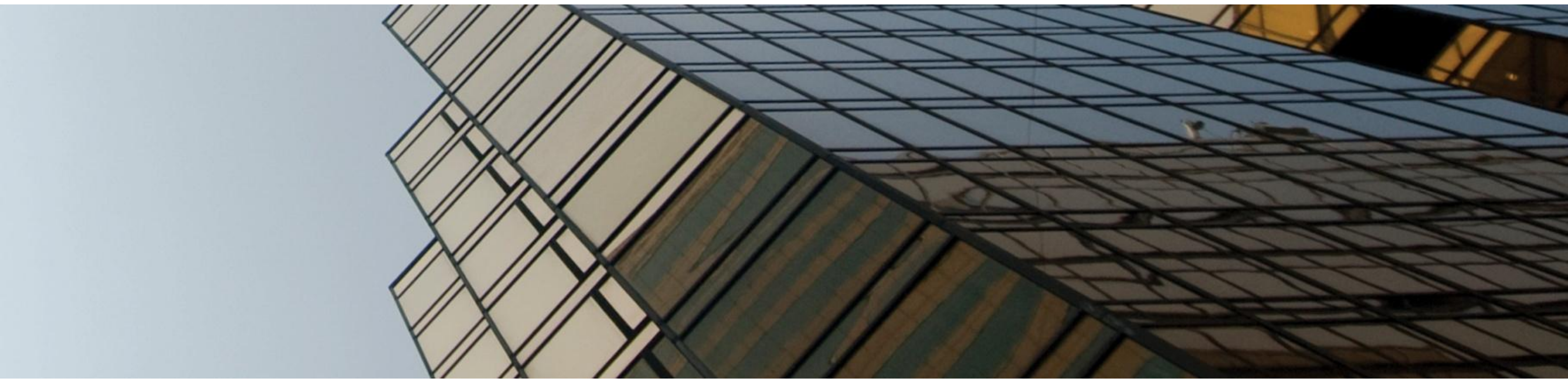

STUDY REPORT SR 260/2 [2011]

BEES INTERIM REPORT

Building energy end-use study - Year 4

DETAILED MONITORING

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BEES (BUILDING END-USE STUDY) YEAR 4: DETAILED MONITORING

BRANZ Study Report SR 260/2

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Reference

Camilleri, M., & Babylon, W.M (2011). BEES (Building energy end-use study) Year 4: Detailed Monitoring, BRANZ study report 260/2, Judgeford.

BEES publications can be downloaded from the BEES website - http://www.branz.co.nz/bees

Following is a list of other reports in the BEES Year 4 series:

- Saville-Smith, K. (2011). BEES (Building energy end-use study) Year 4: Insight into barriers, BRANZ study report 260/1, Judgeford.
- Bishop, R., Camilleri, M & Isaacs, N. (2011). BEES (Building energy end-use study) Year 4: Delivered daylighting, BRANZ study report 260/3, Judgeford.
- Bishop, R., Camilleri, M & Isaacs, N. (2011). BEES (Building energy end-use study) Year 4: Achieved conditions, BRANZ study report 260/4, Judgeford.
- Bishop, R., Camilleri, M. & Burrough, L (2011). BEES (Building energy end-use study) Year 4: Temperature Control, BRANZ study report 260/5, Judgeford.
- Bishop, R. (2011). BEES (Building energy end-use study) Year 4: Electrical loads, BRANZ study report 260/6, Judgeford.
- Isaacs, N. (2011). BEES (Building energy end-use study) Year 4: From Warehouses to Shops - Changing Uses in the Non-residential Buildings Sector, BRANZ study report 260/7, Judgeford.

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) is taking 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 study started in 2007 and will run for six years, gathering information on energy and water use through carrying out surveys and monitoring non-residential buildings. By analysing the information gathered, we aim to answer eight key research questions about resource use in buildings:

1. What is the aggregate energy and water use of non-residential buildings in New Zealand?
2. What is the average energy and water use per unit area per year?
3. What characterises the buildings that use the most energy and water?
4. What is the average energy use per unit area for different categories of building use?
5. What are the distributions of energy and water use?
6. What are the determinants of water and energy-use patterns e.g. structure, form, function, occupancy, building management etc?
7. Where are the critical intervention points to improve resource use efficiency?
8. What are the likely future changes as the building stock type and distribution change?

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

For the BEES study, non-residential buildings have been defined using categories in the New Zealand Building Code, but in general terms the study is mainly looking at commercial office and retail buildings. These vary from small corner store dairies to large multi-storey office buildings. For more information on the building types included in the study please refer to BRANZ report SR224 Building Energy End-use Study (BEES) Years 1 & 2 (2009) available on the BEES website (www.branz.co.nz/BEES).

The study has 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 which included a phone survey, and collecting records of energy and water use and data on floor areas. The information will enable a picture to be built up 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, answering research questions one to four.

The detailed monitoring of individual premises involves energy and indoor condition monitoring, occupant questionnaires and a number of audits, including: appliances, lighting, building, hot water, water, and equipment.

This report presents the process for the detailed monitoring and analysis of audit and electricity end-use data carried out during the fourth year of this six year study. This report looks at the number of appliances by type and their energy use. The report provides guidance on where energy savings can potentially be made. For example, there is a higher than expected overnight lighting load, which could be reduced through lighting controls or changes in user behaviour. The data and analysis in this report contributes to answering research questions four to six. This is one of seven interim reports giving a snapshot of analysis completed to date. When all data collection has been completed further analysis will be reported on with the full sample including relationships between end-uses, building types and services.

At this stage of the project, not all the data required to fully answer the research questions is available. This report only provides analysis and results on buildings less than 9,000 m^2 (size strata 1-4 of the BEES sample). It does not cover the full range of building sizes, therefore these results are not representative of the non-residential building stock. In the remaining two years of the BEES study, further analysis will be carried out using the full sample which will include buildings greater than 9,000 m^2. Detailed monitoring will continue during year 5 with the focus being on the larger buildings. A number of case studies will also be carried out where extensive monitoring is completed along with occupant, building owner and manager interviews.

SUMMARY

- Results are presented from detailed monitoring of buildings less than 9,000 m^2
- The two biggest electricity uses in these buildings are power points and lighting.
- The most common type of heating/cooling in the buildings monitored is by heat pumps, although portable heaters are still used in roughly half of the buildings.
- The monitoring of buildings was more difficult than expected due to complex wiring and frequently out of date labelling.

The Building Energy End-use Study (BEES) has now completed 4 years of a 6-year programme to collect and analyse energy, water, environmental, equipment and occupant data from commercial buildings. It is the most comprehensive study of its type ever undertaken in New Zealand.

With a large quantity of data to work through and further monitoring to be completed, the BEES team will not release the final analysis until the next phase of the project is complete in 2012, but an early examination of the data has yielded some interesting results. This report covers results from the detailed monitoring component of the work for non-residential premises in buildings less than 9,000 m^2, which represent 99% of the non-residential buildings in New Zealand, but only 80% of the floor area.

Tracking energy end use

Common appliances, such as stereos, microwave ovens, fridges and copiers feature largely and are found in more than 80% of non-residential buildings. Each building also powers an average of 11.8 computers – both desktop and laptop varieties – and 9.5 external monitors. A closer look at one of those monitors is four times more likely to reveal an LCD screen than a CRT in the average Kiwi office building, presumably as the older units are replaced. Roughly half of buildings also power a computer server.

Heat pumps are by far the most common method of air conditioning with 59% of premises using an average of 2.5 heat pumps per building. The BEES team found obsolete heating control gear on several distribution boards and it seems likely that heat pump technology will eventually displace fixed electric heaters, which now appear in only 7% of buildings. However, roughly half of non-residential buildings also use portable electric heaters and fans – in some cases as the primary means of heating or cooling – but they are also found in premises with ducted air conditioning systems, where there may be local comfort problems in some places.

Fluorescent tubes dominate the lighting category with over 99% of premises using an average 139 tubes per building. Halogen lights come a distant second with 57% of premises using an

average 19 lamps. Incandescent bulbs are relatively rare – just 5.5 per building – and are outnumbered nearly 3:1 by compact florescent lamps, their modern drop-in replacement.

Clearly, most non-residential building occupants have adopted efficient lighting systems and few opportunities remain to improve energy efficiency by replacing incandescent lamps. However, there may still be scope to improve with more efficient fluorescent tubes and LED technology.

Overall, the top consumers are power points and lighting at about 30% each, followed by heating and cooling at 22%, hot water at 3% and computer servers at 1%. The lighting baseload – the minimum average power consumed by lighting – works out at approximately 250 W per building or 0.5 W/m^2, which equates to roughly 2% of the total power consumed. Some building occupants leave lights on overnight, which suggests there are opportunities to improve energy efficiency in this area.

Difficult electrical installations

While the monitoring work provided a wealth of numeric data, it also revealed some alarming issues in New Zealand's non-residential buildings. The BEES team frequently discovered wiring that was unduly complex or undocumented, and in 3% of buildings they encountered distribution boards that were so dangerous they presented an imminent risk of short circuit, fire or explosion. Many other distribution boards were hazardous, with loose live wires, damaged wiring, exposed busbars and overloaded circuits.

Most of the circuit charts and distribution board labels the team inspected were inaccurate or out of date after electrical work was carried out. Many large buildings, which employ more complex electrical distribution systems spread across several locations, lacked even basic wiring plans to indicate where those systems could be found. In others, the wiring plan consisted of hundreds of pages of documentation that was completely unusable.

These hazards present a significant risk to electricians working in non-residential buildings, especially since electrical work in these buildings is often done live.

The BEES team make several recommendations to improve electrical practice in non-residential buildings, including scheduled inspections, maintenance and rewiring, complete and up-to-date circuit charts, simple wiring plans showing the location of distribution boards and major feeds, design for future expansion and consistent practices across the electrical trades.

These issues complicated a data collection process that was already difficult due to the wide variety buildings, equipment and operation, and building occupants' generally low level of understanding of electrical distribution systems. The data wasn't simply there for the taking – it required careful investigation and monitoring to collect meaningful information.

But robust procedures and processes at each stage of the installation, download, processing and pre-analysis ensure that high-quality data has and will be continue to be collected over the final years of the project.

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1. INTRODUCTION

The detailed monitoring is the most intensive data collection method used in BEES. Energy and environmental monitoring is undertaken, occupant questionnaires are completed and a number of audits are carried out including: appliances, lighting, building, hot water, water and equipment. The main reason for conducting detailed monitoring is to collect information on energy end-uses and environmental data within buildings which can only be obtained by visiting buildings and installing monitoring equipment.

In the 2010/11 BEES Year 4 the full scale monitoring program started in Year 3 has continued, the data collection methodologies have been refined, and the data management systems fully developed and implemented. The outcome is a data collection process that reliably collects energy end-use and other data and delivers it in a form suitable for analysis in a timely manner.

The main focus in Year 4 was the collection and management of data, however preliminary analysis of the lighting and appliance stock survey and of the main electricity end-uses is given in this report, with more extensive analyses planned in Year 5.

Experiences and lessons from the Year 4 monitoring are also presented, highlighting some of the practical issues and difficulties encountered, and describing the state of electrical systems in non-residential buildings.

Results from Year 4 are for the strata1-4 buildings, which are non-residential buildings less than 9,000 m^2. For information on how the sample was divided up by floor area see section 1.1 of Isaacs, Saville-Smith, Babylon et al (2010).

2. DATA COLLECTION PROCESS

The data collection process has been described in previous BEES annual reports.

The detailed monitoring pilot was described in the BEES Year 1&2 report (Isaacs, Saville-Smith, Bishop, Camilleri et al. 2009, Sections 5 and 7) where the selection and purchase of monitoring instruments, and the development of the field data collection methodologies was described.

In the Year 3 report (Isaacs, Saville-Smith, Babylon, Bishop et al. 2010, Section 3.2) the data collection methodologies and survey instruments used for full scale monitoring were described, and preliminary analysis presented for the limited number of premises for which data was available.

The data collection methodologies and survey instruments used in Year 4 were only slightly refined from those described in the Year 3 report, and were mainly improvements to paper forms.

The only new methodology deployed was placing a single long term (one year) temperature and humidity sensor in each monitored building. These temperature and humidity sensors were first placed in buildings in June 2010, and will be removed after one year. The reason for deploying this equipment was to obtain long term temperature and humidity measurements to characterise the internal conditions, which can also be used in conjunction with the long term meter data obtained from energy suppliers.

GPRS cell-phone communications modules were introduced for data collection for the Multivoies[1] circuit monitoring. This sophisticated system sends all the collected data to an FTP server once per day. The data can then be processed without having to perform time consuming manual downloading. The GPRS system saves time and money, and also improves data quality by enabling live status checking on the monitoring and data security by downloading daily.

A vital part of data collection is the management and processing of the data into a form accessible for analysis. These processes were described in the Year 3 report, Section 3.2.4. The flow chart in Figure 1 gives a visual overview of the process.

There are three main phases for the detailed monitoring: 1) Recruiting and booking; 2) Installation; and 3) Data processing and inspection.

In the recruiting and booking phase the premises are recruited from the list of phone survey participants, the installation booked, and arrangements made for travel, electrician, and helpers.

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[1] http://www.omegawatt.fr/gb/index.php

At the installation all the monitoring equipment is installed, and all the audit information collected using pre-prepared forms and following the installation and audit processes. These forms are checked and collated as soon as possible following the installation to ensure all required data has been collected.

Data processing and inspection involves recording the monitoring setup information in a database ready, which also provides the list of equipment to be retrieved at the end of monitoring. Once the equipment is retrieved the monitored data is downloaded, checked, and filed for processing. The processing combines all the monitored data into one file per premise, with circuit and end-use labelling. All monitored data is checked visually and corrected if necessary. The audit and questionnaire data is entered into a database, and checked before being made ready for analysis. A complete list of the data and parameters collection in the detailed monitoring questionnaire and audit is given in Appendix A. In Year 4 the systems for managing this data were fully developed, and this data is now routinely accessible from a database using SQL queries or data exports.

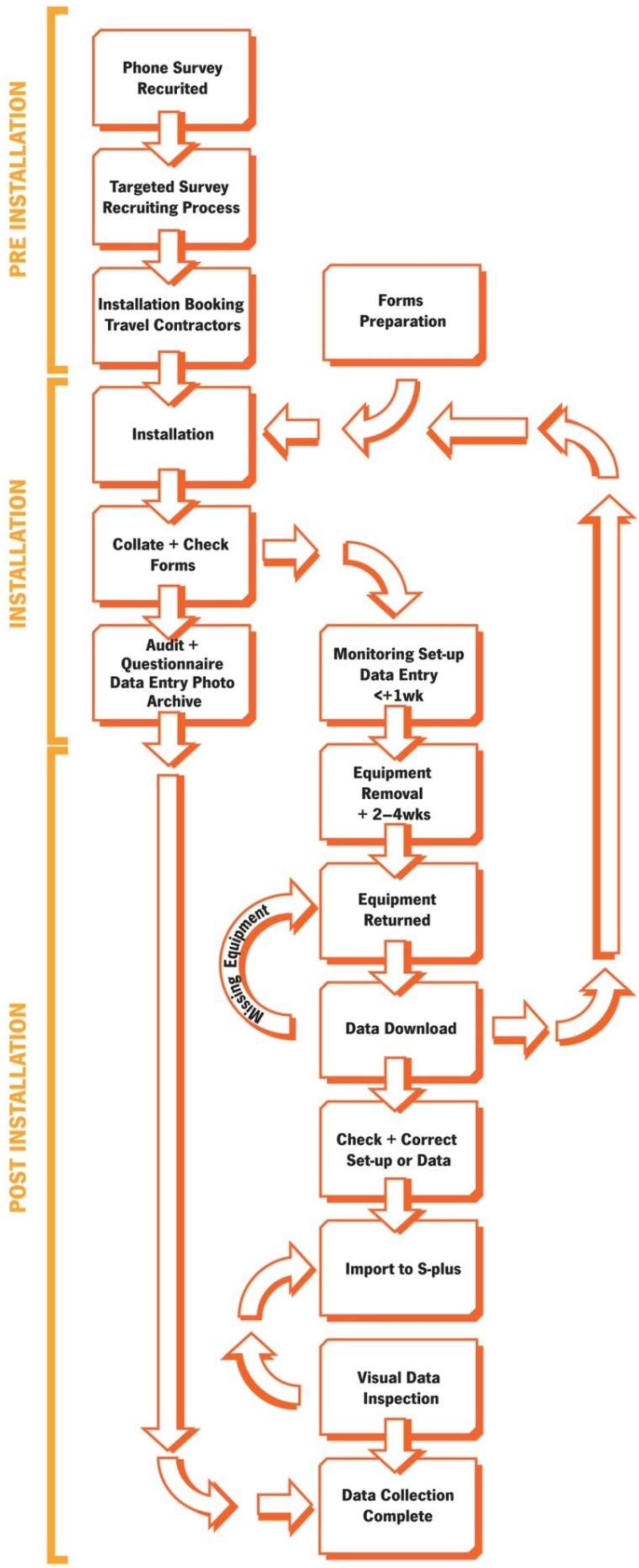

Figure 1. Detailed monitoring flowchart

2.1 Identifying circuits and end-uses

Since the detailed monitoring aims to breakdown end-uses (e.g. lighting, heating, power points etc) it is important that each end-use is identified correctly. However, this is often a difficult process due to issues with the accuracy of electrical distribution board labelling, and sometimes incorrect or illegal wiring. These issues are discussed in detail in Appendix B.

The process used for identifying end-uses from electrical distribution boards is described here.

The first step is to locate the main electrical board(s) and sub-boards, which seems like it should be easy, but as there is usually no wiring plan for the building, nor distribution boards indicated on floor plans, this sometimes is difficult and takes considerable time searching the building. If the electrician working with BEES is responsible for servicing and maintaining the building then they usually know where all the distribution boards are and have a general overview of what each board supplies. In many cases there is no regular electrician responsible for servicing the building, so the building needs to be searched to locate distribution boards, with the assistance of the occupant or owner. In general, the occupant or owner has little or no knowledge of the electrical distribution system, and perhaps only knows where the meter board and the main switches are. Sometimes distribution boards are located in strange places and are very difficult to find.

Once a distribution board is found the supply phases are identified so that the board total can be monitored and the BEES monitoring equipment powered. When phases are incorrectly labelled, swapped, or mixed, or using incorrect wire colours this creates difficulties, and phases can usually be identified by tracing wires, or using special test equipment.

Most distribution boards have labels on the board itself and/or on a circuit chart. Some typical examples are described in Appendix B. However, the standard and accuracy of the labelling is often poor, as there is no common industry practice of labelling circuits and keeping these up to date as repairs and changes are made. If the electrician regularly services the building or installed the wiring then this is very helpful as they usually remember what was done and can confirm the veracity of the labelling.

The labelling is then visually checked against the fuse or circuit breakers for consistency. The size, type and layout of fuses and wires give useful information:

- Size and type of wiring (lighting is usually on smaller 1 mm cables)
- Size of fuses/circuit breakers (lighting is usually on 10 A fuses, power points usually on 20+ A fused)
- Type of fuses/circuit breakers (e.g. RCD, various ages and styles)
- Layout of fuses. e.g. heat pumps added recently on a new bank of large fuses.

Sometimes it is possible to trace circuits by switching them on and off, or by turning lights or equipment on or off. However, in most cases turning off switches at the board is not done due to the risk of switching off critical equipment such as computers and retail till systems, or blacking out areas of the building which could seriously disrupt the business or create a health and safety hazard.

Once the identification process is complete as far as is practicable then the monitoring equipment is installed. If circuits cannot be identified they are usually monitored individually to assist in identifying them later.

Once the BEES electrical monitoring equipment is installed then the identification of the circuits is checked against the measurement readings. The Multivoies system provides instantaneous readouts of the current, voltage, power, power factor and waveform. The most useful information is the waveform, as different types of equipment have different waveforms. A purely resistive load (e.g. incandescent lighting or electrical resistance heating) has a sine-wave shape, with no phase lag (Figure 2). Fluorescent tube lighting has a waveform that is a slightly distorted sine-wave shape with little or no phase lag, provided the transformers and electronics are operating properly (Figure 3). Electronic equipment such as computers and CFL lamps have highly distorted waveforms which has spikes caused by switched mode power supplies (Figure 4).

Some equipment can be identified by the size and pattern of the load, for example a heat pump will cycle from low power to high power (a few kW) frequently, whereas lights will usually be a stable load.

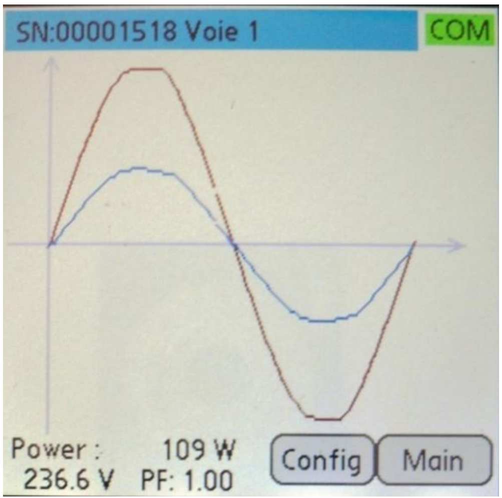

Figure 2. Waveform of a resistive load (incandescent lamp).

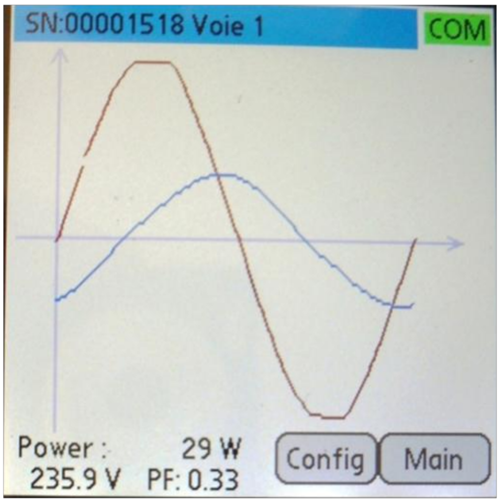

Figure 3. Waveform of a fluorescent tube in poor condition with low power factor

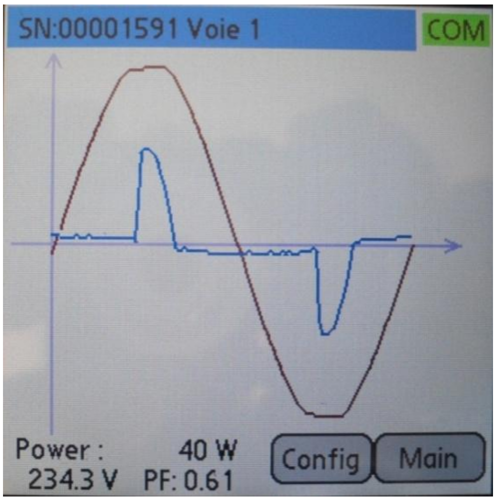

Figure 4. Waveform of an LCD monitor with switched mode power supply.

After the installation is complete the next stage of checking the identity of the circuits is at the data processing stage where various checks are applied to confirm, and if needed to correct, the circuit identification. The electrical monitoring data is recorded at 1 minute intervals, and this high time resolution makes it easy to distinguish most electrical end-uses. For example lights usually have a steady consumption in the range of hundreds to thousands of watts. Power circuits usually have a varying consumption, with switching and peaks from appliances such as refrigerators, microwave ovens etc. Air conditioners usually cycle frequently at high power, with higher power consumption during the day than at night. Every monitored data channel is visually inspected and the identification confirmed or corrected. This identification process builds on the experience of the Household Energy End-use Project (HEEP) (Isaacs, Camilleri, French, Pollard et al, 2010) project and several other major data collection and analysis projects that BRANZ has done, where more than 10,000 channel-years of data have been visually inspected.

If there are two different end-uses on the same circuit, sometimes it is possible to separate them by a process of disaggregation using a purposely built algorithm. This works best when the patterns of use are distinct, for example rapidly switching air-conditioning and stable lighting use.

Once this process is finished the circuit identification process is considered to be complete with a high level of confidence in its accuracy.

2.2 Summary of monitored premises

The total number of premises/buildings monitored so far is 102, and these are all in Size Stratum 1-4 building records (floor area < 9,000 m^2). In Year 4 approximately 2,235 electrical circuits were monitored on 102 distribution boards (minimum of 3, maximum of 234), temperature, humidity and light monitored in 208 locations, and CO_2 in 44 locations. 200 plug in electrical appliance were monitored.

The premises ranged widely in size and use from small retail and food shops, to supermarkets and large multi-storey office buildings. The shortest installation took 2 hours, and the longest 3 days. The great diversity of types of premises and varying installation requirements is a major challenge to deal with.

- In carrying out the detailed monitoring the following has been observed:
- Surveying and monitoring non-residential buildings is difficult, time-consuming and expensive.
- The data is not just there for the taking – it requires investigation to correctly monitor and collect it.
- There is no such thing as a 'typical' commercial building, but there are many sub-types.
- There is great diversity in premises operation and equipment.

Many non-residential buildings are poorly understood by the occupants, managers, owners, and tradespeople as shown by their lack of knowledge about the building equipment and systems.

3. AUDIT DATA ANALYSIS

3.1 Appliances

Information on the appliance stock and energy consumption is collected as part of the BEES detailed monitoring. Appliance stock information is collected by counting the number of appliances of various types (see Appendix A.5). Appliance stock information has been collected for all the monitored premises, with about 80 premises currently available for analysis.

Energy consumption information is collected by monitoring a few selected appliances (usually 2-4) in each premise. So far 200 appliances have been monitored, including appliances such as computers and peripherals, cooking and refrigeration equipment, photocopiers and office equipment. Appliance energy consumption and patterns of use will be estimated in future, but at this stage some analysis by premise of the appliance stock is possible.

3.1.1 Appliance Stock

The appliance stock is determined by counting each of the 77 different types of appliance in each premise. For premises with multiple floors or buildings the appliance tally was usually done floor by floor or building by building. The appliance types are grouped into categories such as Computers, Office, Retail etc, and where appliances vary in size and use (e.g. domestic scale refrigeration vs. commercial scale refrigeration) they were treated as separate appliance types (labelled “resid” for residential and “comm” for commercial). See Appendix A.5 for the full list of appliance types.

For stock and energy modelling the appliance saturation and density are the primary stock parameters of interest:

- Appliance saturation is defined as the percentage of cases (e.g. premises) that have a given appliance (varies from 0 to 100%)
- Appliance density is defined as the average number of a given appliance for those cases (e.g. premises) that have that appliance.

The various levels of entity (e.g. building, premises etc) creates difficulties of interpretation. For example, it makes sense to talk about the saturation and density of appliances per premise, but makes less sense on a per building level, given that there may be several premises in a building with different activities (e.g. restaurant and office). Therefore the appliance saturation and density have been estimated per premise.

The BEES sampling procedure also has divided the non-residential stock into five size strata, so samples large buildings at a higher rate than small buildings. This means that the appliance count information needs to be weighted according to the sample strategy to get overall estimates of saturation and density per premise. A rough cut of this weighting has been attempted here, however it does not take account of the eligibility of buildings, and replacements are still to be done. These preliminary weighted estimates are only approximate; however they are unlikely to be in gross error which would be the case if unweighted estimates were provided.

The preliminary saturation and density per BEES premise are given in the following tables (Table 1 to Table 9). The appliance types with the highest saturations are:

- Computer (86%) (desktop and laptop computers)
- Stereo/Radio (82%)
- Microwave (82%)
- Refrigeration, domestic (82%)
- Printer/Copier (81%) (all types and sizes)

Modern businesses rely heavily on IT services, so the high saturation of computers and printers and related computer equipment is expected. Computers (desktop and laptop) have the highest saturation of 86%, and a density[2] of 13.6. Computer monitors also have a high saturation at 67%, and a density of 14.2. Most computer monitors (81%) are LCD monitors, averaging 7.7 per premise, compared to 1.8 per premise for CRT monitors. It appears that CRT monitors are becoming obsolete and being replaced by LCD monitors, or are not used with a laptop computer. Servers are common, with a saturation of 54%. In the Strata 1-4 buildings, a server is usually a single computer or a small server rack, although for the larger premises there may be a server room with several server racks. Fax machines are still common, with a saturation of 52%.

Most premises have limited kitchen facilities for staff use, typically with a refrigerator, microwave, electric jug (54%) and/or boiling water unit (48%), and less often appliances such as a coffee maker, toaster, and kitchen range. Water coolers are quite common, with a saturation of 41%.

In space conditioning equipment the heat pump (single or multiple split system air conditioner) has the highest saturation at 59%, followed by portable electric heaters at 49% (note that ducted HVAC systems are not included in this table). Fixed electric heaters have a low saturation (7%), and appear to be in the process of being displaced by heat pumps – many older distribution boards still have labelling for fixed electric heaters, complete with timers and control gear. Often these circuits are being used for newly installed heat pumps, with timers and controls bypassed.

Fans are also common, with a saturation of 52%. Fans and portable electric heaters could be viewed as 'personal' comfort appliances, and might be used either if there is no other heating or cooling system, or if the main heating and/or cooling system is inadequate. Anecdotally,

[2] Density is the average number per premises for those premises that have them.

the presence of fans or portable heaters in a fully space conditioned building might be an indicator of comfort issues for some occupants – they were often found in rooms where the occupants expressed their dissatisfaction to the BEES installers.

The saturation and density does not, however, give the full picture, as there can be a wide variation in the number of each appliance between premises. For example, some premises have no computers, whilst some have several hundred. There are likely to be major differences in the appliance stocks for different types of premises (e.g. office vs. restaurant) and floor areas; however this is left for future analysis.

Table 1. Computing equipment stock per premise for Strata 1-4.

Preliminary estimates subject to change

Appliance	Saturation (%)	Density	Average
Desktop computer	80	12.4	10.0
Laptop computer	44	3.9	1.8
CRT monitor	36	5.1	1.8
LCD monitor	65	11.9	7.7
Docking station	9	8.7	0.8
Desktop printer	61	3.5	2.2
UPS	21	1.6	0.3
Ethernet/wireless/router	59	1.3	0.8
Server	54	1.2	0.7
Minicomputer	3	1.9	0.1
Mainframe computer	6	1.0	0.1
Desktop or Laptop	86	13.6	11.8
CRT or LCD Monitor	67	14.2	9.6

Table 2. Office equipment stock per premise for Strata 1-4.

Preliminary estimates subject to change

Appliance	Saturation (%)	Density	Average
Copier (desktop)	32	2.1	0.7
Copier (floor)	52	1.9	1.0
Copier (large production)	30	1.1	0.3
Fax machine	52	1.2	0.7
Charger/power adaptor	63	7.5	4.8
Projector	7	1.6	0.1
Telephone system	58	1.0	0.6
Security system	61	1.0	0.7
Shredder	30	1.2	0.4
Electric whiteboard	5	3.1	0.1
All Printers or Copiers	81	5.1	4.2

Table 3. Entertainment appliance stock per premise for Strata 1-4.

Preliminary estimates subject to change

Appliance	Saturation (%)	Density	Average
Stereo/Radio	82	1.9	1.6
PA Sound System	10	1.3	0.1
TV (small)	39	2.5	1.0
TV (large)	24	2.2	0.5
DVD, VCR or similar	27	2.7	0.8

Table 4. Retail equipment stock per premise for Strata 1-4.

Preliminary estimates subject to change

Appliance	Saturation (%)	Density	Average
Checkout conveyor	3	5.0	0.2
Video game	2	3.4	0.1
Digital photo console	4	1.7	0.1
Exercise equipment	0	-	-
Vending (non-refrigerated)	3	2.0	0.1
ATM	6	1.0	0.1
Cash register	41	2.2	1.0
Advertising display	19	2.9	0.6
EFTPOS terminal	36	3.5	1.3

Table 5. Space conditioning equipment stock per premise for Strata 1-4.

Preliminary estimates subject to change

Appliance	Saturation (%)	Density	Average
Portable electric heater	49	2.0	1.0
Heat pump/airconditioner	59	4.2	2.5
Dehumidifier	6	1.5	0.1
Fixed electric heater	7	10.7	0.8
Portable gas heater	6	1.1	0.1
Fixed gas heater	2	2.5	0.0
Fan	52	3.2	1.7

Table 6. Food preparation equipment stock per premise for Strata 1-4.

Preliminary estimates subject to change

Appliance	Saturation (%)	Density	Average
Boiling water unit	48	1.2	0.6
Oven	18	1.3	0.3
Hobs	10	2.6	0.3
Range	17	1.1	0.2
Grill	4	1.5	0.1
Deep fryer	7	2.2	0.2
Coffee maker	22	1.2	0.3
Food warmer	8	1.6	0.1
Microwave	82	1.4	1.2
Jug	54	1.1	0.6
Coffee machine	11	1.2	0.1
Rangehood	9	1.2	0.1
Small kitchen appliance	64	2.3	1.5

Table 7. Refrigeration appliance stock per premise for Strata 1-4.

Preliminary estimates subject to change

Appliance	Saturation (%)	Density	Average
Resid fridge	64	1.5	1.0
Resid fridge/freezer	27	1.3	0.4
Resid type freezer	12	2.5	0.3
Water cooler	41	1.2	0.5
Cold food table	2	9.0	0.2
Refrigerated vending	14	2.3	0.3
Comm refrigerator	10	4.9	0.5
Comm freezer	8	6.5	0.5
Walk in fridge or freezer	19	1.6	0.3
All Resid Refrigeration	82	2.0	1.7
All Comm Refrigeration[3]	25	6.6	1.7

[3] Includes all commercial size fridges, freezers, and fridge-freezers, but excludes refrigerated vending machines and cold food tables.

Table 8. Cleaning appliance stock per premise for Strata 1-4.

Preliminary estimates subject to change

Appliance	Saturation (%)	Density	Average
Vacuum Cleaner	47	1.2	0.6
Dishwasher (resid)	21	1.0	0.2
Dishwasher (comm)	7	1.1	0.1
Washing machine (resid)	10	1.6	0.2
Washing machine (comm)	2	1.0	0.0
Dryer (resid)	9	1.3	0.1
Dryer (comm)	2	1.5	0.0
Hand dryer	2	2.5	0.0

Table 9. Workshop equipment stock per premise for Strata 1-4.

Preliminary estimates subject to change

Appliance	Saturation (%)	Density	Average
Powered hand tools	17	2.9	0.5
Powered tools	5	3.3	0.2
Large equip	6	1.6	0.1
Misc small appliance	43	4.0	1.7
Misc large appliance	20	1.9	0.4

3.2 Lighting

Detailed lighting stock information is collected as part of the audit process including:

- Room Location
- Location of switch(es) within room
- Lamp type by switch
- Number of luminaires (light fixtures)
- Number of lamps per luminaire
- Switch control type (e.g. on/off, occupant sensor, etc)

The coded lamp type and switch type is recorded for the bulbs of each type on every light switch. The data recorded are the number of luminaires (light fixtures), the number of lamps per luminaire, and their estimated wattage.

The lamp wattage is either determined by reading the lamp label, or by estimating according to known generic values. In many cases it is not practical or possible to read the lamp (e.g. inaccessible or enclosed lamps).

3.2.1 Lighting lamp stock percentages by type

The lighting lamp stock saturation, density, and average by premise were calculated using the same statistical weighting process as appliances. Note again that the weighting used is only approximate and awaits further statistical analysis.

The fluorescent tube is overwhelmingly the most common type of lamp, found in nearly all premises, with an average number of tubes per premise of 139. In terms of overall average, all other lamp types are far less common.

Halogen lamps are the next most common lamp type, found in 57% of premises with a density of 33 lamps per premise that have them.

Incandescent lamps of all types occur in most premises, but the density is low, at 5.3 for GLS incandescent, and 7.6 for incandescent reflector. Incandescent lamps appear to be used mainly in low use areas, such as store rooms and toilets. Further analysis will determine where these lamps are.

Compact fluorescent lamps are much more widely used than incandescent, with on average 14.5 per premise, compared to 5.5 for all types of incandescent lamps. It appears that most GLS light fittings have had incandescent lamps replaced with CFLs.

Metal halide lamps have a low saturation of around 11%, but the density is high at 101 – basically this means that they are not found in many premises, but when they are they are likely to be used in large numbers, for example large 'shed' type retail shops and exterior flood lighting.

LED and compact fluorescent reflector lamps were not found in any of the premises analysed for this report, so their saturation is likely to be very low. In one premise monitored since the analysis was done, two sets of LED lamps had replaced 2 fluorescent tubes in one office, and the occupant raved about them to the BEES installer.

From these lighting stock estimates it appears that the large majority of lamps in premises in non-residential buildings already are efficient fluorescent or gas discharge types, and only 12% of the total lamps are incandescent or halogen types. The scope for reducing lighting energy consumption by replacing inefficient lamp types such as incandescent and halogen would therefore appear to be quite limited.

The lighting audit data is being coded against the room types, and once complete a further breakdown by activity space will be possible, and estimates of the intensity of use and installed lighting power density can be made.

Table 10. Estimates of lamp stock per premise for Strata 1-4.

Preliminary estimates subject to change

Description	Saturation (%)	Density	Average
Fluorescent	99.3	140.2	139.4
Halogen	57.1	32.6	18.7
Compact Fluorescent	56.9	25.5	14.5
Metal Halide	11.1	101.4	11.3
Unknown	12.9	44.5	5.8
Incandescent	59.2	5.3	3.2
Incandescent Reflector	28.8	7.6	2.2
Exit	22.5	2.6	0.6
Incandescent PAR	3.0	2.0	0.1
Other	0.0	0.0	0.0
Mercury Vapour	1.7	1.8	0.0
LED	-	-	-
Compact Fluorescent Reflector	-	-	-

Note: Lamp types with '-' were not found in the premises surveyed.

3.2.2 Lighting controls

The type of lighting controls for each circuit was recorded as part of the lighting audit. For the 2/3 of lighting circuits with the control type identified, 97% by count were a simple on/off switch, with 1.5% motion sensor.

There are unresolved issues for 1/3 of lighting circuits where the control type has not been identified, as timer and daylight controls are sometimes located separately from the lighting circuit so may not be properly identified in the lighting audit. Lighting timers and controls are frequently identified on distribution boards during the BEES electrical installations. Most of these controls are for automated exterior lighting, although in several premises lighting was fully automated with times preset to match the operating hours. Only one surveyed premise has so far been identified that had effective daylighting controls.

3.2.3 Estimated lighting power and power density

The total lighting power and power density has been estimated for those premises where the information is available. Currently, about three-quarters of the detailed monitored buildings have had floor areas calculated, and lighting audit and lighting energy data available.

The average installed lighting power per premise by lamp type is given in Table 11. The average total installed lighting power per premise is about 10,000 W. Most of that (56%) is from fluorescent tubes, with the second largest from metal halide lamps (23%). The installed incandescent lighting power is small, at 411 W for all types. The total power of efficient lamp types (fluorescent, CFL, gas discharge) is about 8,300 W, which clearly shows their dominance. This again highlights that efficient lamps are already extensively used in this sample of non-residential buildings and that there is limited scope to reduce lighting power by changing the type of lamp.

The type of fluorescent tube (e.g. T5, T8 or T12) was not recorded as it was too difficult and intrusive to open up and inspect fluorescent tube fittings during a BEES installation. It is expected that most tubes will be T8 or T12, as T5 lamps are not compatible with existing T8 fittings, and either need a conversion kit or a new luminaire. So perhaps the largest opportunity for improving energy efficiency would be upgrading to T5 lamps and fittings. More research is needed to determine the prevalence of the various tube types.

Table 11. Estimates of lamp power and lamp power density by premise for Strata 1-4.

Preliminary estimates subject to change

Lamp	Watts	%	Watts/m²	%
Total	10,060	100%	21.12	100%
Fluorescent	5,679	56%	15.37	73%
Metal Halide	2,281	23%	0.98	5%
Halogen	1,330	13%	2.42	11%
Compact Fluorescent	267	2.7%	0.44	2.1%
Incandescent	234	2.3%	0.77	4%
Incandescent Reflector	161	1.6%	0.88	4%
Unknown	54	0.5%	0.15	0.7%
Mercury Vapour	36	0.4%	0.06	0.3%
Incandescent PAR	16	0.2%	0.00	0.0%
Exit	1	0.0%	0.00	0.0%
Other	0	0.0%	0.00	0.0%
LED	-	-	-	-
Compact Fluorescent Reflector	-	-	-	-

Note: Lamp types with '-' were not found in the premises surveyed.

The installed lamp power density is calculated by combining the lamp power with the premises floor area, then weighting (approximately) to the BEES sample frame (Isaacs, Saville-Smith, Bishop, Camilleri et al. 2009). The total lighting power density is 21.1 W/m², with the majority of that from fluorescent tubes (15.4 W/m²). This total is higher than the current maximum power density limits prescribed in the Schedule method of NZS 4243:Part 2: 2007 Energy Efficiency – Large Buildings (which is an acceptable solution for lighting energy efficiency for the NZBC), which ranges from 4 W/m² for a covered car park to 18 W/m² for a library or workshop, with 12 W/m² for an office space.

3.2.4 Lighting Electricity and Patterns of use

Lighting is a major end-use in non-residential buildings and for many premises consumes a large fraction of the total electricity consumption (estimated at 31% on average in Section 4.1). The BEES Daylighting topic report (Bishop, Isaacs and Camilleri, 2011) showed that in most premises the lighting is supplied primarily by artificial lighting, not by daylight. Since most spaces are primarily lit by artificial lighting it follows that in most premises the lights would be expected to be on during the hours of operation in the main activities areas. This hypothesis is supported by the daily profiles of electricity consumption for lighting (Figure 5). These graphs show the pattern of use over a day for each premise, where the x-axis is time from midnight to midnight, and the y-axis the normalised total lighting energy consumption, from 0 to 100%.

It can be seen that most of the premises have the lights turning on in the morning, staying on at a reasonably steady level during the day, and then turning off in the late afternoon or evening. This pattern is typical of premises where most or all of the lights are turned on and left on during the day (e.g. retail shop, large office with open plan areas). In some cases the switch on or switch off is very rapid, as in Figure 6 (e.g. all lighting circuits turned on at specific times, or under automatic control), in other cases more gradual (e.g. staged switch on/off).

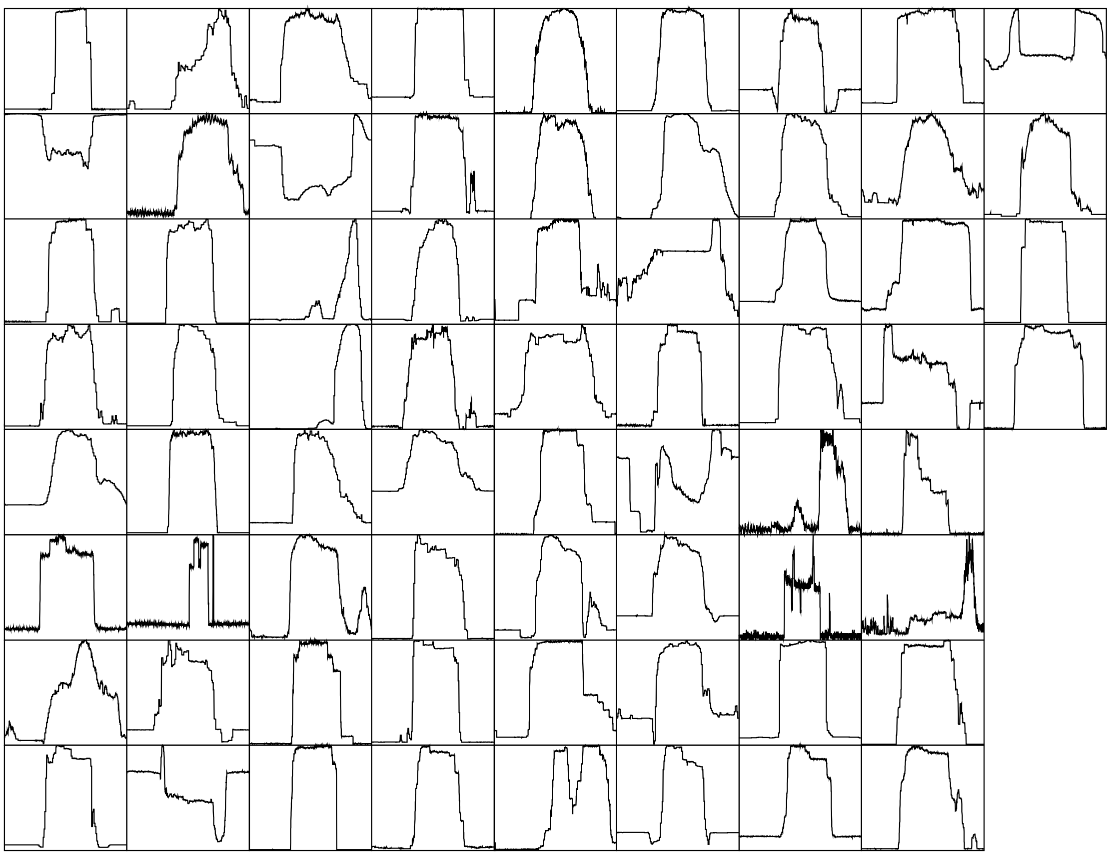

Figure 5. Lighting electricity consumption profiles. Normalised to 0-100%.

Another obvious pattern is some premises having smoothly varying lighting energy during the day, possibly indicating lights being turning on and off as needed as the sun moves across the sky, or lights in individual rooms being turned on and off at varying times depending on the hours of work of the occupant (Figure 7).

Most premises have some overnight lighting use, and in some it is actually larger than the daytime lighting use. In the most extreme case overnight lighting energy consumption is nearly double the daytime consumption (Figure 8). In this premise (a small shop) during the working day fluorescent lighting is used, while overnight these are switched off and incandescent spotlights are turned on inside the store for 'security' – a very wasteful practice in this instance. One opportunity for reducing lighting energy consumption is to reduce unnecessary or wasteful overnight lighting, for example, is it actually needed, or to use fewer or more efficient lamps overnight.

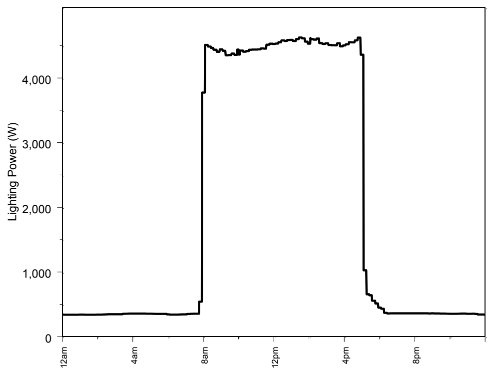

Figure 6. Example of lighting electricity consumption profile with bulk switch on/off of lights.

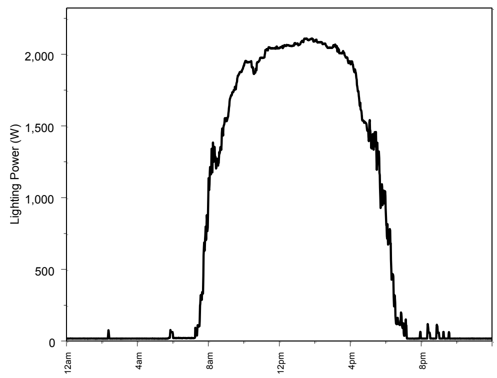

Figure 7. Example of lighting electricity consumption profile with staged (room by room) control of lights.

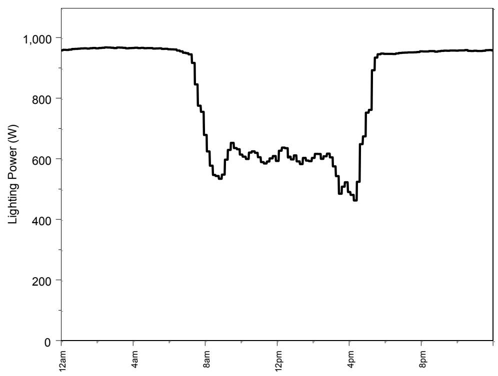

Figure 8. Example of lighting electricity consumption profile with very high after hours use.

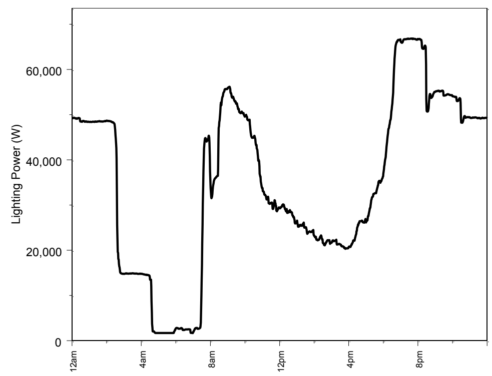

Figure 9. Example of Lighting electricity consumption profile with daylighting and automation controls.

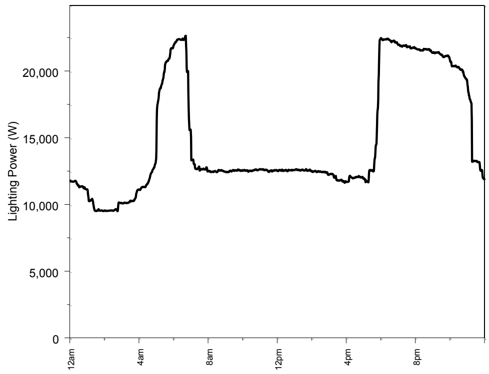

Figure 10. Example of lighting electricity profile with high morning/evening use (car park lighting)

There are a few rather odd looking patterns (e.g. Figure 9) which have high overnight levels, dropping in stages in the early morning before dawn, then high levels in the morning, levels dropping then rising during the day before peaking in the evening. These premises collectively are a large retail store that stocks shelves overnight and reduces lighting levels overnight automatically as work shifts finish. Car park lighting is automatically controlled with the main car park lights turned off at 8 pm, leaving car park lights on only near the building, then the full car park lights go on at 7:30 am as staff arrive and the store opens, then turned off automatically with a daylight sensor. It also has daylight sensor controlled lighting in the store, so during the day as the sun rises more daylight enters through the skylights and the lights are dimmed in response. This is the only BEES monitored premise so far that shows clear evidence of effective daylighting controls, and in this case appears to be very effective, reducing daytime lighting power by more than 10 kW on average.

Another odd looking pattern (Figure 10) has morning and evening peaks, and a lower steady power consumption during the day. This is another large retail store that has a fully lit outdoor car park, with automatically controlled lighting. The morning and evening peaks are caused by the car park lighting switching off during daylight hours. In this case the power for car park lighting appears to be comparable to the power for the store, and perhaps more efficient lamps and reflectors could be used, and a daylight sensor if not already installed.

From the monitored lighting energy consumption an estimate of energy use overnight and after hours can be made, and is reported in Section 4.2.

The potential for daylighting controls is looked at in BEES topic report Delivered daylighting (Bishop, Camilleri and Isaacs, 2011).

4. ELECTRICITY END-USE ANALYSIS

The electricity consumption for the major circuit monitored end-uses of total, lighting, power points, hot water, HVAC (Heating, ventilation and air-conditioning) and servers is summarised for the 77 BEES premises where monitored data was available. These are preliminary estimates only and are subject to change. Once the aggregate survey is completed and Stratum 5 buildings (floor area >9,000 m²) have been monitored, a full statistical analysis will be carried out and these numbers will be superseded.

All the data has been visually inspected and checked for validity. For some premises the monitored total electricity does not tally up to the monitored circuit end-uses (data might be missing or double counted), as it is sometimes difficult to identify distribution boards and premise totals (see section Identifying circuits and end-uses). For this analysis such premises have been removed pending further checking and correction.

4.1 Breakdown of Electricity consumption

There is a huge range in the total electricity consumption in the monitored BEES premises, ranging from a minimum of ~1,300 kWh/yr to 2,200,000 kWh/yr – a factor of nearly 1,700! One reason for this variation is the huge range of size of the premises, ranging from 56 m² to 4,800 m² - a factor of 85. There is also a wide variation in the types of activities within the different premises, and wide variation in operating hours. To enable sensible comparison of electricity consumption normalisation by floor area is used.

The Area Energy Use Indices (AEUI) (kWh/m²/yr) were calculated for the major end-uses in the Strata 1-4 buildings (Table 12, and Figure 11). There is a huge range in the total AEUI, from 15 to 365 kWh/m²/yr – a factor of 24, with an average of 113 kWh/m²/yr [4].

Plug and lighting loads account for 33% and 31% of the total electricity consumption respectively.

Heating and cooling (which includes fixed electric heating, heat pumps, air-conditioners and HVAC) systems account for about 22% of the total. Stratum 1-4 buildings do not usually have a centralised HVAC system, and often do not have a fixed wired heating system either.

Hot water heating electricity use is very low, at ~3%, and is a very minor end-use – some premises do not have reticulated hot water, and some have no water at all.

Servers are at <1% of electricity use, a minor end-use so far; however larger Stratum 5 premises are expected to have more and larger servers.

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[4] Note that the estimated AEUIs in Bishop et al 2011 were calculated using revenue meter data, not BEES detailed monitoring data, and so the premise sets and energy consumption for each premise are different.

These end-uses combined are 89% of the total, so 11% is from other end-uses, such as large scale refrigeration, cooking equipment etc. It was observed that the percentage of these other end-uses was larger in Strata 3 and 4 buildings than Strata 1 and 2. In the BEES monitored buildings there were a number of supermarkets and large retail premises in Strata 3 and 4 buildings, and these have high electricity consumption for end-uses such as refrigeration, cooking equipment, and other process loads.

These estimates are preliminary only and are expected to change, in some cases it could be substantially, once Stratum 5 premises are monitored, and once the full statistical analysis is completed.

Table 12. Preliminary estimates of electric end-use intensity (kWh/m²/yr), Strata 1-4.

Enduse	Average	% of Total	Median	Max
Total	113	100	108	365
Power points	37	33	22	228
Lights	35	31	26	139
Heating and Cooling	25	22	12	98
Hot water	3	3	0	70
Servers	1	<1	0	13
Other	12	11	-	-

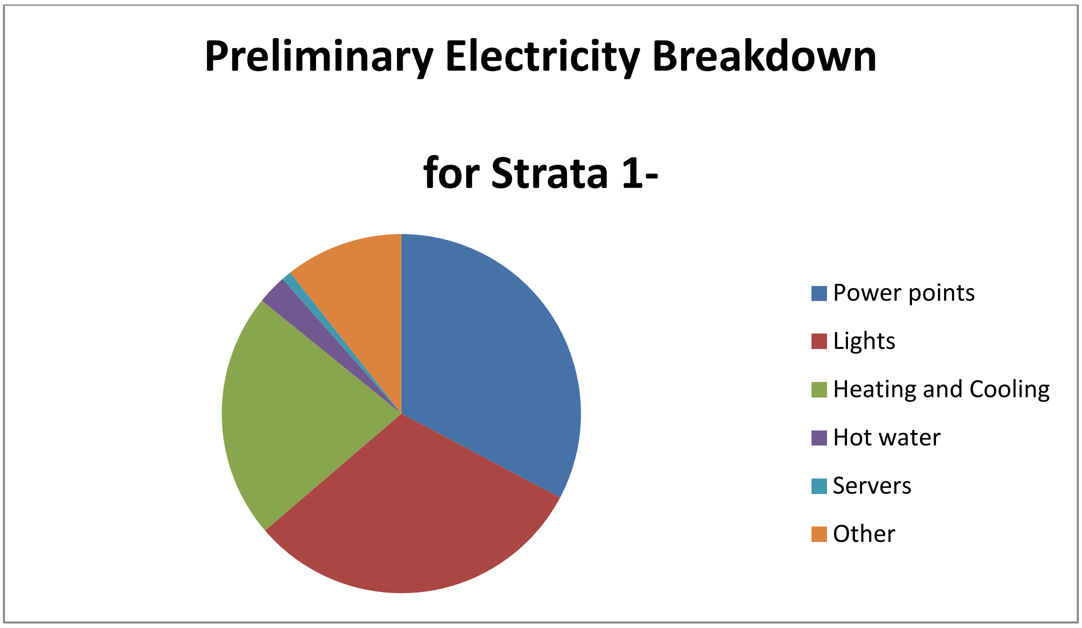

Figure 11. Preliminary breakdown of electricity use in Strata 1-4 premises.

4.2 Baseloads

The baseload is the typical lowest power consumption when all equipment that is usually turned off or cycles is off, and typically this occurs overnight. It is made up of standby power consumption, equipment and lighting left on, and continuously operating equipment (e.g. security system, emergency lighting). From the HEEP analysis, techniques were developed to estimate standby and baseload [see Camilleri, Isaacs & French (2006)]. These same analysis techniques have been used to provide preliminary estimates of baseload for the BEES premises in Strata 1-4. These are preliminary estimates using the same weightings as for the lighting power density analysis and are subject to change.

Most of the total electricity profiles (Figure 12) have significant overnight loads, and in many cases they are constant, which is an indicator of standby type loads. The total electricity baseload averages ~1.6 kW per premise for Strata 1-4 and ranges from 0 to 102 kW, The average is about one-third (31%) of the average load of ~5.1 kW per premise. However, some of these calculated higher baseloads are not true baseloads, as some premises have a lot of refrigeration and HVAC compressors and/or pumps cycling, which cannot be individually resolved at the 1 minute monitoring interval. Therefore these estimates do not represent true baseload. Further analysis on the thousands of individually monitored electrical phases and/or circuits will be done in the future to confirm baseloads. .

Analysis of the lighting baseload has been done, as it does not contain rapidly cycling loads so can be analysed at a whole premise level. From the profiles shown in Figure 5 it can be seen that most of the overnight lighting profiles are constant, which is an indicator that lights are being left on consistently during the night. Therefore the estimation process of the lighting baseload is likely to be accurate.

The lighting baseload averages 250 W per premise for Strata 1-4, compared to an average lighting load of 2,780 W per premise, and ranges from 0 W to 3,200 W. On a per square meter basis the lighting baseload is approximately 0.5 W/m^2, and if it assumed that this load is on for 12 hours per day it would be about 2 kWh/m^2/year, or roughly 2% of the total electricity consumption.

About 60% of premises have a lighting baseload higher than 20 W, so most premises have at least one light left on after hours.

This suggests the total baseload lighting load in the BEES premises approximately 20 MW total for the estimated ~80,000 premises in Strata 1-4. This compares to ~10 MW for the HEEP houses overnight lighting load (Isaacs, Camilleri, French, Pollard et al., 2010). Therefore it would appear that there are significant energy efficiency and conservation opportunities for after hours lighting. Further analysis will be carried out with weighted estimates and also to estimate the total energy consumption inside and outside operational hours based on occupancy schedules.

Other components of baseload (e.g. HVAC, air-conditioning, appliance standby, faulty refrigeration, and appliances/equipment left on constantly) will be estimated in future analysis.

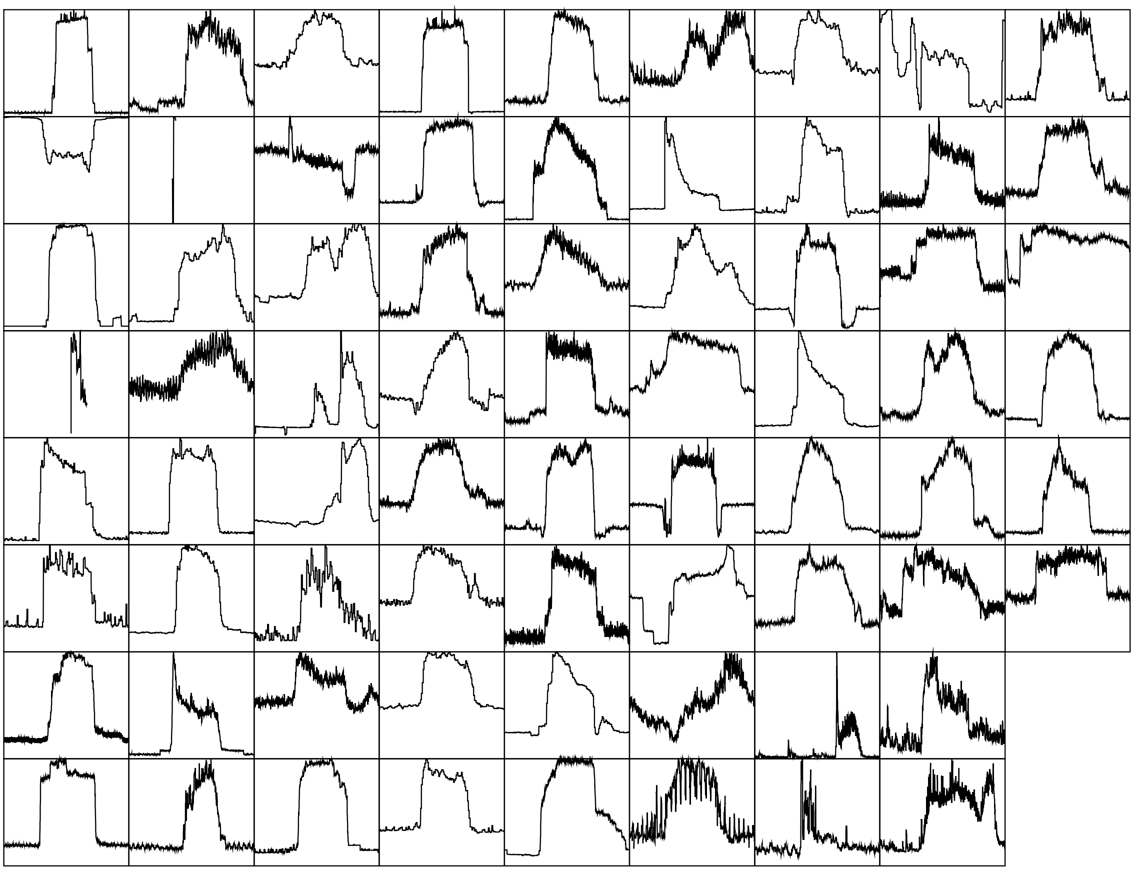

Figure 12. Total premises electricity time of day profiles. Normalised to 0-100%.

5. NEXT STEPS

In Year 5 the BEES detailed monitoring will continue, with the completion of the monitoring for Strata 1-4, and the monitoring of Stratum 5 buildings (floor area >9,000 m²). The analyses reported here will be refined and completed with the full statistical analysis. Full analysis of all baseloads, further analysis of lighting stock, temperature and internal environment, and types of premises (e.g. retail, office) is planned. The detailed monitored data will also be used for the modelling and simulation research, for more topic reports, and be combined with the other datasets to answer the BEES research questions.

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APPENDIX A

A full list of all the information collected in the detailed monitoring questionnaire and audits follows.

A.1 Questionnaire

Question No.	Question
Occupancy	
1	How many employees typically are in the building during your normal opening hours?
2	How many employees are typically in the building outside your normal opening hours?
3	How many other people are typically in the building (includes clients, customers, visitors, contractors) during your normal opening hours?
4	How many other people are typically in the building (includes clients, customers, visitors, contractors) outside your normal opening hours?
BUILDING AND EQUIPMENT OPERATION Start/End times Mon-Sun and Holidays	
5 - Start/End	When is the building normally open for the usual activities.
6 - Start/End	When is the interior lighting normally on for the usual activities.
7 - Start/End	When is the office equipment normally on for the usual activities.
8 - Start/End	When is major cooking equipment (e.g. commercial ovens) normally on for the usual activities.
9 - Start/End	When are major motors/compressors and large machinery normally on for the usual activities.
10 - Start/End	When is heating equipment normally used for the usual activities when heating is required (e.g. winter).
11 - Start/End	When are air conditioners normally used for the usual activities when cooling is required (e.g. summer).
ENERGY EFFICIENCY/CONSERVATION ACTIONS	
12	Has an energy audit been done in the last 5 years?
13	Can we obtain a copy of the energy audit?
14	Is energy use and expenditure tracked and reported against?
15	Does the building have an automated Energy Management System?
16	What energy management procedures are in place?
17	What energy efficiency actions have been implemented over the last 5 years?
WATER USE AND EQUIPMENT	
19	Approximately how many showers per week are taken?
20	Has a water management plan been implemented?
21	When are there water restrictions?
22	Is rainwater collected for use on the site?
23	Are gardens or grounds irrigated?

A.2 Building Fabric

Question No.	Question
1	What is the actual year of construction (if known)?
2	Has the building had major renovations (Y/N)
3	Decade major renovations done (e.g. 1920)
4	Was the building built from 2001 onwards?
5	Does the building have carparking in the building (e.g. basement)
6a	Entire building Floor area
6b	Premises Floor area
7	Number of storeys (count half storeys)
8	Number of units
9	Number of vacant storeys (count half storeys)
10	Number of vacant units
11a	Primary Building Form
11b	Secondary Building Form
12a	Primary exterior wall composition
12b	Secondary exterior wall composition
13	Is there outer wall insulation?
14	If Yes, what type of wall insulation?
15	What percentage of the wall is insulated
16a	Primary roof composition
16b	Secondary roof composition
17	Is there roof insulation?
18	If Yes, what type of roof insulation?
19	What percentage of the roof is insulated?
20a	Ground floor composition
20b	Interfloor composition
21	Is there floor insulation?
22	If Yes, that type of floor insulation?
23	What percentage of the floor is insulated

A.3 Water Use

Question No.	Question
24	Number of single flush toilets
25	Number of dual flush toilets
26	Number of urinals (stalls or capacity)
27	Number of taps
28	Number of mixer taps
29	Number of showers
30	How often are the showers used?
31	Number of observed minor leaks (e.g. dripping tap)
32	Number of observed major leaks (e.g. running tap)
33	Is rainwater collected for use
34	Is there a water management plan
35	What is the area of irrigated grounds

A.4 Elevations and glazing

Question No.	Question
	Elevation ID
	Orientation
36	What percentage of wall is glazed?
37	Can the windows be opened?
38a	Main glazing type?
38b	Secondary glazing type?
39a	Main frame type?
39b	Secondary frame type?
40	What type of tint does it have?
41	What type of reflective coating does it have?
42	Height (m)
43	Height of ground level to building
44	Distance to nearest building (m)
45	Average height of nearest building (m)

A.5 Appliance Counts

BEES Appliance Tally		BEES ID	
Computers		**Food Preparation**	
Desktop computer		Boiling water unit	
Laptop computer		Oven	
		Hobs	
CRT monitor		Range	
LCD monitor		Grill	
		Deep fryer	
Docking station		Coffee maker	
Desktop printer		Food warmer	
Uninterupted Power Supply		Microwave	
Ethernet/wireless/router		Jug	
Server		Coffee machine	
Minicomputer		Rangehood (extractor)	
Mainframe computer		Small kitchen appliance	
Office		**Refrigeration**	
Multifunction copier (desktop)		Resid. fridge	
Multifunction copier (floor)		Resid. fridge/freezer	
Multifunction copier (large)		Resid. type freezer	
Fax machine		Water cooler	
Charger/power adaptor		Cold food table	
Projector		Vending (refrigerated)	
Telephone system		Comm. refrigerator	
Security system		Comm. freezer	
Shredder		Walk in fridge or freezer	
Electronic whiteboard		**Cleaning**	
Entertainment		Vacuum cleaner	
Stereo system		Dishwasher (resid.)	
PA Sound System		Dishwasher (comm.)	
TV (small)		Washing machine (resid.)	
TV (large)		Washing machine (comm.)	
DVD, VCR or similar		Dryer (resid.)	
Retail		Dryer (comm.)	
Checkout conveyor		Hand dryer	
Video game		**Miscellaneous**	
Digital photo console		Powered hand tools	
Exercise equipment		Powered tools	
Vending (non-refrig)		Large equip	
ATM		Misc. small appliance	
Cash register		Misc. large appliance	
Advertising display		**Other (specify)**	
EFTPOS terminal			
Heating/space conditioning			
Portable electric heater			
Heat pump/airconditioner			
Dehumidifier			
Fixed electric heater			
Portable gas heater			
Fixed gas heater			
Fan			

A.6 Lighting Audit

The lighting audit collects information on every light fixture, by type of lamp. For each switch and type of lamp the following are recorded:

- Room Label
- Switch/Circuit
- Lamp Type (coded as in Table 13**Error! Reference source not found.**)
- No. luminaires
- Lamps per luminaire
- Lamp W
- Control Type

Table 13. Lamp type codes.

• Code	• Description
• I	• Incandescent
• IP	• Incandescent PAR
• IR	• Incandescent Reflector
• H	• Halogen
• CFL	• Compact Fluorescent
• CFLR	• Compact Fluorescent Reflector
• F	• Fluorescent
• LED	• LED
• EX	• Exit
• MH	• Metal Halide
• MV	• Mercury Vapour
• O	• Other

A.7 Floor Plans

Annotated floor plans are drawn up for the detailed monitored premise. The location of the temperature sensors is indicated, and rooms coded to match the lighting audit. The information extracted from these plans includes:

- Room Area
- Perimeter
- Floor Covering
- Room Height
- Elevation the room is on (e.g. East)
- Number of walls
- Number of exterior walls
- Has skylights?
- Area of Skylights?
- Has windows?
- Shading

A.8 Photographs

Photographs are a valuable record of the premises and the installations. Some information for energy simulation models is collated from photographs, such as shading, window sizes, and colours of surfaces.

Photographs are taken of:

- Exterior photos of building for each elevation
- Exterior photos of surroundings looking away from each elevation
- Distribution boards
- General interior
- Temperature/Humidity/Lux sensors in place
- Appliance monitoring in place
- Electricity/water/gas meters

APPENDIX B

The most important part of the BEES detailed monitoring is the monitoring of individual electric circuits on distribution boards. This is the only practicable way of monitoring end-uses (e.g. lighting, power points, air-conditioning) in non-residential buildings, given their size and complexity.

In monitoring these circuits and end-uses for BEES a large number of distribution boards have had equipment installed, (about 3,700 circuits so far), with a large variety of types of distribution boards and wiring practices encountered. These observations enable the current state of wiring in Strata 1-4 non-residential buildings to be described, specifically:

What is the present situation? What do the electrical distribution boards in the non-residential sector across New Zealand look like?

Is any change for the future needed and if so, why?

B.1 Electricity Safety regulations

The Electricity Safety Regulations are designed to protect the building, users and contractors from immediate danger. There is a balance between having the safety at the right level and still allowing utility for the consumers.

In order to keep this balance right with the changing requirements and technology the regulations have a major review every five years and a minor review annually.

A key point in the regulation is older wiring installations completed under previous law are recognised as being safe as these older benchmarks are still valid.

When new wiring is installed in a building it is required to be done to the latest standard, however the rest of the wiring in the building does not have to be updated. The reason for this is that it is safer to install only the additional wiring to the new regulation level rather than potentially delaying necessary work by requiring an upgrade of the wiring for the whole building.

In many countries working on a live distribution boards is illegal. In New Zealand there are no rules to prevent electricians working on live boards, but it is discouraged. It is not good practice, but it does seem to be common. Ideally if power to a building cannot be turned off then the distribution board and wiring installation should be designed, so that it can be worked on live.

Labelling of circuits has always been required, but there are different levels of requirement. For example in a building such as a Hospital where the supply electricity is seen as critical the level of labelling is completed to a much higher standard.

Regulation 13 requires a person working on electrical installations in a building to be safe at all times and not to do anything that could put themselves, the building or people at risk. If a person comes across a dangerous situation then regulation 19 must be followed. Which is if any person comes across a situation where the distribution board, wiring or appliance presents an immediate danger to person or building they are to notify the owner or occupier of the building and the Energy Safety Agency (Electricity Safety Regulations, 2010 and Morfee and McLaughlan, 2011). These regulations have been followed for all installations in BEES.

For a copy of the regulations they can be downloaded from the energy safety website - http://energysafety.govt.nz/ .

B.2 Observations of the wiring in the BEES buildings

The installation of BEES monitoring equipment requires that distribution boards are opened to access the wiring. This is done by a registered electrician, and any safety or maintenance issues are identified before installation. The work only proceeds if it is safe to do to so. Identification of circuits is essential for BEES, and this raises another set of issues with identifying and tracing circuits (see Section 2.1).

The main issues identified and described are:

- Dangerous distribution boards or wiring
- Hazardous distribution boards or wiring
- Reconfigured boards
- Labelling of distribution boards
- Complexity
- Selection and categorisation of circuits

B.3 Dangerous distribution boards or wiring

Three dangerous distribution boards were found out of ~100 premises, where the electrician refused to work on the board due to the high likelihood of arcing or explosion. Visual inspection found very old wiring (40+ years) that had not been maintained for many years. Old wiring is nothing unusual, however when attempting to open the boards it became obvious that the insulation around the cables was so old and deteriorated that any movement would cause breaking of the old insulation shield with the possibility of serious damage, short circuits and fire. In one of the cases, the electrician in place suggested an explosion was possible. Non-residential buildings often have large capacity feeds which have a very high short circuit current which is high enough to cause a plasma arc and explosion with the potential for serious injury or even death[5]. Without shutting down the whole business and rewiring the board and/or building, no monitoring could be done, and occupants were informed of the hazard. There are no pictures of these dangers as the distribution boards could not be opened to take useful pictures.

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[5] see http://www.fluke.com/fluke/auen/training/demos/default.htm link to “safety video”

B.4 Hazardous distribution boards or wiring

A surprisingly large number of distribution boards (estimated at about a quarter) were found to have hazards that made the boards potentially unsafe to approach or work on whilst the power was live. The normal practice for routine electrical work on commercial buildings in New Zealand is to leave the power on to avoid disruption. Major work that requires a shutdown is either scheduled or carried out after hours.

These hazards created a potential risk of electrocution or short circuit if contact was made with exposed conductors. Electricians manage this risk by identifying the risk, isolating it if possible, or by working carefully. This slows down their work and requires a high level of concentration and skill.

Modern electrical wiring practice ensures that there are no live conductors exposed when a distribution board is opened, leaving the electrician free to concentrate on the immediate task with no need to be concerned about other parts of the board.

Exposed loose wires are an electrocution and short circuit hazard (Figure 13, Figure 14 and Figure 15). When they occur on a board with a "birds nest" of wiring, it may not be possible to see, even under close inspection.

Melted insulation on wires or busbars are another significant hazard (Figure 16, Figure 17 and Figure 18). For the building in Figure 16 the overloading and melting was so severe that the electrician refused to even touch the board unless the building was powered down – this board supplied several premises so repairs would cause major disruption. The building was built in 2006, and the overloading appears to be due to insufficient capacity at the main board.

There are also a variety of more subtle hazards such as fuses or circuit breakers mounted in the wrong orientation (Figure 17). This makes reading their rating more difficult, and for circuit breakers or RCDs creates the possibility of accidentally thinking a circuit is off when it is in fact on.

Modern wiring practice uses red, white or yellow, and blue cables and wires for the three electric phases. On older boards this practice was not required and a single colour was often used (usually red) or the colours are mixed up and do not correspond to the phases. This also occurs sometimes on newer boards. This makes tracing circuits more difficult, and creates a hazard, as wrongly connecting two different live phases will cause a short circuit.

Exposed wiring at terminals is also common, and can be found on distribution boards of all ages throughout the country (Figure 19 and Figure 20). Exposed busbars are also common, sometimes as a result of melted or degraded insulation (Figure 21), and sometimes due to missing or broken covers (Figure 22). Exposed busbars are a major hazard as they are often placed before the main switch and fuse, so if there is a short circuit there is no fuse or cut-out protection, and the short circuit current can be very large. The short circuit current is then only limited by the capacity of the main cable or the street transformer. These hazards are usually behind the board, so the occupants are not directly exposed to the hazard, but sometimes exposed connectors (Figure 23) and live fuse holders with missing fuses are on the front panel of old boards, creating an electrocution hazard for the occupants (Figure 24).

Hazards can also be outside the distribution boards. Many distribution boards had access to them blocked by shelving (Figure 25), stored items or piles of junk (Figure 26Figure 26), and some had doors that could not be opened due to obstructions from furniture or other panels (Figure 27). These all create both a fire hazard and an access hazard, as the main switch to a building or premise should be easily accessible should power need to be turned off in an emergency.

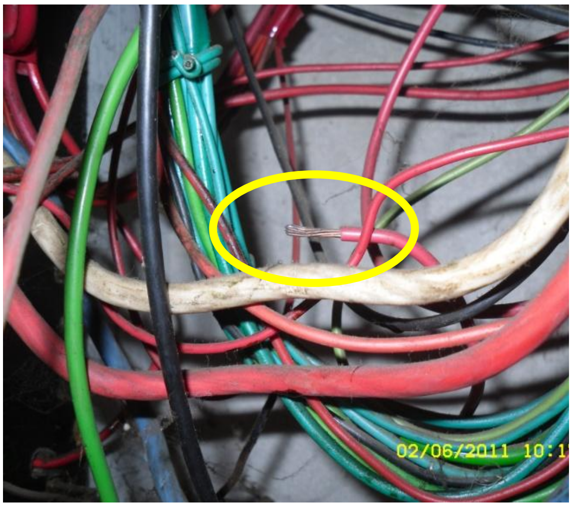


Figure 13. Exposed live wires

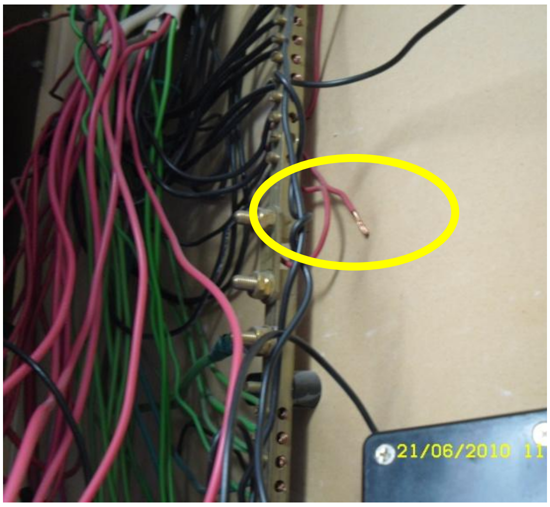


Figure 14. Exposed live wire close to earth busbar

Figure 16. Melted insulation and exposed terminals. The building was newly wired

Figure 15. Loose and exposed wires

in 2006

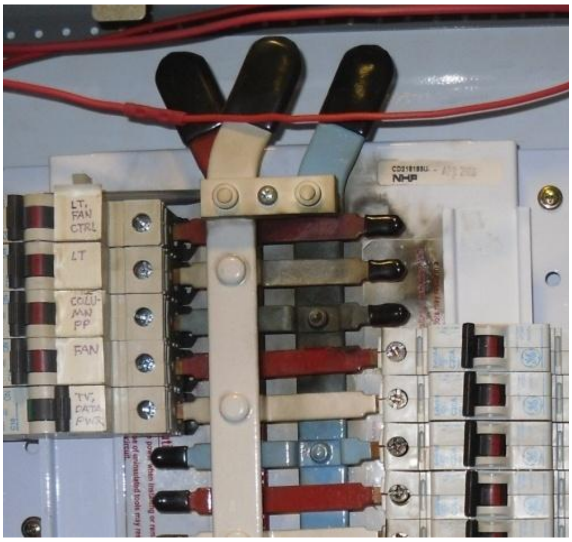


Figure 17. Melted insulation and exposed busbars

Figure 18. Melted wiring. Note the upside down position of the right hand fuse holder

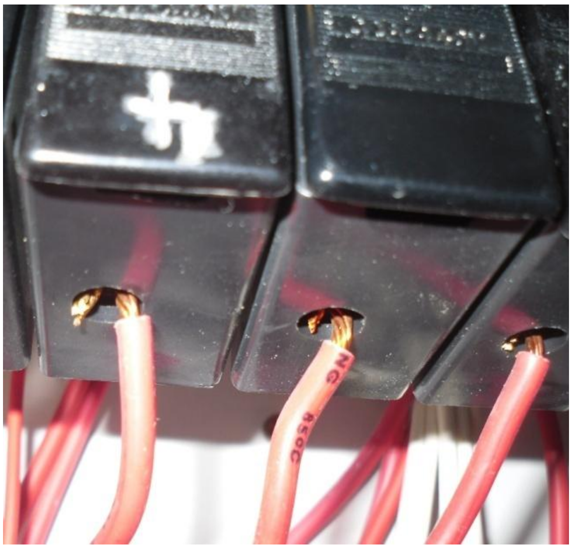


Figure 19. Exposed terminal wiring

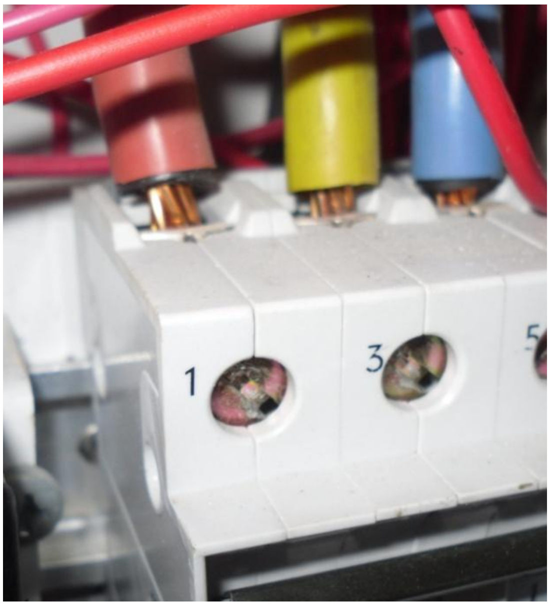


Figure 20. Exposed terminal wiring

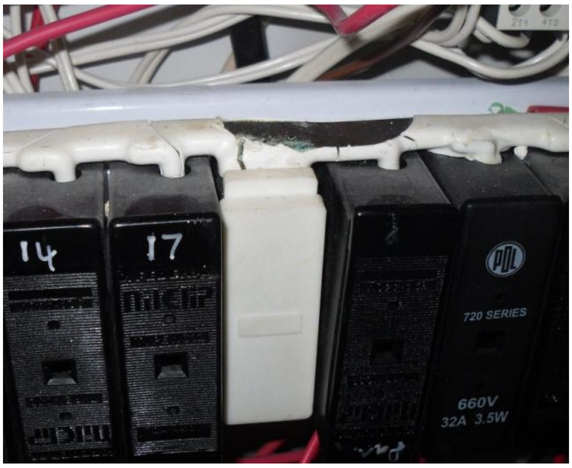


Figure 21. Exposed busbars on an old board –insulation melted and cracked

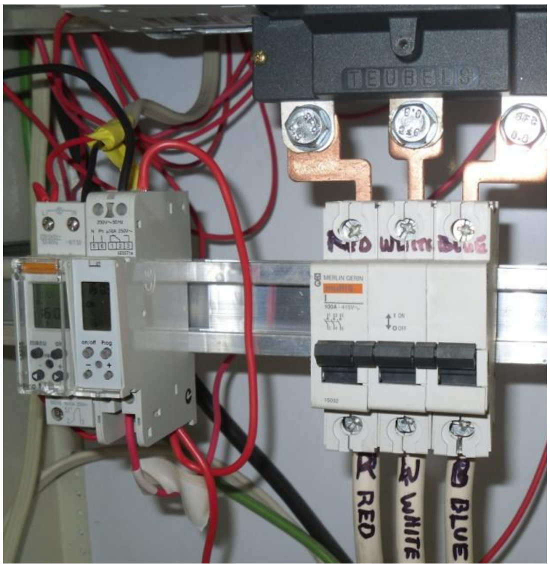


Figure 22. Exposed busbars on a new board – no insulation or cover

Figure 23. Exposed connectors –protruding live bolts (right) are easy to touch accidentally

Figure 24. Exposed fuse holders – fuses removed but terminals live. Board lacking a door or cover

Figure 25. Board blocked by shelving installed after building completion

Figure 26. Board blocked by security panels

Figure 27. Board blocked by a jumbled storage area, both a fire and access hazard

B.5 Reconfigured boards

Figure 28 shows a typical board in an older building which has been upgraded, reconfigured and partially modernised over the years. The first inspection indicated this to be a relatively simple, tidy and straightforward board to work on. In reality once monitoring installation began it was found to be impossible to establish the combination of phases without complete dismantling and re-wiring the board. The assumption is that the premise is fed by two phases from which one was split to two. Thus, it was impossible to establish either the order or the correct rotation of phases, making complete end-use monitoring impossible.

Figure 28. Typical reconfigured, older distribution board

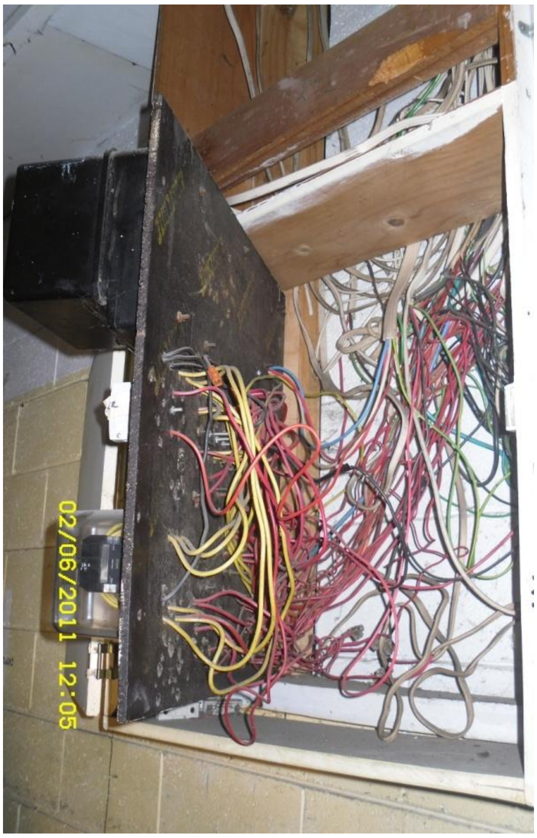


Figure 29. Back of the same board

Figure 29 shows the same board from the back, showing a "birds nest" of wiring, typical for older distribution boards. Closer inspection shows a mixture of old and new wiring including some unused cables, which have been protected accordingly. Often on older boards a single wire colour is used for all phases, which makes tracing wiring even more difficult.

Many buildings have had fixed wired electric heaters replaced with spit system air-conditioners (heat pumps). This installation work is often done by the supplier or their electrician, not by the electrician that usually services the building (if there is a regular electrician), and often the connection to the distribution board is not done well. For example, the air-conditioner might be connected to the most convenient circuit, or be tapped onto a power point circuit, rather than putting in a dedicated breaker. Often old wiring for fixed wired heaters is not removed, and operating timers and other controls left in place. This leaves the board in a more disorganised state than before.

B.6 Labelling of distribution boards

Regardless of age or region, the labelling found on most distribution boards in the monitored BEES premises was poor. Many distribution boards might on casual inspection seem to be tidy and readable, but in fact, very few boards actually have labelling that corresponds closely to the circuit configuration. In most older buildings, distribution boards have been rewired or reorganised at some stage, and in the majority of cases either the circuit charts were not updated, or were labelled incorrectly.

The most interesting example found so far is shown on Figure 30, where there was no circuit chart and the labelling was done directly on circuit breakers, overwriting the old labels. Relabelling has happened at least four times. None of the labelling was correct at the time of monitoring, and a lot of investigation was needed before monitoring could begin.

A large number of distribution boards were found not to be labelled at all. Figure 31 shows an example where not only is the labelling poor, but it is difficult to identify which breaker corresponds to which label. Both boards in Figure 30 and Figure 31 were actually in the same building but on different floors. This shows how complex and diverse wiring practice can be inside just one building.

The labels shown in Figure 32 are behind the board cover, which only an electrician can access.

There are some rare examples of well labelled boards where everything was labelled and correct, such as in Figure 33 and Figure 34. In both of these boards, the labelling corresponded to the position of fuses which were readily identifiable. One of the best examples was one of the buildings on the BRANZ site (which is part of the BEES study as well). Power outlets are individually labelled with a printed code that matches the distribution board and circuit.

Distribution boards may be worked on by a variety of tradespeople, including network meter electricians (sometimes with only limited electrical registration), registered electricians, HVAC and refrigeration services engineers, and even illegal work by unqualified or unregistered people. Each trade deals with only part of the electrical system, and often they work independently, which makes consistent wiring practice difficult when the needs or work of one trade conflicts with that of another. What is convenient or expedient for one trade may cause problems later for another.

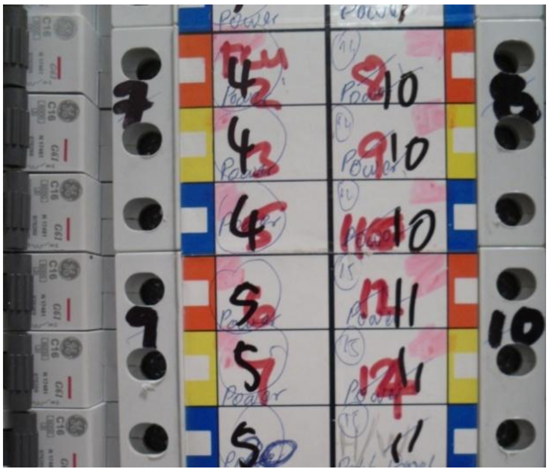


Figure 30. Layers of labelling – all incomprehensible

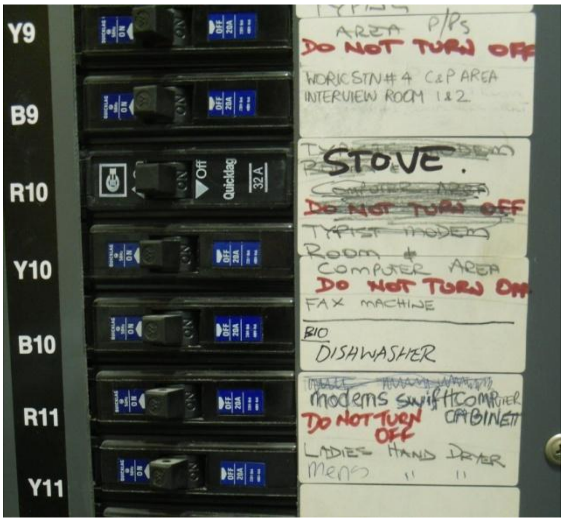
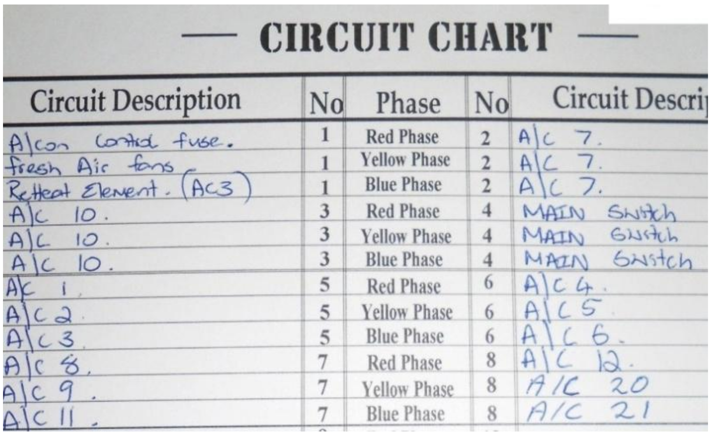


Figure 31. Labelling not aligned

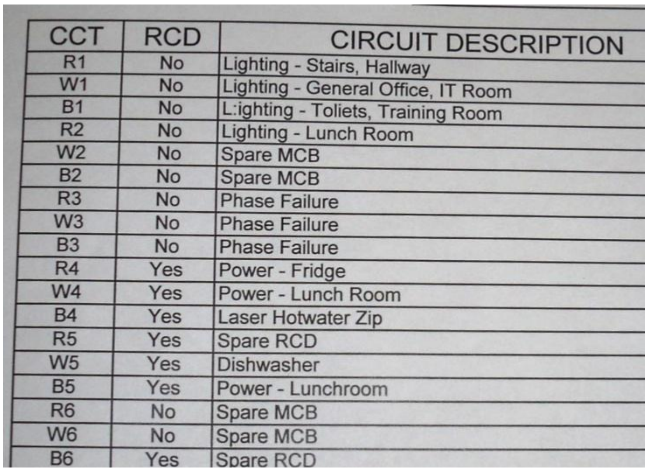
Figure 32. Labelling behind the board cover



— CIRCUIT CHART —

Circuit Description	No	Phase	No	Circuit Descri
A/con control fuse.	1	Red Phase	2	A/C 7.
fresh Air fans	1	Yellow Phase	2	A/C 7.
Reheat Element. (AC3)	1	Blue Phase	2	A/C 7.
A/C 10.	3	Red Phase	4	MAIN Switch
A/C 10.	3	Yellow Phase	4	MAIN Switch
A/C 10.	3	Blue Phase	4	MAIN Switch
A/C 1.	5	Red Phase	6	A/C 4.
A/C 2.	5	Yellow Phase	6	A/C 5.
A/C 3.	5	Blue Phase	6	A/C 6.
A/C 8.	7	Red Phase	8	A/C 12.
A/C 9.	7	Yellow Phase	8	A/C 20
A/C 11.	7	Blue Phase	8	A/C 21

Figure 33. A well labelled board.



CCT	RCD	CIRCUIT DESCRIPTION
R1	No	Lighting - Stairs, Hallway
W1	No	Lighting - General Office, IT Room
B1	No	L:ighting - Toliets, Training Room
R2	No	Lighting - Lunch Room
W2	No	Spare MCB
B2	No	Spare MCB
R3	No	Phase Failure
W3	No	Phase Failure
B3	No	Phase Failure
R4	Yes	Power - Fridge
W4	Yes	Power - Lunch Room
B4	Yes	Laser Hotwater Zip
R5	Yes	Spare RCD
W5	Yes	Dishwasher
B5	Yes	Power - Lunchroom
R6	No	Spare MCB
W6	No	Spare MCB
B6	Yes	Spare RCD

Figure 34. A well labelled board

B.7 Complexity

The complexity of boards and wiring in larger buildings can make identification difficult. Even finding out how many distribution boards there are and where they are located is a challenge, as there are often boards scattered around the building, with no overall wiring plan or labelling on the main board indicating feeds to other boards. Some of these boards are located in strange places or concealed, and no-one available to building users even knows they exist.

The solution would obviously be to have a good wiring plan for the building, however it is recognised that for large buildings these wiring plans can be several folders containing hundreds of pages of wiring diagrams and layouts. It is a huge task to try to read and understand these wiring plans. Often these wiring plans have not been maintained and updated and differ from the current wiring.

Figure 35, Figure 36 and Figure 37 illustrate the multi-panel distribution boards found in larger buildings. It takes a lot of time to investigate the layout of the main board and sub boards and decide on the strategy for monitoring.

In one particular building, after a few hours of unsuccessful study by two people, the name and telephone number of the company that did the installation was found and they were contacted. The electrician who personally installed the wiring then came to the building but was also unable to explain and identify major circuits from the wiring plan!

Three out of over 100 premises had wiring either providing power to other businesses or using power being paid by other businesses. One particularly extreme case was identified where several kW were supplied from an unoccupied neighbouring premise at the time of monitoring.

Figure 35. Large multi-panel distribution board.

Figure 36. Large multi-panel distribution board.

Figure 37. Large multi-panel distribution board showing circuits for end-use monitoring.

B.8 Selection and categorisation

In the majority of installations phases and circuits needed to be identified and new circuit charts drawn. As outlined previously this is a complex task as the main electrical supply, in most cases, cannot just be turned off. The total electrical load of the building and the particular premise is normally not a problem to monitor. However, very often these main boards are located in back rooms with poor access, and often used as storage.

Ideally single end-uses would be monitored separately by BEES. However, the complexities of larger premises sometimes make this impossible, and the monitoring must be rationalised. Loads of the same type (e.g. lighting) on the same phase are combined and monitored as a group. Sometimes a board will supply only plug loads, so board totals only are monitored. If there are a few circuits on these boards with different end-uses these would be separately monitored and the use subtracted from the board totals. This approach reduces the amount of equipment needed, and the amount of time for installation and data processing. The various groupings and subtractions are carried out during the data processing, and BEES has set up efficient systems to do this work automatically.

B.9 Recommendations

The experience of the BEES monitoring teams is that wiring in non-residential buildings is haphazard, with layers of maintenance, repairs, and reconfiguration, historic layers of electrical practice, and the varying practices of the various trades responsible for different parts of the electrical systems. Many boards have hazards caused by obsolete electrical practice and equipment on older boards, previous substandard work, and faults caused by deterioration, damage and overloading. Newer boards are not immune to problems caused by reconfiguration or overloading.

Circuit labelling is also haphazard, and in most cases, investigation is needed to attempt to identify distribution boards and circuits before electrical work can be done. A number of electricians employed for BEES installations have commented that the lack of labelling is an attempt to make it difficult for them to work on buildings that are usually serviced by other electrical companies. This might not be the intention, but the end result is that only electricians familiar with a building are in a position to service that building without investing considerable time in figuring out how it is wired.

The common practice of working on live boards, although it minimises the disruption and cost of the work at hand, makes it difficult to work to best practice when adding or modifying circuits, and makes it difficult to carry out remedial work should faults be seen.

These issues make the maintenance of electrical wiring more difficult and costly than it should be, increases the level of hazard to electricians and the building and occupants, and tend to make boards increasingly messy and potentially hazardous over time.

The recommendations for improving the standard and maintainability of electrical system are:

- Engage an electrician for regular service
- Buildings owners/occupants know where boards are and how to access them
- Conduct safety inspections on older boards
- Conduct scheduled inspection and maintenance
- Rewire old boards and buildings before they become hazardous
- Update and label circuit charts
- Develop simple wiring plans showing location of distribution boards and board feeds
- Allowing for future expansion by having spare load capacity, and spare fuses/breakers
- Develop consistent practices across all electrical trades servicing buildings