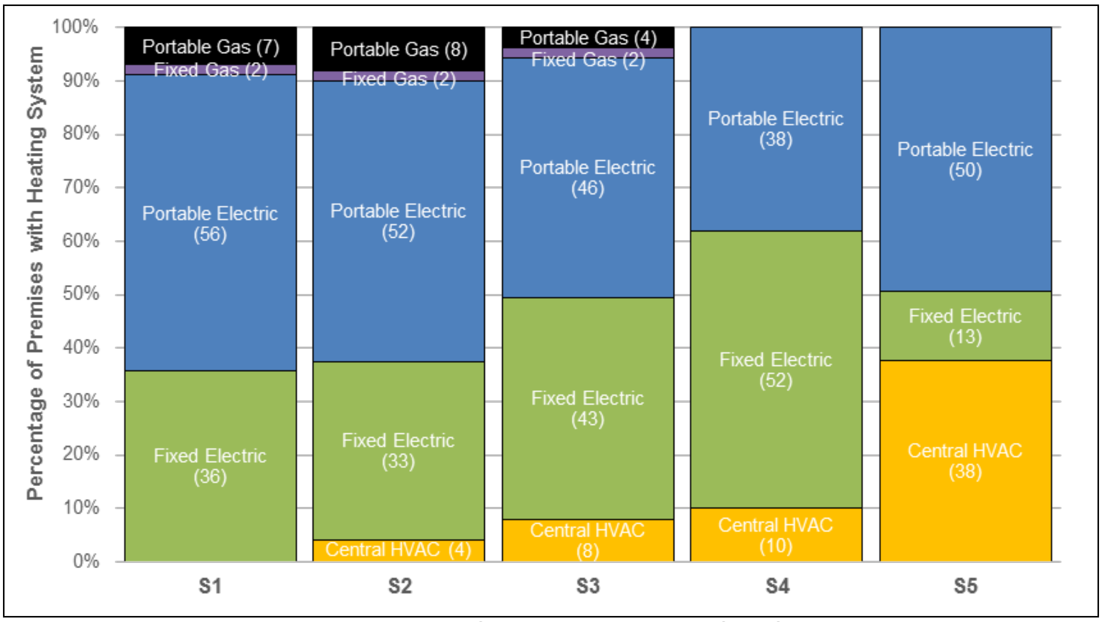


Figure 80: Heating Systems by Building Size Strata.

Figure 80 shows the percentages of the different heating systems by building size strata, based on the sum of heater types in each premise. Note that each heater system type is individually counted, and as noted, there can be more than one heater type in a single premise.

Two strong trends are apparent from Figure 78, Figure 79 and Figure 80. Firstly, electricity is the main heating fuel source across all premises, regardless of the building size strata. Gas (whether a fixed or portable heater) is only used in building size S1, S2 and S3 and then only in 12 out of 72 premises (17%).

Secondly, central HVAC, although present in some premises in building size S2, S3 and S4 buildings, is largely a feature of the largest building size – S5 buildings.

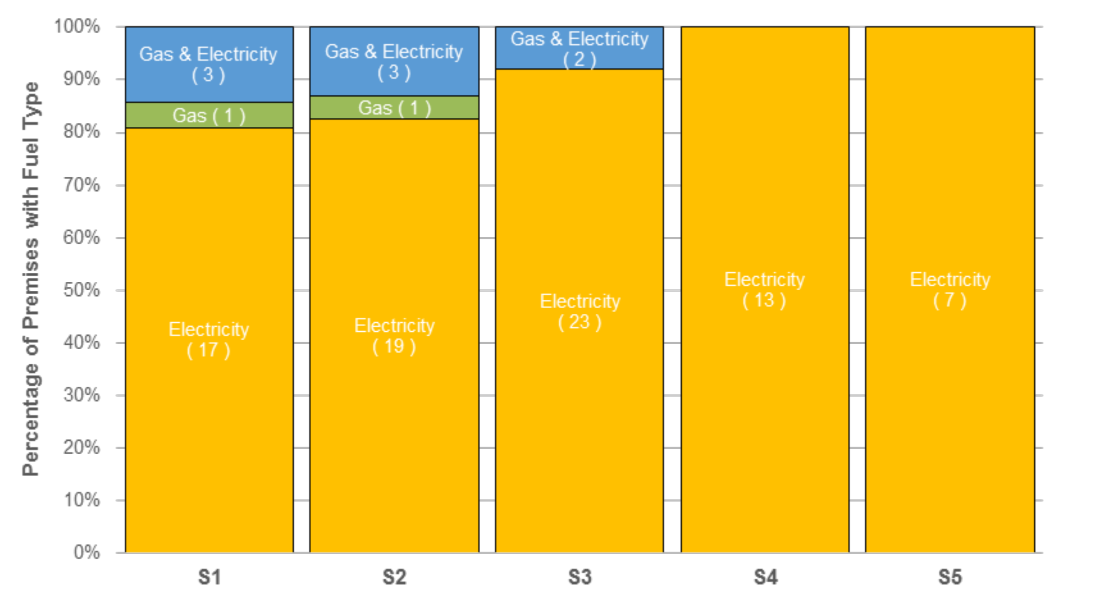


Figure 81: Fuel Combinations in Premises by Building Size Strata.

Figure 81 shows the combinations of fuel types found in the monitored premises by building size strata. For Figure 81, central HVAC has been considered to be electricity, but it should be recognised that this gives equal weight to any heater type – a central HVAC is counted in the same way as an electric fan heater used in one space. Electricity is the predominant fuel in all building size strata, with gas only used for space heating in the first two building size strata. It can also be seen that only the smaller building size strata have more than one heating fuel type.

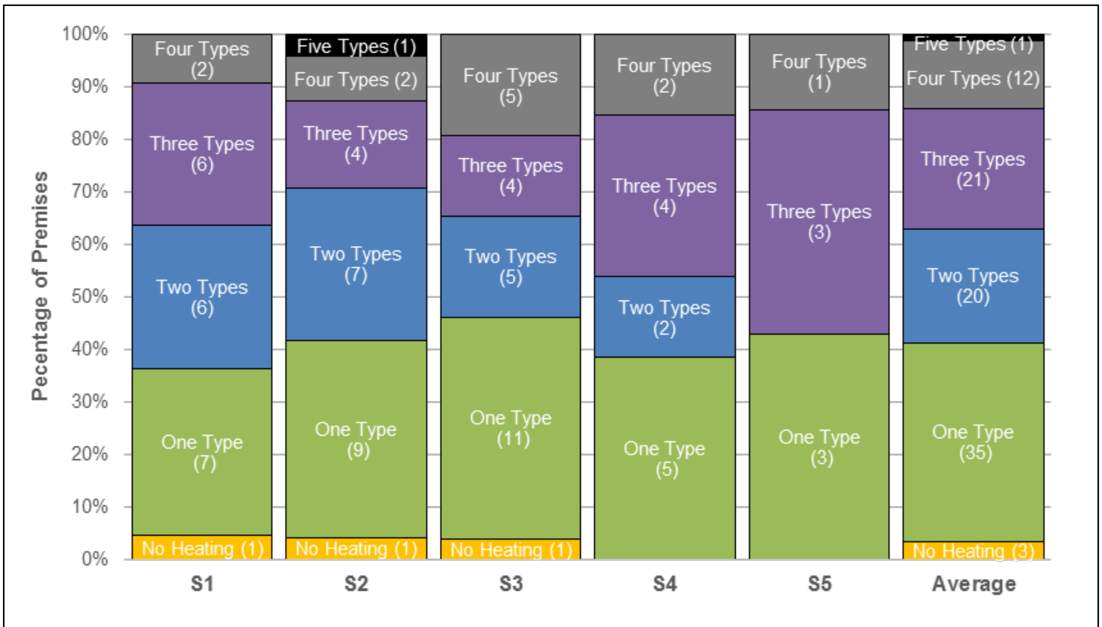


Figure 82: Number of Heating Systems in a Premise by Building Size Strata.

Figure 82 gives the number different types of heating systems found in each premise by building size strata. The maximum number of heating types was five (central HVAC, fixed electric, portable electric, portable electric fan and portable gas heater) found in a building size S2 building in a small rural town. Although the proportion of premises with only a single heater system is similar across the five building size strata, there is an increase in the number of heating systems as the building size strata increases.

This contrasts with the main heating system shown in Figure 79, suggesting that, even in buildings with central HVAC, there is a wide use of supplementary heaters.

Table 30: Number of Premises, Buildings, Heater Types, Premises and Building Areas by Building Size Strata.

Building size strata	Premise count	Building count	Heater types per premise	Total premise area (m²)		Count missing premise area	Total building area (m²)	
S1	21	20	2.14	5,788	6%	1	7,011	3%
S2	23	22	2.09	12,351	14%	1	21,561	9%
S3	25	20	2.12	24,079	27%	1	54,982	23%
S4	13	12	2.23	29,071	32%	-	52,574	22%
S5	7	7	2.29	18,646	21%	-	106,750	44%
Total	**89**	**81**	**2.15**	**89,935**	**100%**	**3**	**242,878**	**100%**

Table 30 documents data for 92 monitored premises, the average numbers of heater types per premise, the premise area and the building area by building size strata. Floor areas were not available for three premises due to the presence in each of two businesses within the area covered by a single revenue meter. It also shows the average number of heating types used in each premise by building size strata. There is a small but steady increase in the number of heating systems as the strata size increases, with an average of 2.15 heating systems being used across all strata.

Table 31: Monitored Premise Heater Types by Building Size Strata.

Building size strata	Electricity					Gas		TOTAL
	Central HVAC	Heat pump	Fixed	Portable	Portable fan	Fixed	Portable	
1	-	14	2	12	13	1	3	45
2	2	14	2	14	11	1	4	48
3	4	17	6	13	10	1	2	53
4	3	10	5	4	7	-	-	29
5	6	2	-	4	4	-	-	16
Average	15	57	15	47	45	3	9	191

Table 31 provides the count of heater types in the monitored premises by building size strata. The different heating system types are broken down in finer way than provided in Figure 80.

7.4 HVAC Performance

Thirteen buildings had their HVAC operating data examined in detail. These were selected based on being ones that had well defined central HVAC systems (instead of fixed unit or portable heaters) and to get a reasonable spread of building and premise types, sizes and monitoring seasons. The summary of this analysis is shown in Table 32.

In Table 32, a description of the premise is listed in the first two columns, with the floor area of the monitored premise in the third and the season that the monitoring was performed in the fourth. The fifth column lists the monitored $EnPI_{elec}$ for HVAC, followed by that for the whole premise. Finally, the fraction of monitored electricity that was attributed to HVAC is shown in the last column. The two HVAC $EnPI_{elec}$ that are asterisked have significant fossil fuel heating supplied, which is not quantified here.

Table 32: Summary of Individual Targeted Monitored Premises.

Premise	Office, Retail, Misc.	Floor area (m²)	Season	HVAC $EnPI_{elec}$ (kWh/m².yr)	Premise $EnPI_{elec}$ (kWh/m².yr)	HVAC% of total
Office Tower 1	Office	3,038	Summer	89	182	49%
Office Tower 2	Office	1,563	Summer	178	302	59%
Department Store	Retail	2,990	Summer	27	127	21%
Clothing Store 1	Retail	1,751	Winter	14	48	29%
Clothing Store 2	Retail	108	Winter	15	254	6%
Housewares 1	Retail	452	Autumn	8	131	6%
Housewares 2	Retail	401	Autumn	13	56	24%
Video Rentals	Retail	336	Winter	23	137	17%
Restaurant	Misc.	1,207	Summer	23	152	15%
Training Centre	Misc.	390	Winter	110	255	43%
Other	Misc.	2,667	Summer	7	13	52%

The mean HVAC $EnPI_{elec}$ was 49 kWh/m².yr, and the mean premises $EnPI_{elec}$ was 128 kWh/m².yr. The median HVAC $EnPI_{elec}$ was 23 kWh/m².yr, and the median premises $EnPI_{elec}$ was 137 kWh/m².yr.

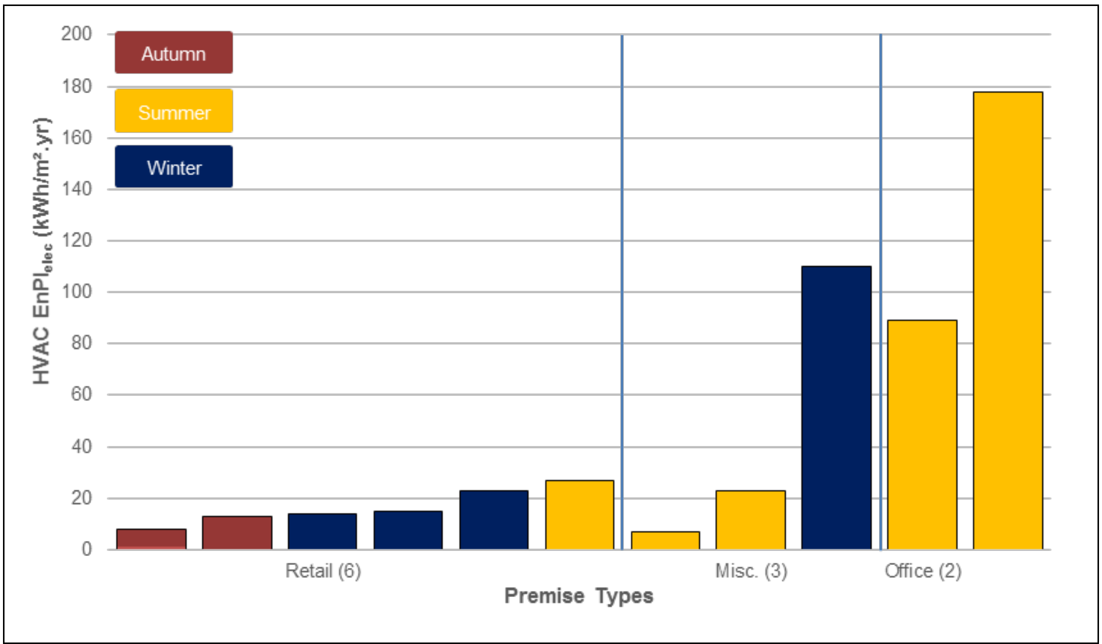


Figure 83: HVAC $EnPI_{elec}$ by Premise Type and Season.

Figure 83 plots the $EnPI_{elec}$ data from Table 32 by premise type and season (Misc. includes hotel, training centre and other premises). The lowest HVAC $EnPI_{elec}$ was for two retail premises monitored in autumn, when space conditioning demands would be expected to be the lowest, and the Other premise monitored in summer, which was in a sheltered location where the overall building loads were very low.

In general, the Office premises had higher $EnPI_{elec}$ for HVAC than other types of spaces and higher fractions of electricity consumption attributed to HVAC than others. This was presumably because retail spaces had high lighting loads, which indirectly provided much of the required space heating for those premises. The highest HVAC $EnPI_{elec}$ for a retail space was for the one measured in summer, when the lighting would cause cooling loads rather than replace the heating system.

8. ENVIRONMENTAL SERVICES

To understand the effectiveness of energy use in buildings, it is necessary to compare the energy use with the service it delivers. One measure of this service is the achieved indoor conditions, which, in turn, provide the environment required to support the comfort and work requirements of the occupants.

This section provides a preliminary analysis of monitored data for temperature, relative humidity, illuminance and CO_2 levels. It provides typical 24-hour profiles for each of these variables. The monitored locations were grouped into three space groups for this analysis: Administration, Shop and Other.

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

Relative humidity was monitored in over 330 locations. The average workday relative humidity ranged from 49% to 57%, while in the Shop space group, the range was from 46% to 57%, and in the Administration space group, from 48% to 57%.

The acceptable illuminance to support clerical type activities is 320 lux. About 50% of the locations in the Administration space group had a recorded mean illuminance level lower than 320 lux, with 8% recording mean values under 100 lux. About 55% of the locations in the Shop space group had a recorded mean illuminance level lower than 320 lux, with 12% below 100 lux. Over 65% of the locations in the Other space group had a mean illuminance level lower than 320 lux, while 40% were below 100 lux.

Air quality 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 higher (300% or more) than required to maintain good air quality. This can cause higher heating and cooling loads when outdoor air is cooler or hotter than indoors.

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. In the Administration space group, about 20% of the locations in winter and 40% of the locations 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, the average weekday maximum exceeded this in 12% of all locations in winter and 15% in summer. These locations are receiving insufficient fresh air.

Temperature and relative humidity were monitored for a whole year in 33 premises. Apart from the winter season, Administration and Shop space group weekday mean temperatures were within ±0.8°C. The Administration and Shop space group weekday mean relative humidities were within ±4%, with slightly higher relative humidity in autumn.

This section provides analysis of the data from monitoring of space conditions (temperature, relative humidity, illuminance and air quality) within the targeted monitored sample of premises. This comprises the measurements from 1,054 locations within 100 premises within 83 buildings. It is an update of the BEES Study Report 260/4 Achieved Conditions (Bishop, et al., 2011b) with the total targeted monitored premise sample included.

The HOBO U12 data loggers used recorded dry-bulb temperatures, relative humidity and illuminance levels every 10 minutes during the monitored period (typically 2–4 weeks). Usually, three of these loggers were placed throughout the premise, with as many as seven for a large premise, and a single separate

Telaire 7001 CO_2 data logger (refer to Appendix E) was placed in a central, reasonably representative space.

Most of the analysis in this section examines the weekday performance of spaces between 10:00 am and 4:00 pm. These were the hours when the majority of premises were occupied and the space conditions were considered to be reasonably stable. Graphically, the data from individual monitoring points is converted into a recurring 24-hour load profile.

Statistical summaries of the results for each variable are segregated by season (summer, winter and intermediate) and space group (Administration, Shop and Other). Seasonal segregation was based on the dates of monitoring, using June/July/August as winter and December/January/February as summer. Other months were combined into an intermediate season (spring or autumn). When monitoring spanned two seasons, the start date was used to define the season.

When the sensors were positioned, the location was reported in the audit documentation. Based on this, locations were assigned a space group for analysis purposes. Table 33 provides a detailed analysis of the sensor by location and the space group allocation. The numbers in each location are given in brackets:

- **Administration** space group includes those recorded as: conference room (1), meeting room (20), office (150) and reception (28).
- **Shop** space group includes only shops (57).
- **Other** space group includes those recorded as: bakery (2), chiller (2), corridor (4), dining room (4), hall (1), other kitchen (32), laboratory (2), lounge (2), showroom (1), storeroom (13), warehouse (3) and workroom (8).

Note that not all locations are designed for human occupation, for example, walk-in chillers.

Table 33: Monitored Locations by Space Group and Sensor.

Recorded location	Space group	Temperature	Relative humidity	Illuminance	CO_2	Total	Percentage
Office	Admin	150	150	143	36	479	45%
Shop	Shop	57	57	47	27	188	18%
Kitchen	Admin	32	32	32	2	98	9%
Reception	Admin	28	28	25	16	97	9%
Meeting room	Admin	20	20	19	1	60	6%
Storeroom	Other	13	13	12	-	38	4%
Workroom	Other	8	8	8	2	26	2%
Corridor	Other	4	4	4	1	13	1%
Dining room	Other	4	4	4	-	12	1%
Warehouse	Other	3	3	3	-	9	1%
Lounge	Other	2	2	1	2	7	1%
Laboratory	Other	2	2	1	1	6	1%
Bakery	Other	2	2	2	-	6	1%
Chiller	Other	2	2	1	-	5	0%
Showroom	Other	1	1	1	1	4	0%
Conference room	Admin	1	1	1	-	3	0%
Hall	Other	1	1	1	-	3	0%
Total		**330**	**330**	**305**	**89**	**1,054**	**100%**

Temperatures and relative humidity were monitored in 330 locations in 100 premises in 83 buildings, illuminance was monitored in 305 locations in 99 premises in 82 buildings and CO_2 was monitored in 89 locations in 83 premises in 73 buildings.

8.1 Monitored Space Groups

Table 34 provides the number of locations that were monitored by space group (Administration, Shop and Other) and season. Figure 84 plots the data from Table 34 for the seasons and Figure 85 for sensor types (temperature, relative humidity, illuminance and CO_2). It is not possible to give a similar detailed breakdown by BEES participant building, as in any premise, monitoring could take place in more than one space group and/or start in more than one season.

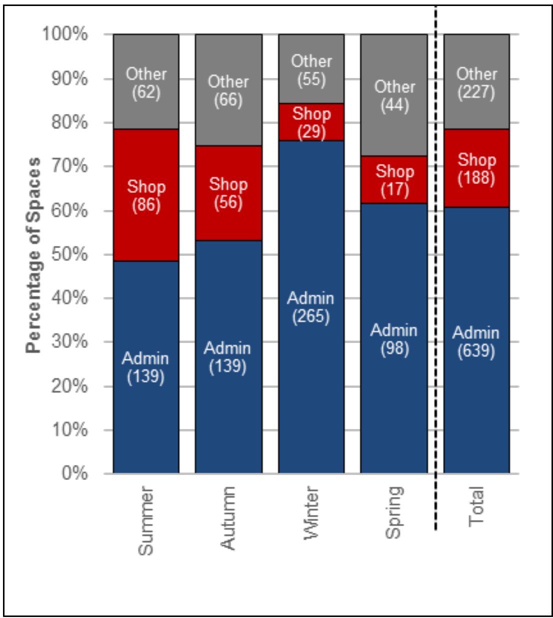


Figure 84: Space Group Monitored by Season.

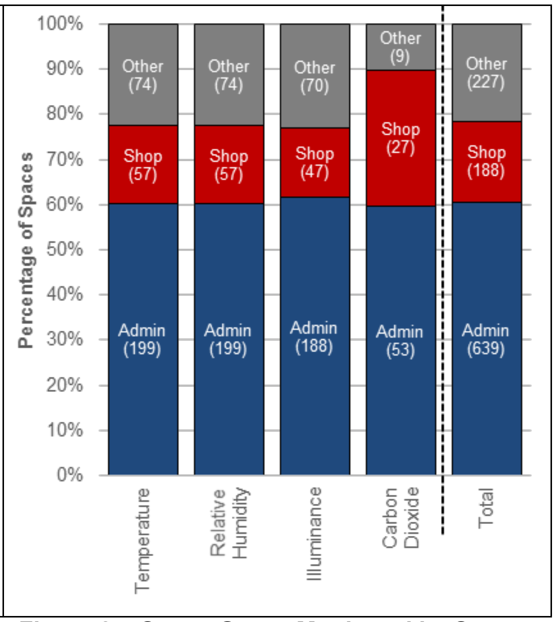


Figure 85: Space Group Monitored by Sensor Types.

All statistics reported in this summary, unless stated otherwise, are for weekdays (Monday–Friday) between 10:00 am and 4:00 pm. The conditions in the monitored locations had generally stabilised during these times and were considered to be representative of normal working conditions. Spring and autumn have been combined into an intermediate season for the rest of this section, including Table 34.

Table 34: Sensor Type by Count of Space Groups and Season.

Sensor type	Season	Space group			Total
		Administration	Shop	Other	
Temperature (330)	Summer	43	26	20	89
	Autumn	43	17	22	82
	Winter	83	9	18	110
	Spring	30	5	14	49
Relative humidity (330)	Summer	43	26	20	89
	Autumn	43	17	22	82
	Winter	83	9	18	110
	Spring	30	5	14	49
Illuminance (305)	Summer	40	22	19	81
	Autumn	39	14	20	73
	Winter	79	7	17	103
	Spring	30	4	14	48
CO_2 (89)	Summer	13	12	3	28
	Autumn	12	8	2	22
	Winter	20	4	2	26
	Spring	8	3	2	13
Count of sensors	**Total**	**639**	**188**	**227**	**1,054**

A single building may contain one or more premises, and each premise may include more than one space group, as illustrated in Figure 86. The premise on the left is General Retail (GEN), which includes Administration and Shop areas, while the premise on the right is Big Box Retail (BOX), which also has Administration and Shop areas (refer to section 4.2 for descriptions of the classification of premise activities (CPA) codes).

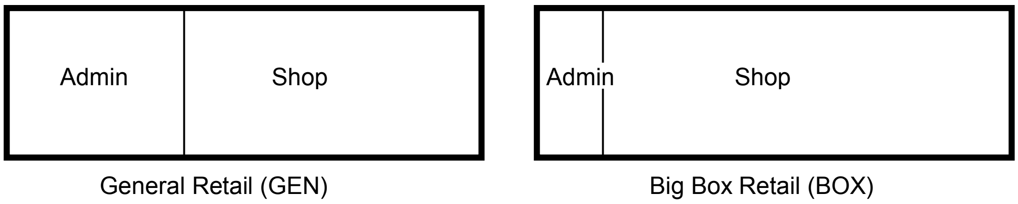


Figure 86: Diagram Illustrating Multiple Space Groups within a Premise.

As a result, two sensors located in one premise may monitor two different space groups or, if in one building, may monitor a number of different premises and therefore CPA. Table 35 analyses the number of buildings monitored by premise activity and sensor type. It can be seen that, although, for example, 83 buildings were monitored for temperature, a total of 90 CPA were included

Table 35: Sensor Type by Count of CPA and Building.

CPA	Premise description	Count of sensors	Number of buildings				
			Temperature	Relative humidity	Illuminance	CO_2	Total
OFF	Office	67	35	35	35	28	**35**
GEN	General Retail	497	16	16	16	15	**16**
BOX	Big Box Retail	163	8	8	8	8	**8**
CSV	Commercial Service	82	8	8	8	6	**8**
ICE	Food Storage	67	8	8	8	7	**8**
HOT	Food Preparation & Cooking	89	7	7	6	6	**7**
MIX	Multiple Use	65	5	5	5	5	**5**
ISV	Industrial Service	27	3	3	3	3	**3**
Number of buildings			83	83	81	80	**83**
Number of premises			90	90	89	78	**90**

Buildings with Office (OFF) premises made up the largest number of buildings, with General Retail (GEN) following next.

8.2 Measured Temperatures

Providing suitable air temperatures is important for ensuring thermal comfort for occupants. Thermal comfort is a complex subject. For example, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) devotes about 30 pages in its Fundamentals Handbook to aspects of thermal comfort. Figure 87, below, is a reproduction of Figure 5 from the 2001 version of that handbook (ASHRAE, 2001) and shows the thermal comfort zones, as specified in ASHRAE Standard 55, where "80% of sedentary or slightly active persons find the environment thermally acceptable", considering different levels of clothing common in summer and winter.

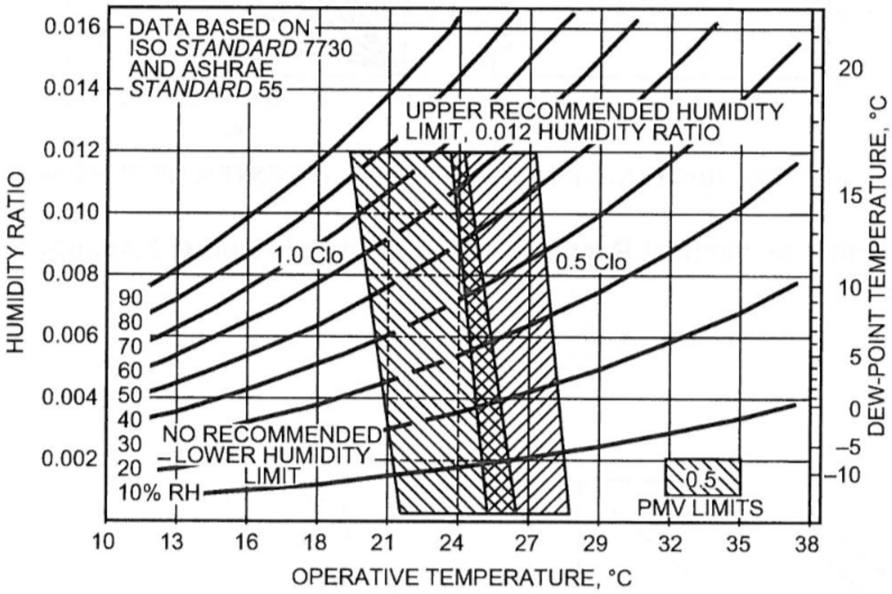


Figure 87: ASHRAE Summer and Winter Comfort Zones.

The winter comfort zone has a lower operative temperature boundary of about 20°C and an upper one of 24°C. The summer comfort zone has a lower boundary of 23°C and an upper one of 27°C. The ASHRAE Handbook also states that “the upper and lower relative humidity levels of the comfort zones are less precise”.

For the purposes of this study, the winter comfort zone is considered to be 20–24°C and the summer one to be 23–27°C. The Clo used in Figure 87 is the unit for the thermal properties of clothing – a Clo of 1 represents a person wearing a typical men’s business suit with cotton underwear, long shirt, woollen socks and shoes.

8.2.1 Examples of Typical BEES Profiles

Examples of typical temperature profiles recorded in the monitored locations are shown in Figure 88 through to Figure 93. Each of these represents the temperature for each weekday as a thin solid grey line, for each weekend day as a thin dashed red line, the mean value for all weekdays as a thick solid black line and the mean value for all weekend days as a thick dashed red line.

The main temperature statistic reported from these profiles is the mean temperature on weekdays between 10:00 am and 4:00 pm (the middle of the normal working day, when temperatures would be expected to be controlled and reasonably stable).

The reported temperature swing (±°C) is the maximum of either the average standard deviation of the temperature during this time or half the difference between the mean daily maximum temperature and mean daily minimum temperature.

The variation in temperature profile shapes meant that these values were not consistently related to each other, and temperatures were not necessarily normally distributed, so standard deviation was not entirely appropriate. Thus, the maximum of these values was taken as representative of the average daily swing.

A visual analysis was undertaken of 328 temperature records (excluding the two chiller rooms), allocating each to one of six categories based on the apparent control system. This took into account the comfort conditions during normal working hours (8:00 am to 5:00 pm) and the measured air temperature. The results are summarised in Table 36. It was found that, on average, there were 2.2 temperature control categories in each building, although this is constrained by the number of measurement points in each building. This was not expected and suggests that temperature control may be variable even in buildings that appear to have the potential for good control. Further analysis is required, but this could not be completed within the current project.

Table 36: Temperature Control Typology of Spaces based on 8:00 am to 5:00 pm Temperatures.

Description (time in comfort zone 8:00 am to 5:00 pm)	Count	Percentage of records
Perfect (~95%)	89	27%
Good (~80%)	72	22%
Variable (~60%)	57	17%
Too warm (< ~60%)	40	12%
Too cool (<~60%)	50	15%
Other	20	6%
TOTAL	**328**	**100%**

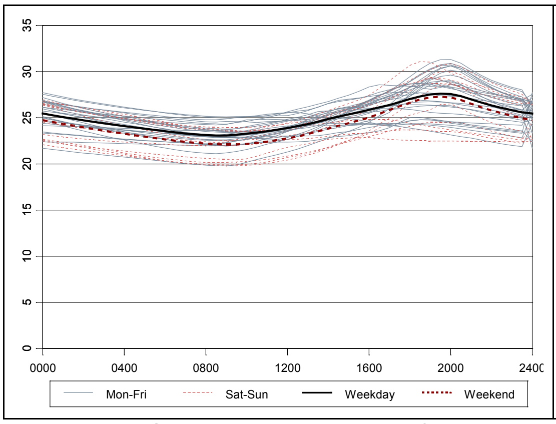


Figure 88: Space Temperature Profile – Well Controlled Wave (Office).

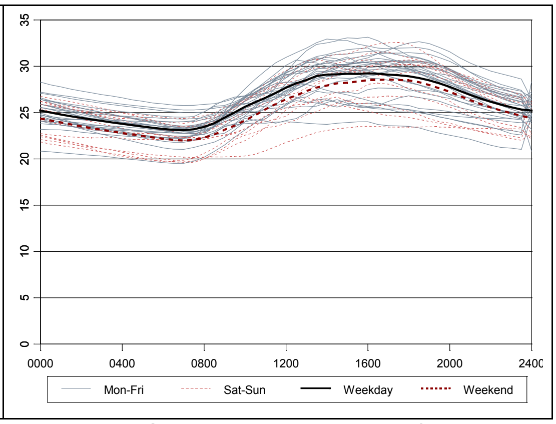


Figure 89: Space Temperature Profile – Less Well Controlled Wave (Store).

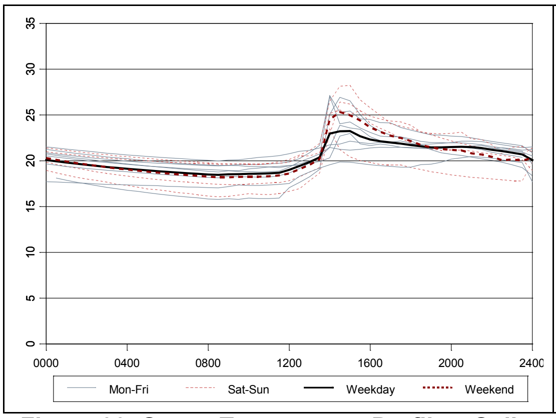


Figure 90: Space Temperature Profile – Spiky Profile.

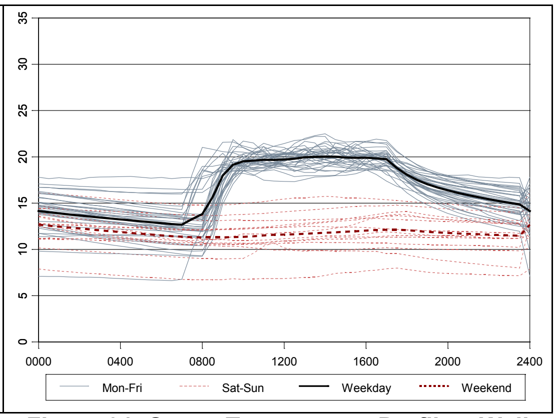


Figure 91: Space Temperature Profile – Well Controlled Daytime.

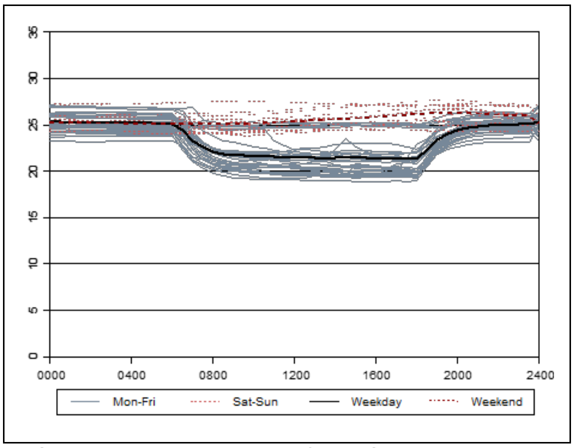


Figure 92: Space Temperature Profile – Summer Air-conditioning.

Figure 88 and Figure 89 show the temperature summer profile (January) for two locations in one premise. Figure 88 shows the office and Figure 89 the store locations. The temperatures vary roughly as a sine wave in response to the outside temperatures. In the office location, the average weekday maximum was 26°C compared to 30°C in the store, while the office maximum was 28°C and the store 33°C. In the office, the average weekday minimum was 23°C compared to 26°C in the store, while the office minimum was 20°C and the store 23°C. This would suggest that the office is better protected than the storage area from the extremes of the external climate, possibly by insulation or the use of fans.

Most weekdays show similar patterns, as seen by the sheaf of thin grey lines around the dark one. Weekend temperatures, as shown by the light solid and dotted red lines, usually showed a similar pattern, although about a degree lower than the weekday average in the store. The weekday 10:00 am to 4:00 pm mean office temperature was 24.5 ±1.3°C and the store 28.1 ±2.2°C. These are the swing of the weekday average temperature; the effect of the day-to-day variability is not addressed in this statistical analysis.

Figure 90 shows a different-shaped profile – one that has a distinct late afternoon peak. This is for a restaurant in the spring, showing the dining area being prepared for the evening meal. The weekday temperature averaged 19.8 ±0.9°C, although the late afternoon average peak reached 23°C in the weekday. A similar pattern can be seen for the weekend, although the late afternoon average reached as high as 25°C

Figure 91 shows a different-shaped profile with a quite well controlled and reasonably constant temperature during working hours. This reception area location in autumn had an air-conditioning system that switched on at around 8:00 am and off at about 4:00 pm. It typically cooled to about 13°C overnight, but the weekday average was 20.6 ±2.5°C. The weekday average minimum was 16°C although the average maximum reached 28°C.

Weekend temperatures in Figure 91 clearly show the air-conditioning system was not operating, resulting in reasonably consistent temperatures over an individual day, presumably in response to the exterior conditions. The weekend (Sunday) 10:00 am to 4:00 pm mean temperature was 20.6 ±2.6°C,

Figure 93 shows the daytime temperatures in an air-conditioned office. It can be seen that the air-conditioning system turns on about 6:00 am and off about 6:00 pm, pulling the temperature down from about 25°C to 20°C. The weekday average temperature is 21.5 ±1.9°C, with an average minimum of 19°C and maximum of 25°C. This compares to the weekend (Sunday) average of 25.8 ±0.9°C with an average minimum of 24°C and average maximum of 28°C.

8.2.2 Monitored Temperature Summaries

Table 37 provides the CPA by count and average temperature for the total number of locations monitored for temperature as well as the same data for locations in offices and shops associated with these premises (see Table 35 for details of the locations and counts). Figure 93 provides just the simple average, which was calculated by summing for each premise activity the workday average temperature then dividing this by the number of premises within that activity group. Office and shop locations are found associated with different premise activities, so for the table, they have been separated for analysis.

Over the 330 monitored locations, the average workday temperature ranged from 19°C to 23°C, while in the subset of office and shop locations, the range was from 20°C to 23°C.

Table 37: Count and Average Temperature by CPA and Location.

Premise activity	Premise description	Total		Office location		Shop location	
		Count	Average (°C)	Count	Average (°C)	Count	Average (°C)
GEN	General Retail	52	21	15	21	24	21
BOX	Big Box Retail	25	21	9	20	8	23
OFF	Office	156	22	96	22	4	23
ICE	Food Storage	29	19	6	20	10	22
CSV	Commercial Service	21	21	4	21	6	23
ISV	Industrial Service	8	23	3	23	1	22
HOT	Food Preparation & Cooking	15	22	2	21	3	23
MIX	Multiple Use	27	22	15	22	1	20
Total		**330**	**21**	**150**	**22**	**57**	**22**

Shop locations were 17% (57 out of 330) and office locations were 45% (150 out of 330) of the monitored locations. As noted above, not all locations monitored were necessarily for human use – the Food Storage (ICE) premise activity included a number of large refrigeration areas that consequently have very low temperatures.

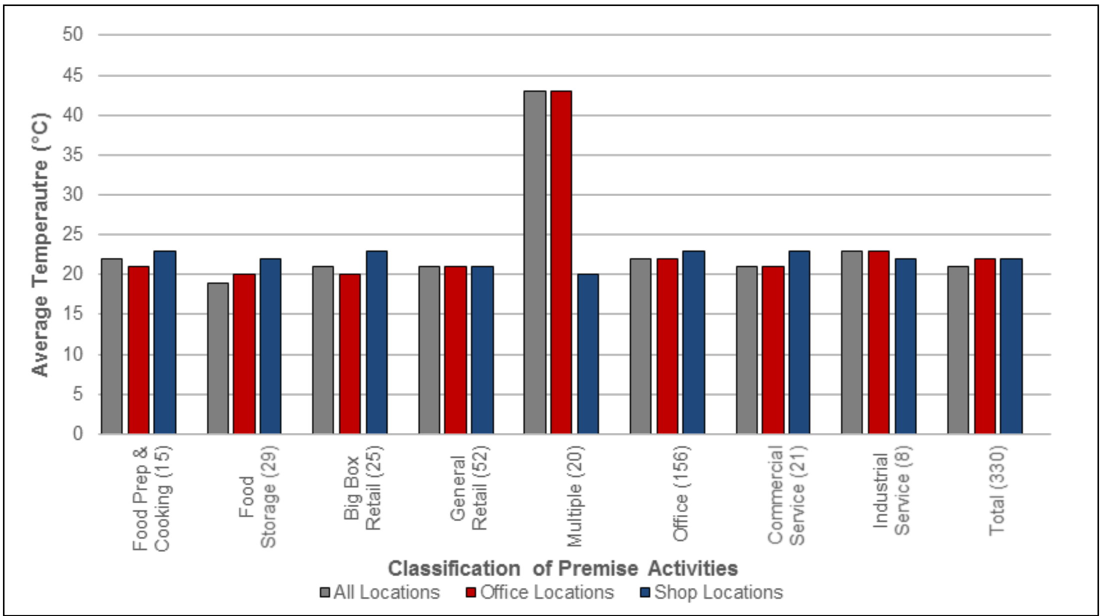


Figure 93: Mean Temperature by CPA and Specific Locations.

Table 38 summarises the temperatures recorded across all three space groups. The minimum (and maximum) temperatures reported here are the average of the daily minimums or maximums during the monitoring period, not the extreme recorded minimums/maximums.

Table 38: Summary of Temperature Recorded in BEES.

Temperature	Mean			Minimum			Maximum		
	Winter	Summer	Intermediate	Winter	Summer	Intermediate	Winter	Summer	Intermediate
≥16°C	96%	100%	100%	93%	96%	100%	98%	100%	100%
≥18°C	89%	96%	100%	75%	88%	100%	94%	99%	100%
≥20°C	70%	84%	100%	47%	64%	91%	84%	90%	100%
≥22°C	27%	49%	86%	5%	33%	65%	44%	64%	90%
≥24°C	2%	8%	33%	1%	1%	12%	4%	19%	52%
≥26°C	1%	0%	2%	0%	0%	0%	1%	4%	12%

Figure 94 shows the summary of the weekday temperatures measured in all the locations in the Administration space group in winter conditions. The mean weekday temperature between 10:00 am and 4:00 pm is shown as the blue diamond with vertical lines giving the weekday day average standard deviation. The points above give the average daily maximum (during this time interval) and below the average daily minimum temperatures.

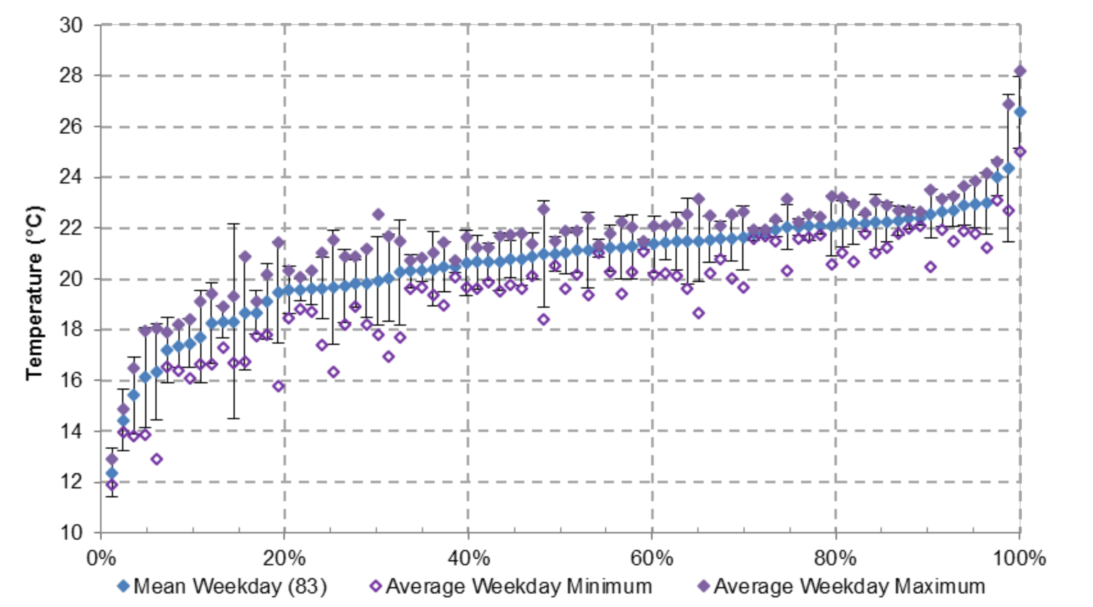


Figure 94: Winter Temperatures for Locations within the Administration Space Group.

As can be seen in Table 38 and Figure 94, during winter, only about 27% of the Administration space group recorded had mean temperatures below 22°C and only about 2% above 24°C. However, about 70% exceeded 18°C, and only 11% had mean temperatures below 16°C.

In terms of average daily minimum space temperatures recorded on workdays from 10:00 am to 4:00 pm, 53% were below 18°C, and only 5% had average minimums above 20°C. These are rather cold conditions and indicate that much of the sample is not maintaining comfort by conventional standards.

An interesting comparison can be made to the results of the Household Energy End-use Project (HEEP), which found that the average winter evening living room temperature was 17.9°C, with the mean range from 10°C to 23.8°C. One-quarter (25%) of the living rooms had mean temperatures under 16°C (Isaacs, et al., 2010a).

A similar analysis was performed on the two other space groups, Shop and Other. The results were generally similar, although there were fewer points in these categories. For a comparison, the distributions of mean temperatures for all three space groups are shown in Figure 95.

In Figure 95, Administration is shown as the blue diamonds, Shop as red squares and Other as grey triangles. As can be seen, the Other and Shop space group temperatures are about the same in winter and always lower than the Administration space group temperatures.

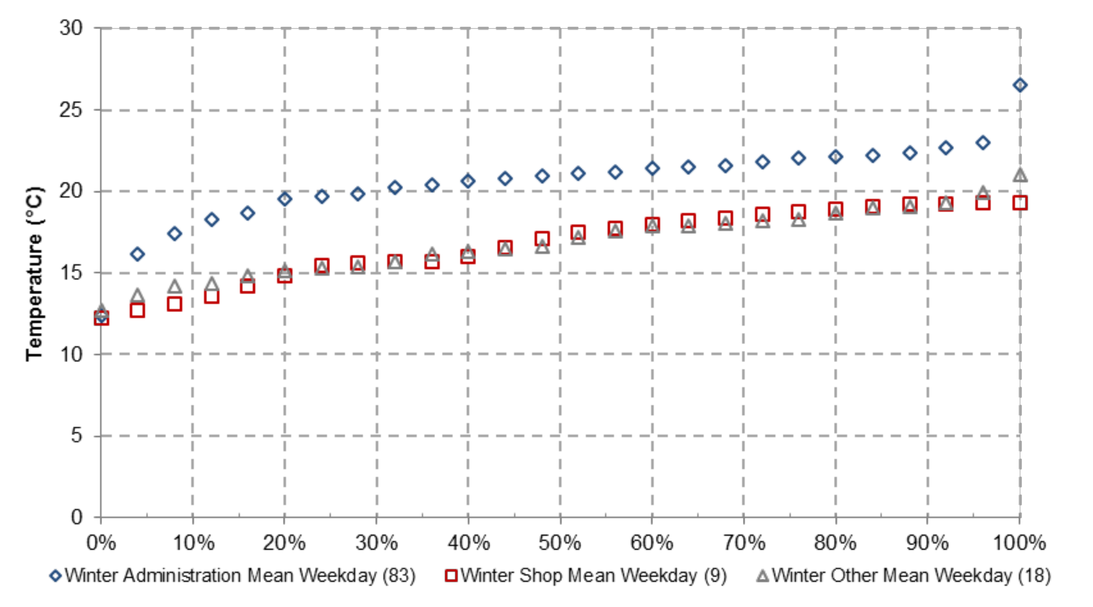


Figure 95: Winter Daily Average Temperature Comparison by Space Group.

The spread of summer temperatures in the Administration space group were also investigated. The results of this are shown in Figure 96, which is formatted the same as Figure 94. In summer, unsurprisingly, the Administration space group had warmer temperatures. All of the mean weekday temperatures are above 20°C, while over a quarter (28%) have mean temperatures above 24°C, and one premise is above the 27°C upper bound of the ASHRAE summer comfort zone.

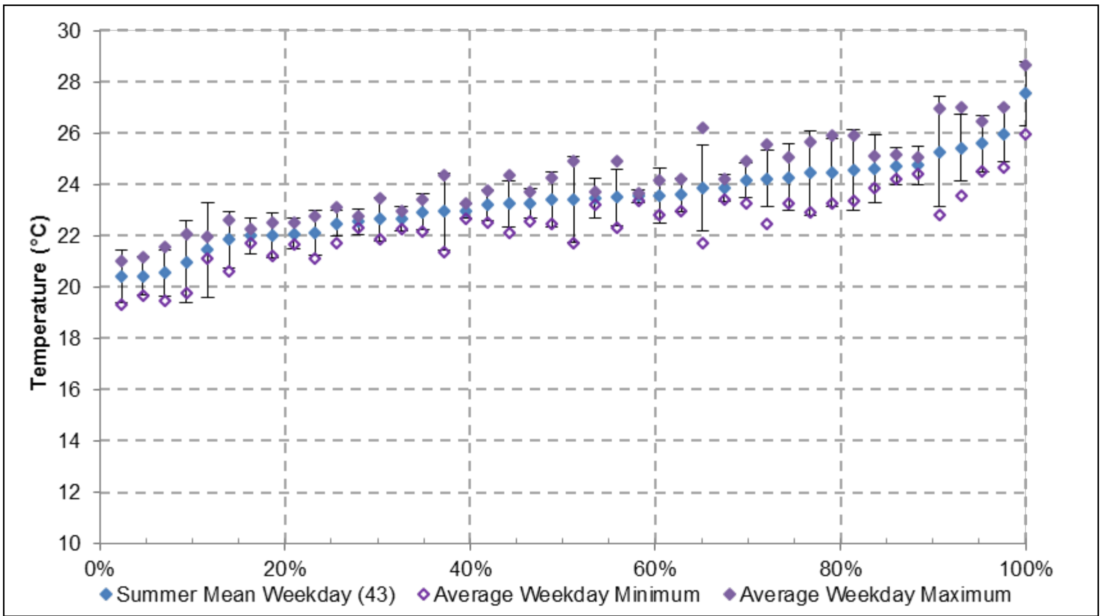


Figure 96: Summer Temperatures for Locations within the Administration Space Group.

The monitored summer temperatures show a generally lower daily swing than in winter, ranging from 20°C to 27°C (compared to the winter average maximum, which ranges from 12°C to 26°C). Only 12% of monitored locations show average summer daily maximum temperatures above 24°C, which may relate more to the location than the presence of any active temperature control.

A comparison of the different space group summer temperatures is shown in Figure 97, using the same symbols as Figure 95. Although the lower and upper ends of the distributions differ, from 40% to 85%, the curves are very similar. The Other space group had extreme mean temperatures slightly higher (10% at 26°C or above) and lower (15% at or below 20°C) than the other two space groups. This is not surprising, given the range of activities in the Other space group and the likelihood of them being unconditioned or only partially conditioned.

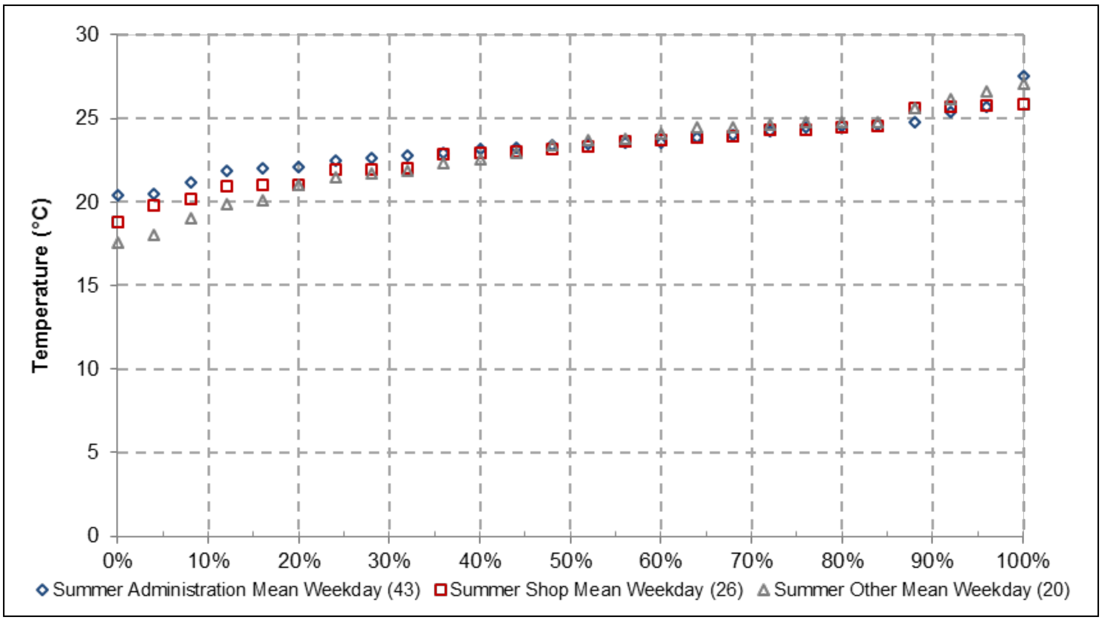


Figure 97: Summer Daily Average Temperature Comparison by Space Group.

For completeness, Figure 98 plots intermediate season temperatures, using the same format as for winter (Figure 94) and summer (Figure 96). 20% of the monitored locations in the Administration space group have intermediate season mean weekday temperatures below 20°C and 6% above 24°C. Most locations (74%) have comfortable temperatures during intermediate seasons.

However, about one in seven (15%) of these locations in the Administration space group have daily average minimum temperatures below 18°C, which is distinctly cool, and about one in five (21%) have daily average maximum temperatures above 24°C.

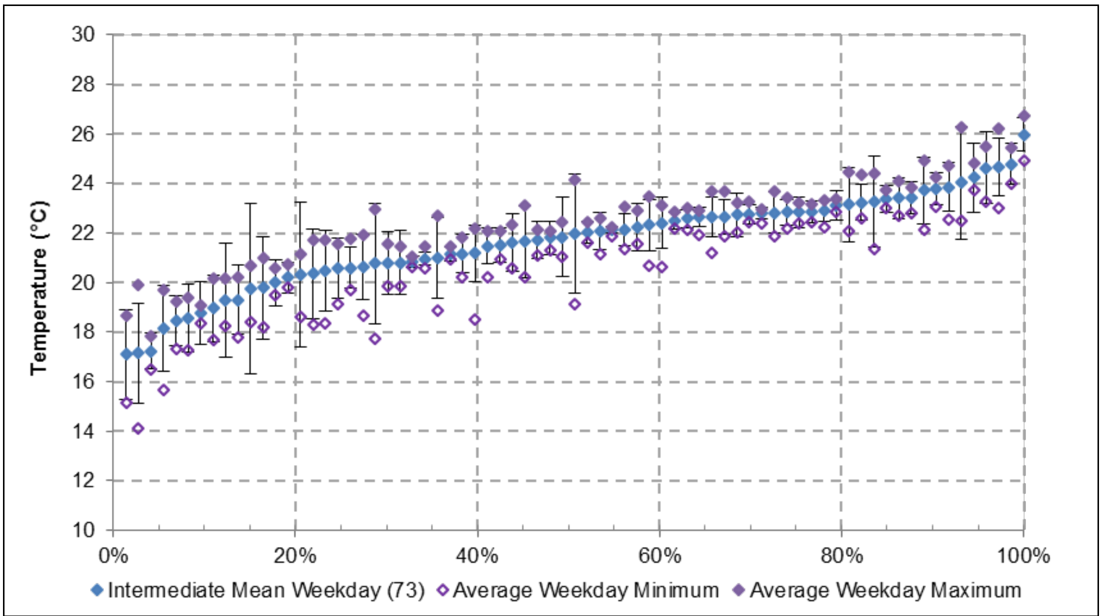


Figure 98: Intermediate Season Temperatures for Locations within the Administration Space Group.

Figure 99 shows the comparison of the different spaces groups and average temperatures during the intermediate seasons. The intermediate season average temperatures are similarly distributed, although again, the Other space group shows lower average temperatures, including four with weekday average temperatures below 16°C (two were chillers, one a workroom that stayed cooler than outdoors and the other was an apparently very well ventilated kitchen).

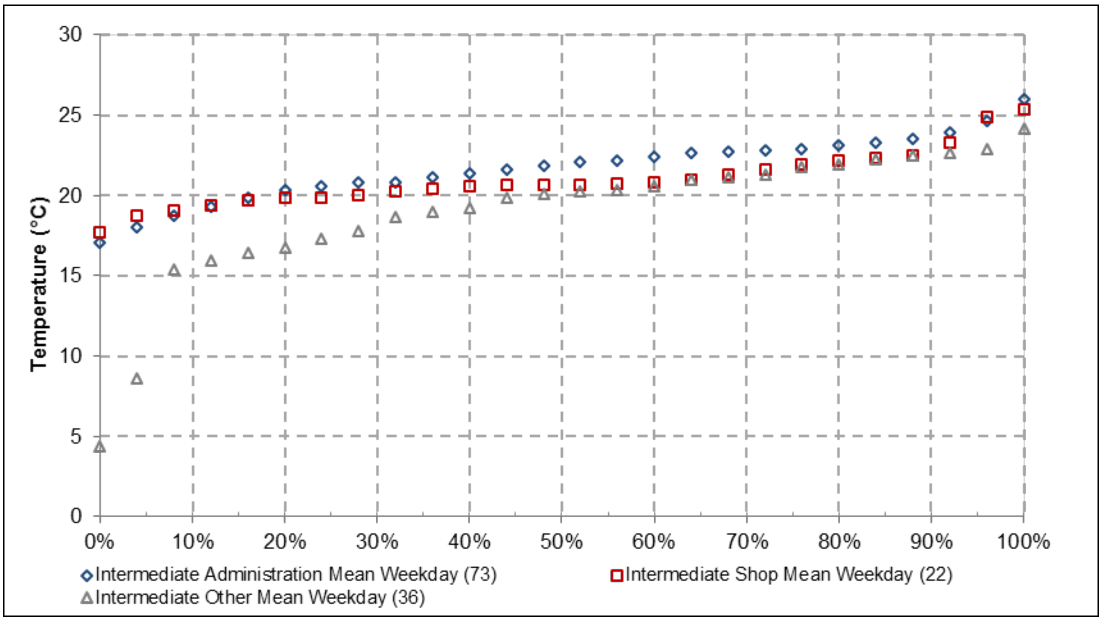


Figure 99: Intermediate Season Daily Average Temperature Comparison Between Space Groups.

Another way of viewing the temperature data is by comparing the weekday temperature swing (up and down from the mean) to the weekday mean temperature. As part of the evaluation of the building, a code was noted as to whether the building appeared to have a central HVAC system. This coding, however, was very simple, so the effectiveness and efficiency of the HVAC systems cannot be determined from the code alone.

Figure 100 compares the winter weekday temperature swing to the mean weekday temperature, with premises reporting HVAC shown as diamonds.

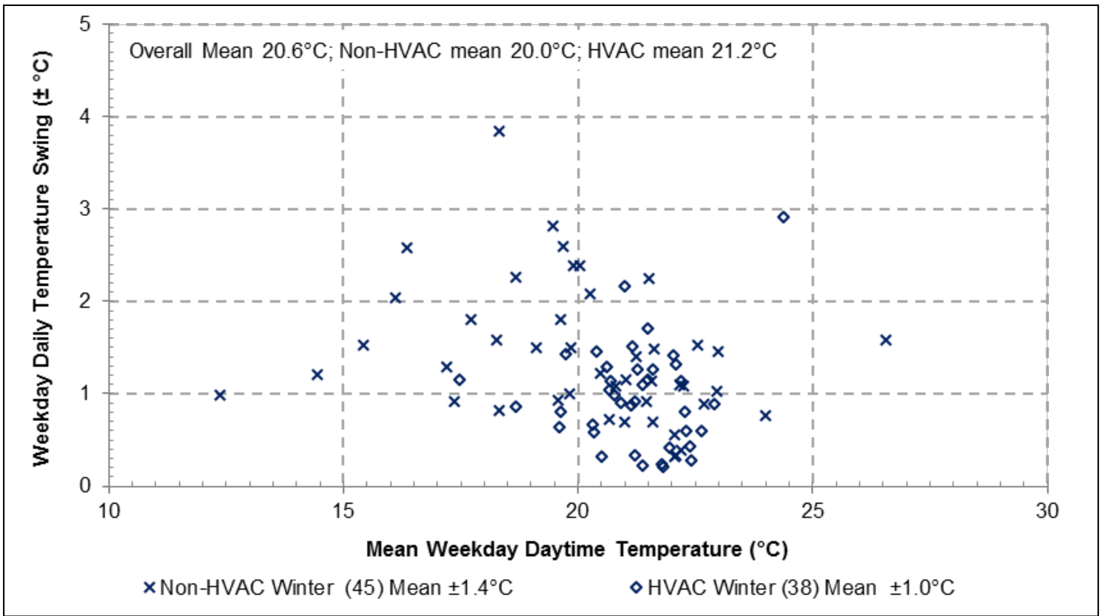


Figure 100: Administration Space Group Daily Winter Average Temperatures and Swings.

Figure 100 illustrates that the winter weekday 10:00 am to 4:00 pm temperature swings were mostly under ±2°C (86%), which are within the ASHRAE comfort zone of about ±2°C. In 6% of the locations, the swings were over ±2.5°C. Although the temperatures in premises with HVAC are, on average, more stable, three premises with HVAC have temperature swings over ±2°C. The mean temperature in the locations with HVAC was 21.2°C with a mean temperature swing of ±1°C. In the non-HVAC locations, the mean temperature was 20°C with a mean temperature swing of ±1.4°C, which is statistically different (t (80) = 3.09, p<0.001).

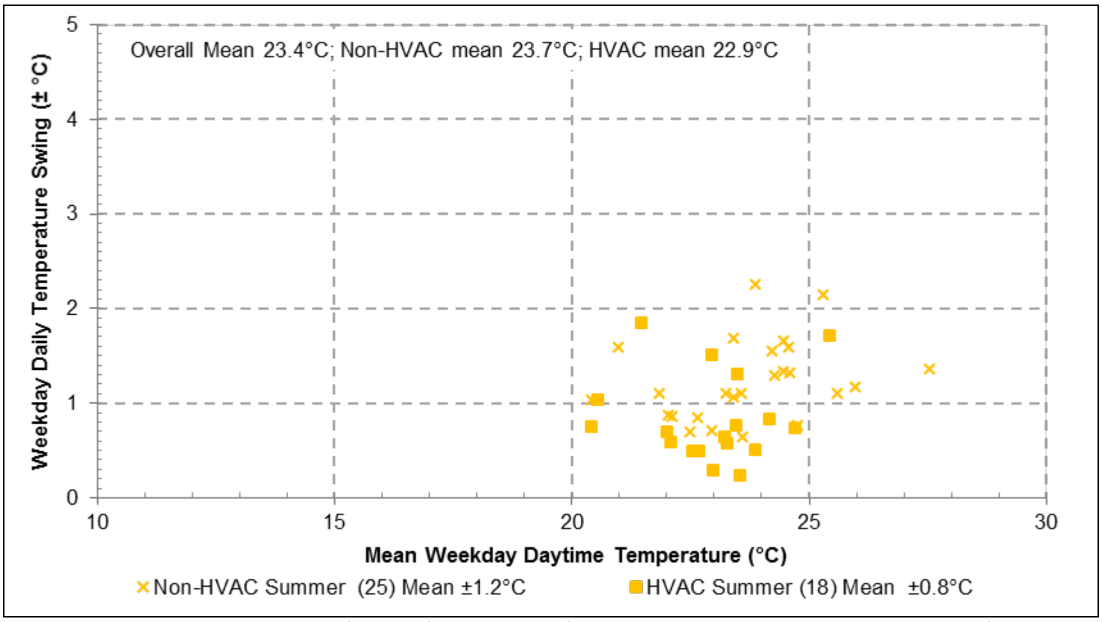


Figure 101: Administration Space Group Daily Summer Average Temperatures and Swings.

When the summer weekday temperature swings are compared to the summer weekday data, as shown in Figure 101, on the same axes, the relative stability of the summer temperatures becomes clear. 95% were under ±2°C, with the remaining 5% at ±2°C. In summer, two premises with HVAC had temperature swings over ±2°C. The mean temperature in the locations with HVAC was 22.9°C with a mean temperature swing of ±0.8°C. In the non-HVAC locations, the mean temperature was 23.7°C with a mean temperature swing of ±1.2°C, which is statistically different (t (35) = 2.87, p<0.003).

Table 39 provides a summary of the percentage of premises by space group and season. Close to three-quarters of Administration space group had the temperature maintained within ±1°C (74– 77% depending on season).

Table 39: Temperature Swings Ranges by Season and Space Group.

Temperature swing	Administration space group			Shop space group			Other space group		
	Winter	Summer	Intermediate	Winter	Summer	Intermediate	Winter	Summer	Intermediate
±0°C	13%	9%	15%	0%	4%	18%	11%	10%	8%
±1°C	75%	77%	75%	56%	69%	64%	50%	50%	67%
±2°C	94%	100%	93%	78%	96%	82%	100%	90%	86%
±3°C	99%		100%	100%	96%	100%		100%	100%
±4°C	100%				100%				

A summary of the temperature swings by space group and season are given in Figure 102. It can be seen that the temperatures in the Administration space group are most controlled, with the lowest proportion of locations recorded as having over ±3°C temperature swings.

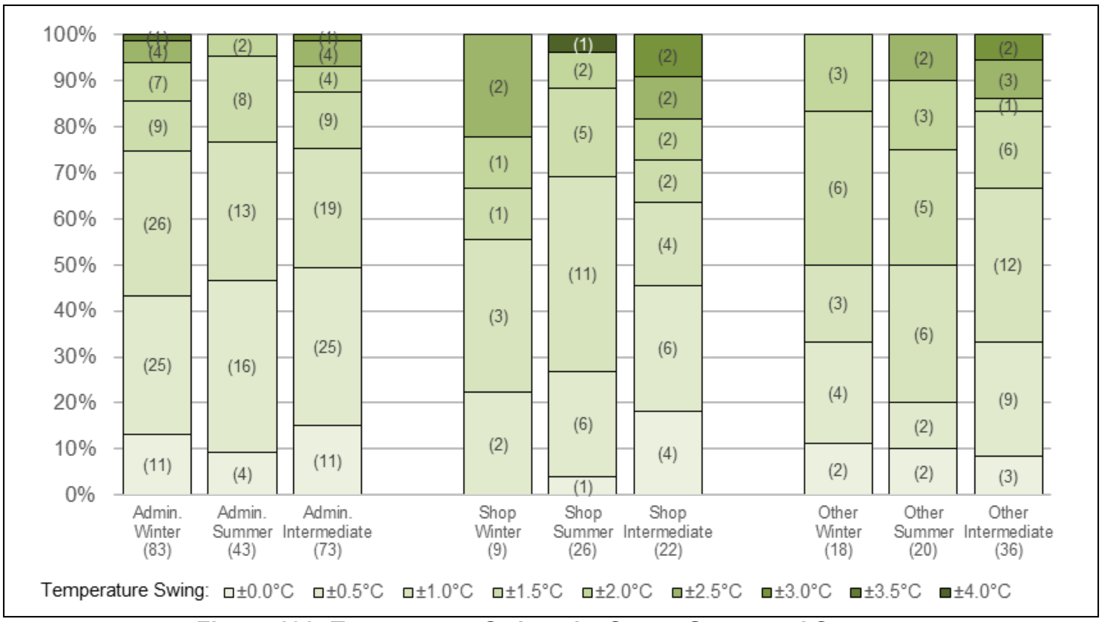


Figure 102: Temperature Swings by Space Group and Season.

8.3 Air Quality Monitoring

The simplest measure of the air quality of a space is its CO_2 content. While other pollutants can affect indoor air quality, CO_2 is a direct measure of human metabolism and not out-gassed by materials. Thus, the concentration of CO_2 can be used to indicate the amount of outside air ventilation, in litres per second per person (L/s per person).

New Zealand standard NZS 4303:1990 *Ventilation for acceptable indoor air quality* defines the ventilation required to provide good indoor air quality. NZS 4303:1990 Appendix D provides a calculation procedure to relate the amount of outside air supplied to a space (in L/s per person) to the difference in concentration of CO_2 between indoors and outdoors. The ventilation rate procedure recommends 10 L/s per person for most spaces. Alternatively, a concentration of 1,000 ppm CO_2 complies using the Indoor Air Quality Procedure.

The daytime CO_2 concentration in outdoor air in urban environments is typically 450 ppm. Using this value, the amount of fresh air supplied to a space, per person, can be calculated using the nomograph in Figure 103. Reading vertically up from the indoor CO_2 concentration (x-axis) to the green line representing a CO_2 concentration in outdoor air of 450 ppm then horizontally across to the y-axis, the number of litres per second of outside air required to be supplied per person can be determined.

The importance of this is that bringing in more outside air than is necessary during periods of hot or cold weather increases the cooling or heating loads in a space. In some conditions, the outside air ventilation can be the dominant heat loss mode from a building and lead to much more space heating to be required than would otherwise be the case.

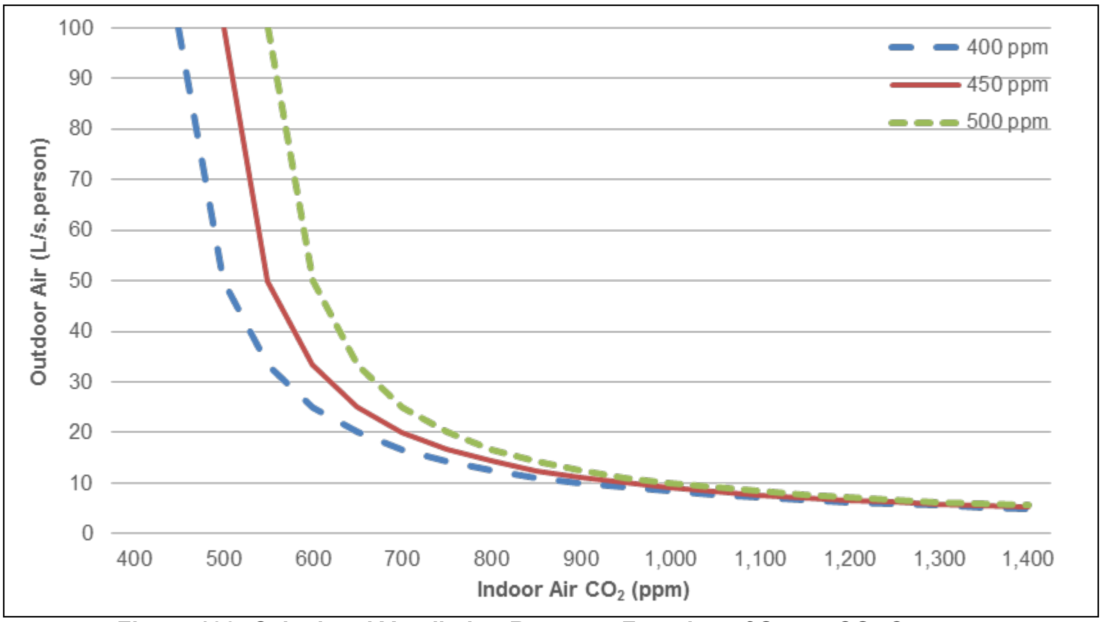


Figure 103: Calculated Ventilation Rate as a Function of Space CO_2 Content.

Figure 103 can be used to show that, if the space CO_2 concentration is measured as 800 ppm and assuming 450 ppm outside, 15 L/s per person of outside air is being supplied or a 50% higher air exchange (ventilation and infiltration) rate than required by the New Zealand standard for good air quality. If the space CO_2 concentration is measured as 600 ppm (assuming 450 ppm outside), about 35 L/s per person of outside air is being supplied or 250% more than required by the New Zealand standard. At 500 ppm, about 100 L/s per person of outside air is being supplied or 900% more than required by the New Zealand standard.

In general, with space CO_2 concentrations less than about 600 ppm, it is difficult to estimate the actual air exchange rate due to its sensitivity to the actual meter accuracy (nominally ±50 ppm) and assumptions about the outside air CO_2 concentrations except to note that the ventilation rate is much higher than necessary to maintain good air quality.

A visual analysis has been undertaken of the 89 CO_2 records allocating each to one of six categories based on the apparent control systems. Table 40 provides the number of locations and buildings by category. Based on this categorisation, only one-third (34%) of the monitored locations had good ventilation control, while half (50%) were over-ventilated. It should be noted that the majority of the locations were not provided with HVAC, so this excessive ventilation may not be due to poor control systems as there are no controls.

Table 40: Carbon Dioxide Profile Categorisation.

Category	Description	Locations count		Buildings count	
Ideal	Often 700 ppm, never over 1,000 ppm	14	16%	13	15%
Very good	Often 700 ppm, sometimes over 1,000 ppm	16	18%	16	19%
Insufficient	Regularly over 1,000 ppm	7	8%	7	8%
Variable	Scattered	7	8%	7	8%
Over-ventilated	Peaks under 600–700 ppm, 3–4 time excess outside air	19	21%	18	21%
Very over-ventilated	Peaks under 500 ppm, 5–10 times excess outside air	26	29%	24	28%
	TOTAL	**89**	**100%**	**85**	**100%**

8.3.1 Examples of Typical BEES CO_2 Profiles

Figure 104 through to Figure 107 show four representative CO_2 concentration profiles monitored in BEES premises to show the variation that can occur in buildings.

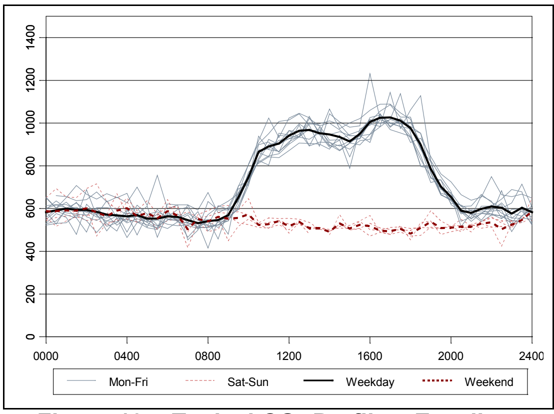


Figure 104: Typical CO_2 Profile – Excellent Ventilation.

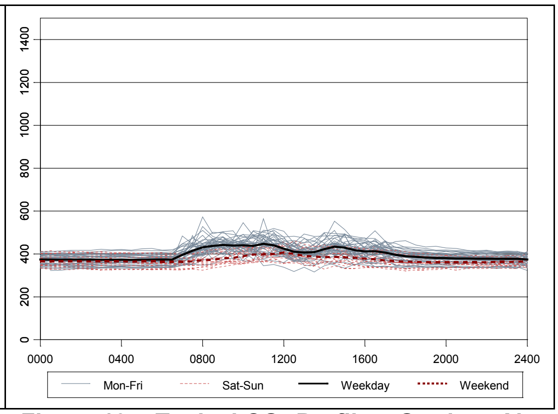


Figure 105: Typical CO_2 Profile – Outdoor Air.

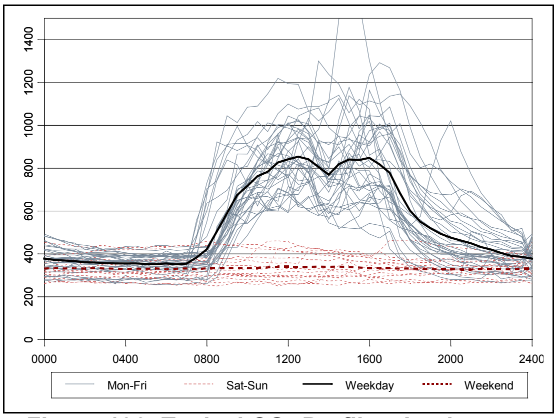


Figure 106: Typical CO_2 Profile – Inadequate Day Ventilation.

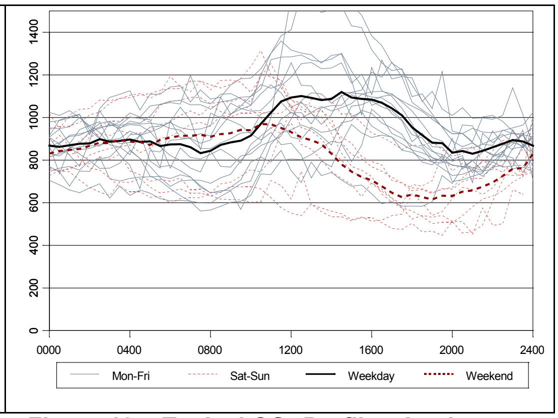


Figure 107: Typical CO_2 Profile – Inadequate Ventilation

Figure 104 shows the CO_2 concentration profile for a location with controlled mechanical ventilation. During the daytime, the CO_2 concentration is between 900 and 1,000 ppm, with fluctuations. Overnight is reasonably constant at around 600 ppm. The average day peak is 930 ±110 ppm, but while the average maximum is 1,130 ppm, the absolute peak was 2,650 ppm.

Figure 105 shows the CO_2 concentration profile for a location with excessive ventilation (compared to its occupancy). The average workday CO_2 level was 430 ±40 ppm, with an absolute maximum of 636 ppm and minimum of 320 ppm.

Figure 106 and Figure 107 show the CO_2 concentration profiles for a location with insufficient ventilation. The reception space in Figure 106 varies from about 400 ppm overnight to an average of 820 ±215 ppm during the working day. As can be seen from the range, the fluctuations are wide, with some periods in the working day over 1,200 ppm. The office location in Figure 107 rarely drops below 800 ppm and again averages about 1,100 ppm during the working day, although the absolute maximum was 1,600 ppm and minimum 430 ppm. The business in Figure 107 works during all or part of the weekend. Both of these locations exceed the recommended 1,000 ppm level from NZS 4303:1990 (Indoor Air Quality Procedure) (Standards New Zealand, 1990). These locations appear to have ventilation systems that cannot deal with the widely varying numbers of people.

8.3.2 Monitored Carbon Dioxide Summary

Table 41 provides a count and the simple average for the total number of locations monitored for CO_2 as well as the same data for office and shop locations associated with these premises (see Table 35 for details of the location types and counts and Table 16 for details on the CPA codes). Figure 108 plots just the simple average, which was calculated by summing for each premise activity the workday average CO_2 levels, then dividing this by the number of premises with that activity. Office and shop locations are found associated with different premise activities, so for the table, they have been separated for analysis.

Table 41: Count and Average CO_2 Level by CPA and Location.

Premise activity	Premise description	Total		Office locations		Shop locations	
		Count	Average CO_2 (ppm)	Count	Average CO_2 (ppm)	Count	Average CO_2 (ppm)
GEN	General Retail	16	605	3	682	10	564
BOX	Big Box Retail	8	476	3	470	4	463
OFF	Office	35	667	24	677	2	489
ICE	Food Storage	7	545	-		5	523
CSV	Commercial Service	6	609	1	1,038	2	476
ISV	Industrial Service	3	579	1	499	-	
HOT	Food Preparation & Cooking	6	592	-		3	580
MIX	Multiple Use	8	761	4	867	1	580
Total		**89**	**626**	**36**	**687**	**27**	**532**

Over the 89 monitored locations, the average workday CO_2 levels ranged from 476 ppm to 764 ppm, in the subset of shop locations, the range was from 463 ppm to 580 ppm, while for Office locations, it was from 470 ppm to 1,038 ppm.

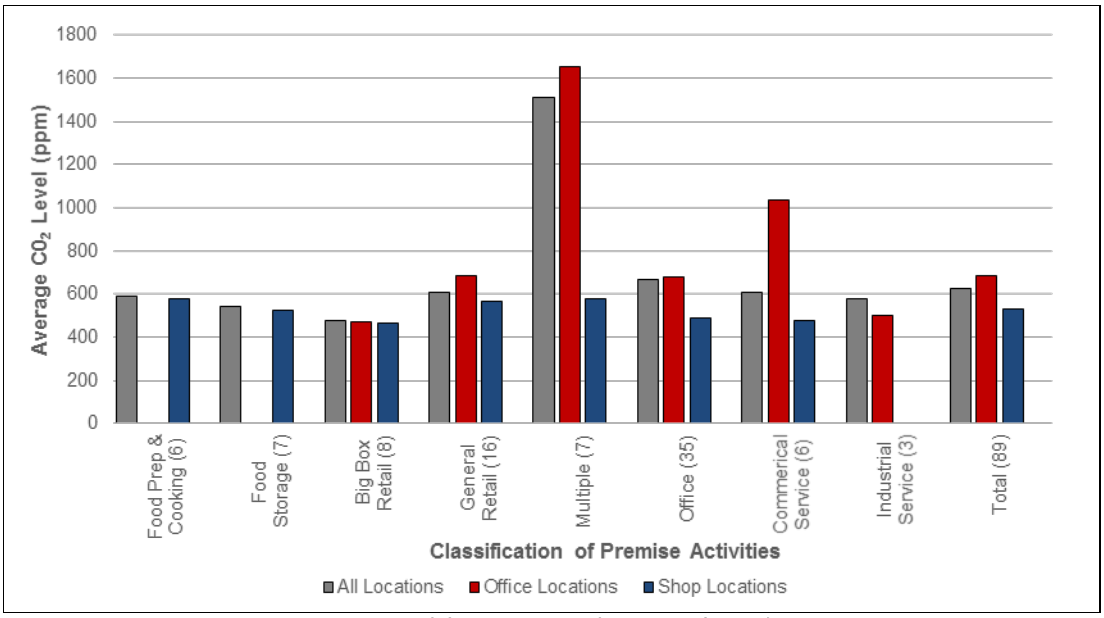


Figure 108: Average CO_2 Levels by CPA and Specific Locations.

Table 42 gives, for the three space groups individually and in total, the weekday range of CO_2 swings by cumulative percent and the mean weekday swing in ppm. The count gives the number of locations in which measurements were taken. The numbers for Other and Shop space groups are too small to support a seasonal analysis. Table 42 shows that just over two-thirds (69%) across all locations and seasons had daily swings in CO_2 level of under ±125 ppm, with a mean swing of ±107 ppm. The Administration space group ranges seasonally from 55% to 69% being within ±125 ppm swing and a season mean from ±98 ppm in summer to ±126 ppm in the intermediate seasons.

Table 42: CO_2 Weekday Average Swing.

Space group Season	Administration Winter	 Summer	 Intermediate	Shop All	Other All	Total All
Count	20	13	20	27	9	89
±25 ppm	0%	0%	0%	11%	11%	4%
±75 ppm	30%	54%	35%	63%	44%	46%
±125 ppm	65%	69%	55%	81%	67%	69%
±200 ppm	90%	92%	90%	96%	67%	90%
±750 ppm	100%	100%	100%	100%	100%	100%
Mean swing	116	98	126	86	126	107

Table 43 tabulates the percent of mean, average weekday minimums and average weekday maximums for a given upper limit of CO_2. The count and mean CO_2 levels are also given. The summer average weekday minimum and maximum could not be calculated for one location, giving a count of 27 instead of 28.

Table 43: CO_2 Weekday All Locations Mean, Minimum and Maximum.

All locations	Weekday mean				Average weekday minimum			Average weekday maximum		
Season	Winter	Summer	Intermediate	All	Winter	Summer	Intermediate	Winter	Summer	Intermediate
Count	25	28	35	88	25	27	35	25	27	35
≥ 400 ppm	96%	96%	97%	97%	96%	85%	89%	100%	100%	100%
≥ 500 ppm	88%	57%	86%	77%	76%	37%	49%	96%	81%	91%
≥ 600 ppm	68%	39%	43%	49%	40%	26%	20%	80%	52%	69%
≥ 700 ppm	40%	29%	26%	31%	8%	11%	11%	56%	41%	46%
≥ 800 ppm	20%	21%	17%	19%		4%		44%	22%	29%
≥ 1,000 ppm		4%	3%	2%				12%	15%	11%
≥ 1,200 ppm								8%	7%	3%
Mean	667	594	622	626	706	644	675	706	644	675

Figure 109 shows the range of measured CO_2 concentrations for the 88 monitored locations. The blue diamonds show the mean value measured on weekdays from 10:00 am to 4:00 pm, the red boxes show the mean value recorded in the same time period on Sundays (when the space would be most likely to be vacant), the small filled purple diamonds show the average weekday maximum and the small open purple diamonds show the average weekday minimum (10:00 am to 4:00 pm). The vertical error bars give ±1 standard deviation.

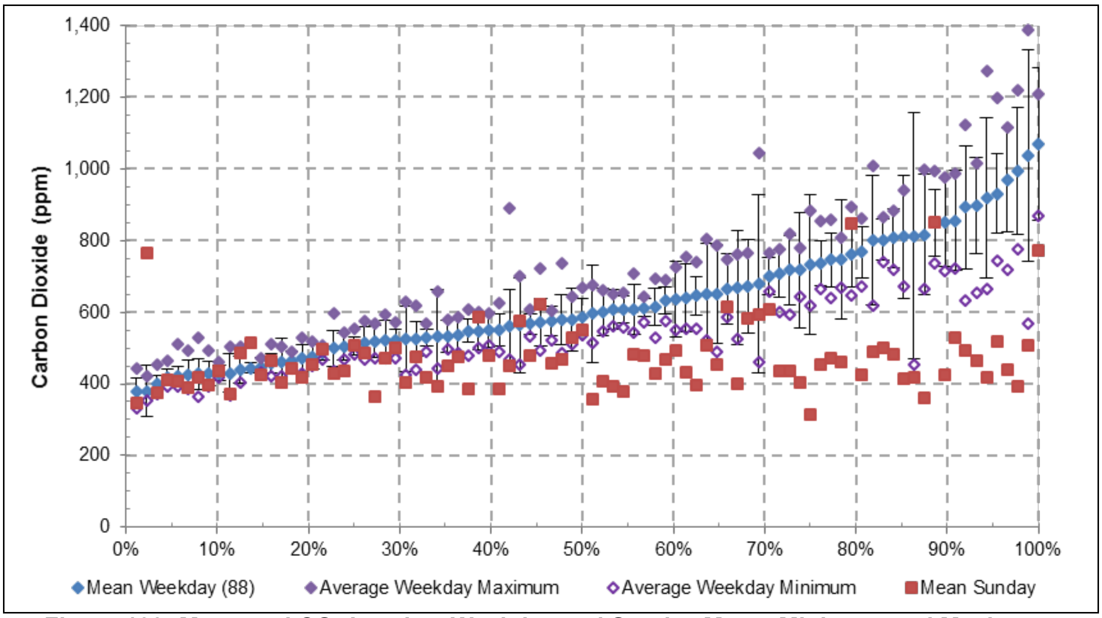


Figure 109: Measured CO_2 Levels – Weekday and Sunday Mean, Minimum and Maximum.

As can be seen from Figure 109 and Table 43, about 23% of the locations monitored show average CO_2 concentrations below 500 ppm (77% above this). This indicates that these locations are ventilated with outside air at more than 10 times the required rate and that this may cause excess heating and cooling loads. Another 28% of the locations are between 500 ppm and 600 ppm, showing excess ventilation rates of between 250% and 900%.

Figure 109 shows that, at the high end of CO_2 concentrations, about 2% of the locations average over 1,000 ppm during normal working hours, and about 19% exceed this at some time each day including 6% that exceed 1,200 ppm. These locations are receiving insufficient fresh air.

A small number of locations have mean Sunday CO_2 levels higher than found during the weekdays. These are all offices attached to some other activity, which, in at least four cases, may have greater numbers of people present than during the normal working week. In other cases, it may be that the normal mechanical ventilation or HVAC system was not operating during the weekend, but a number of people were using the office space.

8.3.3 Carbon Dioxide Levels by Space Groups

Although the sample is relatively limited, it can be segregated by space type and season. When this is done, the resulting weekday distributions of CO_2 concentrations are plotted in Figure 110.

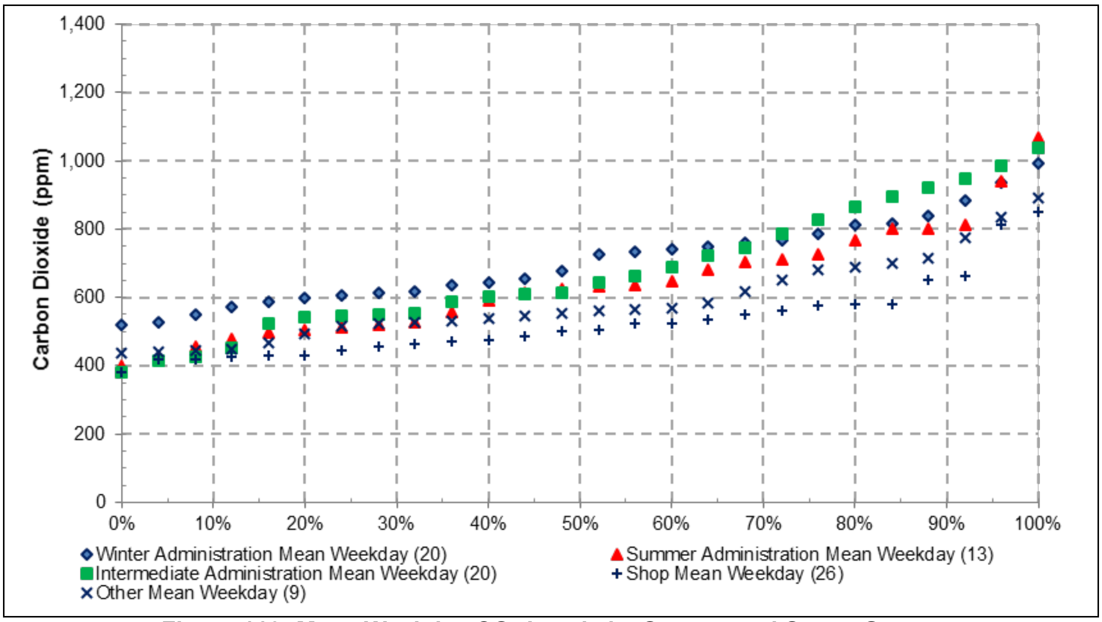


Figure 110: Mean Weekday CO_2 Levels by Season and Space Group.

As can be seen from Figure 110, more than 85% of the locations in the Shop and Other space group in all seasons and 40% of the locations in the Administration space group in the intermediate and summer seasons had mean workday CO_2 concentrations less than 600 ppm, indicating that they are over-ventilated. About 20% of the Administration space group were also in this category in winter.

It is understandable that many locations in the Shop space group would have low concentrations of CO_2, as it is common practice for these premises to leave doors open whenever they can to attract customers.

Likewise, in intermediate seasons, it is common practice for buildings to maximise their outside air ventilation rates, as there are neither heating nor cooling penalties then. In fact, some larger commercial buildings use a 'full fresh air economiser' as an energy-saving strategy, displacing mechanical cooling under moderate ambient temperature conditions.

Even with these considerations, the above analysis shows that the amount of ventilation in the surveyed BEES premises is rarely well controlled.

Only the Administration space group have sufficient monitoring numbers to support a seasonal breakdown. Table 44 gives the weekday mean, average minimum and maximum (calculated by averaging the minimum or maximum for each day of the monitoring) by cumulative percent, the count and the mean CO_2 level in parts per million (ppm) for the Administration space group.

Table 44: Distribution of Weekday Administration CO_2 by Season.

Administration	Weekday mean			Average weekday minimum			Average weekday maximum		
Season	Winter	Summer	Intermediate	Winter	Summer	Intermediate	Winter	Summer	Intermediate
Count	20	13	20	20	13	20	18	12	19
≥ 400 ppm	100%	92%	95%	100%	92%	85%	100%	100%	100%
≥ 500 ppm	100%	77%	85%	90%	62%	65%	100%	92%	89%
≥ 600 ppm	80%	62%	60%	50%	38%	30%	89%	67%	74%
≥ 700 ppm	50%	38%	40%	10%	15%	20%	61%	42%	53%
≥ 800 ppm	25%	23%	30%		8%		44%	17%	37%
≥ 1,000 ppm		8%	5%					8%	16%
≥ 1,200 ppm									
Mean	706	644	675	706	644	675	706	644	675

Table 44 shows that about 8% of the Administration space group averaged over 1,000 ppm during normal working hours during summer and 5% during the intermediate seasons. Considering the average weekday maximum, 8% (1 in 12) exceed this at some time each day during summer and 16% (1 in 6) during the intermediate seasons. As noted earlier, these spaces are receiving insufficient fresh air.

8.4 Illuminance Measurements

The patterns of illuminance measured in the monitored premises were first reported in detail in BEES Study Report 260/3 Delivered Daylighting (Bishop, et al., 2011a). This analysed the amount of daylight supplied to spaces from decomposition of the illuminance profiles. That work has not been repeated.

Care must be taken when measuring illuminance levels to ensure that direct sunlight cannot fall on the sensor, as this can easily result in apparently high illuminance levels. Despite all care, this was found to have occurred in only a very small number of cases. Rather than have the short period of extreme illuminance level distort the averages, it was decided to limit these cases to a maximum of 5,000 lux.

8.4.1 Examples of Typical BEES Illuminance Profiles

Figure 111 through to Figure 115 show four representative monitored illuminance profiles.

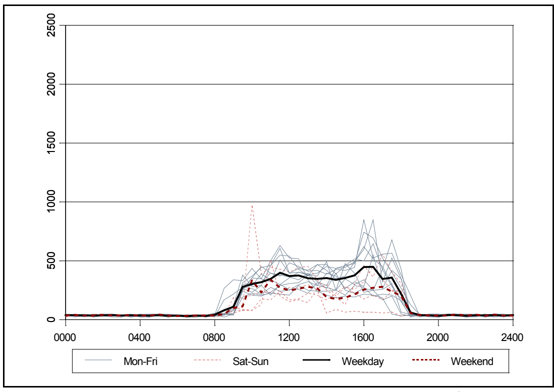


Figure 111: Typical Illuminance Profile – Workday with Some Daylight.

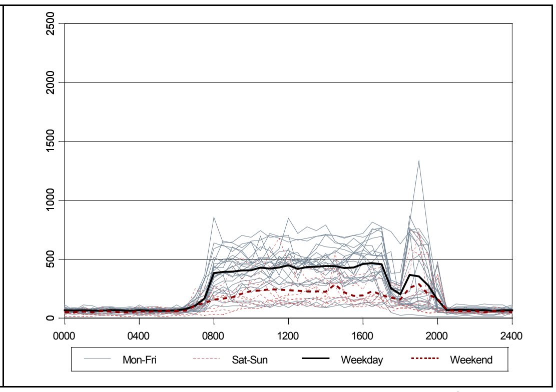


Figure 112: Typical Illuminance Profile – Switching with Some Daylight.

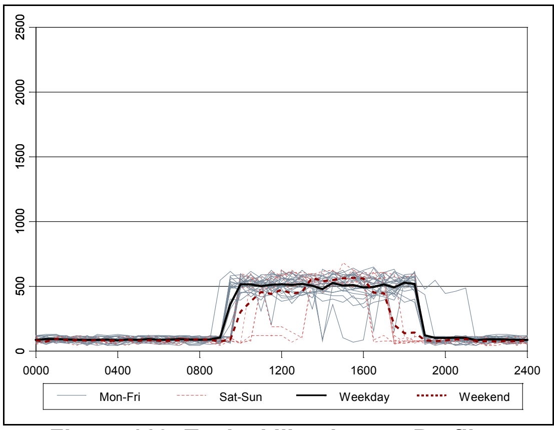


Figure 113: Typical Illuminance Profile – Regular Switching.

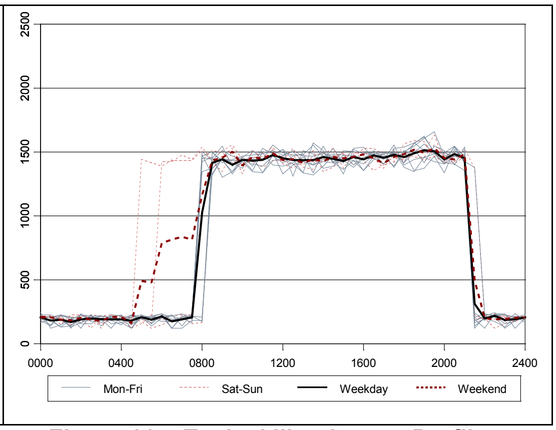


Figure 114: Typical Illuminance Profile – Tight Switching, High Illuminance, No Daylight.

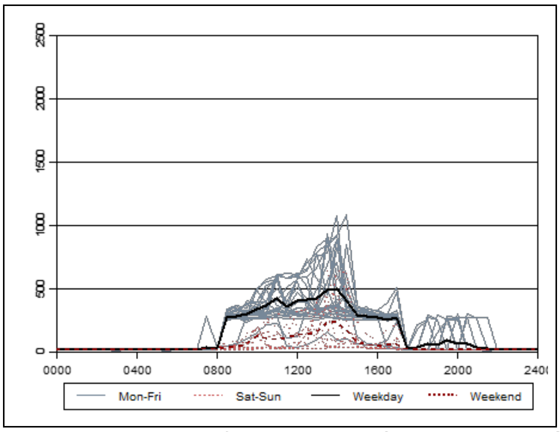


Figure 115: Typical Illuminance Profile – Regular Switching and Good Daylight.

Figure 111 shows the illuminance profile for a shop space with electric lighting operating during the workday and good daylight through the day (indicated by the Sunday morning curve). The mean workday is 360 ±110 lux with an absolute maximum of 1,600 lux and minimum of 24 lux. The electric lights are switched on at about the same time each morning, remaining on till the end of the day.

Figure 112 also shows the illuminance profile for an office reception location with electric lighting operating during the workday and some daylight in the morning. The mean workday is 430 ±170 lux with an absolute maximum of 1,700 lux and minimum of 16 lux. The electric lights are usually switched on at 8:00 am, but some are shut off around 5:00 pm and then switched on again at about 6:00 pm before finally being switched off between 7:00 pm and 8:00 pm, giving the dip and then downward-sloping evening average illuminance profile.

Figure 113 shows the illuminance profile for a reception location with electric lighting operating all day and little or no daylight. It varies from about 450–600 lux during the middle of the working day. The electric lights are switched on and off at consistent times, leading to the square wave pattern. The workday mean illuminance is 510 ±90 lux.

Figure 114 shows the illuminance profile for a 7-day-a-week shop location with tightly controlled electric lighting and very little (if any) daylight. The lights are turned on almost all mornings at 8:00 am and off at 9:30 pm. There is some overnight light, possibly due to display lighting that is permanently on. The weekday mean is 1,440 ±60 lux with a daily average minimum of 1,310 lux and a daily average maximum of 1,580 lux. The absolute maximum was 1,660 lux and minimum 110 lux.

Figure 115 shows the illuminance profile for an office location. While the electric light is well controlled, switching on after 8:00 am and off about 5:00 pm with occasional evening lighting, during the daytime, there is a noticeable amount of daylight provided. The weekday mean is 390 lux ±180 lux with the absolute maximum 2,570 lux and absolute minimum 12 lux.

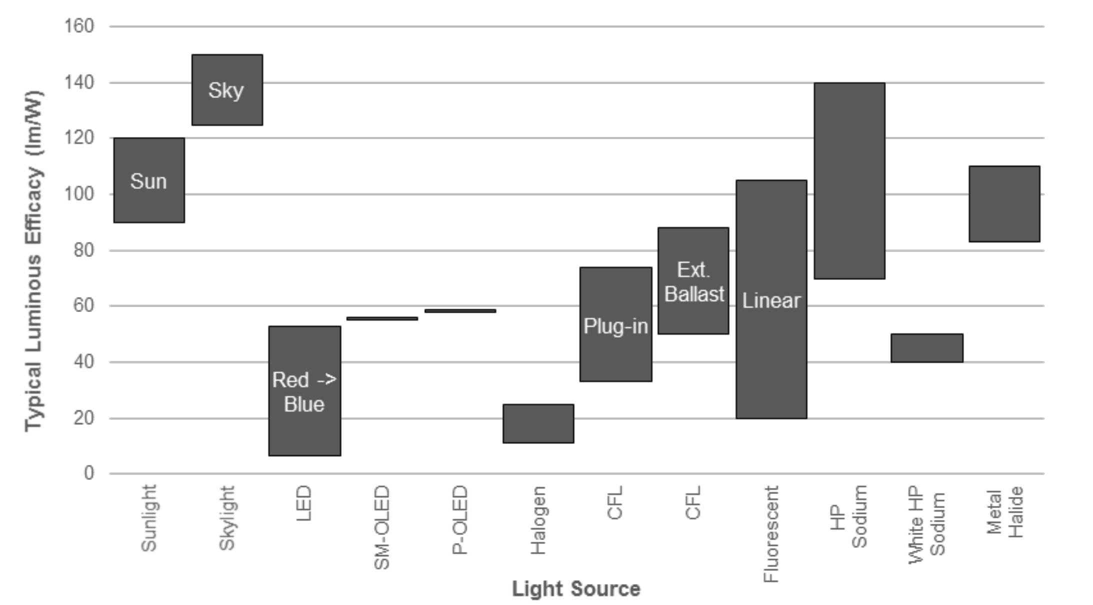


Figure 116: Typical Luminous Efficacy for Selected Light Sources.

Figure 116 provides typical luminous efficiency for a range of light sources (Graves & Ticleanu, 2011). Small molecule (SM-OLED) and polymer (P-OLED) organic light-emitting diodes are currently used for displays, such as found in cell phones. Light sources that offer higher lumens per watt (lm/W) (more light for the same energy) are more desirable. Use of skylight and sunlight, where available, provides the highest efficacy combined with colour rendering – something the nearest competitors, apart from fluorescent lamps, have yet to achieve. Thus, a high-quality lighting design would, where possible or appropriate, include the use of daylighting in order to achieve the highest possible efficacy.

8.4.2 Monitored Illuminance Summary

Table 45 provides a count and the simple average for the total number of locations monitored for illuminance as well as the same data for office and shop locations associated with these premises (see Table 35 for details of the location types and counts). Figure 117 provides the simple average, which was calculated by summing for each premise activity the workday average illuminance, then dividing this by the number of premises with that activity. Office and shop locations are found associated with different premise activities, so for the table, they have been separated for analysis.

Table 45: Count and Average Illuminance by CPA and Specific Locations.

Premise activity	Premise description	Total		Office locations		Shop locations	
		Count	Average (lux)	Count	Average (lux)	Count	Average (lux)
GEN	General Retail	43	345	13	398	18	320
BOX	Big Box Retail	24	403	8	328	8	442
OFF	Office	150	464	93	451	3	1,359
ICE	Food Storage	24	305	5	206	8	428
CSV	Commercial Service	19	384	4	293	5	485
ISV	Industrial Service	8	516	3	526	1	223
HOT	Food Preparation & Cooking	13	208	2	209	3	262
MIX	Multiple Use	24	376	15	378	1	130
Total		**305**	**408**	**143**	**417**	**47**	**433**

Over the 305 monitored locations, the average workday illuminance for each of the premise activity groupings ranged from 252 lux to 516 lux, while in the subset of shop locations, the range was from 130 lux to 1,359 lux, and in office locations, the range was from 206 lux to 526 lux.

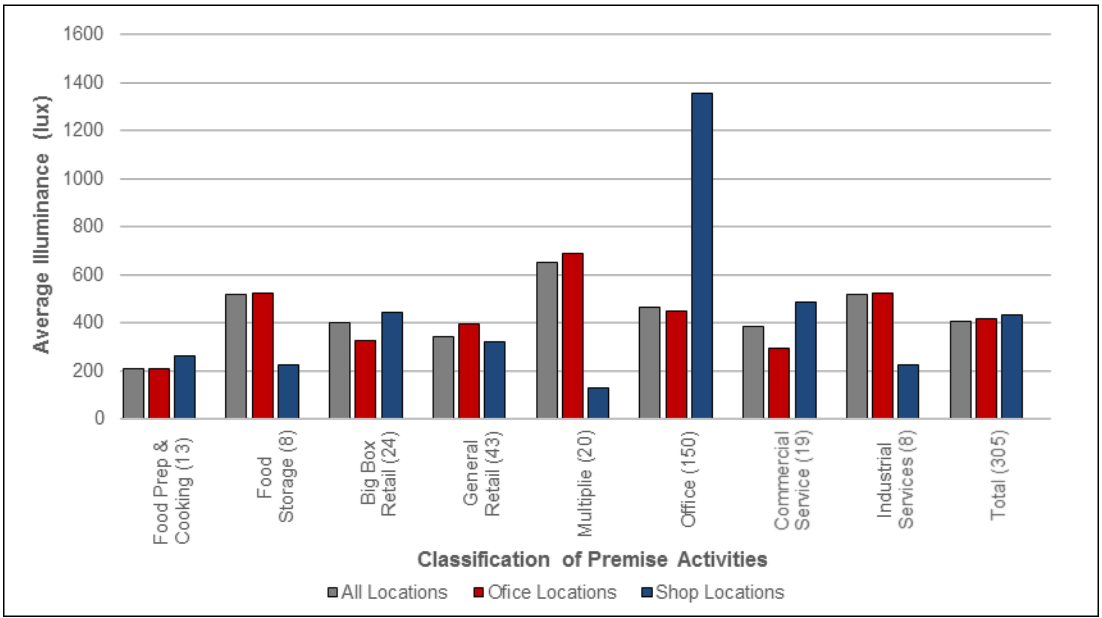


Figure 117: Average Illuminance by CPA and Specific Locations.

Unlike the other monitored environmental conditions, extremely high illuminance levels are unlikely to be due to poor control systems, except where controllable shades or other systems are in place to deal with daytime direct sun. 30,000 lux can be recorded if direct sun reaches the sensor, but this may not be of concern to the users of that space. This occurred for a small number of sensors, leading to the apparently very high average illuminance in the office locations shown in Figure 117.

Figure 118 shows the distribution of the weekday average illumination for Administration (winter, summer and intermediate seasons), Shop and Other space groups. The workday mean (50 percentile) for the Administration space group is 317 lux, but across the locations monitored, it varied from 232 lux in summer to 322 lux in winter to 401 lux in the intermediate seasons. Figure 118 also gives the illumination level distribution of the Shop space group (mean 307 lux) and Other space group (mean 224 lux). The distributions, apart from the Administration space group intermediate season, follow each other reasonably closely. This may indicate some difference in the locations monitored for illuminance over the intermediate seasons compared to the other seasons.

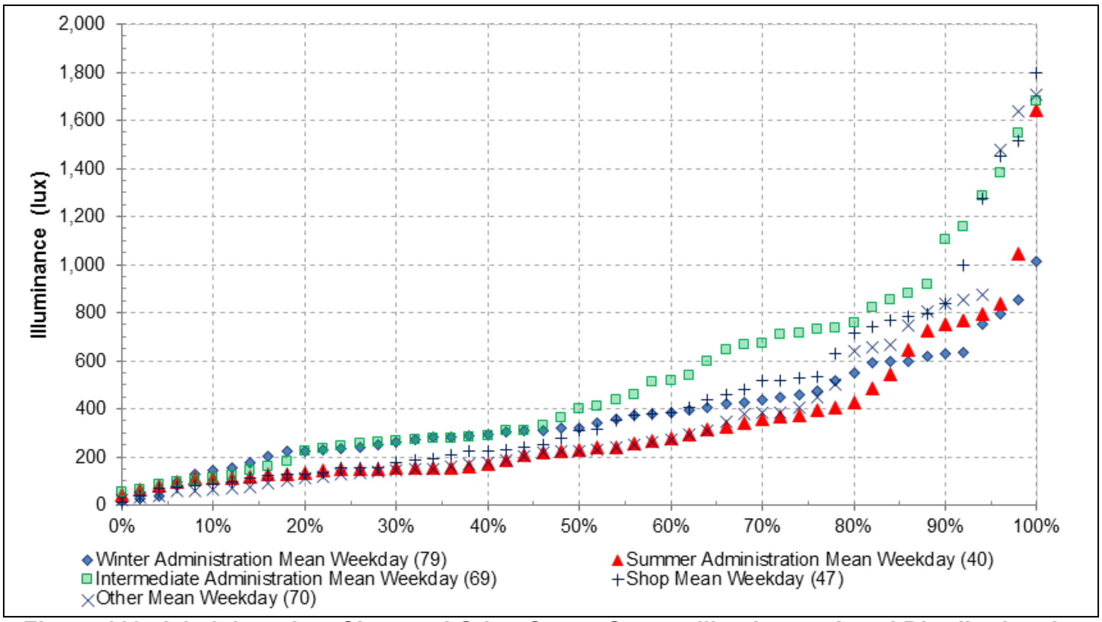


Figure 118: Administration, Shop and Other Space Groups Illuminance Level Distribution, by Season.

Table 46 gives the weekday mean, average minimum and maximum (calculated by averaging the minimum or maximum for each day of the monitoring) by cumulative percent, the count and the mean illuminance level (lux) for all spaces. Table 46 shows that about 4% of all locations average over 1,000 lux during normal working hours during summer and 8% during the intermediate seasons. Considering the average weekday maximum, 12% (1 in 8) exceed this on average at some time each day during summer and 20% (1 in 5) during the intermediate seasons. The reasons (or need) for these high levels of average illuminance have not been explored, but they may possibly offer some opportunity for reduced lighting levels and hence improved energy efficiency.

Table 46: Distribution of Weekday Illuminance for all Locations by Season.

All spaces	Weekday mean				Average weekday minimum			Average weekday maximum		
Season	Winter	Summer	Intermediate	All	Winter	Summer	Intermediate	Winter	Summer	Intermediate
Count	103	81	121	305	103	81	121	103	81	121
≥ 200 lux	71%	60%	76%	70%	52%	44%	55%	80%	75%	83%
≥ 400 lux	30%	30%	47%	37%	11%	21%	28%	46%	44%	60%
≥ 600 lux	11%	23%	31%	22%	3%	11%	16%	22%	27%	42%
≥ 800 lux	3%	14%	17%	11%	1%	4%	8%	14%	21%	31%
≥ 1,000 lux	1%	5%	11%	6%		1%	3%	5%	17%	21%
≥ 1,400 lux		4%	7%	4%			1%	2%	10%	12%
≥ 1,800 lux			1%						2%	8%
Mean (lux)	356	350	597	404	356	350	597	356	350	597

The distribution in weekday average illuminance measured in the Administration space group is shown in Figure 119 and summarised in Table 47 by season. The blue diamonds show the mean value measured on weekdays from 10:00 am to 4:00 pm, the red boxes show the mean value recorded in the same time period on Sundays (when the space would be most likely to be vacant), the small filled purple diamonds show the average weekday maximum and the small open purple diamonds show the average weekday minimum (10:00 am to 4:00 pm). The vertical error bars give ±1 standard deviation.

Table 47: Distribution of Weekday Illuminance for Administration Space Group by Season.

Office	Weekday mean			Average weekday minimum			Average weekday maximum		
Season	Winter	Summer	Intermediate	Winter	Summer	Intermediate	Winter	Summer	Intermediate
Count	79	40	69	79	40	69	79	40	69
≥ 200 lux	84%	58%	81%	63%	40%	59%	89%	73%	87%
≥ 400 lux	38%	25%	51%	14%	18%	32%	56%	35%	64%
≥ 600 lux	14%	15%	36%	4%	10%	17%	29%	23%	46%
≥ 800 lux	4%	8%	19%	1%	3%	10%	18%	13%	32%
≥ 1,000 lux	1%	3%	12%			3%	6%	10%	22%
≥ 1,400 lux		3%	4%			1%	3%	5%	13%
≥ 1,800 lux								3%	7%
Mean	356	350	597	244	266	341	495	460	891

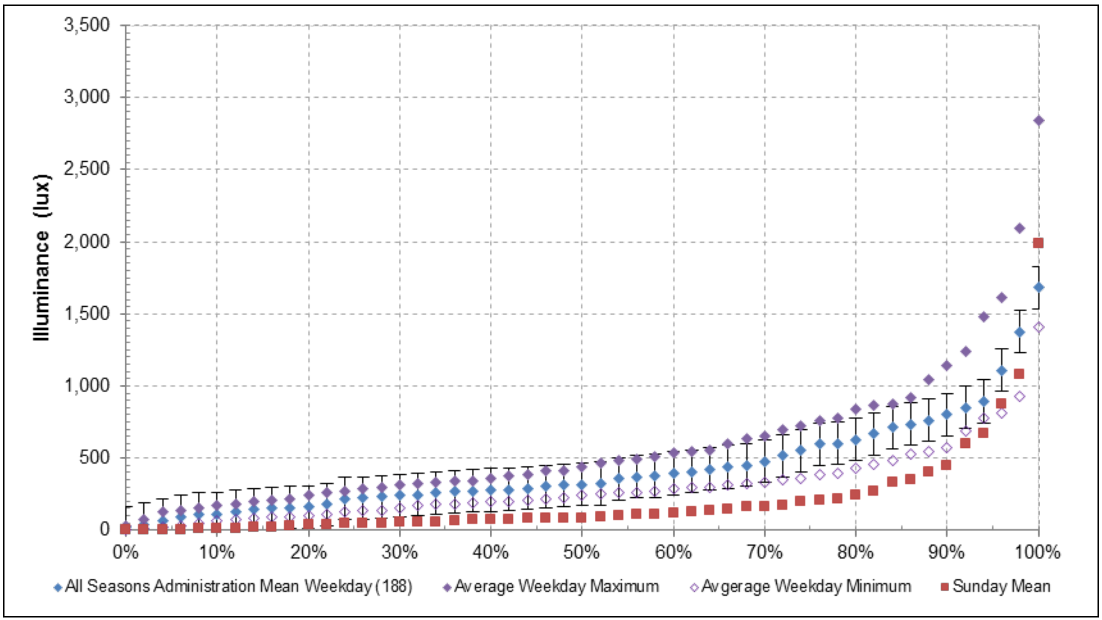


Figure 119: Locations in Administration Space Group Illuminance Level Distribution.

As can be seen from Figure 119, about 50% of the Administration space group had recorded mean workday illuminance levels lower than the target of 320 lux, as shown in Table 48. Table 48 is extracted from AS/NZS 1680.1:2006 *Interior and workplace lighting – Part 1: General principles and recommendations* (Standards New Zealand, 2006) Table 3.1, where 320 lux is the recommended maintained illuminance for routine office tasks. While the highest 30% of mean weekday measurements were above 500 lux, 8% recorded mean values under 100 lux. About half of the Administration space group measured during this study had average daily *maximum* illuminance over 420 lux. As noted earlier, the average maximum can be affected by exposure of the sensor to direct sunlight, so without additional analysis, no comment can be made on average daily maximum lux levels.

Table 48: Recommended Task Illuminances (Standards New Zealand, 2006).

Task requirements	Illuminance
Movement and orientation only	40 lux
Rough intermittent	80 lux
Simple tasks	160 lux
Ordinary tasks	240 lux
Moderately difficult tasks	320–400 lux
Difficult	600 lux
Very difficult	800 lux
Extremely difficult	1,200 lux
Exceptionally difficult	1,600 lux

Figure 120 presents data for the Shop space group. This again has the low illuminance levels already seen in the Administration space group, which is somewhat surprising, as Shop spaces are often thought to be over-illuminated in an attempt to sell more products.

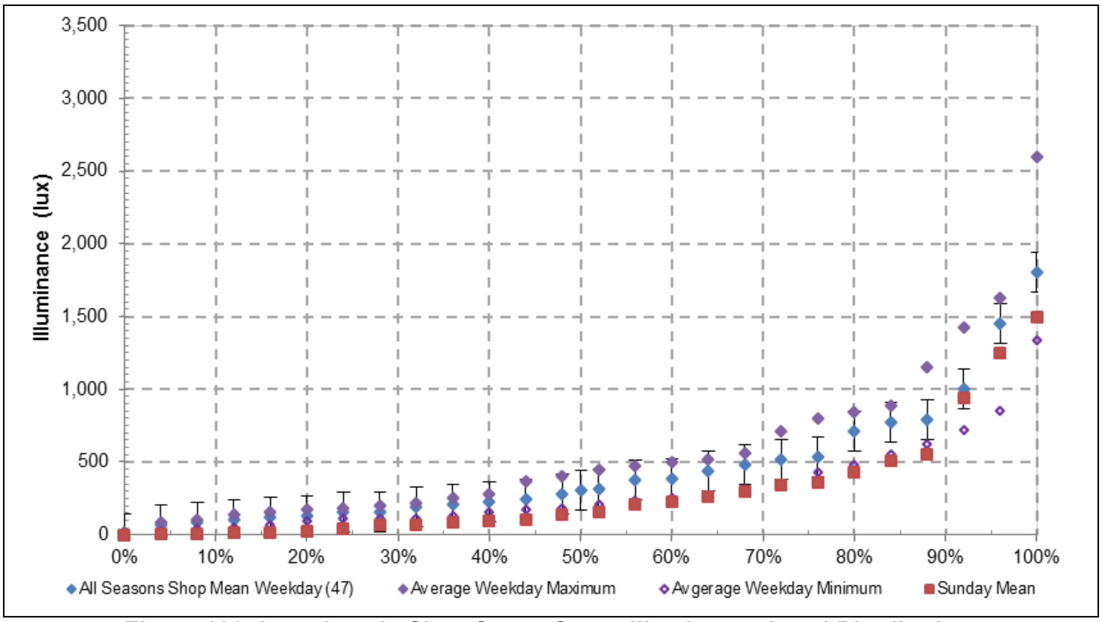


Figure 120: Locations in Shop Space Group Illuminance Level Distribution.

Figure 120 shows that, like the Administration space group, about 50% of the Shop space group had recorded mean illuminance levels lower than the 320 lux target, with 12% below 100 lux. However, 30% of premises had average illuminance measured over 500 lux, with the top 10% over 1,000 lux.

Figure 121 presents the same type of data for the Other space group. These locations, on average, have lower illuminances than the Administration and Shop space groups.

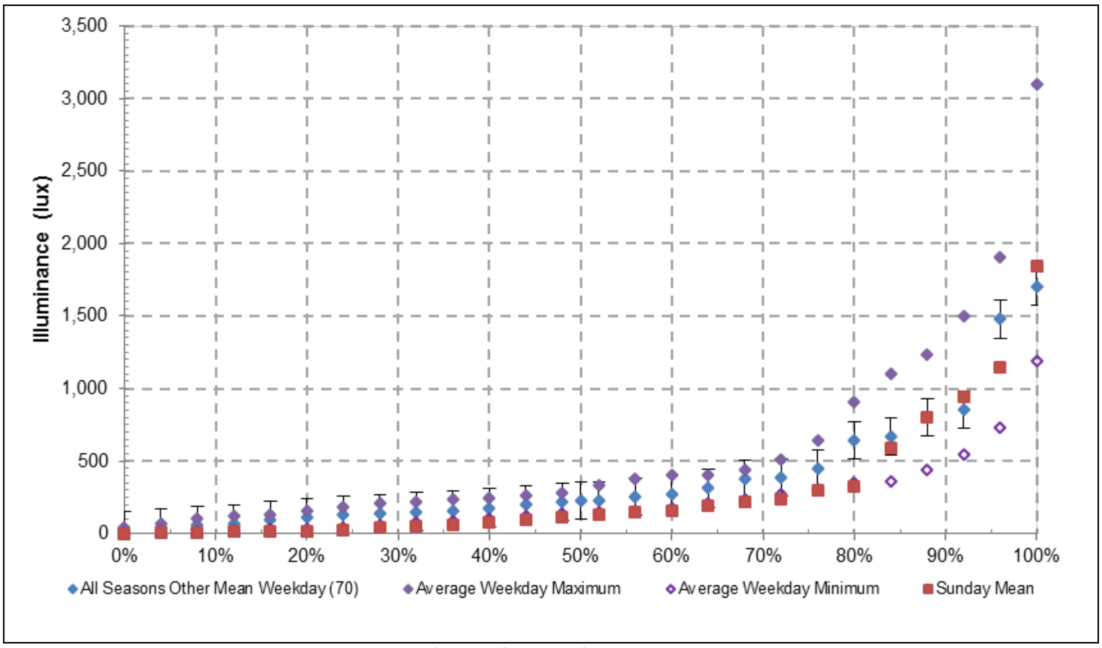


Figure 121: Locations in the Other Space Group Illuminance Level Distribution.

Figure 121 shows that the trend towards low illuminance levels is even more pronounced in the Other space group, with 65% of the Other space group showing mean illuminance levels lower than 320 lux and about 40% below 100 lux. Only the highest 30% of the Other space group had average illuminance measured over 600 lux. These were kitchens and workrooms but also a warehouse and a storeroom. However, several kitchens were at the very low end of the illuminance distribution.

8.5 Relative Humidity

The amount of moisture that air can hold without condensation increases with temperature, as warmer air can hold much more water than cold air. The amount of water held in air is called, variously, moisture content, absolute humidity, humidity ratio, vapour pressure or dewpoint.

The first three quantities have units of grams of water per gram dry air, vapour pressure has units of pascals and dewpoint has units of temperature (the temperature at which air of that moisture content becomes saturated and its water content begins spontaneously condensing when cooled). Relative humidity is a measure of the moisture content of air, divided by the maximum moisture content at that temperature.

In this section, an analysis of relative humidity is presented. The importance of relative humidity is that electronic equipment prefers operating conditions near 50% (too high, and there may be condensation; too low, and there may be static electricity discharges). There are also health effects of very high relative humidity, particularly associated with cooler temperatures.

Figure 122 plots the monthly mean 9:00 am relative humidity and temperatures for Wellington over the period 1981 to 2010. It can be seen that, while the mean temperature shows a very strong seasonal pattern (falling from 17.2°C in February to 8.9°C in July) with a range of 12.9 ±4.2°C, relative humidity shows a more consistent pattern (falling from 86.3% in July to 79.7% in November) with a range of 82.9 ±3.3%. It is expected that, while winter indoor relative humidity will fall (this is due to the absolute amount of moisture not changing while the warmer air is able to hold more moisture), in summer, where there is no temperature control, the indoor conditions will closely follow the outdoor temperature and relative humidity.

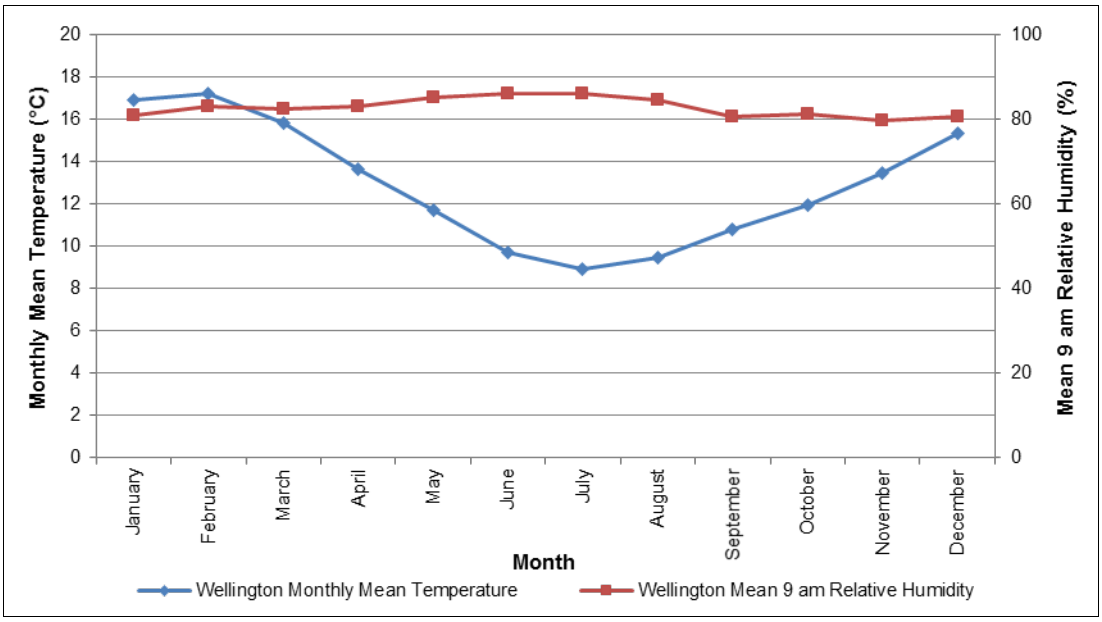


Figure 122: Wellington Monthly Mean Temperatures and 9:00 am Relative Humidity.

(Data sources: www.niwa.co.nz/education-and-training/schools/resources/climate/humidity and www.niwa.co.nz/education-and-training/schools/resources/climate/meanairtemp)

8.5.1 Monitored Relative Humidity Summary

Table 49 provides a count and the simple average for the total number of locations monitored for relative humidity as well as the same data for office and shop locations associated with these premises (see Table 35 for details of the location types and counts). Figure 123 provides just the simple average, which was calculated by summing for each premise activity the workday average relative humidity then dividing this by the number of premises with that activity. Office and shop locations are found associated with different premise activities, so for the table, they have been separated for analysis.

Over the 330 monitored locations, the average workday relative humidity ranged from 49% to 57%, while in the subset of shop locations, the range was from 46% to 57%, and in offices, the range was from 48% to 57%.

Table 49: Count and Average Relative Humidity by Premise Activity and Specific Locations.

Premise activity	Premise description	Total		Office locations		Shop locations	
		Count	Average relative humidity (%)	Count	Average relative humidity (%)	Count	Average relative humidity (%)
GEN	General Retail	52	51	15	51	24	50
BOX	Big Box Retail	25	55	9	54	8	51
OFF	Office	156	49	96	49	4	46
ICE	Food Storage	29	55	6	57	10	48
CSV	Commercial Service	21	56	4	56	6	55
ISV	Industrial Service	8	51	3	51	1	57
HOT	Food Preparation & Cooking	15	57	2	63	3	53
MIX	Multiple Use	24	50	15	48	1	56
Total		**330**	**51**	**150**	**50**	**57**	**51**

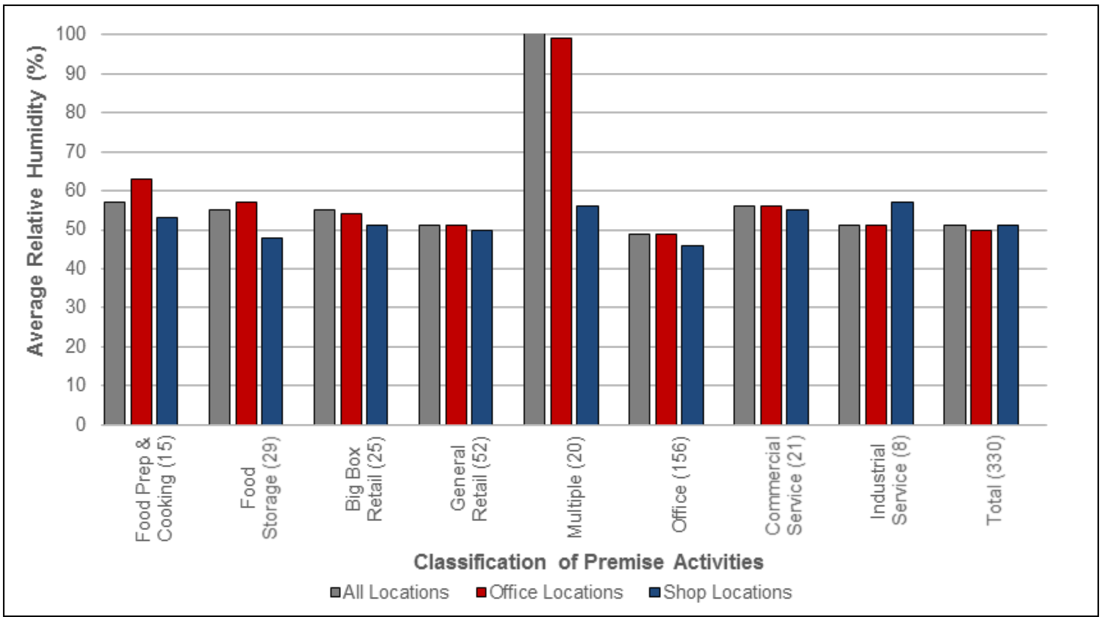


Figure 123: Average Relative Humidity by CPA and Specific Locations.

Figure 124 shows the distribution of weekday relative humidity for all Administration, Shop and Other space groups. The Administration and Shop space group relative humidity results track each other more closely than the relative humidity in the Other space group, perhaps unsurprisingly given the lower temperature levels in the Other space group (see Table 39).

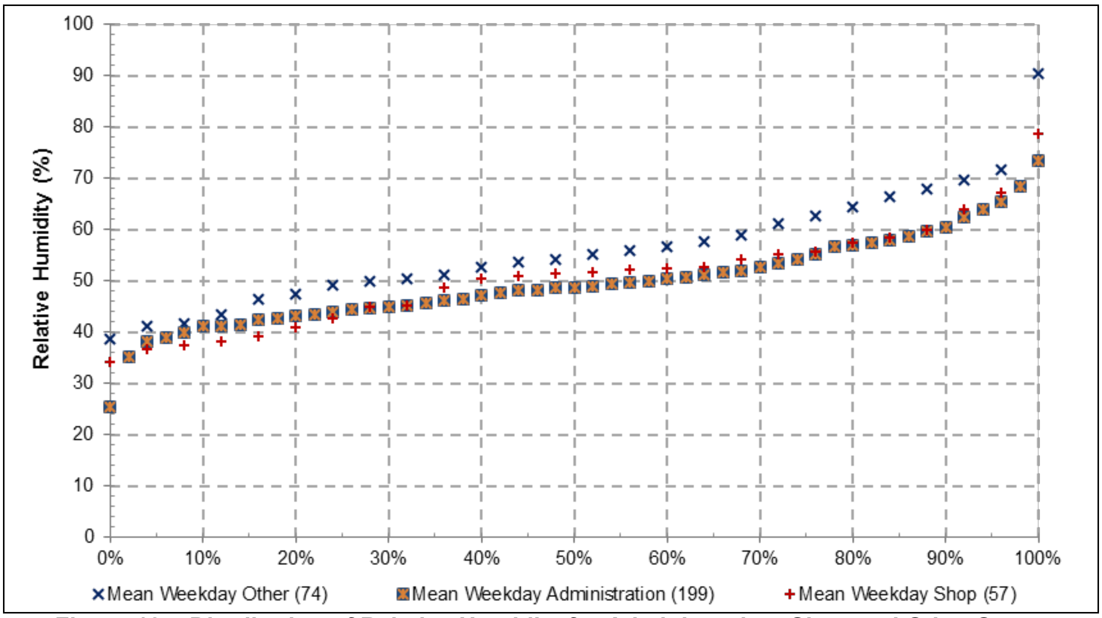


Figure 124: Distribution of Relative Humidity for Administration, Shop and Other Space Groups.

The dataset was segregated by season and building type. Figure 125 shows the measured average relative humidity for the Administration space group (weekday 10:00 am to 4:00 pm) in each of the three season types.

As expected, the summer relative humidity results are higher than those in winter and are close to those in the intermediate seasons except for the 50th to 80th percentiles. This is most likely due to the moisture levels of indoor air generally tracking outdoor air, which has higher moisture content (relative humidity) in summer.

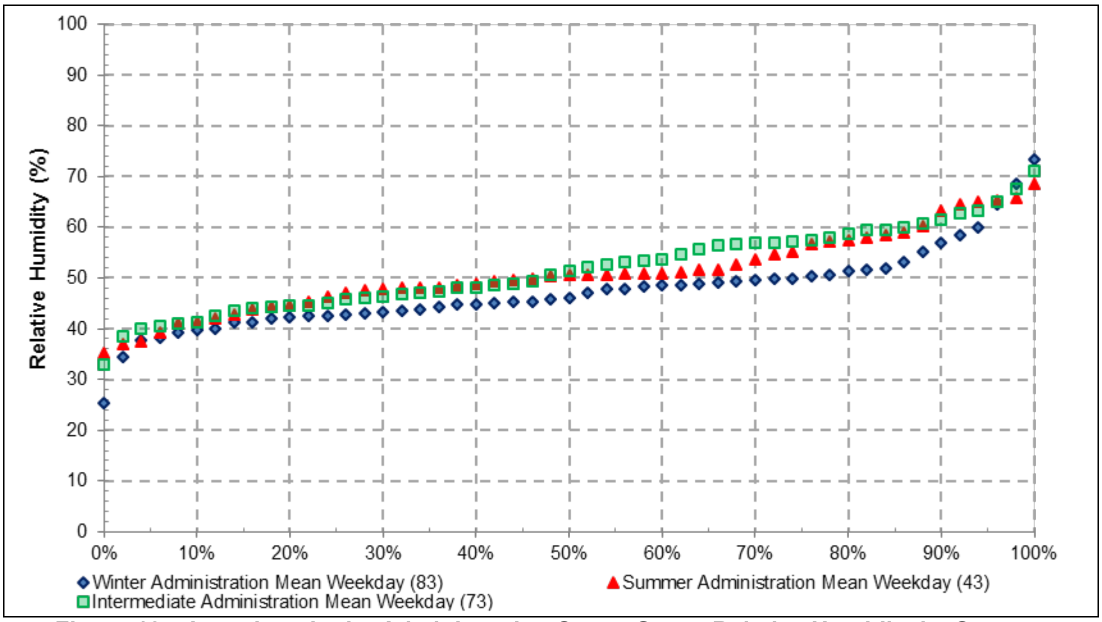


Figure 125: Locations in the Administration Space Group Relative Humidity by Season.

Table 50 tabulates for Administration space group, the weekday mean, the weekday average minimum and the weekday average maximum relative humidity by season. During the winter and intermediate seasons, on average, 53% of the Administration space group had over 50% relative humidity, while in winter, this was found only in 25% of the Administration space group – showing the benefits of winter heating, which, as noted earlier, increases the air temperature and reduces relative humidity.

Table 50: Distribution of Relative Humidity Weekday Administration Space Group Mean, Average Minimum and Average Maximum by Season.

Administration	Weekday mean			Average weekday minimum			Average weekday maximum		
Season	Winter	Summer	Intermediate	Winter	Summer	Intermediate	Winter	Summer	Intermediate
Count	83	43	73	83	43	73	83	43	73
≥ 20%	100%	100%	100%	100%	100%	100%	100%	100%	100%
≥ 30%	99%	100%	100%	99%	100%	100%	99%	100%	100%
≥ 40%	87%	93%	96%	82%	86%	85%	96%	95%	99%
≥ 50%	25%	53%	53%	16%	26%	45%	45%	72%	68%
≥ 60%	6%	14%	14%	4%	7%	10%	11%	26%	25%
≥ 80%							1%		
Mean	46	49	51	44	47	48	49	53	55

Similar relative humidity patterns for Administration spaces were also found for the Shop and Other space groups, as shown in Figure 126 and Figure 127, although for smaller numbers of measurement locations.

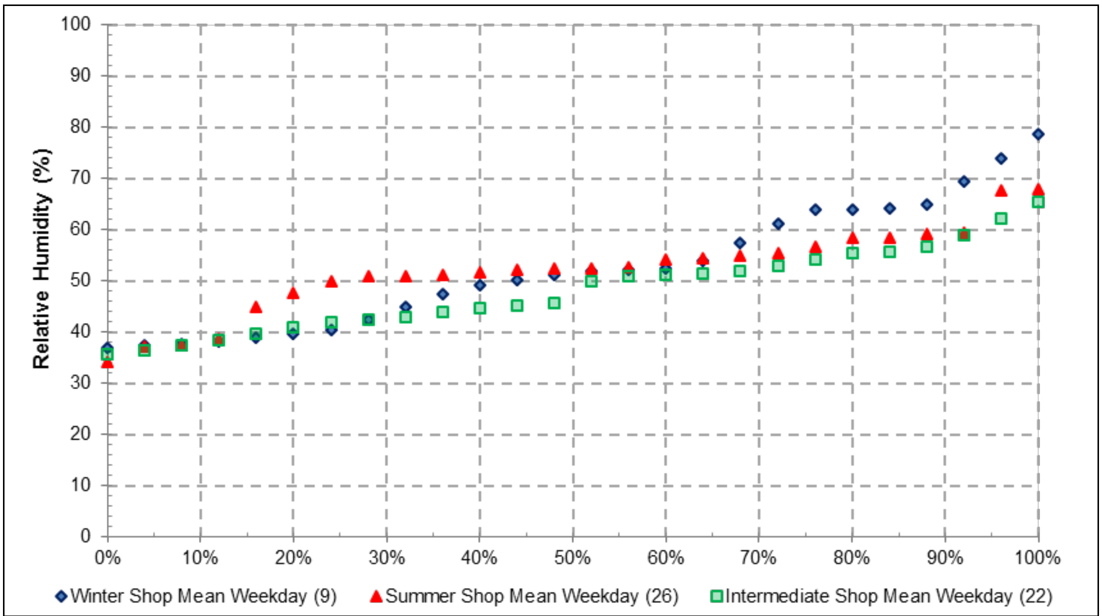


Figure 126: Locations in Shop Space Group Relative Humidity by Season.

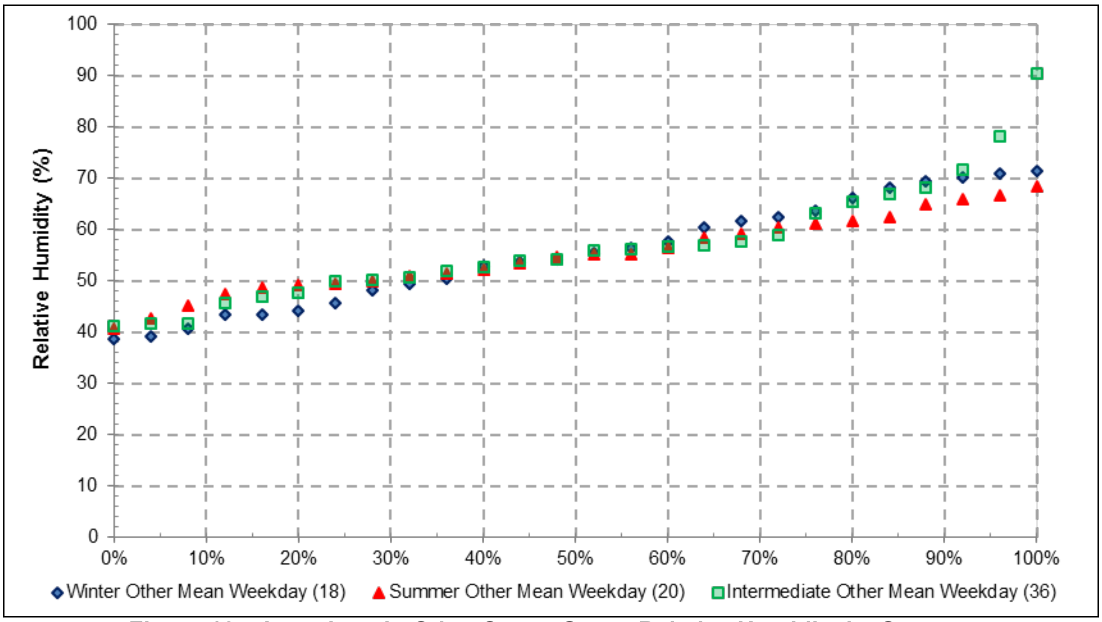


Figure 127: Locations in Other Space Group Relative Humidity by Season.

The distributions of relative humidity for all spaces across all seasons are shown in Figure 128. Again, the blue diamonds represent the mean value recorded on weekdays, 10:00 am to 4:00 pm, the filled diamonds the average weekday maximum and the open diamonds the average weekday minimums.

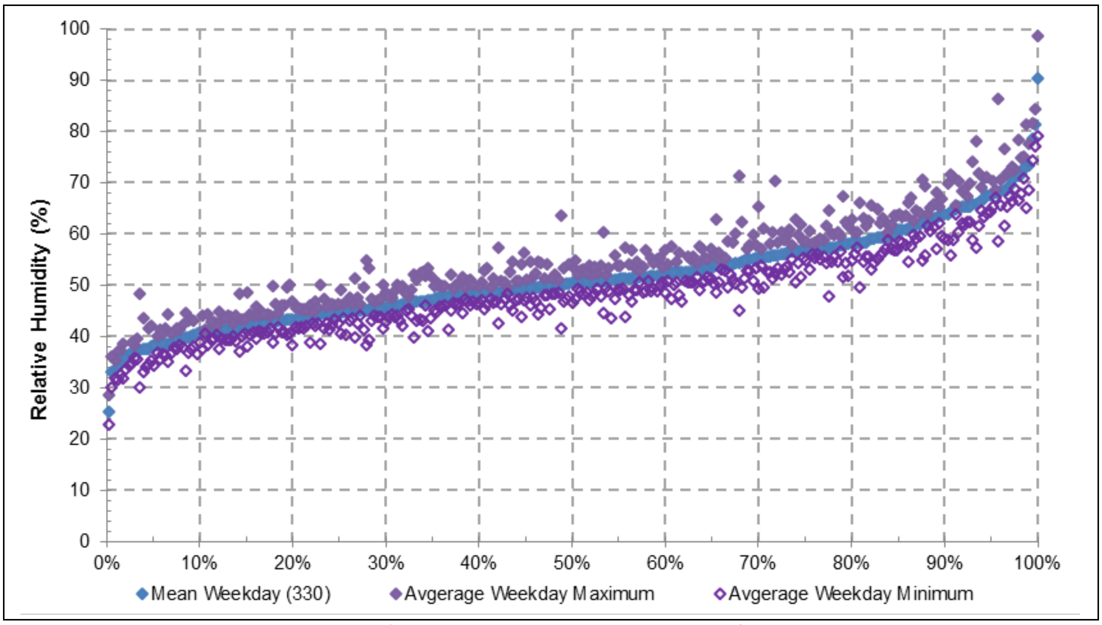


Figure 128: Distribution of Relative Humidity Across All Seasons and Locations.

As shown in Figure 128, about three-quarters (76%) of the sample had a mean relative humidity between 40% and 60%, in the optimal range. The standard deviation was typically +5% to -6%.

Figure 129 shows the seasonal distribution of relative humidity for all locations by season.

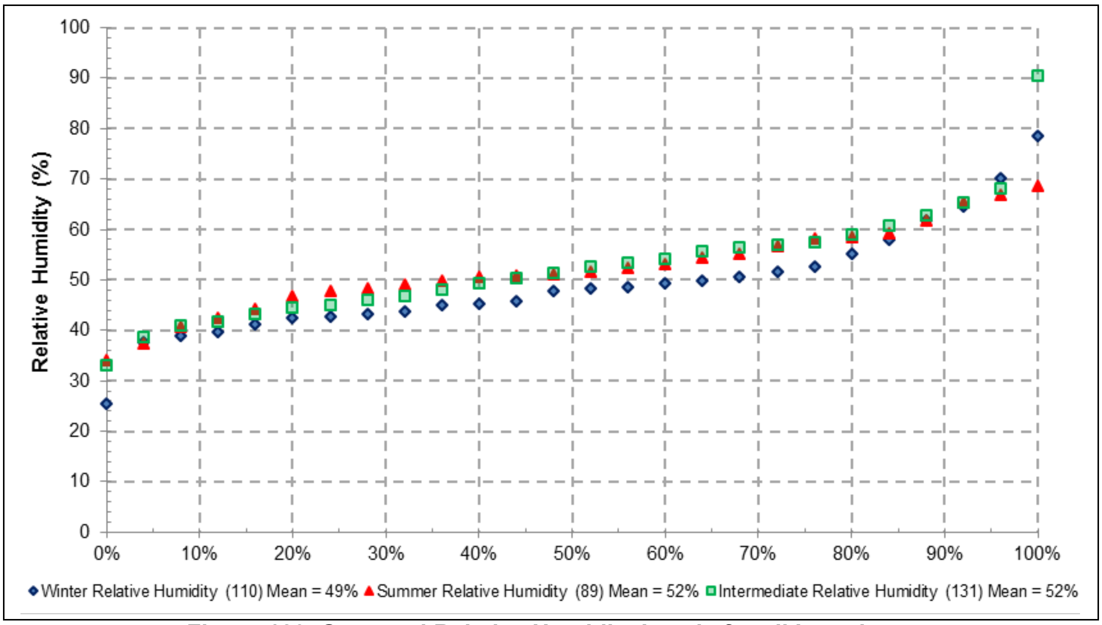


Figure 129: Seasonal Relative Humidity Levels for all Locations.

As can be seen, there was very little difference between seasons, with summer relative humidity typically about 3% higher than winter. In each of the seasons, about 15% of locations had relative humidity over 60%.

8.6 Full-year Monitoring

As well as short-term monitoring, temperatures and relative humidity were monitored for about 1 year in 33 locations in 30 buildings. Table 51 provides a summary by space group, location, number of sensors, buildings and the minimum and maximum number of days monitored. The majority of locations were in the Administration space group (21 out of 33), with only one location in the Other space group. The minimum monitoring period was for under a year (315 days) while the longest was for just under 1½ years (543 days). The average number of days monitored was 495 days (1⅓ years).

Table 51: Spaces Count Monitored by Location, Space Group, Sensor Types and Number of Days.

Space group	Location	Number of sensors			Number of days	
		Temperature	Relative humidity	Buildings	Minimum	Maximum
Administration	Office	16	16	14	357	543
Shop	Shop	11	11	11	375	543
Administration	Reception	5	5	5	315	543
Other	Corridor	1	1	1	496	496
	Total	**33**	**33**	**30**		

Note: There are 30 buildings, as two different location types were monitored in one building.

Figure 130 and Table 52 give the breakdown by the year monitoring commenced – 42% started in 2010, 52% in 2011 and 6% in 2012. Table 52 also gives details of the locations and space groups.

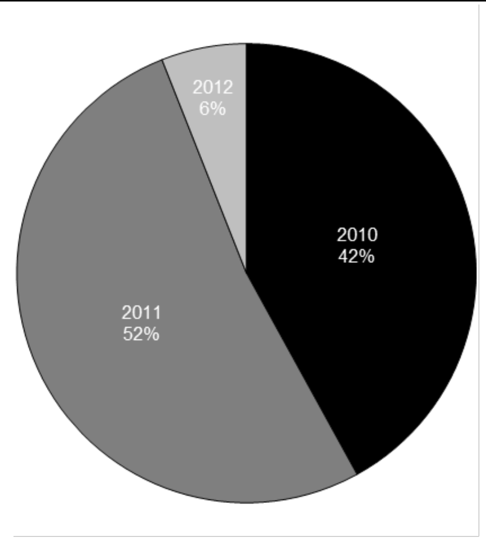


Figure 130: Spaces Monitored by Start Year.

Table 52: Number and Type of Spaces Monitored by Start Year.

Space group	Location	2010	2011	2012
Administration	Office	8	7	1
Shop	Shop	5	6	
Administration	Reception	1	3	1
Other	Corridor		1	
	Total	**14**	**17**	**2**

As there is only one set of data for the Other space group, no summary analysis is provided. The office and reception locations are analysed in the Administration space group, while shop locations come under the Shop space group. The graphs are plotted on consistent vertical axes to support direct comparisons.

One critical difference when this data is compared to the short-term monitored data is that it is possible to examine the temperature and relative humidity changes in a single location over the full monitoring period.

This section provides an initial exploration of this data. The data would support a wide range of analysis, in particular to understand changes over the year in a range of Administration and Shop space group uses. This section is limited to an exploration of the weekday temperature and relative humidity. Analysis of 24-hour, time-of-day, weekend and overnight temperature and relative humidity changes, as well as close examination of specific dates, for example, statutory holidays, are examples of possible future analysis. As noted in Table 52, a number of spaces were monitored in 2010 (14 locations) or 2011 (17 locations) so could be analysed in conjunction with climatic data to examine differences between locations in the same space group.

8.6.1 Seasonal Analysis

This section explores the seasonal weekday temperature and relative humidity for the monitored spaces.

Figure 131 plots the weekday mean temperatures by season for the Administration and Shop space groups. The average maximum and minimum temperatures are indicated by the vertical lines. Apart from the winter season, the Administration and Shop space groups' weekday mean temperatures are within 0.8°C. On average, the Administration space group is 2.8°C warmer than the Shop space group, with the highest Shop space mean temperature only just matching the mean Administration space group temperature. Temperatures are higher in both Administration and Shop space groups in the summer – by 3°C for the Administration space group and 6°C for the Shop space group.

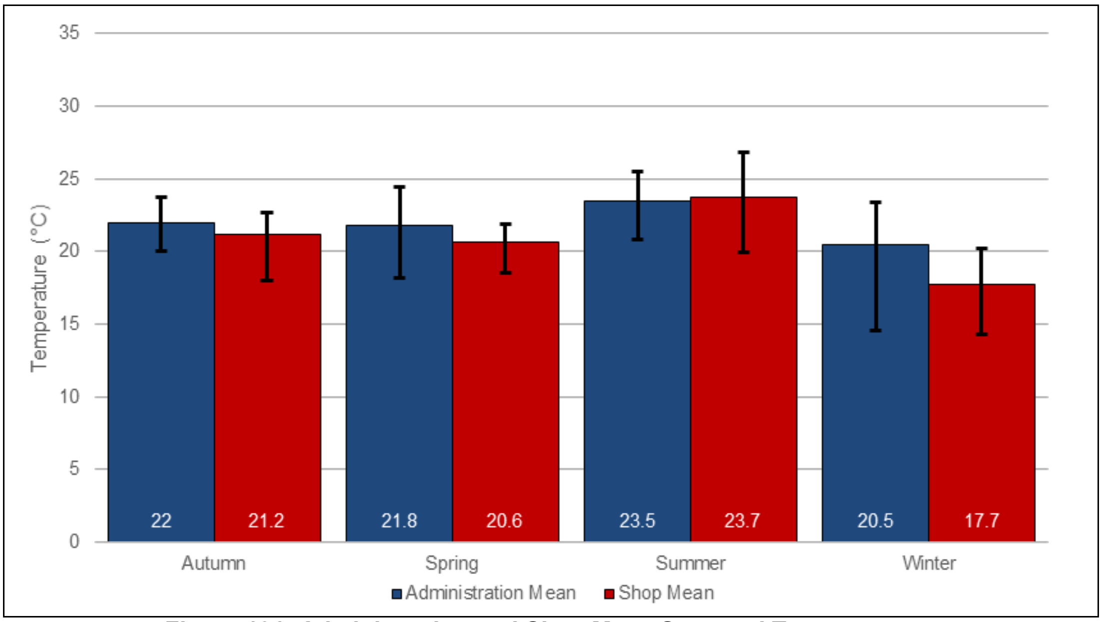


Figure 131: Administration and Shop Mean Seasonal Temperatures.

Minimum and maximum seasonal temperatures are shown in Figure 132 for the Administration space group and Figure 133 for the Shop space group. The temperature groups were calculated by averaging the different results – the mean is the average of the mean temperatures, the mean minimum is the average of the daily minimums and the mean maximum is the average of the daily maximums. The vertical lines show the minimum and maximum for each temperature group.

The weekday minimum temperatures probably align with the local external conditions. The greatest spread between average extremes (marked by the vertical lines) is for winter average minimums, with the Administration space group average minimum temperatures having a spread of 14.5°C and the average minimum Shop space group temperatures having a spread of 10.4°C. For comparison, the spread for the mean is 8.8°C for the Administration space group and 6.0°C for the Shop space group.

The smallest spread is for autumn means, with 3.7°C for the Administration space group and 4.7°C for the Shop space group.

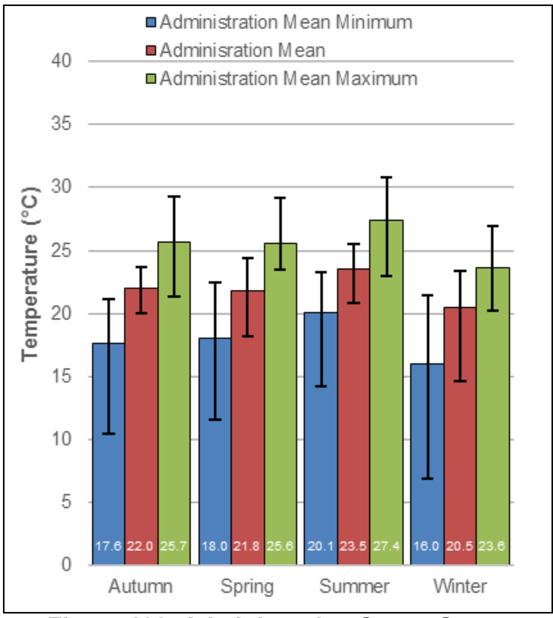


Figure 132: Administration Space Group Mean, Minimum and Maximum Seasonal Temperatures.

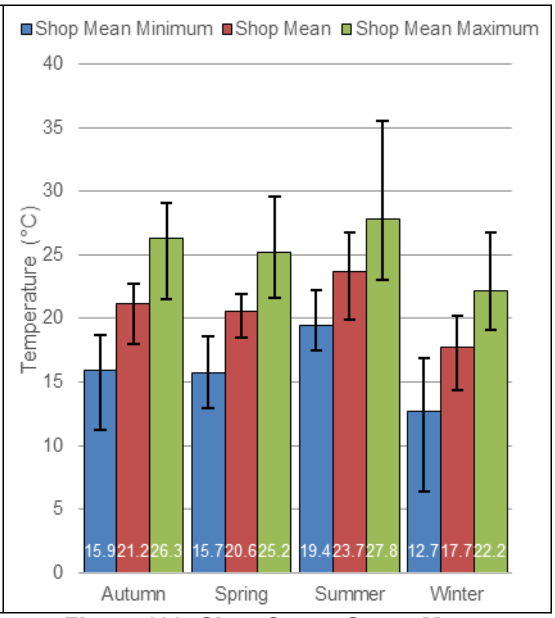


Figure 133: Shop Space Group Mean, Minimum and Maximum Seasonal Temperatures.

Figure 134 plots the weekday mean relative humidity by season for the Administration and Shop space groups. The average maximum and minimum relative humidity are indicated by the vertical lines. The Administration and Shop space groups' weekday mean relative humidity are within 4%, with slightly higher relative humidity in the autumn.

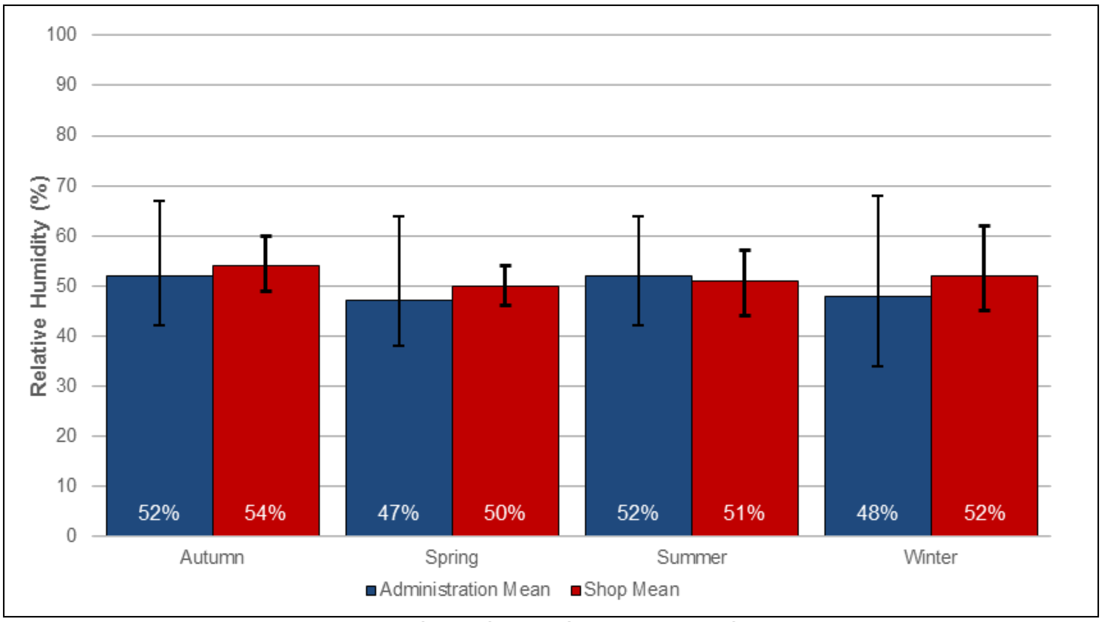


Figure 134: Administration and Shop Space Groups' Mean Seasonal Relative Humidity.

The mean (as shown in Figure 134), minimum and maximum seasonal relative humidity are shown in Figure 135 for the Administration space group and Figure 136 for the Shop space group. The relative humidity groups were calculated by averaging the different results – the mean is the average of the mean relative humidity, the mean minimum is the average of the daily minimums and the mean maximum is the average of the daily maximums. The vertical lines show the minimum and maximum for each relative humidity group.

The wide spread in relative humidity would be due to a combination of local conditions and the level of space heating or cooling in the appropriate seasons. The greatest spread is in the Administration space group average daily maximum (45%) and the Shop space group daily maximum (33%).

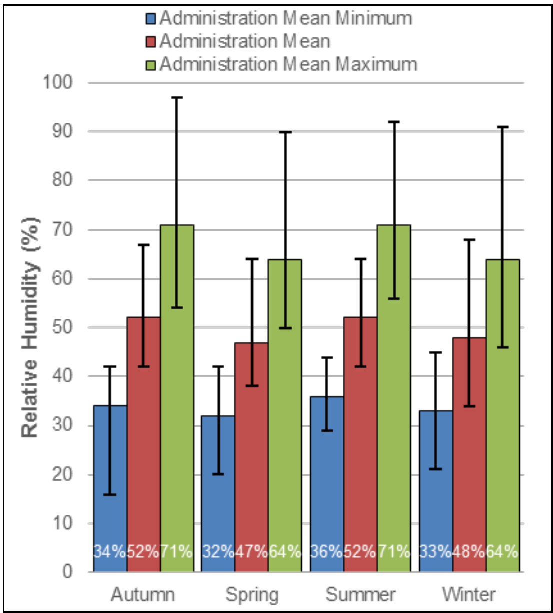


Figure 135: Administration Space Group Mean, Minimum and Maximum Relative Humidity.

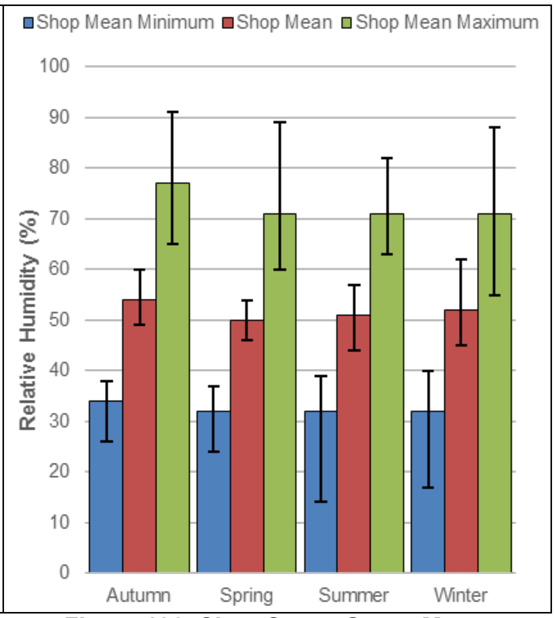


Figure 136: Shop Space Group Mean, Minimum and Maximum Relative Humidity.

8.6.2 Carpet Plots

A carpet plot permits the visual display of extremely large quantities of data. For the following examples, the vertical axis is the time of day (24 hours), running from midnight on the lower edge to midnight on the upper edge, while the horizontal axis is the date. Thus, to plot a full year, 8,760 data points are placed on the graph, each allocated a colour based on the value. The plotted data follows the colour scale, ranging from 0.0°C (dark blue) to 25.2°C (red) in 0.1°C increments. As the carpet plots start with the commencement of monitoring, it is not possible to have a consistent start date or month, so care is required when comparing charts. Annotations are provided to indicate winter periods.

Figure 137 shows an office (OFF) in Auckland where the temperatures are always over 24°C (yellow to red) during the weekday, cooling down to around 20°C overnight and on the weekends (green).

Figure 138 is a not-for-profit office (OFF) south of Auckland. Summer temperatures appear to follow the outside temperatures – near 25°C (red/yellow) during the summer day and reducing overnight to near 20°C (green). During the winter, the space is heated for a limited time giving temperatures around 20°C (green), which fall overnight to around 12°C (blue).

Figure 139 is an office (OFF) in the southern South Island. The temperature is almost constant day and night all year between 20°C (green) and 24°C (yellow). The winter weekends show cooler temperatures around 15°C (blue).

Figure 140 shows the temperatures in a Hawke's Bay general retail (GEN) premise with limited winter heating. The summer temperatures range from 20°C to 25°C (green to red) while the winter conditions reach green (20°C) during some parts of the day but are largely around 15°C (blue) during the day and night.

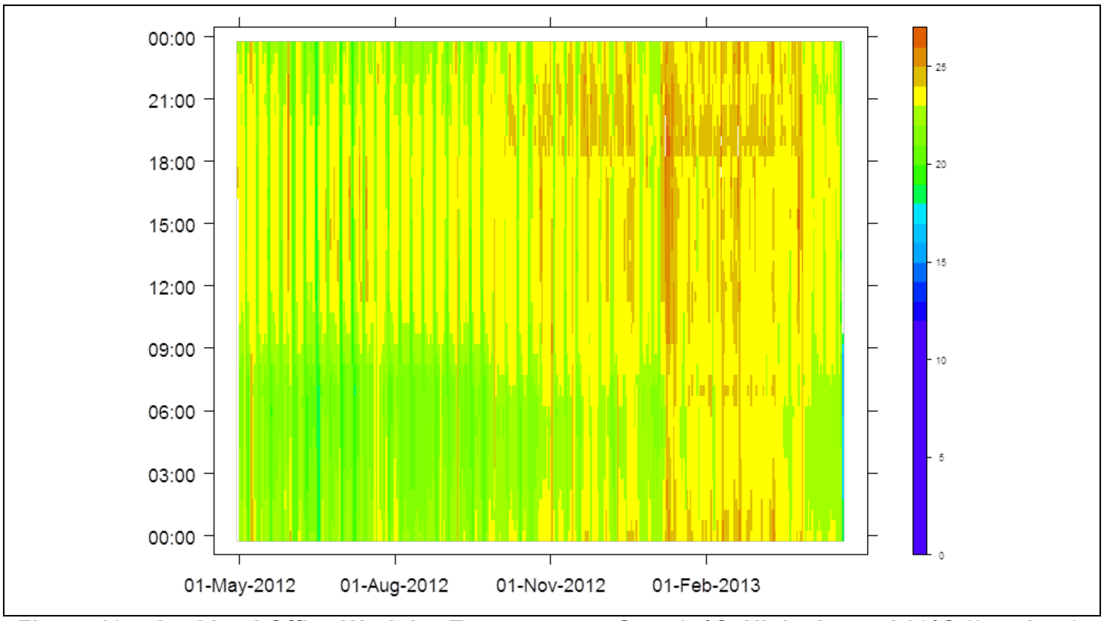


Figure 137: Auckland Office Workday Temperatures Over 24°C, Night Around 20°C (357 days).

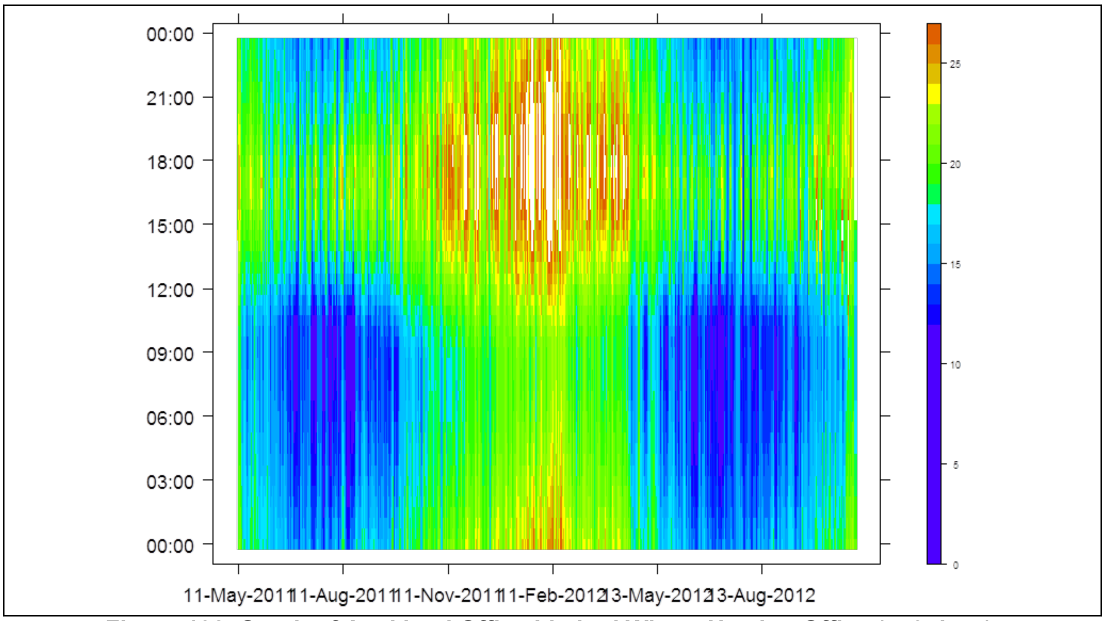


Figure 138: South of Auckland Office Limited Winter Heating Office (543 days).

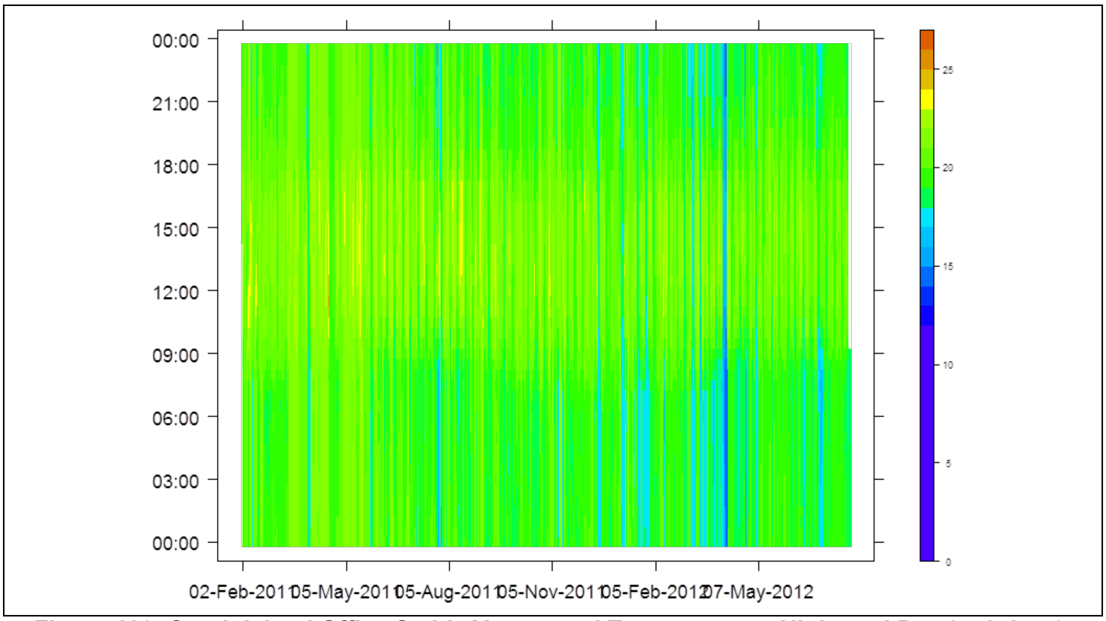


Figure 139: South Island Office Stable Year-round Temperatures, Night and Day (541 days).

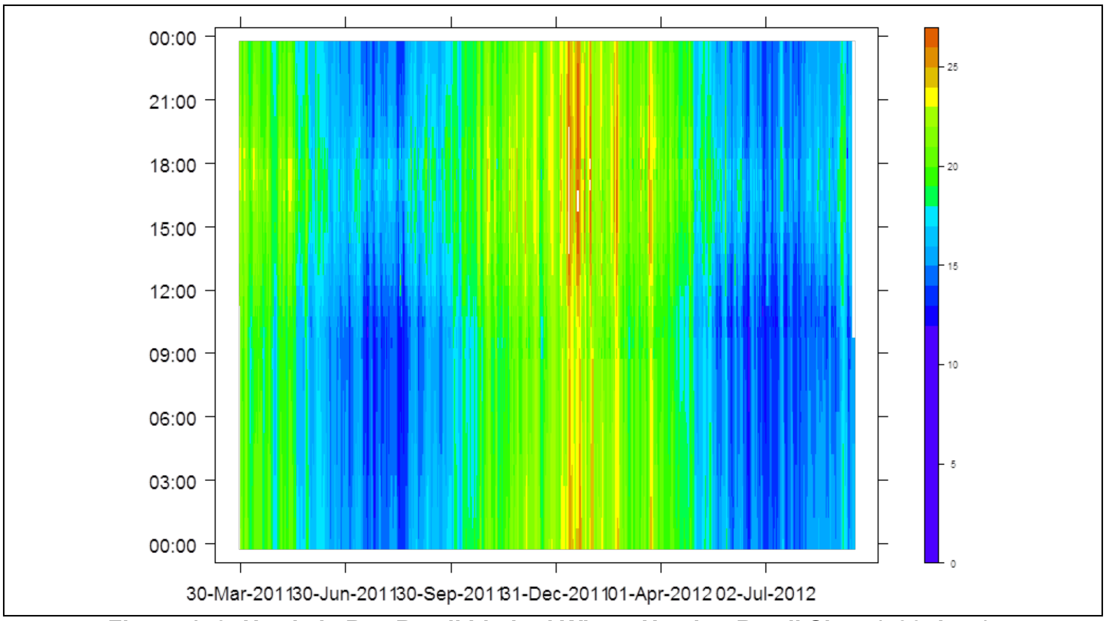


Figure 140: Hawke's Bay Retail Limited Winter Heating Retail Shop (536 days).

9. POST-OCCUPANCY EVALUATION (POE)

This section describes the results from the POE survey used to assess the building environment of five monitored premises. Two of the premises occupy more than two levels, and targeted monitoring was conducted on two generic levels. Therefore, there are seven case studies. It aimed to establish the correlation, if any, between occupant-reported satisfaction and monitored environmental performance.

For the purposes of BEES, a POE cannot replace environmental monitoring. While it appears that the POE can predict temperature distribution in a building and temperatures that are departing from the comfortable range, it cannot definitively predict if they will be towards the upper or lower limits of comfort. The 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 study to compare with energy consumption data, which a POE cannot provide.

This is not to say that the POE is not a highly valuable building evaluation tool. Certainly, some form of occupant survey or feedback should be used by any party endeavouring to gauge a building's performance post-occupation and should be done first and foremost before or at the start of environmental monitoring. By doing so, a quick assessment of year-round building performance can be made, which can then be used to guide the direction monitoring takes.

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 section, it has become evident that blindly using one method of analysis could lead to serious misjudgements of a building's overall performance. As with all analyses, care must be taken to account for external influences biasing results, but it is obvious that a POE used in tandem with environmental monitoring is very effective for post-occupancy evaluation.

From an environmental standpoint, understanding energy consumption in buildings is important so that the knowledge can be used to improve our existing building stock as well as provide lessons for future buildings. However, lowering the operating and embodied energy costs of a building does not by itself necessarily equate to a good building overall. A sustainably built and energy-efficient building is of little practical use if it does not provide a functional workplace in which occupants are satisfied. While building occupants may not be working to directly benefit the environment, it makes sense that they be as productive and happy in their work as possible.

Leaman et al. (2010) state that there are at least three perspectives that must be considered when evaluating a building:

- Occupants and how well their needs are met.
- Environmental performance, normally energy and water efficiency.
- Whether the building makes economic sense, such as value for money or return on investment (Leaman, et al., 2010).

This section aims to establish whether any correlations exist between occupant-reported satisfaction and environmental performance across a number of different variables. The analysis used participating premises that had both a POE and targeted monitoring completed.

9.1 Methods

The POE used in this analysis is a Building Use Studies (BUS) tool that evolved out of the Post-Occupancy Review of Buildings and their Engineering (PROBE) project started in the UK in 1995 (Leaman, 2011).

The BUS POE is a holistic building assessment covering building background, overall building, work requirements, work area, comfort (temperature, noise and illumination), perceived productivity, health, personal control, effect on behaviour and commute to work.

This BUS POE was used to survey five premises from within the BEES targeted monitored sample. However, where multiple storeys existed within the targeted monitored premises, each storey was treated as a separate case study.

9.1.1 Basis for Analysis between Environmental Monitoring and POE

Not all POE variables were directly comparable to the monitored environmental data, although they may be of use when explaining any unexpected results of the comparisons. Table 53 shows the POE variables that are directly comparable to the environmental data.

Table 53: Comparability between POE and Monitored Environmental Variables.

Monitored environmental	POE
Temperature (°C)	Temperature: too hot/too cold
Temperature (°C)	Temperature: stable/varies during day
Relative humidity (%)	Air: dry/humid
Air quality, CO_2 (ppm)	Air: fresh/stuffy
Illuminance (lux)	Lighting: overall

To compare variables between datasets, a reference for comparison must first be established. The POE gives each variable a score that can be compared to a mean, upper and lower benchmark score for that variable based on the last 30 buildings surveyed. A percentile value is also given to assist in assessing where the surveyed building sits amongst the set of POE buildings. Each variable is also given a percentage dissatisfaction score. Each variable is scored on a 7-point scale, which can be right-sided, left-sided or centred. The environmental variables are assessed for each season. Therefore, depending on the period at which the environmental monitoring was done, a comparison between the two datasets could be made for one of summer or winter only.

Comfort criteria for analysis of environmental monitoring data was based on the BEES Study Report 260/4 Achieved Conditions (Bishop, et al., 2011b). This report referenced a range of standards in defining limits or criteria for comfort:

- Temperature – comfort range taken to be 20°C to 24°C for winter and 23°C to 27°C for summer as per ASHRAE 2001 Fundamentals Handbook (ASHRAE, 2001) and ASHRAE Standard 55 2004 (ASHRAE, 2004), refer to section 8.2 for more detail.
- Relative humidity – NZS 4303:1990 recommends that relative humidity should be maintained between 30% and 60% in habitable spaces (Standards New Zealand, 1990). In the SR 260/4 Achieved Conditions report, 40% to 60% is defined as a healthy range (Bishop, et al., 2011b). For this analysis, 40% to 60% was used as it conforms to existing BEES practice, refer to section 8.5 for more detail.
- CO_2 – a CO_2 concentration of 1,000 ppm was taken to be the upper limit for comfort as per NZS 4303:1990 (Standards New Zealand, 1990) and the SR 260/4 Achieved Conditions report (Bishop, et al., 2011b), refer to section 8.3 for more detail.
- Illuminance – for routine office tasks, NZS 1680.1:2006 Table 3.1 Interior and Workplace Lighting recommends a maintained level of 320 lux (Standards New Zealand, 2006), refer to section 8.4 for more detail.

A standard set of working hours was defined for all buildings as 8:00 am to 5:00 pm, Monday to Friday, although there were some premises in which staff often worked longer hours.

Often the monitored premise occupied a number of floors within a building (in part or whole). In some cases, one premise was comprised of more than one building. For premises where this was the case, if possible, the POE data was split into floors or individual buildings and matched to the corresponding data loggers. This meant that the four premises could be represented through seven case studies.

Weather data for each premise region and monitoring period was downloaded from the National Institute of Water and Atmospheric Research's (NIWA) National Climate Database (http://cliflo.niwa.co.nz/). This was available in hourly data only, which was then matched to the corresponding indoor environmental measurements.

9.1.2 Thermal Comfort Calculations

Thermal comfort was calculated using the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices (ASHRAE, 2004). PMV predicts the mean value of the votes of a large group of occupants on a 7-point thermal sensation scale, as shown in Table 54. PPD predicts the percentage of thermally dissatisfied occupants who feel too cool or too warm, based on those who will vote hot, warm, cool or cold on the 7-point thermal sensation scale. This is useful as it can be compared to the POE percentage dissatisfied for Temperature: too hot/too cold and also Temperature: comfortable/uncomfortable.

Table 54: POE 7-point Thermal Sensation Scale.

Score	Description
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

To calculate the PMV, it was assumed:

- clothing insulation value of 1.2 Clo (roughly equal to a heavy business suit) (ASHRAE, 2004)
- metabolic rate of 1.1 Met (office activity such as typing) (ASHRAE, 2004)
- no work (mechanical power) was done
- operative temperature was equal to air temperature (ASHRAE, 2004)
- airspeed was low and equal to 0.1 metres per second.

9.1.3 Assumptions and Potential Inaccuracies

There were a number of assumptions made and potential for inaccuracies to arise:

- Some surveys were not undertaken during the targeted monitoring period. This may mean the indoor environmental conditions had changed, such as installation of new equipment, different operating set points or controls, building upgrades, etc. If a survey was done in summer and the monitoring in winter, there may be changes in occupant perceptions of winter condition, which could affect responses.
- Much of the monitoring data was collected over a short time (usually 2–4 weeks), which was not fully representative of the season for which it was being analysed and compared to the POE results.
- Whilst a reflection of the real world, each POE was used with a different group of respondents with different ages, genders, workplace morale and expectations of facilities. As such, the POE results are context dependent, and care must be taken when comparing from survey to survey to examine all variables.

9.2 Results

9.2.1 Temperature

Figure 141 shows the dissatisfaction with the POE variable temperature in winter: hot/cold plotted against monitored indoor temperatures, with the circles showing individual or portions or premises. All temperatures are median temperatures. Two trends appear to be emerging. Firstly, dissatisfaction increases as indoor temperatures drift away from the middle of the comfort band (22°C), with greater influence given to colder temperatures. Secondly, dissatisfaction increases as the temperature distribution (over the monitoring period) within a premise increases. These two trends are also seen, with small variations, in comparisons of temperature to the POE variables temperature in winter overall (Figure 142), air in winter overall (Figure 143) and comfort overall (Figure 144).

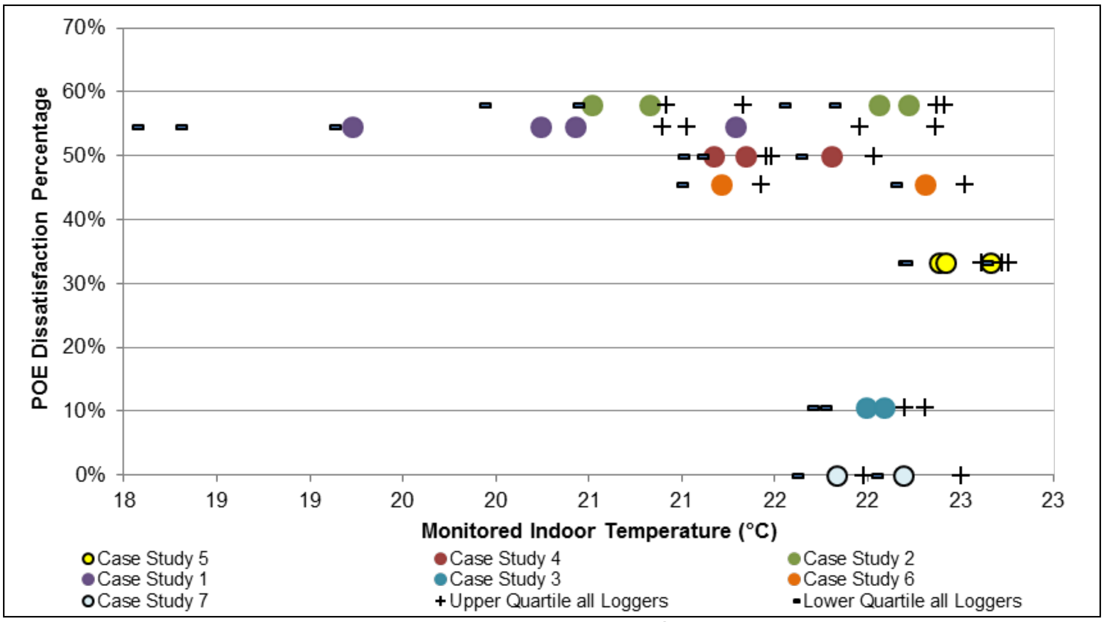


Figure 141: Monitored Temperatures against POE Temperatures in Winter.

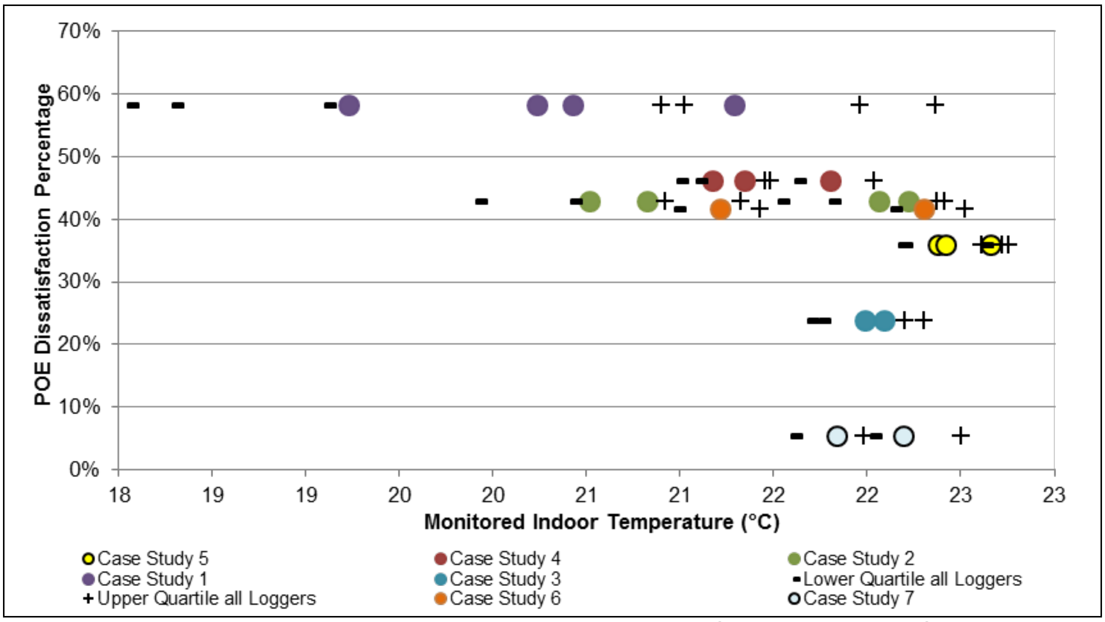


Figure 142: Monitored Indoor Temperatures against POE Temperatures Overall.

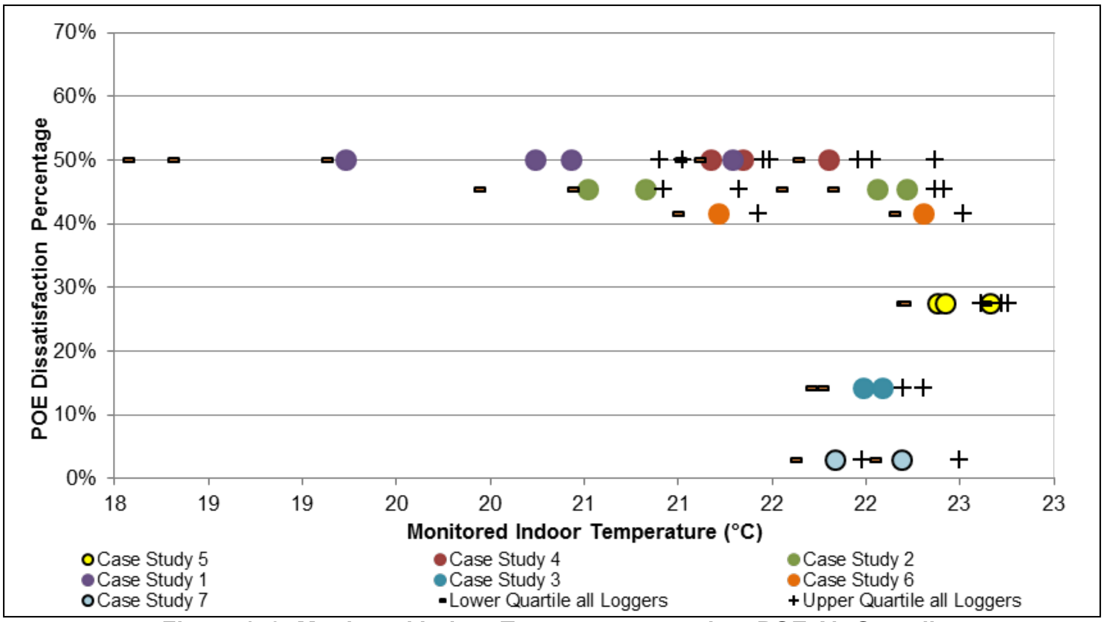


Figure 143: Monitored Indoor Temperatures against POE Air Overall.

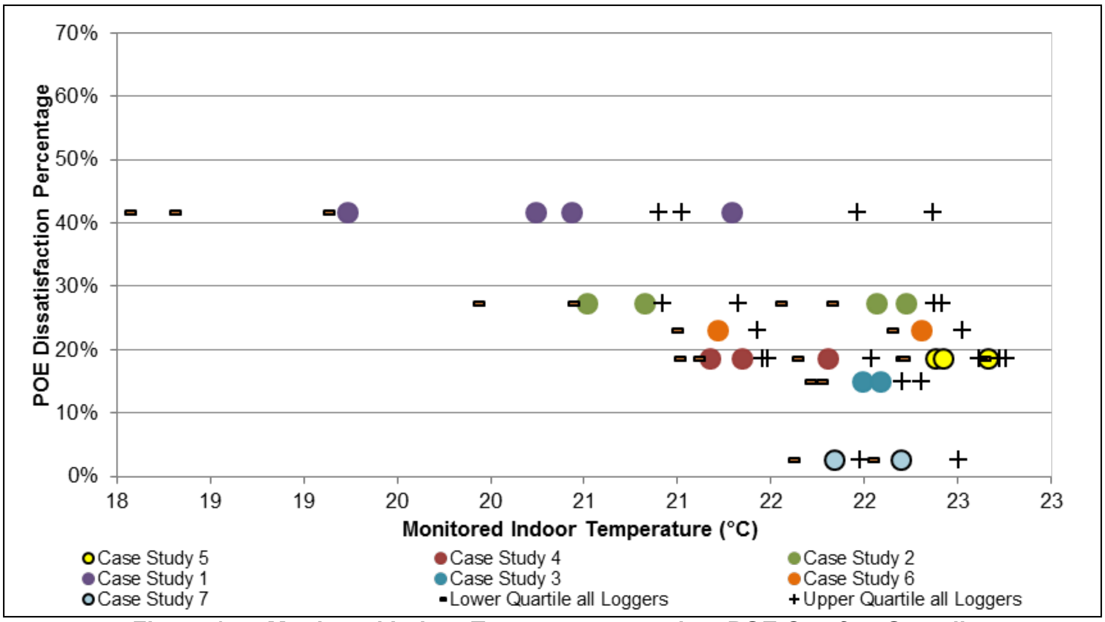


Figure 144: Monitored Indoor Temperatures against POE Comfort Overall.

Dissatisfaction with the temperature variation is generally high for all premises, with 47% being the lowest. This suggests that people are very sensitive to temperature variation. Figure 145, comparing the daily temperature variation to the POE variable for temperature in winter: stable/varies during the day shows that, as the temperature variation increases so does dissatisfaction with the variation. This trend was weaker when comparing the measured temperature variation to the POE temperature in winter variables hot/cold and temperature overall (Figure 146). This is interesting, as dissatisfaction with these variables increased as the measured temperature distribution over the entire monitoring period increased.

Case study 6 has very high dissatisfaction with the temperature variation, which is not expected due to the low measured temperature range. Figure 144 above shows that the two sensors have distinctly different distributions. The sensors were located on opposite sides of the building (north and south), which suggests this dissatisfaction may be due to temperature variation in different areas of the building rather than throughout the day. This was also mentioned in the POE comments.

Case study 4 also has high dissatisfaction and a low measured temperature variation (when excluding the meeting room). A number of POE comments for this building were in regards to the air-conditioning having had problems and being very cold. This may have influenced how people responded and thus the unexpected result, although it may also be due to the relationship between temperature variation and perceived variation in temperature being poor.

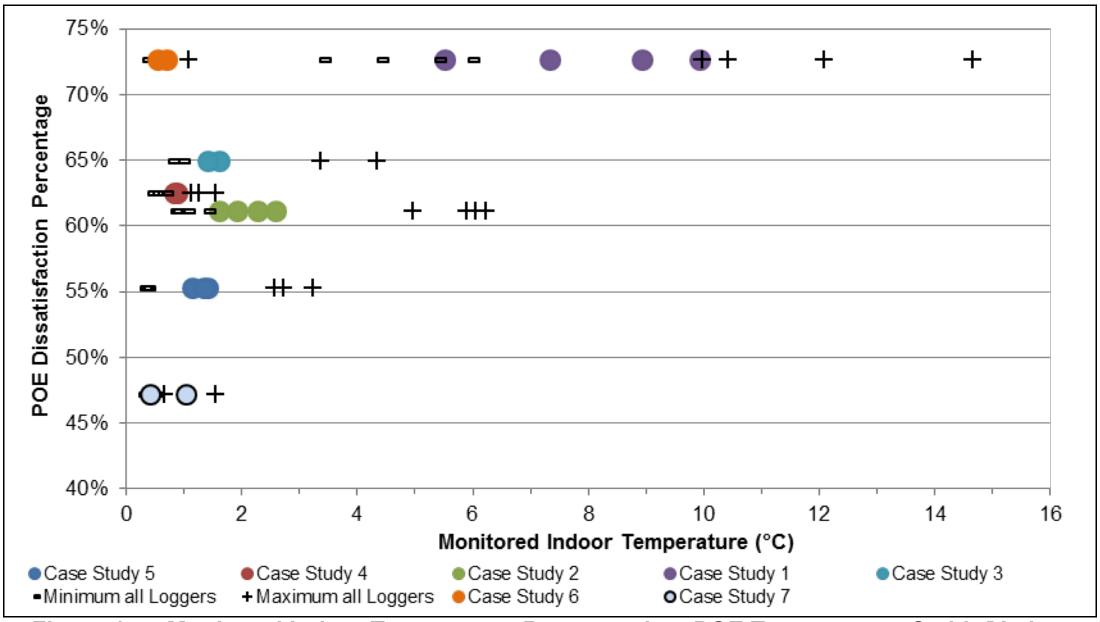


Figure 145: Monitored Indoor Temperature Range against POE Temperature: Stable/Varies.

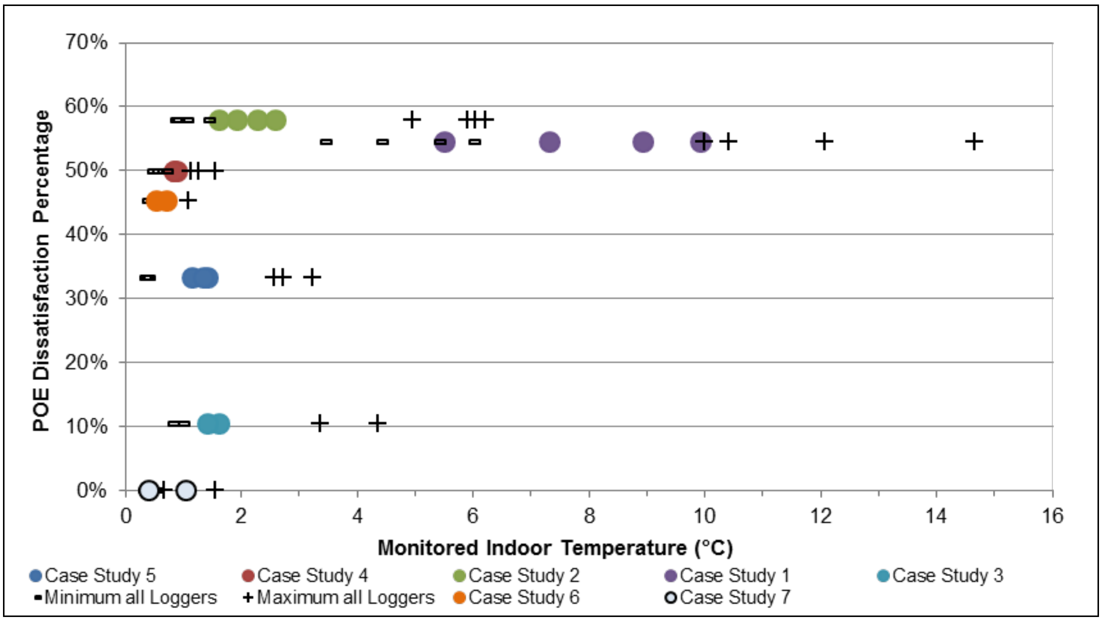


Figure 146: Maximum Daily Temperature Range against POE Temperature: Hot/Cold.

9.2.2 Relative Humidity

Plotting the measured relative humidity results for each building against the POE variable dry/humid was inconclusive in establishing a trend, especially noting that the three most dissatisfied premises mostly expressed dissatisfaction as too dry, with few votes for too humid (Figure 147). It has been found by many other studies that humidity has only a minor effect on thermal comfort, and therefore this weak relationship could be expected (Nicol, et al., 2012).

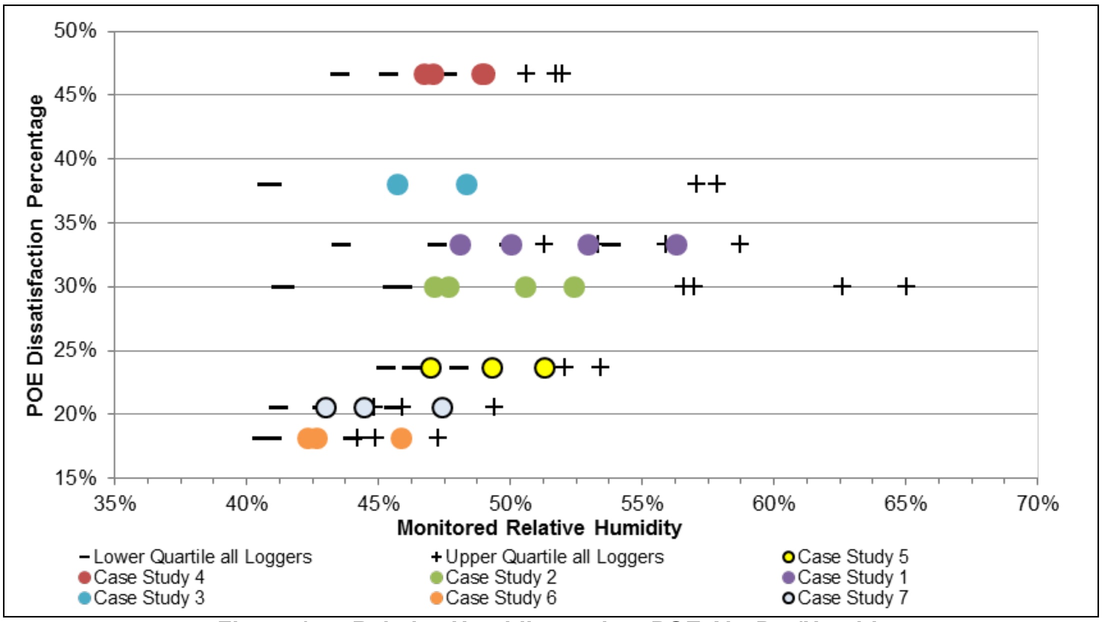


Figure 147: Relative Humidity against POE Air: Dry/Humid.

9.2.3 Predicted Percentage Dissatisfied (PPD)

Analysis of the calculated PPD compared to the POE percentage dissatisfied showed that, as the extreme PPD values became higher, so too did dissatisfaction from the POE results. This was observed for temperature in winter: hot/cold (Figure 148), temperature in winter overall (Figure 149) and air in winter overall (Figure 150). The POE comfort overall had a weaker trend, although it was still apparent (Figure 151). The weaker relationship of PPD to the POE comfort is likely due to the POE comfort variable being inclusive of the summer environmental results as well as other variables such as noise and illumination.

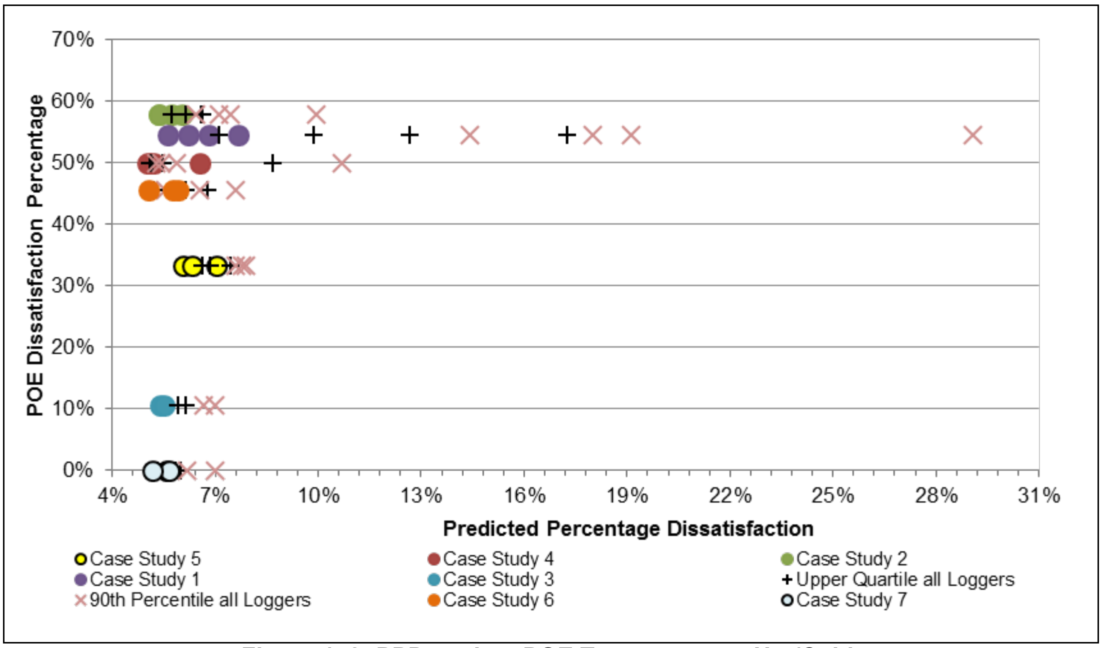


Figure 148: PPD against POE Temperatures: Hot/Cold.

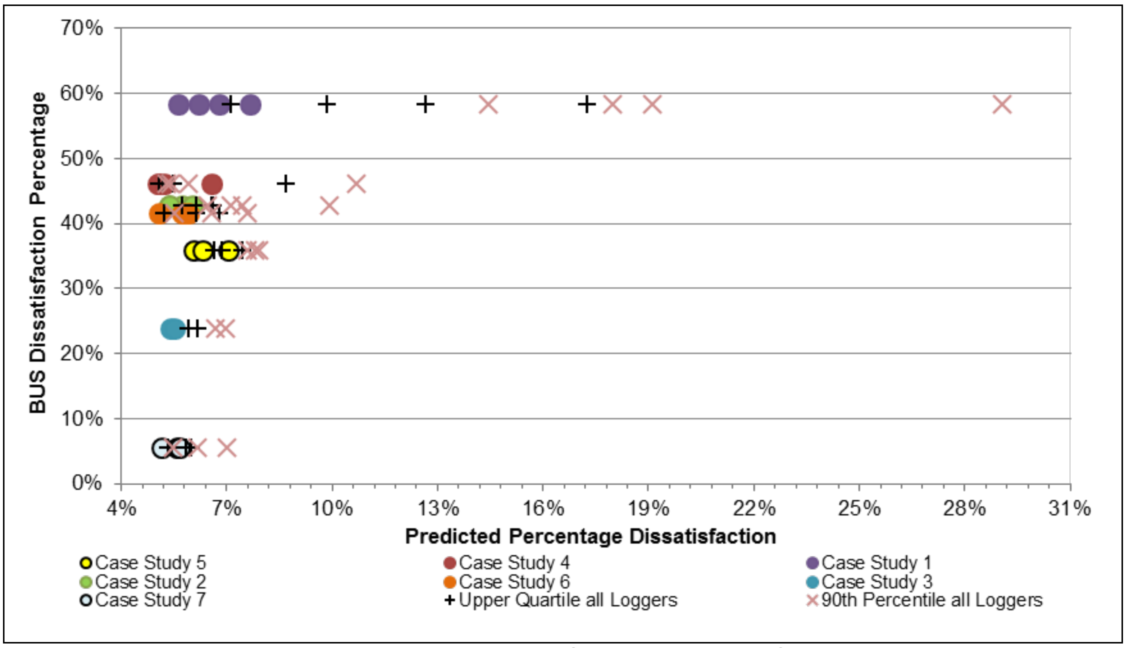


Figure 149: PPD against POE Temperatures Overall.

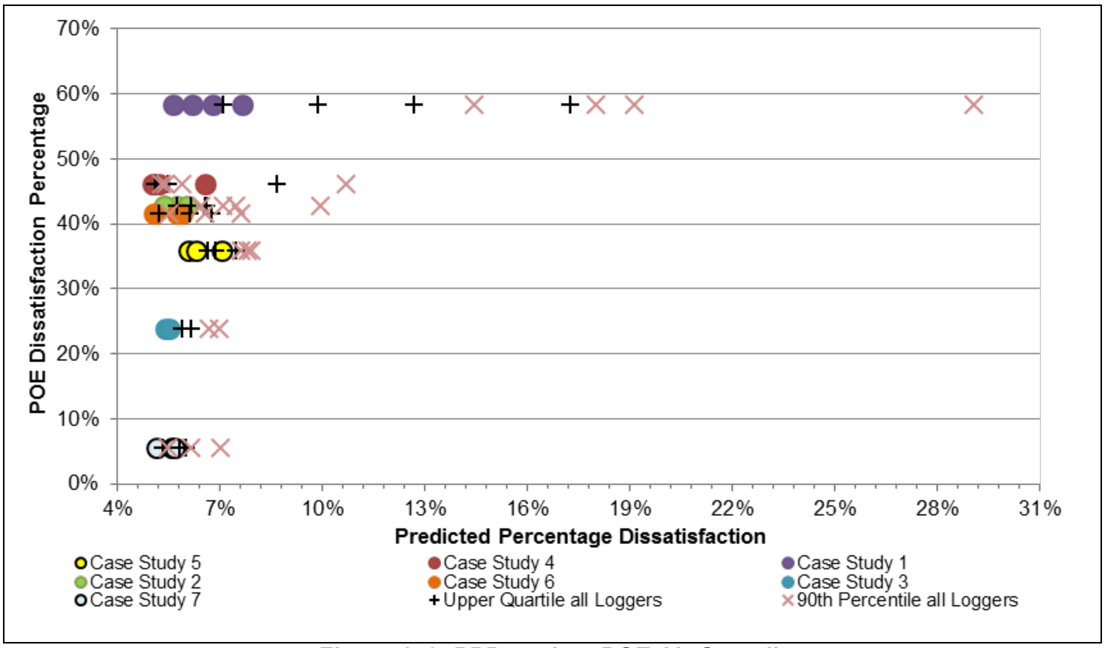


Figure 150: PPD against POE Air Overall.

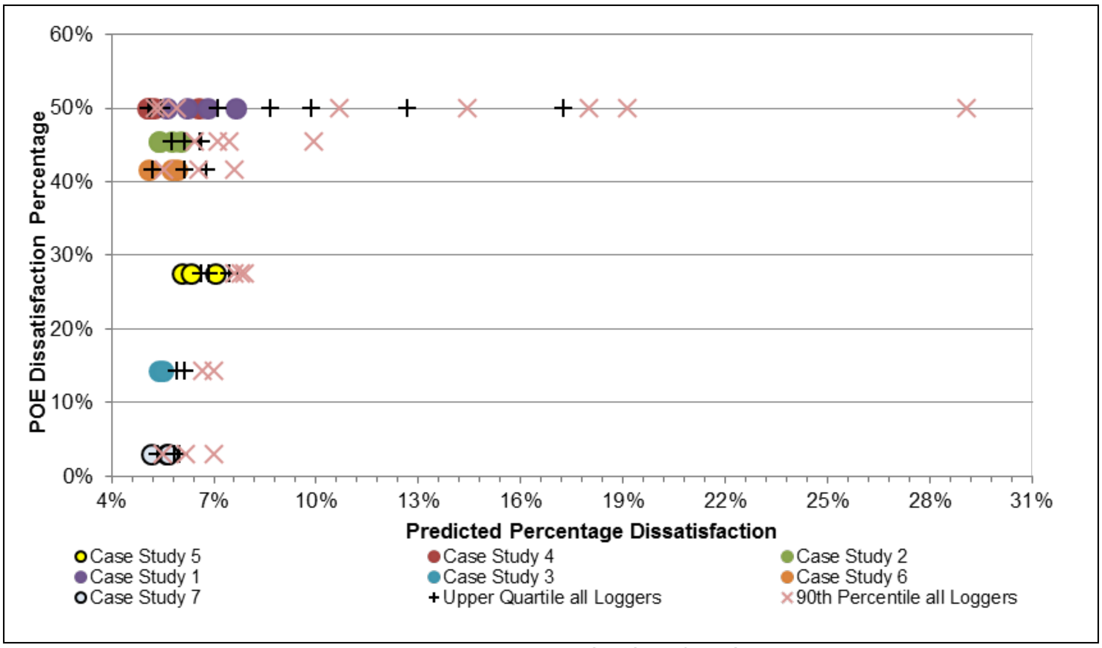


Figure 151: PPD against POE Comfort Overall.

9.2.4 Air Quality

There were only five CO_2 loggers installed in the six premises monitored. Given this small sample size, no conclusive trend can be established. Interestingly, the building with the highest CO_2 levels was the only naturally ventilated building in this study.

9.2.5 Lighting

There appears to be very little relationship between measured illuminance and the POE results. A potential explanation for this lies in the motivation for the layout of monitoring equipment. The HOBO U12 loggers measured dry-bulb temperature and relative humidity as well as illumination. For the temperature and relative humidity measurements to be accurate, the loggers could not be placed where they would have undue influence from radiant temperature sources, such as direct sunlight (although as shown in the case study 2, this was not always the case). This meant that the illuminance measurements do not capture conditions such as glare or reflections falling on a computer screen. As such, they can be used only to predict whether the general illuminance is adequate but not factors that may be of more concern and have a large effect on overall dissatisfaction.

9.3 Discussion

The above results analysis is an assessment of a limited pool of premises only. Although there is detailed data for each premise, the small number of premises in the sample means that conclusively identifying trends is done with low confidence. This is a limitation of any conclusions drawn, but there is also the possibility that, given a larger pool of premises, the results would be just the same.

It seems that the POE can be used as a relatively good indicator of longer-term temperature distribution within a premise and also, at least for winter, that it can indicate premises with temperatures that stray away from the comfort range. Variation between different areas in a premise or unpredictable day-to-day variations also looks to have a greater influence on dissatisfaction with temperature variation than the daily temperature range does. This finding is consistent with results from the PROBE studies, which found that dissatisfaction with thermal comfort resulted from “conditions which are too variable, and thereby difficult for occupants to predict from day-to-day. This leads to seemingly trivial – but unmanageable – complaints like ‘we do not know what to wear’. Conditions may also become uncomfortable – perhaps too cold and draughty in one area, and too hot in another, with no consistency” (Leaman & Bordass, 2001).

Although the relationship between PPD and the POE agrees with the temperature results, there is less confidence in the trend given that PPD is calculated using assumptions about the operative temperature, airspeed, clothing levels and metabolic rate, which are likely to vary from area to area and person to person. Looking around an office during the POE, it was seen that clothing, especially, varied a large amount from person to person. This is a manifestation of personal thermal comfort control, highlighting the variability of comfort criteria for each individual. The POE comments also indicated that airspeed was a major factor, particularly for locations near or under air-conditioning outlets.

Lighting, relative humidity and CO_2 results were difficult to draw meaningful insight from. This may have been due to the small sample size of only six premises or simply the fact that any correlations between environmental monitoring and the POE survey variables is low. In fact, one of the findings from PROBE was that lighting had little influence on occupants' rating of overall comfort or associated variables (Leaman & Bordass, 2001).

The individual case studies show how the POE captures finer details about a premise that are often not easily recognisable or picked up in the monitoring results, for example, occupants in premise case study 5 complaining about localised discomfort from air-conditioning vents or complaints about cold floors in case study 1. In almost every building, there were comments that related to air-conditioning problems, and often these were in a past tense (refer to Appendix I for the POE case studies). This shows how occupants will retain a memory of events that influence their current perception of a premise. Research has shown that, for thermal comfort, occupant memory may not be reliable, and care must be taken when using survey results, for example, winter results of a survey done in summer (Nicol & Roaf, 2005).

This highlights an important point. Environmental monitoring is an exact representation of the measured conditions at the time and place of measurement over a specific duration. In contrast, a POE is an average representation of the perceptions that a buildings' occupants have of it. These perceptions are context dependent and vary with time. This leaves the POE results open to influence from external factors that may not relate to the specific variable in question or even the building, for example, traffic on the commute to work. Although it may be possible to identify external drivers by examining other POE variables and comments, their influence is hard to quantify.

10. BEES WATER USE

As only a small number of premises that participated in the BEES research were able to provide their water use data, this provided a major opportunity to make use of a non-BEES data source to examine this issue. This section uses the results from an examination of data from Watercare Services Ltd (Auckland's supplier of potable water) to explore drivers of water use in non-residential buildings.

Two measures are commonly used in this analysis:

- Water use – either annual (m^3/yr) or average daily (L/day).
- Water use intensity (WUI) – a measure of water use per square metre (m^3/yr.m^2).

The analysis within this water use section found that water-using industrial processes, including food catering and so on, are almost certain in high water-using premises, such as those with a WUI greater than 10 m^3/yr.m^2. Building age was not found to have affected water use, with no evidence of an increase or decrease over the last 50 years.

Building use strata was found to be a very important factor. However, the lack of homogeneity within the building use strata suggests that further disaggregation into smaller activity-based groups is desirable.

This section provides an overview of understanding the water demand generated in non-residential buildings. It is focused on the Auckland region. This is a first step to fill this existing knowledge gap on water use in New Zealand non-residential buildings. The baseline data and information provided is constructed by statistical analysis of water performance of a large representative sample of non-residential Auckland buildings. For more detail on the water analysis for BEES, refer to BEES Study Report 277/8 (Roberti, 2014).

A representative dataset for the analysis of non-residential water use in Auckland was created by linking BEES building records to records of general water metering. This set has been utilised to create a statistical baseline of non-residential water utilisation for the non-residential building stock in New Zealand.

The result of the data matching has allowed statistical analysis to explore the baseline dataset of more than 5,700 non-residential BEES building records in the Auckland region. The dataset represents about 10% of the BEES property population in New Zealand, 20% of Auckland non-residential water demand and 14% of properties in the BEES recruitment sample. The breakdown of the matching by building size strata and building use strata is provided below.

Table 55: Matching BEES Building Records with Water Meter Locations.

Building use strata	Building size strata					Total
	S1	S2	S3	S4	S5	
Commercial Office (CO)	461	247	142	108	36	994
Commercial Retail (CR)	1,511	244	83	24	15	1,877
Commercial Other (CX)	618	242	138	44	10	1,052
Industrial Service (IS)	237	197	64	13	2	513
Industrial Warehouse (IW)	377	428	323	130	31	1,289
Overall	3,204	1,358	750	319	94	5,725

In the dataset, there were a small number of building records that had extremely high water use. The most likely reason for this was they had industrial processes within the building, therefore, they were removed from the sample for the analysis to determine the water use baselines and intensities. Even with removing, at the other end of the scale, there were a number of building records (approximately 100) that appeared to have no water use at all.

There are several reasons why properties can have zero water use over the 2-year period. For instance, the building could be vacant, nobody is using water or the water meter may be dysfunctional.

10.1 Analysis and Results – Water Use in Buildings

The BEES water dataset shows that, for non-residential buildings, the range is tremendous. The data ranges from 1.8 L/day to 1,800,000 L/day, although for the majority of buildings, their water use is less than 10,000 L/day. This is shown in the graph below that compares the total annual water use against the floor area for the building record.

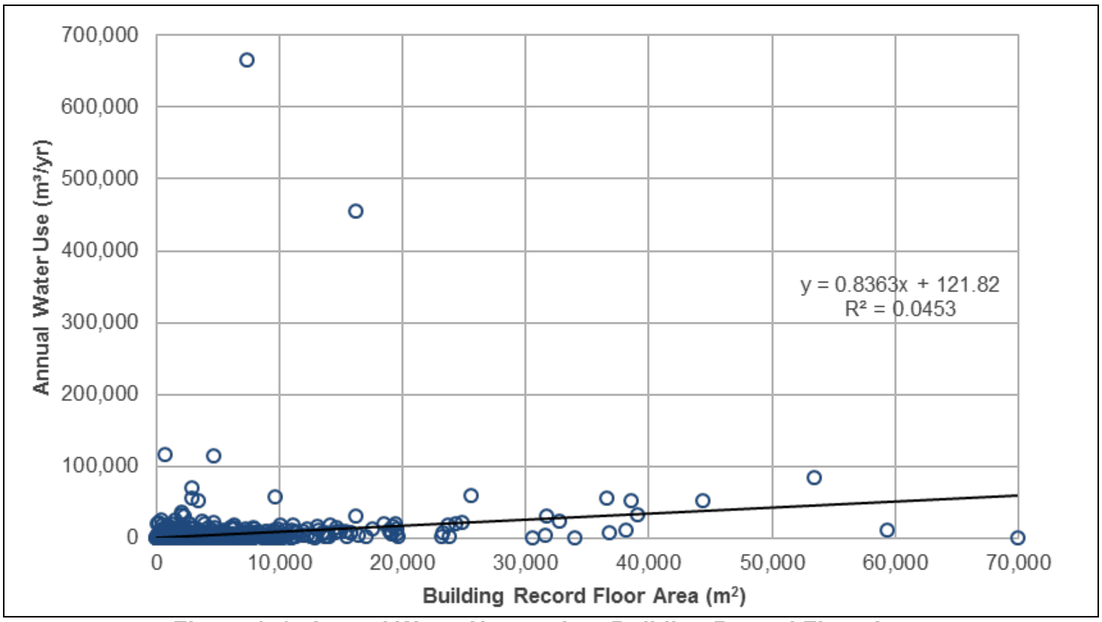


Figure 152: Annual Water Use against Building Record Floor Area.

It is likely that the high users have industrial processes that use significant amounts of water, along with their office or retail use, so should also be removed from the sample when focusing on Commercial Office and Commercial Retail buildings. Figure 153 below provides an enlargement of the graph above showing the sample of building records where the annual water use is less than 30,000 m^3/yr and the floor area less than 25,000 m^2. This shows there is a large variation in water use within buildings, even when the outliers are removed.

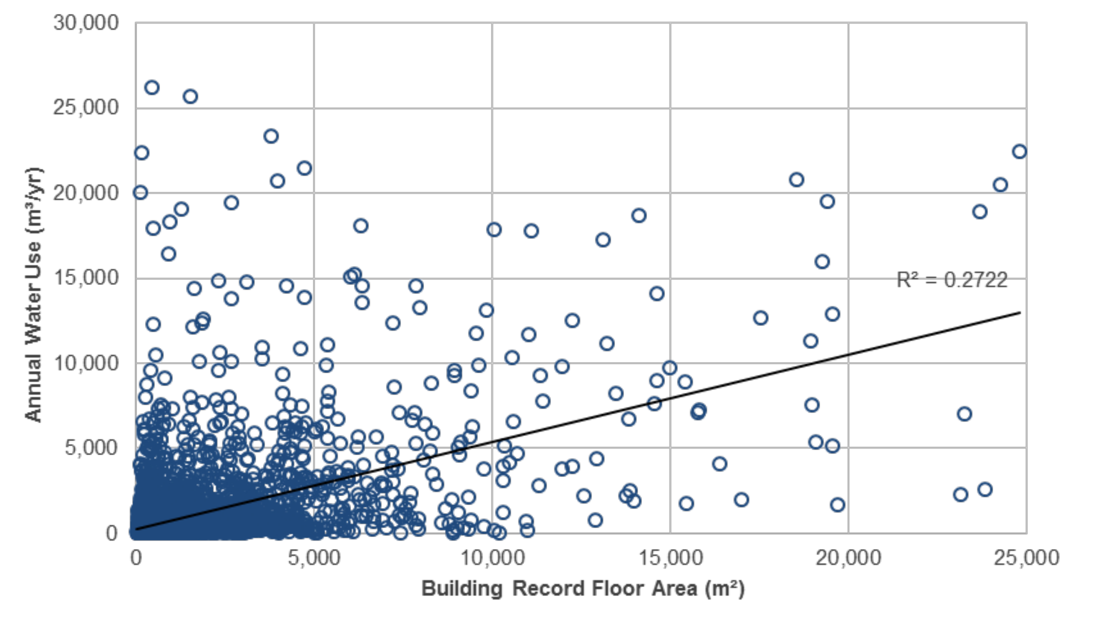


Figure 153: Annual Water Use (Zoomed In).

In Table 56, the daily rate of water use and is given as a function of population percentiles. The median value for the amount of water use per building record is 650 L/day. The first quartile value is 2.6 times lower and the third quartile is 2.8 times higher than the median value.

Table 56: Daily and Annual Water Use.

Percentile	Water use (L/day)	Water use (m^3/yr)
0% (minimum)	1.6	0.58
25% (1st quartile)	250	92
50% (median)	650	240
75% (3rd quartile)	1,800	640
100% (maximum)	1,800,000	670,000

The figures and table above all show the large variation of water use within building records and also indicate that the data is not normally distributed around an average. Therefore, it is necessary to use logarithmic scales to analyse and graphically represent the data. A logarithmic scale is a scale of measurement so each ‘tick’ mark on the scale is the previous tick mark multiplied by a number. For the analysis of Auckland’s water use data, the multiplier used is 10.

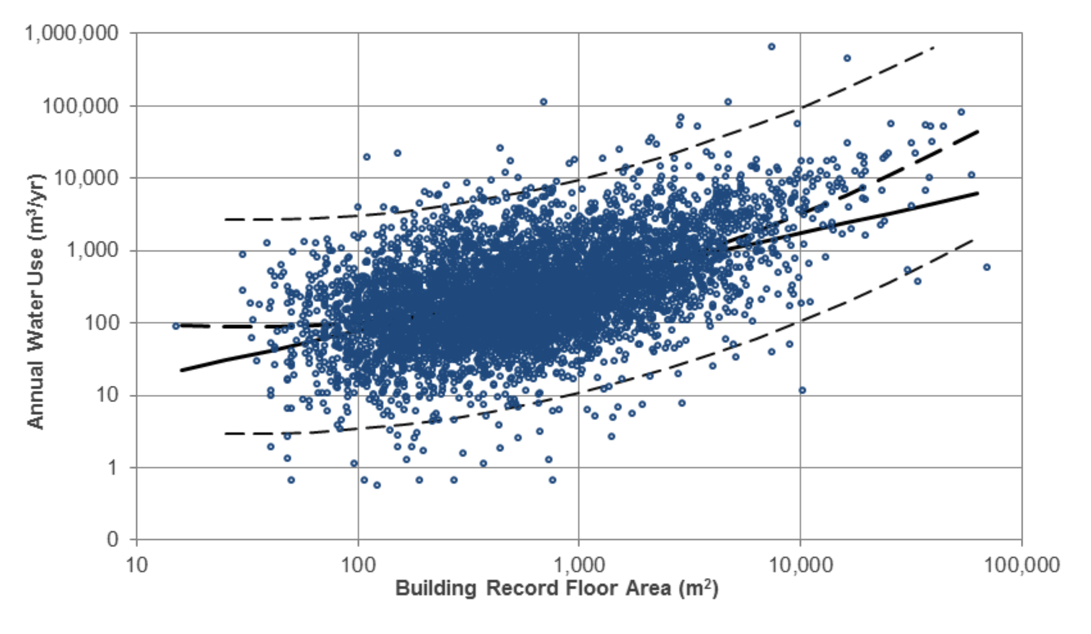


Figure 154: Relationship between Annual Water Use and Floor Area using Logarithmic Scales.

Figure 154 uses the same data as Figure 152 but is graphed using the logarithmic scale on both axes. The straight solid line sloping upwards is the first order trend. This provides a quick indicator that, because it is sloping upwards, shows water use increases as the size of the building increases, as expected. The heavy dashed line is the second order trend line, which shows a more accurate relationship between annual water use and floor area.

The upper and lower dashed lines represent the 95% prediction interval. Because of using a logarithmic scale, it is important to recognise that the water use at the upper limit is 1,000 times more than the water use at the lower limit.

10.2 Water Use Intensity (WUI)

Water Use Intensity (WUI) removes the impact of the size of the building by calculating the annual water use per square metre of floor area ($m^3/yr.m^2$). In Table 57, the WUI is given as a function of population percentiles. The median WUI is 0.41 $m^3/yr.m^2$. Factors for the first quartile and third quartile boundaries are respectively 2.7 times lower and 2.6 higher than the median value. The minimum water use of 1.6 L/day is a significant 1.1 million times smaller than the maximum water use of 1,800,000 L/day.

Table 57: Population Percentiles of the WUI for BEES Building Records.

Percentile	WUI (L/day.m²)	WUI (m³/yr.m²)
0% (minimum)	0.0024	0.00089
25% (1st quartile)	0.49	0.18
50% (median)	1.1	0.41
75% (3rd quartile)	2.9	1.0
100% (maximum)	500	182

The skew in distribution of the WUI data that is suggested in the table above can also be seen in Figure 155 with the exception of the upper limits. It shows the sample of buildings that have an annual WUI of less than 10 $m^3/yr.m^2$. It is assumed that buildings that have a higher WUI are likely to also have industrial processes present that require significant amounts of water. Figure 155 shows that just over 40% of these buildings only use 10% of the water, and at the other end, 20% of the buildings use 50% of the total water. It is likely that 80% of the water use is driven by increased occupancy, but the other 20% has other factors driving the water use. A possibility for this higher use range is that these buildings are linked to food processing and catering.

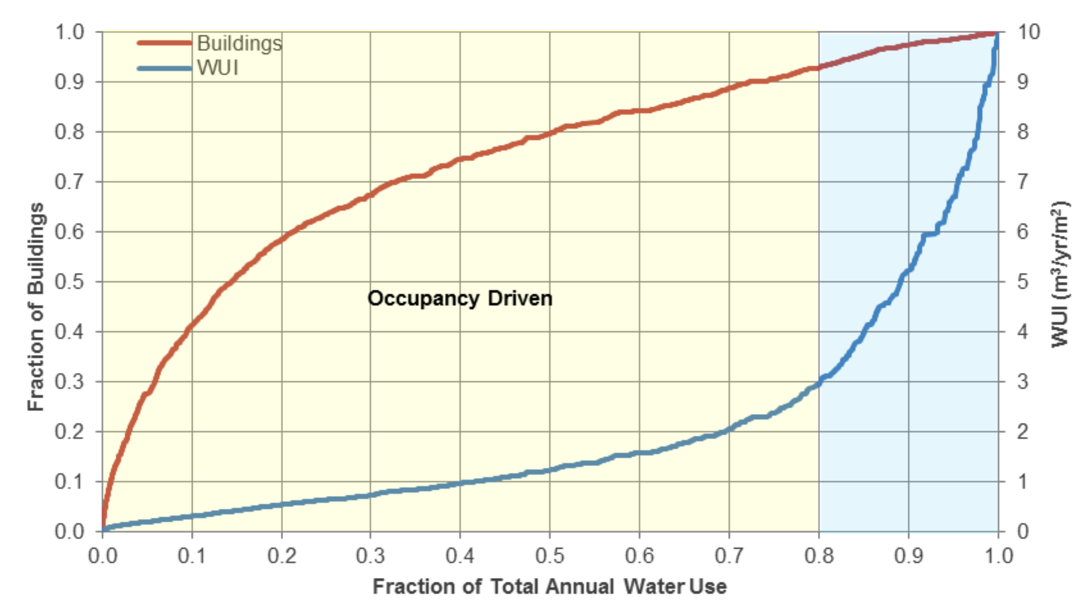


Figure 155: WUI Water Demand Structure for Auckland.

To understand whether the WUI changes with the building record size for the Auckland sample, once again, a logarithmic scale can be used to observe the first and second order trends. Figure 156 shows that the simpler straight line first order trend suggests that, as building records increase in size, the WUI decreases. The heavy dashed second trend line indicates that, for the very large buildings, the WUI starts to increase again with a change in slope at just less than 10,000 m^2. However, this should be used with caution because the sample size (as shown by the number of dots) is much smaller once the building size gets beyond 10,000 m^2.

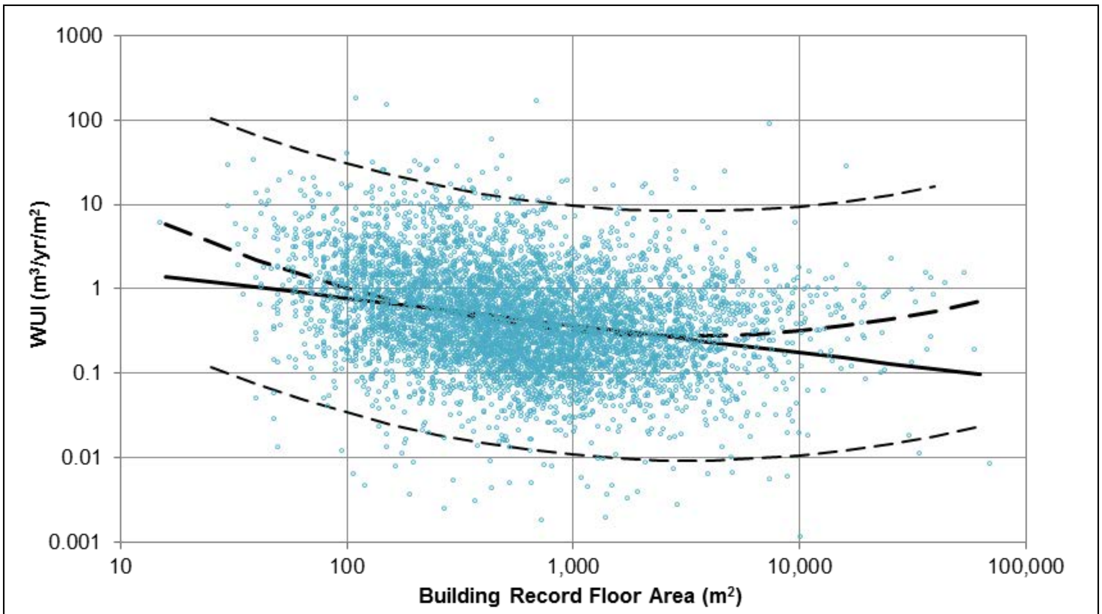


Figure 156: WUI and Floor Area using Logarithmic Scales.

10.3 Water Use and Building Type and Age

The Auckland BEES water sample has sufficient data points that can be linked back to the building use strata from QV and Auckland City Council building records. This allows an investigation of the differences between office buildings, retail and other buildings (Figure 157).

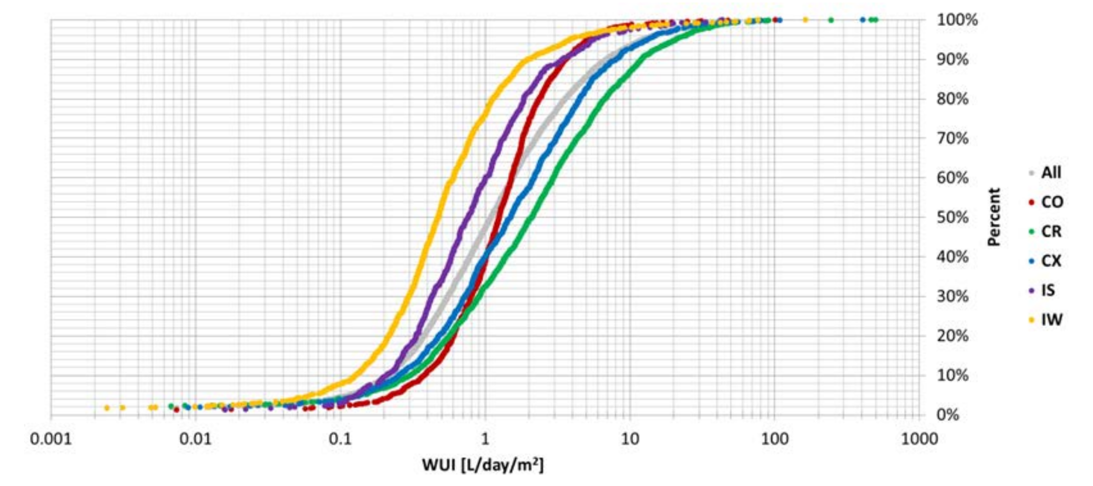


Figure 157: Cumulative Distribution of WUI by Building Use Strata using Full Range Logarithmic Scale.

Figure 157 shows Commercial Retail (CR) building records (green line) have the broadest distribution and the highest water use and Commercial Office (CO) building records (red line) have the narrowest distribution, as determined by the steepness of the curve. A narrow distribution indicates that water use is very similar (homogeneous) in the population, whereas broad distribution indicates heterogeneity in water use between properties.

It is also interesting to analyse whether newer non-residential buildings are more water efficient than older buildings.

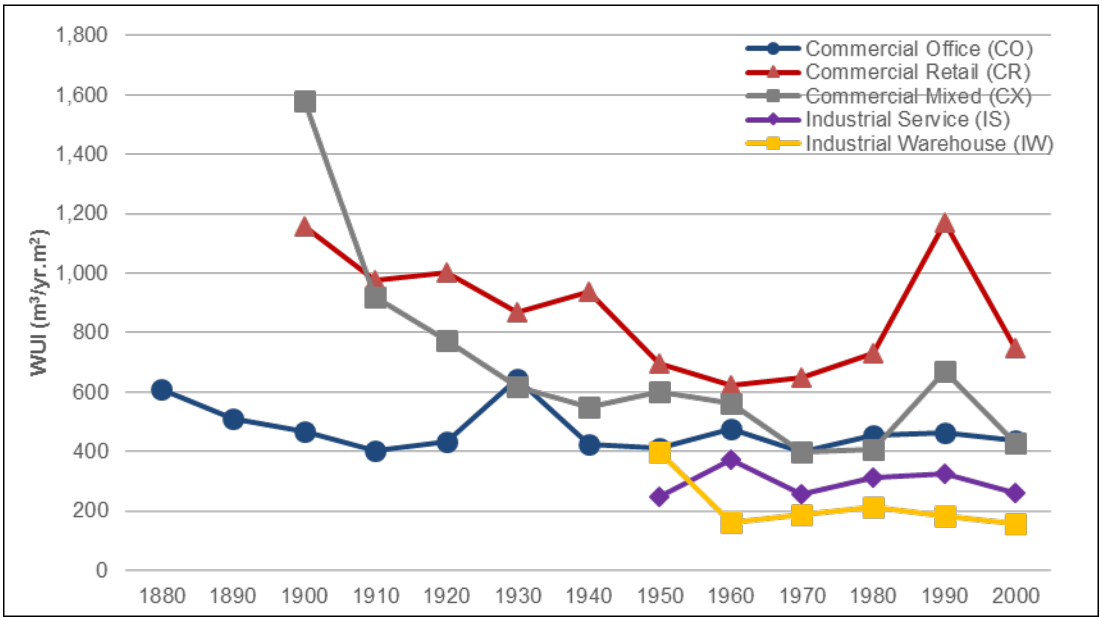


Figure 158: Median WUI of Building Use Strata by Building Age.

The total sample when disaggregated by age suggests that newer buildings are more efficient than older buildings. However, Figure 158, which breaks down the building stock by building use strata, shows a significant factor impacting these use types, with the lower use Industrial Service (IS) and Industrial Warehouse (IW) categories only starting around the 1950s. It highlights the higher use of Commercial Retail building records with a large spike in the 1990s. Furthermore, when looking at each of the building use strata separately, there is no obvious trend, based on the last 50 years, to suggest any improvement in water use.

10.4 Corrected Mean Values

The skewed nature of this sample, as shown by the necessity to use a logarithmic scale for graphing and analyses, also means it is necessary to consider the outlying values carefully. Basically, this is to take into account the few buildings that have very large water use. One way to reduce the impact of these outliers is to consider a fitted distribution of the points. For this sample, a log-normal distribution was used. Table 58 shows the total annual water use sample average and the fitted average and the sample median and fitted median. The difference between the sample and fitted average is significant showing the data is not normally distributed, but it has a significant tail at the higher end creating the skew.

Table 58: Mean and Median Water Use for the Auckland Sample and Building Use Strata.

Water use (m^3/yr)	Mean		Median	
	Simple	Corrected	Actual	Fitted
All	1,170	430	240	260
Commercial Office (CO)	1,400	610	280	340
Commercial Retail (CR)	1,300	410	240	230
Commercial Other (CX)	1,000	510	300	310
Industrial Service (IS)	660	300	190	210
Industrial Warehouse (IW)	1,350	350	200	220

The closeness of the fitted estimate of the median and the actual median values is indication of the acceptability of using fitting against a log-normal distribution.

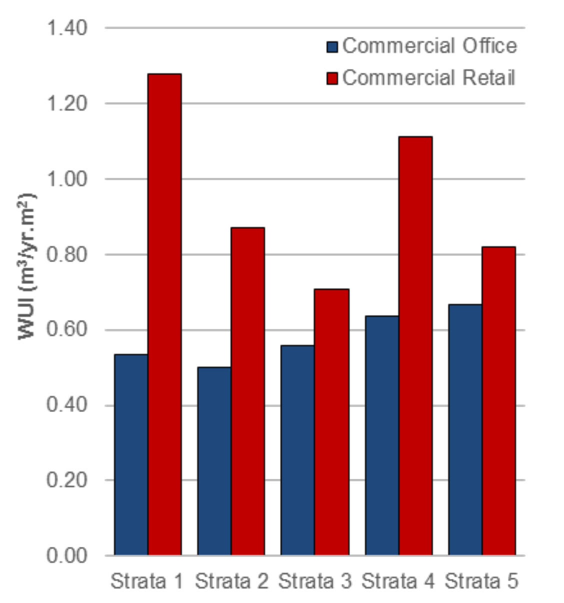


Figure 159: Mean WUI for Commercial Retail and Commercial Office.

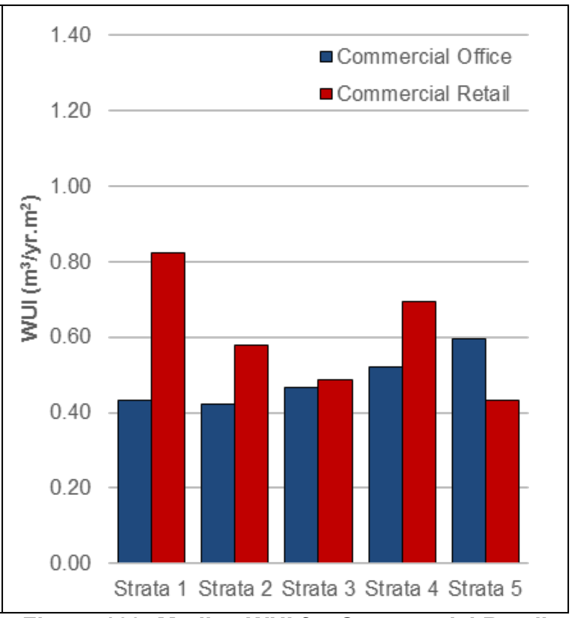


Figure 160: Median WUI for Commercial Retail and Commercial Office.

The WUI average and median for the different building strata and for Commercial Office and Commercial Retail building records were also fitted against a log-normal distribution. These results are shown in Figure 159 and Figure 160 and summarised in Table 59. These provide good baseline estimates for WUI in Auckland Commercial Office and Commercial Retail building records. For all further use, it is recommended to use the fitted values.

Table 59: Mean and Median WUI for the Whole Sample and Building Use Strata.

WUI ($m^3/yr.m^2$)	Mean		Median	
	Simple	Corrected	Actual	Fitted
All	0.93	0.66	0.41	0.44
Commercial Office (CO)	0.72	0.54	0.46	0.45
Commercial Retail (CR)	1.80	1.20	0.79	0.76
Commercial Other (CX)	0.97	0.83	0.56	0.56
Industrial Service (IS)	0.66	0.40	0.28	0.30
Industrial Warehouse (IW)	0.68	0.26	0.18	0.19

10.5 Summary

Water use in non-residential building records was found to vary over a tremendous range. The smallest non-zero water user consumed 100,000 times less than the largest water user.

The analysis has demonstrated that separation of non-residential water users by building use strata is essential as they all have different water use characteristics. However, none of the groups exhibit very homogeneous behaviour given the variability even within each building use stratum.

This analysis has shown that Commercial Office building records use less water than Commercial Retail building records based on the Auckland sample. Given Commercial Retail is a heterogeneous group, to better understand the relationship between water use and Commercial Retail building records, it is recommended for future research to divide this group into more homogeneous retail business groups and link them to particular space utilisation to bring more understanding.

The size of a building explained 28% of the variance in water use in the dataset, because larger properties use more water than smaller properties. WUIs were calculated for all properties as a first order correction for size. Going from smaller to larger buildings, the water use per square metre of floor area was found to be first decreasing until a minimum was reached for building records with a floor size of around 3,000 m^2. The WUI then increases for the larger properties (10,000 m^2 or more).

10.5.1 Largest Water Using Characteristics in Non-residential Properties

Current water demand for the sample of Auckland non-residential building records is dominated by a relatively small set of building records with very large water consumption. Half of the total demand was generated by only 2% of the building records, which had an annual water use in excess of 7,000 m^3/yr. However, this threshold is not useful for small building records with large water use. Business verification indicated that the high consumption rate in the top 10 of these particular properties is linked to the presence of industrial processes.

Business types such as breweries, meat processing plants and beverage companies were found to occupy the building records at the high end. It is almost guaranteed that a building record will contain some form of water using industrial process when the WUI for a building record is found to be in excess of 10 $m^3/yr.m^2$. Looking at the structure of demand corrected for size, 50% of total demand was found to be generated by 12% of building records. These building records had a WUI that exceeded 2.3 $m^3/yr.m^2$. The likelihood of finding water-using production processes in these building records is significant. However, these processes do not have to be industrial – they can also be food related. In Figure 155, a range is indicated where food processing might be the dominant water use. However, this section does not provide for further evidence to support this possibility. Cross linkage with data of other parts of the BEES research such as targeted monitoring and the telephone survey is needed to build that evidence.

With regard to water use of the other 88% of building records, the contribution of occupancy-driven water end-use becomes a major contributor to overall water use. There are different degrees of service provisions to occupants. An additional factor, for instance, indoor catering, might be important for water use.

The average performance of Commercial Office building records, with a median water use of 0.46 $m^3/yr.m^2$, is indicative for water use driven by occupancy. The low water use in the industrial warehouses indicates storage spaces in buildings do not generate a large demand for water, since the likelihood to find a significant part of a warehouse is dedicated to storage is high. Therefore, in the absence of industrial processes, if the occupant density of a building decreases, the other water-using processes such as cleaning and building climate control become more dominant. Therefore, the largest water use in non-residential building records is governed by the presence of particular functional activities and services in the building.

11. THE TAKE-UP CHALLENGE

This section uses the results from detailed interviews with building owners, designers, managers and tenants to examine the New Zealand-specific challenges to the take-up of energy and water efficiency opportunities.

The use of energy and water was seen as the tenant's responsibility. It was found that the data emerging from these detailed interviews reinforces a persistent sense of under-awareness on the part of building owners and property managers in relation to active management of energy and water use.

Three-quarters of the building owners and property managers interviewed had no energy or water use reduction targets set. A similar proportion provided no information to their occupants, tenants or staff about ways to reduce energy or water consumption. Almost 82% of the building owners and property managers interviewed reported that they had no formal energy or water management procedures in their buildings.

A large number of owner-occupiers take no action to improve the management of energy, with the exception of installation of a limited range of products such as energy-efficient light bulbs and independently monitoring energy consumption. For the owner-occupiers that do address energy and water use issues, those actions tend to only be implemented within their own business rather than across the building as a whole.

It has long been recognised overseas that improving energy efficiency in non-residential buildings has been more inhibited by the decisions of building owners, designers, managers and tenants than the technological barriers. Internationally, considerable attention has been given to identifying what factors prompt different interests to design, build, manage and lease energy-efficient buildings. BEES has also explored the extent to which key stakeholders in the non-residential building chain perceive benefits in improving the resource performance of buildings.

Preliminary work into the non-technological barriers to resource optimisation in non-residential buildings consisted of in-depth interviews with four types of stakeholders in the non-residential building sector. Table 60 summarises the categories of building managers interviewed and the focus of the interviews.

Table 60: Categories of Building Managers.

Sector	Focus
A. Facilities management • Hands-on landlords/multi-tenant building • Owner-occupier landlord with tenants • Provider of facilities management on behalf of landlords • High-end complex building facilities management	• Extent/intensity of management and scope of work • Focus of facilities management in particular building • Engagement with tenants • Key priorities for facilities manager • Mechanisms used to define facilities manager performance • Mechanisms to measure building performance
B. Property portfolio managers	• Priority of resource (energy and water) optimisation in investment, acquisition and disposal choices • Mechanism for ensuring resource optimisation in building design • Mechanisms to manage tenant resource use • Extent of control over facilities management in buildings and focus/priorities for facilities management
C. Property managers for green/social responsibility companies	• Extent green brand drives building selection/operation • Criteria for building selection • Extent of management to optimise resource use • Management tools and user education

Those interviews revealed two quite different approaches among owners and property managers, which have been labelled broadly as:

- building ownership for self-employment
- non-residential buildings for investment.

The former take a do-it-yourself approach to building management and are interested in reducing their own – not necessarily their tenants' – exposure to direct and indirect costs, having uncomplaining and undemanding tenants, securing a steady but not necessarily maximised income stream and being able to work for themselves.

Those concerned with non-residential buildings as an investment are concerned with buildings that show strong income potential and investment returns. Their management approach is focused on reducing the operational costs of the building and recruiting and retaining tenants willing to pay premium pricing within the market using buildings of that particular rating. This can involve dedicating significant in-house and contracted resources to building management for higher performance.

The former were largely unconcerned with the building performance of their assets, and the maximisation of income had a very different meaning for the self-employed landlords compared to those operating within an investment paradigm. For the self-employed, the stability of income was the underpinning theme, and performance and income were largely decoupled. By way of contrast, the investment-oriented looking to maximise the income potential of the asset linked building performance and income. For the investors, energy and water consumption were seen as important aspects of a building in terms of attracting and retaining tenants.

Irrespective of those differences, however, there was strongly shared discourse around resource consumption being a tenant matter. The use of energy and water was seen very much as part of tenant independence and a space of tenant decision-making. Even among those oriented to generating value for investors in non-residential buildings, getting tenants to be committed and willing to invest in resource optimisation was not necessarily an actively pursued challenge. There were also considerable contrasts around the extent to which building owners and managers coupled or decoupled building performance in relation to their income and business goals.

Subsequent surveying reinforces a persistent sense of this under-awareness 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 section presents the results of surveying in 2012 of three very different populations of building owners and property managers. Those populations were:

- owner-occupiers of non-residential buildings participating in BEES
- property managers and non-occupant owners of non-residential buildings participating in BEES
- property managers and owners listed as members of the Property Council of New Zealand (PCNZ) collated to remove any duplicates arising from the sets above.

This section presents the data from the above stated surveying and explores:

- the extent of engagement with non-residential building property ownership and management and the geographical distribution of buildings managed or owned by respondents
- the nature of the building and activities undertaken within those buildings
- the priorities and motivations around energy and water use management
- actions taken to manage energy and water use.

11.1 Owners and Property Managers

Among the 109 respondents to the owner and property manager surveys, 23.9% owned no buildings at all, although 61.5% undertook no property management for other owners. They are associated with a considerable stock of buildings. They own between them a stock of 1,090 non-residential buildings and manage 823 non-residential buildings.

Their ownership and property management interests tend to be concentrated on Auckland and the larger metropolitan areas. Of the 78 respondents who owned non-residential buildings, 46.2% had at least one non-residential building in the Auckland area. Of the 42 respondents that were involved in property management for other non-residential building owners, 45.2% managed at least one building in Auckland. Over one-fifth (23.8%) managed at least one non-residential building in Wellington (Table 61), noting that, because building owners and property managers can operate in multiple locations, the percentages presented here will exceed a total of 100%.

Table 61. Proportion of Owners and Property Managers with Buildings by Region

Region	Building owners (*n* = 78)		Property managers (*n* = 42)	
	Number	Percentage	Number	Percentage
Northland	2	2.6%	0	0.0%
Auckland	36	46.2%	19	45.2%
Waikato	10	12.8%	4	9.5%
Bay of Plenty	8	10.3%	4	9.5%
Gisborne	0	0.0%	0	0.0%
Hawke's Bay	4	5.1%	0	0.0%
Taranaki	3	3.8%	2	4.8%
Manawatu-Wanganui	2	2.6%	1	2.4%
Greater Wellington	13	16.7%	10	23.8%
Tasman	2	2.6%	0	0.0%
Nelson	2	2.6%	0	0.0%
Marlborough	0	0.0%	0	0.0%
West Coast	0	0.0%	0	0.0%
Canterbury	7	9.0%	3	7.1%
Otago	7	9.0%	4	9.5%
Southland	2	2.6%	0	0.0%

The pattern of use to which buildings are put is a little more complex. Over two-thirds (69.2%) of building owners report owning at least one building used primarily for retail purposes while 80.8% have at least one non-residential building used primarily as offices (Table 62). However, of the total number of non-residential buildings owned by the respondents, 457 (about 42.0%) were reported as primarily used for retail purposes.

Table 62. Owned and Managed Building Portfolios – Use.

Primary building function	Building owners (*n* = 78)		Property managers (*n* = 42)	
	Number	Percentage	Number	Percentage
Primarily retail	54	69.2%	26	33.3%
Primarily office	63	80.8%	27	34.6%
Primarily warehouse	33	42.3%	16	20.5%
Other	15	19.2%	7	9.0%

By way of contrast, only 30.7% of the owned stock accounted for by the owner respondents were used for offices. Clearly, across their portfolios, many of these owners deal with retail businesses as well as office-based businesses. In a small number of cases, owners reported that they had buildings that were primarily used for storage and also buildings that had no primary use but were divided across multiple uses.

Of the total number of non-residential buildings managed by respondents, 310 (about 38.0%) were reported as primarily used for retail purposes while 28% of the managed stock accounted for by the property manager respondents were used for offices. That is, they are likely to specialise in buildings that are primarily offices or primarily retail. This suggests that property managers tend to specialise in servicing particular building types.

There was much less diversity and much more consistency around owner views about their building ownership goals. These had a clear resonance with the conclusions drawn from the in-depth interviews. Certainly, the desire to meet specified rates of return, retaining tenants, maximising income and reducing operational outgoings were all evident. So too were goals that appear much more like the residential rental sector than goals associated with the non-residential sector. Those included an apparent reliance on capital gains and a desire for a steady and predictable income from non-residential building ownership. The latter was associated in part with owners reporting that they had purchased a non-residential building as a means of providing a retirement income. Finally, a minority of owners commented that non-residential buildings allowed them to, effectively, be their own boss.

Within these broad ownership goals, it would be expected that non-residential building owners would give a different level of priority to different aspects of building management and building provision. This was explored in relation to a specified set of both energy and water issues as well as some broader issues around workplace environments.

Table 63: High Priorities for Own Buildings – Views of Building Owners.

Owner – high priority	Building owners (*n*=78)	
	Number	Percentage
Improving workplace environments	50	64.1%
Increasing energy efficiency	35	44.9%
Secure energy supply	32	41.0%
Reducing energy costs	29	37.2%
Reducing water costs	28	35.9%
Increasing water efficiency	26	33.3%
Reputation as energy conscious	25	32.1%
Secure water supply	22	28.2%
Reputation as water efficient	22	28.2%
Reducing energy-related emissions	17	21.8%
Reducing water-related emissions	16	20.5%

The relatively low proportions of owners that give high priority to resource-efficient buildings as a pathway to enhancing their business reputation are consistent with the European experience. These so-called soft benefits tend to be seen as ancillary to hard benefits such as reduced operating costs or higher investment returns rather than a primary benefit and of benefit in themselves (Rosall, et al., 2009).

The areas building owners believe substantial proportions of tenants give high priority to, such as reducing energy costs, are also areas that many building owners and property managers are not exposed to themselves. In the case of energy costs, building owners and property managers overwhelmingly report that energy billing tends to be through direct tenant-supplier relationships. Less than 7.0% report that energy costs are typically incorporated into the rent (Table 64).

Table 64: Tenant Energy Payments Reported by Owners and Property Managers.

Typical tenant payment across property portfolio	Owners and property managers	
	Number	Percentage
Energy included in rent	7	6.4%
Paid direct to supplier	80	73.4%
It varies in different buildings – some directly, some included in rent	17	15.6%
It varies for different tenants – some directly, some included in rent	5	4.6%
Total	109	100%

Building owners tend to see their tenants as giving high priority to both cost reduction and workplace environments for staff. Security of energy and water supply are perceived by building owners to be important for only substantial minorities of tenants. Reputational advantage is seen as less likely to be important (Table 65).

Table 65: Owner Perceptions on Tenant High Priorities.

Owner perceptions of tenant high priority	Building owners (n = 78)	
	Number	Percentage
Reducing energy costs	45	57.7%
Improving workplace environments	45	57.7%
Secure energy supply	35	44.9%
Secure water supply	35	44.9%
Increasing energy efficiency	34	43.6%
Reputation as energy conscious	26	33.3%
Reducing water costs	23	29.5%
Increasing water efficiency	21	26.9%
Reputation as a water-conscious business	17	21.8%
Reducing energy-related emissions	14	17.9%
Reducing water-related emissions	13	16.7%

In some cases, owners are more likely to see their tenants as giving higher priority to an issue than they are themselves. This is the case with:

- reducing energy and water costs
- reducing energy and water-related emissions
- ensuring secure energy and water supplies for the future
- reputation as an energy-conscious or water-conscious business
- improving workplace environments
- increasing energy and water efficiency.

Property managers working for others were asked about resource optimisation priorities in relation to the building owners with whom they work and the tenants located in the buildings they manage. Table 66 presents property manager perceptions for each of those groups respectively. Property managers are much less likely to see building owners and tenants as giving resource optimisation high priority than building owners.

Table 66: Property Manager Views on Building Owner and Tenant High Priorities.

Property manager perceptions of high priorities	Owner high priorities (n = 42)		Tenant high priorities (n = 42)	
	Number	Percentage	Number	Percentage
Improving workplace environments	12	28.6%	13	31.0%
Secure energy supply	9	21.4%	12	28.6%
Secure water supply	8	19.0%	12	28.6%
Increasing energy efficiency	7	16.7%	11	26.2%
Reducing water costs	7	16.7%	9	21.4%
Reducing energy costs	6	14.3%	7	16.7%
Reducing energy-related emissions	4	9.5%	5	11.9%
Reducing water-related emissions	4	9.5%	5	11.9%
Increasing water efficiency	4	9.5%	4	9.5%
Reputation as energy conscious	3	7.1%	3	7.1%
Reputation as a water-conscious business	3	7.1%	3	7.1%

There is little evidence of active energy and water management practices either among building owners or among property managers. While 51.4% of building owners and property managers are aware of mechanisms such as green leases, none of the property managers use green leases in any of the buildings with which they are associated, and only two building owners report using green leases. Additionally, while 45.8% of building owners and property managers report that they at least monitor energy use in their buildings (Table 67), the majority make no active attempts to act on resource consumption in buildings.

Table 67: Monitoring Energy or Water Use or Costs.

Monitoring building resource use or costs	Building owners and property managers (*n* = 109)	
	Number	Percentage
Energy only	13	11.9%
Water only	6	5.5%
Both energy and water	37	33.9%
No monitoring	52	47.7%
Do not know	1	0.9%
Total	109	100.0%

While 65.1% of property managers and building owners claim to undertake some sort of installation of water or energy-saving devices such as installing energy-efficient lights bulbs, only between a quarter and a third undertake the broader array of activities used internationally to optimise resource use. Most take none of the internationally recognised pathways to optimising resource use (Table 68).

Table 68: Inaction around Resource Efficiency among Property Managers and Building Owners.

No action to:	Building owners and property managers (*n* = 109)	
	Number	Percentage
Set targets for energy or water use reductions	83	76.1%
Provide information to staff or tenants	80	73.4%
Establish formal policy	89	81.7%
Have a person responsible for resource management	72	66.1%
Do formal resource audits	77	70.6%
Benchmark use	71	65.1%

Over three-quarters of building owners and property managers set no targets for energy or water use reductions, with similar proportions providing no information to occupants, tenants or staff about ways to reduce energy or water consumption. About two-thirds of property managers and building owners report having no position with responsibility to optimise water or energy management or benchmarking use. A slightly larger proportion (71.6%) of property managers and building owners report they have not undertaken energy or water audits in their buildings. Not surprisingly, given that they have failed to undertake any of the tasks necessary to establishing a formal policy on energy or water efficiency, the vast majority – almost 82.0% of property managers and building owners – report they have no formal energy or water management policy in the their buildings

11.2 Owner-occupiers

This pattern of limited action in relation to resource optimisation is also found among owner-occupiers. Fifty-one BEES owner-occupiers participated in the telephone survey around resource optimisation. The buildings of owner-occupiers also tend to be smaller (Table 69). Over half of the buildings are less than 3,500 m^2. Among this set of owner-occupiers, 60.8% are sole occupants of their building. The remaining owner-occupiers report between one and seven tenants also located in the building (Table 69). Most of these buildings are relatively small, with 31.8% being on one level and a further 37.3% in two-level buildings (Table 70). As a consequence, only 36.0% of these buildings had an elevator, and about the same proportion had public areas. The buildings of owner-occupiers also tend to be smaller (Table 70).

Table 69: Owner-occupied Buildings and Tenants.

Occupancy	Owner-occupiers	
	Number	Percentage
No tenants	31	60.8%
1 tenant	7	13.7%
2 tenants	5	9.8%
3 tenants	2	3.9%
4 tenants	4	7.8%
6 tenants	1	2.0%
7 tenants	1	2.0%
Total	51	100%

Table 70: Owner-occupied Buildings and Number of Levels.

Number of levels	Owner-occupiers	
	Number	Percentage
1 level	16	31.4%
2 levels	19	37.3%
3–6 levels	8	15.7%
7 levels or more	8	15.7%
Total	51	100.0%

Over half of the buildings are less than 3,500 m^2. The owner-occupied buildings are not generally air-conditioned. Only 33.3% are reported as being so, and 68.6% of owner-occupiers report the building has windows that can be opened and closed by the occupiers. Less than one-fifth (15.7%) of the buildings were reported as being double glazed.

Table 71: Owner-occupied Buildings by Building Floor Area.

Building floor area (m^2)	Owner-occupiers	
	Number	Percentage
5–649 m^2	10	19.6%
650–1,499 m^2	8	15.7%
1,500–3,499 m^2	11	21.6%
3,500–8,999 m^2	8	15.7%
9,000+ m^2	8	15.7%
No estimate – multiple buildings on site	2	3.9%
No estimate	4	7.8%
Total	**51**	**100.0%**

In managing their tenants, owner-occupiers were interested primarily in building ownership for either use value or as a form of self-employment, that is, they took a do-it-yourself approach to building management and were interested in reducing their own – not necessarily their tenants' – exposure to direct and indirect costs, having uncomplaining and undemanding tenants and securing a steady but not necessarily maximised income stream.

These owner-occupiers reported little use of outside professionals in managing their building or their tenants. Only 10.5% of owner-occupiers with tenants used an agent, property or building manager to check rental payments and liaise with tenants. Even fewer (5.3% of these owner-occupiers) used them for tenant recruitment. Previous interview data suggests that owner-occupiers use real estate agents but also manage their own direct advertising. Most importantly, it should be noted that recruitment of new tenants is not a frequent event for many owner-occupiers.

In relation to charging for energy and water, it appears that public areas tend to be ignored in allocation of rent or charging processes. Just over half (52.6%) of the owner-occupiers expect their tenants to acquire their electricity through direct supply, while the others simply include energy costs in the lease arrangement. Among the latter, half do not itemise those costs. The situation regarding water is unclear, with 26.3% indicating that water costs are included in the lease and 60.0% of those reporting that they do not separately itemise water costs within the rental charge.

The data presented above relates to the buildings in which owner-occupiers themselves are also located. However, about a third (31.4%) of these owner-occupiers own and rent out other non-residential buildings. When dealing with tenants in other buildings as well as the ones in which owner-occupiers are located, there is strong desire to retain existing tenants rather than maximise income. Tenant retention is cited more by these building owners than any other consideration.

Only 2.0% of owner-occupiers report using building or property managers to manage central systems such as heating systems, while 3.9% of owner-occupiers reported using a building manager for maintenance and repairs. There is considerable variation around what owner-occupiers give high priority to, but the proportions giving high priority to water optimisation tends to be very low (Table 72).

Table 72: Owner-occupier High Priorities in their Occupied Building.

High priorities	Owner-occupiers (*n* = 51)	
	Count	Percentage
Improving workplace environments	30	58.8%
Secure energy supply	20	39.2%
Secure water supply	18	35.3%
Reputation as energy conscious	14	27.5%
Increasing energy efficiency	12	23.5%
Reputation as a water-conscious business	12	23.5%
Reducing energy costs	11	21.6%
Reducing energy-related emissions	10	19.6%
Increasing water efficiency	6	11.8%
Reducing water costs	5	9.8%
Reducing water-related emissions	5	9.8%

Two other tendencies emerge:

- A large majority of owner-occupiers take no action to improve the management of energy (Table 73) with the exception of installation of a limited range of products such as energy-efficient light bulbs and monitoring energy use.
- Where owner-occupiers do institute actions to address energy and water use issues, those actions tend to involve implementing them within their own business rather than across the whole building (Table 74 and Table 75).

For instance, only 17.6% of owner-occupiers report monitoring the energy use in the building, although 33.3% of owner-occupiers report monitoring their own energy use.

Table 73: Inaction among Owner-occupiers on Energy Management.

No action to:	Owner-occupiers (*n* = 51)	
	Count	Percentage
Monitor energy use	25	49.0%
Set targets for energy reductions	42	82.4%
Provide information to occupants on energy use	42	82.4%
Establish formal energy management policy	45	88.2%
Have a person responsible for energy management	41	80.4%
Do formal energy audits	44	86.3%
Benchmark energy use	48	94.1%
Dedicate a budget for energy management	46	90.2%
Install energy-saving technologies	27	52.9%

Table 74: Owner-occupier Actions on Building or Own Business for Energy.

Action to:	Own business	Whole building
Monitor energy use	17	9
Set targets for energy reductions	6	2
Provide information to occupants on energy use	4	4
Establish formal energy management policy	3	2
Have a person responsible for energy management	5	4
Do formal energy audits	2	4
Benchmark energy use	0	2
Dedicate a budget for energy management	2	2
Install energy-saving technologies	11	12

Table 75: Owner-occupier Actions on Building or Own Business for Water.

Action to:	Own business	Whole building
Monitor water use	7	7
Set targets for water reductions	3	2
Provide information to occupants on water use	2	1
Establish formal water management policy	2	1
Have a person responsible for water management	2	3
Do formal water audits	1	1
Benchmark water use	0	2
Dedicate a budget for water management	1	2
Install water-saving technologies	1	4

Effectively, where owner-occupiers deal with the whole building fabric and systems, they are more likely to – if they are going to at all – institute some resource optimisation actions. They are least likely to attempt to encourage their tenants to optimise resource use despite often being the on-supplier of energy and water. Indeed, owner-occupiers seem largely unaware of alternative ways of encouraging tenants to optimise resource use. Only six of the 21 owner-occupiers with tenants had, for instance, heard of mechanisms such as green leases, and none of those intended to institute them.

At the heart of this issue appears to be a view among owner-occupiers that the business of resource management in their buildings is quite separate from the business of tenants and that they should not be managing tenants closely in this regard. Certainly, it is not because owner-occupiers believe that tenants give a high priority to energy or water optimisation, as Table 76 shows.

Table 76: Owner-occupier Perception of Tenant High Priorities.

High priorities for tenants	Owner-occupiers with Tenants (*n* = 20)	
	Count	Percentage
Improving workplace environments	5	25.0%
Secure energy supply	3	15.0%
Secure water supply	3	15.0%
Reputation as energy conscious	2	10.0%
Increasing energy efficiency	3	15.0%
Reputation as a water-conscious business	2	10.0%
Reducing energy costs	4	20.0%
Reducing energy-related emissions	3	15.0%
Increasing water efficiency	2	10.0%
Reducing water costs	3	15.0%
Reducing water-related emissions	2	10.0%

11.3 Discussion

The data emerging from these surveys reinforces a persistent sense of under-awareness 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 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 that:

- 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 or consume more resource than New Zealand can sustain means recognising that not only are buildings different but 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.

12. DISCUSSION AND CONCLUSIONS

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.

This section provides a summary of the important learnings from the BEES research for the building stock and its characteristics, energy and water use, opportunities for efficiency and policy tools.

12.1 Building Stock and Characteristics

For the first time, New Zealand's non-residential building stock has been quantified. Based on the data gathered from valuation data, WebSearch, telephone surveys, revenue meter readings and targeted monitoring, estimates have been provided for:

- the total number of BEES buildings in New Zealand (41,154 buildings)
- the floor area they contain (39.93 million m^2)
- the average size of a BEES building (970 m^2).

There is a significantly larger number of small buildings than expected, with 80% of the stock by count being less than 3,000 m^2. Using WebSearch, it was estimated that over half (58%) of the buildings were only one-storey high, accounting for 41% of the floor area, and 24% were two storeys and represented 21% of the floor areas. At the other end of the scale, 4% of buildings were 10 storeys or more and accounted for 16% of the floor area.

The BEES research used the building use strata, based on valuation data descriptors (for example, Commercial Office, Retail and Other) as the base unit for analysis, as there was a clear need to supply data and information at the building level. However, the in-depth analysis of the BEES data has shown that the activities within a building will often be varied and not necessarily relate to the building use strata for that particular building. There are no clear rules around the categorisation nor any database or methods to record buildings, the building type and the activities that are carried out within to provide a good base structure for research or analysis.

Recommendation 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.

Considerable time, effort and cost for the project was simply to develop building stock information. However, this information is already collected at a building level, and it also often includes business activities. It is recommended that the practicality and associated costs of the proposed central Building Warrant of Fitness database be investigated. This will ensure robust information on our building stock is available for further understanding and would also provide an avenue to better understand the 'Other' BEES buildings and building typologies, provided a requirement was to also include the type of businesses using the building.

Recommendation 2

It is recommended to continue building upon the BEES database through NABERS 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.

12.1.1 Building Classifications

Of the 41,154 BEES buildings estimated, only 16% (6,692) were classified as Commercial Office buildings, with an average floor area of 1,287 m^2. It is estimated 60% (4,022) of the Commercial Office buildings have a floor area of less than 650m^2, while a minor 137 of the buildings have a floor area greater than 9,000m^2.

A further 47% (19,453) were classified as Commercial Retail buildings, and the remaining 37% (15,009) as Other BEES buildings. The average Commercial Retail building has a gross floor area of 664 m^2, which is approximately half the size of the average Commercial Office building and Other BEES building (1,227 m^2).

12.1.2 Premise Classifications

The number of buildings estimated for each building use stratum was based on valuation data. The relationship between the building valuation classification and the actual activities is not always the same. In reality, these buildings are often of a changing and mixed use. This makes it difficult to classify the buildings in a way that clearly represents the uses within a building to then determine factors that impact or drive energy use.

Recommendation 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.

In order to better explore the wide ranges of characteristics and energy use, four premise use classifications were developed under the BEES research. Each classification provided a way to explore the drivers of energy use and the services provided:

- Business activity sector (BAS) – promulgated by Statistics New Zealand and based on Australia New Zealand Standard Industrial Classifications (ANZSIC).
- 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.

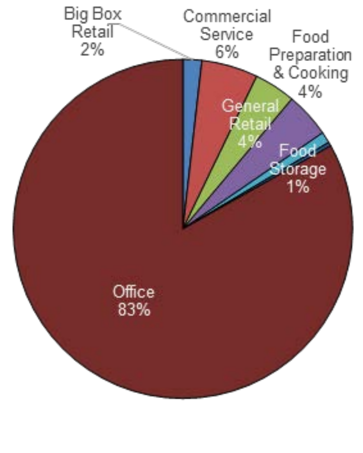


Figure 161: Participating Premises within Commercial Office Buildings.

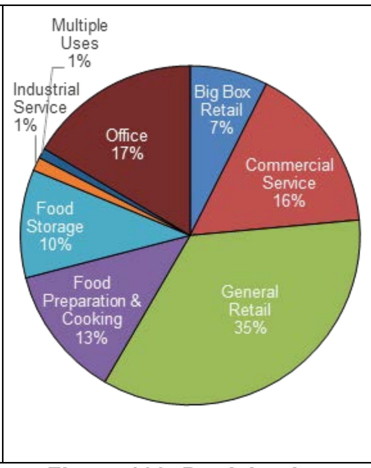


Figure 162: Participating Premises within Commercial Retail Buildings.

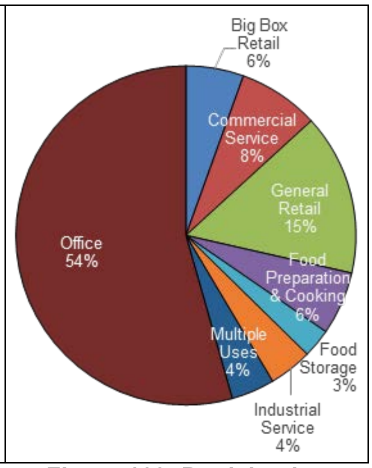


Figure 163: Participating Premises within Other BEES Buildings.

There was no perfect classification system for non-residential buildings for future analysis of energy use. The BAS enables the data to potentially be linked to other New Zealand statistical databases. The proposed revised QV premise categories or the CPA could also provide a strong basis for future policy development as well as improved energy audit and efficiency guidance.

Recommendation 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).

Through the data and analysis, Commercial Retail buildings have displayed an extremely diverse mixture of activities and uses that cannot simply be lumped into one homogeneous group. These varied from a few large shopping complexes through to a large number of small retail buildings in suburban areas, such as the typical corner dairy.

BEES-participating premises within a Commercial Retail building demonstrated a broader distribution across the CPA than the Commercial Office or even Other BEES buildings. General Retail was the most common (35%), with Offices, Commercial Service, Food Preparation & Cooking, Food Storage, Big Box Retail, Industrial Service and Multiple making up the remainder.

Of the premises participating that were within an Other BEES building, their premises were mainly Offices (54%) and General Retail (15%), but they also included Commercial Service, Food Preparation & Cooking, Big Box Retail, Industrial Service, Multiple and Food Storage.

12.2 Non-residential Energy Use

Energy was analysed by understanding both the total energy use and Energy Performance Indicator (EnPI) – the amount of energy used per square metre – for each building.

There are three distinct analysis groups: overall stock, building type by classification and premises.

Electricity was by and large the dominant fuel type found within the BEES participant buildings, with very few buildings having gas and even fewer with solid fuel, diesel or other fuel types. This is consistent with the estimated energy supply breakdown nationwide.

The estimated aggregate energy use for BEES buildings in New Zealand is:

- Electricity:
  - 6,370 GWh/yr.
  - 16% of nationwide electricity consumption.
  - NZ$1.09 billion of the nationwide electricity consumption.

- Gas:
    - 1,130 GWh/yr.
    - 7% of nationwide gas consumption.
    - NZ$0.65 billion of the nationwide gas consumption.

These are shown in Figure 164 and Figure 165 which use the energy demand data from Energy in New Zealand (Ministry of Business, Innovation & Employment, 2013) to place the BEES building electricity and gas use in context.

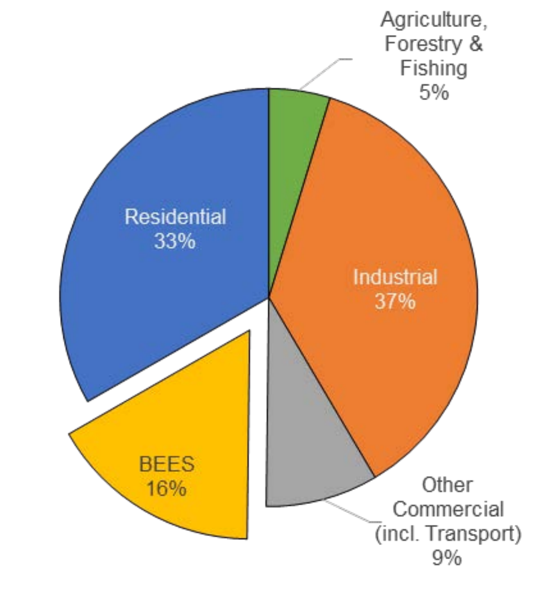


Figure 164: BEES Estimated Electricity Use as a Proportion of Total NZ Consumption.

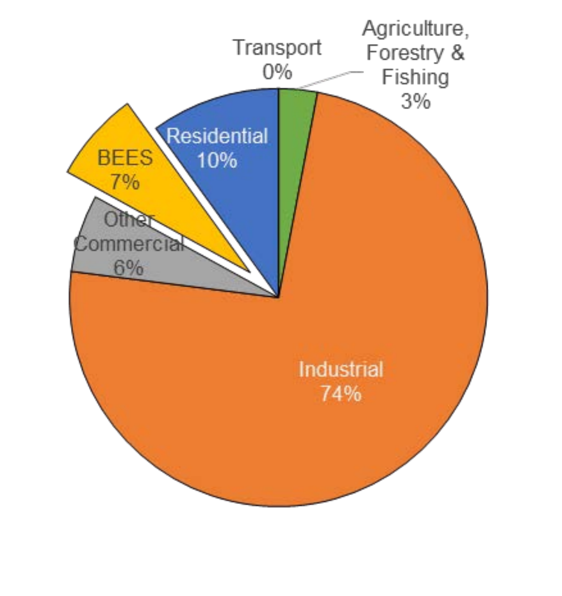


Figure 165: BEES Estimated Gas Use as a Proportion of Total NZ Consumption.

For the overall stock, the average $EnPI_{e+g}$ was estimated to be 203 kWh/m^2.yr. However, it should be noted that the variability of energy use was very large, and the analysis of the data showed there was a small number of buildings that had much higher energy use than typical, so the data was not normally distributed.

The most dominant fuel type was electricity, with an $EnPI_{elec}$ of 173 kWh/m^2.yr for all BEES buildings. Gas made up the remaining 31 kWh/m^2.yr. The occasional presence of other fuel types was negligible.

Commercial Office buildings were the most homogeneous of all the building categories in terms of the characteristics of energy use and efficiency. The baseline $EnPI_{elec}$ was estimated to be 186 kWh/m^2.yr. This was marginally higher than the estimate for those designated as Commercial Retail buildings, which was estimated to be 176 kWh/m^2.yr.

The diversity within the building stock is represented by the large confidence intervals displayed within Figure 8 and Figure 9. This shows the variability of energy use across this building stock even when the size of the building is taken into account. Further exploration showed that, within each building size stratum and building use stratum, the distribution of the energy data has an extremely long tail. This means the median values give a better representation of the typical energy use or energy intensity rather than the average. Once the size of the building is accounted for to determine the energy performance, there are no other specific variables that can be used to determine the energy intensity across the entire non-residential stock. This is because of the diversity of use (for example, Retail cannot be compared with Office use).

Despite Commercial Office buildings being the most homogeneous building typology, the actual values from the participating BEES buildings still had a large variation around this baseline as shown in section 2.4 (Figure 10). However, for Commercial Retail buildings, once again, the variation across the

Commercial Retail buildings was large. Retail was highly variable and dependent on key activities being present.

An $EnPI_{elec}$ of 158 kWh/m^2.yr was calculated for the Other BEES buildings. This lower EnPI is assumed to be due to the influence of Industrial Service and Industrial Warehouse buildings, which typically would have fewer people and/or less energy uses per square metre while having larger storage spaces.

Based on the averages, there was a trend for smaller buildings to use less energy per square metre. However, the error bars for these averages (refer Figure 8) clearly showed that this was not a statistically robust trend so should not be used or used with caution.

When gas was present within the participating premises, the increase in overall $EnPI_{e+g}$ was significant, with the gas often double the electricity consumption. Almost half the premises that used gas were Food Preparation & Cooking or Food Storage premises, which typically are more energy intensive in general. Thus, showing this high level of intensity is linked to the premise activities rather than the simple presence of gas.

At a premise level, activities could be systematically assigned and were far easier to classify than the whole building. However, the analysis of the data showed it was not normally distributed but skewed with a long tail of high energy use premises.

When looking at energy use in participating premises, retail had a higher $EnPI_{elec}$ compared to office premises. This was the opposite of the result at a building level. The likely reason for this is due to a greater level of central services in buildings designated as Commercial Office compared to Commercial Retail. The much smaller average floor area for Commercial Retail buildings compared to Commercial Office buildings supports this, as smaller buildings have either very limited or no central services.

12.3 Energy End-uses

All targeted monitored premises had lighting and plug load end-uses. A form of space conditioning was present in around three-quarters of these monitored premises. Therefore, out of the eight categorised end-uses (refer section 6), it is not surprising that, across the non-residential building stock, end-uses of lighting, plug loads and space conditioning have been identified as having notably and consistently higher $EnPI_{elec}$ and energy usage proportions than any other end-use.

For the Office premises, a clear one-third split was apparent at an end-use level. This was consistent across all building size strata and confirms a breakdown first determined in the 1980s (Baird & Newsam, 1986). It also indicates that no particular end-use has improved its energy efficiency significantly over the others:

- 1/3 lighting.
- 1/3 plug loads.
- 1/3 space conditioning and miscellaneous.

For retail premises the proportion of energy used for lighting was larger than in office. For example, in General Retail lighting was over half the total energy use. For the Food Storage premises the dominant energy end use was refrigeration. When the activities included Food Preparation and Cooking, plug loads were the most dominant, reflecting the appliances used for this purpose.

Lighting audits found that fluorescent lamps were present in 98% of the targeted monitored premises, with an average of 227 lamps per premise. However, they were generally not the only lamp type found in each premise. Up to six different lamp types were recorded in a premise.

For the lighting end-use, the choices now include types that are considerably more energy efficient than those 15–20 years ago. The overall energy use for lighting is still large, indicating the potential for energy reductions through the selection of more efficient lighting types that do not compromise the delivery or quality of the lighting.

Recommendation 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.

In General Retail and Big Box Retail premises, lighting can be as much as 68% of total energy use. The BEES research has revealed opportunities for improvements that will potentially decrease operational costs and energy use in this sector.

Current regulatory approaches focus on the energy performance of lighting in use. The current New Zealand standard (NZS 4243.2:2007) relates to lighting energy efficiency but sets maximum requirements in terms of lighting power density (W/m^2) rather than energy use (kWh/m^2). It was found that lighting energy use relates strongly to floor area.

Recommendation 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.

Refrigeration, when present as a specific energy end-use in Food Storage and Food Preparation & Cooking premises, had very high energy use (averaging 56% of total energy use, ranging from 6% to 65% when present). This shows the importance of efficient refrigeration appliances to manage ongoing energy use and cost. Examples of premises where this occurred included supermarkets, butchers and liquor stores. Whilst in some situations, improvements to the building envelope or sectioned part of the building would improve efficiency, often these are tenanted premises.

For premises with food processing (Food Storage and Food Preparation & Cooking), the most dominant energy end-use was for cooking and preparing the food. The $EnPI_{elec}$ of these premises (398 kWh/m^2.yr) was typically much higher than the average retail (General Retail and Big Box Retail) premise (96 kWh/m^2.yr).

Central space conditioning systems were mainly in large office buildings (building size S4 and S5). Typical performance levels could not be determined because of the diversity of types and ages of HVAC systems and difficulties gathering data at a premise level. However, it is clear that space conditioning systems are managed at a building level and not by each premise. This offers an engagement point for energy efficiency improvements in HVAC systems at a property owner level.

As building size decreased, the most common heating and cooling system at a premise level became electric heat pumps. Only in premises within the smallest building size stratum were simple electric resistance heaters the primary source of heating.

Based on the targeted monitoring, an average of 2.15 different heating types was found per premise. This was consistent across all building size strata and building use strata, both with and without central space conditioning systems. This shows that the level of service delivery is not always satisfactory for every person occupying the targeted monitored premises and that supplementary heating (or cooling) is required, or found desirable by some occupants, at various stages of the year.

The level of service provided, based on the temperature and environmental monitoring, over this entire building stock seemed reasonable, and there were no obvious signs of significant under-heating as seen in the residential sector. However, based on the telephone survey information and detailed interviews, the performance and effectiveness of heating systems to deliver uniform heat in general was poor. The large number of premises with multiple heating systems is another indicator of low satisfaction levels.

Based on those Office premises that were targeted monitored, overall, they appear to be adequately serviced and slightly better environmental conditions (both summer and winter) than premises within Commercial Retail or Other BEES buildings.

This means the temperature, relative humidity, illuminance and air quality were mainly of a satisfactory level.

12.4 Opportunities for Energy Efficiency

The BEES research has shown that there are significant opportunities to increase the energy efficiency of New Zealand's non-residential building stock. These can be achieved through several avenues, such as through appliance, lighting and space conditioning end-use monitoring, a better level of engagement between building owner and property managers with their tenants and through energy modelling.

The energy performance in non-residential buildings reflects a complex interaction between the behaviour of building users and ownership and managerial arrangement of the building and its operation within the context of those arrangements.

Not only are buildings different, neither tenants nor property owners can be treated as homogeneous groups. Not all tenants are the same, nor do they have the same preoccupations. Property owners are also a diverse set of organisations and individuals. Larger buildings are more likely to be managed by building managers, while smaller buildings are more likely to be managed by owner-occupiers. Larger buildings are more complex due to the tenant, building manager and property owner relationships.

It was found that there was a persistent sense of under-awareness on the part of property owners and building managers in relation to active management of energy and water use.

The building management interviews identified that most (three-quarters) of the property owners and building managers surveyed set no energy or water use reduction targets. Similarly, little information was provided to the building occupants, tenants and staff on ways to reduce energy and water consumption, with 82% reporting no formal energy or water management procedures.

Energy modelling, based in Christchurch, showed that a Commercial Office building, if passively designed, could reduce its energy use by almost 50%. This is a one-case study example, and it is recommended that further information and guidelines are developed to encourage an improvement in new buildings using a passive design approach. The findings from the modelling suggest:

- Savings from natural ventilation and daylight design can only be significant if the building form is kept narrow (less than 17 m width).
- An optimal combination of solar shading, insulation and free cooling can almost eliminate cooling energy consumption for Christchurch commercial buildings.
- Courtyards in conjunction with laneways could deliver a significant reduction in energy of up to 47% per square metre.
- The Christchurch City Council Central City Plan façade step-backs are not effective in saving energy or creating sunnier streets during the winter period.

The current New Zealand Building Code and supporting New Zealand standards for energy efficiency measures of Commercial Office buildings have largely been unchanged for over a decade. The BEES analysis has not shown different-sized buildings have a marked difference in energy performance or EnPI.

Recommendation 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.

Recommendation 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.

The building estimates and stock characteristics provided are a significant stepping stone in understanding not only the commercial building stock in New Zealand but the potential impact from energy-efficiency measures on a nationwide scale. With this data, there is the ability to improve nationwide energy use through modelling New Zealand buildings more accurately. The New Zealand Energy Consumption Dashboard, in Appendix K, demonstrates that simple modifications of lighting, equipment or miscellaneous power densities can halve the energy consumption.

12.5 Non-residential Water Use in Auckland

For non-residential buildings, water is typically metered at a building level only, as opposed to the premise level, which meant a premise breakdown was not possible.

Based on analysis of a detailed data set of Auckland meter data, the most important finding was that just over 40% of the buildings use 10% of the aggregate water use (low users), while at the other end of the scale, 20% of the buildings use 50% of the total water use (high users). It is likely that 80% of the water use is driven by increased occupancy, but the other 20% has other factors driving the water use. A possibility for this higher use range is that these buildings are linked to food processing and catering.

For both water and energy, industrial or transformational activities within premises and buildings appears to be a significant driver of consumption.

12.6 Policy Instruments and Efficacy

A multi-dimensional approach to initiatives designed to promote take-up and discourage the over-consumption of resources is required. This has already been recognised internationally. Although debate around the relative merits of each of various instruments has been dominated by theoretical economics with little reference to empirical evaluation or, indeed, experience (Jaffe & Stavins, 1994), there is now emerging a body of empirical evaluation that compares these tools directly.

The 2007 United Nations Environment Programme (UNEP) undertook a comprehensive review (Koeppel & Urge-Vorsatz, 2007) of instruments directed to optimising building energy performance. The findings are summarised in Table 77. UNEP concluded that combinations of instruments are more effective than the use of single instruments; regulatory and control instruments can be necessary; economic instruments, subsidies and informational levers as single items have variable results but are important to a mutually reinforcing package (McCormick & Neij, 2009; Circo, 2007) and these packages need to be tailored specifically to prevailing institutional, cultural and market conditions (Birner & Martinot, 2003).

Table 77: Policy Instrument Efficacy.

Policy instrument	Effectiveness	Cost-effectiveness	Success contingencies
Regulatory and government control			
Mandatory standards	High	High	Agreed and updated standards maintained by an independent body supported by information, communication and education.
Building codes	High	Medium	Dependent on enforcement.
Mandatory audits	Variable	Medium/high	Effective standards, tools and reporting processes required. Suitable for some stakeholders only.
Mandatory labelling, certification or disclosure	High	High	Depends on ability of end-user to assess and continuous end-user engagement.
Procurement regulation	High	High/medium	Ambitious targets needed if to provide demonstration to the market, clear standards required and tools to measure compliance against standards.
Economic and market-based instruments			
Co-operative procurement	Medium/high	High/medium	Establishes economies of scale.
Fiscal instruments			
Taxation	Low/medium	Low	Dependent on price elasticity.
Tax or fee exemptions or reductions	High	High	Need to be properly structured and monitored.
Capital subsidies, grants, loans	High/medium	Variable	Can be cost-effective when properly targeted to households confronting price barriers.
Information, leadership and voluntary action			
Public leadership	Medium/high	High/medium	Useful to demonstrate new technologies and practices.
Voluntary compliance with standards	Medium/high	High/medium	Effective if combined with fiscal incentives and possibility of regulation.
Voluntary labelling, certification or disclosure	Medium	Medium	Clear standards and comparative tools needed.
Promotional information and campaigns	Low/medium	Medium/high	Potential is limited unless supported by other instruments. Clear and properly targeted messages needed.

To improve New Zealand's non-residential buildings, a mix of instruments is best, including regulatory, economic, market and fiscal instruments. Policy to transform and improve our building stock will need to be shaped to the particular segments (for example, building characteristics, ownership relationship models, etc.) and across the value chain. These should be supported by guidance, information, tools and value cases.

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.

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 property owners, building managers and tenants.

13. RECOMMENDATIONS

Building on those very key recommendations identified in the previous section and highlighted below are a number of further recommendations for future work efforts and policy development.

13.1 Summary of Key Recommendations

13.1.1 Recommendation 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.

13.1.2 Recommendation 2

It is recommended to continue building upon the BEES database through NABERS 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.

13.1.3 Recommendation 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.

13.1.4 Recommendation 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).

13.1.5 Recommendation 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.

13.1.6 Recommendation 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.

13.1.7 Recommendation 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.

13.1.8 Recommendation 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.

13.2 Further Recommendations

A repository framework, similar to the premise database in the United States, could be useful for schemes such as NABERS NZ. The proposed BEES meta-hive is a very static database that will require updating over time. The proposed meta-hive also requires detailed instructions and should be used with caution, in conjunction with consulting BRANZ on its intended uses.

Time-of-use, half-hourly electricity revenue data is often recorded in larger (either by size or energy consumption) premises. This level of data collection is extremely useful in understanding energy use premise by premise, particularly for understanding how and when energy is being used.

Through the targeted monitoring, wiring and circuits were found to be inefficiently labelled and maintained. There is, however, no standard or guidance on how these must be labelled and/or maintained. This is demonstrated through the usability of the 101 premises targeted monitored for end-use analysis, where only 84 were able to be analysed due to unsafe and hazardous or poorly labelled circuit boards.

13.3 Opportunities for Future Work

The analysis and results from BEES have laid the foundation for many future research opportunities that are important to the progression of the building industry and understanding the energy and resources used within. These are listed below:

- The relationship between design, operation, indoor environmental quality and occupant satisfaction and management.
- A larger sample of POEs is recommended simultaneous to energy and environmental monitoring. This would provide, in a larger context, whether the internal environments produced within non-residential premises and buildings are satisfactory and provides an opportunity to examine the effects of different building systems on the internal environment, as well as dealing with the supplementary heaters issue, etc.
- Understanding central services, such as central space conditioning systems and their diversity and effectiveness in different building types.
- Opportunities for energy efficiency using passive design techniques through computer modelling.
- Lighting and policy instruments.
- Individual appliance energy models.
- Refrigeration end-use and efficiency opportunities.
- Food Storage and Food Preparation & Cooking premises.
- Investigation into circuit board maintenance standards/requirements.
- Water use outside of Auckland.
- Water-using processes at a premise level.
- Geographical/climate related energy use differences.
- How different sustainable or green buildings are from traditional buildings.
- Other energy fuels (including further investigation on gas usage).

Any future work based on the BEES results and/or the data provided from the BEES research is to be used with extreme caution. The significant complexity of the datasets has been consistently discussed throughout this report and needs to be considered with any future work.

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(2009) **BEES Overview.** (Victorious Magazine, February, VUW news magazine).

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Workshops and Presentations

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Amitrano, L. (2014) **BEES Findings and Opportunities** (EMANZ Conference 2014: The Rise of Consumer Power) 27-28 May, Auckland 2014.

Amitrano, L., Saville-Smith, K., Pollard, A., Isaacs, N. & Donn, M. (2013) **BEES Wellington seminar presentations: interim results** – Wellington 3 December 2013

Amitrano, L., Saville-Smith, K., Isaacs, N., Bishop, R., Burrough, L., Roberti, H. & Donn, M. (2012) **BEES Wellington and Auckland seminar presentations: interim results** – Wellington 19 July 2012 and Auckland 23 July 2012

Amitrano, L., Donn, M., Saville-Smith, K., Burrough, L., Bishop, R., Roberti, H., Vale, B. & Finch, R. (2012). **BEES Christchurch seminar presentations: interim results** – Christchurch 13 July 2012.

Camilleri, M. (2010) **The Building Energy End-use Study (BEES): Study design and early findings**. (Workshop at UCL) 17 May.

Donn, M., Creswell-Wells, T. & Cory, S. (2012) **Christchurch Urban Form and Energy Workshop** – Christchurch June 2012.

Donn, M. (2008) Chaired the **Architectural Integration sessions** of the two-day research planning workshop for the IEA 'Net Zero Energy Buildings' planning meeting in Lisbon prior to the EuroSun conference, 7-10 October 2008.

Isaacs, N. (2012) **New Zealand domestic and non-domestic buildings – HEEP and BEES.** (Presentation to International Energy Epidemiology Network Workshop) Berkeley, CA, USA: LBNL, 15-16 November – http://www.bartlett.ucl.ac.uk/energy/research/rcuk-centre-energy-epi

Isaacs, N. (2010) **Energy in building design: What is possible and how do you measure success?** (Public presentation at Christchurch Energy Awareness Week) Christchurch City: Gallery Theatre, 5 May – presentation and podcast online www.energyawarenessweek.co.nz.

Isaacs, N. (2010) **'An update on the BEES project'.** (In Proc. EMANZ Annual Conference – The Business of Energy Management) Wellington, New Zealand: Intercontinental Hotel, 25-26 February.

Isaacs, N. (2009) **Building Energy End-use Study (BEES).** (Presentation to CIBSE/EMANZ) 3 September.

Isaacs, N. (2008) **Where does all the energy go – The HEEP and BEES studies in New Zealand.** (Seminar, Environmental Energy Technologies Division) Berkeley, California: LBL, 5 September.

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Isaacs, N. (2008) **BEES Introduction for Electricity Commission staff.** (March 2008).

Conference Papers

Amitrano, L. (2013). **The Building Energy End-use Study.** (Poster paper presented at NERI 2013 Energy Conference: Energy at the Crossroads) Wellington, New Zealand.

Bint, L., Vale, R. and Isaacs, N. (2011). **Water use in Auckland and Wellington office buildings.** (Poster presented at EMANZ 2nd Annual Conference 2011: Energy Management – your responsibility and your reward) Auckland: New Zealand.

Bint, L., Vale, R. and Isaacs, N. (2011) **Water performance in New Zealand office buildings.** (Paper presented at Water New Zealand's Annual Conference & Expo: Advancing Water Reform) Rotorua, New Zealand.

Bint, L., Isaacs, N. and Vale, R. (2011) **Water Efficiency Rating Tool (WERT): Calculating water performance in office buildings.** (Poster paper presented at Water New Zealand's Annual Conference & Expo: Advancing Water Reform) Rotorua, New Zealand.

Bint, L., Vale, R. and Isaacs, N. (2010) **Water use in Auckland and Wellington office buildings.** (Poster paper presented at Water New Zealand's Annual Conference & Expo: Water Our Key Strategic Resource) Christchurch, New Zealand. Received Award – Best Poster Paper.

Bint, L., Vale, R. and Isaacs, N. (2009) **Water and office buildings – Performance benchmarks for commercial office buildings in CBD Wellington, New Zealand: Preliminary results.** (Poster paper to Water 2020 'From Fragmentation to Efficiency', Water New Zealand Annual Conference) Rotorua: Rotorua Energy Events Centre, 23-25 September. Received Award – Best Poster Paper.

Bishop, R. (2013) **Optimising the fresh air economiser.** Presented at ICEBO Conference, Montreal.

Hills, A., Donn, M. and Isaacs, N. (2012) **Creating an automated/open source 3D city visualization of building resource use + potential.** (4th Digital Earth Summit) Wellington, New Zealand, 2-4 September – http://www.digitalearth12.org.nz/view_event/creating-an-automated---open-source-3d-city-visualization-of-building-resource-use--potential.

Hills, A. (2011) **Visualising building energy in 3D: Collecting and communicating energy benchmarks and potential using emerging web applications and omnidirectional imagery.** (London: Network for Comfort and Energy Use in Buildings (NCEB), Proceedings of Conference: People and Buildings) UK: Arup office, 23rd September – http://nceub.org.uk Paper MC1

Hsu, C.Y. and Donn, M. (2009) **Commercial building façade design: The relationship between early design lessons and detailed design lessons.** (ANZAScA) Hobart, Tasmania, December.

Isaacs N. (2010) **HEEP & BEES studies – How energy is used in houses and commercial office.** (Invited paper to the New Zealand and Germany Energy Efficiency in Buildings – 2010 Industry Conference) Auckland: Hyatt Hotel, 1 November – http://www.germantrade.co.nz/renewables/energy_efficiency_2010.asp

Peer-Reviewed Conference Papers

Amitrano, L., Isaacs, N. and Bishop, R. (2013) **Understanding energy use in New Zealand's non-residential buildings.** (CIB World Building Congress Paper 447) Australia: Brisbane Convention and Exhibition Centre, 5 - 9 May.

Bint, L., Vale, R., and Isaacs, N. (2011) **An example of water performance indices development in New Zealand.** (Proc. 37th International Symposium of CIB W062 on Water Supply and Drainage in Buildings) Aveiro, Portugal – ed. Prof. Dr Armando B. Silva Afonso.

Bint, L., Vale, R. and Isaacs, N. (2010) **'Water performance benchmarks for New Zealand: Understanding water consumption in commercial office buildings'.** (Proc. SB10 Innovation and Transformation. NZ Sustainable Building Conference) Wellington, May – Awarded 'Highly Commended Student' paper.

Camilleri, M. and Isaacs, N. (2010) **The Building Energy End-use Study (BEES): Study design and early findings.** (Proc. CIB World Congress, Paper 656) Salford Quays, United Kingdom: University of Salford, 10 -13 May

Donn, M., Selkowitz, S. and Bordass, B. (2009) **Simulation in the service of design – Asking the right questions** (International Building Performance Simulation Association Biennial Conference) Glasgow, Scotland – presented session: APP4: Simulation and the User, 29 July

Isaacs, N., Jowett, J., Saville-Smith, K. and Hills, A. (2012) **Understanding energy and water use in New Zealand non-residential buildings – An ad hoc survey.** (Proceedings of the Fourth International Conference of Establishment Surveys), Montréal, Canada, 18-21 June – American Statistical Association: Index: http://www.amstat.org/meetings/ices/2012/proceedings/ICESIV_TOC.pdf; Paper: http://www.amstat.org/meetings/ices/2012/papers/302177.pdf

Isaacs, N., Camilleri, M. and Saville-Smith, K. (2010). **'Understanding buildings – A key step to sustainability'.** (Proc, SB10 Innovation and Transformation, NZ Sustainable Building Conference) Wellington, May – Awarded 'Highly Commended' paper.

Pollard, A. & Babylon, W.M. (2013) **Non-residential building energy use today and tomorrow** (CIB World Building Congress Paper 316) Australia: Brisbane Convention and Exhibition Centre, 5 - 9 May.