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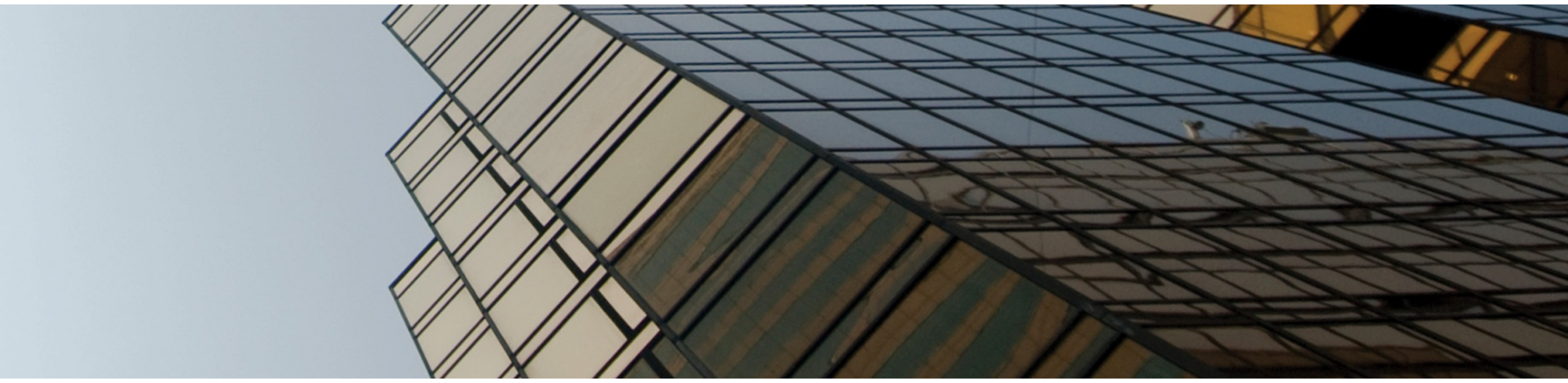

STUDY REPORT SR 297/2 [2014]

BEES PART 2: APPENDICES TO 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

Funded by BRANZ from the Building Research Levy

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BUILDING ENERGY END-USE STUDY (BEES) PART 2: APPENDICES TO FINAL REPORT

BRANZ Study Report SR 297/2 (2014)

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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 and part 2.

Part 1 provides an overview of the research with key results, discussion and conclusions.

Part 2, this part, is a series of appendices to the final report (part 1) that provide detail on the methodologies used to obtain the results and information created through this research.

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APPENDICES

A. Survey Methodology and Results

Both social surveying and in-depth interviewing have been used to collect critical data about buildings, their use and management. Three surveys were undertaken:

- A premise survey.
- Detailed interviews with property owners and building managers.
- Detailed interviews with owner-occupier building owners.

Additionally, a set of in-depth interviews were undertaken with property managers, building owners and landlords.

These methods have been described in various reports. This provides a brief summary of each method, notes their analytic purposes and comments on technical issues and data limitations.

A.1. Premise Surveys

The premise survey was designed to provide representative data of the BEES eligible non-residential building stock. It was designed to complement data derived from valuation records and public information sources about building characteristics. In addition, the premise surveys were expected to be the primary source of data that could not be captured through those sources or through targeted monitoring. The telephone survey also allowed initial contact to seek access to energy revenue data.

Table A-1 below sets out the premise survey in the context of the broader information domains covered by the BEES programme.

Table A-1: Information Domains and Primary Sources.

Information Domain	Information	Source
Building	Age	QV
	Number of floors	StreetView/Google/Targeted Monitoring
	Size of floor plate	StreetView/Google/Targeted Monitoring
	Total building floor area (m^2)	StreetView/Google/Targeted Monitoring/QV
	Building materials	StreetView/Google/Targeted Monitoring
	Building characteristics	StreetView/Google/Targeted Monitoring
Location	Region	QV and Business Directory
	City	QV and Business Directory
	Suburb	QV and Business Directory
	Address	QV and Business Directory
	Density and mix environment	Beacon Neighbourhood Study
Use	QV classification	QV
	Business names, phone number, postal address	Business Directory
	Business types	Business Directory, StreetView/Google/Targeted Monitoring
	Business activity	Premise Survey
Occupation	Total number of businesses	Business Directory/Premise Survey
	Businesses per floor	Premise Survey
	Employees per business	Premise Survey
	Hours of use per business	Premise Survey
	Appliance stocks	Premise Survey/Targeted Monitoring
Building Ownership and Management	Owner	QV
	Contact address for owner	Premise Survey
	Owner-occupier	Business Directory/Premise Survey
	Tenanted	Business Directory/Premise Survey
	Tenancy agreement	Premise Survey
	Building manager	Premise Survey
	Refits	Premise Survey
	Heating and cooling	Premise Survey
Resource Types	Water	Supplier and Premise Survey
	Electricity	Supplier and Premise Survey
	Gas	Supplier and Premise Survey
	Other	Supplier and Premise Survey
Suppliers and Billing	Water	Supplier and Premise Survey
	Electricity	Supplier and Premise Survey
	Gas	Supplier and Premise Survey
	Other	Supplier and Premise Survey

The premise surveying was undertaken after a pre-surveying pilot and subsequently telephone surveying of a stratified random sample of premises. Piloting was undertaken in early 2009 and to test key processes including generating contacts for occupants of eligible buildings and interview instrumentation. It also provided an insight into likely yields and response rates. It concluded that, while valuation data might have 25% or less of missing and incorrect data, the business/building matching process using business directories showed less certainty. Business/building matching through the business directory process generated matches for only 59.7% of buildings. In addition, there were errors of around 12% of identified businesses. Moreover, business directory matching generated an average of 2.7 businesses per building, while other search processes generated an average of 5.8 businesses per building.

The pilot also highlighted difficulties around yield and response rates – 14% of businesses agreed to complete the questionnaire while 35% refused and 33% suggested that the interviewer needed to call back. A significant proportion of businesses could not be contacted or were ineligible (Table A-2). On the basis of the pilot, it was estimated that response rates would be uncertain and could be as low as 20%.

Table A-2: Pilot Response Categories after Two Weeks Telephone Contacting (*n* = 100).

Response Category	Percentage of Pilot Sample Businesses
Agreed	14%
Refused	35%
Non-complete	1%
Call Back	33%
No Engagement	5%
Not Eligible/Not Contactable	12%
Total	**100%**

The pilot also indicated that building yield was sensitive to rules regarding the proportions of premises that were required to recruit a building for use in the estimation of aggregated energy and water use. The subsequent handling of this issue is set out in the method for aggregate energy estimation.

Subsequent to the pilot, the premise survey was undertaken progressively in three waves from 2010. Wave 1 involved a set of size strata 1 to 4 buildings. This was followed by a set of size stratum 5 buildings. In the latter part of 2011 and early 2012, both Wave 2 and Wave 3 premises were surveyed. Table A-3 sets out the numbers of premises participating in each wave by their building size.

Table A-3: Estimated Size of Buildings by Strata for Participant Premises.

Estimated Building Floor Area	Surveying Wave			
	Wave 1, 2010	Wave 2, 2011	Wave 3, 2012	Total
1–649 m^2	53	11	26	90
650–1,499 m^2	54	15	31	100
1,500–3,499 m^2	69	14	45	128
3,500–8,999 m^2	91	34	69	194
9,000+ m^2	90	99	91	280
Not estimated	13	12	26	51

The questionnaire used in surveying was redeveloped by CRESA in the light of the pilot findings and to better accommodate the needs of computer-assisted telephone interviewing (CATI) technology. It was also slightly amended in the light of building size strata 1–5 Wave 1 survey results and to assist data matching from other datasets.

In Wave 1 (building size strata 1–4), 19% of premises were non-contactable or unusable. In stratum 5, however, this proportion rose significantly to 44%. This reflected the inaccuracies associated with attempts to reduce front-end work by matching web-identified buildings with commercial directories. For Waves 2 and 3, premises and telephone numbers for premises in sampled buildings were identified through WhoisWhere. This provided an improvement on the directory approach used in building size stratum 5 of Wave 1, with only 32% of premises unusable or non-contactable. The response and yield for each wave are as follows:

- Of the 1,656 business listing for strata 1–4:
    - 170 were unusable (10.3%)
    - 142 were non-contacts (8.6%)
    - 1,020 were refusals (61.9%)
    - 63 were head office referrals (3.8%)
    - 261 were completed interviews
    - the response was 20.3% for contacted, eligible and non-referred premises.
- Of the 1,659 business listing complied for stratum 5:
    - 383 were unusable (23.0%)
    - 347 were non-contacts (20.9%)
    - 735 were refusals (44.0%)
    - 87 were head office referrals (5.2%)
    - 107 were completed interviews
    - of the contacted, eligible and non-referred premises, the response was 12.7%.

- Of the 1,949 businesses listed for survey in Waves 2 and 3:
  - 314 were unusable (16.1%)
  - 314 were non contacts (16.1%)
  - 98 were head office referrals (5.0%)
  - 821 refused (42.1%)
  - 402 were completed interviews (20.6%)
  - of the 122 in which contact was made, the building eligible and not referred to head office, the response was 32.9%.

In addition, a separate data collection exercise was undertaken with head offices to collect data on premises that referred interviewers to a head office or for businesses that were sampled and clearly organised around a head office structure and were generally retail based.

This group was then separated further into three groups: franchised or independently operated businesses, New Zealand head offices and those with international head offices. The franchised and independently operated businesses were generally more difficult to get the chance to talk to, as they were on the cash register while answering the phone and had no head office as such to deal with calls of this nature. Very few had email addresses that could be used. This meant the uptake in participation in BEES was much lower than those with actual head offices, within the head office process only.

International head offices could mean that referrals come left, right and centre before you finally end up with someone in the right department. In bigger firms, asking to speak directly with someone in the property team helped. However, the personnel working on the BEES telephone surveys and revenue data consents ranged from office managers to property managers and accounting teams.

Email chase-ups, together with read-receipts and high-importance stamps, were sometimes far more effective than speaking over the phone, depending on their preference in communication method. Giving a final deadline, which meant threatening that they would be excluded from the study if not consented prior to a specific date, proved very efficient for the multiple-premise head office businesses.

Table A-4: Summary of Participants.

Participation	Head Offices	Premises	Independently Operated	Total Premises
Consent	25	95	12	107
No Response	75	373	205	578
Declined	30	195	20	215
Too Busy	7	37	-	37
Moved	21	65	29	94
Total				1,031

This means at 10% response rate. The head office businesses provided an additional 114 premises that were outside the sample frame for revenue data.

The total number of premises subject to surveying is 848. Of those 848 premises, BRANZ was able to secure energy revenue data for 255 premises. Analysis has been undertaken to identify differences between those premises that provided revenue data and those that did not. The frequencies for key variables of each set are set out below. The most notable differences in the two sets are loss of premises who pay for electricity or gas by way of their lease to landlords. There is some over-representation of premises in smaller buildings, premises that occupy the whole building, premises that own the building, premises with longer occupancy durations and premises that use energy and fuel other than reticulated electricity. There is also some under-representation of premises with cooking and refrigeration as dominant energy constellations.

Table A-5: Electricity Revenue Data Status for Premises by Building Use Strata.

Electricity Revenue Data Status	Building Use Strata	Frequency	Percent
No Electricity Revenue Data	Commercial Office (CO)	175	29.5%
	Commercial Retail (CR)	194	32.7%
	Commercial Multiple/Other (CX)	169	28.5%
	Industrial Service (IS)	32	5.4%
	Industrial Warehouse (IW)	23	3.9%
	Total	**593**	**100.0%**
Electricity Revenue Data	Commercial Office (CO)	86	33.7%
	Commercial Retail (CR)	69	27.1%
	Commercial Multiple/Other (CX)	73	28.6%
	Industrial Service (IS)	14	5.5%
	Industrial Warehouse (IW)	13	5.1%
	Total	**255**	**100.0%**

Table A-6: Electricity Revenue Data Status for Premises by BAS.

Electricity Revenue Data Status	Business Activity Sector (BAS)	Frequency	Percent
No Electricity Revenue Data	Retail trade	175	29.5%
	Property and business sector	142	23.9%
	Finance and insurance	41	6.9%
	Health and community services	53	8.9%
	Accommodation, cafés and restaurants	53	8.9%
	Personal and other services	40	6.7%
	Education	9	1.5%
	Construction	13	2.2%
	Government administration and defence	25	4.2%
	Manufacturing/other manufacturing	11	1.9%
	Communications services	8	1.3%
	Cultural and recreational services	13	2.2%
	Wholesale trade	4	0.7%
	Electricity, gas and water	5	0.8%
	Not stated/unclear	1	0.2%
	Total	**593**	**100.0**
Electricity Revenue Data	Retail trade	74	29.0%
	Property and business sector	62	24.3%
	Finance and insurance	27	10.6%
	Health and community services	18	7.1%
	Accommodation, cafés and restaurants	10	3.9%
	Personal and other services	10	3.9%
	Education	5	2.0%
	Construction	5	2.0%
	Government administration and defence	27	10.6%
	Manufacturing/other manufacturing	6	2.4%
	Cultural and recreational services	4	1.6%
	Wholesale trade	4	1.6%
	Electricity, gas and water	2	0.8%
	Transport	1	0.4%
	Total	**255**	**100.0%**

Table A-7: Electricity Revenue Data Status for Premises by Building Size Strata.

Electricity Revenue Data Status	Building Size Stratum	Frequency	Percent
No Electricity Revenue Data	S1	46	7.8%
	S2	67	11.3%
	S3	96	16.2%
	S4	177	29.8%
	S5	207	34.9%
	Total	**593**	**100.0%**
Electricity Revenue Data	S1	28	11.0%
	S2	31	12.2%
	S3	54	21.2%
	S4	63	24.7%
	S5	79	31.0%
	Total	**255**	**100.0%**

Table A-8: Electricity Revenue Data Status for Premises by Building Floor Area.

Electricity Revenue Data Status	Building Floor Area	Frequency	Percent
No Electricity Revenue Data	5–649 m^2	56	9.4%
	650–1,499 m^2	65	11.0%
	1,500–3,499 m^2	82	13.8%
	3,500–8,999 m^2	132	22.3%
	9000 + m^2	209	35.2%
	No estimate	49	8.3%
	Total	**593**	**100.0%**
Electricity Revenue Data	5–649 m^2	38	14.9%
	650–1,499 m^2	36	14.1%
	1,500–3,499 m^2	47	18.4%
	3,500–8,999 m^2	61	23.9%
	9,000+ m^2	71	27.8%
	No estimate	2	0.8%
	Total	**255**	**100.0%**

Table A-9: Electricity Revenue Data Status for Premises by Occupation of Building.

Electricity Revenue Data Status	Building Occupation	Frequency	Percent
No Electricity Revenue Data	Business occupies whole building	60	10.1%
	Business occupies only part of the building	532	89.7%
	Not stated	1	0.2%
	Total	**593**	**100.0%**
Electricity Revenue Data	Business occupies whole building	35	13.7%
	Business occupies only part of the building	220	86.3%
	Total	**255**	**100.0%**

Table A-10: Electricity Revenue Data Status for Premises by Reported Building Floors.

Electricity Revenue Data Status	Building Floors	Frequency	Percent
No Electricity Revenue Data	1 floor	85	14.3%
	2 floors	124	20.9%
	3 floors	28	4.7%
	4 floors	21	3.5%
	5–9 floors	60	10.1%
	10 or more floors	85	14.3%
	Do not know/number of floors not specified	17	2.9%
	This question not asked	173	29.2%
	Total	**593**	**100.0%**
Electricity Revenue Data	1 floor	43	16.9%
	2 floors	40	15.7%
	3 floors	12	4.7%
	4 floors	9	3.5%
	5–9 floors	28	11.0%
	10 or more floors	32	12.5%
	Do not know/number of floors not specified	8	3.1%
	This question not asked	83	32.5%
	Total	**255**	**100.0%**

Table A-11: Electricity Revenue Data Status for Premises by Premise Tenure Status.

Electricity Revenue Data Status	Tenure	Frequency	Percent
No Electricity Revenue Data	Tenant	512	86.3%
	Subtenant	10	1.7%
	Owner-occupier	66	11.1%
	Do not know	5	0.8%
	Total	**593**	**100.0%**
Electricity Revenue Data	Tenant	209	82.0%
	Subtenant	2	0.8%
	Owner-occupier	44	17.3%
	Total	**255**	**100.0%**

Table A-12: Electricity Revenue Data Status for Premises by Building Management.

Electricity Revenue Data Status	Building Management	Frequency	Percent
No Electricity Revenue Data	Building manager	254	42.8%
	Landlord	161	27.2%
	Building manager and landlord	48	8.1%
	No management	72	12.1%
	Landlord is the building manager	45	7.6%
	Do not know	13	2.2%
	Total	**593**	**100.0%**
Electricity Revenue Data	Building manager	115	45.1%
	Landlord	60	23.5%
	Building manager and landlord	21	8.2%
	No management	35	13.7%
	Landlord is the building manager	21	8.2%
	Do not know	3	1.2%
	Total	**255**	**100.0%**

Table A-13: Electricity Revenue Data Status for Premises by Duration of Premise Occupancy.

Electricity Revenue Data Status	Duration of Premise Occupancy	Frequency	Percent	Valid Percent
No Electricity Revenue Data	1 year or less	90	15.2%	16.2%
	2–6 years	248	41.8%	44.6%
	7–11 years	113	19.1%	20.3%
	12–16 years	47	7.9%	8.5%
	17–21 years	18	3.0%	3.2%
	22 years or more	40	6.7%	7.2%
	Total	556	93.8%	100.0%
	Not stated	37	6.2%	-
	Total	**593**	**100.0%**	**-**
Electricity Revenue Data	1 year or less	16	6.3%	6.5%
	2–6 years	98	38.4%	39.8%
	7–11 years	60	23.5%	24.4%
	12–16 years	32	12.5%	13.0%
	17–21 years	14	5.5%	5.7%
	22 years or more	26	10.2%	10.6%
	Total	246	96.5%	100.0%
	Not stated	9	3.5%	-
	Total	**255**	**100.0%**	**-**

Table A-14: Electricity Revenue Data Status for Premises by Refit Status.

Electricity Revenue Data Status	Refit Status	Frequency	Percent
No Electricity Revenue Data	Refitted	352	59.4%
	No refit	219	36.9%
	Do not know	22	3.4%
	Total	**593**	**100.0%**
Electricity Revenue Data	Yes	183	71.8%
	No	62	24.3%
	Do not know	10	3.9%
	Total	**255**	**100.0%**

Table A-15: Electricity Revenue Data Status for Premises by Energy and Fuel Reported.

Electricity Revenue Data Status	Premise Energy and Fuel Profile	Frequency	Percent
No Electricity Revenue Data	Electricity from the grid only	486	82.0%
	Natural gas only	2	0.3%
	Electricity from the grid and natural gas	75	12.6%
	Electricity from the grid, natural gas and self-generated electricity	2	0.3%
	Electricity from the grid and self-generated electricity	4	0.7%
	Electricity and wood	1	0.2%
	Electricity from the grid, natural gas and wood	1	0.2%
	Electricity and fuel oil/diesel	12	2.0%
	Electricity, coal, wood, diesel or fuel oil	1	0.2%
	Electricity from the grid, diesel/fuel oil and self-generated electricity	3	0.5%
	Electricity, natural gas, diesel or fuel oil	2	0.3%
	Electricity from the grid and geothermal	1	0.2%
	Not stated	3	0.5%
	Total	**593**	**100.0%**
Electricity Revenue Data	Electricity from the grid only	220	86.3%
	Electricity from the grid and natural gas	23	9.0%
	Electricity from the grid, natural gas and self-generated electricity	1	0.4%
	Electricity from the grid and self-generated electricity	1	0.4%
	Electricity and wood	2	0.8%
	Electricity and coal	3	1.2%
	Electricity and fuel oil/diesel	5	2.0%
	Total	**255**	**100.0%**

Table A-16: Electricity Revenue Data Status for Premises by Electricity Payment Types.

Electricity Revenue Data Status	Payment Type	Frequency	Percent	Valid Percent
No Electricity Revenue Data	Paid direct to supplier	390	65.8%	65.8%
	Itemised and paid to landlord	90	15.2%	15.2%
	Electricity included in rent and not itemised	56	9.4%	9.4%
	Do not know	52	8.8%	8.8%
	Missing	5	0.8%	0.8%
	Total	**593**	**100.0%**	**100.0%**
Electricity Revenue Data	Paid direct to supplier	232	91.0%	91.0%
	Itemised and paid to landlord	13	5.1%	5.1%
	Electricity included in rent and not itemised	2	0.8%	0.8%
	Do not know	8	3.1%	3.1%
	Total	**255**	**100.0%**	**100.0%**

Table A-17: Electricity Revenue Data Status by DAC.

Electricity Revenue Data Status	Dominant Appliance Cluster (DAC)	Frequency	Percent	Valid Percent
No Electricity Revenue Data	Cooking & Refrigeration	69	11.6%	11.7%
	ICT	329	55.5%	55.8%
	Other	165	27.8%	28.0%
	Refrigeration	27	4.6%	4.6%
	Total	590	99.5%	100.0%
	Missing	3	0.5%	-
	Total	**593**	**100.0%**	**-**
Electricity Revenue Data	Cooking & Refrigeration	17	6.7%	6.7%
	ICT	185	72.5%	72.8%
	Other	46	18.0%	18.1%
	Refrigeration	6	2.4%	2.4%
	Total	254	99.6%	100.0%
	Missing	1	0.4%	-
	Total	**255**	**100.0%**	**-**

A.2. In-depth Interviews with Buildings Owners and Property Managers

The original research plan for BEES envisaged a set of qualitative interviews associated with a selected subset of buildings that were being targeted monitored. Difficulties in achieving a representative distribution of targeted monitored buildings made this impossible. However, the diversity of building management arrangements revealed in the premise survey in its early waves suggested that having a preliminary exploration at least of the way in which those that manage non-residential buildings perceive and act on their priorities would be desirable. Three sets of individuals concerned with non-residential building management were identified (Table A-18).

Table A-18: 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 given to resource (energy and water) optimisation in investment, acquisition and disposal choices. • Mechanism for ensuring resource optimisation in building design, build. • 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 to which green brand drives building selection and operation. • Criteria for building selection. • Extent of management to optimise resource use • Management tools and user education.

Four interviews were undertaken with managers in two of those sets – those concerned with the facilities management and those concerned with property portfolio management. A property manager involved in providing for the property needs of a business presenting itself as a green, socially responsible business also provided information about his experiences and priorities in the property market. These interviews, contextualised by relevant international literature, were reported in BEES Year 5 Study Report: Buildings – Size, Management and Use (Saville-Smith & Fraser, 2012).

A.3. Surveying Building Owners, Property Managers and Owner-Occupiers

Two surveys of property managers/building owners and owner-occupiers respectively were designed to consider the extent to which these stakeholders recognise or are committed to resource efficiency and the actions that they do or do not institute to optimise resource use in non-residential buildings.

One of the most difficult aspects of surveying non-residential building owners, property managers and owner-occupiers was establishing a population from which to sample. There was no single, accessible repository of these sets of stakeholders. Consequently, three population sets were established:

- First, a population of businesses that we knew were owner-occupiers in non-residential buildings from the results of the premise surveying of non-residential buildings in the BEES programme.
- Second, also from the surveying of premises in non-residential buildings undertaken as part of the BEES programme, a list was compiled of property managers and owners that premise respondents had identified.
- Third, property managers and owners listed as members of the New Zealand Property Council were collated, removing any duplicates arising from the sets above.

All interviewing was undertaken by telephone using structured interview schedules. The interview schedules for property managers and owners drawn from the BEES premise surveying as well as members of the Property Council were the same. The interviewing was undertaken by a dedicated telephone survey company using a CATI system. CRESA undertook interviews with owner-occupiers of non-residential buildings using the interview schedule.

Although there are some differences between the questionnaire for the owner-occupiers, the property managers and owners respectively, they all focused on the same issues. Those are:

- 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 water and energy use management
- actions taken to manage energy and water use.

A total of 109 non-residential building owners and property managers responded to the survey, and 51 of the 101 owner-occupiers of premises already participating in the BEES premise survey at the time were also interviewed. The data is analysed as a quota survey.

B. BEES Sample Frame Development

The following section sets out a summary of the development of the BEES sampling frame.

B.1. Sampling Frame

The sampling frame was constructed from the two valuation rolls covering all buildings in New Zealand; one provided by Auckland City Council covering central Auckland and one provided by Quotable Value (QV). Copies of the relevant records from these rolls were provided in 2008 and the sampling frame constructed from them early in 2009.

Records from the extracts were aggregated using information contained in them into combined records, each supposed to represent a single building, although it turned out later that, in some small proportion of cases, the combined records in fact represented more than one building or only a part of a building.

From these combined records, potential BEES buildings were screened using the building use codes contained in the rolls. Each roll contained an estimate of the total floor area in the building, and this, together with the use code, was used to divide the records into 5 strata by floor area as in Table B-1.

Table B-1: Floor Area Strata.

Size Group	1	2	3	4	5
Number of combined records	33,781	10,081	4,288	1,825	564
Minimum floor area (m^2)	0	650	1,500	3,500	9,000
Frame total (million m^2)	9.9	9.6	9.5	9.6	9.8

As will be seen from the final line in Table B-1, the five floor area strata gave roughly equal floor areas in each building size stratum. The sample was to be distributed equally among these five building size strata to enable efficient estimation of total energy consumption to be carried out. Over the large scale, energy usage was expected to be roughly proportional to floor area. Simply taking a random sample of records without increasing the sampling rate for larger properties would have led to a sample consisting almost entirely of small buildings with a handful of larger ones having undue impact on the final estimates, resulting in estimates of poor precision. As a further benefit of this strategy, a set of buildings with a wide range of sizes was made available for further study.

Within each of these building size strata, 10 substrata were defined. Distinction was made between Auckland Authority and the rest of New Zealand. The purpose of this distinction was to enable allowance, either by post-weighting or appropriate replacement policies or both, to be made for an alleged ‘survey fatigue’ effect in Auckland.

A second substratification was carried out by the use code from the valuation rolls into five categories Commercial Retail (CR), Commercial Office (CO), Commercial Multiple (CX), Industrial Service (IS) and Industrial Warehouse (IW). While warehousing was not a BEES use, instances had been noted where Industrial Warehouse buildings were in fact large buildings mainly used as retail premises. While it was not expected to find a high proportion of Industrial Warehouse buildings with BEES usage, following further investigation, these buildings were included to ensure good coverage of retail outlets. This was fortunate, as the WebSearch part of the survey found that about 40% of these buildings had only BEES usage, mostly of the Commercial Retail building type.

The combination of the five building size strata, the two geographic strata and the five building use strata gave rise to 50 strata in total. Within each building size stratum, the records were to be sampled from the substrata in proportion to the numbers of records in each.

A listing of the 50 strata with numbers of records and total floor area is given in Table B-2 and Table B-3.

Table B-2: Sampling Frame: Distribution of Parent Records by Building Stratum.

Building Use Strata	Region	Building Size Strata					Total
		S1	S2	S3	S4	S5	
Commercial Office (CO)	Auckland	905	402	256	170	58	1,791
	Rest of NZ	3,310	794	378	190	73	4,745
Commercial Office Total		**4,215**	**1,196**	**634**	**360**	**131**	**6,536**
Commercial Retail (CR)	Auckland	2,912	545	217	76	39	3,789
	Rest of NZ	13,433	2,524	738	247	74	17,016
Commercial Retail Total		**16,345**	**3,069**	**955**	**323**	**113**	**20,805**
Commercial Multiple (CX)	Auckland	1,398	505	267	126	31	2,327
	Rest of NZ	2,910	1,117	444	239	95	4,805
Commercial Multiple Total		**4,308**	**1,622**	**711**	**365**	**126**	**7,132**
Industrial Service (IS)	Auckland	520	484	262	104	18	1,388
	Rest of NZ	5,672	1,786	547	184	48	8,237
Industrial Service Total		**6,192**	**2,270**	**809**	**288**	**66**	**9,625**
Industrial Warehouse (IW)	Auckland	491	644	550	264	73	2,022
	Rest of NZ	2,230	1,280	629	225	55	4,419
Industrial Warehouse Total		**2,721**	**1,924**	**1,179**	**489**	**128**	**6,441**
Grand Total		*33,781*	*10,081*	*4,288*	*1,825*	*564*	*50,539*

Table B-3: Sampling Frame: Distribution of Floor Area (000 m^2) by Building Stratum.

Building Use Strata	Region	Building Size Strata					Total
		S1	S2	S3	S4	S5	
Commercial Office (CO)	Auckland	240	401	598	918	937	3,093
	Rest of NZ	909	754	844	1,005	1,041	4,552
Commercial Office Total		**1,149**	**1,154**	**1,442**	**1,922**	**1,978**	**7,646**
Commercial Retail (CR)	Auckland	777	516	488	398	792	2,971
	Rest of NZ	3,640	2,352	1,616	1,271	1,293	10,171
Commercial Retail Total		**4,417**	**2,869**	**2,103**	**1,669**	**2,085**	**13,143**
Commercial Multiple (CX)	Auckland	436	496	585	640	926	3,083
	Rest of NZ	899	1,065	980	1,293	1,585	5,822
Commercial Multiple Total		**1,335**	**1,561**	**1,565**	**1,932**	**2,511**	**8,905**
Industrial Service (IS)	Auckland	204	476	586	517	346	2,130
	Rest of NZ	1,850	1,690	1,175	981	696	6,392
Industrial Service Total		**2,054**	**2,166**	**1,761**	**1,498**	**1,042**	**8,522**
Industrial Warehouse (IW)	Auckland	211	653	1,276	1,419	1,300	4,859
	Rest of NZ	749	1,228	1,399	1,176	850	5,402
Industrial Warehouse Total		**960**	**1,881**	**2,676**	**2,595**	**2,150**	**10,261**
Grand Total		*9,916*	*9,630*	*9,547*	*9,616*	*9,767*	*48,476*

B.2. Sampling of the Frame

As stated above, equal sample sizes were to be devoted to the five building size strata, and within each building size stratum, the sample was to be distributed among the 10 substrata in proportion to the number of frame records in each.

The numbers of records to be taken was initially expected to be 1,000. However, there was a strong possibility that more or fewer would be used depending on resources and the way the precision of the estimates worked out. Accordingly, the frame was arranged in a special order. Within each stratum, the records were placed in random order, then records were extracted one by one in such a way that the correct distribution of records was continually maintained so that, until the records for one stratum ran out, any initial part of the frame gave a correctly distributed stratified random sample. Sampling was then to be carried out by working through the list from the beginning until the desired number of records had been sampled.

C. Total BEES Area and Energy Consumption Estimation

C.1. Data Collection

Three approaches to data collection were used: WebSearch, telephone survey and aggregate energy survey.

C.2. WebSearch Survey

3,042 records from the beginning of the sample frame were used in a survey referred to as the WebSearch survey. This sample in fact exhausted the records from building size stratum 5. Using various strategies, the status of the relevant buildings (BEES or non-BEES) was decided, and independent estimates of gross building floor area for the majority of buildings were calculated using Google Earth. In order to determine the BEES status of buildings, various strategies were used, including obtaining lists of occupants using business directories, site visits, visual observation of the relevant buildings using Google Earth and so on. In addition, much valuable technical information was obtained on the form of the building, its type of construction, orientation and so on. This survey is of particular value because it is not open to bias due to non-response to the same extent that other parts of the project were.

C.2.1. Telephone Survey

Attempts were made to contact each of the premises listed in the WebSearch to elicit further information on the types of activities taking place in the buildings and the types of energy-consuming activities taking place. Permission was also sought to access energy consumption records and possibly to carry out monitoring studies on the premises concerned.

C.2.2. Aggregate Energy Survey

For a subsample of 335 of those records shown in the WebSearch or telephone survey to have BEES uses, further investigations were been made by the BEES team to enable accurate estimation of the gross floor area, floor area devoted to BEES uses, common floor area (shared space in use by all occupants of the building such as stairwells, lift shafts, etc.) and estimates of annual power consumption (gas and electricity only) to be made, for the most part by obtaining records of power bills from participating buildings and premises. In many cases, the power bills covered only part of the building concerned, and in such cases, the floor area to which the bill related was ascertained, and, essentially by floor area scaling but with some modifications, an estimate of the annual power consumption for the whole building was obtained. It should be noted that imprecision due to this estimation procedure may be expected to average out to some extent and to be incorporated in the imprecision estimated for the overall survey results (via the increased variability of the estimates from building to building). However, bias in the estimation procedure will affect the survey results without being allowed for in the overall estimates of imprecision. It was not possible to obtain estimates of energy consumption for all the records for which area estimates were made. For 258 of these records, electricity consumption could be estimated, and for 197 of these, gas consumption could also be estimated (sometimes because it was zero).

C.3. Procedures Used for Overall Estimates of Area and Energy Use

With only around 200 records available for the estimation of energy consumption, some of the original substrata within each building size stratum had to be combined in order to give a reasonable number of observations in each stratum. It was assumed for the purposes of analysis that, within each of the 21 combined strata, the set of records for which the relevant estimates were available could be treated as a random sample of the BEES records in the frame. While this is a fairly big assumption, it is hard to see any way around it. This part of the survey had a fairly low response rate, partly due to the difficulty in contacting people in a position to give authority for the further investigations required and getting them to agree to them. Possible types of bias in respect of the types of buildings eventually used may be looked for, and no doubt some would be found. Whether they in fact lead to biased energy estimates would remain uncertain, and attempts to correct for them would be based on sparse information and may do more harm than good. It is hoped that the stratification used deals with much of the evenness of response.

C.3.1. Basic Estimation Technique

The basic estimation technique was used to estimate the numbers and gross areas of BEES records in the sampling frame from the WebSearch survey and to extrapolate by stratum the averages, by records or by area, from the aggregate energy survey to the sampling frame via these WebSearch estimates.

While the extrapolation by area was expected to yield the better (more precise) results, there was a complicating factor in that, in the two largest building size strata, the WebSearch estimate of gross floor area tended be lower on average, for corresponding records, than the presumably more accurately measured estimates obtained in the aggregate energy survey, leading to underestimation (by an estimated 4% in total) of the area to which the extrapolation was to be applied. The underestimation was particularly large in the largest stratum, where it appeared to be around 17%. There was no evidence of bias in the three smallest strata in extrapolating by area, and it seems necessary to adjust for this bias in the WebSearch estimates of area. The imprecision attached to this empirically estimated bias adjustment resulted in a significant increase in the imprecision of estimates calculated by area extrapolation, and in the end, the two techniques gave rise to estimates of very similar imprecision.

The choice between the two extrapolation techniques was essentially made by comparing the precision of the estimates obtained. To estimate the BEES area in the sample frame, the average BEES area from the aggregate energy survey was applied to the estimate of the number of BEES records in the frame from the WebSearch survey in each of the 21 combined strata. To estimate total BEES energy consumption for the frame, the ratio of energy use to gross floor area was extrapolated, again for each stratum, using the WebSearch estimates of gross floor area adjusted as outlined in the previous paragraph. This gave a significantly more precise estimate of total energy consumption, though the individual components gas and electricity were estimated slightly better using extrapolation as for area. It was considered desirable to present a consistent set of estimates, so area extrapolation was used for all three components.

It should be noted that the electricity consumption (estimated from 258 records) was added to the gas consumption (estimated from 197 records) to give the total, rather than estimating the total from the 197 records for which both electricity and gas were available. Partly, this was done for consistency – either we would have had to ignore 61 electricity records or present inconsistent totals – but an equally important reason was to avoid possible bias in the electricity results. It was easier to obtain gas estimates for buildings that are known to use no gas.

C.3.2. Estimates of Precision

This is a rather technical matter and will be only briefly described. The basic assumption used was that the WebSearch estimates are statistically independent of the results for the aggregate energy survey. This is reasonable because the WebSearch survey covers a much larger group of records. Within strata, the standard errors of products, ratios etc. were calculated using the various appropriate mathematical formulae rather than by applying subsampling techniques (which would have been extremely demanding). These were sometimes rather questionable because of small sample sizes. To apply the area adjustment, the estimates and relevant variances were accumulated into building size strata and the bias adjustments to gross area applied to the two largest building size strata, the imprecision of estimation of the bias adjustment being incorporated into the relevant estimates of sampling variance.

In calculating the standard error of the total of energy and gas consumption, an estimate of the correlation between the energy and gas consumption estimates obtained using only the smaller group 197 records in both quantities was used.

To estimate the standard error of the consumption per square metre estimates, allowance was made for a correlation of about 0.4 (0.2 for gas) between the estimates of consumption and the estimate of area, this being the average within-stratum correlation observed between these two variables.

The adjustments made as described in the last two paragraphs must be considered approximate, as exact mathematical formulae from which the adjustments could be made seemed very difficult to derive.

D. Extrapolation from Premise to Building

This appendix focuses on how energy revenue data was applied to determine whole-building estimates of energy use. These measures have been expressed as measures such as energy use intensity (EnPI, $kWh/m^2.yr$).

There were several subtleties involved with translating the energy records of BEES premises to whole-building estimates, as some parts of the buildings were not participating or BEES ineligible but still use resources. One of the most important aspects is that, in many larger buildings, some energy services are supplied to spaces directly without metering the energy used by individual premises, such as for centralised heating, ventilation and air-conditioning (HVAC) and hot water.

D.1. Assumptions

Relatively few large buildings have adequate data to completely characterise the energy-use patterns of the entire building, so a series of assumptions have been used to estimate whole-building energy use from the information that BEES did have.

The total energy used by the building was therefore taken to be the sum of the energy use in these areas: the centrally provided services and assumed energy use of unoccupied, non-participating and ineligible spaces within the building.

The basic method is to assume that the participating premises are representative of all occupied, non-participating premises in the building, excluding any ineligible areas.

Unoccupied areas are typically assumed to use no energy (outside of that provided by central services). This is not necessarily true, as lights, etc. may be left on even when a part of a building is vacant. However, in the absence of better information, this operation is assumed.

Some areas have been specifically excluded from BEES. This particularly applies to residential premises and car parks. Both have different patterns and energy use compared to BEES eligible premises. Rather than defining some buildings as being smaller than they actually were (to exclude the floor area attributed to ineligible activities), simple approximate values for energy use intensities have been assigned to these spaces. The suggested values are:

- 200 $kWh/m^2.yr$ for regularly occupied spaces, such as residential premises
- 100 $kWh/m^2.yr$ for not regularly occupied spaces, such as car parks.

Central services energy use for unoccupied areas is the same as for occupied areas and ineligible areas within a building. This is an approximation, as the actual use can easily be more, or less. For example, the amount of energy expended in delivering centralised HVAC services depends on the nature of the HVAC system, its control, the demand for conditioning and the time of year. So, if a part of a building is left unoccupied in winter and HVAC is not switched off, then this area will require more heat than other areas, as it has no lighting, equipment and people heat gains to reduce its heating needs. Conversely, the unoccupied part of a building in summer would require less cooling for the same reason.

Therefore, central services energy use for ineligible areas was the same as for occupied areas. In other words, the central services energy was distributed evenly across all building spaces.

D.2. Nomenclature

Floor Areas

A_{AA}, A_{AB}, A_{AC}	Measured floor area of individual participating premises
A_{ZA}	Measured floor area of non-participating BEES areas within the building
A_{ZC}	Measured common floor area of the building
A_{ZL}	Measured net lettable building floor area
A_{ZN}	Measured net building floor area
A_{ZP}	Sum of measured participating premise floor areas
A_{ZZ}	Measured floor area of ineligible floor areas within the building

Energy

E_{AA}, E_{AB}, E_{AC}	Revenue energy use of individual participating premises
E_{ZA}	Revenue energy use of all non-participating premises within the building
E_{ZC}	Revenue energy use in common areas of the building (including central services)
E_{ZP}	Sum of energy use for participating premises
E_{ZN}	Building energy use, based on A_{ZN}
E_{ZZ}	Revenue energy use for the ineligible spaces within the building

Energy Performance Indicators

$EnPI_{AA}$, $EnPI_{AB}$, $EnPI_{AC}$	Energy performance indicator for the participating premises within the building
$EnPI_{ZA}$	Energy performance indicator for the non-participating premises within the building
$EnPI_{ZC}$	Energy performance indicator for the common areas of the building (including central services)
$EnPI_{ZN}$	Building energy performance indicator, based on A_{ZN}
$EnPI_{ZP}$	Average energy performance indicator over the participating premises within the building
$EnPI_{ZZ}$	Energy performance indicator for the ineligible areas within the building

D.3. Method

In terms of extrapolating the energy use to a whole building from the participating premise and central service energy revenue data, there appeared to be 8 possible combinations of building types and energy revenue data.

Table D-1: Building Type and Energy Revenue Data Combinations.

No Common Areas	Common Area Energy Use Not Known	Common Area Energy Use Known	Description
SP0 (*n* = 45)	-	-	Single premise (one premise in one building), participating
MP0 (*n* = 18)	**MPN** (*n* = 4)	**MPY** (*n* = 0)	Multiple premises, all participating
MX0 (*n* = 73)	**MXN** (*n* = 133)	**MXY** (*n* = 5)	Multiple premises, some participating
-	-	**nY** (*n* = 8)	No premises participating within the building

This shows that the majority of buildings either had no common area or had a common area but the energy revenue data was not available. This was mainly due to participants being surveyed at a premise level, while the common area energy revenue data needed to be sourced through a building manager.

The BRANZ Study Report on Whole Building Energy Use (Bishop, et al., 2012) was used for those buildings with no common area. However, for those with common area energy use not known, further work was needed to determine the most accurate method of extrapolating for this. Common area energy revenue data from the 13 buildings has been used to determine a default factor that can be applied to the remaining cases with no data available.

The Property Council of New Zealand (PCNZ) Operating Expenses 2008 (Property Council New Zealand, 2008) provides information on a number of building types in $\$/m^2$.yr. This, together with the Ministry of Economic Development (MED) 2007 electricity prices (Ministry of Business, Innovation and Employment, 2013), gives an effective EnPI for the PCNZ common areas, which was compared to the BEES data.

Table D-2: PCNZ Common Area Energy Use for 2008.

Region	Type	PCNZ E_{ZC} by A_{ZL} kWh/m^2.yr	Average BEES E_{ZC} by A_{ZL} kWh/m^2.yr	Average BEES E_{ZC} by A_{ZC} kWh/m^2.yr
Auckland CBD Office	Overall	76	50	515
	<10,000 m^2	75	44	378
	>10,000 m^2	77	62	515
Auckland Non-CBD Office	Overall	67	103	404
	<3,000 m^2	53	-	-
	>3,000 m^2	70	103	404
Wellington CBD Office	Overall	57	61	136
	<10,000 m^2	56	71	543
	>10,000 m^2	57	18	83
Christchurch CBD Office	Overall	32	-	-
Hamilton CBD Office	Overall	54	-	-
Shopping Centre	Neighbourhood & Town Centre	33	45	106
	City Centre	69	73	378
	District & Regional Centre	72	-	-
Average		61^	68	450

^An unweighted average of the above figures, individual figures were not available.

The PCNZ data is based on common area energy data per square metre of net lettable floor area, A_{ZL}. Noting that the method of calculating A_{ZL} may differ between PCNZ and BEES, the PCNZ measurements were based on the BOMA Standard (1995), while BEES uses the following equation to arrive at A_{ZL}:

$$A_{ZL} = A_{ZN} - A_{ZC}$$

When considering this, the BEES data demonstrates similarities with the PCNZ figures, giving an average value of 67.5 kWh/m^2.yr in the 13 buildings participating in BEES with common area revenue data.

The common area energy use, E_{ZC}, was used with the common floor area, A_{ZC}, to calculate the total energy use, as it relates directly to the relevant floor area for aggregation purposes. The equation used for those buildings with a common floor area and no common area energy revenue data available is therefore:

$$E_{ZC} = A_{ZC} \times 450.12 \text{ kWh/m}^2.\text{yr}$$

Below is an indication of the scaling of common floor areas to net building floor area, by size of building.

Table D-3: Proportion of Common Floor Area, A_{ZC}, to Net Building Floor Area, A_{ZN}.

Building Size Strata	Proportion A_{ZC}/A_{ZN}
<650 m^2	0.3%
650–1,499 m^2	1.6%
1,500–3,499 m^2	3.8%
3,500–8,999 m^2	6.9%
>9,000 m^2	10.4%
Average	5.3%

The following examples illustrate the use of the discussed methodology in calculating whole-building energy use and EnPI's for increasingly complex situations.

D.4. Single Premise Building with No Common Area (SP0)

This is a building with only one premise, which is participating in BEES, and no common area. The energy revenue data is available for the participating premise, as is the measured floor area.

Figure D-1: Single Premise Building with No Common Area.

EXAMPLE: Participating premise of 1,500 m^2 using 273,000 kWh/yr and no common area. This is the simplest case.

$$\mathrm{EnPI}_{ZN} = \mathrm{E}_{NZ}/\mathrm{A}_{ZN}$$
$$= 273{,}000/1{,}500$$
$$= \mathbf{182\ kWh/m^2\ per\ year}$$

$$\mathrm{EnPI}_{AA} = \mathrm{E}_{AA}/\mathrm{A}_{AA}$$
$$= 273{,}000/1{,}500$$
$$= \mathbf{182\ kWh/m^2\ per\ year}$$

The energy use for the building is the same as for the premise, **273,000 kWh/yr**. The annual EnPI for the premise and the building is **182 kWh/m^2.yr**.

Table D-4: Single Premise Building with No Common Area.

Premise	Floor Area, A m^2	Energy Use, E kWh/yr		EnPI kWh/m^2.yr
Participating (AA)	1,500	273,000	=	182
Whole Building (ZN)	1,500	273,000	=	182

D.5. Multiple Premise Building with All Premises Participating and No Common Area (MP0)

This is a building with multiple premises, all of which are participating in BEES, and has no common area present. The energy revenue data is available for all participating premises and the measured floor areas for each premise are also available.

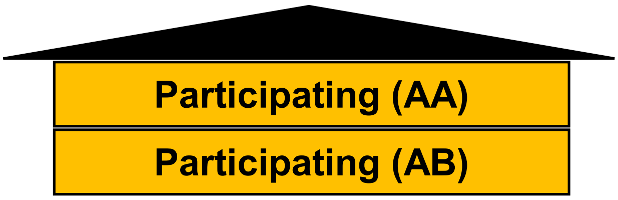

Figure D-2: Multiple Participating Premise Building with No Common Area.

EXAMPLE: There are two premises, both participating, one with 1,500 m^2 floor area and 273,000 kWh/yr premise energy use and the other with 1,800 m^2 floor area and 201,600 kWh/yr premise energy use.

In this case, where the records of all the energy use in the building are available, the energy used can be simply totalled and the EnPI calculated directly.

$$\mathrm{EnPI}_{AA} = \mathbf{182\ kWh/m^2.yr}$$

$$\mathrm{EnPI}_{AB} = \mathrm{E}_{AB}/\mathrm{A}_{AB}$$
$$= 201{,}600/1{,}800$$

$$= \mathbf{112\ kWh/m^2.yr}$$

$$\mathrm{EnPI_{ZN}} = \mathrm{E_{ZP}}/\mathrm{A_{ZP}}$$

$$= \sum_{i=AA,AB,\ldots} E_i \Big/ \sum_{i=AA,AB,\ldots} A_i$$

$$= (273{,}000 + 201{,}600)/(1{,}500 + 1{,}800)$$

$$= 474{,}600/3{,}300$$

$$= \mathbf{144\ kWh/m^2.yr}$$

This indicates that the EnPI for the second participating premise is **112 kWh/m².yr**, the EnPI for the whole building is **144 kWh/m².yr** and the total energy use for the building is **474,600 kWh/yr.**

Table D-5: Multiple Participating Premise Building with Common Area Energy Usage Known.

Premise	Floor Area, A m²	Energy Use, E kWh/yr		EnPI kWh/m².yr
Participating (AA)	1,500	273,000	=	182
Participating (AB)	1,800	201,600	=	112
Whole Building (ZN)	3,300	474,600	=	144

D.6. Multiple Premise Building with All Premises Participating and Common Area Energy Usage Known (MPY)

This is a building with multiple premises, all of which are participating in BEES. The building has common area present. The energy revenue data is available for all participating premises and the common areas, as well as the measured floor areas for each premise.

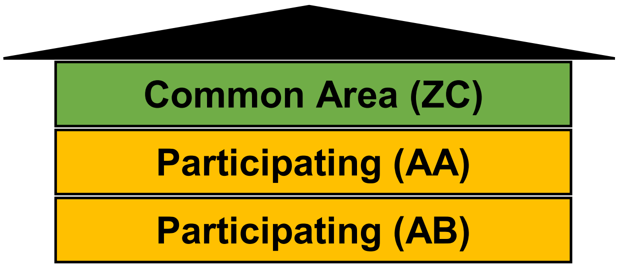

Figure D-3: Multiple Participating Premise Building with Common Area Energy Usage Known.

EXAMPLE: There are two premises, both participating: one with 1,500 m² floor area and 273,000 kWh/yr premise energy use and the other with 1,800 m² floor area and 201,600 kWh/yr premise energy use. The common floor area and energy use are also known, 30 m² and 18,000 kWh/yr.

In this case, as per Appendix D.5, where the records of all the energy use in the building are available, the energy used can be simply totalled and the EnPI calculated directly. The overall EnPI and annual energy use is calculated as follows:

$$\mathrm{EnPI_{AA}} = \mathbf{182\ kWh/m^2.yr}$$

$$\mathrm{EnPI_{AB}} = \mathbf{112\ kWh/m^2.yr}$$

$$\mathrm{EnPI_{ZC}} = \mathrm{E_{ZC}}/\mathrm{A_{ZC}}$$

$$= 18{,}000/30$$

$$= \mathbf{600\ kWh/m^2.yr}$$

$$EnPI_{ZN} = (E_{ZP} + E_{ZC})/(A_{ZP} + A_{ZC})$$

$$= (273{,}000 + 201{,}600 + 18{,}000)/(1{,}500 + 1{,}800 + 30)$$

$$= 492{,}600/3{,}330$$

$$= \mathbf{148\ kWh/m^2.yr}$$

This indicates that the EnPI for the whole building, including common areas, is **148 kWh/m².yr** and the total energy use for the building is **492,600 kWh/yr.**

Table D-6: Multiple Premise Building with Common Area Energy Usage Known.

Premise	**Floor Area, A** m²	**Energy Use, E** kWh/yr		**EnPI** kWh/m².yr
Participating (AA)	1,500	273,000	=	182
Participating (AB)	1,800	201,600	=	112
Common Area (ZC)	30	18,000	=	600
Whole Building (ZN)	3,330	492,600	=	148

D.7. Multiple Premise Building with All Premises Participating and Common Area Energy Usage Unknown (MPN)

This is a building with multiple premises, all of which are participating in BEES. The building has common area present. The energy revenue data is available for all participating premises as well as the measured floor areas for each premise. The energy revenue data is not available for the common areas and will be estimated.

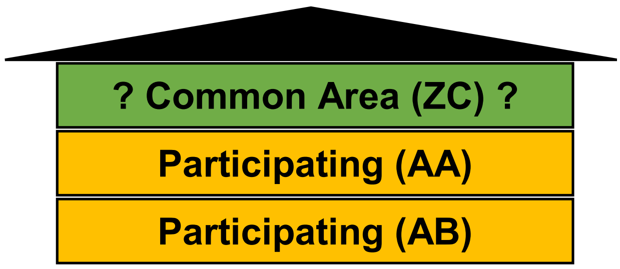

Figure D-4: Multiple Participating Premise Building with Common Area Energy Use Unknown.

EXAMPLE: As per in Appendix D.6, the participating premise areas are 1,500 m² and 1,800 m², with common floor area of 30 m². However, in this case, the energy use attributed to common areas is unknown.

$$EnPI_{AA} = \mathbf{182\ kWh/m^2.yr}$$

$$EnPI_{AB} = \mathbf{112\ kWh/m^2.yr}$$

$$E_{ZC} = EnPI_{ZC} \times A_{ZC}$$

$$= 450.12 \times 30$$

$$= \mathbf{13{,}504\ kWh/yr}$$

$$EnPI_{ZN} = (E_{ZP} + E_{ZC})/(A_{ZP} + A_{ZC})$$

$$= (273{,}000 + 201{,}600 + 13{,}504)/(1{,}500 + 1{,}800 + 30)$$

$$= 488{,}104/3{,}330$$

$$= \mathbf{147\ kWh/m^2.yr}$$

Using the EnPI for the common areas of **450 kWh/m².yr** gives an annual energy usage of **13,504 kWh/yr**. The EnPI for the whole building is estimated to be **147 kWh/m².yr** and the total energy use for the building is **488,104 kWh/yr.**

Table D-7: Multiple Premise Building with Common Area Energy Usage Unknown.

Premise	Floor Area, A m²	Energy Use, E kWh/yr		EnPI kWh/m².yr
Participating (AA)	1,500	273,000	=	182
Participating (AB)	1,800	201,600	=	112
Common Area (ZC)	30	**13,504***	=	**450****
Whole Building (ZN)	3,330	**488,104***	=	**147***

**Estimated. **Common area assumption based on 450.12 kWh/m².yr.*

D.8. Multiple Premise Building with Mixture of Premises and No Common Area (MX0)

This is a building with multiple premises, some of which are BEES eligible, both participating and non-participating, and ineligible. The building has no common area present. The energy revenue data is available for the participating premises only, as well as the measured floor areas for each premise within the building.

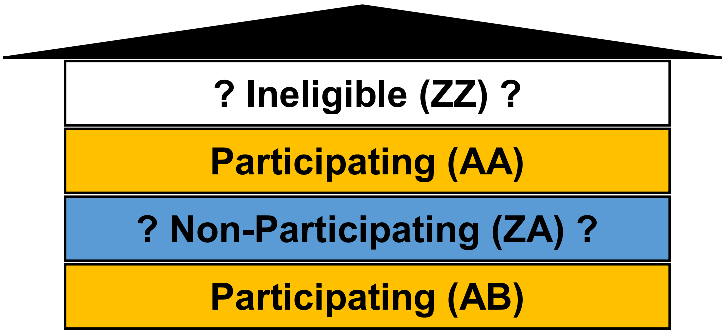

Figure D-5: Multiple Premise Building with Mixture of Premises and No Common Area.

EXAMPLE: As previously, the participating premise areas are 1,500 m² and 1,800 m², while the non-participating premise is 1,400 m² and the ineligible premise is 1,475 m². In this case, the ineligible space is a car park, so the assumed energy usage of 100 kWh/m².yr has been applied. However, if this ineligible premise was in fact a residential or similarly occupied premise, then 200 kWh/m².yr would be the assumed energy use intensity.

$$\mathrm{EnPI_{AA}} = \mathbf{182\ kWh/m^2.yr}$$

$$\mathrm{EnPI_{AB}} = \mathbf{112\ kWh/m^2.yr}$$

$$\mathrm{EnPI_{ZA}} = \mathrm{EnPI_{ZP}} = \mathbf{144\ kWh/m^2.yr}$$

$$\mathrm{EnPI_{ZZ}} = \mathbf{100\ kWh/m^2.yr}$$

$$\mathrm{EnPI_{ZN}} = \big((\mathrm{E_{ZP}}/\mathrm{A_{ZP}}) \times (\mathrm{A_{ZP}} + \mathrm{A_{ZA}}) + (100 \times \mathrm{A_{ZZ}})\big)/\mathrm{A_{ZN}}$$

$$= \Big(\big((273{,}000 + 201{,}600)/(1{,}500 + 1{,}800)\big) \times (1{,}500 + 1{,}800 + 1{,}400) + (100 \times 1{,}475)\Big) /6{,}175$$

$$= \big((474{,}600/3{,}300) \times 4{,}700 + 147{,}500\big)/6{,}175$$

$= 823{,}407/6{,}175$

$= \mathbf{133\ kWh/m^2.yr}$

The EnPI for the participating premises has been extrapolated to the non-participating premise, assuming that it has a similar use. The whole building is estimated to have an EnPI of **133 kWh/m².yr**, and the total energy use for the building is **823,407 kWh/yr.**

Table D-8: Multiple Premise Building with Mixture of Premises and No Common Area.

Premise	**Floor Area, A** m²	**Energy Use, E** kWh/yr		**EnPI** kWh/m².yr
Participating (AA)	1,500	273,000	=	182
Participating (AB)	1,800	201,600	=	112
Non-Participating (ZA)	1,400	**201,307***	=	**144***
Ineligible (ZZ)	1,475	**147,500***	=	**100*****
Whole Building	6,175	**823,407***	=	**133***

**Estimated. ***Ineligible premise assumption based on 100 kWh/m².yr for car park or 200 kWh/m².yr for residential premises.*

D.9. Multiple Premise Building with Mixture of Premises and Common Area Energy Usage Known (MXY)

This is a building with multiple premises, some of which are BEES eligible, both participating and non-participating, and ineligible. The building has common area present. The energy revenue data is available for the participating premises and the common area, as well as the measured floor areas for each premise within the building.

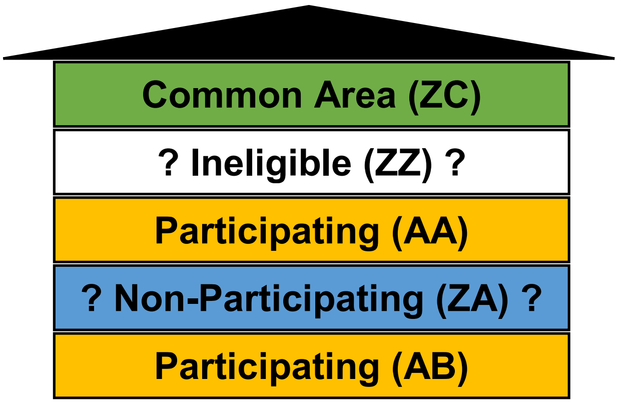

Figure D-6: Multiple Premise Building with Mixture of Premises and Common Area Energy Usage Known.

EXAMPLE: In this case there are five space types. As previously, the participating premise areas are 1,500 m² and 1,800 m², while the non-participating premise is 3,000 m² and the ineligible premise is 1,000 m². Common areas are again 30 m². In this case, the ineligible space is a residential premise, so the assumed energy usage of 200 kWh/m².yr has been applied. However, if this ineligible premise was in fact a car park or similarly occupied space, then 100 kWh/m².yr would be the assumed energy usage.

The annual EnPI of the two participating premises are averaged and applied to the non-participating premise.

$\mathrm{EnPI_{AA}} = \mathbf{182\ kWh/m^2.yr}$

$\mathrm{EnPI_{AB}} = \mathbf{112\ kWh/m^2.yr}$

$\mathrm{EnPI_{ZA}} = \mathrm{EnPI_{ZP}} = \mathbf{144\ kWh/m^2.yr}$

$$\text{EnPI}_{ZZ} = \mathbf{200\ kWh/m^2.yr} \text{ ***}$$

$$\text{EnPI}_{ZC} = \text{E}_{ZC}/\text{A}_{ZC}$$

$$= 18{,}000/30$$

$$= \mathbf{600\ kWh/m^2.yr}$$

$$\text{EnPI}_{ZN} = \big((\text{E}_{ZP}/\text{A}_{ZP}) \times (\text{A}_{ZP} + \text{A}_{ZA}) + (100 \times \text{A}_{ZZ}) + \text{E}_{ZC}\big)/\text{A}_{ZN}$$

$$= \Big(\big((273{,}000 + 201{,}600)/(1{,}500 + 1{,}800)\big) \times (1{,}500 + 1{,}800 + 3{,}000) + (200 \times 1{,}000) + 18{,}000\Big)/7{,}330$$

$$= \big((474{,}600/3{,}300) \times 6{,}300 + 218{,}000\big)/7{,}330$$

$$= 1{,}124{,}003/7{,}330$$

$$= \mathbf{153\ kWh/m^2.yr}$$

The EnPI for the participating premises has been extrapolated to the non-participating premise, assuming that it has a similar use. The whole building is estimated to have an EnPI of **153 kWh/m^2.yr**, and the total energy use for the building is **1,124,003 kWh/yr.**

Table D-9: Multiple Premise Building with Mixture of Premises and Common Area Energy Usage Known.

Premise	Floor Area, A m^2	Energy Use, E kWh/yr		EnPI kWh/m^2.yr
Participating (AA)	1,500	273,000	=	182
Participating (AB)	1,800	201,600	=	112
Non-Participating (ZA)	3,000	**431,403***	=	**144***
Ineligible (ZZ)	1,000	**200,000***	=	**200*****
Common Area (ZC)	30	18,000	=	600
Whole Building (ZN)	7,330	**1,124,003***	=	**153***

**Estimated. ***Ineligible premise assumption based on 100 kWh/m^2.yr for car park or 200 kWh/m^2.yr for residential premises.*

D.10. Multiple Premise Building with Mixture of Premises and Common Area Energy Usage Unknown (MXN)

This is a building with multiple premises, some of which are BEES eligible, both participating and non-participating, and ineligible. The building has common area present. The energy revenue data is available for the participating premises and the measured floor areas for each premise within the building. The common area energy revenue date is unknown and will need to be estimated.

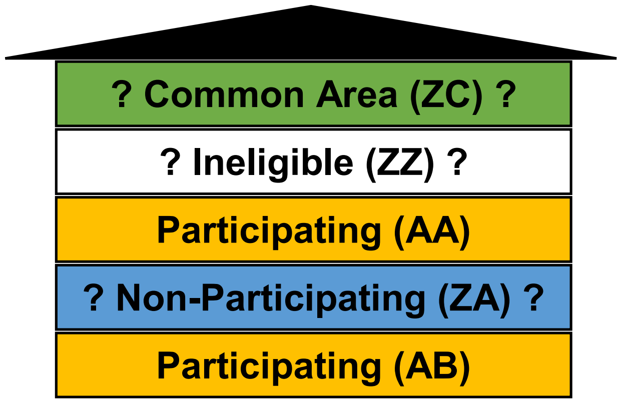

Figure D-7: Multiple Premise Building with Mixture of Premises and Common Area Energy Usage Unknown.

EXAMPLE: In this case there are five premises. As previously, the participating premise areas are 1,500 m^2 and 1,800 m^2, while the non-participating premise is 3,000 m^2 and the ineligible premise is 1,000 m^2. The common areas are 30 m^2. In this case, the ineligible space is a residential unit, so the assumed energy usage of 200 kWh/m^2.yr has been applied. However, if this ineligible premise was in fact a car park or similarly occupied space, then 100 kWh/m^2.yr would be the assumed energy usage.

The annual EnPI of the two participating premises are averaged and applied to the non-participating premise.

$$\mathrm{EnPI_{AA}} = \mathbf{182\ kWh/m^2.yr}$$

$$\mathrm{EnPI_{AB}} = \mathbf{112\ kWh/m^2.yr}$$

$$\mathrm{EnPI_{ZA}} = \mathrm{EnPI_{ZP}} = \mathbf{144\ kWh/m^2.yr}$$

$$\mathrm{EnPI_{ZZ}} = \mathbf{200\ kWh/m^2.yr}$$

$$\mathrm{E_{ZC}} = \mathrm{EnPI_{ZC}} \times \mathrm{A_{ZC}}$$

$$= 450.12 \times 30$$

$$= \mathbf{13,504\ kWh/yr}$$

$$\mathrm{EnPI_{ZN}} = \left((\mathrm{E_{ZP}}/\mathrm{A_{ZP}}) \times (\mathrm{A_{ZP}} + \mathrm{A_{ZA}}) + (100 \times \mathrm{A_{ZZ}}) + \mathrm{E_{ZC}}\right)/\mathrm{A_{ZN}}$$

$$= \left(\left((273{,}000 + 201{,}600)/(1{,}500 + 1{,}800)\right) \times (1{,}500 + 1{,}800 + 3{,}000) + (200 \times 1{,}000) + 13{,}504\right)/7{,}330$$

$$= \left((474{,}600/3{,}300) \times 6{,}300 + 213{,}504\right)/7{,}330$$

$$= 1{,}119{,}507/7{,}330$$

$$= \mathbf{153\ kWh/m^2.yr}$$

The EnPI for the participating premises has been extrapolated to the non-participating premise, assuming that it has a similar use. The whole building is estimated to have an EnPI of **153 kWh/m².yr**, and the total energy use for the building is **1,119,507 kWh/yr.**

Table D-10: Multiple Premise Building with Mixture of Premises and Common Area Energy Usage Unknown.

Premise	Floor Area m²	Energy Use kWh/yr		EnPI kWh/m².yr
Participating (AA)	1,500	273,000	=	182
Participating (AB)	1,800	201,600	=	112
Non-Participating (ZA)	3,000	**431,403***	=	**144***
Ineligible (ZZ)	1,000	**200,000***	=	**200*****
Common Area (ZC)	30	**13,504****	=	**450****
Whole Building (ZN)	7,330	**1,119,507***	=	**153***

**Estimated. **Common area assumption based on 450.12 kWh/m².yr. ***Ineligible premise assumption based on 100 kWh/m².yr for car park or 200 kWh/m².yr for residential premises.*

D.11. Issues with Revenue Data

Ideally, the daily purchase records for the premises should be analysed, and the 365 days of records would be summed to give the annual purchases. However, due to the vagaries of revenue metering, recording and energy supplier co-operation, daily records are not generally available. Most premises evaluated in BEES investigations had some historical monthly electricity and gas purchase data available, usually for at least 1 year. Where possible at least 2 years' worth of purchase data was requested. However, some premises had less than 1 year of data available while other premises have many years. In some cases, there have been changes of use or not all of the building or space has been occupied for the entire period for which purchase data is available.

Of the premises with multiple years of energy purchase data, the most recent year's data was taken as representative of the premise. Due to frequent changes in occupants, it is not appropriate to take more than the previous year's data unless there are valid reasons for doing so.

If there was less than 1 year worth of energy revenue data for a building, but more than 330 days, then its average daily use (kWh/day) was calculated but highlighted as a special case to be used with caution. The average daily use was then multiplied by 365 days to get an estimate of the annual consumption.

If the energy revenue data contained less than 330 days, the extrapolation may be inaccurate, and that case was excluded from further analysis.

E. Targeted Monitoring

This section documents a summary of the targeted monitoring data collection process and provides the steps taken for the final analysis from the 101 monitored premises in BEES.

The targeted monitoring was the most intensive data collection used in BEES. Both energy and environmental monitoring was undertaken for 2–4 weeks along with occupant questionnaires and numerous audits including appliance, lighting, building, hot water, HVAC systems and other energy sources. The main reason for conducting the targeted monitoring was to collect information on energy end-uses and environmental data within the monitored premises that could only be obtained by visiting the selected premises and installing monitoring equipment. Premises from all five floor area strata were selected, and each strata had its own monitoring strategy. This strategy and the costs associated for the amount of equipment required to complete this data collection process can be found in the BEES Year 1 & 2 report, page 34 (Isaacs, et al., 2009).

The main survey instruments in the targeted monitoring process were:

- monitored electricity and environment data
- appliance audit
- lighting audit
- building audit
- hot water audit
- HVAC audit
- occupant questionnaire.

A total of 101 premises were monitored throughout New Zealand. Over 4,000 electrical circuits were monitored on over 150 distribution boards. Temperature, humidity and illuminance were monitored in over 300 locations, CO_2 levels in 89 locations, and 33 locations had yearly temperature and humidity loggers. Over 220 plug-in appliances 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 was a major challenge to deal with.

In carrying out the targeted monitoring, the following was observed:

- Surveying and monitoring non-residential buildings was difficult, time consuming and expensive.
- The data was not just there for the taking – it required investigation to correctly monitor and collect it.
- There was no such thing as a ‘typical’ non-residential building, but there were many subtypes.
- There was great diversity in premises operation and equipment.

Many non-residential buildings were poorly understood by the occupants, managers, owners and tradespeople. This was illustrated by their lack of knowledge in regards to the building equipment and systems.

E.1. Monitoring Equipment

A range of monitoring equipment was used to collect data on the different aspects of supply and end-uses. Once the ordered equipment and any spare parts arrived at BRANZ, they were checked, assigned inventory ID numbers and finally entered into an inventory list.

All equipment that was used in the BEES research was tested for conformance and performance according to their specifications and requirements of the study. All computers were configured according to the requirements. Software packages for equipment configuration, data upload and primary data processing were installed and made operational. Instruction and process manuals were prepared and documented for the majority of the equipment.

The monitoring equipment used in the BEES study is illustrated below:

Figure E-1: Energy Logger Pro H22-01 and Interface Modules.

Figure E-2: Bluetooth Module.

Figure E-3: GPRS Module.

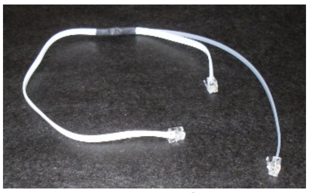

Figure E-4: Specially Designed 6/6 RJ11 Plug Cables.

Figure E-5: Multivoies Logger.

Figure E-6: Multivoies Rogowsky Clamp Current Coils.

Figure E-7: Multivoies Logger with 25 mm and 130 mm Rogowsky Coils.

Figure E-8: Hobo Environmental Logger.

Figure E-9: Telaire 7001 CO_2 Sensor.

Figure E-10: Enerplug Appliance Logger.

Figure E-11: Brinno Garden Watch Camera with LED.

Figure E-12: Onset Micro-Logger Stations.

Robust Pelican 1560 protective cases were purchased and fitted out with the monitoring and installation equipment. An example is illustrated in Figure E-13.

Figure E-13: BEES Monitoring Kit.

E.2. Calibration

Calibration processes were developed for all the measurement equipment used in the targeted monitoring. All temperature and humidity loggers were calibrated to a reference traceable to the National Standards Laboratory at IRL. Illuminance loggers were calibrated relative to each other to give consistent readings. Electrical power (Multivoies) monitoring equipment was checked against a unit calibrated by the National Standards Laboratory, and all units performed within the manufacturer's specifications. CO_2 loggers were sent to an independent laboratory for calibration.

E.3. Monitoring Electricity

To monitor the electricity usage in the premise, Multivoies[1] were mainly used, and an Energy Logger Pro[2] was used if the premise was required to be monitored for longer than the 2-week period.

The targeted monitoring used the Multivoies system because:

- it was easy and installation processes were safer
- there were a large number of available channels
- its small size meant it was easier to fit in the distribution boards and less likely to cause electrical problems
- it had greater accuracy.

The Multivoies system was proven to be reliable and easy to use. Data collected was proved to be reliable with very low rates of data loss. Data loss was more likely to occur due to operator error than equipment failure, and the installation and downloading process was improved to minimise data loss.

GPRS cell-phone communications modules were introduced in Year 3 for remote data collection for the Multivoies. This sophisticated system sent all the collected data to an FTP server daily. The data could then be processed without having to perform time-consuming manual downloads on site. The GPRS system saved time and money and also improved data quality by enabling live status checking on the monitored premises and data security by downloading daily.

There were several benefits using this system:

- Ability to check the monitored data while it was still in progress.

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[1] www.omegawatt.fr
[2] www.onsetcomp.com/data-logger

- Ability to reconfigure loggers from anywhere in New Zealand if there were any problems with the data collected.
- Ability to reuse the monitoring equipment without having to send it back to BRANZ for data downloading.
- Ability to record at 1-minute intervals due to large onboard memory.
- Increased data collection reliability. The data could still be recovered even if the GPRS module failed to communicate.

A registered electrician was required to install all the monitoring equipment under the instructions and supervision of a BEES team leader. An installation manual was developed for electricians so that they were familiar with the system before their first installation.

Plug-in electrical appliance monitoring was done using the Enerplugs.

E.4. Data Collection Process

A range of techniques and monitoring equipment were used to collect as much data as possible in each of the targeted premises in the BEES research. The data collection for the pilot studies was documented in the BEES Year 1 & 2 report (Isaacs, et al., 2009), where the selection and purchase for the monitoring instruments and the development of the field data collection methodology was described.

In the BEES Year 3 report (Isaacs, et al., 2010b), the data collection methodologies were refined from the pilot studies, and the survey instruments used for the full-scale monitoring were documented and preliminary analysis presented for the limited number of premises for which data was available.

The monitoring process for Year 4 was further refined, with one new piece of monitoring equipment added into the monitoring process in June 2010. This was placing one HOBO temperature and relative humidity sensor in the monitored premises for a period of 1 year.

A vital part of data collection was 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 (Isaacs, et al., 2010b). The flow chart in Figure E-14 provides a visual overview of the process.

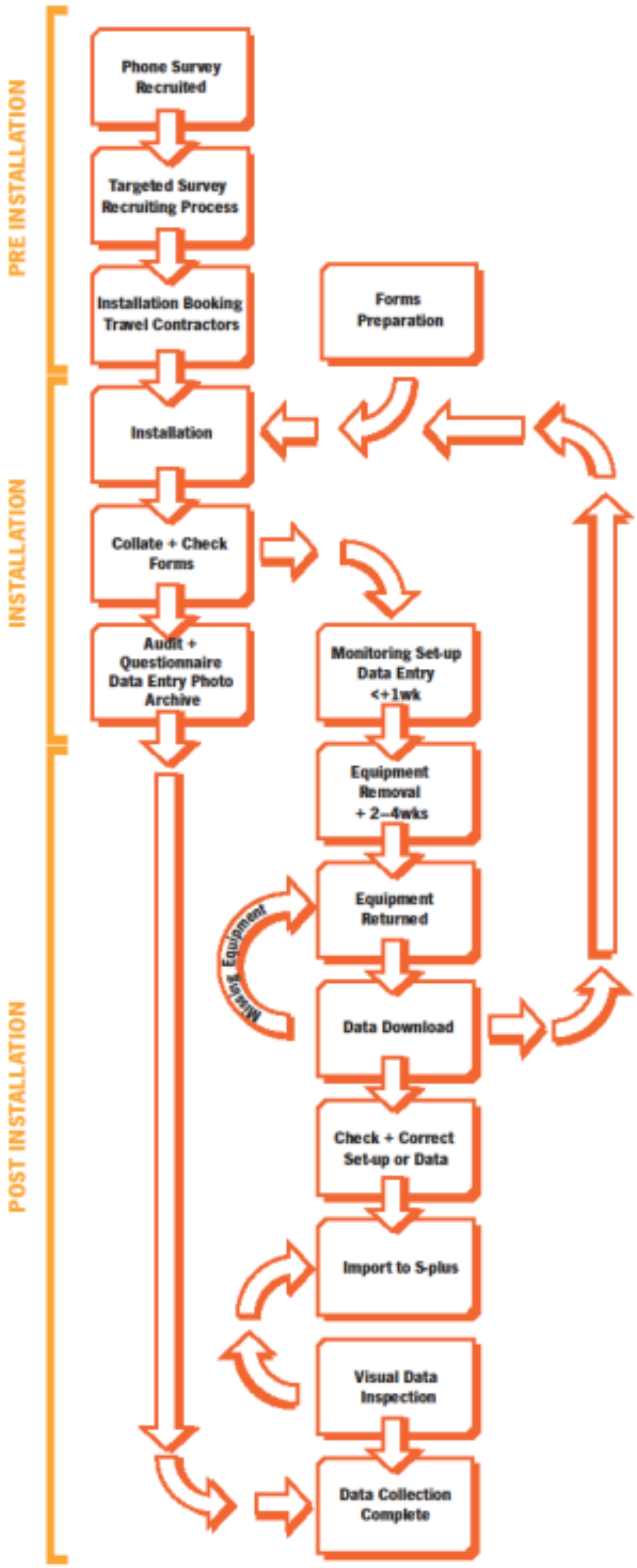


Figure E-14: Targeted Monitoring Flowchart.

There were three main phases for targeted monitoring:

1. Recruiting and booking – the premises were recruited from the list of telephone survey participants. Getting in contact with the business owner and/or managers to arrange a suitable installation time and making arrangements for travel, electrician and any additional helpers.
2. Installation – monitoring equipment was installed and the audit information were collected using the pre-prepared forms, following the installation and audit processes. These forms were checked and collated as soon as possible following the installation to ensure all required data was collected.
3. Data process and inspection – this phase included re-coding the set-up information in a database, which also provided the list of equipment to be retrieved at the end of the monitoring period. Once the equipment was retrieved, for the premises monitored in Year 1 & 2, the monitored data was downloaded, checked and filed for processing. The premises monitored in Year 3 or later used a GPRS system where the data was downloaded from the FTP server daily. The processing combined all the monitored data into one file per premise, with circuit and end-use labelling. All monitored data was checked visually and corrected if necessary. The audit and questionnaire data was entered into a database and checked before being made ready for analysis. In Year 4, the systems for managing this data were fully developed, and this data was routinely accessible from a database using SQL queries or data exports.

The installation time varied depending on the size and complexity of the installation. A small shop or office, between 50 and 150 m^2, usually took approximately 2 hours with three people. A large shop or office, approximately 1,000 m^2, took about 3–5 hours with three people. The longest installation took around 3 days. The installation time did not scale in proportion to the floor area but to the complexity of the installation in terms of the number of circuits, distribution boards, rooms and equipment.

The biggest uncertainty in the installation time was the time required to install the Multivoies system. This depended on:

- the number of distribution boards that required monitoring
- the number of circuits on each distribution board (ranging from six to approximately 40 circuits)
- how well labelled and organised the distribution boards were
- the physical condition of the distribution boards (some of the boards were very old and potentially dangerous)
- the physical size and location of the distribution boards (some were hard to work on in very tight store rooms)
- whether the electrician was familiar with the distribution boards and wiring of the premise
- the skill level of the electrician.

The number of distribution boards and circuits was not easy to predict. Even a small premise (<150 m^2) could have two or three distribution boards and might have as few as six circuits or as many as 40 circuits. The installation time required could therefore be unpredictable.

To mitigate these issues, the occupants or the building owner were asked if they had a regular electrician who maintained distribution board(s) for the premise. These electricians were usually used as they were familiar with the distribution boards and how the premise was wired. In some cases, the number of boards and circuits was obtained by asking the electrician or the occupant before the installation date. This enabled a better estimate of the time required for the installation and monitoring to be completed.

It proved very difficult to install within more than one premise or building per day, due to the unpredictability of installation time required. Also, with the targeted monitoring installation spread out over the year according to a present schedule (time and geographic location), it was uncommon to have installation in a large group of buildings in one location at one time.

The BEES participant agreement, BEES data access policy and BEES energy company permission form were sent out once the occupant agreed to participate in the study. Sometimes, scheduling a site visit appointment proved to be very difficult, requiring more than one phone call.

E.4.1. Field Staff

Field staff were often used to assist with the installations and undertaking the audit tasks. In some locations, there were field staff that BRANZ has regularly employed. However, in locations that were less frequently visited, field staff were recruited on a one-off basis from staff used by BRANZ on other projects, personal contacts or support staff supplied by the electrician. As the audit work was well prescribed, most field staff learned it very quickly and did a good job with minimal supervision. A field training manual was developed to support the training of temporary staff before the actual installation.

Using field staff reduced costs, by reducing the time spent by the BEES team leader, and also reduced the duration of the installation. This was an important factor, as some businesses did not want people working in their building for too long.

E.4.2. Installation

The installation of BEES monitoring equipment required the distribution boards to be opened so that the wiring could be accessed. This was done by a registered electrician, and any safety or maintenance issues were identified before installation. The monitoring installation only proceeded if it was safe to do so. Identification of the circuits was essential for BEES, and this raised another set of issues with identifying and tracing circuits.

The main issues identified in the distribution boards were:

- dangerous or hazardous distribution boards or wiring
- reconfigured boards
- labelling of distribution boards
- complexity
- selection and categorisation of circuits.

E.4.3. Installing Monitoring Equipment

The first step was to locate the main electrical distribution board(s) and sub-boards, if any. This task may seem simple, but as there was usually no wiring plan for the premise and the distribution boards were not labelled on the floor plans, this task could occasionally be difficult and take a considerable amount of time to search for the boards within the premise. If the electrician working alongside the BEES team was responsible for servicing and maintaining the building, they usually knew where all the distribution boards were and had a general overview of what each board supplied. In most cases, there was no regular electrician responsible for servicing and maintaining the premise, so a search of the premise was required, with assistance from the occupant or owner if possible. In general, the occupant or owner had little or no knowledge of the electrical distribution system and perhaps only knew where the distribution board(s) and the main switches were. Sometimes, distribution boards were located in strange places and were very difficult to locate.

Once the distribution board and any sub-boards were located, the supply phases were identified so that the board total could be monitored and to power the BEES monitoring equipment. Difficulties often occurred when phases were incorrectly labelled, swapped or incorrect wire colours were used. Phases could usually be identified by tracing wires or using special test equipment.

Most distribution boards had labels on the board itself and/or on a circuit chart. However, the standard and accuracy of the labelling was often poor, as there is no common industry practice for labelling circuits, and keeping the circuit charts up to date as repairs and changes were made was poorly done. If the electrician was the person who regularly serviced and maintained the distribution boards or installed the wiring, they usually remembered what was done and could confirm the veracity of the labelling.

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

- Size and type of wiring (lighting is usually on smaller 1 mm cable).
- Size of fuses/circuit breakers (lighting is usually on 10 A fuses, plug loads usually on 20+ A fuse).
- 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 was possible to trace circuits by switching them on and off or by turning the lights or equipment on and off. However, in most premises, turning off switches at the distribution boards was not done due to the risk of switching off critical equipment such as computers and retail till systems or blacking out areas of the premise, which could seriously disrupt the business or create a health and safety hazard. It would be unreasonable to expect participating businesses to tolerate such potentially serious disruptions.

Once the identification process was completed, the monitoring equipment was installed. If there was a circuit where the use could not be identified, it was usually monitored individually so it could be identified at a later date.

Once the BEES electrical monitoring equipment was installed, the identification of the circuits was checked against the measured readings. The Multivoies system provided instantaneous readouts of the current, voltage, power, power factor and waveform. The most useful information was the waveform, as different types of equipment have different waveforms. The Year 4 topic report Detailed Monitoring provided the typical waveform of the most common circuits (Camilleri & Babylon, 2011).

E.4.4. Water and Gas

If water and gas meters were present in the monitored premise and/or building, both the start and end readings and times were recorded, along with any meter information available.

As there were a variety of meter types, it was determined early on in the study that it would be too difficult to carry a sufficient range of meter reading sensors with the monitoring team. The process required to identify which sensor should be used would provide a slow and unreliable field monitoring method. Connecting and wiring sensors with data loggers on site also significantly increased the time required for installation. The decision was made to rationalise down to one type of water meter sensor during the pilot study, the Elster (Kent) meter, which is the one most commonly used in New Zealand.

Onset micro-logger stations were used to monitor the Elster (Kent) water meters, as this avoided the wiring connections required on site as well as proper watertightness. The installation of the reading sensors and loggers usually took about 10 minutes.

For those meters where the reading head would not fit, Brinno GardenCam time-lapse cameras were used instead. This built on the experience of trying to use optical methods to capture and read images of meter displays, which did not lead to a reliable and practical field data collection method. The time-lapse cameras were modified slightly by setting the focal distance to ~50 mm for clear close-up images and by having LEDs fitted to provide light at night or in dark water meter holes. This provided an almost identical lighting condition during the monitoring period, and further processing using an OCR method was implemented instead of manual data entry. If possible, gas meters were also monitored with the time-lapse cameras.

E.4.5. Equipment Removal

The equipment removal was completed by the electrician. This was to save time and money, as most of the monitored premises were located outside of Wellington, where the BRANZ team was located.

During the installation process, the electrician was shown where all the equipment was installed. After the monitoring period, the electrician was sent a list of all the installed equipment and locations, compiled from the monitoring installation forms, and a copy of the floor plan on which all the equipment locations were marked. If there were any issues in locating the equipment, the electrician contacted a BEES team member for support. Where equipment was moved during the monitoring period, the occupants were asked to assist the electrician in finding the equipment. All the equipment deployed had the BRANZ logo and contact information if any equipment was left behind.

The removal process was quicker than the installations – typically less than 1 hour was required to remove all the electrical equipment from the distribution board(s) and return the distribution board to its original condition and an additional 5–10 minutes to retrieve the environmental and appliance plug-in loggers. The electrician was also asked to record the water and gas meter reading(s) along with the time and date of reading, if present in the premise.

The equipment retrieved by the electrician was stored in the provided cases. The retrieved equipment was either left with the electrician, if another installation was planned for the same city, or returned by courier to BRANZ.

E.4.6. Downloading and Processing Data

Once the equipment was returned to BRANZ, it was checked off the installation form to ensure all equipment was returned and then connected to a computer, if necessary, to download the data.

If the equipment was left with the electrician, it was either downloaded remotely through the FTP server, downloaded on site before it was installed in the next building or swapped for fresh equipment and taken back to BRANZ with the BEES team for downloading.

After the data from all the monitoring equipment was downloaded, the next stage was to verify the identity of the circuits that were identified on site. This was done during the data processing stage where various visual checks were applied to confirm and, if required, correct the circuit identification. The electrical monitoring data was recorded at 1-minute intervals, and this high time resolution made it easier to distinguish most electrical end-uses, for example:

- lighting generally had a steady consumption in the range of hundreds to thousands of watts
- plug load circuits usually had a varying consumption, with switching and peaks from appliances such as refrigerators, microwave ovens, etc.
- air-conditioners usually cycle frequently at higher power consumption during the day than at night.

This identification process built on the experience of the Household Energy End-use Project (HEEP) and several other major data collection and analysis projects that BRANZ has conducted, where more than 10,000 channel-years of data was visually inspected.

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

Once this process was completed, the circuit identification process was considered to be completed with a high level of confidence in its accuracy.

After the monitored data was checked and corrected where required, strict naming and filing conventions were applied before data was stored in the relevant folders so that it could be processed. The installation forms were used to ensure that all data logger files were downloaded.

To reduce the processing time and improve the reliability of the data, the files were usually not altered once they were downloaded. For example, if a data logger was not stopped when it was retrieved, data would still be recorded after removal, and this would be required to be removed from processing. This process was handled by a master monitoring set-up file that stored the name and location of every data logger, the start and end time for monitoring and any other related information such as a descriptor of the data and other information required for processing. There were several benefits of this system:

- The majority of the data processing was done by making entries in a spreadsheet rather than editing or processing individual data files.
- The downloaded data files were not altered.
- No extra copies of the data files were required.
- No chance of irreversible changes made to data files.
- No chance of data file corruption.
- Faster than editing thousands of individual files.
- Master processing list was the record of processing.
- Could be done as a batch process.

E.4.7. Importing Data into S-Plus

The processing of data was done using the S-Plus statistical package. This package was used for HEEP, with modifications made for the BEES project. Building on the existing HEEP platform saved an enormous amount of effort in developing the software.

The data was imported into S-Plus using a custom set of importing and processing functions. The raw data files consisted of multiple separate files for the Multivoies logger(s), temperature/relative humidity/illuminance loggers and any other data loggers. All this data was required to be combined into a single file for processing and analysis.

For each data file:

- the data was imported
- known problem data was removed automatically (e.g. start-up values)
- the time base was aligned to 1-minute intervals and data interpolated if required
- names were assigned to each item of data from the monitoring set-up
- start and end times were applied to each item of data from the monitoring set-up
- calibration corrections were applied.

The data from all files was then combined into one data object:

- All data was trimmed to the start and end times for the premise.
- Totals and other processing was done (e.g. add all air-conditioning units (Aircn) to give air-conditioning total).
- The data object was stored.

After the data had been imported, all the data was visually inspected using Exploratory Data Analysis (EDA) plots. An example is provided in Figure E-15 for a temperature sensor located in an office. The label ‘TempTof1a’ indicated the temperature end-use (Temp), data type temperature (T), located in office number 1, with ‘a’ indicating the first sensor, matched to the floor plan coding. The EDA plot had a description of the data and basic statistics in the title. The upper plot is a histogram of the data, from which extreme values, zero or negative values and other potential problems can be readily identified. The middle plot is the time series of the data, in this case at 10-minute intervals. The lower plot has the average by time of day (midnight to midnight) and the 7-day moving average. By inspecting this plot, an experienced analyst can identify any problems very quickly and identify any interesting or unusual patterns. For this case, the time of day profile is unusual as it is maintained within a very narrow band (average only varies between 22.7°C and 23.0°C) and shows evidence of tight active control (at 8:00 am the temperature drops, presumably when the air-conditioning system starts on a timer). Any data problems detected from the EDA were then traced, fixed and the data re-imported.

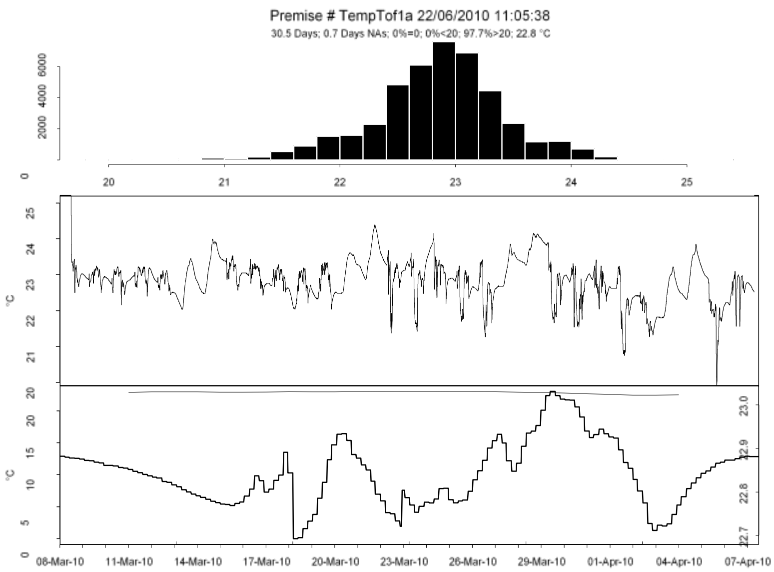


Figure E-15: Example Exploratory Data Analysis (EDA) plot for Temperature.

E.4.8. Targeted Monitoring Buildings

Table E-1 illustrates the summary statistics on the BEES targeted monitoring installations completed between 15 December 2009 and 28 August 2012.

Table E-1: BEES Monitored Statistics.

Activity	Count
Premises	101
Buildings	89
Distribution boards	~150
Electrical circuits	~4,785
Temperature/humidity/light loggers	330
CO_2 loggers	89
Yearly temperature/humidity loggers	33
Lighting audit	101
Appliance audit	100
Water meter readings	54
Gas meter readings	7
Time-lapse cameras on water meters	9
Time-lapse cameras on gas meters	3
Plug-in appliance loggers	~220

In most cases, all the distribution boards and electrical circuits were monitored within the participating premises. In a few cases where several floors were occupied by one premise, a subselection of floors was monitored, and on occasion in multi-floor buildings, the distribution board for the building total, located in the basement, was also monitored.

E.5. Electrical Board Issues

In monitoring over 4,000 electrical circuits and end-uses for BEES, a large variety of distribution boards and wiring practices were encountered. The following observations enabled the current state of wiring in non-residential buildings to be described:

- What is the present situation?
- What do electrical distribution boards in the New Zealand non-residential sector look like?
- Are there any changes for the future required, and if so, why?

E.5.1. Distribution Board Hazards

There were three dangerous distribution boards encountered through the BEES programme that the electrician refused to work on due to the high likelihood of arcing or explosion. Visual inspection of these distribution boards determined that the wiring was very old (40+ years) and did not have regular maintenance.

Even though old wiring was not an uncommon discovery, when the electrician attempted to open these distribution boards, it was obvious that the insulation around the cables was old and had deteriorated and that any movement would cause breaking of the old insulation with the possibility of serious damage, short circuits or fire. In one of the monitored premises, the electrician suggested an explosion was possible. Non-residential buildings often have large-capacity feeds with a very high short circuit current that is high enough to cause a plasma arc and explosion with the potential for serious injury or even death.[3] Without shutting down the whole premise and possibly the whole building and rewiring the board, no monitoring could be done, and the occupants were informed of the hazard.

Surprisingly, a large number of distribution boards (estimated to be about a quarter) were found to have a hazard that caused the boards to be potentially unsafe to approach or work on whilst the power was live. The normal practice for routine electrical work on non-residential buildings in New Zealand was to leave the power on to avoid disruption. Major work that required a shutdown was 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. The electrician managed these risks by identifying the risk, isolating the risk if possible or by working carefully. These hazards slowed down the electrician's work and required a high level of concentration and skills. Modern electrical wiring practice ensured that there were no live conductors exposed when a distribution board was opened, leaving the electrician free to concentrate on the immediate task with no need to be concerned about other parts of the board. Refer to BEES Year 4 topic report Detailed Monitoring for hazardous distribution board examples (Camilleri & Babylon, 2011).

E.5.2. Reconfigured Boards

Figure E-16 shows a typical board in an older building that has been upgraded, reconfigured and partially modernised over the years. The first inspection indicated this distribution board was 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 completely dismantling and rewiring the board. The assumption was that the premise was fed by two phases from which one was split into two. Thus, it was impossible to establish either the order or the correct rotation of phases, making complete end-use monitoring impossible.

Figure E-16: Typical Reconfigured, Older Distribution Board.

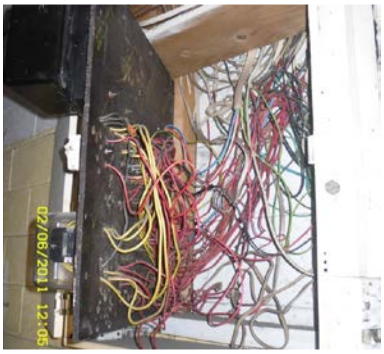


Figure E-17: Back of the Same Distribution Board.

Figure E-17 shows the same board from the back, with a mess of wiring that is typical for older distribution boards. Closer inspection shows a mixture of old and new wiring including some unused cables, which

[3] See http://download.fluke.com/video-safety/flukesafetyvideo.html

have been protected accordingly. Often on older boards, a single wire colour was used for all phases, which made tracing wiring even more difficult.

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

E.5.3. 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, on casual inspection, might seem to be tidy and readable, but in fact very few boards actually had labelling that corresponded closely to the circuit configuration. In older buildings, distribution boards were rewired or reorganised at some stage, and in the majority of cases, either the circuit charts were not updated or were labelled incorrectly (Camilleri & Babylon, 2011).

E.5.4. Complexity

The complexity of distribution boards and wiring in larger premises could make identification of end-uses difficult. Even determining how many distribution boards were present and where they were located was a challenge, as there were 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 were located in strange places or were concealed.

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

Figure E-18, Figure E-19 and Figure E-20 illustrate the multi-panel distribution boards found in larger buildings. It took a lot of time to investigate the layout of the main board and sub-boards and decide on the strategy for monitoring.

Figure E-18: Large Multi-Panel Distribution Board.

Figure E-19: Large Multi-Panel Distribution Board.

Figure E-20: Large Multi-Panel Distribution Board showing Circuits for End-Use 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 the monitored 101 premises had wiring either providing power to other businesses or using power being paid for by other businesses. One particularly extreme case was identified where several kilowatts were supplied from an unoccupied neighbouring premise at the time of monitoring.

E.5.5. Selection and Categorisation

In the majority of installations, phases and circuits were required 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 was normally not a problem to monitor. However, very often, these main boards were 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 made this impossible, and the monitoring has to be rationalised. Loads of the same type (e.g. lighting) on the same phase were combined and monitored as a group. Sometimes, a board would supply only plug loads, so board totals were monitored instead of individual circuits. If there were a few circuits on these boards with different end-uses, these would be monitored separately, and the end-use total would be subtracted from the board total. This approach reduced the amount of equipment required and the amount of time for installation and data processing.

The various groupings and subtractions were carried out during the data processing, and BEES set up efficient systems to do this work automatically.

E.5.6. Recommendation

Through the 101 premises monitored, the BEES monitoring team felt that the wiring in non-residential buildings were haphazard, with layers of maintenance, repairs and reconfigurations required on some distribution boards. Historic layers of electrical practice and the varying practices of the various trades responsible for different parts of the electrical systems meant there was often not an organised system.

Many distribution boards had hazards caused by obsolete electrical practice and equipment on older boards, previous substandard work and faults caused by deterioration, damage and overloading.

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

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

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

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

- engage an electrician for regular service
- ensure building owners/occupants know where boards are located 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 the location of distribution boards and board feeds
- allow for future expansion by having spare load capacity and spare fuses/breakers
- develop consistent practices across all electrical trades servicing buildings.

E.6. Electricity Consumption

Since the targeted monitoring aimed to break down end-uses (lighting, plug loads, water heating, etc.), it was important to identify each end-use correctly. However, this was often a difficult process, as sometimes the electrical distribution board labelling was not accurate and was not kept to date.

E.6.1. Electricity End-Use

There was a huge range in the total electricity consumption in the monitored BEES premises, ranging from a minimum of ~3,500 kWh/yr to ~4,200,000 kWh/yr. The main reason for this variation was the huge range of floor areas of the monitored premises, ranging from 40 m^2 to 4,800 m^2. There was also a wide variation in the types of activities within the different premises and wide variation in opening hours.

All the monitored data was visually inspected and checked for validity. For some premises, the monitored total electricity did not tally to the monitored circuit end-uses. This could be due to various reasons, for example, not all circuits were monitored on the distribution board, they were labelled as a spare circuit or it could be because there was something else being fed into the main total that the monitoring team and the electrician missed.

For this analysis, such premises were removed pending further checking and correction. Therefore, the end-use analysis was only for 84 premises.

The major electrical end-uses in the surveyed buildings were:

- premises total
- lighting
- air-conditioning
- plug loads
- water heating.

The full report on this work provided for each premise included the approximate breakdown of end-uses, where the data was available for processing. Note that, as each premise was only monitored for 2–4 weeks, these breakdowns did not represent the annual end-use breakdown on an annual basis.

E.7. Monitoring Environmental Conditions

Temperature, relative humidity and illuminance were monitored in 330 locations ranging from offices to retail areas to kitchens or lunch rooms. The environmental conditions monitored were for a short period – typically 2–4 weeks. Therefore, this dataset did not represent an annual average.

E.7.1. Temperature, Relative Humidity and Light

Battery-powered Hobo U12 Data Loggers were used to monitor the temperature, relative humidity and illuminance levels of a premise for 2–4 weeks. Typically, two U12 data loggers were deployed with at least one placed in the main area (e.g. office, shop) and at least another one in a secondary area (e.g. kitchen). They were installed away from heat sources, draughts and direct sunlight at heights that occupants were typically at (between 0.4 m and 2.0 m).

E.7.2. Carbon Dioxide

The air quality of a premise was monitored by recording the CO_2 concentration of a space. This was recorded using a Telaire meter connected to a Hobo data logger and was typically placed in the main area of a premise as only one unit was deployed (e.g. office, retail floor, etc.). It measured CO_2 concentrations of up to 2,500 ppm (which is very high – the ASHRAE standard recommends that the indoor air quality of a space should not exceed 1,000 ppm).

It was necessary to adjust some of the CO_2 data records in order to manage the effects of sensor drift. This sensor drift was observed by comparing the overnight minimum recorded CO_2 concentration and checking it for reasonableness. According to Schell and Int-Hout (2001), “in urban areas, outside concentrations have been in the 375 to 450 ppm range” and “for most applications, outside air can be assumed to be at 400 ±50 ppm”. This matches BEES observations of 450 ppm being typical in New Zealand urban areas during daytime.

In a survey of CO_2 monitoring history in buildings, Schell notes that there are two main issues affecting the Non-Dispersive Infrared Detection sensors (as used in the Telaire) used by BEES. There are issues with particle build-up in the sensor and ageing of the IR light source, so the “long-term drift of the sensor required calibration annually or more frequently”.

The CO_2 sensors used in BEES were initially calibrated, then used in field studies for about 3 years without subsequent calibration. For most buildings, measurements show the overnight and weekend CO_2 readings drop to approach ambient air concentrations. However, several of the CO_2 records showed concentrations below 300 ppm. This was considered to be unreasonable, and that data was taken as suspicious so was subject to further checking. This follows the basic approach developed by the instrument manufacturer (Telaire, 2000).

All the CO_2 data was processed into 24-hour profiles for visual analysis. For each monitored premise, the average overnight/weekend minimum reading and the absolute minimum reading was noted. If these were significantly different from 400–500 ppm, the building records were checked to see if there was a plausible reason for this difference. If there was no obvious reason for this difference (e.g. 24-hour building or premise operation), an offset value was chosen (in increments of 50 ppm) to add to each measurement to make the minimum readings plausible. This was a subjective estimate based on experience with these types of CO_2 profiles.

Before this estimated offset was accepted, a sequential list of premises monitored with each sensor was compiled to determine if there was a systematic post-calibration sensor drift associated with that sensor. For five of the 10 CO_2 sensors used, there were apparent systematic offsets that were corrected. Two sensors had offsets of +100 ppm and one of +200 ppm added to the data they recorded after about a year of operation. One sensor was assigned a +150 ppm offset to all the datasets it generated. A fifth sensor briefly showed unusually high readings (for about 6 months) and had an offset of -250 ppm assigned to two premise datasets, after which the readings became reasonable again, presumably as the dirt temporarily occluding the sensor dissipated or was dislodged.

The offset value was added to all the readings recorded in the reworked datasets. As an example, a premise with an (original) average overnight reading of 300 ppm, an absolute low of 250 ppm, an average weekday reading of 650 ppm and an absolute high of 800 ppm was adjusted with an offset of +150 ppm so that the corrected, reported values were average overnight reading 450 ppm, absolute low 400 ppm, average weekday reading 800 ppm and absolute high 950 ppm.

E.7.3. Yearly Monitored Data

Of the 101 premises monitored, 48 of these had a Hobo U10-003 temperature/relative humidity logger in the premise for 1 year recording the temperature and humidity levels every 30 minutes. These were placed in a common area, e.g. an open-plan office. The reason for deploying this equipment was to obtain long-term temperature and relative humidity measurements to characterise the internal conditions, which can also be used in conjunction with the long-term meter data obtained from energy suppliers. The difficulty that arose in this aspect of data collected was that some of the businesses closed or moved to another building before the 1-year monitoring period was up and therefore the equipment was lost.

E.7.4. Examples of Environmental Conditions in a Typical Office Location

Figure E-21 through to Figure E-24 show the performance of a typical office location in terms of temperature, relative humidity, illuminance and CO_2 levels.

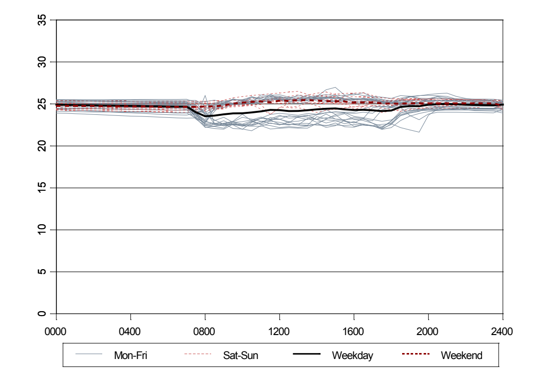


Figure E-21: Office Location Summer Temperature Profile.

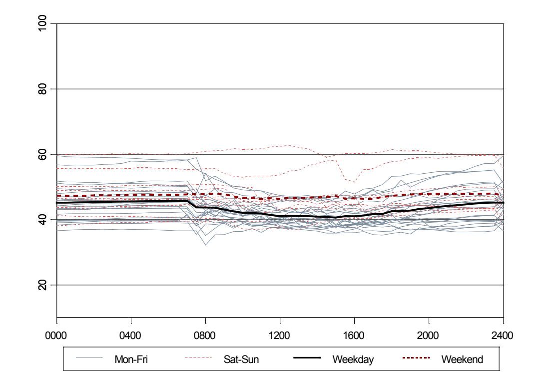


Figure E-22: Office Location Summer Relative Humidity Profile.

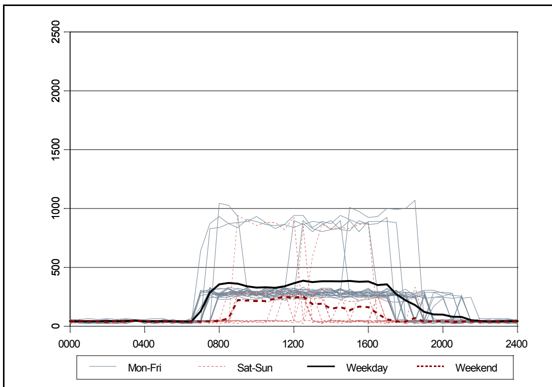


Figure E-23: Office Location Summer Illuminance Profile.

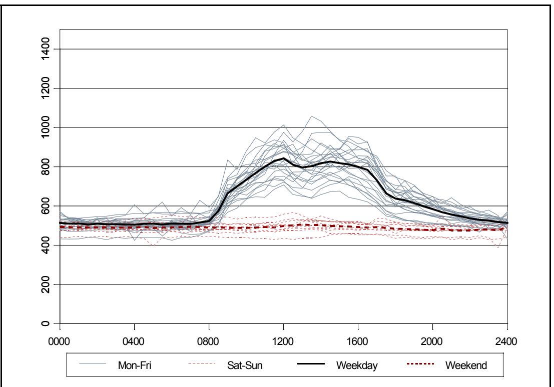


Figure E-24: Office Location Summer CO_2 Profile.

Figure E-21 to Figure E-24 show the monitored profiles of a well managed and cooled office location monitored in summer. The temperature profile shows that space cooling starts at about 7:00 am each weekday morning and switches off around 6:00 pm (Figure E-21), a pattern also found for illuminance (Figure E-23) and CO_2 (Figure E-24). During the working weekday, it can be seen that the temperature and relative humidity fall, while both the illuminance and CO_2 levels rise. During the daytime in the weekend, the temperature, relative humidity and CO_2 are reasonably stable, while the effects of some daylight can be seen in the illuminance graph.

Figure E-25 to Figure E-28 show the same performance parameters for another typical office location, except that this one is heated during the winter.

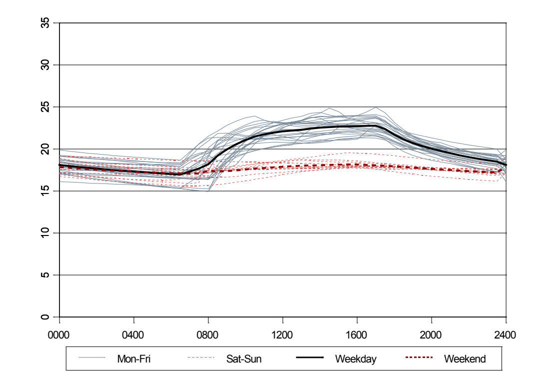


Figure E-25: Office Location Winter Temperature Profile.

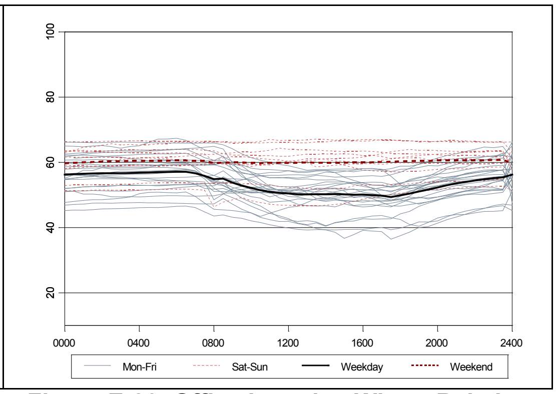


Figure E-26: Office Location Winter Relative Humidity Profile.

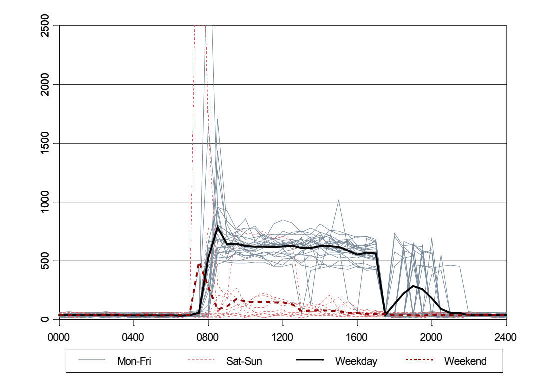


Figure E-27: Office Location Winter Illuminance Profile.

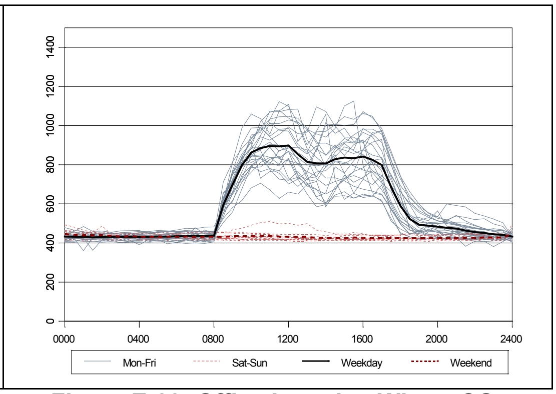


Figure E-28: Office Location Winter CO_2 Profile.

Figure E-25 to Figure E-28 show the monitored profiles of a heated office location monitored in the winter. From about 8:00 am, occupancy starts, as seen by the rise in the illuminance in Figure E-27 and CO_2 profile in Figure E-28.

Figure E-25 shows the temperature profile, with weekday temperatures rising from about 8:00 am, starting to fall about 6:00 pm and then dropping slowly all night. The heating also reduces the relative humidity (Figure E-26), although the reduction depends on the external and internal (people) moisture load as demonstrated by the range across the days (light grey lines). Figure E-27 shows that the electric lights are turned off most days about 6:00 pm, although evening work occurred on some days with electric lights being on from about 7:00 pm through to about 9:00 pm. This evening occupancy can also be seen in some days in the higher evening CO_2 levels in Figure E-28.

The weekend temperatures, relative humidity, illuminance and CO_2 patterns are largely stable, with some variations as the sun penetrates the room or the relative humidity varies.

E.8. Audit Data Analysis

Forms for each of the different audits were prepared before the installations. Some audit tasks were required to be completed in a specific order so that the information could assist with the monitoring equipment installation:

1. Floor plan and dimensions for building audit.
2. Lighting audit.
3. Appliance audit.
4. The other audits could be completed in no particular order.

The floor plan was required to be annotated before the lighting audit so that locations could be allocated to lighting circuits. The floor plan and lighting audit assisted in identifying and tracing circuits. The appliance audit was required to be completed before the monitoring of appliances in more detail so that they could be selected appropriately.

E.8.1. Building Audit

The purpose of the building audit was to collect information on the physical layout and structure of the building, permitting the creation of computer simulation models.

The first stage of the audit was to collect a copy of the floor plan from the occupant. Sometimes, they were available ahead of time. If this was not possible, a floor plan was mapped and drawn. The floor plan was annotated identifying activity areas, room height, floor covering, glazing, etc. This was a time-consuming process. The time taken depended more on the number of rooms than on the floor area, however.

Data including glazing percentages and the type of glazing on each elevation was also recorded. Photographs of each elevation were also captured so that any missing information could be completed at a later date. Some information that was desired often turned out to be practically impossible to collect, for example, floor insulation for slab-on-ground floors. There was no other viable way to collect and annotate this type of information. Obtaining plans from relevant council records has been found to take too long and required too much time to identify the correct plans in the available records for this part of the data collection process.

E.8.2. Appliance Audit

A list of 77 different appliance types were developed for the auditing process. In each premise, an appliance stock was determined by a walkthrough of the monitored premise and counting each of the appliance types. This was a fast process with little or no disruption to the occupants. For premises occupying multiple floors or building, the appliance tally was separated by floor or building. The appliance types audit was subsequently used to randomly select which appliances were to be monitored in more detail.

The 77 appliance types were grouped into nine categories for the auditing process. These were Computers, Office, Entertainment, Retail, Heating/space conditioning, Food preparation, Refrigeration, Cleaning, Miscellaneous and Other to make the auditing process easier. In some cases, the appliances varied in size and use, for example, residential size refrigeration and commercial size refrigeration. They were treated as separate appliance types by labelling 'resid' for residential and 'comm' for commercial.

The appliance types list was further grouped into 34 appliance groups for further analysis, as discussed in Section 7 of Part 1: Final Report.

It was determined early in the study that it would be impractical to conduct the appliance audit based on the HEEP study. During the study, the appliance type, make, model, serial number, spot power measurements and photographs (prioritised for different appliance types) were recorded. Due to the amount of information required to be recorded, the following impracticalities arose:

- Time required to record all the information.
- Caused too much disruption to the occupants' normal work (e.g. computer being turned off).
- Difficulty in accessing power outlets.
- Potential disruption to critical equipment (e.g. networks, retail tills).
- Difficulty accessing the model/serial number details.
- Rapid stock changes for most appliances.

The decision was made to not collect such detailed information, as the costs, time and disruption outweighed the value of the information collected.

Instead, information on energy consumption, time-of-use (TOU), operating modes and standby power were obtained directly from the selected appliances (usually 2–4) monitored in each premise.

Approximately 220 appliances had been monitored including appliances such as computers and peripherals, cooking and refrigeration equipment, photocopiers and office equipment.

E.8.3. Lighting Audit

Lighting was identified as one of the major end-uses in non-residential buildings. Therefore, considerable effort was put into monitoring and auditing to measure and characterise lighting. The lighting audit evolved rapidly from the typical process used in an energy audit to one suited for the BEES study. The detailed lighting stock information collected as part of the lighting audit process included:

- room location in the premise (matched to the building audit floor plans)
- switch/circuit number(s)
- lamp type (halogen, fluorescent, etc.)
- number of luminaires (light fixtures)
- number of lamps per luminaire
- lamp wattage (W)
- switch control type (manual, occupant sensor, etc.).

The lamp wattage was either determined by reading the lamp label or estimated from a table of typical values. In some cases, it was not practical or possible to read the lamp wattage (e.g. inaccessible or enclosed lamps). This lighting audit data enabled room-by-room or area-by-area calculations of lighting stock and lighting power densities.

Although it was preferable to confirm which switch or circuit related to a specific set of lights, it was impractical to trace lighting circuits by turning lights on and off. Some businesses did not want the lights turned off at all, and if they were happy with the process, it was very time consuming. Lights were only traced using this method if they were unable to be identified on the distribution boards.

E.8.4. Lighting Controls

The type of lighting control for each circuit was recorded as part of the lighting audit. For 94% of the lighting circuits with the control type identified, 97% by count were a simple on/off switch, with 1.6% a motion sensor.

There were unresolved issues for 6% of lighting circuits where the control type was not identified, as timer and daylight controls were sometimes located separately from the lighting circuit so it might not be properly identified in the lighting audit. Lighting timers and controls were frequently identified on distribution boards during the BEES electrical installations. Most of these controls were for automated exterior lighting, although in several premises, lighting was fully automated with times pre-set to match the operating hours. The potential for daylighting controls was explored in BEES topic report Delivered Daylighting (Bishop, et al., 2011a).

E.8.5. Hot Water System Audit

The main difficulty in the hot water system audit was locating the hot water system. Hot water systems in non-residential buildings were often in out-of-the-way places, and access was often difficult or impossible. Normally, the occupants were not the owners of the building. This meant that, in most cases, the occupant did not know where the hot water systems were located or could not provide any information on it. There were a large variety of systems, from small kitchen bench models to domestic size or larger. There were also a variety of circulating hot water systems that ran off central boilers and HVAC systems. In the premises where a hot water cylinder was found, information on type, fuel and size was collected.

E.8.6. HVAC System Audit

The HVAC system audit covered all the heating, cooling and ventilation systems in the premise. This included any central heating and/or cooling systems, heat pumps, panel or portable heaters, ceiling fans and both ducted and extract fans.

At a minimum, the numbers of portable and fixed gas and electric heaters, heat pumps and/or air-conditioners, dehumidifiers and fans were collected in the appliance audit.

E.8.7. Photographs

During the auditing process, photographs were taken of:

- all exterior elevations
- surrounding buildings and terrain from all exterior elevations
- adjacent buildings
- the general interior
- all distribution boards where monitoring equipment was installed
- all environmental loggers and appliance loggers placed in the monitored location
- all major equipment (hot water systems, HVAC, chillers, etc.)

The photographs serve several purposes. Some were a record of the installation to assist in recalling and identifying any problems later. Some were to record information that was extracted and coded later (photographs of the exterior elevations assisted in identifying the glazing area or whether there was any site shading on exterior elevations, etc.). Using photographs particularly for the exterior elevations greatly reduced the amount of time required on site. They were stored electronically with other material and data relating to the building.

E.9. Occupant Questionnaire

An occupant questionnaire form was typically given to the manager or the contact person of the monitored business at the start of the installation day and collected at the end of day. The questionnaire covered occupancy and client numbers, opening hours and hours that major equipment and/or appliances were turned on and any energy management and efficiency measures the business had in place before the study.

The data from the occupant questionnaire ended up also being collected in other survey instruments. A POE[4] was implemented in 2012. Refer to Section 9 of Part 1: Final Report, for the POE analysis.

E.10. Detailed Results

E.10.1. End-use Consumption

Based on the monitored premises, the daily electricity use varies widely, from ~3 kWh/day for a small shop to about 5,600 kWh/day for a large office building.

The smaller shops were usually small suburban or provincial town shops, which often had no dedicated heating or HVAC system. Their energy consumption was usually very low (3–97 kWh/day). For these types of business, lighting was often the dominant end-use and was often a high percentage of the total electricity consumption. One small shop had 84% of the electricity used for lighting. This proportion was verified, as the shop had no hot water system, no heating and only a handful of small appliances.

Air-conditioning was present in some premises. Some were central HVAC systems, but most were single or multi-split systems (i.e. heat pumps). As the time of year monitoring was varied, the electricity consumption for air-conditioning did not represent a full year. Consequently, the air-conditioning electricity consumption for the short monitored period was highly variable, ranging from 1–63% of total electricity consumption.

Plug load electricity consumption ranged from 1–97% of total electricity consumption, whereas lighting loads ranged between 2% and 84% of total electricity consumption.

Water heating appeared to be a minor end-use. For those premises where a water heating system existed and was monitored separately, the consumption was usually between 1% and 19% of the total consumption. Some premises had water heating systems that were turned off or disconnected.

Computer servers were difficult to monitor as occupants often refused to allow monitoring equipment to be installed due to concerns over possible power interruptions (which we noted was unlikely with the

[4] www.usablebuildings.co.uk

BEES monitoring equipment). For the 14 servers monitored, consumption ranged from 0.1 kWh/day to 29.9 kWh/day. These were typical business-sized servers – there was one large server farm in a monitored BEES premises, which consumed 160 kWh/day (~60,000 kWh/yr) for one of two server rooms, excluding the HVAC room. These results could suggest that server electricity consumption might be larger on average than hot water energy consumption in commercial buildings.

The monitored electricity data showed the wide variation of electricity consumption between premises and between end-uses.

E.10.2. Appliance Audit Analysis

The following graphs illustrate the appliance penetration in all the monitored premises (Figure E-29), and the premises were further separated into three different groups (Office, Retail, and Other) using the Classification of Premise Activity (CPA) grouping.

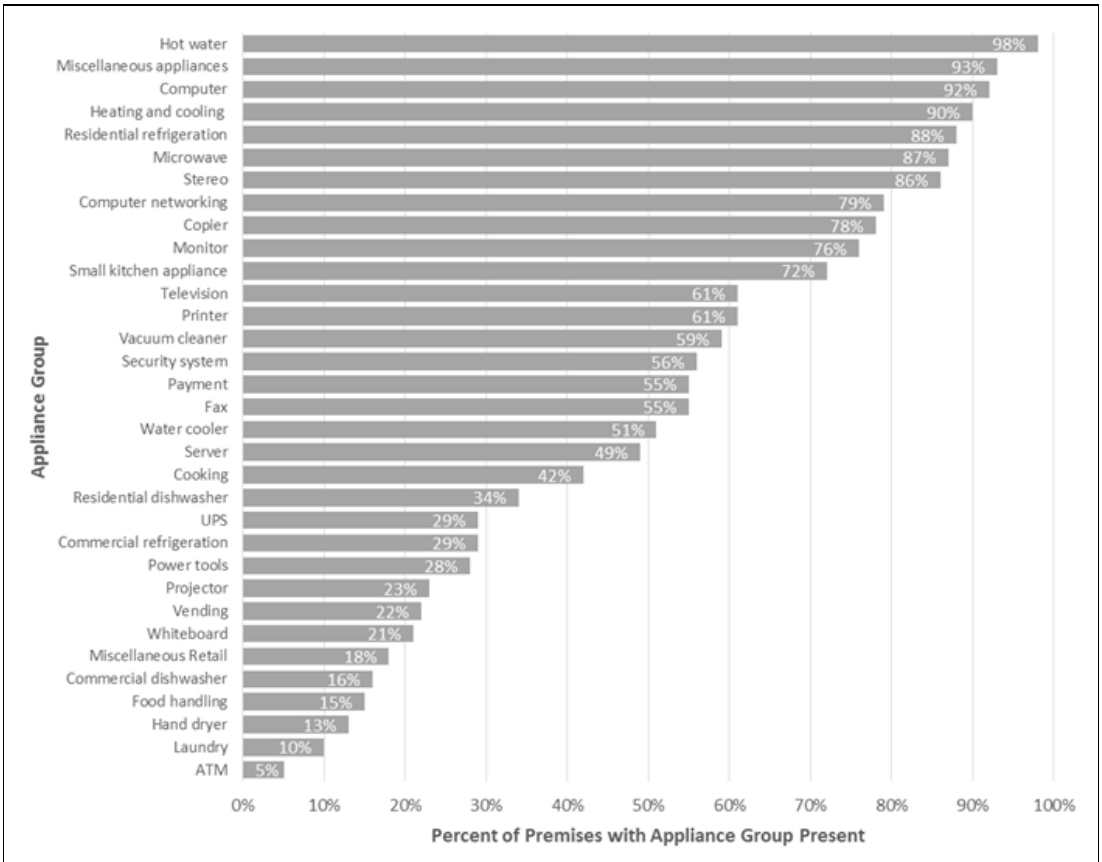


Figure E-29: Appliance Group Penetration.

Modern businesses relied heavily on ICT services 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.

The third-largest activity group was heating and cooling, appearing in 90% of the monitored premises. In some cases, it was the primary means of heating and cooling, but they were 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 expressed their dissatisfaction to the BEES team.

Within this appliance group, heat pump (either 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 penetration (16%) and appeared to be in the process of being displaced by heat pumps – 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 penetration and average count did not, however, provide the full picture, as there could be a wide variation in the number of each appliance between premises. For example, some premises had no computers, whilst some had several hundred. There were likely to be major differences in the appliance stocks for different types of premises (e.g. office and restaurant) and floor areas.

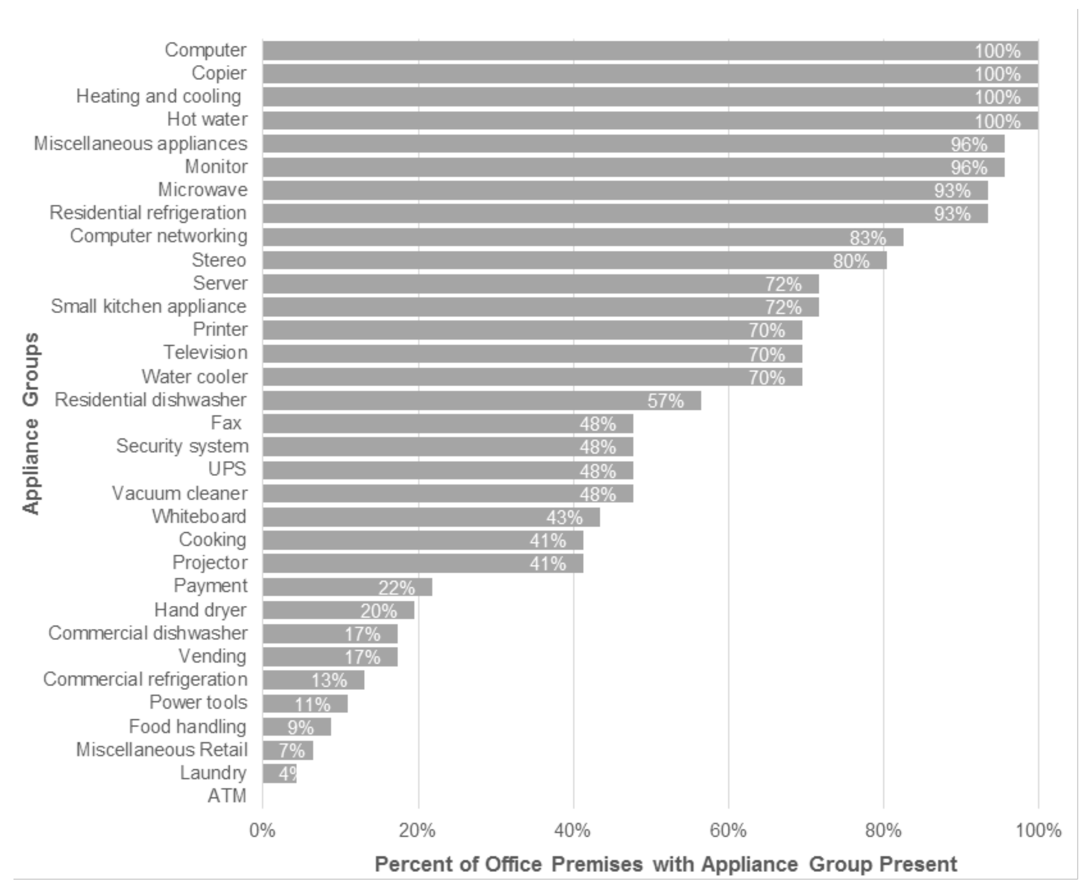


Figure E-30: Appliance Penetration in Office (OFF) Premises.

There were 46 premises within the Office classification, Figure E-30. All of the monitored office premises were ICT dominated with desktop computers (100%) and/or laptops (80%) and copiers (100%). Within the computer grouping, desktop computers were the most common, with an average count of 31.2 per premise, whereas laptops had an average count of 10.6 per premise.

The other appliance groups that dominated the Office premises were the heating and cooling appliances and hot water appliances. Within the heating and cooling appliance group, fans (76%) were the most common. Heat pumps had the second highest penetration at 72%, using an average count of 4.0 heat pumps per premise, followed by portable electric heaters at 63%.

The only appliance group that did not appear in any Office premises were ATMs.

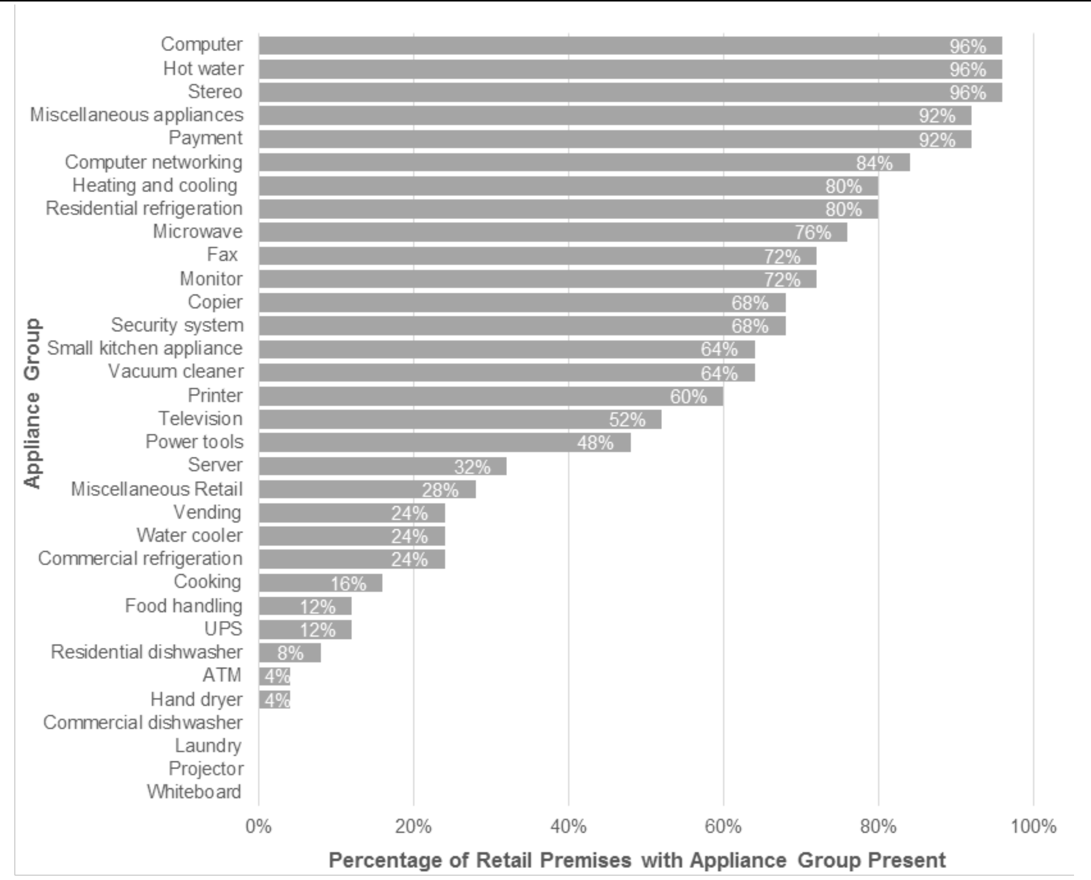


Figure E-31: Appliance Penetration in General Retail (GEN) and Big Box Retail (BOX) Premises.

There were 25 premises within the Retail classification. These range from small retail shops to large hardware stores. None of the appliance groups appear in all the premises, however, computer (96%), hot water appliance (96%) and stereo (96%) were the most common. 80% of the retail premises had a desktop computer with an average count of 5.9 per premise, whereas only 28% of the retail premises had laptops, with an average count of 1.3 per premise.

The appliance groups that did not appear in any retail premises were commercial dishwasher, laundry appliance, projector and electronic whiteboards.

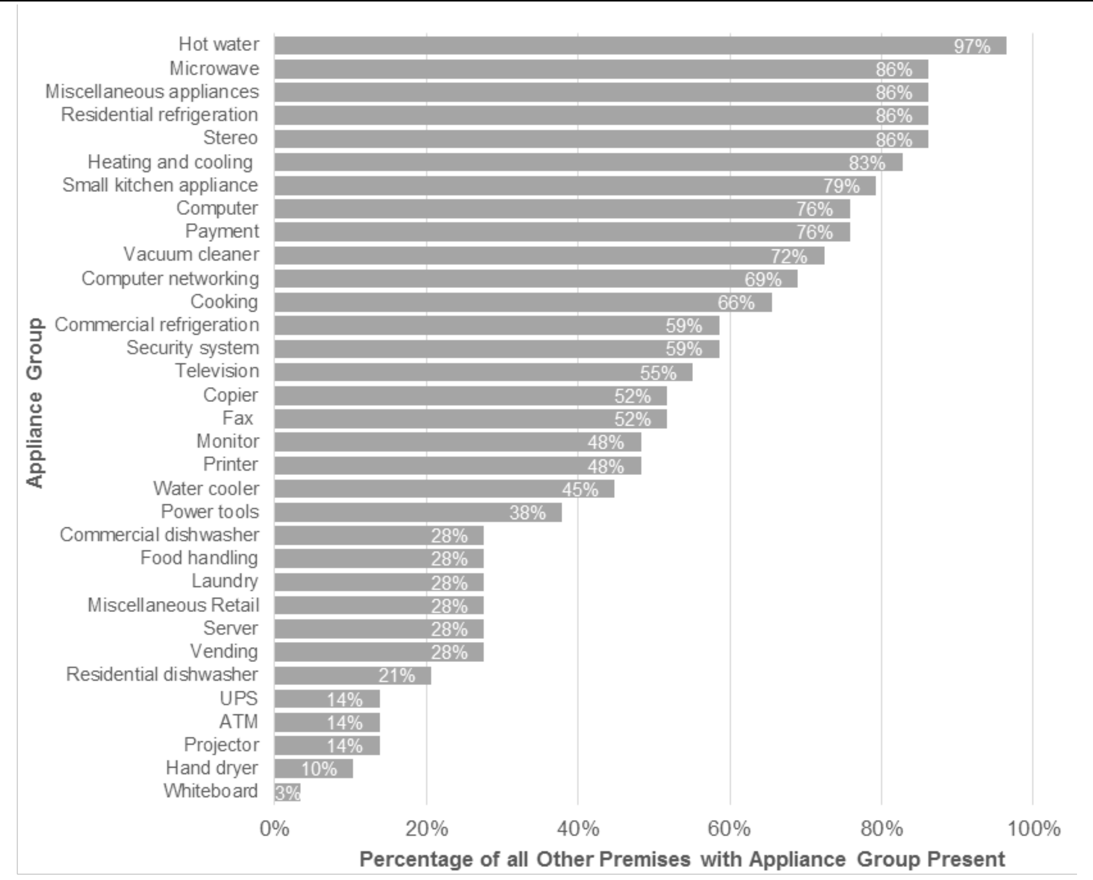


Figure E-32: Appliance Penetration in ICE, HOT, CSV, ISV and MIX Premises.

The remaining premise category ranged from fast food outlets to supermarkets to industrial or warehouse buildings. The most dominant appliance group was hot water appliances, appearing in 97% the premises with an average count of 1.7 per premise.

E.10.3. Lighting Audit Analysis

The total lighting power (W/m^2) was estimated for all the monitored premises. The average installed lighting power per premise by lamp type is provided in Table E-2. The average total installed lighting power per premise was approximately 28,000 W. Approximately 39% of that was from metal halide (MH) lamps, with fluorescent (F) lamps the second largest group (32%).

Table E-2: Estimated Lamp Power and Lamp Power Density.

Lamp	Watts	Percentage	W/m^2	Percentage
Total	28,591	100%	39.7	100%
Metal Halide (MH)	11,288	39%	15.7	39%
Fluorescent (F)	9,118	32%	12.7	32%
Halogen (H)	3,258	11%	4.52	11%
Other (O)	1,608	6%	2.23	6%
Incandescent Reflector (IR)	980	3%	1.36	3%
Compact Fluorescent Lamp (CFL)	645	2%	0.90	2%
Incandescent PAR (IP)	693	2%	0.96	2%
Light Emitting Diode (LED)	502	2%	0.70	2%
Incandescent (I)	499	2%	0.69	2%

E.10.4. Lighting Electricity and Patterns of Use

Lighting was a major end-use in non-residential buildings and, for many premises, consumed a large fraction of the total electricity consumption (estimated at 28% on average). The BEES Daylighting topic report (Bishop, et al., 2011a) 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 activity areas.

Most premises had artificial lights switched on during the morning, staying on at a reasonably steady level during the day and then turned off in the late afternoon or evening. This pattern was typical of premises where most or all of the artificial lights were 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 was very rapid, where all lighting circuits were switched on at a specific time or under an automatic control, as in Figure E-33. In other cases, the lights were more gradual, where switching on and switching off was staged, as in Figure E-34.

Another obvious pattern was that some premises had smoothly varying lighting energy during the day, possibly indicating lights being turned on and off as required as the sun moved 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 E-34.

Most premises had 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 was nearly double the daytime consumption, as shown in Figure E-35. In this premise (a small shop), during the working day, fluorescent lighting was used, while overnight, these were switched off and incandescent spotlights were switched 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 if it is not actually required or to use fewer or more efficient lamps overnight.

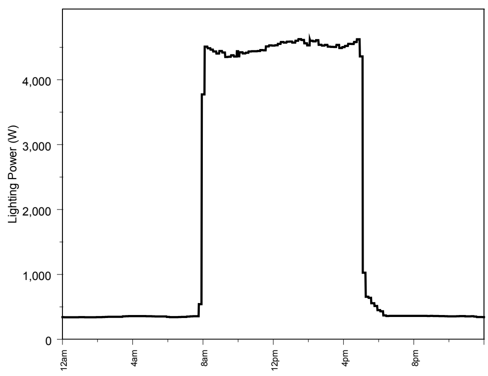


Figure E-33: Lighting Electricity Consumption with Bulk Switch-On/Off.

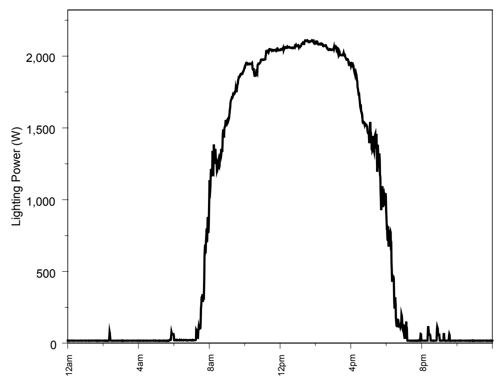


Figure E-34: Lighting Electricity Consumption with Staged (Room-by-Room) Control.

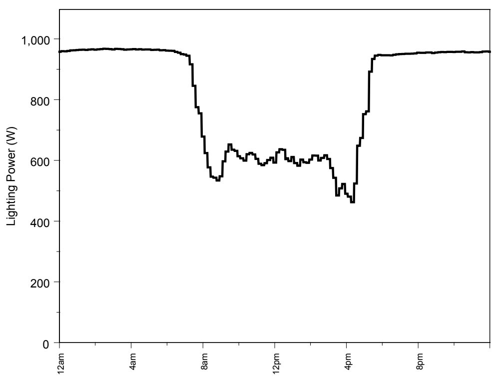


Figure E-35: Lighting Electricity Consumption with Very High After Hours Use.

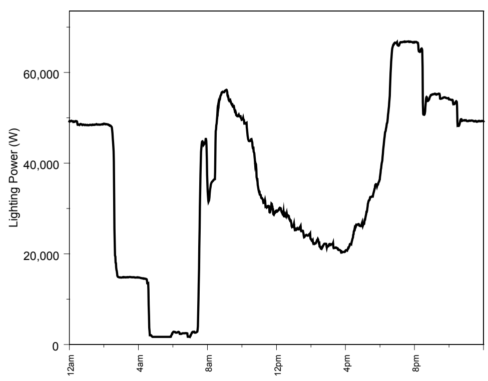


Figure E-36: Lighting Electricity Consumption with Daylighting and Automated Controls.

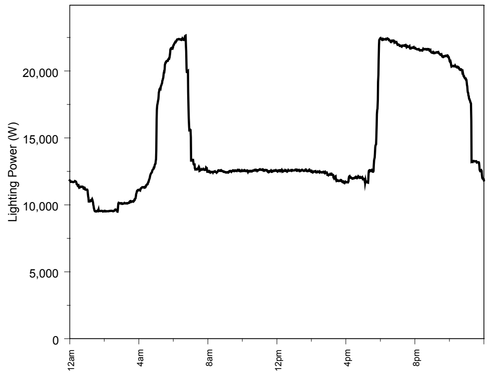


Figure E-37: Lighting Electricity Consumption with High Morning/Evening Use (Car Park Lighting)

There are a few rather odd looking patterns (e.g. Figure E-36) that had high overnight levels, dropped in stages in the early morning before dawn, then high levels in the morning, and levels dropped then rose during the day before the evening peak. These premises collectively were a large retail store that stocks shelves overnight and reduces lighting levels overnight automatically as work shifts finish. Car park lighting was automatically controlled, with the main car park lights turned off at 8:00 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 and then turned off automatically with a daylight sensor. It also had 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 monitored premise that showed clear evidence of effective daylighting controls and, in this case, appeared to be very effective, reducing daytime lighting power by more than 10 kW on average.

Another odd looking pattern (shown in Figure E-37) had morning and evening peaks and a lower steady power consumption during the day. This is another large retail store that had a fully lit outdoor car park, with automatically controlled lighting. The morning and evening peaks were caused by the car park lighting being switched off during daylight hours. In this case, the power for car park lighting appeared 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.

E.11. Premise Reports

The outcome provided to the businesses and building managers was a report documenting the findings from the targeted monitoring process. Over 80 reports were sent out to the monitored premises documenting the energy usage, environmental conditions and an electricity end-use breakdown. The following is an example report.

BEES Monitoring Report for [Business Name]

[Contact person]
[Address line 1],
[Address line 2],
[City]

This report covers the results from **[Business name]** for the period **[monitoring start date]** through to **[monitoring end date]**. BRANZ have processed the data, and have produced the following results. The results contained within this report cover only what was monitored during this period along with any billing information provided to us.

This report contains information on utilities, appliances and resource use specific to your premises, and to the dates shown. Included is information on energy use, temperature, humidity, air quality, lighting and a breakdown of where the energy goes. Where gas or water data is available, this is also included – please note that if you do not pay gas or water bills, this section will not be included.

BUILDING INFORMATION

The following information outlined in Table E-3 was recorded for your premise at the time of visit. These influence the results, so if you see an error, please contact Peony Au on (04) 238 1369.

Table E-3: Premise Information.

Business	**[Business Name]**
Premise floor area (m^2)	**[xx.x]** m^2
Monitored floor area (m^2)	**[if different than premise floor area]** m^2
Nature of use	**[Big box retail/Commercial services/Food preparation and cooking/Food storage/General office/General retail with display lighting/Industrial service/Mixed use]**
Number of staff	**[xx]**
Opening hours	**[Monday to Friday: xx:xx – xx:xx; Saturday and Sunday: xx:xx – xx:xx]**

ENERGY CONSUMPTION

Total

From the billing records provided, the annual energy consumption in the business covered by this report between **[revenue data start date]** and **[revenue data end date]** are illustrated in Table E-4 below:

Table E-4: Estimated Annual Energy Use.

Energy Source	Energy Consumption 20[xx]
Electricity	**[xxx]**kWh/yr
Gas	**[if present]** kWh/yr
Total	**[Electricity/Electricity + Gas]** kWh/yr

Based on a floor area of [xx] m^2, an energy use index figure can be calculated. For **[Business name]** the **[electricity/electricity and gas]** energy performance indicator (EnPI) was calculated to be **[xx]** kWh/m^2.yr. Based on New Zealand Standards 4220:1982 (Standards New Zealand, 1982), the EnPI target for a **[existing/new] [bank/industrial building/office building/personal service building/restaurant/retail trading building/technical service building/wholesale trading building]** (built **[before/after]** 1982) is **[xxx]** kWh/m^2.yr. This is **[lower/higher]** than the New Zealand EnPI target.

Figure E-38 and Figure E-39 below, illustrates the reticulated energy use (electricity and gas, if applicable), taken from billing records for your premise.

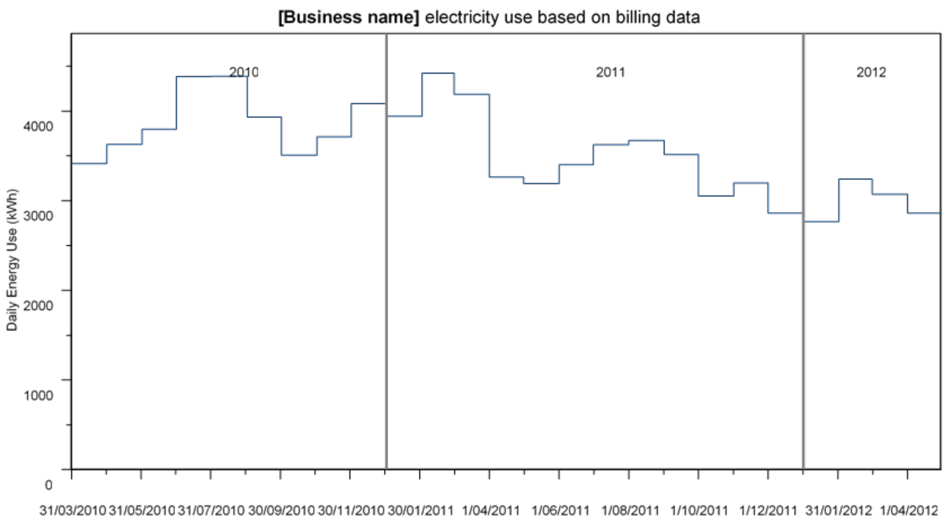


Figure E-38: Daily Electricity Use, Based on Billing Data.

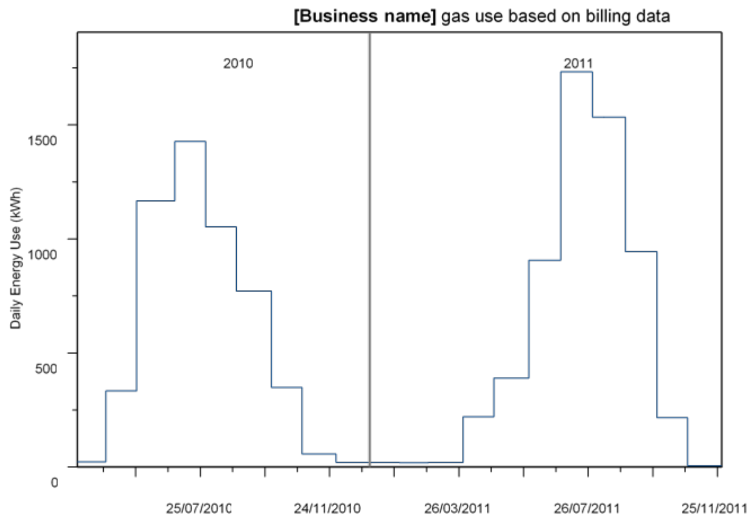


Figure E-39: Daily Gas Use, Based on Billing Data.

Monitored Period Time Series

Between **[monitoring start date]** and **[monitoring end date]**, the daily electricity time series for the monitored areas are illustrated below in Figure E-40. Weekends are banded in grey. The electricity usage may vary quite dramatically depending on the season and the equipment being used.

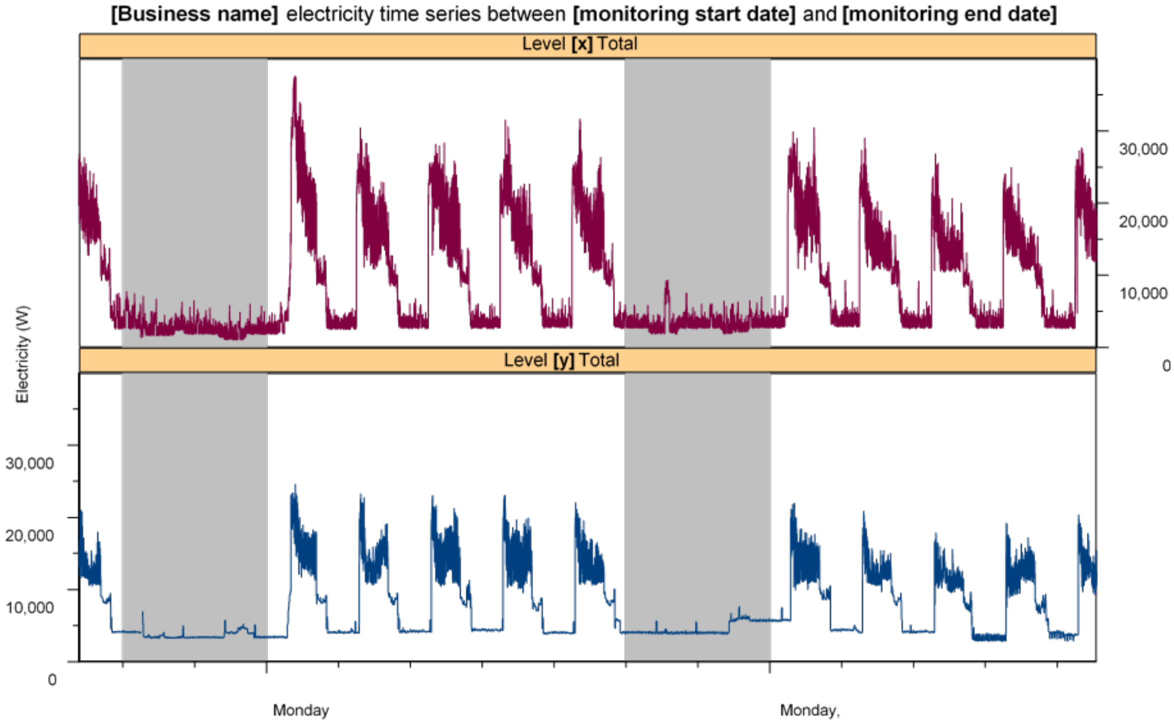
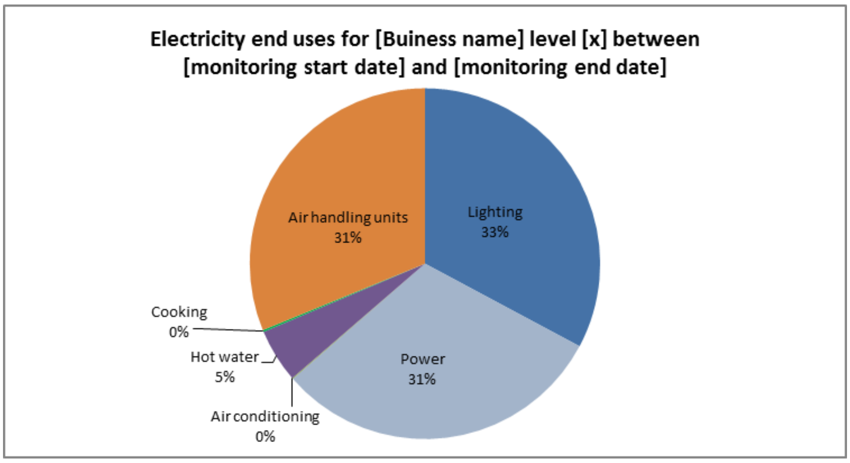
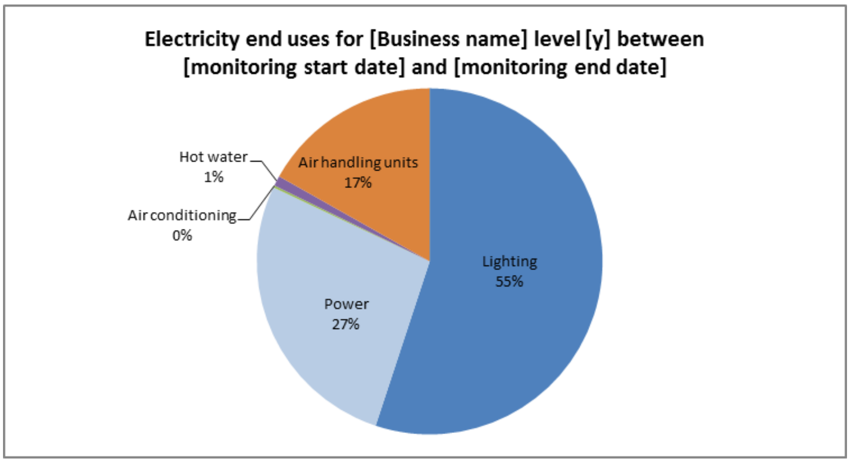


Figure E-40: Daily Electricity Time Series Total During Monitoring Period.

Split of Electricity End Uses

The following graphs illustrate the breakdown of monitored electricity end-uses within **[business name]** for the monitored period.





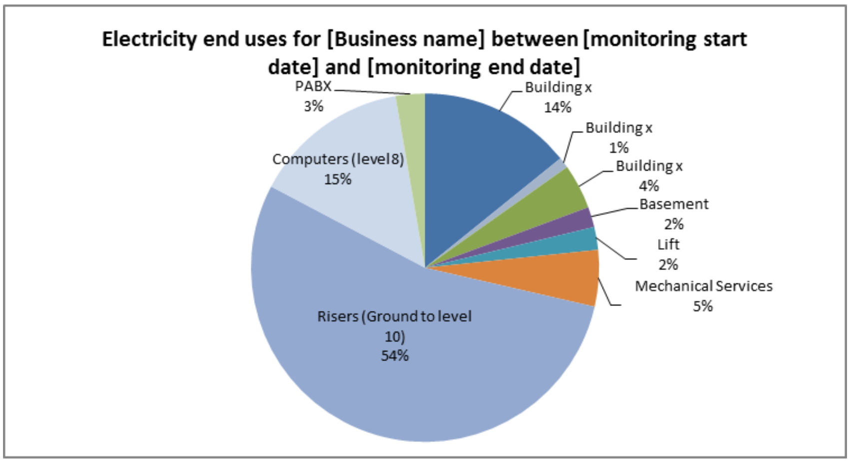


Figure E-41: Electricity End-Uses during Monitored Period.

WATER USE

Between **[revenue start date]** and **[revenue end date]**, **[xxx]** m^3 of water was used, which works out to be an average of **[x.xx]** m^3 per day over this period. The water consumption for **[business name]** during this billing period was **[x.xx]** $m^3/m^2.yr$. The benchmark for commercial buildings in New Zealand is 0.84 $m^3/m^2.yr$ (Bint, 2012).

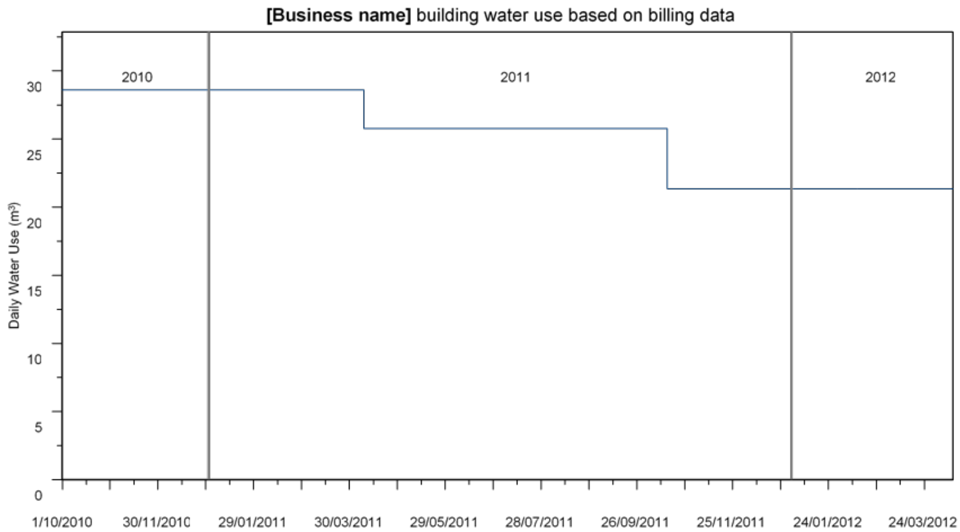


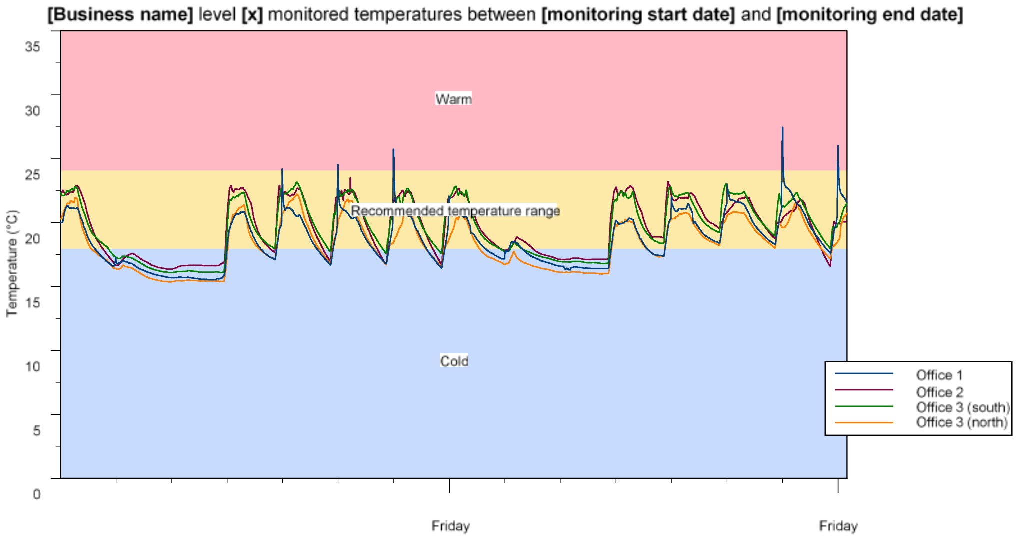
Figure E-42: Water Use, Based on Billing Data.

MONITORED ENVIRONMENTAL CONDITIONS

This section covers the environmental conditions measured in **[business name]** during the monitored period between **[monitoring start date]** and **[monitoring end date]**. The environmental conditions monitored include temperature, relative humidity, air quality, and illuminance measurements. Each graph is separated into three different colour bands. The area with the yellow band is when the measurement values fall within the recommended level; the red and blue bands are when the measurement values fall above or below the recommended levels respectively.

Temperature

The following graphs illustrate the indoor temperatures observed in the premises during the monitoring period. Each logger location monitored is illustrated in a different series in the following graphs, broken up by floors. The World Health Organisation recommends an indoor temperature should be between 18°C and 24°C during occupied hours. This is illustrated by the yellow band.



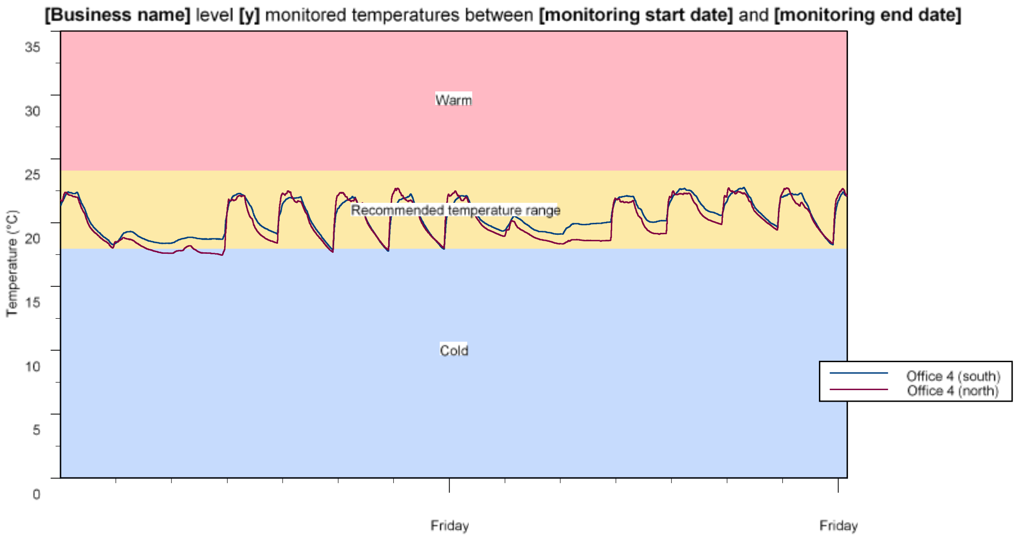
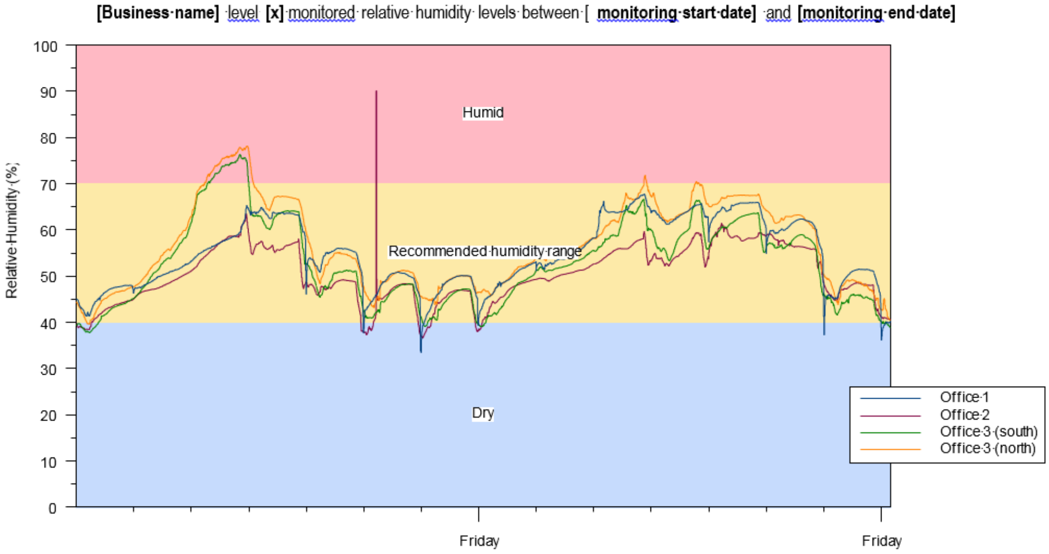


Figure E-43: Monitored Temperatures.

Humidity

The observed humidity levels are illustrated in the graph below. The recommended humidity range, between 40% and 70% is illustrated by the yellow band. Each logger location monitored is illustrated in a different series in the following graphs, broken up by floors.



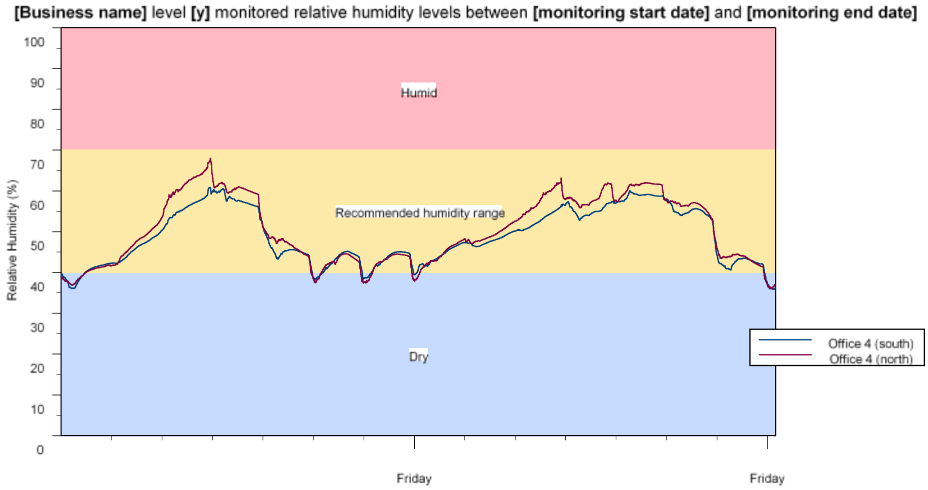


Figure E-44: Monitored Relative Humidity Levels.

Air Quality

The air quality of the space was measured by recording CO_2 levels. The CO_2 levels of **[business name]** are illustrated in the graph below. The typical CO_2 level in an occupied space is between 450 and 1000 ppm. ASHRAE standards recommend that the indoor air quality of a space should not exceed 1000 ppm

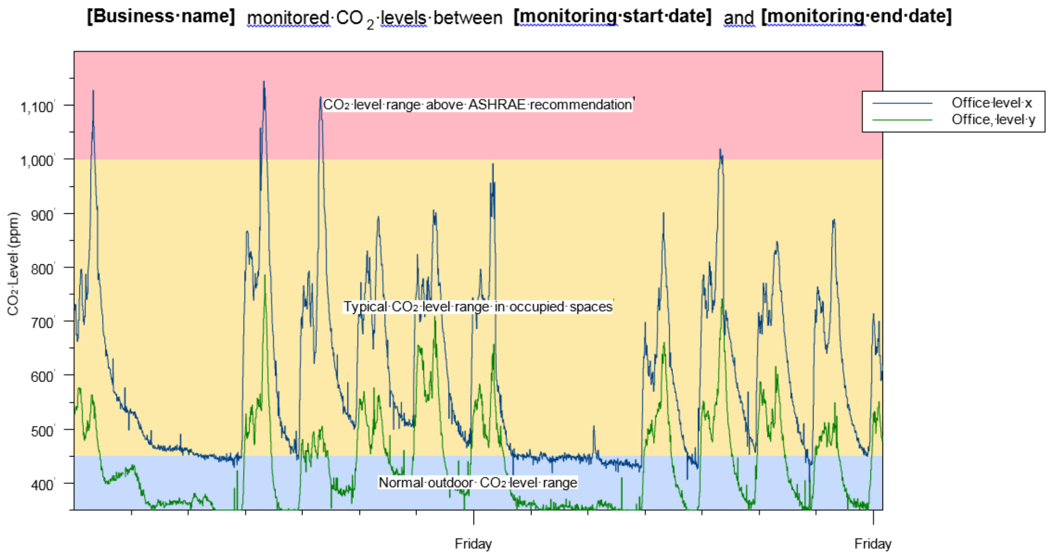
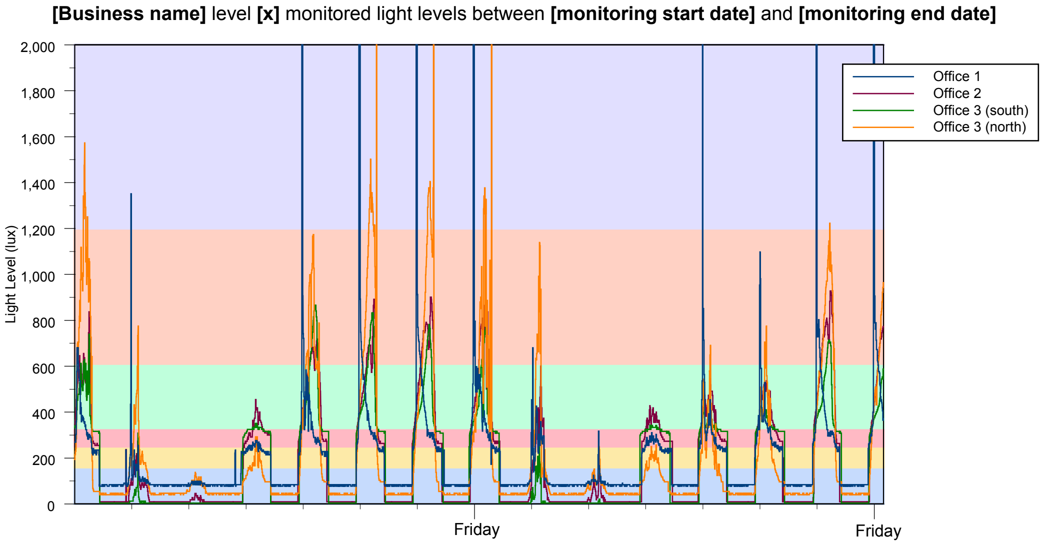


Figure E-45: Monitored CO_2 Levels.

Light Levels

The observed light levels are illustrated below. The generally accepted range of light levels for safe movement is illustrated within the blue band, and the acceptable lighting levels for simple tasks are illustrated in the yellow band. Please refer to Table E-5 on the next page for the explanation of what each colour band represents. Each logger location monitored is illustrated in a different series in the following graphs, broken up by floors.



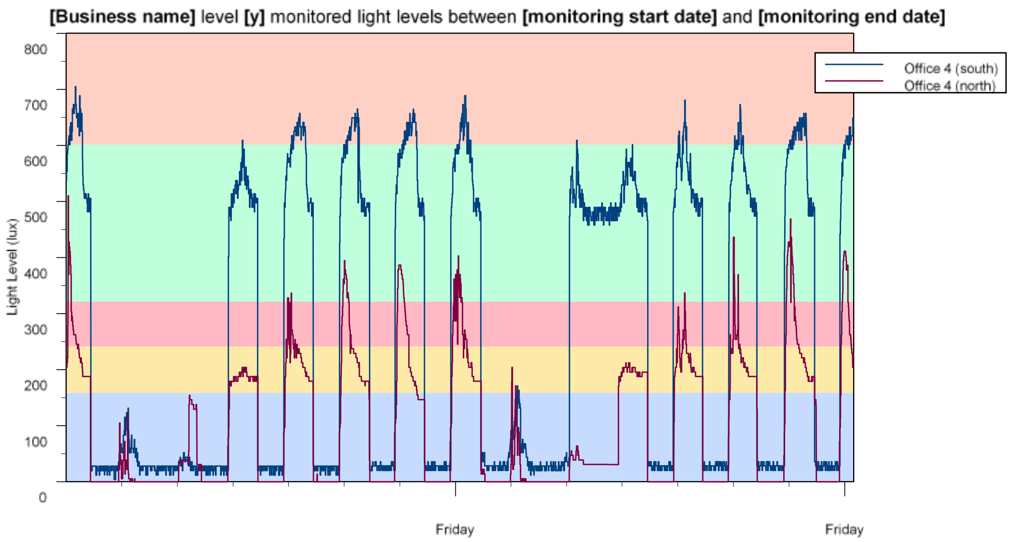


Figure E-46: Monitored Light Levels.

Table E-5 provide the generic lighting levels for working environments as described in AS/NZS 1680.1. Note that these are rough guidelines – specialised tasks and activities may require different lighting levels than those mentioned.

Table E-5: Recommended Maintained Illuminance Levels for Various Types of Tasks, Activities or Interiors from AS/NZS 1680.1 (Standards New Zealand, 2006).

Class of task		Representative activities/interiors	Recommended maintained illuminance (lux)	Characteristics of the activity/interior
Movement and orientation*		Corridors; cable tunnels; indoor storage tanks; walkways.	40	Interiors rarely visited with visual tasks limited to movement and orientation
Rough intermittent*		Staff change rooms; live storage of bulky materials; dead storage of materials needing care; locker rooms, loading bays.	80	Interior tasks requiring intermittent use with visual tasks limited to movement, orientation and coarse detail
Normal range of tasks and work places	Simple	Waiting rooms; staff canteens; rough checking of stock; rough bench and machine work; entrance halls; general fabrication of structural steel; casting concrete; automated process monitoring; turbine halls.	160	Any continuously occupied interior where there are no tasks requiring perception of other than coarse detail. Occasional reading of clearly printed documents for short periods.
	Ordinary or moderately easy	School chalkboards and charts; medium woodworking; food preparation; counters for transactions.	240	Continuously occupied interiors with moderately easy visual tasks with high contrasts or large detail (>10 min arc)
	Moderately difficult	Routine office tasks, e.g. reading, writing, typing, enquiry desks.	320	Areas where visual tasks are moderately difficult with moderate detail (5-10 min arc or tolerances to 125μm) or with low contrast.
		Inspection of medium work; fine woodwork; car assembly.	400	
	Difficult	Drawing boards; most inspection tasks; proofreading; fine machine work; fine painting and finishing; colour matching.	600	Areas where visual tasks are difficult with small detail (3-5 min arc or tolerances to 25μm) or with low contrast.
	Very difficult	Fine inspection; paint retouching; fine manufacture; grading of dark materials; colour matching of dyes.	800	Areas where visual tasks are very difficult with very small detail (2-3 min arc) or with very low contrast.
	Extremely difficult	Graphic arts inspection; hand tailoring; fine die sinking; inspection or dark goods; extra-fine bench work.	1200	Areas where visual tasks are extremely difficult with extremely small detail (1-2 min arc or tolerances below 25μm) or of low contrast. Visual aids may assist.
	Exceptionally difficult	Finished fabric inspection; assembly of minute mechanisms, jewellery and watchmaking.	1600	Areas where visual tasks are exceptionally difficult with exceptionally small detail (<1 min arc) or with very low contrasts. Visual aids will be of advantage.

* Refer also to AS/NZS 1680.0 for minimum requirements for safe movement.

NOTE: See AS/NZS 1680.2 series for the recommended maintained illuminance for specific tasks and interiors.

YEARLY TEMPERATURE AND HUMIDITY LEVELS

A HOBO data logger was left in **[business name]** for one year. The temperature and humidity recorded during this period are illustrated in the graphs below.

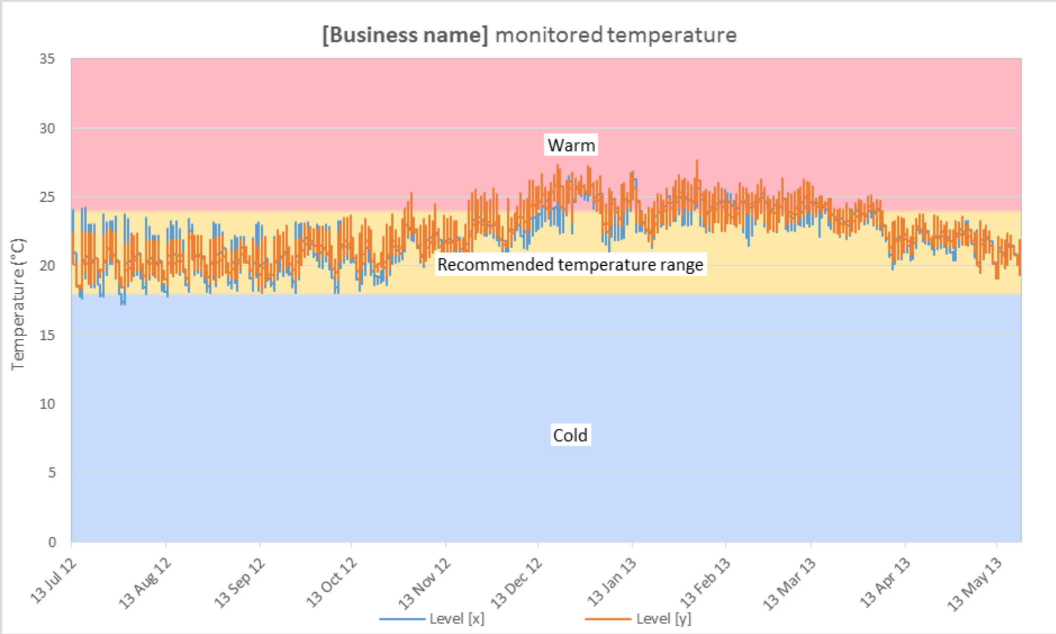


Figure E-47: Monitored Temperature in [business name] between [yearly Hobo start month] and [yearly Hobo end month].

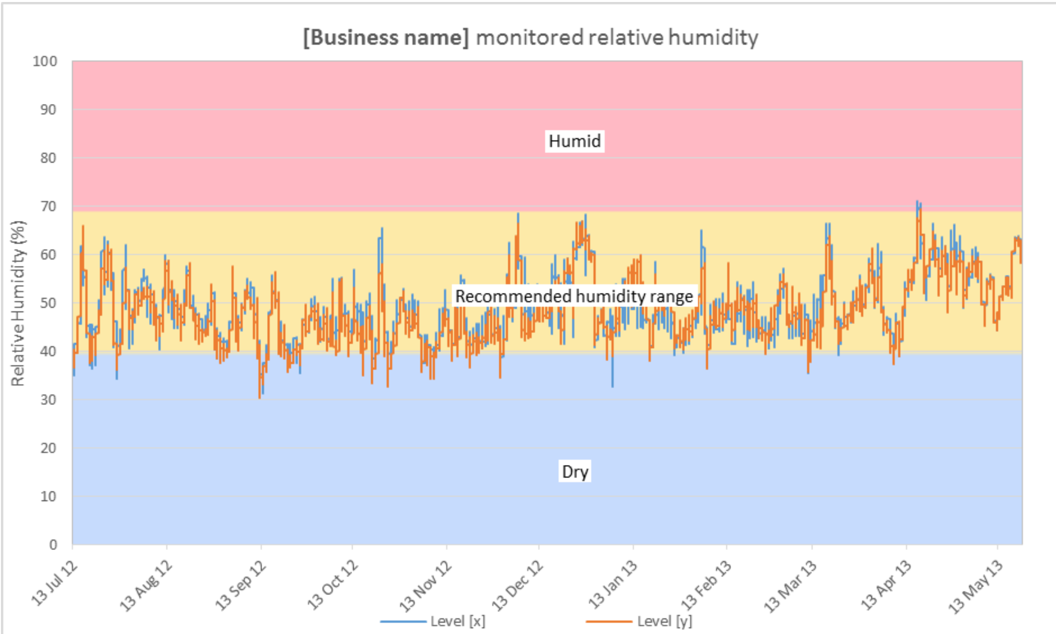


Figure E-48: Monitored Relative Humidity in [business name] between [yearly Hobo start month] and [yearly Hobo end month].

POTENTIAL ISSUES

- **[any issues during installation]**

F. Lighting Information

F.1. Lighting Matrix for Targeted Monitored Premises

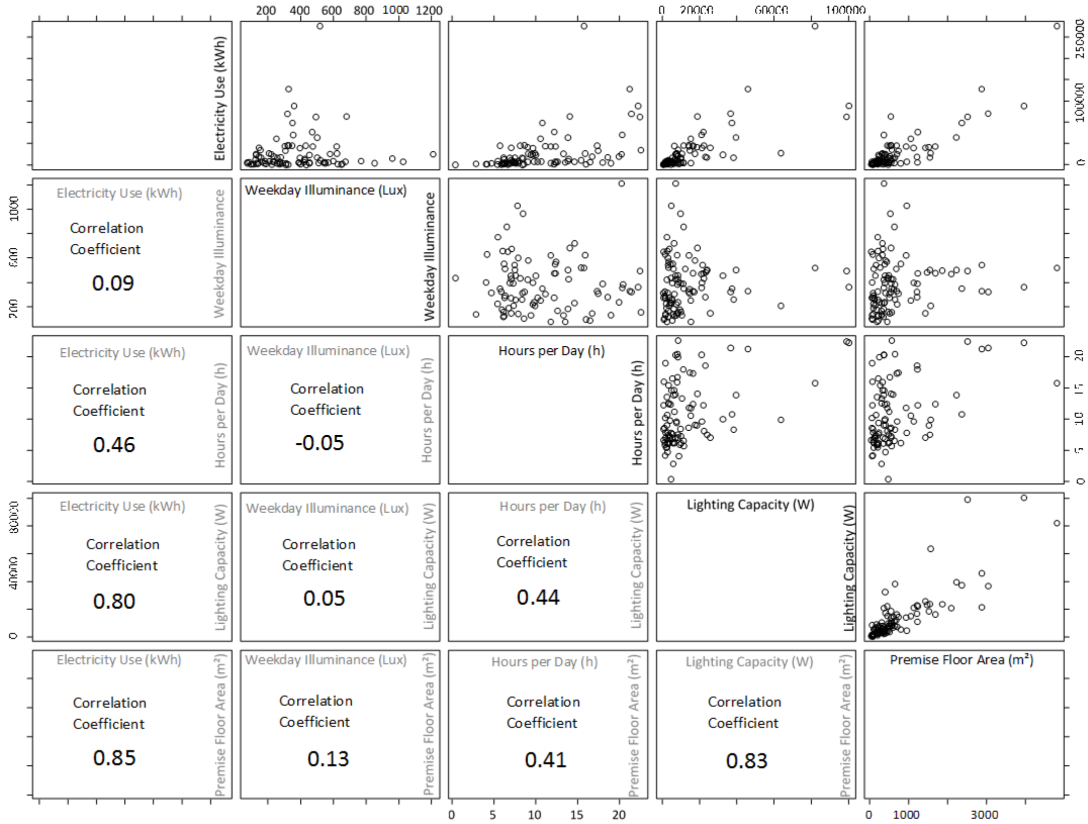


Figure F-1: Matrix Plot of the Annual Electricity Lighting Use, Average Illuminance over Weekdays 10:00 am – 4:00 pm, Estimated Hours of Use, Installed Lighting Capacity and Size of the Premise.

F.2. Lighting Power Density

Table F-1: Lighting Density for Office (OFF) Premises using CPA.

Building Size Strata			Total W of Different Lamp Types									Total W in Premise	Floor Area m²	Lighting Density W/m²
			Compact Fluorescent (CFL)	Fluorescent (F)	Halogen (H)	Incandescent (I)	Incandescent PAR (IP)	Incandescent Reflector (R)	Light Emitting Diode (LED)	Metal Halide (MH)	Other			
	1	Premise 9	-	444	-	300	-	-	-	-	-	744	66	11.3
	1	Premise 43	-	7,750	100	300	-	-	-	-	-	8,150	547	14.9
	1	Premise 58	-	6,104	-	400	-	480	-	-	-	6,984	139	50.2
	1	Premise 75	75	1,740	-	50	-	200	-	-	-	2,065	93	22.2
	Premise Average													**24.7**
	2	Premise 3	1,614	29,715	320	-	-	745	-	-	-	32,394	395	82.0
	2	Premise 5	-	2,392	-	160	-	-	-	-	-	2,552	209	12.2
	2	Premise 47	1,342	12,084	12,300	-	-	-	-	-	-	25,726	1,425	18.1
	2	Premise 57	-	2,016	72	-	-	-	-	-	928	3,016	160	18.9
	2	Premise 66	436	6,390	2,936	1,275	-	-	-	6,900	5,000	22,937	1,212	18.9
	2	Premise 67	1,092	6,348	-	-	-	-	-	-	-	7,440	699	10.6
	2	Premise 68	-	33,892	72	-	-	-	-	-	-	33,964	647	52.5
	2	Premise 69	-	13,668	550	280	-	-	-	-	-	14,498	614	23.6
	2	Premise 80	252	12,874	1,000	-	-	520		-	-	14,646	734	20.0
	Premise Average													**28.5**
	3	Premise 12	-	4,350	-	1,148	-	-	-	1,600	-	7,098	366	19.4
	3	Premise 14	1,176	43,712	800	150	-	-	-	-	-	45,838	2,875	15.9
	3	Premise 223	20	3,552	-	100	-	-	-	-	-	3,672	500	7.3
	3	Premise 23	120	36,518	-	420	-	2,250	192	-	-	39,500	2,225	17.8
	3	Premise 24	-	5,854	-	-	-	-	-	-	-	5,854	103	56.8
	3	Premise 31	-	7,286	3,520	225	-	-	-	-	-	11,031	561	19.7
	3	Premise 32	64	2,832	2,570	300	-	-	-	-	-	5,766	298	19.4
	3	Premise 33	192	2,380	180	40	-	-	-	-	-	2,792	400	7.0
	3	Premise 34b	-	5,076	650	-	-	-	-	-	-	5,726	412	13.9
	3	Premise 60	766	4,974	-	-	-	475	-	-	-	6,215	325	19.1
	3	Premise 61	460	11,884	2,800	-	-	-	-	-	-	15,144	1,052	14.4
	3	Premise 77	160	2,416	270	-	-	-	-	-	-	2,846	235	12.1
	3	Premise 78	324	5,174	2,550	1,050	-	600	-	-	-	9,698	526	18.4
	3	Premise 87	-	1,212	-	-	-	-	-	-	-	1,212	87	13.9
	3	Premise 96	-	7,678	-	240	-	-	-	16,000	-	23,918	1,543	15.5
	Premise Average													**18.0**
	4	Premise 13	756	59,958	2,935	-	-	-	-	-	-	63,649	1,563	40.7
	4	Premise 35	36	15,618	850	-	-	2,000	-	-	-	18,504	1,521	12.2
	4	Premise 36	288	9,340	400	-	660	-	-	-	500	11,188	1,228	9.1
	4	Premise 37	-	3,982	-	320	-	-	-	-	500	4,802	372	12.9

		Total W of Different Lamp Types									Total W in Premise	Floor Area m²	Lighting Density W/m²
		Compact Fluorescent (CFL)	Fluorescent (F)	Halogen (H)	Incandescent (I)	Incandescent PAR (IP)	Incandescent Reflector (R)	Light Emitting Diode (LED)	Metal Halide (MH)	Other			
	Premise 38	208	4,496	650	-	-	-	-	-	-	5,354	218	24.6
	Premise 40	2,106	18,666	350	-	-	-	-	-	-	21,122	1,129	18.7
	Premise 70	1,620	20,886	2,420	-	-	-	-	12,400	-	37,326	2,360	15.8
	Premise 74	4,776	16,560	150	-	-	-	-	-	-	21,486	2,876	7.5
	Premise 76	-	13,284	300	-	-	450	-	-	-	14,034	542	25.9
	Premise 82	13	3,378	-	-	-	-	-	-	-	3,391	441	7.7
	Premise 83		4,698	-	-	-	-	-	-	-	4,698	950	4.9
Premise Average													**16.4**
	Premise 25	911	15,380	700	-	-	-	-	-	-	16,991	1,210	14.0
	Premise 45	1,976	20,782	968	-	-	-	-	-	-	23,726	1,864	12.7
	Premise 90	136	13,207	-	-	-	-	812	-	-	14,155	936	15.1
5	Premise 91	720	16,848	4,450	-	-	-	-	-	-	22,018	1,234	17.8
	Premise 92	-	9,960	-	-	-	-	-	-	-	9,960	550	18.1
	Premise 94	947	17,262	4,950	-	-	-	-	-	-	23,159	1,474	15.7
	Premise 100	1,066	18,786	336	645	-	-	-	-	-	20,833	2,900	7.2
Premise Average													**14.4**
Total W of each lamp type		23,652	563,406	50,149	7,403	660	7,720	1,004	36,900	6,928	**Average lighting density for activity**		**20.4**
% of lamp types		3%	81%	7%	1%	0%	1%	0%	5%	1%			
Number of premises with each lamp type		29	48	29	18	1	9	2	4	4			
% of lamp types		20%	33%	20%	13%	1%	6%	1%	3%	3%			

Lighting power density limit for commercial office = 12 W/m² (Standards New Zealand, 2007).

"Lighting Power Density Limit (LPDL): the limit that the lighting load shall not exceed. It is set in terms of watts per square metre of lit area and based on recommended maintained illuminances and other factors" (Standards New Zealand, 2007).

Table F-2: Lighting Density for General Retail (GEN) and Big Box Retail (BOX) Premises.

Building Size Strata		Total W of Different Lamp Types									Total W in Premise	Floor Area m²	Lighting Density W/m²
		Compact Fluorescent (CFL)	Fluorescent (F)	Halogen (H)	Incandescent (I)	Incandescent PAR (IP)	Incandescent Reflector (R)	Light Emitting Diode (LED)	Metal Halide (MH)	Other			
1	Premise 4	734	5,130	550	610	-	-	-	-	-	7,024	599	11.7
1	Premise 6	54	2,320	-	-	-	-	-	-	-	2,374	188	12.6
1	Premise 26	198	7,286	220	130	-	-	-	-	-	7,834	322	24.3
1	Premise 42	20	6,670	700	600	-	300	-	-	-	8,290	244	34.0
1	Premise 50	-	432	-	800	-	-	-	-	-	1,232	203	6.1
1	Premise 88	-	2,544	-	570	-	750	-	-	480	4,344	384	11.3
1	Premise 98	54	2,264	-	500	-	-	-	7,600	-	10,418	305	34.2
1	Premise 99	-	1,246	900	-	-	100	-	-	-	2,246	88	25.5
1	Premise 101	36	2,378	-	-	-	890	-	-	-	3,304	298	11.1
	Premise Average												**19.0**
2	Premise 1	-	580	250	75	-	600	-	-	-	1,505	57	26.4
2	Premise 10	-	2,948	-	-	-	1,575	-	-	-	4,523	473	9.6
2	Premise 54	-	5,765	680	-	-	100	-	-	-	6,545	210	31.2
2	Premise 56	-	1,296	72	-	-	-	-	1,000	-	2,368	206	11.5
2	Premise 59	-	2,340	-	150	750	2,217	-	-	2,800	8,257	486	17.0
2	Premise 65	180	5,792	450	-	-	-	-	-	-	6,422	497	12.9
2	Premise 71	110	16,788	100	1,720	-	-	-	-	-	18,718	543	34.5
2	Premise 73	23	1,000	-	860	-	-	-	3,600	-	5,483	798	6.9
2	Premise 86	-	1,168	-	18	-	-	-	19,800	-	20,986	807	26.0
	Premise Average												**19.5**
3	Premise 2	-	9,628	-	1,100	-	-	-	4,800	800	16,328	1,684	9.7
3	Premise 8	73	8,352	-	300	-	675	-	-	-	9,400	169	55.6
3	Premise 34a	-	5,114	1,450	-	-	-	-	-	-	6,564	270	24.3
3	Premise 44	246	34,352	720	75	880	400	-	-	-	36,673	3,041	12.1
3	Premise 52	-	17,418	-	-	-		-	4,800	-	22,218	1,000	22.2
3	Premise 64	-	8,558	-	980	480		-	-	-	10,018	473	21.2
3	Premise 79	-	83,098	6,480	-	-	-	-	6,900	3,734	100,212	3,961	25.3
3	Premise 95	-	1,624	-	-	-	-	-	-	-	1,624	110	14.8
	Premise Average												**23.1**
4	Premise 20	90	12,180	480	450	-	-	-	2,000	1,100	16,300	691	23.6
4	Premise 21	-	7,286	300	450	-	-	-	-	-	8,036	515	15.6
4	Premise 49	70	960	97,812	-	-	100	-	-	-	98,942	3,471	28.5
4	Premise 55	166	2,262	250	1,000	-	-	-	-	-	3,678	127	29.0
4	Premise 72	-	5,064	-	240	-	-	-	-	-	5,304	216	24.6
4	Premise 84	-	6,336	9,684	75	-	-	-	65,950	-	82,045	4,807	17.1
	Premise Average												**23.0**

			Total W of Different Lamp Types									Total W in Premise	Floor Area m²	Lighting Density W/m²
			Compact Fluorescent (CFL)	Fluorescent (F)	Halogen (H)	Incandescent (I)	Incandescent PAR (IP)	Incandescent Reflector (R)	Light Emitting Diode (LED)	Metal Halide (MH)	Other			
	5	Premise 93	-	4,416	500	100	-	-	-	-	2,548	7,564	220	34.4
	Premise Average													**34.4**
Total W of each lamp type			2,054	274,595	121,598	10,803	2,110	7,707	-	116,450	11,462	**Average lighting density for activity**		**23.8**
% of lamp types			0%	50%	22%	2%	0%	1%	0%	21%	2%			
Number of premises with each lamp type			14	33	18	21	3	11	0	9	6			
% of lamp types			12%	29%	16%	18%	3%	10%	0%	8%	5%			

Lighting power density limit for supermarkets and shopping malls = 16 W/m² (Standards New Zealand, 2007).

"Lighting Power Density Limit (LPDL): the limit that the lighting load shall not exceed. It is set in terms of watts per square metre of lit area and based on recommended maintained illuminances and other factors" (Standards New Zealand, 2007).

Table F-3: Lighting Density for Service Establishment Premises.

Building Size Strata		Total W of Different Lamp Types: Compact Fluorescent (CFL)	Fluorescent (F)	Halogen (H)	Incandescent (I)	Incandescent PAR (IP)	Incandescent Reflector (R)	Light Emitting Diode (LED)	Metal Halide (MH)	Other	Total W in Premise	Floor Area m²	Lighting Density W/m²
1	Premise 18	-	504	-	120	-	-	-	-	-	624	40	15.6
1	Premise 19	894	1,832	800	160	-	456	-	-	-	4,142	376	11.0
1	Premise 39	234	4,952	-	150	-	-	-	-	-	5,336	385	13.9
1	Premise 41	-	1,624	2850	-	-	-	-	-	450	4,924	117	42.1
1	Premise 85	2912	-		100	-	-	-	-	-	3,012	348	8.7
Premise Average													**18.2**
2	Premise 27	684	2,528								3,212	269	11.9
Premise Average													**11.9**
3	Premise 7	-	4,252	-	550	-	3,975	-	-	-	8,777	63	139.3
3	Premise 63	-	474	-	-	-	-	-	-	-	474	85	5.6
3	Premise 89	115	1,328	-	960	-	-	-	-	-	2,403	359	6.7
Premise Average													**50.5**
4	Premise 81	-	1,404	-	-	-	-	-	-	-	1,404	78	18.0
Premise Average													
Total W of each lamp type		4,839	18,898	3,650	2,040	-	4,431	-	-	450	**Average lighting density for activity**		**24.7**
% of lamp types		14%	55%	11%	6%	0%	13%	0%	0%	1%			
Number of premises with each lamp type		5	9	2	6	0	2	0	0	1			
% of lamp types		20%	36%	8%	24%	0%	8%	0%	0%	4%			

Lighting power density limit for service establishment = 14 W/m² (Standards New Zealand, 2007).

"Lighting Power Density Limit (LPDL): the limit that the lighting load shall not exceed. It is set in terms of watts per square metre of lit area and based on recommended maintained illuminances and other factors" (Standards New Zealand, 2007).

Table F-4: Lighting Density for Warehouse Premises.

Building Size Strata			Total W of Different Lamp Types									Total W in Premise	Floor Area m²	Lighting Density W/m²
			Compact Fluorescent (CFL)	Fluorescent (F)	Halogen (H)	Incandescent (I)	Incandescent PAR (IP)	Incandescent Reflector (R)	Light Emitting Diode (LED)	Metal Halide (MH)	Other			
	1	Premise 11	566	2,238	985							3,789	338	11.2
		Premise 30	1,440	6,306	3,600							11,346	629	18.0
	Premise Average													**14.6**
	2	Premise 97	114	12,320	344					4,680		17,458	740	23.6
	Premise Average													**23.6**
	3	Premise 28	160	3,892	250							4,302	301	14.3
		Premise 29	624	4,824	550							5,998	356	16.8
	Premise Average													**15.6**
Total W of each lamp type			2,904	29,580	5,729	-	-	-	-	4,680	-	**Average lighting density for activity**		**17.9**
% of lamp types			7%	69%	13%	0%	0%	0%	0%	11%	0%			
Number of premises with each lamp type			5	5	5	0	0	0	0	1	0			
% of lamp types			31%	31%	31%	0%	0%	0%	0%	6%	0%			

Lighting power density limit for warehouses = 8 W/m^2 (Standards New Zealand, 2007).

"Lighting Power Density Limit (LPDL): the limit that the lighting load shall not exceed. It is set in terms of watts per square metre of lit area and based on recommended maintained illuminances and other factors" (Standards New Zealand, 2007).

Table F-5: Lighting Density for Cafeteria and Restaurant Premises.

Building Size Strata			Total W of Different Lamp Types									Total W in Premise	Floor Area m²	Lighting Density W/m²
			Compact Fluorescent (CFL)	Fluorescent (F)	Halogen (H)	Incandescent (I)	Incandescent PAR (IP)	Incandescent Reflector (R)	Light Emitting Diode (LED)	Metal Halide (MH)	Other			
Building Size Strata	1	Premise 16	-	1,044	-	40	-	-	-	-	-	1,084	53	20.5
		Premise 17	270	464	950	60	-	-	-	-	-	1,744	84	20.8
	Premise Average													**20.6**
		Premise 15	399	6,922	150	960	-	-	-	-	-	8,431	564	14.9
		Premise 46	100	232	1,300	-	-	-	-	-	-	1,632	62	26.3
		Premise 48	528	1,056	800	100	-	-	-	-	48	2,532	165	15.3
		Premise 51	2,800	636	7,848	2,700	-	1,300	-	-	-	15,284	447	34.2
		Premise 53	1,028	1,232	-	1,400	-	2,360	-	-	2,015	8,035	647	12.4
	Premise Average													**20.6**
	3	Premise 62	120	-	72	450	-	-	-	-	-	642	66	9.7
	Premise Average													**9.7**
Total W of each lamp type			5,245	11,586	11,120	5,710	-	3,660	-	-	2,063	**Average lighting density for activity**		**17.0**
% of lamp types			13%	30%	28%	14%	0%	9%	0%	0%	5%			
Number of premises with each lamp type			7	7	6	7	0	2	0	0	2			
% of lamp types			23%	23%	19%	23%	0%	6%	0%	0%	6%			

Lighting power density limit for cafeteria and restaurants = 8 W/m² (Standards New Zealand, 2007).

"Lighting Power Density Limit (LPDL): the limit that the lighting load shall not exceed. It is set in terms of watts per square metre of lit area and based on recommended maintained illuminances and other factors" (Standards New Zealand, 2007).

G. Lessons – How to Monitor HVAC Loads

BEES was designed to collect standardised energy-use data for a wide range of New Zealand non-residential buildings. It did not capture enough 'cause and effect' data to rigorously define HVAC energy use in detail.

For future reference, this section describes the lessons learned from the monitoring of HVAC in this study. It uses the concept of levels of detail, like the Level 1, Level 2, Level 3 terminology used in the existing energy audit standard (NZS 3598:2014 *Energy audits*) and practice.

The following describes four levels of monitoring and analysis of HVAC systems, each rising in complexity and delivered information. They are specified in terms of how they monitor:

- the thermal loads on the building
- the air delivery system that supplies the heating and cooling to those loads
- the heating and cooling mechanical plant that provides the energy to the system(s).

Then the methods of analysis and modelling that are required for this level are listed and finally the information about the HVAC system that results from the monitoring.

HVAC systems are conceptualised in their design and operation as consisting of primary and secondary elements, though these are sometimes combined into the classic book on energy analysis for buildings (Knebel, 1983), which states:

> The type of HVAC systems and equipment serving the building, their capacities, and method of control have a significant effect on the energy requirements of a building. It is important to gain a thorough understanding of these items to obtain reliable results. The information gathered should include the operating schedules of the HVAC systems and equipment, the generic system type, component control method and component performance data.
>
> The secondary system is the delivery mechanism by which conditioned air is introduced into the space in order to achieve comfortable room temperatures and humidity levels.
>
> The primary (plant) system consists of energy conversion equipment (chillers, boilers, etc.) which supply heating and cooling media (hot water, steam, chilled water, etc.) to the coils located in the secondary system air streams. The primary systems respond to meet the loads imposed by secondary systems.

G.1. Level 1 – Overview

This is monitoring of the overall loads for HVAC and the building, without any attempt to discern the logic of the design or operation of the systems (this was the level used in the standard BEES monitoring).

Load Monitoring:

Log temperatures (spaces and external) as a time series.

Log whole-building energy (or use revenue data) as a time series.

Record the floor area of each premises/building.

System Monitoring:

(None at this level).

Plant Monitoring:

Log plant room power as a time series.

Modelling and Analysis:

Only on a floor area (m^2) basis.

Results:

HVAC (plant room) energy use: 24-hr patterns, kW_{peak} and kWh/day (electricity and gas) by weekday and weekend day, kWh/m^2.day.

Whole-building energy use: kW_{peak} and kWh/day (electricity and gas), kWh/m^2.day.

HVAC energy as a fraction of whole-building energy.

Extrapolated annual kWh/yr for HVAC.

Comfort: consistency of temperatures, fraction of occupied hours within comfort range, internal temperature stability vs. difference between internal and external temperatures (as covered in the previous year's topic report).

Control: temperature load profiles for workdays and non-workdays; how these temperatures correspond to operating times of plant room equipment.

HVAC performance line: (from revenue data) monthly average whole-building kWh/day versus monthly average Tout.

HVAC performance line: (from monitored data) daily plant room kWh/d versus daily 24-hr average Tout.

G.2. Level 2 – Design Analysis

This level examines the HVAC design, from observations about the building and its visible HVAC systems, using equipment nameplate ratings, mechanical plans and manuals, and surveys of the system operators and maintenance contractors.

Load Monitoring:

Define the comfort intentions for the space, including the desired temperature range and hours it applies.

Describe the building spaces, in terms of exposed areas to outside air, and R-values of glazed and opaque surfaces.

Describe the intended outside air supply rate and control (if any).

System Monitoring:

Describe the type(s) of conditioned air delivery systems (whether variable air volume [VAV], constant volume, etc.).

Include areas where small split systems or computer room process coolers are in place.

Define the intended supply air flow rates and temperatures by each supply air fan or air handling unit (AHU).

Use mechanical documents or if possible commissioning results – if neither are available, then divide estimated peak loads by ΔT.

Plant Monitoring:

Describe the plant equipment sizing (peak kW input loads for all major plant items: chillers, boilers, fans, pumps).

Modelling and Analysis:

Calculate the heat loss coefficient of the space using reasonable assumptions about R-values and infiltration rates.

Calculate the average and peak internal heat gains, using monitored lighting and equipment load data, and estimates of solar and metabolic gains.

Results:

Space temperature-dependent loads: W/°C, W/m^2 °C, kW_{peak}, W_{peak}/m^2.

Space temperature-independent loads: internal electric (lights and plugs) loads, solar gains, metabolic gains, in kW_{peak}, W_{peak}/m^2.

Air flow rates: supply air and outside air by individual system, in L/s and $L/s.m^2$ (and show that these will meet the peak loads).

Plant sizing and diversity: for all chillers, boilers, etc. W_{peak}/m^2 (importance – how this compares to the defacto standard of 100 W_{peak}/m^2).

Expected component performance lines, based on design loads, operating times and estimated efficiencies: kWh/day versus temperature.

G.3. Level 3 – System Operation

This level comprises detailed monitoring of the operation of the HVAC system.

Load Monitoring:

As above, plus log space CO_2 concentration as a time series.

System Monitoring:

Record (from Building Management System (BMS)) all zone temperatures, set points and heating/cooling responses (for specific analyses).

Log time series of main duct air temperatures: outside air, supply air, mixed air, some zone air temperatures (particularly important for 'problem' zones with comfort problems or anomalous operation.

Log time series (from BMS) of outside air damper position (to infer varying outside air delivery rate).

Log (if VAV) duct trunk pressure downstream of AHU; if constant volume, one-time measurement of duct pressure.

Plant Monitoring:

Log main HVAC components' power as time series.

Boiler efficiency (flue gas) test.

Modelling and Analysis:

Duct and zone temperatures – model dynamic operation of systems based on this, and use it to identify simultaneous heating and cooling (extrapolate year-round building load profiles and energy totals).

Duct pressure logs (for VAV systems) – show if VAV system operation matches loads, so if VAV system is performing as intended.

Outside air management – how much extra heating and cooling is required by outside air delivery, compared to optimal.

Plant component operation – are on/off times reasonable? Are part/peak loads reasonable?

Results:

HVAC maximum demands and diversity, based on measurements, and compared to design assumptions.

Including peak loads (perhaps extrapolated) in W_{peak}/m^2, load profiles (% of time at each fraction of full load), typical daily load profiles. Observe and see if they are consistent and intuitively appropriate.

Outside air supply rate and its effect on heating and cooling.

Plot of (simultaneous) space heating and cooling demand by zone.

Plot of the response of the heating and cooling systems, by observed BMS points.

Plots of dynamic operation of some 'problem' zones, giving insights into their operation (like Te Papa dashboard).

Plot the correlation between each day energy use for each piece of equipment and the average outside air temperature. Expect to see more cooling when warmer, more heating when cooler and set temperatures beyond which no heating or cooling is done.

Compare the amount of power used by each piece of equipment with the difference between supply air and RA temperatures.

Examine the amount of outside air supplied to the space to see if it is too much during periods of high or low outdoor temperatures.

See how chiller power follows indoor (RA) temperature to see how well the chiller maintains a set RA temperature, as intended.

G.4. Level 4 – Component Efficiency

This level comprises detailed monitoring of individual items of HVAC plant to determine their in situ efficiency and how the actual flow rates achieved compare to those from the original design.

Load Monitoring:

As above, plus (perhaps) log luminance near windows to infer actual solar heat gains.

System Monitoring:

As above.

Plant Monitoring:

As above, plus one-time measurements of water and air flow rates and pressure rises across pumps and fans.

Log a time series of chiller and boiler flow and return temperatures, as well as condenser flow and return temperature.

Modelling and Analysis:

Calculations of the delivery efficiencies of the monitored plant items at a range of operating conditions.

The observed on time of main plant items and the amount of heat they deliver.

Results:

See how the actual design conditions (flow rate and pressure drop) across the main system fans and pumps compares with the conditions assumed for the design. Note how this impacts on the efficiency of the plant.

Calculate a time series of inferred loads on the heating and cooling plants from (flow rate x ΔT) for the HHW and CHW loops; perform consistency check on chiller from an energy balance: (flow rate x ΔT) for the condenser water should equal (flow rate x ΔT) for the chilled water plus chiller power input.

One of the most important factors to understand is how much reheat is required. If hot water heating is used, the boiler heating hot water supply and return temperatures can be measured to show this. If electric reheat is used, it would normally be supplied on a zone level and not be practical to measure for the whole building.

Calculate the above inferred loads more accurately, using better estimates of the flows.

Calculate fan, pump and chiller efficiencies.

EECA has produced their own standards for auditing the energy efficiency of electric motor-powered fan and pump systems. They provide checklists for the observations required and a space to put the results of measurements but do not describe how to actually perform the required fan and pump measurements, particularly of flow rate, which is notoriously difficult to measure reliably. Without an adequate flow (or pressure) measurement, an estimate must be used, which can often be wildly inaccurate. Anecdotal data suggests that equipment often operates well away from its design parameters, so even relying on manufacturers' or designers' data is not necessarily indicative of in situ performance.

Thus, the existing EECA standards must be considered insufficient for determining the actual energy efficiency of HVAC components.

H. Observations from Outliers Report

An earlier report (Bishop & Isaacs, 2012) examined energy use for a small number of very large or very small energy-using premises. It found that the highest HVAC fractions were from the two under-serviced premises, where HVAC made up 36% and 65% of the annual energy loads. For the restaurants and factory/retail premises, there was no explicit HVAC energy use.

Table H-1: HVAC Loads.

Name	Use	Floor Area (m²)	EnPI (kWh/m².yr)	Peak Load Density (W/m²)	Full Load (hr/day)	HVAC Percentage of Total Energy
High 5	Butcher shop	216	149	27	15.2	19%
High 3	Supermarket	3,621	30	10	7.9	7%
Low 5	Activity centre	85	28	-		65%
High 2	Liquor store	298	17	6	7.8	4%
Low 1	Hardware store	384	5	-		36%
Low 4	Building supplies	1,680	2	2	4.0	6%
Low 2	Office/warehouse	1,543	1	1	2.3	4%

The only large HVAC load measured among the outliers was for the butcher shop, which was monitored over Christmas when heat pumps were running almost constantly.

The highest HVAC fractions were from the two under-serviced premises, where HVAC made up 36% and 65% of the annual energy loads.

For the restaurants and factory/retail premises, there was no explicit HVAC energy use.

H.1. Descriptions of Individual Premises

Graphical information in the following section is presented as load profiles, with many 24-hour periods overlain to allow the patterns of operation to be seen. For all the measurements presented in these graphs, each individual weekday profile is shown as a light grey line, and each individual weekend day profile as a light pink line. The weekday average is shown as a solid black line and the weekend average as a solid red line. Temperature load profiles show a pale green band, representing the nominal comfort zone of temperatures between 20°C and 24°C.

H.1.1. Office Tower 1

This was a portion of a seven-storey office tower that was monitored in the summer. The temperature was tightly controlled and usually only varied by ±0.5°C between 7:00 am and 6:00 pm on weekdays and weekends. This caused relatively large HVAC loads, averaging 89 kWh/m².yr, which accounted for 49% of the total premises load of 182 kWh/m².yr.

The following two graphs (Figure H-1 and Figure H-2) show the load profile of monitored building temperatures and CO_2 levels in January.

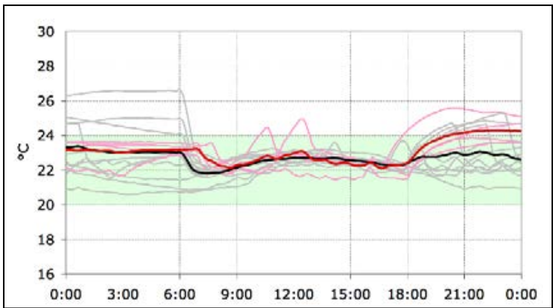


Figure H-1: Monitored Temperatures by Time of Day.

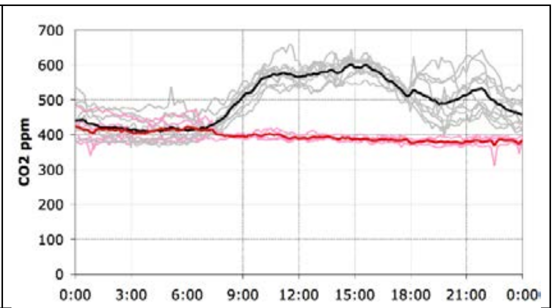


Figure H-2: Monitored CO_2 by Time of Day.

As shown, all the recorded weekday temperatures were within this comfort zone, as were most of the weekend temperatures. The building's cooling systems started at 6:00 am each day and dropped the temperature to an average of 22°C by 7:00 am. After 6:00 pm each weekday, the temperature was allowed to rise slightly, up to about 23°C. On weekend evenings, the temperature was not controlled and typically rose to about 25°C.

The load profiles of space CO_2 concentrations are also shown in Figure H-2. The CO_2 concentration remained at about 400 ppm overnight and on weekends and showed a consistent profile with a peak of about 600 ppm during working hours on weekdays.

The electrical load profiles of the premises' HVAC systems are shown in Figure H-3 below. The units are normalised as W/m^2, with the total demand divided by the floor area of the space.

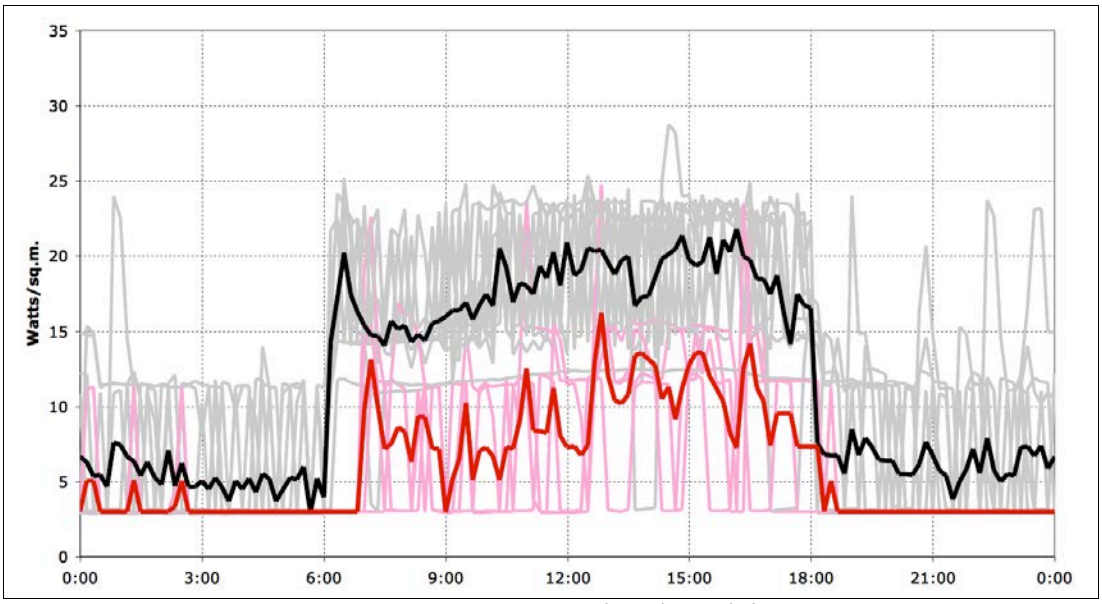


Figure H-3: Electrical Load Profile of HVAC Systems.

There is a constant base load of about 3 W/m^2 and a continual, but varying, demand of at least 15 W/m^2 from 6:00 am until 6:00 pm each weekday, with a lower demand, sometimes dropping to zero overnight. On weekends, there is an occasional load between 7:00 am and 6:00 pm, with almost no overnight load.

H.1.2. Local Government

This premise was a complex of local government offices of eight buildings comprising 2,875 m^2 around a central (coal-fired) boiler plant, monitored during the winter period.

This premise had a variety of HVAC systems, with HVAC electrical loads measuring 38 kWh/m².yr, which accounted for 38% of the total premises electrical load of 100 kWh/m².yr.

The following graph (Figure H-4) shows the load profile of temperatures monitored in an office in the main building from May 2011.

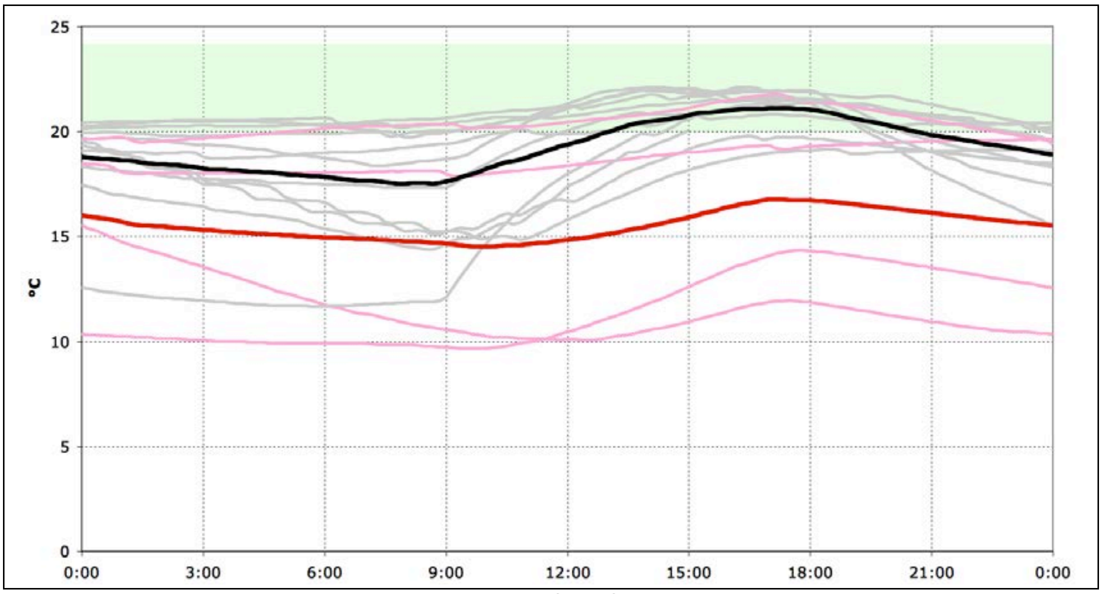


Figure H-4: Load Profile of Temperatures.

As can be seen, on working days, the space temperature rarely exceeded 20°C and dipped to 10°C on two separate weekend days.

As shown in the following graph (Figure H-5), the space ventilation rate was not excessive, with measured space CO_2 concentrations averaging 800 ppm on weekday afternoons and around 1,000 ppm on the peak days. Weekend CO_2 concentrations stayed at 400 ppm, indicative of no occupancy.

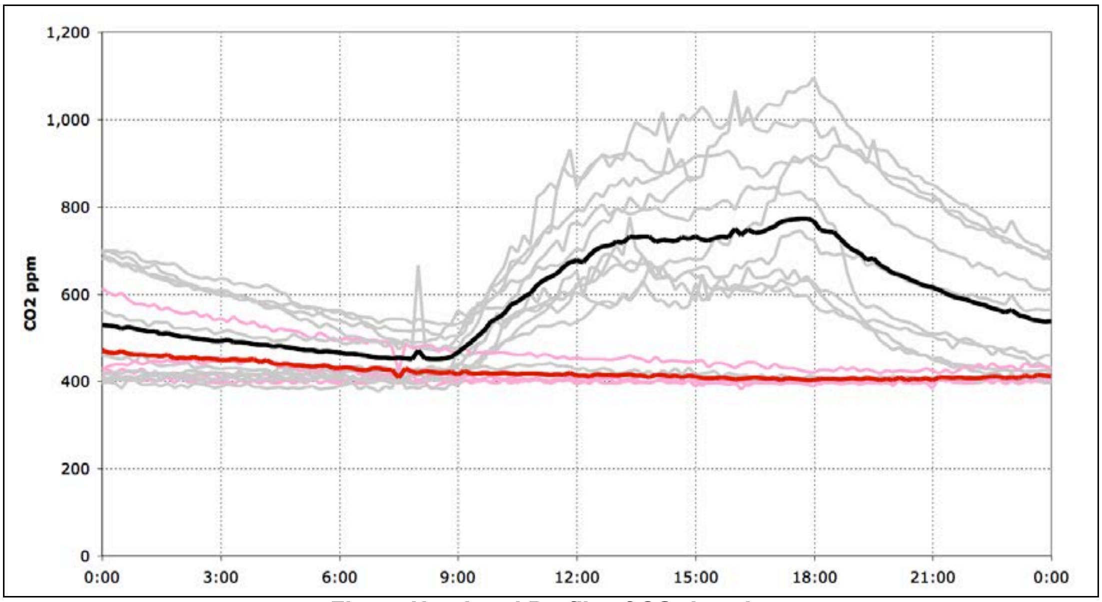


Figure H-5: Load Profile of CO_2 Levels.

This complex had many different HVAC systems, none of them interconnected, and few of them well controlled. Figure H-6 shows HVAC systems conditioning the spaces shown above. It operates virtually continually, with a small peak in the morning, presumably when its set point is increased for morning warm-up.

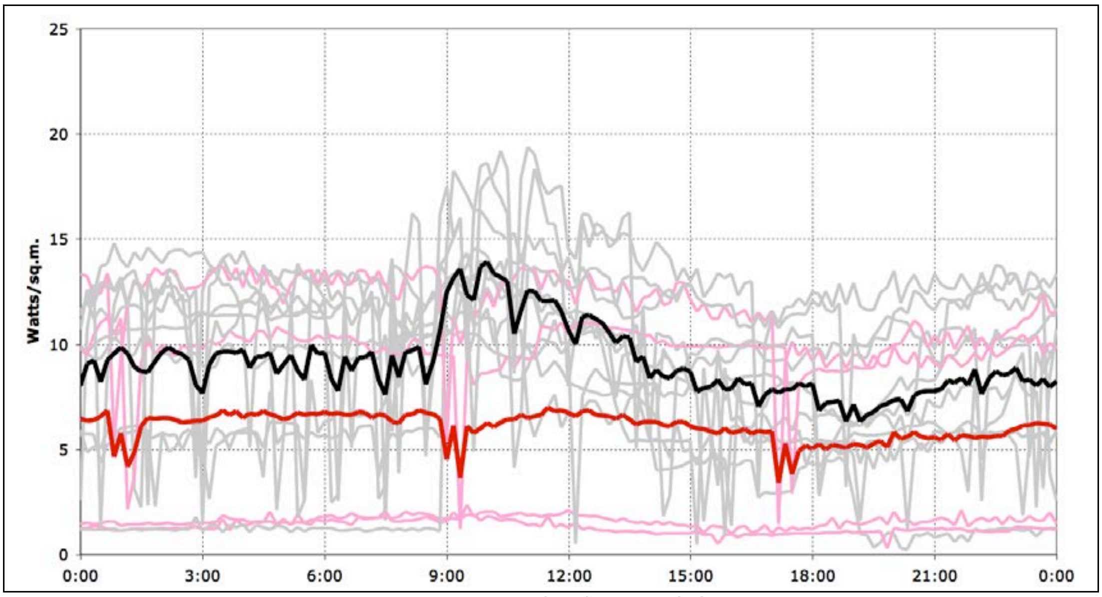


Figure H-6: Load Profile for HVAC Systems.

Other systems run continuously, switching on and off 24 hours per day, on both weekdays and weekends, as shown in Figure H-7 below.

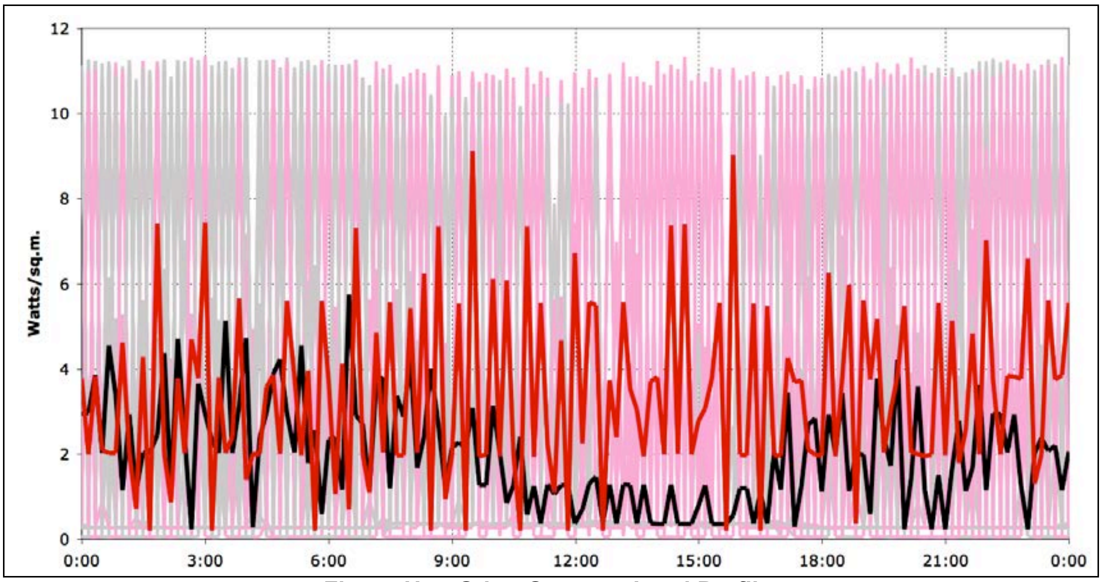


Figure H-7: Other Systems Load Profile.

Other heaters only ran during occupation. Figure H-8 shows one running on weekdays each day from about 6:30 am until 8:30 am, then throttling as required until 6:30 pm.

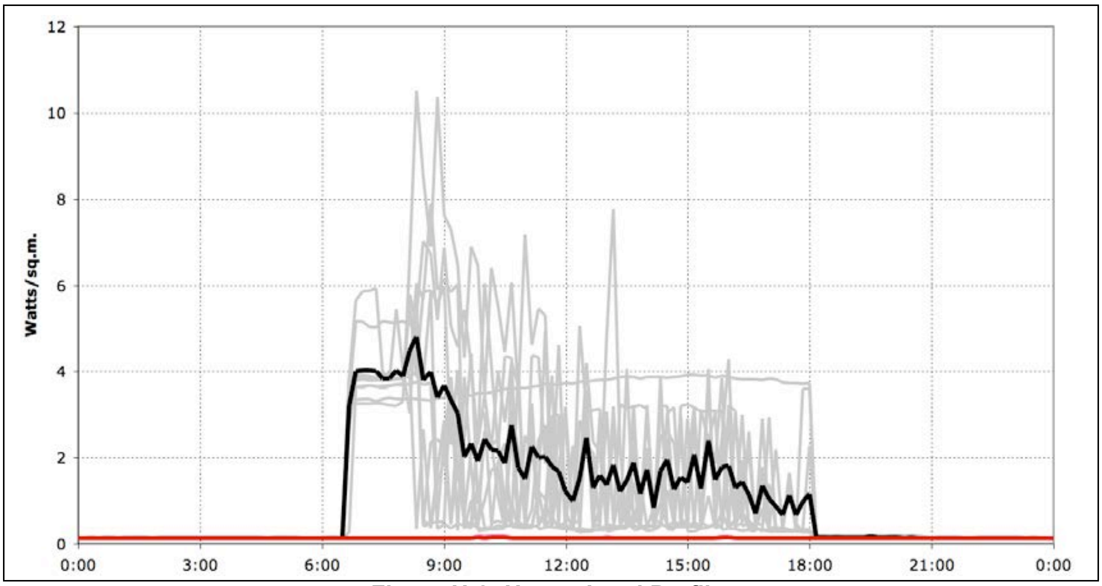


Figure H-8: Heater Load Profile.

H.1.3. Office Tower 2

A portion (about one-quarter) of an office tower was monitored during the summer period. HVAC loads and total premise electrical loads were particularly high here. HVAC loads were measured as 178 kWh/m².yr, which accounted for 59% of the total premises load of 302 kWh/m².yr.

Figure H-9 shows the temperatures recorded in the space during the monitoring period.

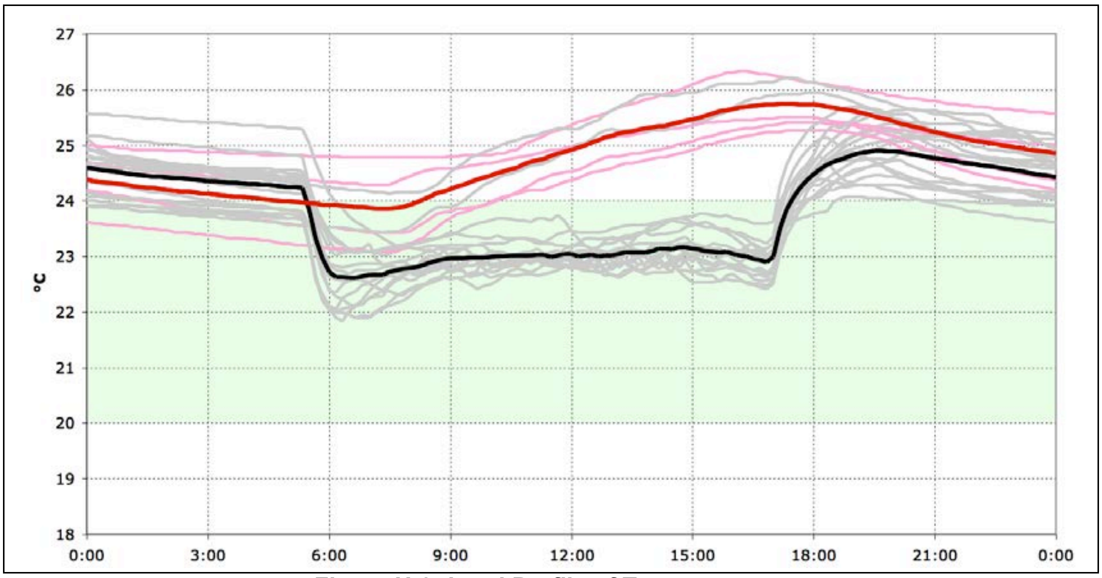


Figure H-9: Load Profile of Temperatures.

Overnight temperatures are normally in the range 24–26°C, dropping to about 23°C when the air-conditioning system starts just before 6:00 am. Temperatures are very closely controlled, typically within ±0.3°C for the duration of the working day.

Figure H-10 shows the electrical demand of the HVAC systems in the space. As seen, there is virtually zero weekend and overnight load, and after the morning peak load required to drop the space temperature to its desired level, the morning load drops and peaks again in the afternoon.

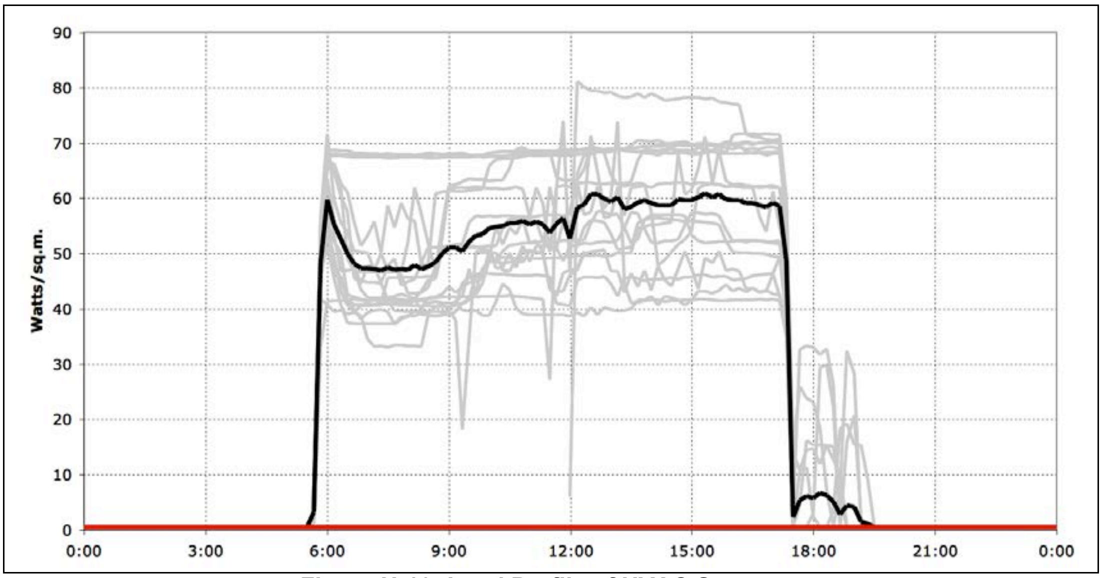


Figure H-10: Load Profile of HVAC Systems.

H.1.4. Department Store

This large (~3,000 m²) store was monitored during the summer period. It had rather small cooling systems. HVAC electrical loads were measured as 27 kWh/m^2.yr, which accounted for 21% of the total premises electrical load of 127 kWh/m^2.yr.

Figure H-11 shows the temperatures recorded in the space during the monitoring.

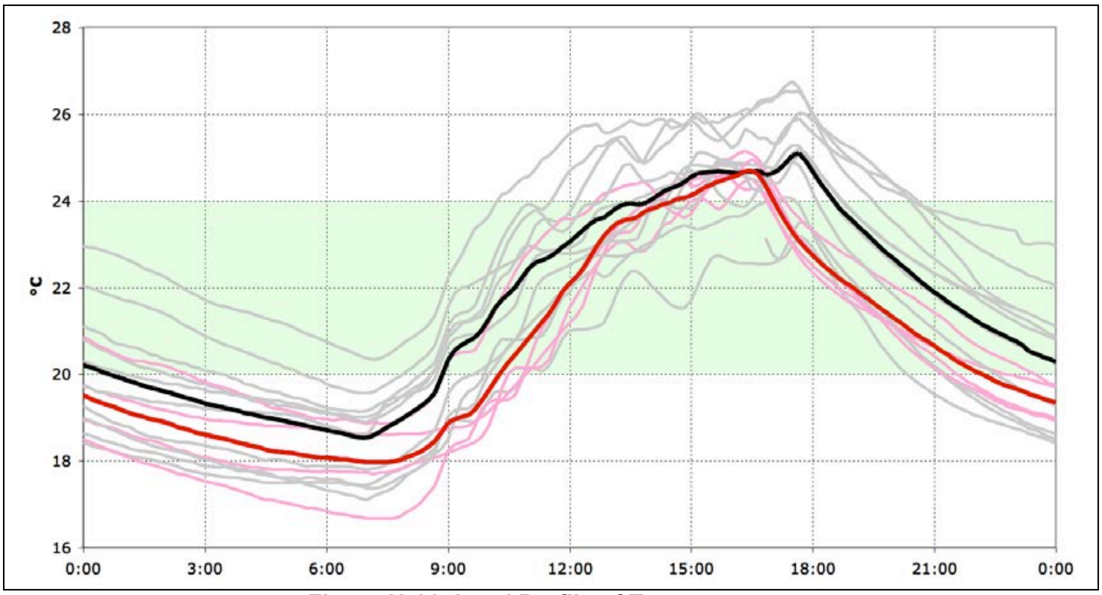


Figure H-11: Load Profile of Temperatures.

The space cooled down in the evening from about 6:00 pm when the store closed, and cooling was needed all day to displace the loads caused by the lighting and other internal heat gains.

Figure H-12 shows the electrical load profile of the space's HVAC (cooling) systems.

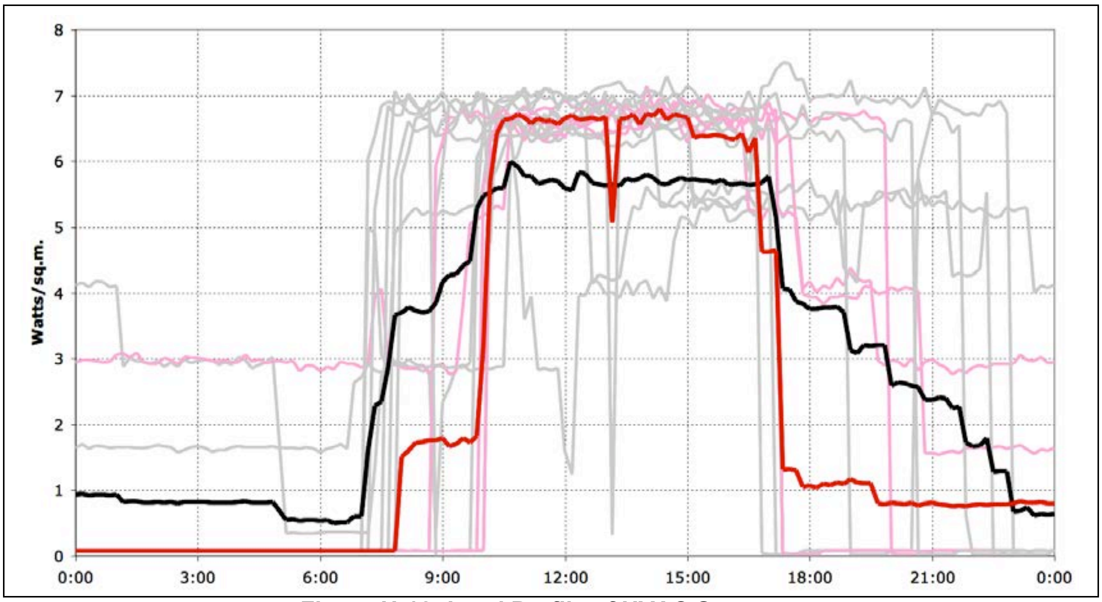


Figure H-12: Load Profile of HVAC Systems.

This graph shows that the HVAC system is possibly manually controlled or has a reasonably sophisticated optimising start/optimising stop controller, as it can be seen to be turned on and off at different times almost every day and night.

H.1.5. Clothing Store 1

This was a fairly large (~1,750 m²) shop that was monitored in winter. This also had a small HVAC system, with HVAC electrical loads measured as 14 kWh/m².yr, which accounted for 29% of the total premises electrical load of 48 kWh/m^2.yr.

The temperatures recorded during monitoring are shown in the following graph (Figure H-13).

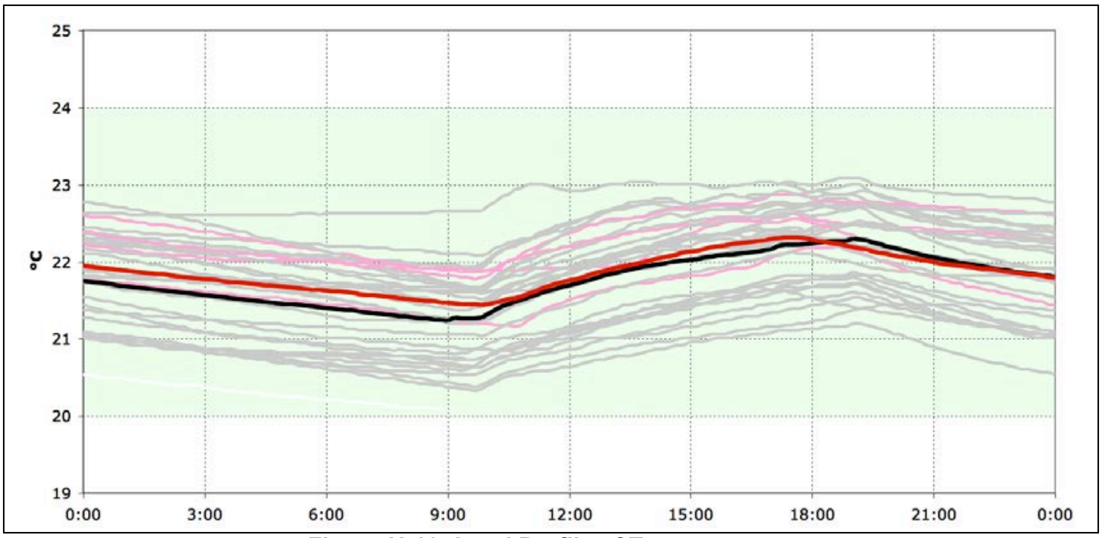


Figure H-13: Load Profile of Temperatures.

As can be seen, the temperatures remained very stable, and were constantly within the nominal comfort zone. It is notable that this space was very well ventilated, with CO_2 levels below 500 ppm most of the time and only barely exceeding 600 ppm at the peak.

Figure H-14 shows the measured electrical loads of the HVAC systems. These are relatively low but with a constant load of about 2 kW. Peaks of up to about 11 kW occurred when the system was running at consistent times in the afternoon of each day. This indicates that the system was controlled by a timer rather than a thermostat, which is an unusual practice.

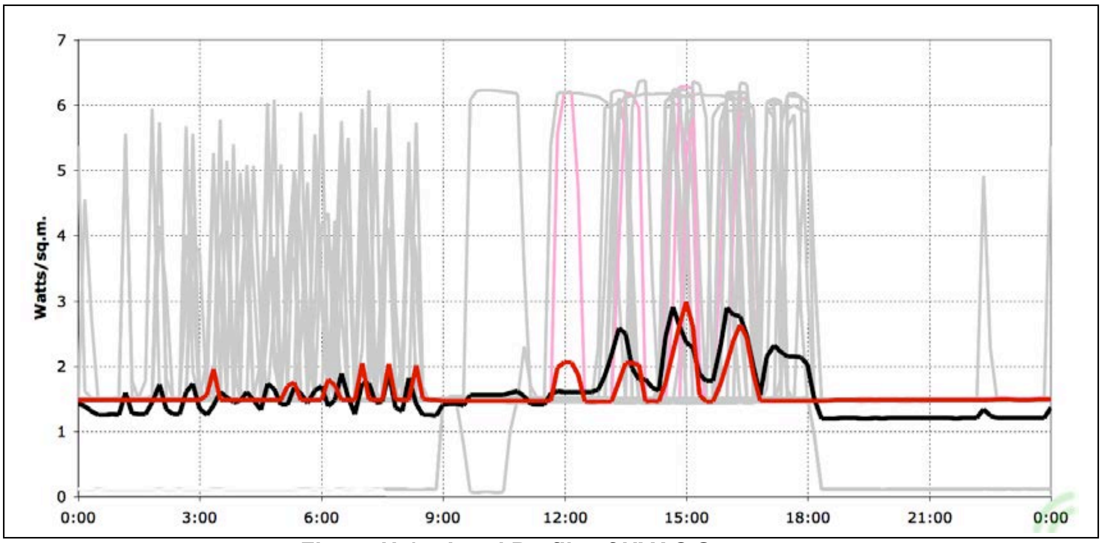


Figure H-14: Load Profile of HVAC Systems.

H.1.6. Housewares

This was a 450 m^2 shop monitored during the autumn period. HVAC was a small load, comprising 8 kWh/m^2.yr, about 6% of the total of 131 kWh/m^2.yr. Almost 80% of the electrical load in this shop was lighting.

The measured temperatures are shown in Figure H-15 below. They were warmer than the nominal comfort zone every afternoon. This is probably an effect of the large amount of lighting in the store.

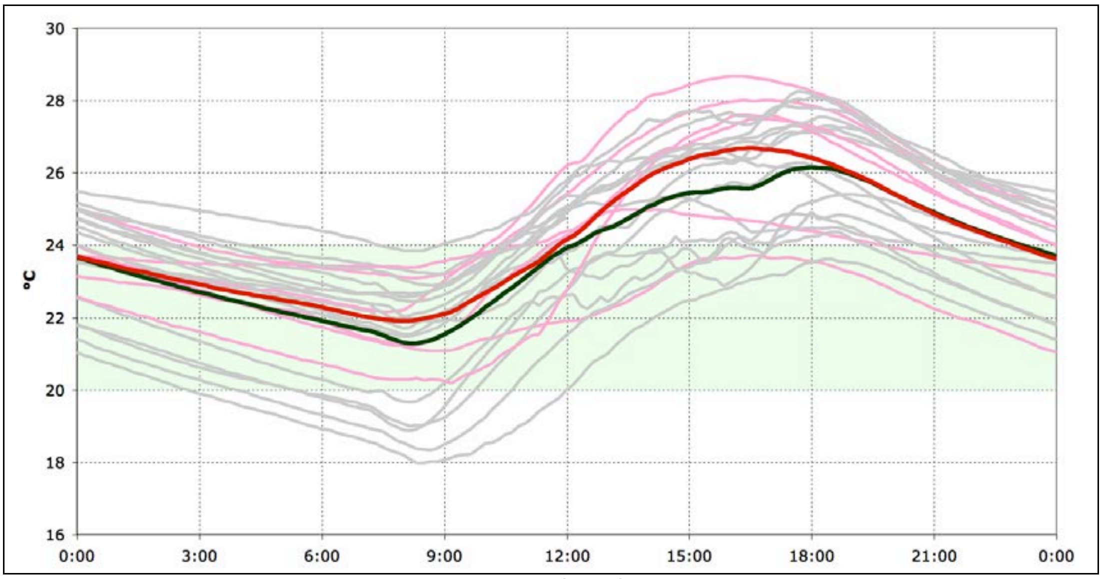


Figure H-15: Load Profile of Temperatures.

The electrical load drawn by the HVAC (cooling) systems is shown in Figure H-16 below.

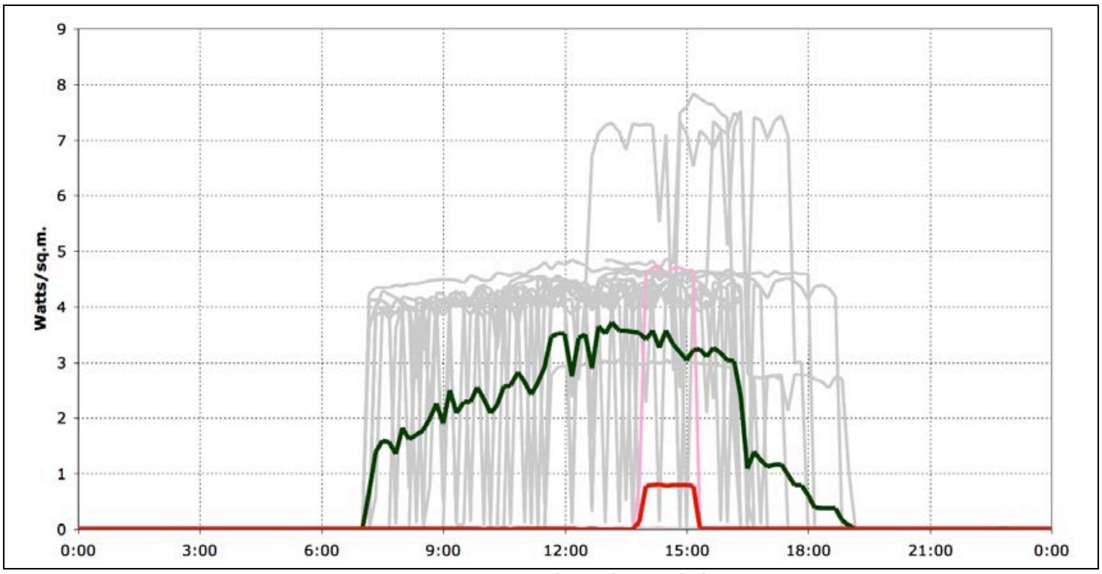


Figure H-16: Load Profile of HVAC Systems.

This HVAC system is operating in cooling mode to overcome the heat released by the large amount of electrical lighting used in the store. As can be seen, the loads peak in the afternoon as both outdoor and indoor temperatures peak.

H.1.7. Housewares 2

This was a 400 m^2 shop, also monitored during autumn. Again, HVAC was a relatively small load, comprising 13 kWh/m^2.yr, about 24% of the total electrical load of 56 kWh/m^2.yr. Lighting was the dominant load, making up almost 70% of the electrical load in this shop.

The measured temperatures are shown in Figure H-17 below. They mostly stayed within the nominal comfort zone during operating hours but slightly exceeded it at the end of every afternoon. This is probably an effect of the large amount of lighting in the store.

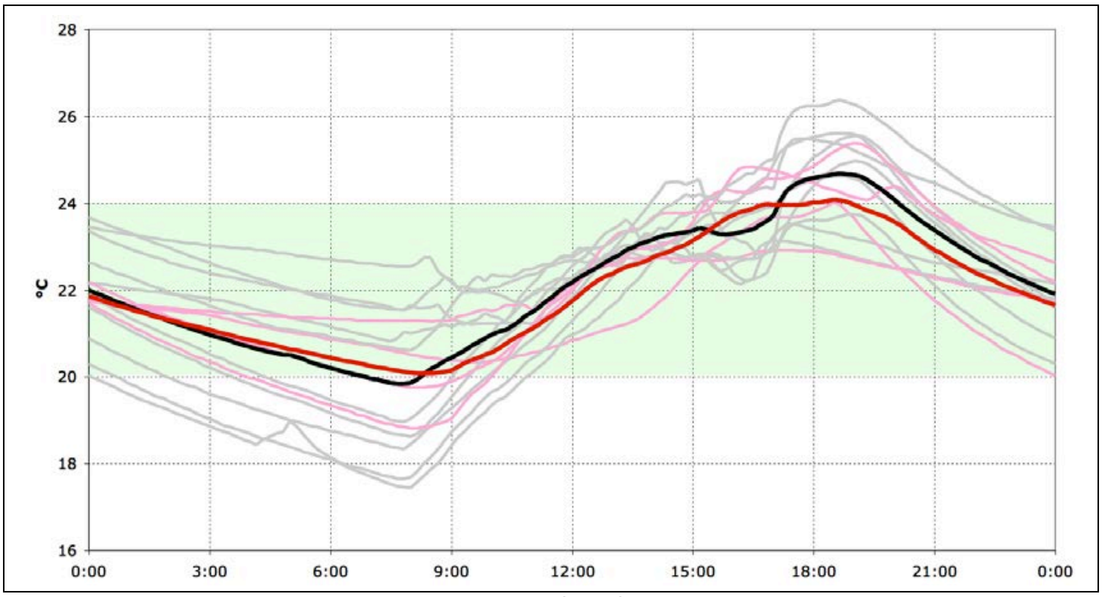


Figure H-17: Load Profile of Temperatures.

The outside air ventilation rate was reasonable, as shown in Figure H-18 below. This is a load profile of measured CO_2 concentration.

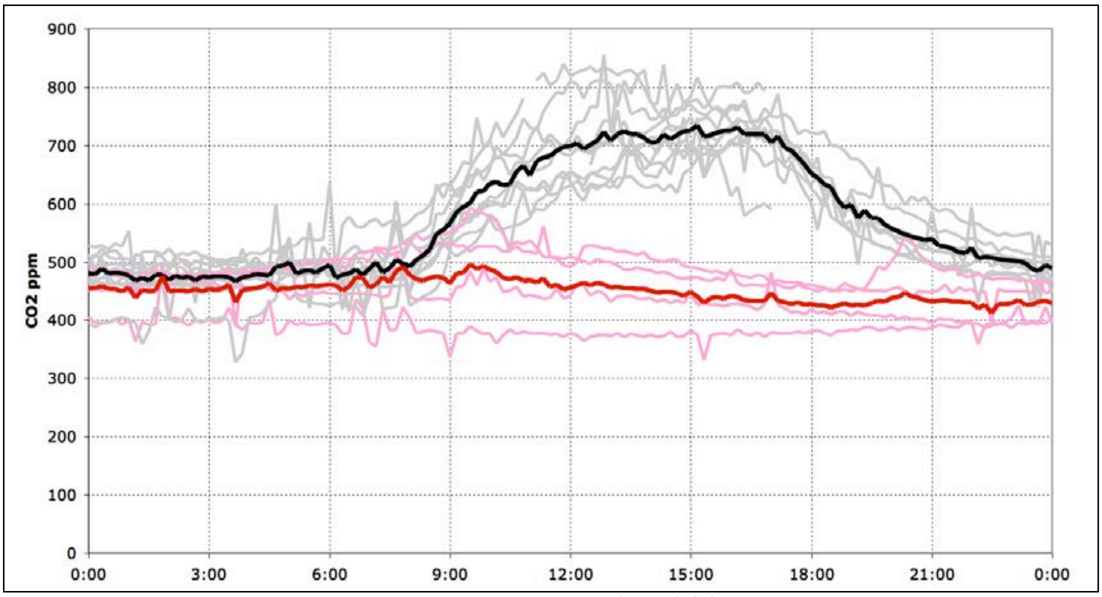


Figure H-18: Load Profile of CO_2.

As seen, the average workday afternoon CO_2 concentration was about 700 ppm, dropping off to under 500 ppm each night.

The electrical power demands of the HVAC systems are shown in Figure H-19 below. The system started each workday at 8:00 am and ran as needed until about 5:00 pm. As it was cooling, it operated more in the afternoon of each day. On weekends, it only ran between around 9:00 am and 12:30 pm, when the shop was open for customers.

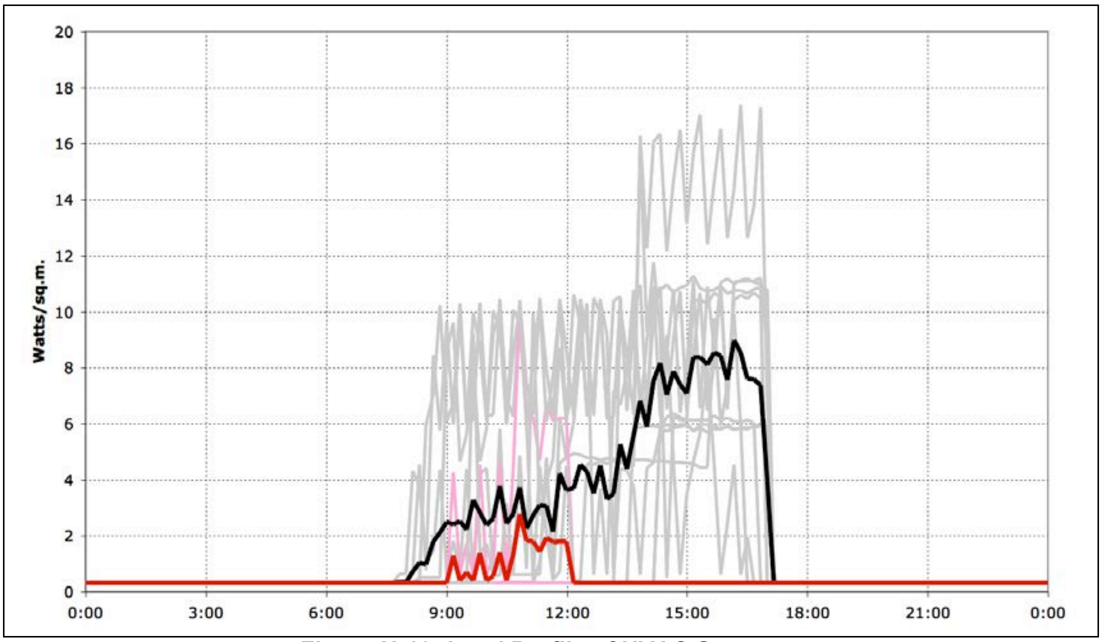


Figure H-19: Load Profile of HVAC Systems.

H.1.8. Video Rentals

This was a 336 m^2 shop, monitored during winter. Again, HVAC was a relatively small load, comprising 23 kWh/m^2.yr, about 17% of the total electrical load of 137 kWh/m^2.yr. Lighting again was the dominant load, making up about 60% of the electrical load in this shop.

The measured temperatures are shown in Figure H-20 below. They only rarely reached the nominal comfort zone during operating hours, averaging about 16°C on weekday afternoons.

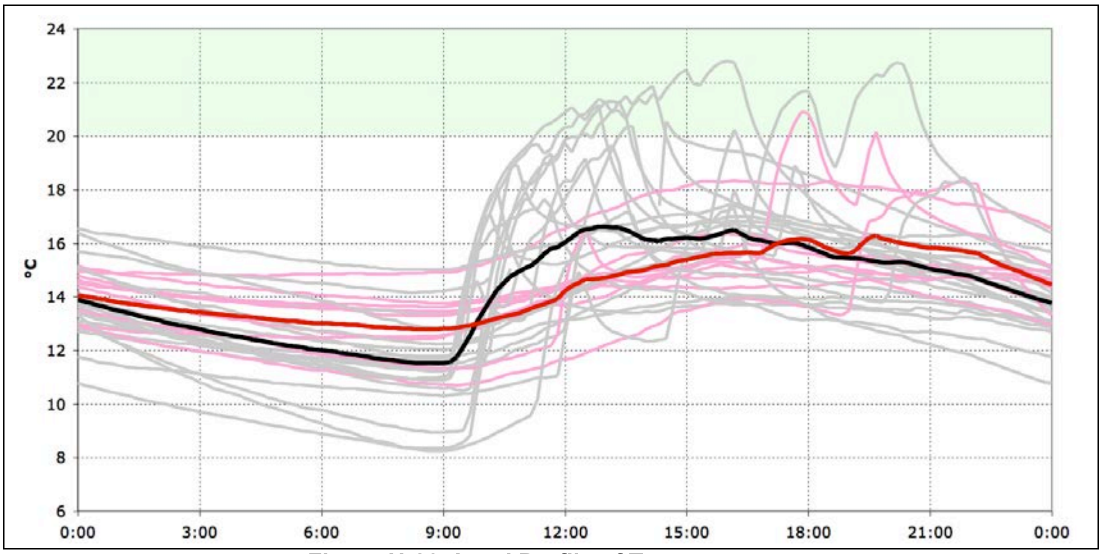


Figure H-20: Load Profile of Temperatures.

The electrical heating load of the space is shown in Figure H-21 below. As can be seen, it started each day at 9:00 am and ran at a reduced rate in the late afternoon and evenings. Presumably there was a relatively low set point on the system thermostat that was maintained (even if it did not correspond to space temperature), because the HVAC load dropped away after a few hours of operation on weekdays, and the space temperature stabilised at the same time. If the system was still attempting to reach its set point, the temperature would have kept rising and heating power demand would have stayed high.

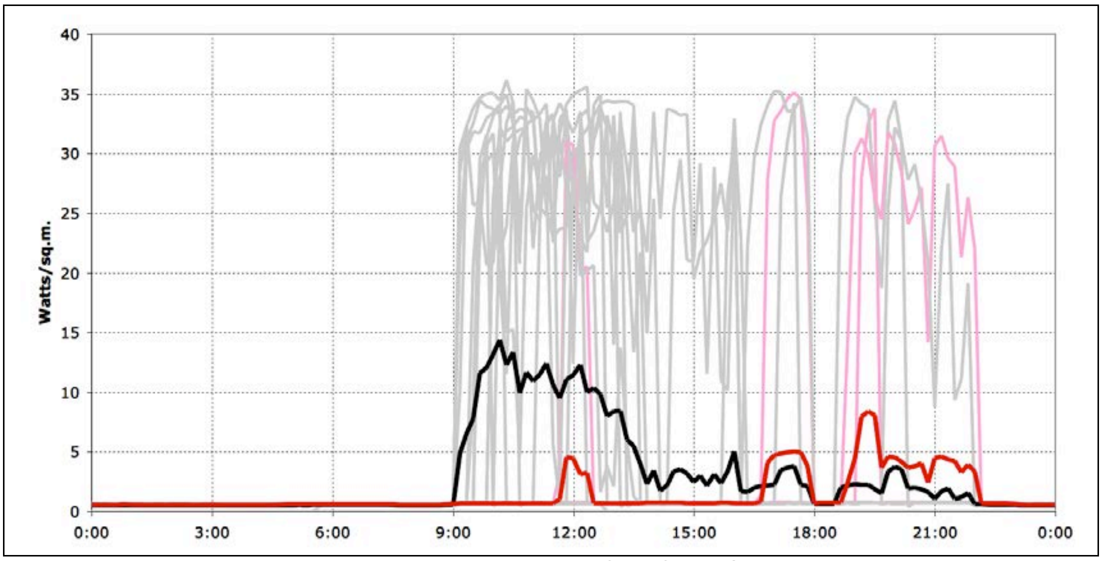


Figure H-21: Load Profile of HVAC.

H.1.9. Clothing Store 2

This was a 108 m^2 shop monitored in winter. Again, HVAC was a relatively small load, at 15 kWh/m^2.yr, about 6% of the total electrical load of 254 kWh/m^2.yr. Lighting made up about 80% of the electrical load in this shop.

The measured temperatures are shown in Figure H-22 below. Although heating began before 9:00 am, the space rarely achieved 20°C before 11:00 am. On weekends and overnight, space temperatures were below 18°C.

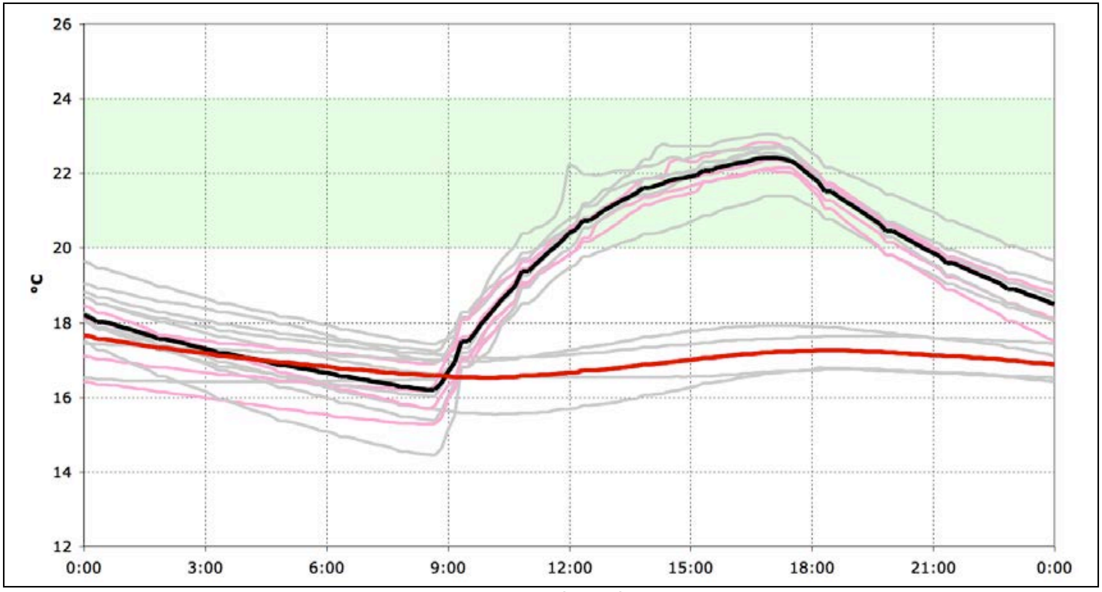


Figure H-22: Load Profile of Temperatures.

The electrical load profile of the heating system is shown in Figure H-23 below. As can be seen, the heating runs much more in the morning than the afternoon to bring the space up to temperature. In the afternoons, the lighting in the space will provide most of the heating. This amount of lighting would likely cause a significant summer cooling load.

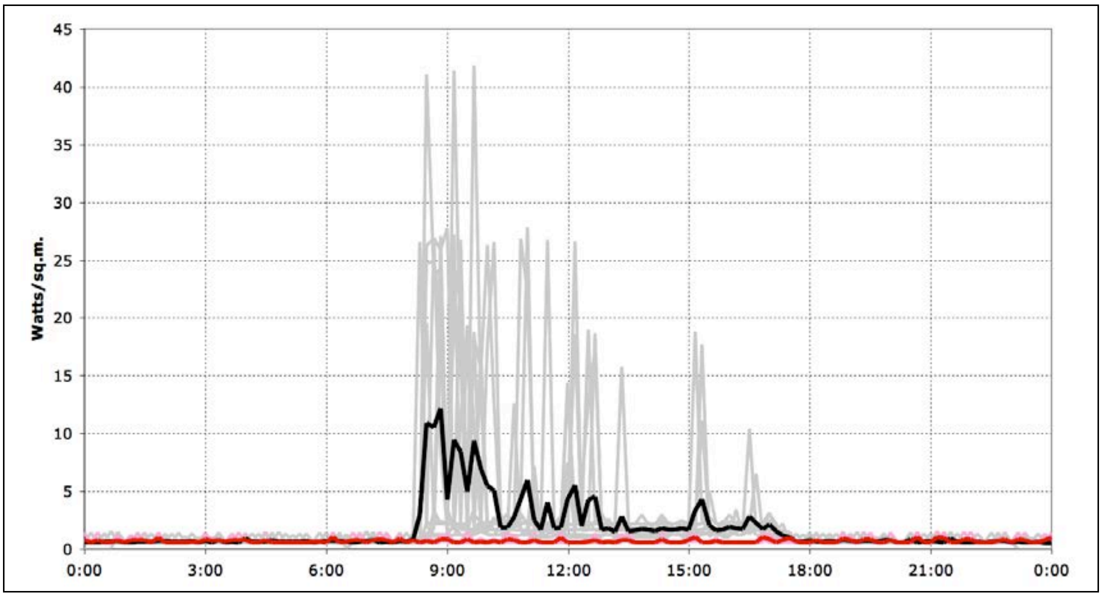


Figure H-23: Load Profile of Heating System.

H.1.10. Restaurant

This restaurant was 1,207 m² in area, monitored in summer. Again, HVAC was a relatively small load, at 23 kWh/m2.yr, about 15% of the total electrical load of 152 kWh/m^2.yr.

The measured temperatures are shown in Figure H-24 below. For most of each day, the temperatures are warmer than the nominal comfort zone.

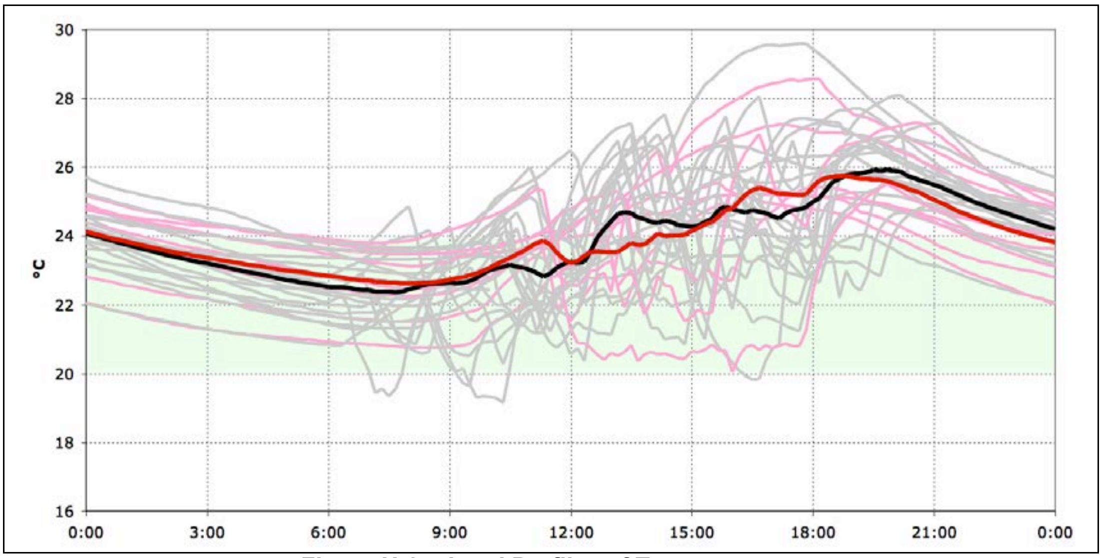


Figure H-24: Load Profiles of Temperatures.

Figure H-25 shows the load profile of the CO_2 in the space. There are regular spikes of over 1,000 ppm, indicating that the occupancy then overwhelms the ventilation system, which does not provide sufficient ventilation air during those times.

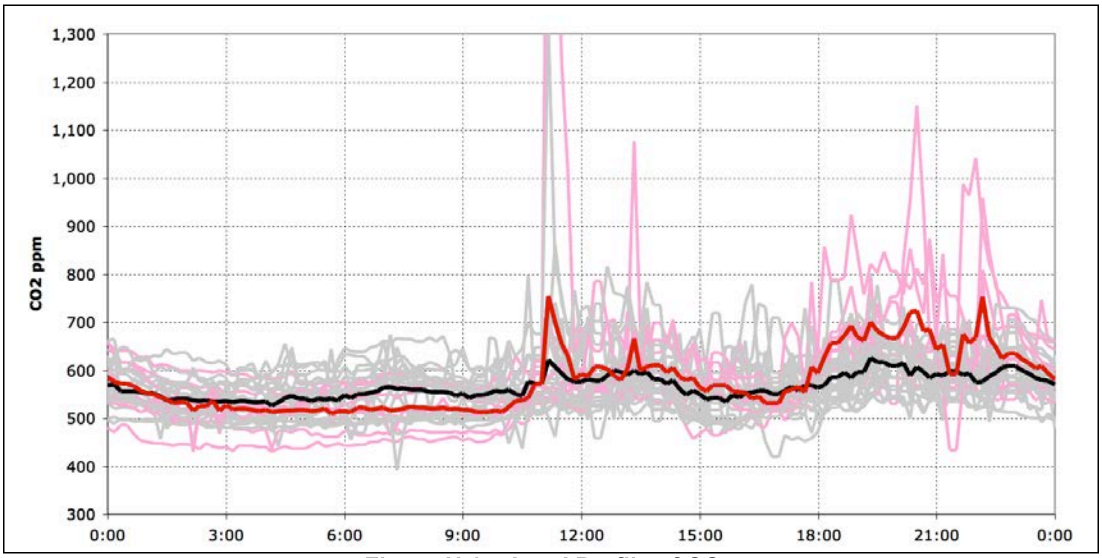


Figure H-25: Load Profile of CO_2.

The electrical load profile of the HVAC system is shown in Figure H-26 below. As can be seen, it has two peaks, corresponding to the hours of service, and is consistent between weekdays and weekend days.

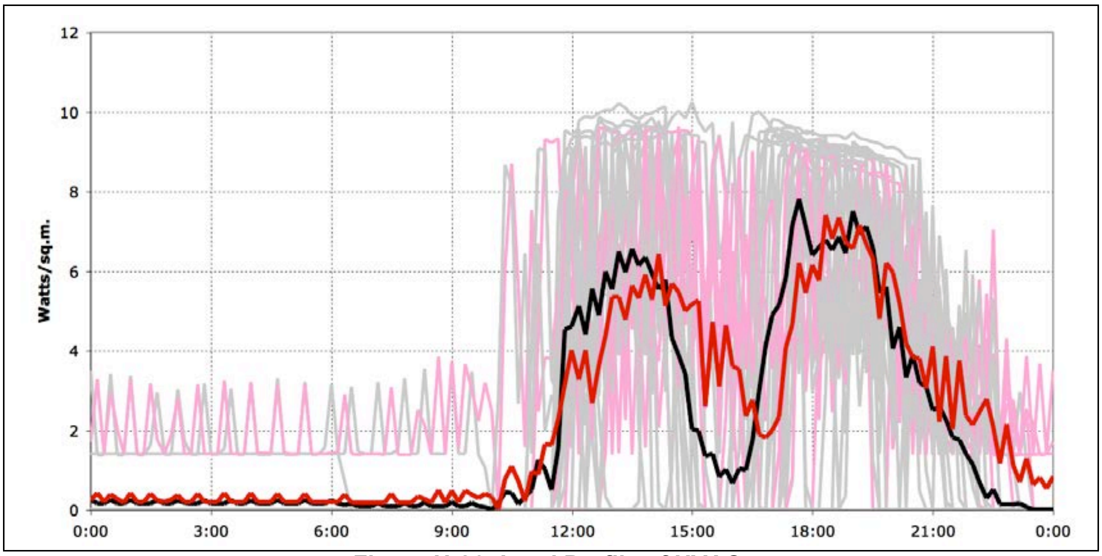


Figure H-26: Load Profile of HVAC.

H.1.11. Provincial Hotel

This building was 460 m^2 in area, monitored in winter. The electrical HVAC loads were relatively low, but this premise also had portable gas space heaters and a centralised coal boiler. The electrical HVAC load was 40 kWh/m^2.yr., about 24% of the total electrical load of 168 kWh/m^2.yr.

Figure H-27 shows the temperatures recorded in the space (in the lounge). It almost never reached 20°C, averaging about 12°C at 9:00 am each weekday and about 18°C in the evening.

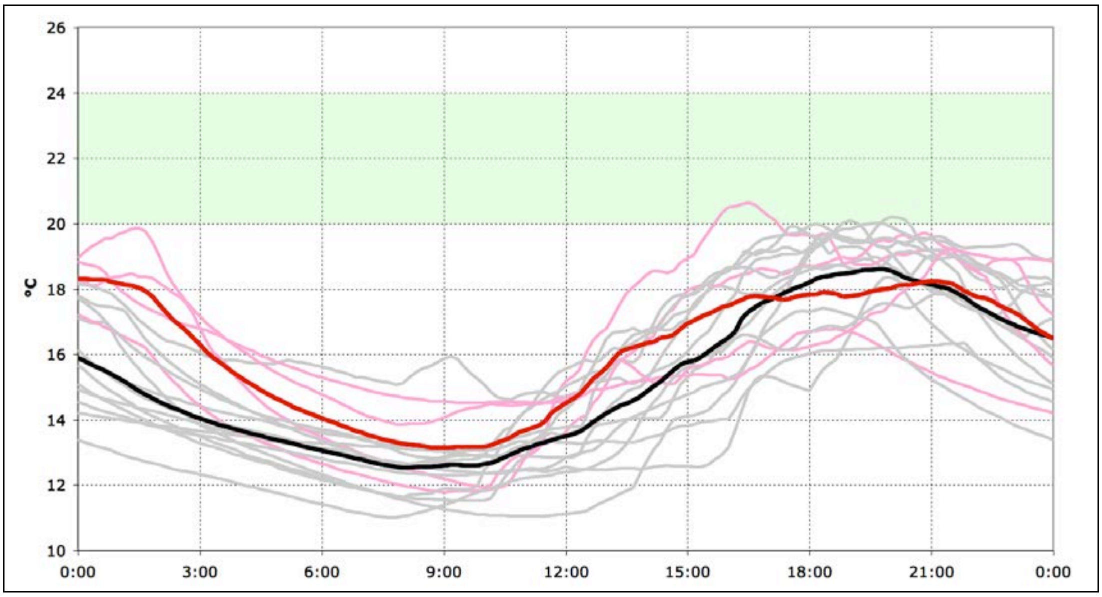


Figure H-27: Lounge Temperatures.

The measured space CO_2 concentration is shown in Figure H-28 below. The regular peaks over 1,000 ppm, lasting until early morning, are probably due to emissions from unvented combustion space heaters instead of occupancy greater than the ventilation system is designed for.

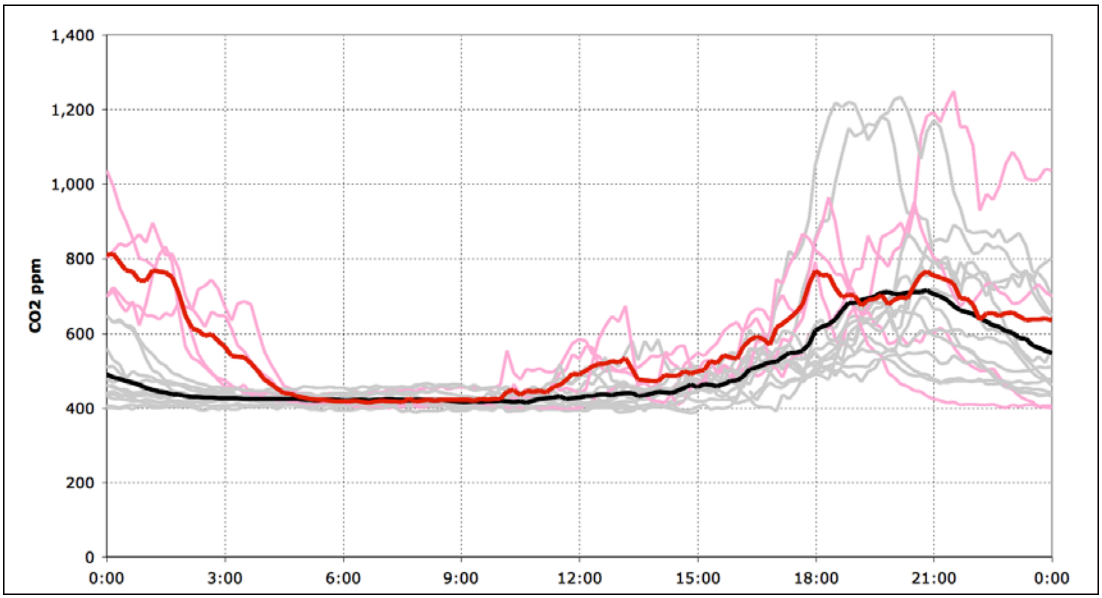


Figure H-28: Load Profile of CO_2.

The electrical load profile of the HVAC systems for this space is shown below (Figure H-29). This is a relatively constant load, with slight peaks in the middle of the day and in the evening, especially on weekends.

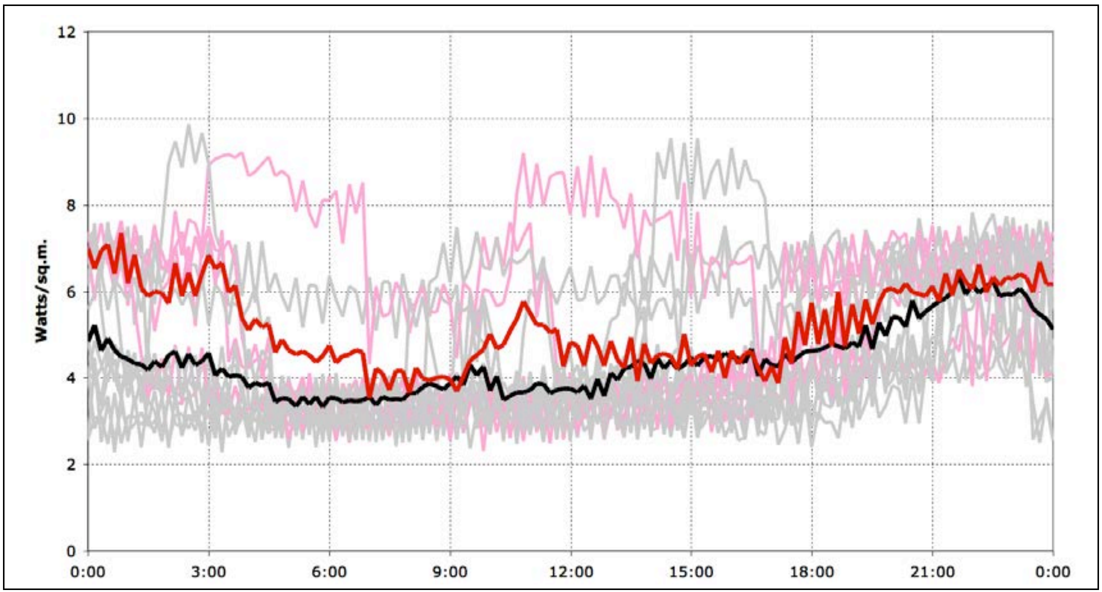


Figure H-29: Load Profile of HVAC.

H.1.12. Training Centre

This building was 390 m^2 in area, monitored in winter. The electrical HVAC loads were significant, at 110 kWh/m^2.yr, about 43% of the total electrical load of 255 kWh/m^2.yr.

Figure H-30 shows the temperature recorded in a typical office in the space. It was relatively consistent and well controlled, with heating starting at about 5:30 am each day. The temperature reached 21°C by 9:00 am each weekday, about 22°C in the middle of the day and dropping off after 5:00 pm.

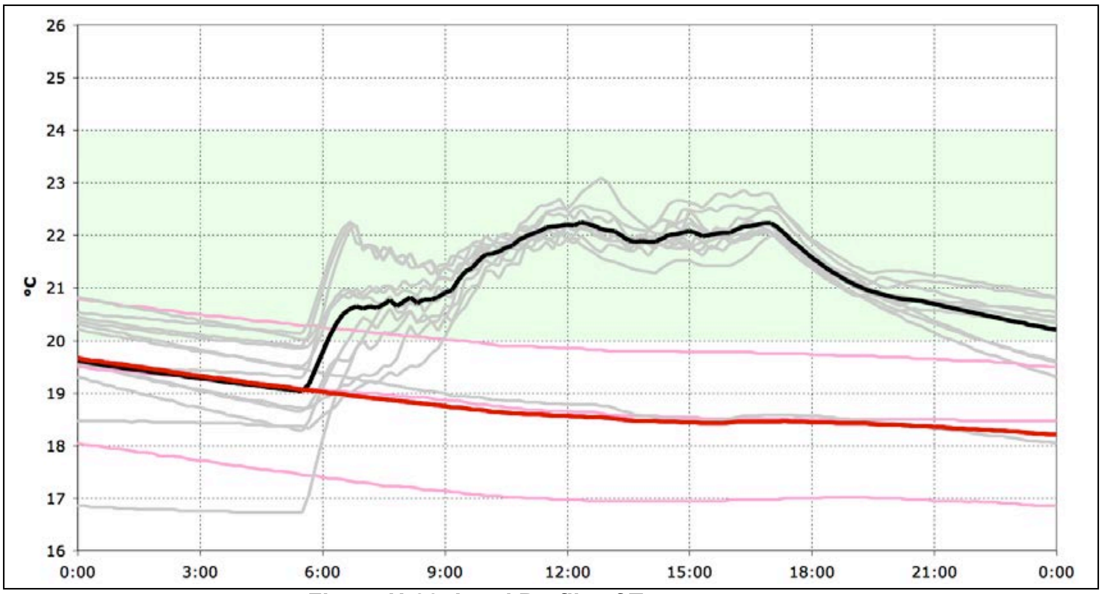


Figure H-30: Load Profile of Temperatures.

Figure H-31 shows the temperature recorded in a meeting room in the space. Its temperature was more variable, reaching 20°C between 7:00 am and 1:00 pm on weekdays. The temperature rise observed on weekends was probably due to solar gains through windows.

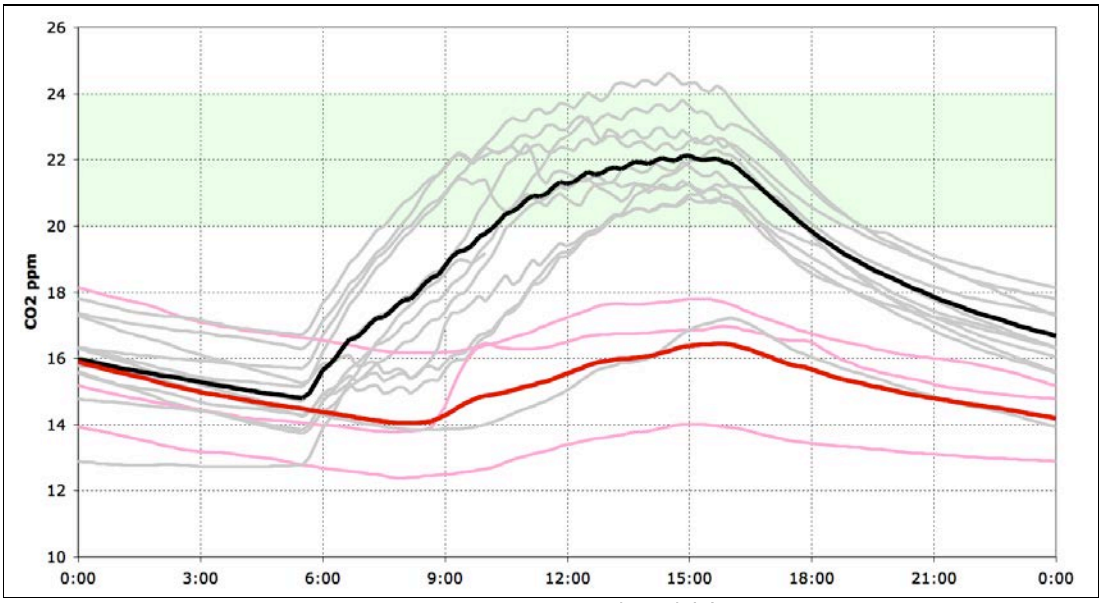


Figure H-31: Load Profile of CO_2.

The combined electrical load profiles of the HVAC systems in the space are shown in Figure H-32 below. Some heating occurred from 5:30 am each weekday morning, though one morning all the heating ran then. Most heating of the premises started from about 10:30 am, which ran until about 9:00 pm each evening. There was minimal weekend heating.

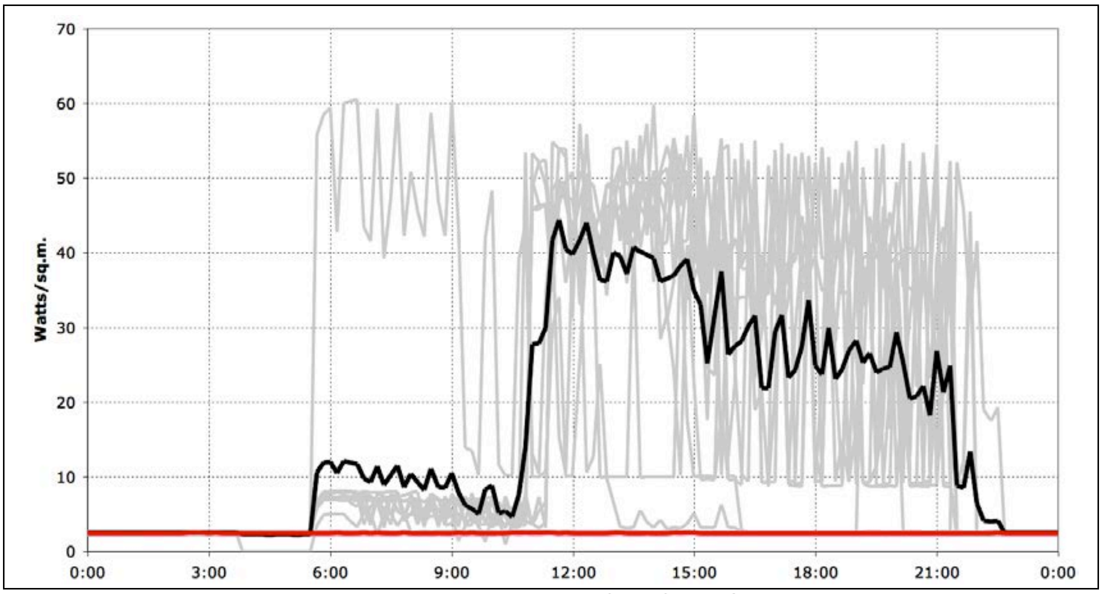


Figure H-32: Load Profile of HVAC.

H.1.13. Other

This building was 2,667 m^2 in area, monitored during summer. This is a very unusual premise. It is a building enclosed within another building and has almost no external loads. Accordingly, the electrical HVAC loads were very low, at 7 kWh/m^2.yr., which is about 52% of the total measured electrical load of 13 kWh/m^2.yr.

The HVAC electrical load profile is shown in Figure H-33 below. Some loads run overnight, with the peaks on weekday afternoons, as shown.

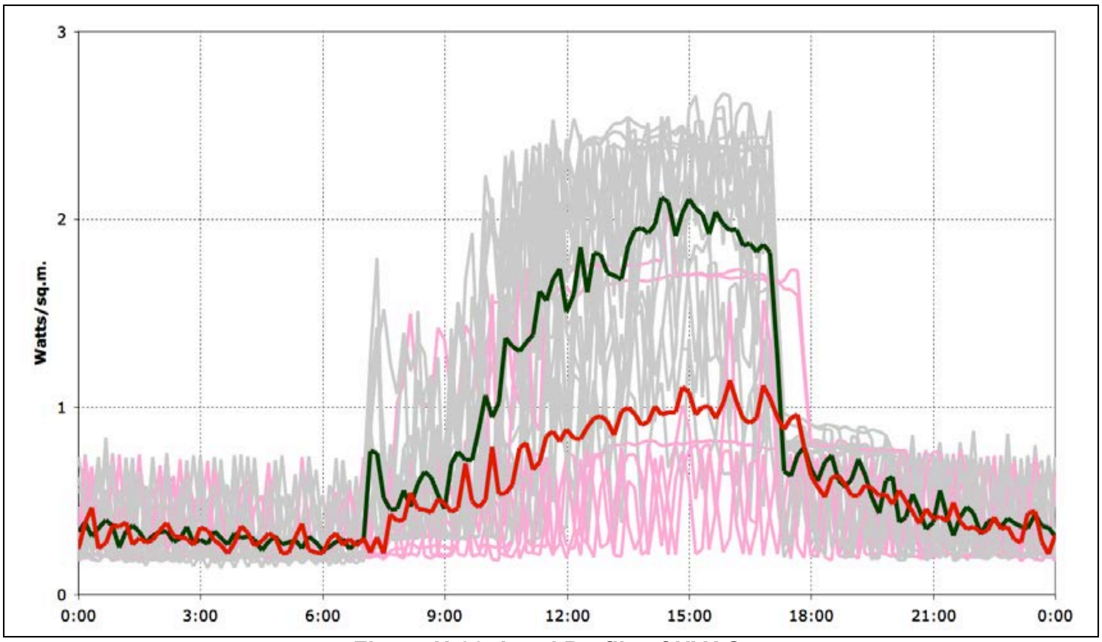


Figure H-33: Load Profile of HVAC.

I. POE Case Studies

I.1. Case Study 1

- Monitoring Period: winter (29 June – 20 July 2010). In addition, temperature and relative humidity from one sensor for 29 June – 10 August 2010.
- POE Period: 8 April 2012.

Four HOBO U12 sensors were installed in different locations, measuring (dry bulb) temperature, relative humidity and illuminance. One Telaire 7001 CO_2 sensor was also installed. Sensors were placed in two offices, a resource/printing room, and the kitchenette. These collected data for varying amounts of time; two sensors recorded data from 29 June – 20 July 2010, one from 29 June – 10 August 2010 and one that recorded only 29 June – 1 July 2010.

Overall, the environmental monitoring results show that the premise is:

- cold in the mornings and slow to warm up
- subject to moderately high CO_2 levels
- often lit below recommended office lighting levels
- dry.

I.1.1. Temperature and Relative Humidity

During the monitoring period, outdoor temperatures were below 16°C 100% of the time, while indoor temperatures were above 16°C at least 80% of the working hours (Figure I-1). The building is characterised by morning temperatures well below the acceptable comfort zone of 20–24°C, which slowly rise into the comfort range by late morning or midday and remain there until the end of the workday. Over the monitoring period, temperatures during the working day ranged across the building from a minimum of 9.3°C to a maximum of 25.6°C. The greatest daily workday range was 14.7°C, recorded on 12 July 2010, which was also the coldest day of the monitoring period. The average daily temperatures by sensor location for the working day were 6.7°C, 6.9°C, 8.1°C and 9.5°C.

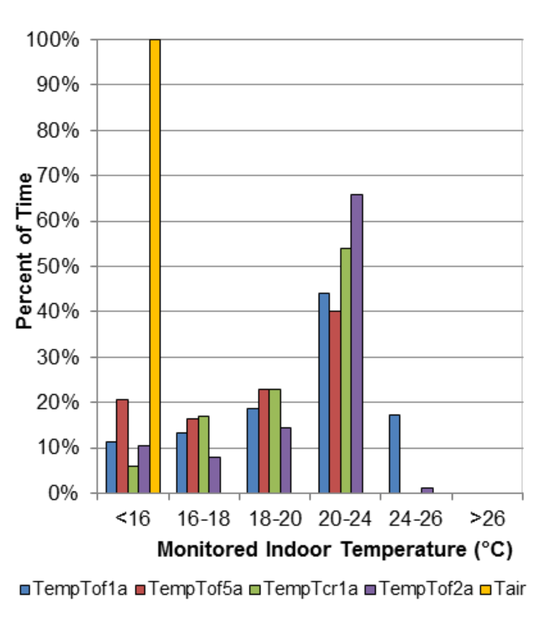


Figure I-1: Case Study 1 Workday Temperature Distribution.

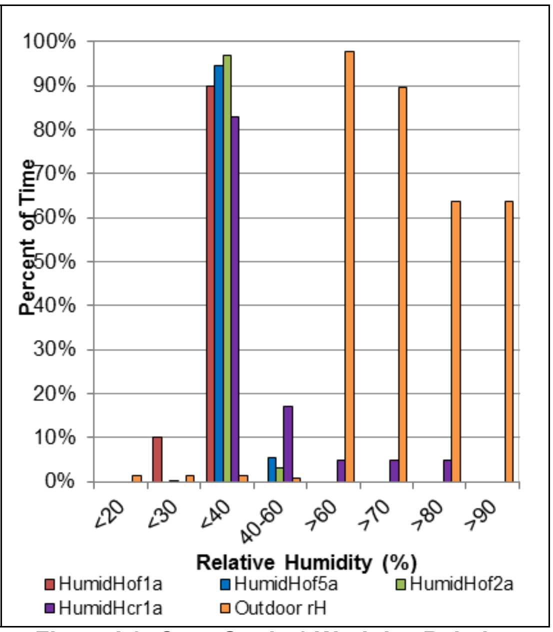


Figure I-2: Case Study 1 Workday Relative Humidity Distribution.

Outdoor relative humidity was above 70% most of the time (Figure I-2). Indoor relative humidity was reasonably stable, between 30% and 40%, with small variations mostly driven in direct response to changes in indoor temperature.

I.1.2. CO_2

The average daily CO_2 profile for the monitoring period rises above 1,000 ppm around 12:30 pm and continues to be above 1,000 ppm for the rest of the working day (Figure I-3). The CO_2 level was above 1,000 ppm for 33% of the time during the working day. This indicates that there can often be insufficient ventilation during much of the working day to satisfy comfort and air quality criteria of <1,000 ppm, as recommended by NZS 4303:1990 (Standards New Zealand, 1990).

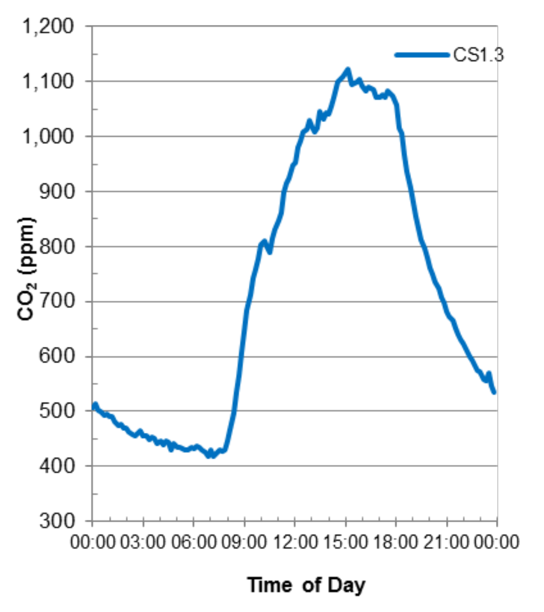


Figure I-3: Case Study 1 Average Workday CO_2 Profile.

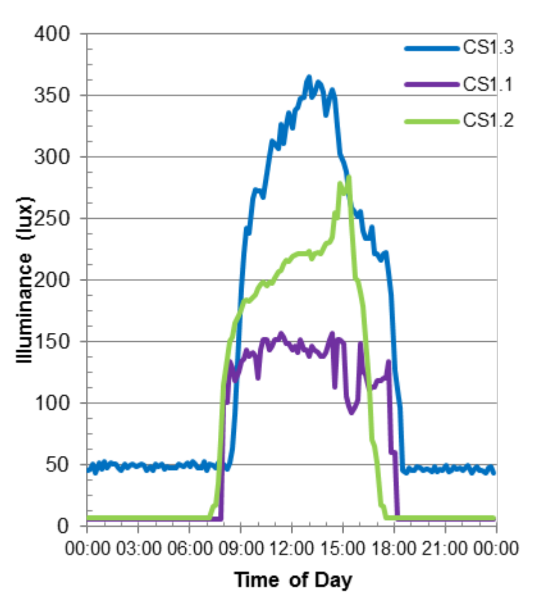


Figure I-4: Case Study 1 Average Workday Illuminance Profile.

I.1.3. Lighting

Figure I-4 shows the average daily illuminance profiles for the three sensor locations. Sensor CS1.1 was located in the kitchenette, which is in a hallway with little daylight. This is reflected in the relatively flat daily profile concurrent with artificial lighting only. Two sensors were located in single offices on the north and west side of the building respectively, and their profiles are driven by natural light as well as electric lighting. One of these single offices has a peak in illuminance concurrent with afternoon sun, while the other has a peak coinciding with the midday sun. Particularly for the space containing sensor CS1.2, the influence of sudden increases in daylight levels suggests there may be issues with glare.

The two sensors located in offices were both often below the 320 lux level recommended in NZS 1680.1:2006 Table 3.1 for routine office tasks (Standards New Zealand, 2006). In particular, sensor CS1.2 was above 320 lux only 3% of the time during working hours. Sensor CS1.3 was much better, with illuminance levels of 320 lux or above 30% of the time. The data also suggests that office 5a was not occupied on some weekdays during the monitoring period. Although this cannot be determined for certain, if these days are excluded from the working day analysis, the percentage of time above 320 lux increases to 35%.

I.1.4. POE Results

The significant time gap between the environmental monitoring and POE survey meant that there had been some staff changeover; however, all of the staff surveyed had worked in the building for a year or more. During this time, environmental controls within the building had not significantly changed, so the results from the environmental monitoring can be assumed to be relevant.

As the environmental monitoring period was during winter, the POE results relating to environmental comfort in winter have been analysed only. Although the survey response rate of 80% is high, the small sample size of 11 means that the results are very sensitive to variation in survey scores by even one person.

I.1.5. Temperature and Relative Humidity

The POE results for the temperature in winter were in general agreement with the environmental monitoring results and also displayed relatively high dissatisfaction with the internal air quality. There was 54% dissatisfaction with the temperature in winter (36% too cold and 18% too hot). Given the environmental monitoring results, the Too Hot POE results are unexpected and highlight how the small sample size can skew the results as well as the variation in personal thermal comfort. Dissatisfaction with the temperature variation during the day was 73%. Overall, there was 58% dissatisfaction with the temperature in winter. The POE score for temperature in winter was 3.67 – well below the benchmark mean of 4.14.

I.1.6. CO_2

For the Fresh/Stuffy POE category of air in winter, there was 42% dissatisfaction, and 94% of respondents scored 4 or above (with 1 being Fresh and 7 Stuffy). This is concurrent with the environmental monitoring results for CO_2, which are often close to or moderately above acceptable levels.

The POE result for air in winter overall was 50% dissatisfaction.

I.1.7. Lighting

Overall, there was only 8% dissatisfaction with lighting. Lighting overall scored 5.33, well above the upper BUS benchmark score of 5.13. There was some dissatisfaction with glare from the sun and sky, at 17%. This was also the same for glare from artificial light. Given the environmental monitoring results, it was expected there would be a larger percentage of dissatisfaction with the lighting overall.

I.1.8. Discussion

Overall, the POE results are in general agreement with the environmental monitoring data. The cold temperatures stand out as the most easily identifiable issue from the monitored data, and this is also reflected strongly in the survey. Although there is 42% dissatisfaction with comfort overall, the POE score of 4.67 is above the mean benchmark score of 4.53. Of note is that needs scores strongly, with 8% dissatisfaction and a score of 5.42, compared to the benchmark score of 4.73. This indicates that, although there is obvious dissatisfaction with the indoor temperature, there are other factors balancing out the overall satisfaction. For instance, the well met needs of staff may provide forgiveness in part for the dissatisfaction with temperature.

Also worth noting is that the POE survey was performed just after completion of adjacent upgraded facilities occupied by other staff of the same company. Apart from modern heating and natural ventilation features, the main difference between the two facilities was that the building in this case study had single offices, whereas the new building was largely open plan. A number of comments on the survey mentioned the benefit of having an office in being able to control noise. Control of environmental variables scored well above benchmark scores for all of heating, cooling, lighting, ventilation and noise. This may also influence forgiveness.

There were also a number of survey comments regarding how cold the floor was in winter. This was not factored into the environmental monitoring results for thermal comfort; however, the effect of cold floors can have a significant effect on thermal comfort as shown in the European Standard EN ISO 7730:2005 6.4 (ISO, EN, 2005).

I.2. Case Study 2

- Monitoring Period: winter (13 July – 27 July 2012)
- POE Period: 12 July 2012

I.2.1. Environmental Monitoring Results

Environmental monitoring equipment was installed on the first floor and measured data for 14 days.

It was noted that two of the sensors were subject to direct sunlight at certain points of the day. This could be seen by comparing the sensor data to outdoor illuminance levels. On a sunny day, there were large spikes that occurred every morning from 8:50 am to 9:20 am in sensor CS2.1 and an afternoon spike at

4:10 pm in the office containing sensor CS2.4. A sharp spike was also seen in the temperature measurement from sensor CS2.1 as a result of the solar radiation. Temperature and relative humidity data from 8:50 am to 10:00 am was removed from the entire dataset for sensor CS2.1. Data from sensor CS2.4 was left as is, as the spike in illumination at 4:10 pm returned to normal by the next 10-minute reading, and there was no apparent effect on temperature.

Overall, the environmental monitoring results show that the premise is:

- within the comfortable temperature range of 20–24°C for 87% of the time across all sensors during work hours
- well ventilated
- usually lit to recommended office lighting levels.

I.2.2. Temperature and Relative Humidity

The average daily temperature profiles show sensors CS2.2 and CS2.3 to have very similar profiles, which are both significantly higher temperatures than sensors CS2.1 and CS2.4. Interestingly, sensors CS2.3 and CS2.4 were both located in the same open-plan office, no more than 5 m apart. The sensors were installed at heights above floor level of 0.8 m, 1.1 m, 1.5 m and 1.7 m. The two lowest sensors in height are also the two sensors that have lower temperatures, indicating that the building is subject to vertical temperature stratification. ASHRAE recommends air temperature measurements to be made at 0.1 m, 0.6 m and 1.1 m for sedentary occupants; for standing activity, measurements are to be made at 0.1 m, 1.1 m and 1.7 m (ASHRAE, 2004). Given that the office occupants are predominantly sitting at their desks, sensors CS2.1 and CS2.4 (the two lowest) have greatest relevance to this study.

Even with the above considerations, the indoor temperature was within the comfort range at least 71% of the time during working hours and below 18°C at most 1.9% (less than 2 hours) of the time.

Table I-1: Case Study 2 Monitored Temperatures.

Workday Temperature (°C)	Sensor CS2.1	Sensor CS2.2	Sensor CS2.3	Sensor CS2.4	Outside
Minimum	15.9	16.9	16.2	15.5	-2.8
Lower Quartile	20.4	21.5	21.8	19.9	10.3
Median	20.8	22.1	22.2	20.5	12.4
Mean	20.8	21.8	21.9	20.3	11.1
Upper Quartile	21.3	22.4	22.4	20.9	13.2
Maximum	23.0	23.5	23.2	22.2	16.8
Standard Deviation	0.9	0.9	0.9	1.0	3.9
Minimum Range	1.4	1.0	0.8	0.8	3.8
Median Range	2.3	1.9	1.6	2.6	8.2
Mean Range	2.4	2.2	2.0	2.5	9.4
Maximum Range	5.0	6.0	6.2	5.9	15.5

Indoor humidity was generally between 40% and 60%. Sensors CS2.1 and CS2.4 were above 60% relative humidity for 36% and 43% of the time respectively. These higher relative humidity levels are likely caused by the lower temperatures of these two sensors. Relative humidity never exceeded 70% for extended periods of time, therefore occupants may find the building too humid at times, but the growth of mould and other pathogens would not be expected in large amounts.

I.2.3. CO_2

CO_2 levels were below 1,000 ppm for 98% of the time and were below 800 ppm for 82% of the time. The average concentration was 738 ppm across the monitoring period. This indicates an efficient level of ventilation to maintain acceptable air quality but with CO_2 concentrations well above outdoor air concentrations.

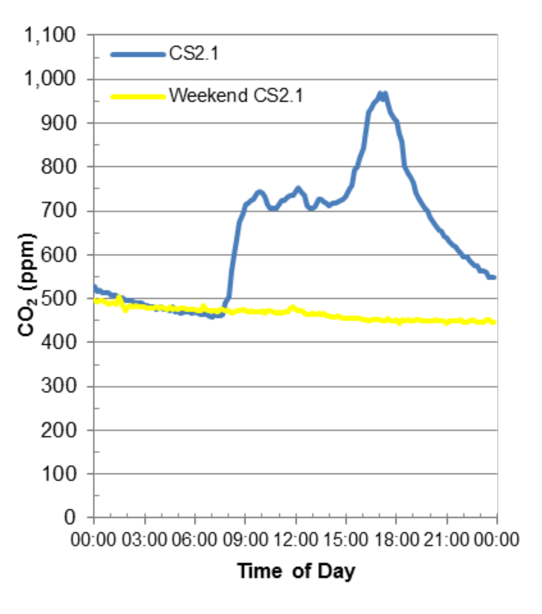


Figure I-5: Case Study 2 Average Daily CO_2 Profile.

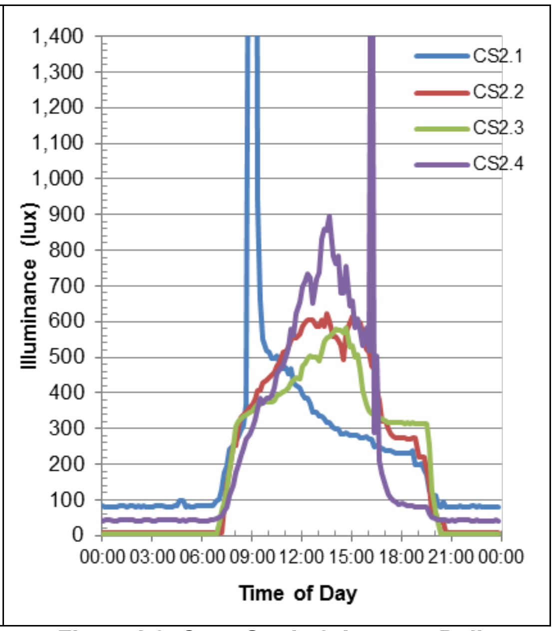


Figure I-6: Case Study 2 Average Daily Illuminance Profiles.

I.2.4. Lighting

The average daily profiles for sensors CS2.2, CS2.3 and CS2.4 show good daylight levels until the sun goes down, when the profile shows steady electric lighting, which is usually turned off around 7:00 pm. Sensor CS2.1 shows morning daylight exposure, then the profile tapers off to be dominated by steady electric lighting. Spikes in the daily profile can be seen as mentioned above, when the sensors were in direct sunlight. Sensors CS2.2 and CS2.3 had illuminance levels above 320 lux for 85% and 93% of the time respectively. On the other hand, sensors CS2.1 and CS2.4 had illuminance levels below 320 lux for 55% and 42% of the time respectively. As was the case with temperature, these two sensors were at lower heights.

Table I-2: Case Study 2 Illuminance Levels

Workday Illuminance (lux)	Sensor CS2.1	Sensor CS2.2	Sensor CS2.3	Sensor CS2.4
Minimum	173	9	241	96
Lower Quartile	269	355	334	201
Median	310	455	359	390
Mean	589	493	428	534
Upper Quartile	444	632	469	687
Maximum	11,921	928	866	15,904
Standard Deviation	1,363	171	141	778
Minimum Range	62	155	25	161
Median Range	5,005	446	431	1,008
Mean Range	5,521	457	311	2,853
Maximum Range	11,673	882	549	15,717

Although the spikes in illuminance readings show that the sensors were placed in direct sunlight, these were true readings and suggest that the building may experience glare at certain times of the day. Sensor CS2.4 in particular also had an average daily illuminance profile with levels much higher than 320 lux, which may also cause glare.

I.2.5. POE Results

The BUS was conducted on the same level as the environmental monitoring and a day before the monitoring period started. There was a total of 22 respondents; it is unknown what response rate this equated to.

The POE results for temperature in winter all showed significant dissatisfaction (Table I-2). Those that were dissatisfied with the Too Hot/Cold variable all voted too cold. Worth noting is that staff from the communications and marketing section of the building scored particularly poorly. All of the staff in this area scored either a 6 or above for the Too Hot/Cold variable (with one being too hot and seven being too cold).

Air in winter: Too Dry/Humid scored 30% dissatisfaction, with 25% too dry and 5% too humid. The average score of 3.53 was better than the benchmark upper limit.

Air in winter: Too Dry/Humid scored 30% dissatisfaction, with an average score of 4.15, which was just below the benchmark lower limit. Overall dissatisfaction with the air in winter was 45%.

Table I-3: Case Study 2 POE Winter Results.

POE Variable	Dissatisfaction Percentage	Average Score	Lower Benchmark	Mean Benchmark	Upper Benchmark
Temperature in Winter, Too Hot/Too Cold	58%	5.47	4.3	4.46	4.62
Temperature in Winter, Stable/Unstable	61%	5.11	4.66	4.78	4.9
Temperature in Winter, Overall	43%	3.81	3.89	4.14	4.39
Air in Winter, Too Dry/Humid	30%	3.53	3.18	3.3	3.42
Air in Winter, Fresh/Stuffy	30%	4.15	4.16	4.38	4.6
Air in Winter, Still/Draughty	33%	4.43	3.63	3.77	3.91
Air in Winter, Overall	45%	3.86	3.93	4.17	4.44

Dissatisfaction with lighting overall was very low, although glare from both lights and sun/sky was higher with 32% and 18% respectively (Table I-4).

Table I-4: Case Study 2 Overall POE Results.

POE Variable	Dissatisfaction Percentage	Average Score	Lower Benchmark	Mean Benchmark	Upper Benchmark
Lighting Overall	5%	5.00	4.77	4.95	5.13
Daylight	9%	4.59	3.54	3.7	3.86
Glare from Sun and Sky	18%	4.68	3.39	3.61	3.83
Electric Light	9%	4.27	4.19	4.29	4.39
Glare from Lights	32%	3.64	3.59	3.69	3.79

I.2.6. Discussion

Overall, the POE results are in general agreement with the environmental monitoring results, particularly for lighting, where both sets of results showed that overall illuminance was almost always adequate and also that there were some glare problems.

At first glance, it could be expected that dissatisfaction with the temperature would not be as high as recorded by the POE. However, there a number of points touched on above that may explain the results. Considering the more appropriate lower height sensors CS2.1 and CS2.4, their lower quartile temperatures are just above the lower limit for comfort (Table I-2). Minimum temperatures recorded during working hours are between 15.5°C and 16.9°C, which is well below the comfort range. The average daily temperature range of between 2°C and 2.5°C would not be expected to produce the very high dissatisfaction result from the POE for daily temperature variation; however, the maximum range certainly would (Nicol et al., 2012). There are a number of comments about frequent problems with the air-conditioning, cold corridors and bathrooms, and cold walls. All of these factors were not picked up by the environmental monitoring, but they would explain why the POE results are higher than expected given the monitoring results.

Comfort overall had 27% dissatisfaction. Control scores were all above the benchmark upper limit of control, indicating that occupants have significant control.

I.3. Case Study 3

- Monitoring Period: winter (13 July – 27 July 2012)
- POE Period: 12 July 2012

I.3.1. Environmental Monitoring Results

Monitoring equipment was installed on the fourth floor of the building and recorded data for 14 days.

Overall, the environmental monitoring results show that:

- the premise is tightly controlled
- it is within the comfortable temperature range of 20–24°C for 99% of the time across all sensors during work hours
- it is well ventilated
- illuminance is variable across the building in plan.

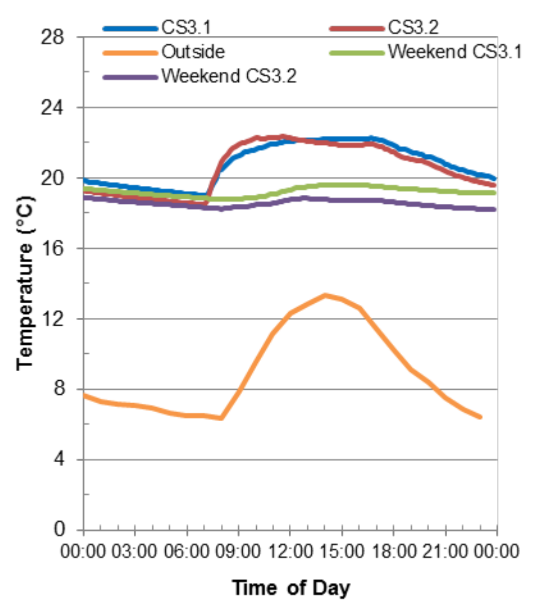
I.3.2. Temperature and Relative Humidity

The average daily temperature profiles for each sensor over the monitoring period were very similar during work hours and on the weekends. The effect of the heating being turned on at 7:00 am each morning is distinctly clear in the profile (Figure I-7). Recorded temperatures during working hours by both sensors are inside the comfort range of 20–24°C almost 99% of the time. This shows how tightly controlled the space is, although the maximum daily temperature range of 4.3°C indicates that there may be some occasional discomfort due to temperature variation.

Table I-5: Case Study 3 Temperatures.

Workday Temperature (°C)	Sensor CS3.1	Sensor CS3.2	Outside
Minimum	18.9	17.8	-2.8
Lower Quartile	21.7	21.7	10.3
Median	22.0	22.1	12.4
Mean	21.9	22.0	11.1
Upper Quartile	22.2	22.3	13.2
Maximum	22.8	22.7	16.8
Standard Deviation	0.6	0.5	3.9
Minimum Range	0.9	0.7	3.8
Median Range	1.6	1.4	8.2
Mean Range	1.8	1.6	9.4
Maximum Range	3.4	4.3	15.5

Indoor relative humidity was between 40% and 60% most of the time and did not rise above 70%. Relative humidity between 30% and 40% was recorded 26% of the time and 29% of the time for sensors CS3.1 and CS3.2 respectively. It could be seen in the average daily relative humidity profile that relative humidity was driven mainly by indoor temperature.



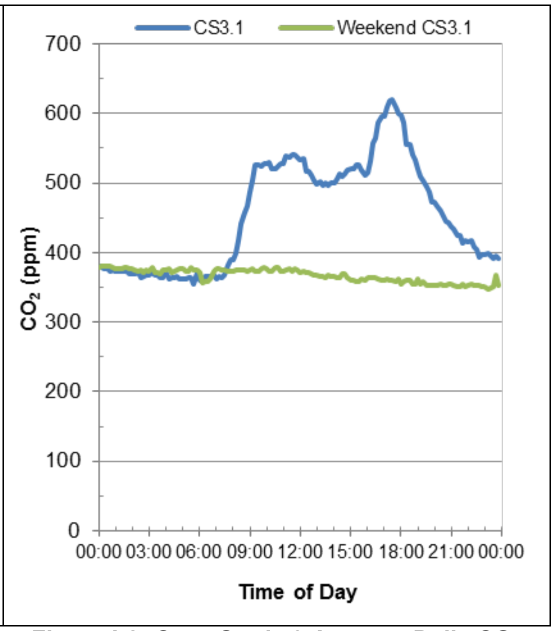


Figure I-7: Case Study 3 Average Daily Temperature Profiles.

Figure I-8: Case Study 3 Average Daily CO_2 Profile.

I.3.3. CO_2

The average CO_2 concentration of 515 ppm is not much above outdoor air concentrations. This suggests that the building is very well ventilated, perhaps excessively so to the point of discomfort caused by draughts from high air change rates (Standards New Zealand, 1990). The daily profile rises as the building is occupied during the day and generally stays stable around 500–600 ppm (Figure I-8).

I.3.4. Lighting

The average daily lighting profiles showed a clear distinction between the two sensor locations (Figure I-9). The space containing sensor CS3.1 was much more poorly lit than the space containing sensor CS3.2. Sensor CS3.2 upper quartile does not reach the minimum 320 lux recommended for office work, while sensor CS3.2 minimum reading is well above this (Table I-6). On face value, it could be assumed that the lighting is not consistent throughout the floor plan, although this may also be explained as a function of each sensor location.

Table I-6: Case Study 3 Illuminance Levels.

Workday Illuminance (lux)	Sensor CS3.1	Sensor CS3.2
Minimum	466	155
Lower Quartile	545	196
Median	593	229
Mean	585	250
Upper Quartile	625	279
Maximum	705	510
Standard Deviation	49	68
Minimum Range	104	33
Median Range	143	215
Mean Range	154	172
Maximum Range	191	273

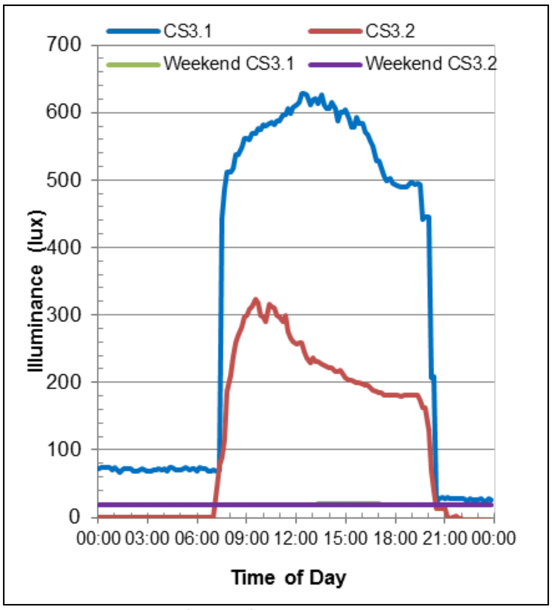


Figure I-9: Case Study 3 Average Daily Illuminance Profiles.

I.3.5. POE Results

Table I-7: Case Study 3 POE Winter Results.

POE Variable	Dissatisfaction Percentage	Average Score	Lower Benchmark	Mean Benchmark	Upper Benchmark
Temperature in Winter, Too Hot/Too Cold	11%	4.53	4.3	4.46	4.62
Temperature in Winter, Stable/Unstable	65%	4.90	4.66	4.78	4.9
Temperature in Winter, Overall	24%	4.52	3.89	4.14	4.39
Air in Winter, Too Dry/Humid	38%	3.30	3.18	3.3	3.42
Air in Winter, Fresh/Stuffy	40%	4.25	4.16	4.38	4.6
Air in Winter, Still/Draughty	45%	3.45	3.63	3.77	3.91
Air in Winter, Overall	14%	4.48	3.93	4.17	4.44

The POE survey was conducted on the fourth floor of the building – the same level as the environmental monitoring and a day before the monitoring period started. There were 21 respondents to the survey.

Apart from dissatisfaction with the temperature in winter, which was 65%, the other POE temperature variables had low levels of dissatisfaction (Table I-7). Dissatisfaction with the POE variable Too Hot/Cold was all for Too Cold. Of the 38% dissatisfaction with Air in Winter Too Dry/Humid, 34% voted too dry.

Table I-8: Case Study 3 Overall POE Results.

POE Variable	Dissatisfaction Percentage	Average Score	Lower Benchmark	Mean Benchmark	Upper Benchmark
Lighting Overall	20%	4.65	4.77	4.95	5.13
Daylight	20%	4.30	3.54	3.7	3.86
Glare from sun and sky	30%	4.55	3.39	3.61	3.83
Electric Light	5%	4.30	4.19	4.29	4.39
Glare from lights	10%	4.25	3.59	3.69	3.79

Dissatisfaction with overall lighting was moderately low.

I.3.6. Discussion

The POE results for temperature agree with the environmental monitoring results that depict a tightly controlled building that is within the comfort range almost all of the time. There is unexpected high dissatisfaction with temperature variation during the day. As with Case Study 2, there are numerous comments about very cold bathrooms and problems with the air-conditioning, which may explain why dissatisfaction is so high with the temperature variation.

The relative humidity POE results also agree well with the environmental monitoring, as both of these show that there are periods where the relative humidity is low.

The relatively high dissatisfaction with POE Fresh/Stuffy is unexpected given that CO_2 is very low. Although control of heating, cooling, lighting and noise scored mostly above average, control of ventilation was below the lower benchmark score. This suggests that the lack of control could be influencing occupant perceptions of the air quality.

Comparison of lighting results is difficult given the large differences between results from each of the sensors.

I.4. Case Study 4

- Monitoring Period: winter (7 August – 28 August 2012)
- POE Period: 6 August 2012

I.4.1. Environmental Monitoring Results

Monitoring equipment was installed on the 15th floor of the building and recorded data for 21 days.

Overall, the environmental monitoring results show that:

- the premise is very tightly controlled
- it is within the comfortable temperature range of 20–24°C for 99% of the time across all sensors during work hours
- it is very well ventilated
- illuminance is variable from room to room.

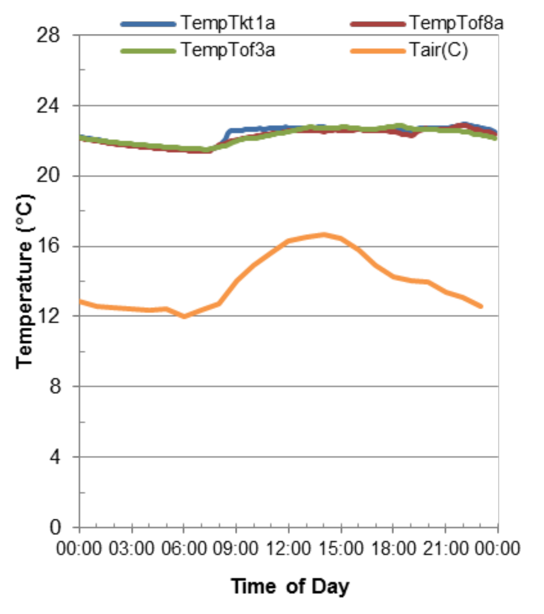
I.4.2. Temperature and Relative Humidity

The average daily profiles for each sensor in the building show that the temperature is very tightly controlled (Figure I-10). Indoor temperatures are almost 100% of the time within the 20–24°C comfort band, apart from the meeting room, which experiences some overheating. All sensors except for the meeting room did not drop below 20°C during the monitoring period.

Table I-9: Case Study 4 Temperatures

Workday Temperature (°C)	Sensor CS4.1	Sensor CS4.2	Sensor CS4.3	Sensor CS4.4	Outside
Minimum	20.0	20.4	19.8	20.7	7.9
Lower Quartile	21.1	21.0	21.9	21.6	12.9
Median	21.3	21.2	22.6	21.8	14.1
Mean	21.3	21.3	22.6	21.9	13.8
Upper Quartile	21.5	21.4	23.3	22.0	15.1
Maximum	22.3	22.7	24.7	23.3	18.3
Standard Deviation	0.3	0.4	1.0	0.3	1.9
Minimum Range	0.4	0.6	1.8	0.5	3.2
Median Range	0.8	0.9	3.0	0.8	6.6
Mean Range	0.9	1.0	2.9	0.8	6.4
Maximum Range	1.2	1.5	3.7	1.1	8.7

Relative humidity was between 40% and 60% during working hours almost 100% of the time.



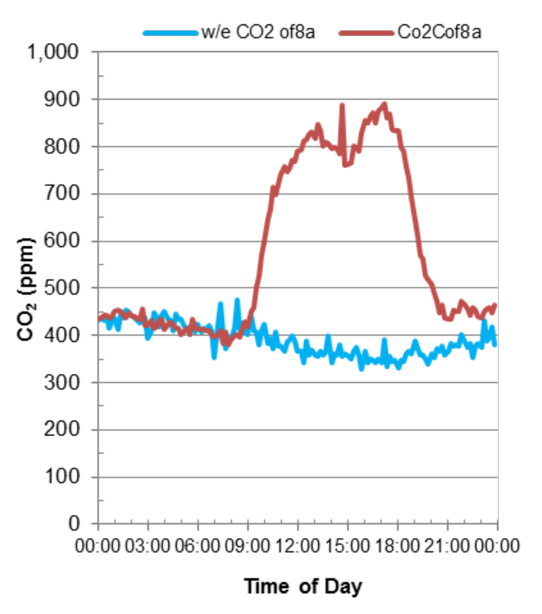


Figure I-10: Case Study 4 Average Daily Temperature Profile.

Figure I-11: Case Study 4 Average Daily CO_2 Profile.

I.4.3. CO_2

The average daily CO_2 profile shows that the CO_2 levels usually never rise above 450 ppm (Figure I-11). Over the monitoring period, the maximum CO_2 recorded was 504 ppm, which is not far above outdoor concentrations. This suggests the ventilation system may be bringing in more fresh air than necessary. This result may not be representative of the closed offices locations.

I.4.4. Lighting

Daily lighting profiles for sensors CS4.1 and CS4.2 were both fairly consistent around or above acceptable illuminance, with medians of 328 lux and 324 lux respectively (Figure I-12). Sensors CS4.3 and CS4.4 both had much higher measured illuminance. Sensor CS4.3, a meeting room, looked to be driven by daylight, while sensor CS4.4 has a very flat profile consistent with electric lighting (Figure I-12). Sensor CS4.2 was located in the open-plan support staff area with no access to daylight. The median illuminance level of 868 lux is much higher than recommended for normal office tasks, which may be causing discomfort, or the support staff may require more light for specific tasks.

Table I-10: Case Study 4 Illumination.

Workday Illuminance (lux)	Sensor CS4.1	Sensor CS4.2	Sensor CS4.3	Sensor CS4.4
Minimum	9	195	76	754
Lower Quartile	87	315	832	845
Median	328	324	936	868
Mean	254	322	948	866
Upper Quartile	346	332	1071	883
Maximum	428	358	1318	967
Standard Deviation	130	17	154	30
Minimum Range	82	34	327	69
Median Range	337	60	458	111
Mean Range	299	66	473	112
Maximum Range	418	154	916	153

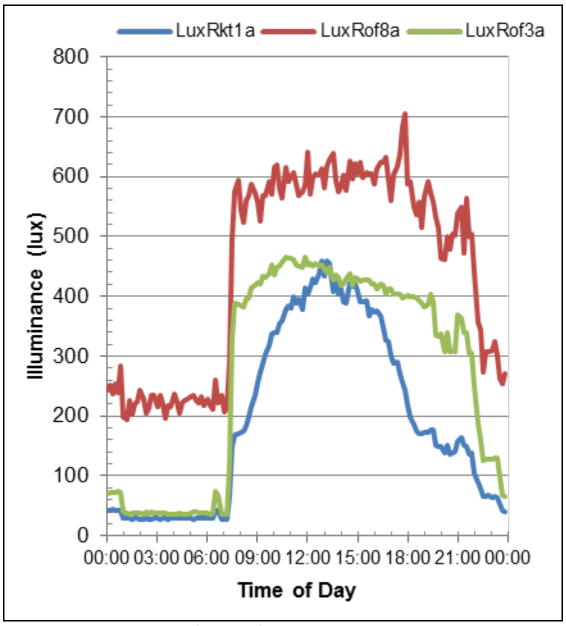


Figure I-12: Case Study 4: Average Daily Illuminance Profiles.

I.4.5. POE Results

The POE results for the temperature in winter showed significant dissatisfaction (Table I-11). Of the 50% dissatisfied with the temperature being too hot or cold, 7% voted too hot and 43% too cold. Apart from Fresh/Stuffy, dissatisfaction with the air in winter was also high. All of the people who were dissatisfied with the Dry/Humid variable voted too dry.

Table I-11: Case Study 4 POE Winter Results.

POE Variable	Dissatisfaction Percentage	Average Score	Lower Benchmark	Mean Benchmark	Upper Benchmark
Temperature in Winter, Too Hot/Too Cold	50%	4.90	4.3	4.46	4.62
Temperature in Winter, Stable/Unstable	63%	5.00	4.66	4.78	4.9
Temperature in Winter, Overall	46%	4.38	3.89	4.14	4.39
Air in Winter, Too Dry/Humid	47%	2.87	3.18	3.3	3.42
Air in Winter, Fresh/Stuffy	7%	3.13	4.16	4.38	4.6
Air in Winter, Still/Draughty	38%	3.50	3.63	3.77	3.91
Air in Winter, Overall	50%	3.63	3.93	4.17	4.44

Lighting overall had low dissatisfaction, but occupants expressed relatively high dissatisfaction with glare from both daylight and electric light (Table I-12).

Table I-12: Case Study 4 Overall POE Results.

POE Variable	Dissatisfaction Percentage	Average Score	Lower Benchmark	Mean Benchmark	Upper Benchmark
Lighting Overall	13%	5.73	4.77	4.95	5.13
Daylight	0%	4.27	3.54	3.7	3.86
Glare from Sun and Sky	47%	3.33	3.39	3.61	3.83
Electric Light	7%	4.20	4.19	4.29	4.39
Glare from Lights	27%	3.53	3.59	3.69	3.79

I.4.6. Discussion

The environmental monitoring results indicated a very stable building with environmental variables almost always inside the comfort range and/or recommended levels. However, POE results show that there was high levels of occupant dissatisfaction with the temperature being too cold, varying during the day and generally overall. 47% of people were also dissatisfied with the building being too dry. Analysis of the POE comments showed that the majority of people complained about the air-conditioning being too cold and variable. From the comments, it appears that this has been an ongoing problem and has taken many attempts to remedy, although it now seems to be operating correctly. There are also a large number of comments about noise from the air-conditioning. The monitoring period may have coincided with a period where the air-conditioning was operating well or that the problem was fixed. Either way, this shows how the influence of persistent historical problems can influence POE voting. In this case, it cannot be conclusively said which dataset is more reliable without a longer term of monitoring.

POE results were consistent with the monitoring data, which indicated that overall illuminance was satisfactory; however, there was evidence of glare from both daylight and electric light. 7% dissatisfaction with the air being too stuffy was also consistent with the measured CO_2 levels, which were consistently very low.

Another factor that may be influencing the POE results is the level of control occupants have. POE scores for control of heating, cooling and ventilation all showed that the occupants feel they have little to no control of these variables, and dissatisfaction was almost 100%.

I.5. Case Study 5

- Monitoring Period: winter (2 May – 19 May 2012)
- POE Period: 1 May 2012

I.5.1. Environmental Monitoring Results

Monitoring equipment was installed on the second floor of the building and recorded data for 17 days.

Overall, the environmental monitoring results show that the premise is:

- tightly controlled
- within the comfortable temperature range of 20–24°C for 99% of the time across all sensors during work hours
- usually lit above recommended office lighting levels.

I.5.2. Temperature and Relative Humidity

The average daily profiles for each sensor in the building show that the temperature is very tightly controlled (Figure I-13). Indoor temperatures are within the 20–24°C comfort band almost 100% of the time. All sensors did not drop below 20°C during the monitoring period, and there were only two temperatures recorded above 24°C (Table I-13).

Table I-13: Case Study 5 Temperatures.

Workday Temperature (°C)	Sensor CS5.1	Sensor CS5.2	Sensor CS5.3	Outside
Minimum	20.5	20.8	20.7	7.9
Lower Quartile	22.6	22.2	22.2	12.9
Median	22.7	22.4	22.4	14.1
Mean	22.6	22.4	22.4	13.8
Upper Quartile	22.8	22.6	22.7	15.1
Maximum	24.1	24.1	23.9	18.3
Standard Deviation	0.3	0.4	0.5	1.9
Minimum Range	0.3	0.3	0.3	3.2
Median Range	1.1	1.4	1.3	6.6
Mean Range	1.4	1.5	1.5	6.4
Maximum Range	2.6	3.2	2.7	8.7

Relative humidity was between 40% and 60% for over 90% over the time for all sensors. The two offices (sensors CS5.2 and CS5.3) had relative humidity levels between 30% and 40% for 7.5% and 6.8% of the time respectively.

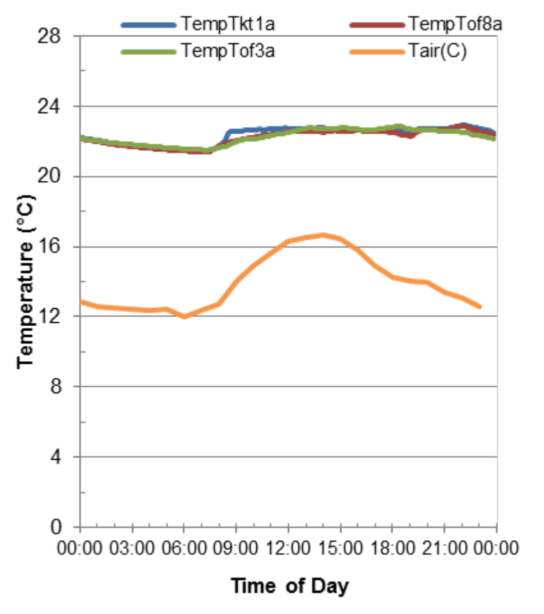


Figure I-13: Case Study 5 Average Daily Temperature Profiles.

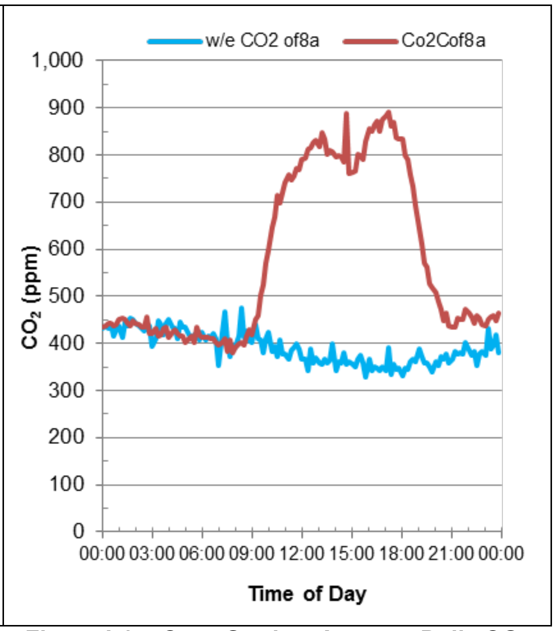


Figure I-14: Case Study 5 Average Daily CO_2 Profiles.

I.5.3. CO_2

CO_2 levels exceeded 1,000 ppm only 0.5% of the time during the monitoring period. The median CO_2 level was 764 ppm, indicating an efficient level of ventilation to maintain acceptable air quality but with CO_2 concentrations well above outdoor air.

I.5.4. Lighting

Illuminance profiles for the two offices, sensors CS5.2 and CS5.3, were well above the recommended illuminance level of 325 lux most of the working day, with median illuminance levels of 604 lux and 426 lux respectively (Figure I-15, Table I-14). Measured illuminance in the kitchen was lower than for the offices, but this is to be expected, as it is not continuously in use.

Table I-14: Case Study 5 Illumination.

Workday Illuminance (lux)	Sensor CS5.1	Sensor CS5.2	Sensor CS5.3
Minimum	161	393	359
Lower Quartile	281	545	401
Median	384	604	426
Mean	360	593	433
Upper Quartile	435	646	459
Maximum	581	790	544
Standard Deviation	98	75	40
Minimum Range	249	262	76
Median Range	356	304	143
Mean Range	349	305	142
Maximum Range	420	347	185

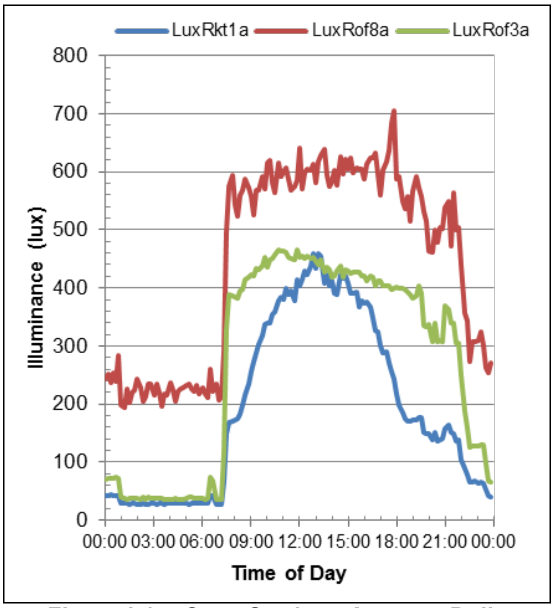


Figure I-15: Case Study 5: Average Daily Illuminance Profiles.

I.5.5. POE Results

POE results for the temperature in winter showed relatively low dissatisfaction (Table I-15). Of the 33% of people dissatisfied with the temperature being too hot or too cold, 31% voted too cold and 2% too hot. Dissatisfaction with the daily temperature variation was high. All of the 34% dissatisfaction with the relative humidity felt the air was too dry. Overall, there was low dissatisfaction with the air in winter.

Table I-15: Case Study 5 POE Winter Results.

POE Variable	Dissatisfaction Percentage	Average Score	Lower Benchmark	Mean Benchmark	Upper Benchmark
Temperature in Winter, Too Hot/Too Cold	33%	4.74	4.3	4.46	4.62
Temperature in Winter, Stable/Unstable	55%	4.53	4.66	4.78	4.9
Temperature in Winter, Overall	36%	4.41	3.89	4.14	4.39
Air in Winter, Too Dry/Humid	34%	3.24	3.18	3.3	3.42
Air in Winter, Fresh/Stuffy	22%	3.81	4.16	4.38	4.6
Air in Winter, Still/Draughty	26%	3.47	3.63	3.77	3.91
Air in Winter, Overall	28%	4.38	3.93	4.17	4.44

Lighting overall had low dissatisfaction, but there was significant dissatisfaction with glare from both daylight and electrical light (Table I-16).

Table I-16: Case Study 5 Overall POE Results.

POE Variable	Dissatisfaction Percentage	Average Score	Lower Benchmark	Mean Benchmark	Upper Benchmark
Lighting Overall	20%	4.71	4.77	4.95	5.13
Daylight	25%	3.73	3.54	3.7	3.86
Glare from Sun and Sky	44%	3.37	3.39	3.61	3.83
Electric Light	10%	4.15	4.19	4.29	4.39
Glare from Lights	44%	3.22	3.59	3.69	3.79

I.5.6. Discussion

POE results for CO_2 were in agreement with the results from environmental monitoring data. Dissatisfaction with the air being too dry was slightly higher than expected, given that the measured relative humidity was mostly within 40–60% during the monitoring period.

While dissatisfaction with the temperature in winter being too hot or too cold, and overall, was relatively low, dissatisfaction with the temperature variation was much higher than expected given that the daily temperature range was low. Looking at the POE comments, there were a number of people who commented on the air-conditioning often being too cold and varying in different regions through the office. There were also complaints about temperatures being very cold under air-conditioning vents – including one that said that a vent had been taped over as a remedy. This suggests that the monitoring period was not long enough to reflect the true conditions in the building. One comment mentioned that the air-conditioning problems seemed to have been fixed. This suggests that previous problems with the air-conditioning may have influenced voting in the POE survey.

Although measured illuminance appeared to be adequate overall and the POE survey results agreed with this, they did not capture the glare problems expressed in the POE results. This may be due to the limitations of only having three light loggers and that light levels can be highly variable across a space.

I.6. Case Study 6

- Monitoring Period: winter (24 August – 14 September 2012)
- POE Period: 29 January 2013

I.6.1. Environmental Monitoring Results

Monitoring equipment was installed on the 12th floor of the building and recorded data for 22 days.

Overall, the environmental monitoring results show that:

- the premise is very tightly controlled
- it is within the comfortable temperature range of 20–24°C 100% of the time across all sensors during work hours
- it is very well ventilated
- illuminance is variable from room to room.

I.6.2. Temperature and Relative Humidity

The average daily profiles for sensors CS6.1 and CS6.2 show that the temperature is very tightly controlled in the open-plan office location, while sensor CS6.3 shows that the meeting room is not as tightly conditioned. There is on average a 1°C difference in temperature between sensors CS6.1 and CS6.2, with the location containing sensor CS6.2 being warmer (Table I-17). Sensor CS6.2 is located on the northern side of the building at 1.5 m above floor level, while sensor CS6.1 is on the south at 1 m above floor level. This suggests two possible reasons for the difference in temperature. Firstly, the sunny (north) side of the building is warmer than the south side, and secondly, there is temperature stratification from floor to ceiling level.

Temperatures across all sensors were 100% of the time within the comfort range of 20–24°C during work hours.

Table I-17: Case Study 6 Temperatures.

Workday Temperature (°C)	Sensor CS6.1	Sensor CS6.2	Sensor CS6.3	Outside
Minimum	20.1	21.6	20.9	0.0
Lower Quartile	21.0	22.1	21.9	12.7
Median	21.2	22.3	22.4	14.0
Mean	21.2	22.3	22.4	13.7
Upper Quartile	21.4	22.5	22.8	15.4
Maximum	21.9	23.1	24.0	18.5
Standard Deviation	0.4	0.3	0.6	2.8
Minimum Range	0.3	0.4	0.7	3.7
Median Range	0.5	0.7	1.7	7.2
Mean Range	0.5	0.8	1.6	7.8
Maximum Range	0.7	1.1	2.1	16.0

Relative humidity measurements from sensors CS6.1, CS6.2 and CS6.3 were between 40% and 60% for 97%, 88% and 80% of the time, respectively. The remainder of the time, measured relative humidity was between 30% and 40%.

I.6.3. CO_2

The average daily CO_2 profile shows that the CO_2 concentration was usually between 500 ppm and 550 ppm during work hours. The maximum CO_2 concentration was 619 ppm, which is much lower than the recommended limit. This suggests that the office is provided with ample fresh air and also that the ventilation system may be bringing in more fresh air than necessary.

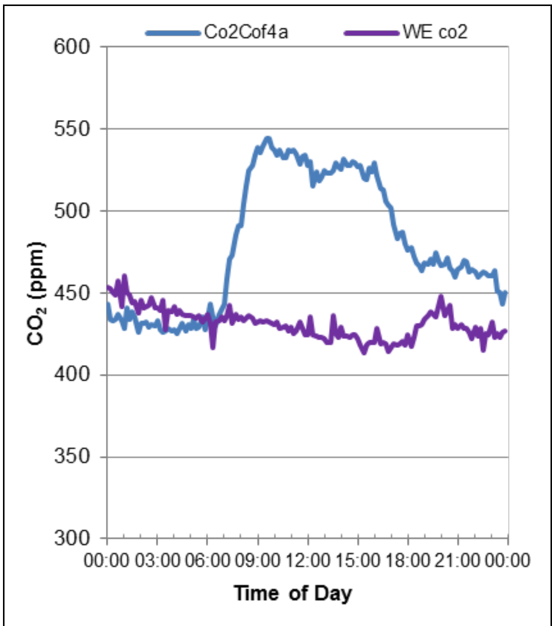


Figure I-16: Case Study 6 Average Daily CO_2 Profiles.

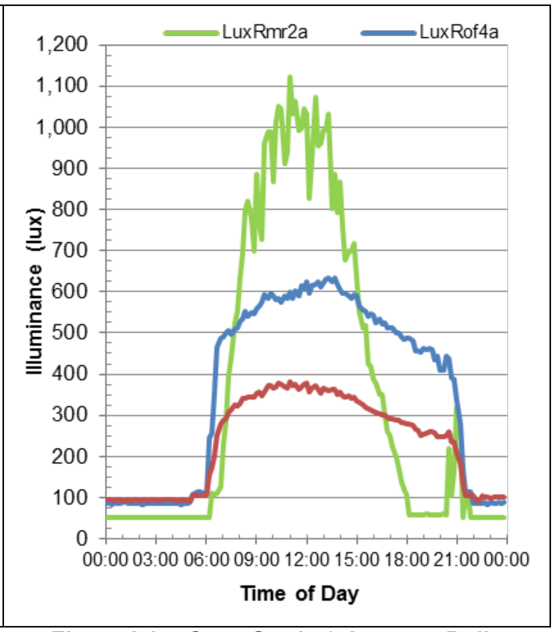


Figure I-17: Case Study 6 Average Daily Illuminance Profiles.

I.6.4. Lighting

Figure I-17 shows that sensor CS6.2 is usually lit to or just above recommended office illuminance levels. Sensor CS6.1 has a similar profile, but illuminance levels are consistently around 200 lux higher. Sensor CS6.3, the meeting room, which is on the north side of the premise, has a daily illuminance profile that is driven mainly by daylight and has much higher measurements than the offices. This is likely due to the blinds being open when the meeting room is not in use, allowing unrestricted daylight access.

Table I-18: Case Study 6 Illumination.

Workday Illuminance (lux)	Sensor CS6.1	Sensor CS6.2	Sensor CS6.3
Minimum	472.3	263.6	73.7
Lower Quartile	542.0	303.4	385.8
Median	576.8	329.9	676.7
Mean	578.9	347.3	772.7
Upper Quartile	611.8	376.3	1,002.9
Maximum	730.3	542.2	3,124.0
Standard Deviation	47.4	54.8	521.3
Min Range	146.4	59.7	524.9
Median Range	198.7	122.7	1,032.1
Mean Range	191.8	136.5	1,357.5
Maximum Range	244.1	252.1	2,709.8

I.6.5. POE Results

The POE results for temperature in winter showed moderate dissatisfaction (Table I-19). Of the 45% dissatisfied with the temperature being too hot or too cold, 27% voted to cold and 18% too hot. Dissatisfaction with the daily temperature variation was very high. Overall, dissatisfaction with the air in winter was moderately high.

Table I-19: Case Study 6 POE Winter Results.

POE Variable	Dissatisfaction Percentage	Average Score	Lower Benchmark	Mean Benchmark	Upper Benchmark
Temperature in Winter, Too Hot/Too Cold	45%	4.55	4.3	4.46	4.62
Temperature in Winter, Stable/Unstable	73%	5.00	4.66	4.78	4.9
Temperature in Winter, Overall	42%	4.25	3.89	4.14	4.39
Air in Winter, Too Dry/Humid	18%	3.60	3.18	3.3	3.42
Air in Winter, Fresh/Stuffy	55%	4.91	4.16	4.38	4.6
Air in Winter, Still/Draughty	30%	4.80	3.63	3.77	3.91
Air in Winter, Overall	42%	4.00	3.93	4.17	4.44

There was little dissatisfaction with the illuminance overall, but greater dissatisfaction was expressed with glare (Table I-20).

Table I-20: Case Study 6 Overall POE Results.

POE Variable	Dissatisfaction Percentage	Average Score	Lower Benchmark	Mean Benchmark	Upper Benchmark
Lighting Overall	15%	5.54	4.77	4.95	5.13
Daylight	15%	4.23	3.54	3.7	3.86
Glare from Sun and Sky	23%	4.85	3.39	3.61	3.83
Electric Light	8%	4.15	4.19	4.29	4.39
Glare from Lights	38%	3.54	3.59	3.69	3.79

I.6.6. Discussion

The low dissatisfaction expressed with the illuminance from the POE results was expected, given the measured illuminance was mostly above recommended office illuminance levels.

There was also low dissatisfaction with the relative humidity, which was all voted as too dry. This was expected as the environmental monitoring results show that, although most of the time relative humidity was between 40% and 60%, there were short periods of time that it dropped to 30–40%.

The significant dissatisfaction expressed with the air being too stuffy was unexpected. No obvious explanation for this is apparent in the sensor location or POE comments.

The POE results for temperature were also unexpected. The very high dissatisfaction with the temperature variation was not expected due to the low measured temperature range. However, the temperature variation between sensors, as noted above, suggests that this dissatisfaction is an expression of dissatisfaction with spatial temperature variation rather than daily temperature variation. This may in part lead to the dissatisfaction expressed with the temperature being too hot or too cold, so that people feel one part of the building is too hot and the other too cold, especially if they have to move between areas.

Although the majority of people did not see control as important, another factor that may be influencing the POE results is the level of control occupants have. POE scores for control of heating, cooling and ventilation all showed that the occupants feel they have little to no control of these variables, and dissatisfaction was almost 100%.

The possibility for this building is also that unexpected results may be due to the occupants' memory of winter conditions being unreliable, as the survey was conducted in summer while monitoring was done in winter.

I.7. Case Study 7

- Monitoring Period: winter (24 August – 14 September 2012)
- POE Period: 29 January 2013

I.7.1. Environmental Monitoring Results

Monitoring equipment was installed on the 17th floor of the building and recorded data for 22 days. A CO_2 logger was not installed on this floor.

Overall, the environmental monitoring results show that:

- the premise is very tightly controlled;
- it is within the comfortable temperature range of 20–24°C 100% of the time across all sensors during work hours
- illuminance is variable across the locations, but it is usually well lit.

I.7.2. Temperature and Relative Humidity

The average daily profiles for sensors CS7.1 and CS7.3 show that the temperature is very tightly controlled in the open-plan office location, while sensor CS7.2 shows that the meeting room is not as tightly conditioned. Temperatures for sensors CS7.1 and CS7.3 were 100% of the time within the comfort range of 20–24°C during work hours, while sensor CS7.2 was 94% of the time within the comfort range.

Relative humidity appears to be largely driven by temperature and reflected the tightly controlled temperature range. 89% of the time during monitoring, sensor CS7.1 was within 40–60% relative humidity, while the other two sensors were in this range at least 95% of the time. All other recorded relative humidity measurements were between 30% and 40% relative humidity.

Table I-21: Case Study 7 Temperatures.

Workday Temperature (°C)	Sensor CS7.1	Sensor CS7.2	Sensor CS7.3	Outside
Minimum	20.9	18.3	21.2	0.0
Lower Quartile	22.0	20.4	21.6	12.7
Median	22.2	20.5	21.8	14.0
Mean	22.3	20.4	21.8	13.7
Upper Quartile	22.5	20.6	22.0	15.4
Maximum	23.4	21.0	22.2	18.5
Standard Deviation	0.4	0.4	0.2	2.8
Minimum Range	0.5	0.2	0.2	3.7
Median Range	1.0	0.5	0.4	7.2
Mean Range	1.0	0.9	0.4	7.8
Maximum Range	1.5	2.7	0.7	16.0

I.7.3. Lighting

The daily illuminance profiles are all daylight driven (Figure I-18). During the monitoring period, illuminance levels in the meeting room did not meet the recommended level for office illuminance (Table I-22). This may have been due to infrequent use and the location of the meeting room in the centre of the floor plan, which restricts daylight penetration. Measured illuminance in the two open-plan office locations was usually above the 325 lux recommended for office locations.

Table I-22: Case Study 7 Illumination.

Workday Illuminance (lux)	Sensor CS7.1	Sensor CS7.2	Sensor CS7.3
Minimum	273.9	93.2	260.0
Lower Quartile	354.6	124.6	356.8
Median	441.6	231.2	412.1
Mean	497.7	199.1	411.7
Upper Quartile	652.8	268.8	467.5
Maximum	888.8	312.6	605.8
Standard Deviation	166.1	73.6	70.7
Minimum Range	217.5	37.6	172.9
Median Range	493.8	197.4	276.7
Mean Range	474.3	183.6	262.3
Maximum Range	590.0	219.4	331.9

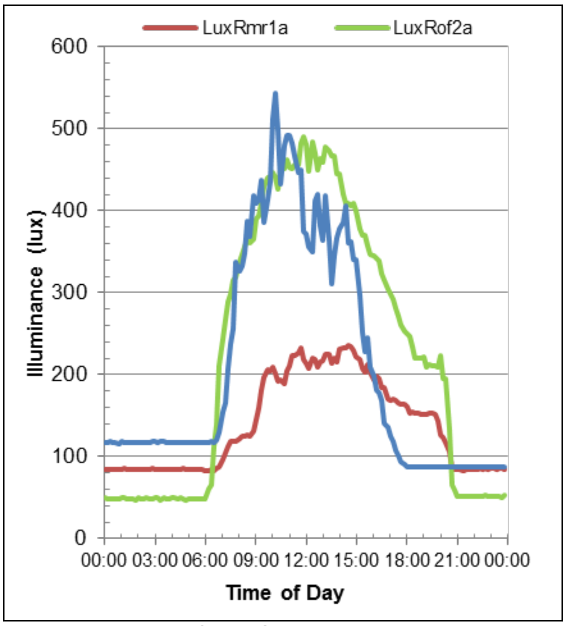


Figure I-18: Case Study 7 Average Daily Illuminance Profiles.

I.7.4. POE Results

The POE results for temperature in winter show that there is very little dissatisfaction with the temperature except for the variation. Of the 21% dissatisfied with the Too Dry/Humid variable, the main reason was with the air being too dry.

Table I-23: Case Study 7 POE Winter Results.

POE Variable	Dissatisfaction Percentage	Average Score	Lower Benchmark	Mean Benchmark	Upper Benchmark
Temperature in Winter, Too Hot/Too Cold	0%	4.17	4.3	4.46	4.62
Temperature in Winter, Stable/Unstable	47%	4.33	4.66	4.78	4.9
Temperature in Winter, Overall	6%	5.61	3.89	4.14	4.39
Air in Winter, Too Dry/Humid	21%	3.39	3.18	3.3	3.42
Air in Winter, Fresh/Stuffy	11%	3.51	4.16	4.38	4.6
Air in Winter, Still/Draughty	26%	3.32	3.63	3.77	3.91
Air in Winter, Overall	3%	5.44	3.93	4.17	4.44

Dissatisfaction with the lighting was very low apart from the 30% dissatisfaction expressed with glare from electric lighting.

Table I-24: Case Study 7 Overall POE Results.

POE Variable	Dissatisfaction Percentage	Average Score	Lower Benchmark	Mean Benchmark	Upper Benchmark
Lighting Overall	13%	5.32	4.77	4.95	5.13
Daylight	8%	4.35	3.54	3.7	3.86

Glare from Sun and Sky	16%	4.65	3.39	3.61	3.83
Electric Light	0%	4.27	4.19	4.29	4.39
Glare from Lights	30%	3.35	3.59	3.69	3.79

I.7.5. Discussion

Apart from temperature variation, all of the POE results agree with the environmental monitoring results. 47% dissatisfaction with the daily temperature variation is significant and much higher than could be expected given the low measured daily temperature variation. Unlike for Case Study 6, there were no obvious differences between the sensors. There is the possibility that the expression of dissatisfaction is related to exposure to varying radiant temperature from solar radiation, which would not be picked up by the temperature sensors.

As with Case Study 6, although the majority of people did not see control as important, another factor that may be influencing the POE results is the level of control occupants have. POE scores for control of heating, cooling and ventilation all showed that the occupants feel they have little to no control of these variables, and dissatisfaction was almost 100%. This lack of control may be a factor in the overall results for dissatisfaction with the temperature variation being high for all the buildings studied.

Results showed that occupant perception may be a reliable indicator of temperature predictability and extremes of temperature; however, little relationship was identified for relative humidity, CO_2 and illuminance.

J. Modelling

J.1. Practice Building

To determine what the possible outcomes of this study could be prior to applying it to a BEES monitored building, a practice building was used to develop the methodology. The practice building allowed for the development of a useful data-gathering and modelling process. The practice building also determined two key factors: firstly, what level of detail was necessary to model in order to generate results that are representative of the real building energy performance; and secondly, what data was required to be collected from a building to attain and produce the identified level of modelling detail.

The five levels used for modelling are presented in Table J-1. Please refer to Section 2.5.2 of the BEES Year 5 topic report: Modelling Detail Analysis (Gates, et al., 2012) on the intent and creation of each level of modelling.

Table J-1: Levels of Modelling Detail.

Level	Geometry Type	HVAC Type
1	Template adjusted to match the scale and orientation of each building.	Ideal Loads – the energy that must be delivered to the zones in the space for heating, cooling and lighting but have no information on the energy that is consumed by the HVAC equipment that delivers this energy to the zones.
2	Template adjusted to match the scale and orientation of each building.	Default Values from EnergyPlus of the HVAC system delivering the heating and cooling to the zones.
3	Template adjusted to match the scale and orientation of each building.	Detailed Values using detailed HVAC input values.
4	Detailed geometry and thermal zone definitions based upon analysis of the building plans.	Default Values from EnergyPlus of the HVAC system delivering the heating and cooling to the zones.
5	Detailed geometry and thermal zone definitions based upon analysis of the building plans.	Detailed Values using detailed HVAC input values.

J.2. Calibration of the Practice Building

The aim of using a practice building was to determine the process of modelling different levels of detail and identify which level was most effective (accuracy of model versus effort required on the model) for the modelling process.

The selected practice building was a Wellington-based office building. The practice building has the following features:

- Period built: 1970s
- Strata: S4 (3,500–8,999 m^2)
- Height: 12 storeys
- Setting: Commercial (mainly office use)
- Primary material: Concrete
- Window material: Aluminium/metal – single glazed
- Template built form classification: large open plan (OP5)

The data collection and modelling methodology comprised three stages under two categories.

Table J-2: Data Collection and Modelling Methodology Stages.

Category	Stage	Description
Data Collection	1) Site visit	Site visit accompanied by the building manager to capture photos of plant equipment, manufacturer plaques/installation details of major plant items and to collect notes on the make and model of each major plant items. If the brand and model of plant equipment could not be found, a request was sent to the building manager. This type of problem can be expected for any model of a real building.
	2) HVAC equipment research	Operation manuals/BMS settings for temperature set points, fresh air intake rates, equipment makes/models and operational schedules; review of manufacturer data on the plant performance values and plans for detailed geometry modelling. Specific information about the building was required to complete the model with the installed HVAC equipment. An internet search was sufficient to obtain performance values in order to create an accurate HVAC model in EnergyPlus. To complete the modelling, technical drawings of the HVAC system were obtained from the Wellington City Council Archives.
Modelling	3) Modelling of building	The building models were constructed as described in Table J-1. The five models were constructed using EnergyPlus and OpenStudio. The purpose of constructing five different versions of the same building was to test various levels of detail systematically.

J.3. BEES Buildings: Applying the Modelling Method

Having developed and tested a modelling methodology on a practice building, a BEES building was used to test the same process and levels of detail applied in the practice building modelling process. The test BEES building had the following construction features:

- Period Built: 1970s
- Strata: S4 (8,027 m^2)
- Height: 9 storeys
- Setting: Commercial (office)
- Primary material: Concrete
- Window material: Aluminium/metal with single clear glazing
- Built form template classification: Cellular Strip (CS)
- HVAC system type: Variable air volume with electric heating coils

As with the practice building, the test BEES building also followed the methodology of using three stages, refer to Table J-2.

The difference with the second attempt was that all collected building data such as floor plans, HVAC system data and schedules were obtained from the facility manager and the BEES team. This meant that a site visit was not essential to collect information. This enabled far more efficient gathering of resources and meant information was current for the operating building.

Modelling of each level of detail for the test BEES building followed the same process and steps as explained for the practice building. The results of the five levels of detail show a similar trend to that seen with the practice building.

J.4. Christchurch Base Building Model

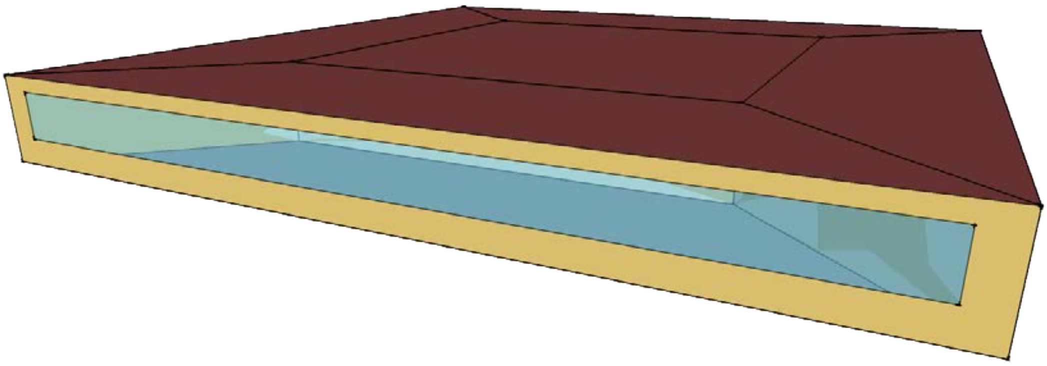


Figure J-1: Christchurch Base Scenario Model.

Figure J-1 displays the EnergyPlus base scenario building model for Christchurch. The model is a 1,000 m^2 single-storey building that is split into five zones: four perimeter zones and one core zone. The zones are visible in Figure J-1 as the lines on the roof of the model. Modelling these perimeter and core zones separately better simulates the interaction between the external environment and the internal building environment. The New Zealand Building Code (NZBC) building parameters are as follows:

Table J-3: Christchurch Base Model Parameter Values.

Building Parameter	Parameter Value
Wall Insulation	1.2 m^2-K/W (Standards New Zealand, 2007b)
Roof Insulation	1.3 m^2-K/W (Standards New Zealand, 2007b)
Floor Insulation	1.9 m^2-K/W (Standards New Zealand, 2007b)
Glazing	No requirement in the standard, so assumed to be single glazing (Standards New Zealand, 2007b) Insulation: 0.15 m^2-K/W (Standards New Zealand, 1992) Solar Heat Gain Coefficient: 0.81 (National Institute of Building Sciences, 2012) Visible Transmission: 0.89 (National Institute of Building Sciences, 2012)
Window-to-wall Ratio (WWR)	50% (Standards New Zealand, 2007b)
Lighting Power Density	12 W/m^2 (Standards New Zealand, 2007)
Electric Equipment Power Density	8.5 W/^{2} (Standards New Zealand, 2007b)
People Density	0.1 person/m^2 (Standards New Zealand, 2007b)
Fresh Air Rate	10 L/s.person (Standards New Zealand, 1990)

The building has a concrete slab installed for use as thermal mass.

The typical operational schedule found for a 1,000 m^2 commercial office building is from 8:00 am to 5:00 pm (Saville-Smith & Fraser, 2012). The occupancy, electric light, electric equipment, heating and cooling are all assumed to be on from 8:00 am to 5:00 pm every day.

The heating and cooling set points were established from the 30 International Energy Agency (IEA) Task 40 case study buildings from Europe, Asia and North America. It was found that buildings in similar climates to Christchurch, not just those in tropical climates, can save a significant amount of cooling energy by using a much higher cooling set point than what is considered normal in New Zealand. For example, with the use of ceiling fans, occupants in temperate climates like Paris, reported being comfortable in temperatures up to 30°C (Cory, et al., 2012b). This is considerably higher than the accepted temperatures of 25–26°C when cooling would conventionally be turned on in temperate climates like those in New Zealand. In this study, a higher than normal but still relatively conservative 27°C is used as the cooling set point. The heating set point is 18°C, which is the minimum comfort temperature for healthy occupants (ASHRAE, 2004).

J.4.1. Christchurch Design Change and Optimisation Building Model

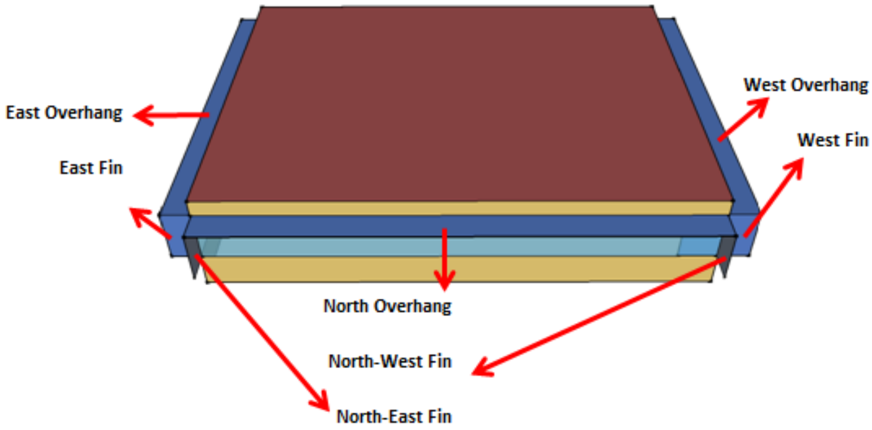


Figure J-2: Christchurch Design Change and Optimisation Scenario Model and Solar Shading Location.

Figure J-2 shows the EnergyPlus design change and optimisation scenario building model for Christchurch. The model is the same 1,000 m^2 single-storey building split into five zones but with overhangs, side fins and/or louvres.

The first scenario tested is the base model with no external solar shading but with natural ventilation and electric light controls installed in the perimeter zones. Natural ventilation opens the external windows at 26°C to cool the building naturally. This is set below the mechanical cooling set point to ensure that the program only calculates the energy use for cooling when the natural ventilation is inadequate. The electric light controls turn off the perimeter electric lights when the minimum illuminance set point is reached. The minimum illuminance set point used in this study is 350 lux and is 30 lux higher than the minimum value set for general office tasks in the NZBC (Standards New Zealand, 2009).

The second scenario tested incorporates the first scenario design changes of natural ventilation and electric light controls but also optimises various other building parameters, as shown in Table J-4. With GenOpt, the program requires minimum and maximum values to be set for each parameter, which are displayed in Table J-4.

Table J-4: Christchurch Optimisation Building Parameters.

Building Parameter	Minimum and Maximum Parameter Values
North, East, and West Overhang	0–3 m
North-East, North-West, East and West Fins	0–3 m
Wall, Roof, Floor Insulation	0.1–12 m²-K/W
Glazing Insulation	0.15–10 m²-K/W
Solar Heat Gain Coefficient and Visible Transmission (*Linked Parameter*)	0.1–0.9
Window-to-wall Ratio	10–90%
Window Height	The ability to move the window sill to 0.1 m above the ground and the window head to 0.1 m below the roof

J.5. Central City Plan Testing Parameters

J.5.1. Central City Plan Proposed Urban Form Features

Passive design is a response to a site's conditions, which form the basis of a building's performance. Because they are fundamental to the form and the design appearance of a building, passive design measures can only be implemented at the beginning of a project. This is because changes in building design form and appearance are expensive and time consuming to make late in the design process. A passive urban form study for Christchurch is therefore only useful now during the planning stages while significant design changes affecting the form of buildings and the form of the city itself can still be made. For this reason, this study focuses on the passive elements of a proposed sustainable urban Christchurch.

Sunlight is beneficial in providing natural heat both to buildings and the street and can be utilised to create thermally comfortable environments passively. Daylight enhances visual capacity and comfort naturally, at the same time reducing the need for expensive artificial lighting. Finally, building occupants require high-quality fresh air to function properly (old or used air in buildings typically has higher levels of CO_2 than outdoor air, which can cause drowsiness). This passive approach to bringing fresh outdoor air through windows into buildings is often described as natural ventilation to distinguish it from the delivery of the same fresh air by mechanical means to people in commercial buildings.

Increasing permeability through the city (laneways and courtyards) brings more building surface area into contact with outdoor air and thus makes natural ventilation more likely to be employed. As fan energy is often a large component of any HVAC, using simple openings like windows and passive ventilation openings has the potential to save energy while still delivering better indoor air quality.

J.5.2. Building Height Limits

As a result of the earthquakes, people in Christchurch have become concerned about the safety of tall buildings. For this reason, and to create a more open sunny atmosphere, residents of Christchurch requested smaller buildings through the Share an Idea initiative: “Keep the buildings low rise – it lets more natural light into the city” (Christchurch City Council, 2011b). Figure J-3 illustrates the Central City Plan proposed maximum building height limitations for different zones. The focus central core zone, seen in red, is subject to a 29 m (seven storey) maximum limit, with a minimum of three storeys. This proposed building height restriction will be used as a modelling constant throughout this study. The seven storey model will not be tested against taller city models because of the Central City Plan limit.

The study does look at the implication of maximising profit by maximising the floor area of buildings under this height limit. One possible result of placing a height restriction like this seven-storey limit is that land owners see the only possible means of maximising returns on their site is to develop all the floor area of each site up to the height limit. The eventual result could be covering all the land area of the city blocks with buildings up to a limit of 29 m.

In all situations presented in this study the ground floor height is 5.0 m, and the floors above have 4.0 m inter-floor heights, in accordance with the Central City Plan.

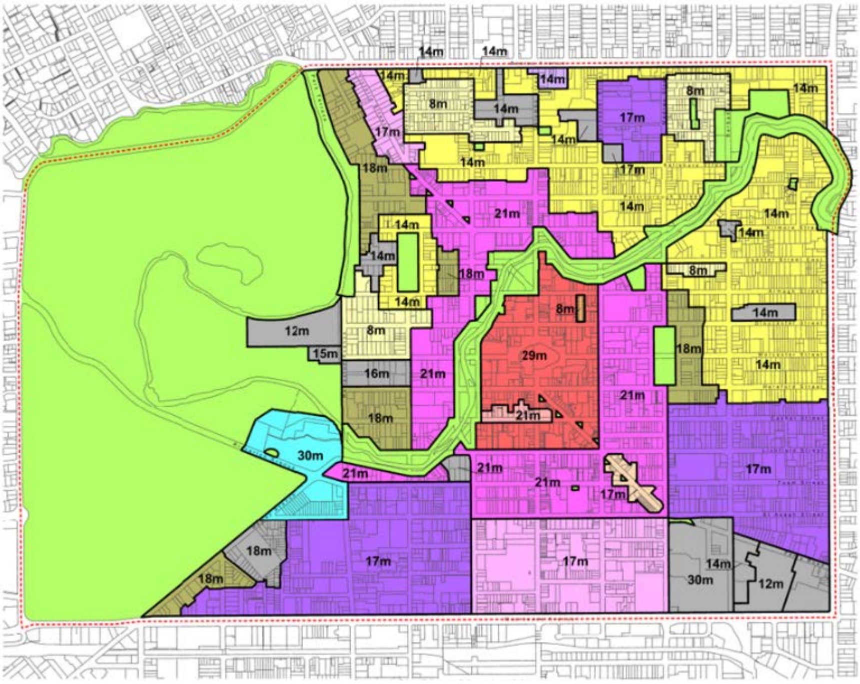


Figure J-3: Central City Planning Map 3: Regulatory Framework- Illustrating Intended Building Height Restrictions (Christchurch City Council, 2011a).

J.5.3. Façade Step-Backs

The first passive urban form feature studied is the façade step-back, shown in Figure J-4. This is a method proposed by the Central City Plan to increase solar penetration to the urban canyon (urban canyon describes the result of a road cutting through dense buildings). Applied on the southern side of buildings at a 45° angle, the step-back intends to allow more sunlight (direct solar beam) and daylight (diffused light) deeper into the city. Figure J-5 demonstrates how cutting the top two (sixth and seventh) floors back to a 45° angle will result in sunlight reaching two floors lower on the opposite side of the road (at equinox). The desired result is more daylight to buildings and more sunlight to the street for greater pedestrian comfort.

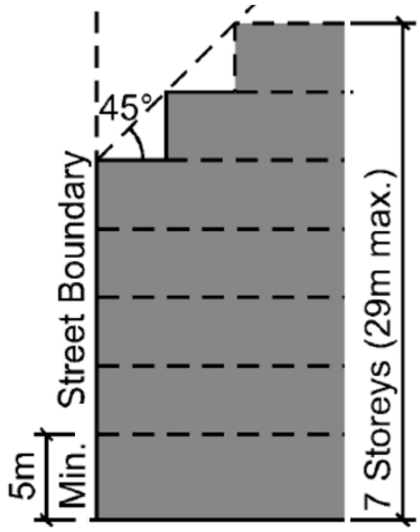


Figure J-4: Central City Plan Proposed Step-backs (Christchurch City Council, 2011b).

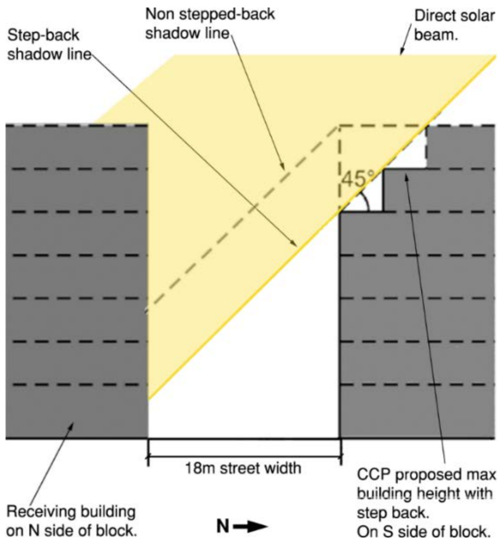


Figure J-5: Central City Plan Intended Effect of Step-backs on Solar Access to Urban Canyon.

J.5.4. Laneways and Alleyways

The existing/retained CBD grid consists of rectangular blocks approximately 100 m long in the north-south direction by 200 m long in the east-west direction. These are substantial distances, which create difficulty in pedestrian movement and accessibility. The Central City Plan's 'Strengthening the Grid' project (increasing permeability through the large 200 m x 100 m city block system) proposes to add seven laneways to the 13 existing in the central core zone (Christchurch City Council, 2011b). The Crown (via CERA) is prepared to, and intends to, secure the land targeted for transformation into public access routes by purchasing obstructing land parcels. Laneways (refer Figure J-6, which shows in black the laneways that existed pre-earthquake but also large blocks with no laneways) are expected to increase urban canyon area and allow more natural light and air to buildings (Christchurch City Council, 2011b).

There are three types of laneways proposed in the Central City Plan – wide laneways (4–10 m wide), narrow laneways (2–4 m) and service laneways (3–5 m). This study tested two variations of laneway. The first is 4 m wide, as this width represents the distinction between narrow and wide laneway types and is also the mid-range size for a service laneway. The second is 10 m wide, as it demonstrates the effects the largest possible laneway size will have on surrounding buildings. The goal was to bracket the range of small to large and thus establish what effect laneway width might have on building performance rather than test a myriad of combinations of laneway width, none of which would be precisely right.

Despite the suggestion in the Central City Plan of having laneways covered to provide shelter from rain, all laneways were modelled as open to the sky to best determine their influence on daylight to those spaces.

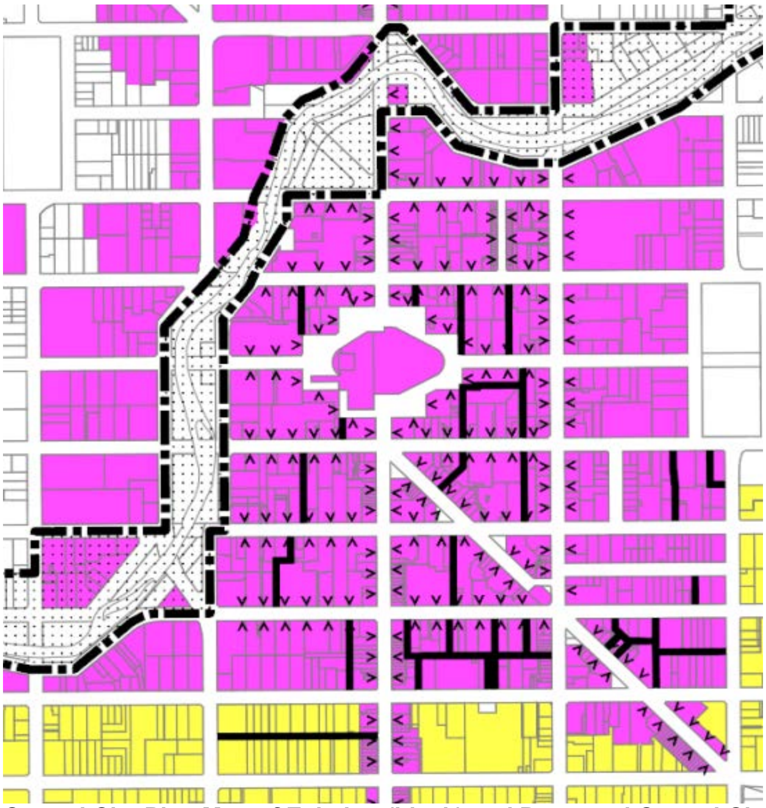


Figure J-6: Central City Plan Map of Existing (black) and Proposed Central City Laneways (Christchurch City Council, 2011c).

J.5.5. Internal Courtyards

The intention of introducing internal courtyards is to increase proximity of internal spaces to the ambient environmental amenity of light, sun and fresh air. Courtyards work on the theory that elimination of central core zones of deep-plan buildings, which rely entirely on artificial heating/cooling, lighting and ventilation, will be of benefit to a building's performance through greater access to these natural amenities.

The BEES Year 5 topic report Building Design Optimisation (Cory, et al., 2012a) demonstrated perimeter zones possess not only better access to natural amenities in terms of energy but also provide more desirable working conditions due to their proximity to the outdoors (views, natural light, etc.). Replacing part of the energy-intensive core zone of the building with a courtyard converts more of the total floor area to perimeter zones. Because of their access to views, these lower energy use and higher environmental quality spaces are also of greater prestige and thus potentially higher rents. Section J.5.7 explains how desirable working conditions contribute to higher productivity and better returns for businesses.

An additional benefit of courtyards is the outdoor public space they provide (refer Figure J-7). Courtyards can also be used as entertainment precincts as they provide effective shelter from all winds but still receive useful sunlight and daylight.

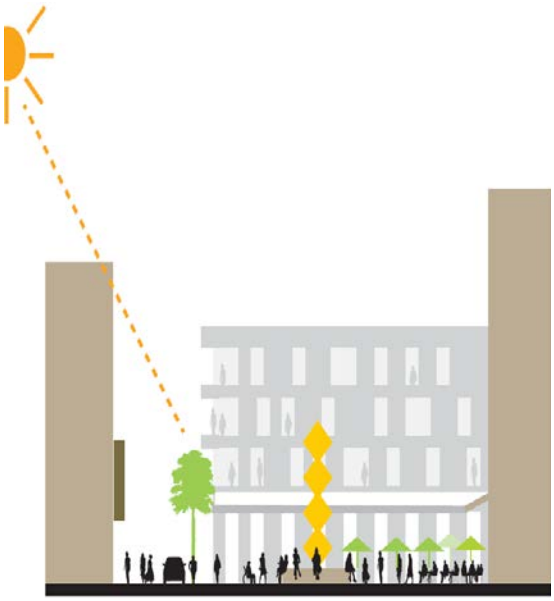


Figure J-7: CCP Impression of the Public Environment from Courtyards (Christchurch City Council, 2011b).

J.5.6. Restrictive Parameters Set by the Christchurch City Council

J.5.6.1 Retaining the Central City Grid

The existing central city grid has been retained in the Central City Plan because:

- there is a potentially enormous cost involved in changing grid layout and the associated legal infrastructure
- there is little difference in passive solar performance between the existing layout and other layouts such as the Spanish Grid (same orthogonal form but on a diagonal orientation) (van Esch, et al., 2012)
- the Christchurch people have expressed a desire to retain the heart of their city through the Share an Idea scheme (Christchurch City Council, 2011c)
- it is feasible because geotechnical data indicates it is safe to rebuild (Tonkin & Taylor Ltd., 2011).

J.5.6.2 Road Widths

The measurement tool in Google Earth was used to determine street widths within the central core zone existing in 2010. Lichfield, Cashel, Hereford, Colombo, Manchester and High Streets were measured for width, with an average of 18 m calculated. If an inaccuracy of ±1 m was allowed for in the measurement (Google Earth is not a precise tool), over a distance of 18 m, this is a possible inaccuracy of only 5.6% in the final measurement. In street widths up to 20 m, the overall conclusions of the study would not change.

J.5.7. Major Issues Regarding the Central City Plan Passive Urban Form Features

J.5.7.1 Net Lettable Area and Productivity

Opposition to the concept of sacrificing net lettable area (NLA) to make way for urban form features (Christchurch City Council, 2011a) is likely to stem from property owners who see themselves as losing NLA that could otherwise be rented. However, the flipside of that concept is that the level of quality of those remaining spaces will be much higher.

A study by Leaman and Bordass (2001) suggests that factors of staff comfort, health and satisfaction can contribute financial gains or losses of up to 15% of turnover in a typical office organisation. They also state that productivity increases when staff have opportunity for personal control of their environment with rapid changes to comfort. This is best achieved with shallow-plan building forms as they allow for simple adjustments (like opening a window), which deliver quick results. Added benefits of shallow plans include views and interaction with outdoors. Productivity is increased when staff are situated in desirable locations such as near windows. Such situations are increased with the inclusion of laneways and courtyards.

Although some undesirable windowless space is indeed being sacrificed, this building form is contributing to developing highly productive, desirable spaces. These desirable perimeter spaces offer greater potential for productivity (and reduced energy costs) than lower-quality core spaces and are therefore more likely to be attractive and return higher per square metre rentals.

J.5.7.2 Density and Urbanisation

Density is a key issue within the urban form topic. The Central City Plan Technical Appendices (Christchurch City Council, 2011a) document describes how there are polarised views on the matter across the Christchurch population. Most people agree that medium-to-high population density is required to maintain life, energy and economic viability in the city centre. However, there is debate as to the level of building density required to sustain the population required for socio-economic fertility in the central city. While this study does not look at such factors, it may aid in discerning an appropriate built form density. Section 12.2.3 Policy: Building Density of the Central City Plan Regulatory Changes document states:

> The scale and concentration of built development will be greater in the central city than elsewhere in the city. Development is encouraged to take full advantage of the potential provided, having regard to an appropriate urban shape and form, within the central city to ensure maximum environmental benefit, and value in terms of city identity.
>
> (Christchurch City Council, 2011c)

By determining which urban form features provide benefit in terms of energy and comfort, these findings could inform a level of building density that is environmentally sustainable.

J.6. Modelling the Baseline

The Baseline Model is illustrated in Figure J-8. This model embodies the Central City Plan 29 m building height limit defined in Appendix J.5.1 and the restrictive parameters (200 m x 100 m grid form and 18 m street width) set out in Appendix J.5.6. All identified passive urban form features will be applied to this Baseline Model in turn and tested using the measures established in Section 5.2.1. These baseline tests will provide a datum against which the passive urban form features can be compared.

J.6.1. Baseline Core Area Zone

The baseline core zone is important to this study as it lays the foundation for which laneways, courtyards and overall energy effects are compared. The model simplifies the block to a single building. It is recognised that city blocks are typically many individually owned building sites. What is explored here is the extreme if every site owner built to the full extent of their site. Then there would only be a small 7 m deep perimeter around the edge of the city block where access to daylight and fresh air could be guaranteed. There is a large central core area that is unaffected by the Central City Plan proposed façade step-back change but will be altered by the laneway and courtyard changes. As the core is bound within the four perimeter zones, it possesses no access to daylight or fresh air. As a result, all heating and lighting to that space is artificial.

The effect of the step-backs, laneways and courtyards is essentially measured by the improvement they generate over the core zone. The perimeter zones retain the same access to fresh air and daylight. Results from laneway and courtyard changes will be compared to the 100% artificial environments of the Baseline Model core zone.

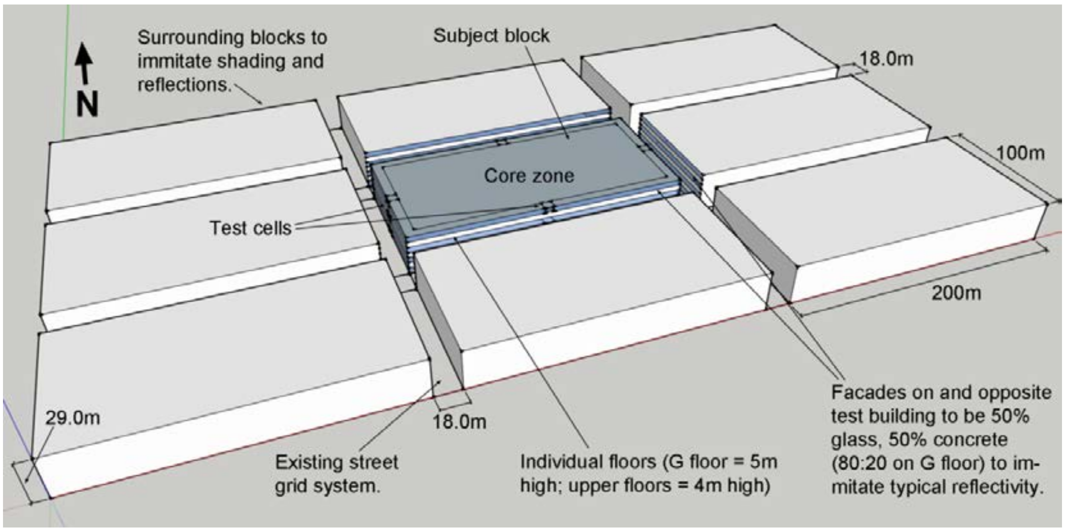


Figure J-8: Daylighting Baseline Model with Foundation Parameters Identified.

J.7. Modelling the Central City Plan Model

J.7.1. Modelling the Central City Plan Step-backs

The only alteration here from the geometry methodology established in Appendix J.1 is adding the step-backs. The step-backs, explained in Appendix J.5.1, can be seen applied to the model in Figure J-9.

This alteration is identical for both the daylight and thermal/energy model geometries in their respective ways.

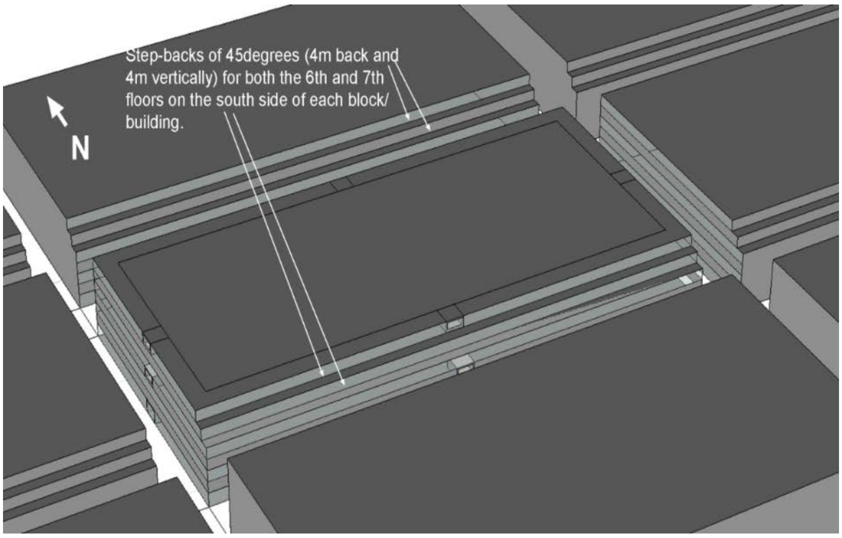


Figure J-9: Perspective of Central City Plan Step-backs – Ecotect Model Geometry.

J.7.1.1 Central City Plan Step-backs Daylight Analysis

The methodology here is exactly the same as for the Baseline Model (refer Appendix J.1) but for one difference. As the step-backs are only applied to the southern side of the blocks, differences will only be noticed on the opposite north-facing façades (although minor effects may also be experienced on the south-facing façade). East and west-facing façades will not be affected. Therefore, daylight testing will only be done for north and south-facing façades.

J.7.1.2 Central City Plan Step-backs Thermal and Energy Analysis

For the same reasons as with the daylight analysis, thermal and energy tests were only done for the north-facing façade. It was too difficult to model south-facing cells with a step-back included (due to geometric complexities within the OpenStudio software) and difficulties were not justified for such minor effects (<6%) as seen in daylight analysis on the south façade. Differences seen in the north-facing perimeter zones can then be directly compared to the Baseline Model north-facing perimeter zones results. Additionally, those localised improvements can be added to the baseline results to determine an overall square metre improvement. These two approaches will provide insight into how much effect improvements in north-facing zones have across the entire block.

J.7.2. Modelling Central City Plan Laneways

As described in Appendix J.5.1, a 4 m wide laneway and a 10 m wide laneway, each cutting through a city block from north to south, will be tested. Laneways will create new perimeter zones (refer dark grey areas of Figure J-10) that will benefit from daylight and natural ventilation and therefore create more area with a lower energy consumption and higher desirability over the baseline core zone.

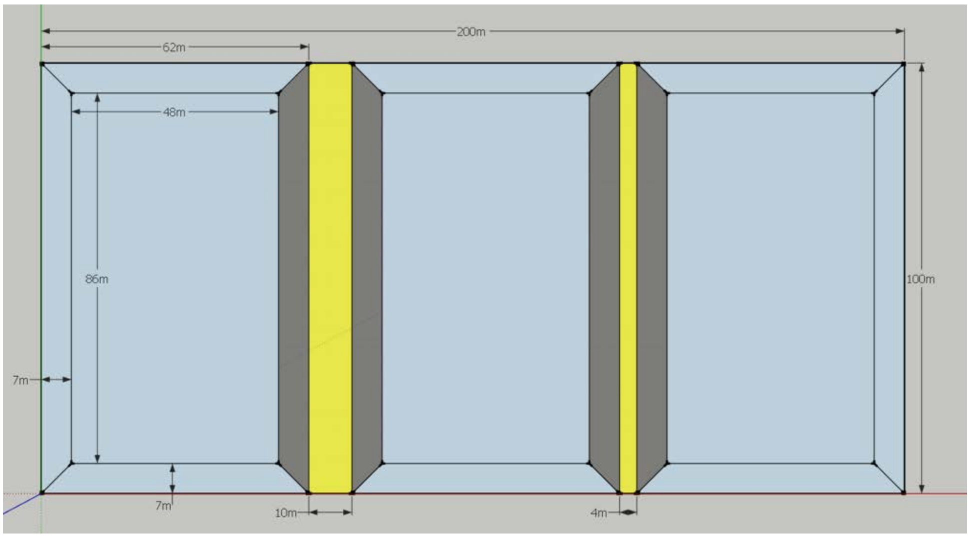


Figure J-10: Diagram of Central City Plan Laneways in Context of City Block.

Laneways are inserted into the original model, rather than into the step-backs model, to ensure all changes are standalone and comparable to the baseline. Figure J-11 displays the 4 m wide laneway situation. The 10 m wide model is executed in exactly the same manner but with the laneway (to the right in Figure J-11) now set to 10 m instead of 4 m.

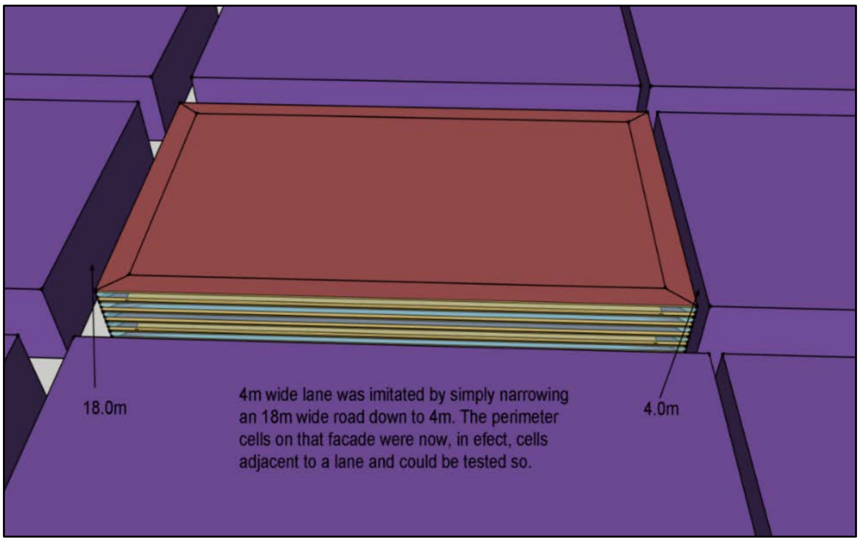


Figure J-11: Perspective of Central City Plan Laneways – OpenStudio 4 m Model Geometry.

J.7.2.1 Central City Plan Laneways Daylight Analysis

As the city blocks in Christchurch's CBD are oriented due north, it was assumed cells facing east and west would perform identically. Therefore, daylight analysis could be carried out in only a single cell for laneways. This cell was situated, in both the 4 m and 10 m laneway width models, at the fourth level to represent an average of daylight performances across the full seven levels.

J.7.2.2 Central City Plan Laneways Thermal and Energy Analysis

Zones for thermal and energy analysis encompassed the entire length of the perimeter zone adjoining the laneways. As with the daylight analysis, this was also applied to the fourth level.

J.7.3. Modelling Central City Plan Courtyards

The Central City Plan does not define sizes for their proposed courtyards. A recent study on the most effective courtyard width-to-height (W/H) ratio for natural ventilation found that a width-to-height ratio of 1:1 provides the best shelter from wind in the courtyard space while retaining sufficient air movement for natural ventilation in internal spaces (Tablada, et al., 2005). This would indicate a 29 m wide courtyard (equal to the 29 m building heights) should be used to realise best natural ventilation.

Building spaces adjacent to the courtyard now become perimeter zones and can thus be naturally lit and naturally ventilated (refer dark grey sections in Figure J-13). Now the original perimeter zones (7 m wide) plus the new internal perimeter zones (also 7 m wide), plus a 3 m wide movement route between them, can all be naturally lit and cross-ventilated. Using this model (refer Figure J-12), a full courtyard plus building totals 63m width.

The courtyard is reduced to 28 m in width in order to split the full block into three courtyards, each separated by a 4 m or 10 m wide laneway.

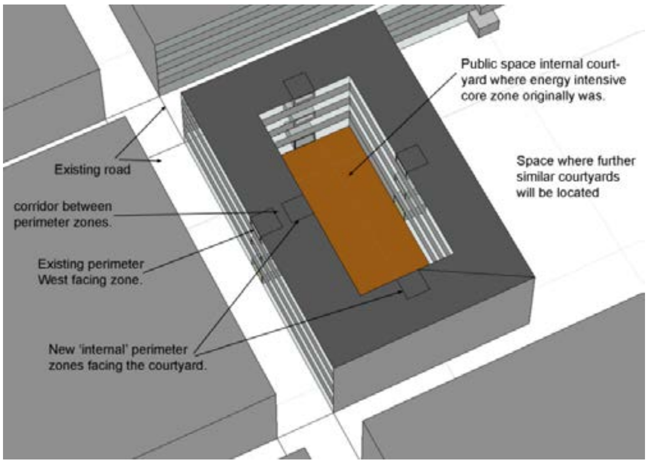


Figure J-12: Central City Plan Courtyard – Ecotect Model Geometry.

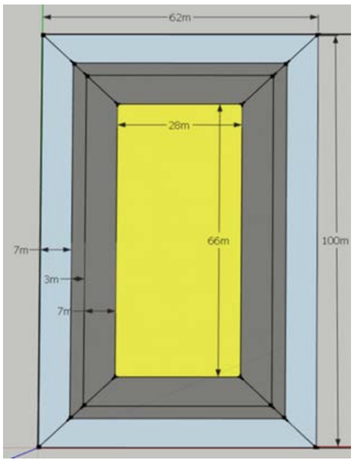


Figure J-13: Central City Plan Courtyard Dimensions.

J.7.3.1 Central City Plan Courtyard Daylight Analysis

Analysis of daylight availability was done for all of the new internal perimeter zones opening out onto the courtyard to determine the overall effectiveness of this urban form feature. East and west-facing zones were again considered to perform identically. As was done for the laneways, daylight was only assessed at the fourth level. This was to represent an average situation of the full height.

A total sunlight hour analysis was also done for the outdoor public courtyard space at ground level. This was done using the same method and scale as was used for the assessment of sunlight to the street in the step-backs model.

J.7.3.2 Central City Plan Courtyard Thermal and Energy Analysis

Geometry was manipulated so shading objects represented the building sections that enclose the courtyard. All other modelling and simulation factors were identical to the technique employed for the analysis of laneways.

K. New Zealand Dashboard

This section discusses the development of energy estimates of New Zealand non-residential building stock resulting from the use of a highly populated energy database. The BEES database allowed a computational model to be created that can be representative of the nation's non-residential building stock energy behaviour.

The method used to predict the energy consumption of the entire non-residential building stock was broken into four stages (Figure K-1):

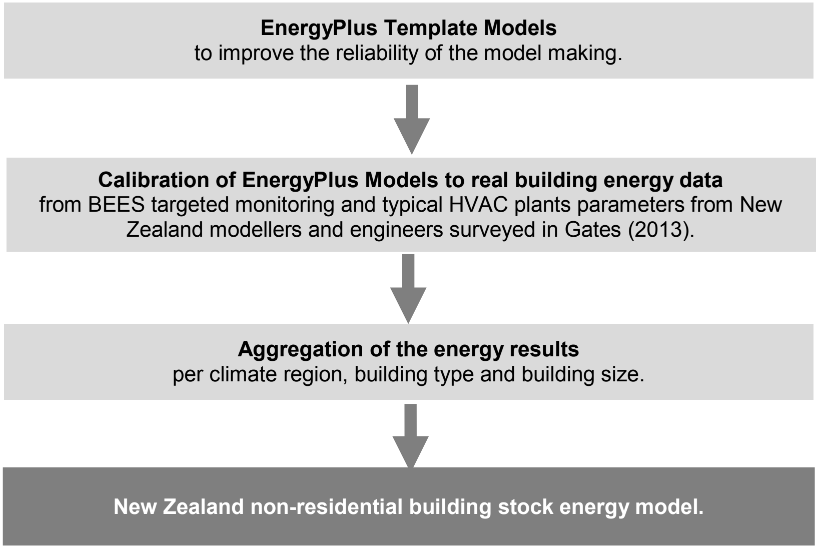


Figure K-1: New Zealand Non-Residential Model Construction Flow Chart.

Due to the different approaches utilised within this section and the different sample of buildings, the estimates and predictions presented here will vary to those presented previously within this report.

The national model generated is used as a baseline to demonstrate the potential of utilisation of the method materialised by the exploration of several market-available and highly feasible energy-saving measures. The effects of these measures are assessed by the use of energy efficiency indicators selected as the total energy consumption (electricity and gas) and the energy performance indicator (EnPI). An analysis of the different case results aggregated in a statistically representative manner is finally performed by using a dashboard. The dashboard created for this section is a visualisation tool allowing users to compare energy performance patterns amongst different building size strata, building use strata or climate regions to identify and prioritise cost-saving energy efficiency improvements and assess the range of likely savings from these improvements.

Finally, the methodology and its application proposed in this section materialised by the dashboard are intended to be used by building owners, managers, government departments or energy efficiency contractors. It is also intended to evolve in the future in order to explore other large-scale energy-saving measures and/or be adapted to other building sectors, which could ideally support the conversion of the net-zero energy building (Net ZEB) concept from an idea into practical reality in the marketplace.

K.1. Template Models

To assess the current energy performance of the non-residential building stock and the effects of innovative energy efficient technologies, comprehensive and representative energy models are needed. However, the complexity linked to the dynamic of the building and the presence of multiple variables and interdependent factors affecting the energy efficiency of a building require the use of computer simulation.

Modelling individual buildings usually involves assumptions of spatial and temporal resolution of the physical models used. Therefore, modellers are faced with the time-consuming task of collecting data representative of the different factors affecting the energy efficiency of a building: from the construction details to schedules of occupancy and uses of appliances. However, such level of details might not be required when analysing the energy performance of a whole building stock.

A previous report developed standardised energy simulation template models for typical New Zealand non-residential buildings (Gates, et al., 2012). The template models contained pre-defined modelling parameters based on averaged values from generic New Zealand non-residential building information that are consistent with current building practices. Whereas detailed simulations involves a large amount of inputs that could cause errors, inaccuracies and delays, using pre-developed templates, modellers are able to select the most suitable template and focus on the adaptation of particular parameters. For this section, the parameters are limited to building floor area, HVAC systems and loads from typical building uses. One of the main advantages of using the BEES data for energy simulation was that the schedules of use were not assumed. Real data collected using the telephone survey method was used and the New Zealand modellers and engineers surveyed by Gates (2013) through previous research.

According to the difficulty and time required for modelling and a high level of accuracy from the outputs, this was identified as an appropriate modelling level. The use of template models also enhances the applicability and reproducibility of the method to any set of buildings.

K.2. Calibration of Energy Models

As a basic principle, the calibration of an energy model consists of matching the simulated energy consumption results to the building's actual energy consumption. For this section, both hourly monitored data and monthly revenue data collected during the data collection process in BEES was used. Two calibration metrics exist to assist in determining whether a simulation is calibrated or not:

- "Mean bias error indicates how well the energy consumption is predicted by the model as compared to the measured data. Positive values indicate that the model over-predicts actual values; negative values indicate that the model under-predicts actual values. However, it is subject to cancellation errors, where the combination of positive and negative values serves to reduce mean bias error. To account for cancellation errors, the coefficient of variation of the root-mean-squared error is also needed." (Nexant Inc., 2008)
- "Coefficient of variation of the root-mean-squared error. This value indicates the overall uncertainty in the prediction of whole-building energy usage. The lower the coefficient of variation of the root-mean-squared error, the better the calibration. This value is always positive." (Nexant Inc., 2008)

The ultimate aim of calibrating the energy model to the actual energy consumption data collected is to attain a simulation match of ±5% (mean bias error) for monthly data or ±10% (mean bias error) for hourly data. This is recommended in *ASHRAE Guideline 14:2002* (ASHRAE, 2002). However, Nexant Inc. (2008), suggests "specific calibration goals should be set for each individual project based on the appropriate level of effort". Therefore, if an energy model is very difficult to calibrate to the recommended mean bias error percentage, the acceptable tolerance of the mean bias error should be increased based of the known level of error in the data used to construct the model.

Using EnergyPlus as the energy simulation tool, the calibration of the energy models was undertaken in two parts: pre-simulation and post-simulation.

K.2.1. Pre-Simulation Calibration

Pre-simulation calibration "involves a process of using genuine as-built information, surveys, and measured data to update the input parameters of the initial simulation model so that it closely represents the real operation of the building" (Raftery, et al., 2009).

As found in a previous study, not matching the thermal zones of individual spaces within the building does not reduce the reliability or hinder the capabilities when calibrating (Cory, et al., 2011). Therefore, the 48 buildings have been modelled by using the generic built forms generated by the BEES templates and were rescaled to match the buildings' floor area.

Regarding as-built material and construction data, the method used to identify these characteristics was through on-site observations provided by the building audits. The actual material properties data (thermal resistance, specific heat, conductivity and density) could not be measured. Therefore, a database of generic New Zealand material properties were used.

The internal loads are provided by the monitored electricity data measured in each building. For lighting, plug loads, domestic hot water and miscellaneous equipment inputs, the maximum end-use loads were used (Table K-1). They are calculated from the hourly measurements of each end-use during the monitored period. This is illustrated by Stage 1 displayed in Table K-2.

Table K-1: Example of Initial Model Input Parameters.

Floor Area	
Real	9,439 m^2
Modelled	9,436 m^2
HVAC	
System Type	VAV – Electric Heating
Heating Set Point	19.6°C
Cooling Set Point	22.2°C
Fresh Air Flow Rate	0.01 m^3/s.person
Loads	
Lighting	2.75 W/m^2
Equipment	2.4 W/m^2
Domestic Hot Water	0 W/m^2
Miscellaneous	3.69 W/m^2
Elevator	0 W/m^2
Occupancy	0.0466 occupants/m^2

Schedules of use for lighting, plug loads, domestic hot water, miscellaneous equipment and HVAC systems are calculated using data collected from the telephone survey on occupancy schedules and questionnaires from the targeted monitoring and from monitoring the various systems in the building. These ensured the operation of the various building systems are modelled as accurately as possible. The lighting, plug loads, domestic hot water and miscellaneous equipment inputs were as an average weekday and weekend load. The average hourly loads for both weekdays and weekend days are calculated using the energy end-use monitored data. This is illustrated by Stage 2 displayed in Table K-2.

K.2.2. Post-Simulation Calibration

Post-simulation calibration implements new automated process using a signature calibration method. The signatures are graphical representations, in ratio, of the changes in heating and cooling energy consumption to the maximum baseline for heating and cooling energy consumption, when a parameter is altered by a certain value – this is a function of the outdoor air temperature (Wei, et al., 1998). This includes comparing each building's heating and cooling calibration signatures to pairs of heating and cooling characteristic signatures. The heating and cooling characteristics indicate the input variable changes needed in the model input to achieve a matching simulation (Bensouda, 2004). The use of the signatures as a calibration tool is only possible for the buildings with installed space-conditioning systems. Identifying whether internal loads have been under or overestimated is also completed at the post-simulation stage. Heating and cooling calibration signatures are generated for each case study building using the monitored and simulated energy consumption. The heating and cooling calibration signatures are compared to a library of characteristic signatures, which are generated for each case study building's climate region and HVAC type. Trends of mismatched simulation results are attained by comparing monthly simulated energy consumption with the real monthly energy revenue data for each building. The identified monthly trends help understand what the problem parameter(s) are and to what degree, on an annual scale, these problems can create. This is illustrated by Stage 3 displayed in Table K-2.

Table K-2: Example of Calibration Stages.

Stage	Description
1	Increase Loads
2	Update Schedules, Weekends
3	Temperature Schedules, Summer/Winter Settings

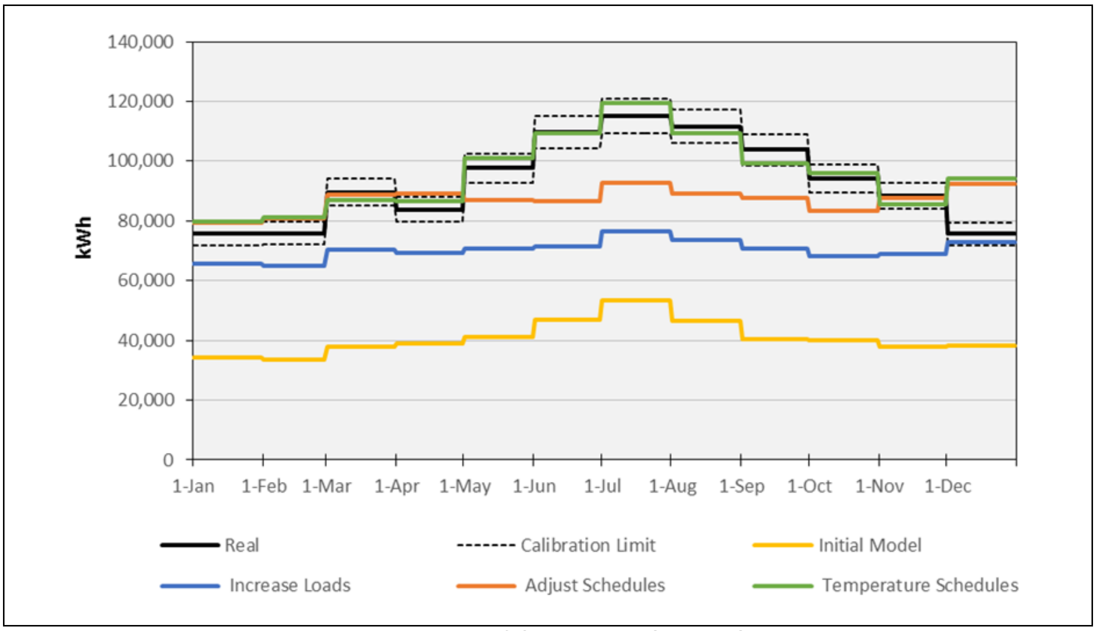


Figure K-2: Example of Calibration Stages Summary.

Table K-3: Calibration Range Details (EnPI) in Relation to Figure K-2.

Calibration Range	Real	Initial Model (0)	Increase Loads (Stage 1)	Adjust Schedules (Stage 2)	Temperature Schedule (Stage 3)
EnPI ($kWh/m^2.yr$)	118.79	51.89	89.41	110.71	121.73
Difference to Real	-	-0.56	-0.25	-0.07	0.02

As illustrated by Stage 3 (the green profile in Figure K-2), the total energy consumption of the calibrated model falls between the calibrated limits for most of the year. The calibration limits were set with an annual difference of ±2% for the EnPI of the selected example (Figure K-2).

K.3. Aggregation of the BEES Models to a National Picture

Over the last 6 years, a highly populated database representative of 848 premises (buildings participated in the telephone survey) has been created (Saville-Smith & Fraser, 2012). The BEES Year 5 topic report on Estimating Whole Building Energy Usage (Bishop, et al., 2012) documents the methodology and assumptions used to develop estimates of the whole-building energy consumption from premise energy data. This source of information was used to construct computer simulations for the 48 case study buildings and extrapolate their simulated energy results to a national picture. The aggregation of the models to a national picture is made from several successive stages dealing with the building types, the building size and climate regions.

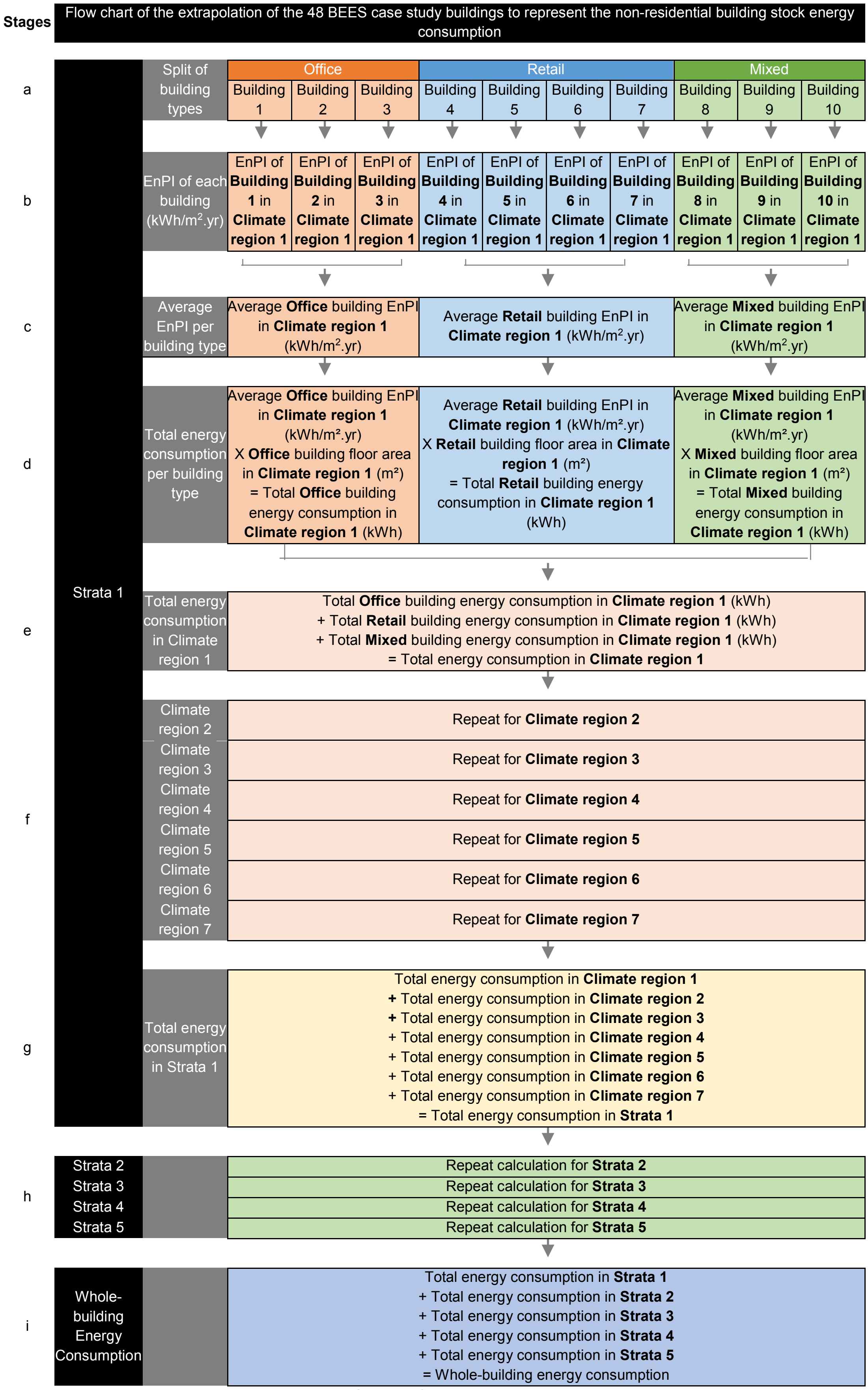


Figure K-3: Flow Chart of the Extrapolation Process.

K.4. Energy Efficiency Indicators

In this context, the use of normalised metrics such as energy efficiency indicators is crucial. The total energy consumption represents the raw data – the picture of the energy performance of a building over the year. The two main fuel types that are of the most interest are electricity (main fuel type of 99.6% of the non-residential buildings) and gas. Therefore, in this study, the total energy consumption is for electricity and gas combined. The total energy is a more suitable and comparable factor than keeping the record of each energy type individually, despite the fact that, ideally, energy consumption should be separated into different metrics according to the energy type delivered to a site. This would imply the creation of new subsectors for the analysis in case of buildings of the same type with very different direct fuel consumptions.

The EnPI is a metric derived for building standards, audits or energy statistics and usually used as standard normalisation of the energy performance of a sample of buildings. The amount of energy per unit of floor area allows a reasonable estimate to be made of the typical energy consumption of buildings and to scale it up to larger sets of buildings with the same characteristics (location, activity and size). EnPI is also useful to aggregate heterogeneous energy behavioural subsectors/subcategories to a larger representative category of buildings.

K.5. Seven National Climate Regions – Calibrated Models and Typical Meteorological Year Data

The external climate conditions have more influence on residential buildings than non-residential buildings. Figure K-4 shows the three New Zealand climate zones as defined by the NZBC and locates the 18 climate stations (which have associated weather files) developed for the Home Energy Rating Scheme (HERS).

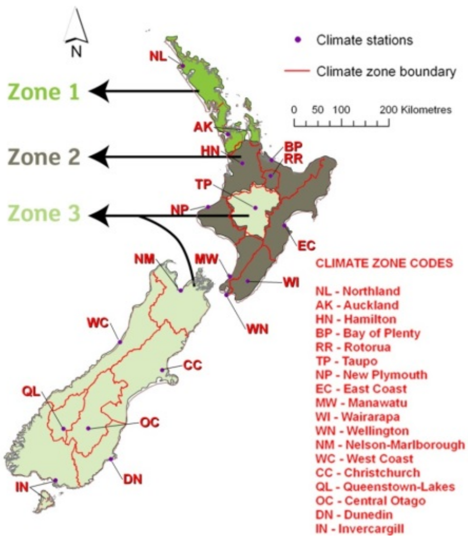


Figure K-4: New Zealand Climatic Zones and Stations.

Due to the external environment potentially having less of an influence on non-residential buildings, the 18 weather stations developed for the HERS research were not required. Therefore, reducing the number of weather files used in this section reduced the amount of potential double-up simulation of a building in similar climatic conditions.

To reduce the 18 climate stations to a strict number of climate regions required for the simulations, an amalgamation process is used. The amalgamation process considers the floor area and similarities between climate stations as deciding factors. Figure K-5 illustrates the decision process leading to the first decision stage of amalgamation of a climate station with another according to their proportion of the national non-residential floor area. This remains a crucial point, since the extrapolation of our sample to the national level is being undertaken by multiplying the EnPI by floor area in the region.

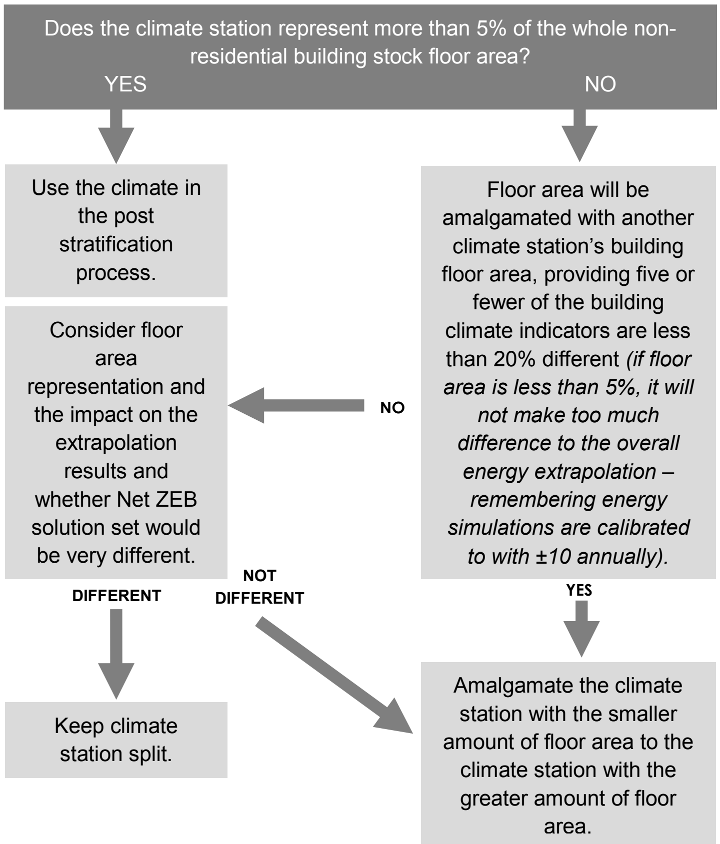


Figure K-5: Floor Area Amalgamation Decision Process.

The similarities between climate stations that have the potential to be grouped are then identified using the building climate classification. This classification uses thermal simulation to identify the predominant design challenges posed by a climate. It uses climate indicators that not only use the external conditions of a location but also the thermal performance of a reference building (in accordance with the NZBC minimum performance level).

Climatic indicators, such as temperature (heating hours), relative humidity (cooling humidifying hours), solar (useful), daylight (useful), wind (useful) and comfort hours are used as comparison factors. Each indicator was compared between a number of climate stations to see whether it was within ±20%. If all six indicators are within ±20%, the two climates are very similar and should be amalgamated. If fewer than six of the indicators are within ±20%, the two climate stations can be considered for amalgamation but need to be weighed up with the amount of floor area in each climate station.

After careful analysis and assessment, the 18 available climate stations are reduced to seven climate regions. Table K-4 summarises the amalgamated groups and the final climate regions and the weather files used to simulate the energy models and extrapolate the generated energy results to New Zealand's building stock. Finally, six out of the seven climate regions used in the extrapolation have 5% or greater of the whole building stock floor area.

Table K-4: Summary of the Climate Regions/Weather Files Amalgamation.

EnergyPlus Weather	Region Split	Floor Area (m^2)	(%)	Amalgamated Group	Weather File Used	Floor Area (m^2)	(%)
Northland	Northland	302,314	1	Northland/Auckland	Auckland	12,097,863	41
Auckland	Auckland	11,795,550	40				
Waikato	Waikato	1,552,710	5	Waikato/Taupo/ Tauranga/Rotorua	Waikato (Hamilton)	2,886,308	10
Taupo							
Tauranga	Bay of Plenty	1,333,598	5				
Rotorua							
Napier	East Coast/ Napier	1,422,058	5	Napier/Nelson/West Coast	Napier	1,784,312	6
Nelson	Nelson	319,580	1				
West Coast	West Coast	42,674	0				
Taranaki	Taranaki	408,307	1	Manawatu/Taranaki	Manawatu	1,336,576	5
Manawatu	Manawatu-Whanganui	928,269	3				
Wairarapa	Wellington	744,195	25	Wairarapa/ Wellington	Wellington	7,444,195	25
Wellington							
Christchurch	Canterbury	2,866,521	10	Christchurch	Christchurch	2,866,520	10
Dunedin	Otago	880,116	3	Dunedin/Lauder/ Queenstown/ Invercargill	Dunedin	1,276,223	4
Lauder							
Queenstown							
Invercargill	Southland	396,107	1				

K.6. Typical Buildings

The estimation of energy consumption of the non-residential building stock involves a series of sampling from the BEES database. A sample of 48 non-residential buildings was selected, modelled and calibrated against their real energy consumption data. These 48 non-residential buildings were classified by their building size strata and building use strata.

In order to ensure the representativeness of the national model, the statistical validity of the data was tested. The standard deviation and mean bias error of the national model have been calculated (Table K-5) by removing one building of the sample at a time. A standard deviation or coefficient of variation of root-mean squared error of 3.13% and a mean bias error of 2.08% means the constructed model has an acceptable overall uncertainty as recommended by the US Department of Energy in the *Measurement and Verification for Energy Projects Guidelines* (Nexant Inc., 2008).

Table K-5: Statistical Validity of the Model.

Parameter Evaluated	Recommended Values	Actual Values	Purpose
Coefficient of Variation of Root Mean Squared Error	<15%	3.1%	Calculates the standard deviation of the errors, indicating the overall uncertainty in the model
Mean Bias Error	±7%	2.1%	Overall indicator of bias in regression estimate

K.6.1. Building a Dashboard for Viewing Aggregated Data

When all of the data produced has been treated and compiled under a technical format, the visualisation of the overall result is the next stage. The national energy model was created in a way that multiple combinations and trends of building size, use and climate region can be analysed via the use of EnPI and total energy consumption. This represents a multitude of information that is almost impossible to synthesise under a raw format.

The use of a dashboard appears to be the most suitable way to display a large amount of information and aggregated data on a unique support. Not only does the dashboard present the aggregated building performance data prediction, but it also produces both numerical and graphical representations of those predictions. The dashboard also makes the data visually accessible to non-experts and enables users to focus on the information most important and relevant to them.

The New Zealand Building Stock Energy Consumption Dashboard (Figure K-6) is articulated around two main boards. Users are able to select the data displayed on the different graphs and visualisation supports according to the size of the building, the building type and energy strategy applied to the national model used as baseline (Figure K-7). Every graph, tag, label, value or caption is automatically updated every time a new selection is made. This is made possible by the use of Visual Basics code coupled with advanced filtered data tables made with Microsoft Excel. This dashboard was designed with the aim of making the visualisation efficient by using appropriate features such as a high data-ink ratio – this measures the proportion of ink used to represent data to the total ink used to print the graph (Tufte, 2006) – and the use of colours that improves the process of visualisation and a level of flexibility introduced by the selection of filtering cells.

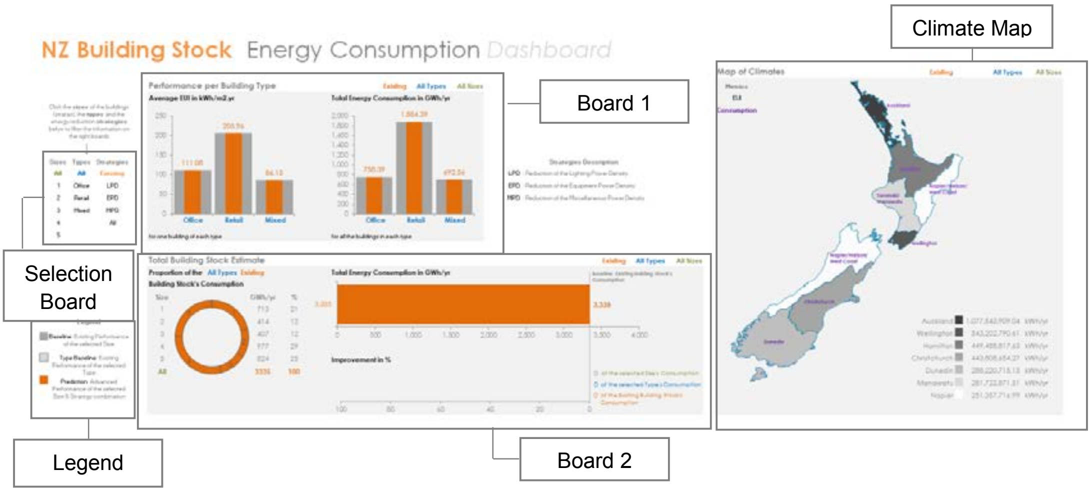


Figure K-6: New Zealand Building Stock Energy Consumption Dashboard.

Sizes	Types	Strategies
All	All	Existing
1	Office	LPD
2	Retail	EPD
3	Mixed	MPD
4		All
5		

Figure K-7: Selection Board.

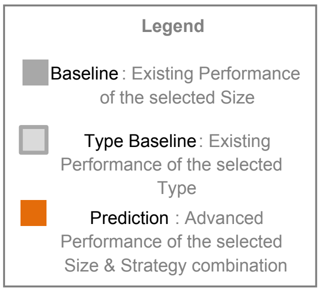


Figure K-8: Legend.

The Selection Board in Figure K-7 allows users to filter the data by building size stratum, building use stratum and energy reduction strategy (LPD: light power density, EPD: equipment power density and MPD: miscellaneous power density). The 15 cells that comprise the Selection Board are the only clickable cells of the dashboard. The Legend, in Figure K-8, describes the colour range used.

K.6.2. Board 1

Board 1 (Figure K-9) illustrates the energy performance per building use stratum. The first bar chart displays the average EnPI for one building of each building use stratum. As indicated on the Legend (Figure K-8), the grey bars represent the baseline, i.e. the existing performance of the selected building size. Since this bar is the baseline for comparison, it only updates when the user clicks on one of the size or strategy cells. The orange bars represent the prediction, i.e. the advanced (in comparison with the baseline) performance of the selected size and strategy combination and updates for each new selection. The right bar chart displays the aggregated total annual energy consumption (electricity and gas, in GWh/yr) of all the buildings in each building use stratum.

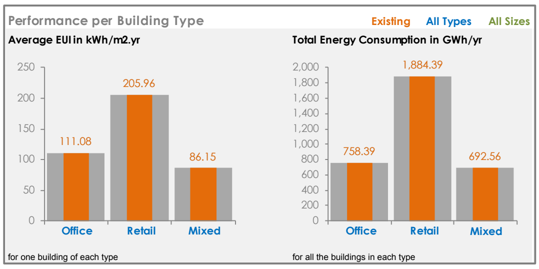


Figure K-9: Board 1.

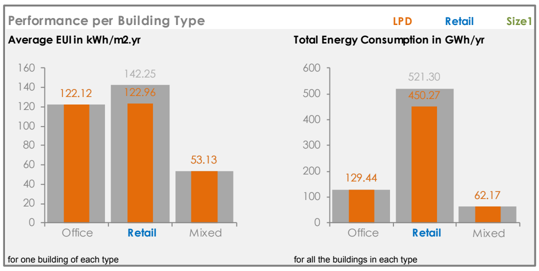


Figure K-10: Board 1 with Retail Building Type Selected and Light Power Density Reduction.

Figure K-9 displays Board 1 before selecting the Retail building use stratum. Figure K-10 displays Board 1 after selecting the Retail building type and the light power density reduction. It can be seen on Figure K-10 that the light power density reduction has been applied to only the Retail building type, and that only the Retail label stayed blue.

K.6.3. Board 2

Board 2, Figure K-11, is comprised of three different displays and deals with the total building stock estimates.

On the left of this board, a ring chart (Figure K-11: A) presents the proportion that represents the selected size of buildings amongst the selected building type and strategy combination in terms of total energy consumption. This aims to vary the different scales of analysis and enhance the identification of the most consuming strata over a sample of buildings.

The top bar chart (Figure K-11: B) allows the comparison of an advanced case energy consumption (orange bar) against its existing consumption by building size (dark grey), its existing consumption by building use (light grey bar) and finally against the baseline total building stock energy consumption materialised by the vertical grey line (3,335 GWh/yr). Users are then able to see the effect of applying energy-saving measures to a specific set of buildings. For the example in Figure K-11: B, the bar chart shows the energy data of the reduced lighting power density in size 1 Retail buildings.

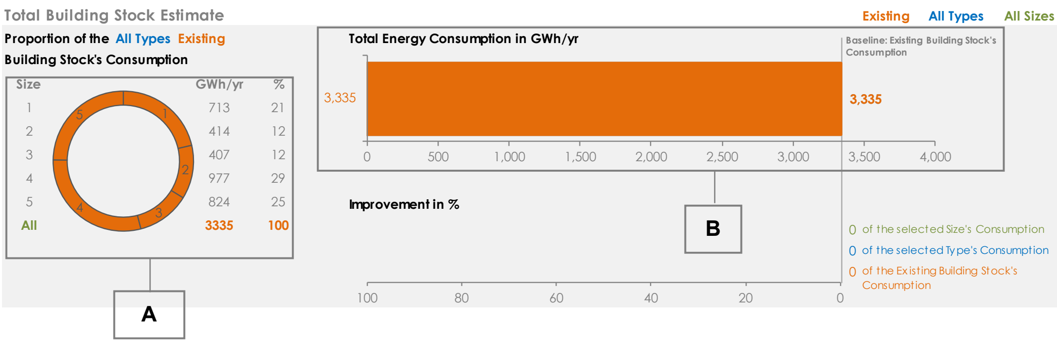


Figure K-11: Board 2.

For the ring chart in board 2 (Figure K-12: A), the selected building size stratum, stratum 1, is on the left of the chart highlighted in green as on the selection board. The portion 1 of the chart is highlighted in orange, and it represents 26% (450 GWh/yr) of the Retail light power density.

The top bar chart (Figure K-12: B) illustrates the energy reduction involved by selecting the Retail building type and light power density reduction against the baseline (3,335 GWh/yr). The orange bar (450 GWh/yr) represents the consumption of the advanced case, while the dark grey one (541 GWh/yr) represents the Retail size 1, and the light grey one represents the existing consumption of all sizes of retail buildings.

The total energy consumption graph is finally enhanced by combining it with the bottom bar chart display in Figure K-12: C. By clicking on one building size, building type and strategy, users are able to see the percentage of improvement or energy reduction caused by the application of the selected energy reduction strategy in comparison with the existing size, type and building stock total energy consumption. The green bar (Figure K-12: C) represents the 12% of improvement of the existing energy consumption of size 1 buildings due to the light power density reduction. The blue bar represents the 8% of improvement of the existing energy consumption of the Retail building type due to the light power density reduction. The orange bar represents the 2% of improvement of the energy existing consumption of the building stock due to the light power density reduction.

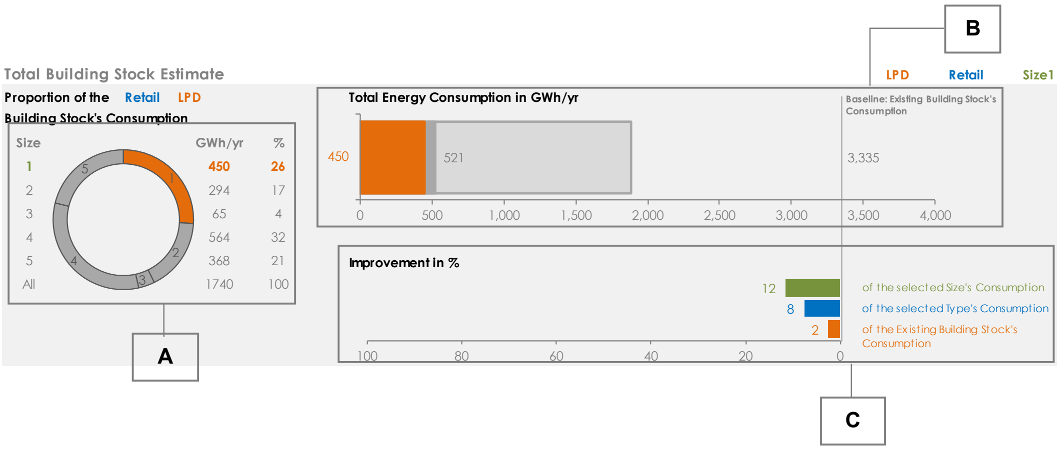


Figure K-12: NZ Building Stock Energy Consumption Dashboard, Board 2.

K.6.4. Climate Map

The third tool on the dashboard adds a new level of information to the previously presented boards. The Climate Map allows the user to select two different datasets. They are the EnPI or the average energy consumption of the selected climate region. When the user selects one of these two metrics (Figure K-13: A), the colours and values of the different climate regions are automatically updated. The seven climate regions can then be easily compared. The values per climate region are both displayed by placing the cursor on the location of interest (an example is shown in Figure K-13: B) and along the colour scale (Figure K-13: C). Figure K-13: C ranks the seven climate regions according to their energy performance.

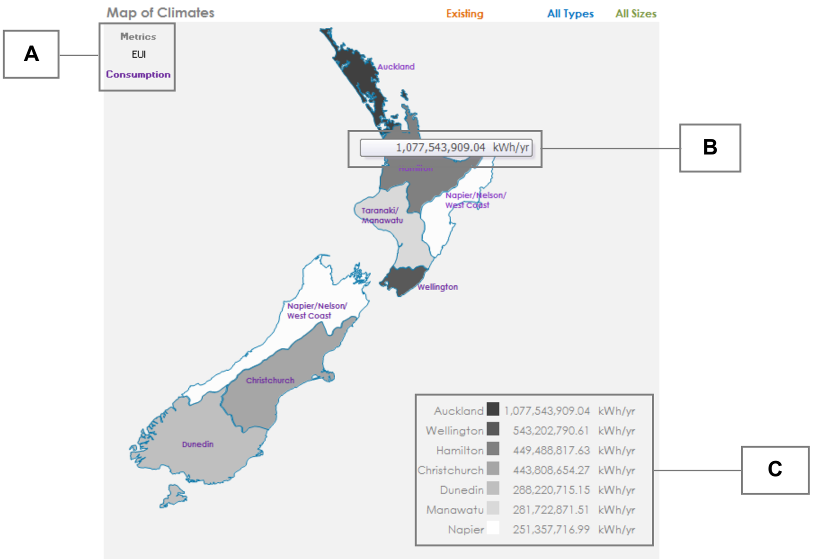


Figure K-13: Climate Map.

K.6.5. Energy Conservation Opportunities

Having a representative energy model of the non-residential building stock allows researchers to explore energy-reduction strategies or energy-saving measures on a large scale. Therefore, the produced national model has been used as a baseline model. In order to limit the uncertainty and enhance the reliability of the simulations, the energy-saving measures assessed do not involve non-technological measures or occupant behaviours and are only focused on the energy efficiency of the electric equipment, which can be easily changed.

These simple and highly feasible strategies are recommended as first good design practices by ASHRAE to achieve 50% energy saving towards Net ZEB. The assessment of the power density reductions was carried out via upgrading currently installed equipment to market-available high-efficiency equipment, reflected in the power wattage reduction of each equipment. The reliability and realism of these improvements was ensured by the use of real data such as equipment inventories, surveys and audits for the baseline and EnergyStar qualified equipment data for the advanced cases.

K.7. Future Development Potential

Use of this dashboard can *s*upport the conversion of the Net ZEB concept from an idea into practical reality in the marketplace. This tool is an introduction to the Net ZEB concept since it demonstrated the potential of energy savings by applying simple energy-saving measures at a national building stock level. However, in the current context dealing with global challenges such as the climate and resource shortages, much more is required than incremental increases in energy efficiency. Indeed, Net ZEB should be designed to work in synergy with a non-100% green grid without implicating its operation. The Net ZEB core principle is the import/export or load/generation balance between the delivered energy and the exported energy of the building. In order to respect this two-way flow principle while not interfering with the comfort of occupants, Net ZEB shall be both low energy demand and energy efficient.

Therefore, this Net ZEB framework would require the analysis of the energy generation side, which could be assessed via EnergyPlus as well, and the addition of new scenarios to the list of current available strategies depicting passive solutions such as passive solar heat gain, optimised building form, advanced envelope or natural ventilation features.

The dashboard also illustrates the effect of different energy efficient measures on the same set of buildings. The predictions generated for different types of equipment power densities applied to the building stock have demonstrated the feasibility of the method. However, the addition of new strategies usable on the final product that is the dashboard would require several adaptations or additions to the overall structure of the tool and the method.

Every prediction displayed on the dashboard is the visual representation of the data generated with the help of the simulation engine. This means that any new scenario requires the modification of the initial simulation model. Such tasks remain easy in terms of application when the involved input parameters are unique and for simple values like power density. More complex strategies involve the adaptation of current models or templates and even more time or effort required to create new computational models of the physical reality. This is mostly the case for the application of passive solutions that tend to be unique for each simulation and involve specific and parametric design according to numerous factors such as the location, orientation and surrounding environment. Table K-6 presents typical passive solutions and their technical means of application. The technology is obviously hardly able to be integrated into simple model templates of large sets of buildings without the construction of a parametric model that is adaptable to any building. The selection of a limited set of energy solutions that must be able to be applied to a large sample of buildings would be one of the most appropriate solutions in order to limit the changes to the current model.

Table K-6: Passive Solutions.

Passive Solutions	Means/Technical Solutions
Optimised Building Form	Optimised orientation/length-width
	Building form follows sun path
	Design for stairs not lifts
	Volume-to-surface ratio
Thermal Zoning	Heat-buffer rooms
	Thermal and equipment zoning (e.g. deported computer units), zoning of interior
Improved/Advanced Envelope	High insulation/advanced thermal insulation
	Vacuum insulation
	Green roof and/or façade
Maximisation of Passive Solar Heat Gain	Building orientation and form
	Sun capturing
	Isolated solar heat gain
Thermal Inertia	High mass construction
	Phase change materials
Solar Shading	External shades fixed
	External shades moveable
	Solar shield
Site Vegetation	Solar shading
	Moderation of winds
Natural Ventilation	Wind and stack ventilation
	Cross ventilation
	Night cooling
Advanced Ventilation/Cooling	Double skin façade
	Thermal chimney
	Evaporative cooling
Advanced Daylight Measures	Large amounts of glazing
	Skylights
	Solar tubes

The display of the predictions is automated. The treatment of the data that is behind mainly remains manual and involves the use of a multitude of calculations and manipulations due to the large amount of data generated. The process leading to the final aggregated data includes the following stages:

- Grouping of all output files in a single folder per climate region.
- Use of a code opening each of the output files, copying and pasting all the data available in a single file (involves manual modifications of the code).
- Use of code filtering the data to find the annual total energy data for the 48 buildings.
- Import of the total energy data into the aggregation/extrapolation file.

Further work on the automation of the data generation process and the statistical and visual treatment could bring this tool a professional level platform such as the online Buildings Performance Database (Energy Efficiency and Renewable Energy, 2013).

REFERENCES

Adler, D., 1999. *Metric handbook planning and design data.* Second ed. Auckland, New Zealand: Architectural Press.

Architecture New Zealand, 2012. The emergence of Christchurch. *ArchitectureNZ*, February, pp. 25-46.

ASHRAE, 2001. *ASHRAE handbook of fundamentals.* Atlanta, Georgia(Georgia): ASHRAE.

ASHRAE, 2002. *Guideline 14 - Measurement of energy and demand savings,* Atlanta, Georgia: ASHRAE.

ASHRAE, 2004. *ANSI/ASHRAE Standard 55: Thermal environmental conditions for human occupancy,* Atlanta, Georgia: ASHRAE.

Aulakh, H. & Toop, A., 1997. *Energy efficiency trends in New Zealand,* Wellington, New Zealand: Energy Efficiency and Conservation Authority (EECA).

Aulakh, H. & Toop, A., 2000. *The dynamics of energy efficiency trends in New Zealand: A compendium of energy end-use analysis and statistics,* Wellington, New Zealand: Monitoring and Analysis Unit, Technical and Research Group, EECA.

Baird, G., 2010. *Sustainable buildings in practice: What the users think.* First ed. Abingdon, U.K.: Routledge.

Baird, G. & Bruhns, H., 1986. *Evaluation of some conservation procedures for the office and hospital subsectors of the commercial building sector,* Wellington, New Zealand: Energy Research Group, School of Architecture and Design - Victoria University of Wellington.

Baird, G. et al., 1984. *Energy performance of buildings,* Florida, U.S.: Boca Raton.

Baird, G. & Newsam, G., 1986. *Estimation of Energy Consumption in the New Zealand Commercial Sector. Publication P103,* Auckland: New Zealand Energy Research Research and Development Committee.

Baird, G. & Pool, F., 1985. *Energy use and performance monitoring of commercial sector buildings,* Auckland, New Zealand: NZERDA Report 123.

Bellenger, L., 2011. *Building energy modelling innovation summit - Vision statements.* [Online] Available at: http://rmi.org/rmi/BEMSummitConferenceLogistics [Accessed February 2012].

Bensouda, N., 2004. *Extending and formalizing the energy signature method for calibrating simulations and illustrating with application for three california climates,* Tesax, U.S.: Texas A&M University.

Bint, L. E., 2012. *Water performance benchmarks for New Zealand: Understanding water consumption in commercial office buildings,* Wellington, New Zealand: Victoria University of Wellington.

Birner, S. & Martinot, E., 2003. Market transformation for energy efficient products: Lessons from programs in developing countries. *Energy Policy,* 33(14), pp. 1765-1779.

Bishop, R., Camilleri, M. & Isaacs, N., 2011a. *Building Energy End-use Study (BEES) Year 4: Delivered Daylighting. BRANZ Study Report 260/3,* Judgeford, New Zealand: BRANZ Ltd.

Bishop, R., Camilleri, M. & Isaacs, N., 2011b. *Building Energy End-use Study (BEES) Year 4: Achieved Conditions. BRANZ Study Report 260/4,* Judgeford, New Zealand: BRANZ Ltd.

Bishop, R. & Isaacs, N., 2012. *Building Energy End-use Study (BEES) Year 5 Interim Report: Energy Use Outliers. BRANZ Study Report 277/3,* Judgeford, New Zealand: BRANZ Ltd.

Bishop, R., Pollard, A. & Isaacs, N., 2012. *Building Energy End-use Study (BEES) Year 5 Interim Report: Estimating Whole Building Energy Usage. BRANZ Study Report 277/4,* Judgeford, New Zealand: BRANZ Ltd.

Bordass, B., Cohen, R. & Field, J., 2004. *Energy performance of non-domestic buildings: Closing the credibility gap.* Frankfurt, Germany, Building Performance Congress.

Bordass, B. & Leaman, A., 2005. Making feedback and post-occupancy evaluation routine 3: Case studies of the use of techniques in the feedback portfolio. *Building Research & Information,* 33(4), pp. 364 - 375.

British Property Federation, 2010. *Improving the energy performance of buildings regime: A response to a request for evidence by Lord Marland and Andrew Stunnell by the British Property Federation (21st December 2010).* London, U.K., British Property Federation (BPF).

Bruhns, H. & Baird, G., 1988. *Production of a database of commercial buildings sector energy consumption,* Wellington, New Zealand: Energy Research and Development Committee.

Building Owners and Managers Association International, 1995. *Office buildings: Standard methods of measurement and calculating rentable area (ANSI/BOMA Z65.1-2010).* Washington, D.C.: Building Owners and Managers Association International (BOMA).

Camilleri, M. & Babylon, W., 2011. *Building Energy End-use Study (BEES) Year 4: Detailed Monitoring. BRANZ Study Report 260/2,* Judgeford: BRANZ Ltd.

Chartered Institution of Building Services Engineers, 1999. *Guide A: Environmental design - Chapter 3: Thermal properties of building structures (Appendix 3:A7 Table 3.41-3.44),* London, U.K.: Chartered Institution of Building Services Engineers (CIBSE).

Christchurch City Council, 2011a. *Central city plan technical appendices,* Christchurch: Christchurch City Council.

Christchurch City Council, 2011b. *Draft central city plan - Volume 1.* [Online]
Available at:
http://resources.ccc.govt.nz/files/AllCommsStuff/(2)DraftCentralCityPlanVolume1.pdf
[Accessed May 2012].

Christchurch City Council, 2011c. *Draft central city plan volume 2 - Regulatory framework,* Christchurch: Christchurch City Council.

Christchurch City Council, 2012. *Mayor welcomes new Christchurch central development unit.* [Online]
Available at:
http://www.ccc.govt.nz/thecouncil/newsmedia/mediareleases/2012/201204182.aspx
[Accessed 18 April 2012].

Circo, C. J., 2007. Placing the commercial and economic loss problem in the construction industry context. *J. Marshall L. Rev,* Volume 39, p. 45.

Cory, S., Gates, A. & Donn, M., 2011. *The creation of generic energy simulation models which represent typical commercial buildings and their calibration against real energy data.* Sydney, Australia, IBPSA, pp. 1473-1480.

Cory, S. et al., 2012b. *Lessons learned in seven near-zero or net-zero energy buildings,* Wellington, New Zealand: Victoria University of Wellington.

Cory, S., Munn, A., Gates, A. & Donn, M., 2012a. *Building Energy End-use Study (BEES) Year 5 Interim Report: Building Design Optimisation. BRANZ Study Report 277/6,* Judgeford, New Zealand: BRANZ Ltd.

Crawley, D. B., Hand, J. W., Kummert, M. & Griffith, B. T., 2005. Contrasting the capabilities of building energy performance simulation programs. *Building and Environment,* 43(4), pp. 661 - 673.

Creswell-Wells, T., Donn, M. & Cory, S., 2012. *Building Energy End-use Study (BEES) Year 5 Interim Report: Christchurch Urban Form and Energy. BRANZ Study Report 277/7,* Judgeford: BRANZ Ltd.

Davies, H., Nutley, S. & Smith, P., 2000. *What works? Evidence-based policy and practice in public services,* Bristol, U.K.: Policy Press.

Department for Communities and Local Government, 2008. *Improving the energy efficiency of our buildings: A guide to energy performance certificates for the construction, sale and let of non-dwellings,* West Yorkshire, U.K.: Communities and Local Government Publications.

Department of Building and Housing, 2011. *New Zealand Building Code Handbook.* Third ed. Wellington, New Zealand: Department of Building and Housing.

Dowden, M., 2008. *Green leases in the U.K. letting market.* London, U.K., Royal Institution of Chartered Surveyors (RICS).

Ecotect, 2012. *Daylighting: Design strategies.* [Online]
Available at: http://wiki.naturalfrequency.com/wiki/Daylight_Strategies
[Accessed June 2012].

Energetics Ltd. & George Wilkenfeld & Associates, 1994. *Feasibility of introducing minimum energy performance standards into New Zealand: Report J523,* Wellington, New Zealand: Report to Energy Efficiency and Conservation Authority (EECA).

Energy and Technical Services, 2003. *Utility profiling trial: Report for the Ministry of Education (October 2003),* Wellington, New Zealand: Energy and Technical Services (ETS).

Energy and Technical Services, 2004a. *Utility profiling trial: Preliminary statistics and supplementary report for the Ministry of Education (February 2004),* Wellington, New Zealand: Energy and Technical Services (ETS).

Energy and Technical Services, 2004c. *Utility profiling trial: Further evaluation of energy use formula for the Ministry of Education (August 2004),* Wellington, New Zealand: Energy and Technical Services (ETS).

Energy Efficiency and Conservation Authority, 1993, 1995, 1996-2001. *Energy-wise monitoring quarterly,* Wellington, New Zealand: Energy Efficiency and Conservation Authority (EECA).

Energy Efficiency and Conservation Authority, 2002. *Energy end-use data base,* Wellington, New Zealand: Energy Efficiency and Conservation Authority (EECA).

Energy Efficiency and Conservation Authority, 2003. *Minimum energy performance standards for commercial refrigeration cabinets: Impact analysis,* Wellington, New Zealand: Energy Efficiency and Conservation Authority (EECA).

Energy Efficiency and Conservation Authority, 2004. *Minimum energy performance standards for air-conditioners: Impact analysis,* Wellington, New Zealand: Energy Efficiency and Conservation Authority (EECA).

Energy Efficiency and Renewable Energy , 2007. *EnergyPlus documentation, EnergyPlus manual.* s.l.:s.n.

Energy Efficiency and Renewable Energy, 2013. *Building Performance Database.* [Online] Available at: http://www1.eere.energy.gov/buildings/commercial/bpd.html [Accessed 05 09 2013].

Energy Information Administration, 2007. *Annual energy outlook 2007,* Washington, D.C.: U.S. Department of Energy.

European Parliment, Council of the European Union, 2010. Directive 210/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. *Official Journal of the European Union,* Volume 53, pp. 13-35.

Friedrich, K., Amann, J., Vaidyanathan, S. & Elliot, R., 2010. *Visible and concrete savings: Case studies of effective behavioral approaches to improving customer energy efficiency,* Washington, D.C.: American Council for an Energy Efficient Economy.

Gates, A., 2013. *Determining the modelling input parameters for heating, ventilation, and air-conditioning systems in New Zealand commercial buildings,* Wellington, New Zealand: Victoria University of Wellington.

Gates, A., Cory, S. & Donn, M., 2012. *Building Energy End-use Study (BEES) Year 5 Interim Report: Modelling Detail Analysis. BRANZ Study Report 277/5,* Judgeford, New Zealand: BRANZ Ltd.

Givoni, B., 1976. *Man, climate and architecture.* Second ed. London, U.K.: Applied Science Publishers.

GlassTech, M., 2010. *Catalogue and reference guide - 6th Edition.* [Online] Available at: http://www.metroglasstech.co.nz/catalogue/cata_default.aspx [Accessed June 2012].

Golove, W. & Eto, J., 1996. *Market barriers to energy efficiency: A critical reappraisal of the rationale for public polices to promote energy efficiency,* Berkeley: Lawrence Berkeley National Laboratory.

Graves, H. & Ticleanu, C., 2011. *LED lighting: A review of the current market and future developments,* Garston, U.K. : IHS BRE Press.

International Energy Agency, 2011. *Solar Heating and Cooling task 40 - ECBCS Annex 52: Towards net zero energy solar buildings.* [Online] Available at: http://www.iea-shc.org/task40/ [Accessed 15 May 2011].

Isaacs, N. et al., 2010a. *Energy use in New Zealand households: Final report on the Household Energy End-use Project (HEEP),* Judgeford, New Zealand: BRANZ Ltd..

Isaacs, N. et al., 2010b. *Building Energy End-use Study (BEES) Year 3. BRANZ Study Report 236,* Judgeford: BRANZ Ltd.

Isaacs, N. et al., 2009. *Building Energy End-use Study (BEES) Year 1 & 2. BRANZ Study Report 224,* Judgeford, New Zealand: BRANZ Ltd.

ISO, EN, 2005. *EN ISO 7730:2005 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.* Oslo, Norway: Standards Norway.

Itron Inc., 2006. *California commercial end-use survey,* Sacramento, California: California Energy Commission.

Jaffe, A. B. & Stavins, R. N., 1994. The energy paradox and the diffusion of conservation technology. *Resource and Energy Economics,* 16(2), pp. 91-122.

Knebel, D. E., 1983. *Simplified energy analysis using the modified bin-method.* Atlanta, Georgia: ASHRAE.

Koeppel, S. & Urge-Vorsatz, D., 2007. *Assessment of policy instruments for reducing greenhouse gas emissions from buildings,* Paris, France: United Nations Environment Programme (UNEP).

Lawrence Berkeley National Laboratory, 2010. *GenOpt - Generic Optimisation Program.* [Online]
Available at: http://gundog.lbl.gov/GO/
[Accessed 5 November 2011].

Leaman, A., 2011. *The Building Use Studies (BUS) occupant survey.* [Online]
Available at: http://www.busmethodology.org.uk/process/

Leaman, A. & Bordass, B., 2001. Assessing builidng performance in use 4: The PROBE occupanct surveys and their implications. *Building Research & Information,* 29(2), pp. 129 - 143.

Leaman, A., Stevenson, F. & Bordass, B., 2010. Building evaluation: Practice and principles. *Building Research & Information,* 38(5), pp. 364 - 577.

Littlefair, P., 2011. *Site layout planning for daylight and sunlight: A guide to good practice.* Berkshire: Bre Press.

McCormick, K. & Neij, L., 2009. *Experience of policy instruments for energy efficiency in buildings in teh Nordic countries,* Lund, Sweden: International Institute for Industrial Environmental Economics, Lund University.

Ministerial Council on Energy, 2007. *Second consultation regulatory impart statement proposed minimum energy performance standards for external power supplies,* Wellington, New Zealand: Ministerial Council on Energy (MCE).

Ministry for the Environment, 2007. *Levels of atmospheric greenhouse gases.* [Online]
Available at: http://www.mfe.govt.nz/environmental-reporting/atmosphere/greenhouse-gases/atmospheric-levels.html
[Accessed September 2012].

Ministry for the Environment, 2013. *Development of standard definitions for common district plan terms.* [Online]
Available at: http://www.mfe.govt.nz/publications/rma/development-standard-definitions-common-district-plan-terms/development-standard-definitions-district-plan-terms.pdf

Ministry of Business, Innovation and Employment, 2013. *Energy in New Zealand 2014.* [Online]
Available at: http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/data/prices.xlsx
[Accessed 8 July 2014].

Ministry of Business, Innovation and Employment, 2013. *Prices.* [Online]
Available at: http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/data/prices.xlsx

Ministry of Economic Development, 2012. *New Zealand energy data file 2012.* Wellington, New Zealand: Ministry of Economic Development.

National Institute of Building Sciences, 2012. *Windows and glazing.* [Online]
Available at: http://www.wbdg.org/resources/windows.php
[Accessed 27 February 2012].

National Project Consultants Pty Ltd., Exergy Australia Pty Ltd., 2009. *Low energy high rise building research study,* Australia: The Warren Centre.

Neill, S. P., 2009. Energy efficiency lease guidance to address the "split incentive". *Lessons Learned,* Volume 6, pp. 51-59.

Nelson, A., Rakau, O. & Dorrenberg, P., 2010. *Green buildings: A niche becomes mainstream,* Frankfurt: Deutsche Bank Research.

New Zealand Green Building Council, 2009. *Office 2009 rating tool.* [Online] Available at: http://www.nzgbc.org.nz/images/stories/downloads/public/GS%20tools/OFF.pdf [Accessed June 2012].

Nexant Inc., 2008. *M&V guidelines: Measurement and verification for federal energy projects - Version 3.0,* Washington, D.C.: U.S. Department of Energy - Federal Energy Management Program.

Nicol, F., Humphreys, M. & Roaf, S., 2012. *Adaptive thermal comfort: Principles and practice,* Abingdon, Oxion and New York, U.S.: Routledge.

Nicol, F. & Roaf, S., 2005. Post-occupancy evaluation and field studies of thermal comfort. *Building Research & Information,* 33(4), pp. 338 - 346.

OPUS, 2011. *OPUS building structures PIN workshop.* Christchurch, New Zealand: OPUS.

Pawson, R., 2001a. *Evidence based policy I: In search of a method,* London: ESRC UK Centre for Evidence Based Policy and practice.

Pawson, R., 2001b. *Evidence based policy II: The promise of realistic synthesis,* London: ESRC U.K. Centre for Evidence Based Policy and Practice.

Perez-Lombard, L., Ortiz, J. & Pout, C., 2008. A review on buildings energy consumption information. *Energy and Buildings,* 40(3), pp. 394-398.

Peterson, K. & Gammill, R., 2009. *Analyzing capital allocation for energy efficiency improvements by commercial real estate investment managers,* California, U.S.: Massachusetts Institute of Technology.

Peterson, K. & Gammill, R., 2010. *The economics of sustainability in commercial real estate,* Houston: IFMA Foundation.

Petticrew, M., 2001. Systematic reviews from astrology to zoology: Myths and misconceptions. *British Medical Journal,* 322(7278), pp. 98-101.

Pett, J. & Ramsay, L., 2003. *Energy efficiency in commercial offices: Who can transform the market?,* Stockholm: ECCE 2003 Summer Study: Time to Turn Down Energy Demand, European Council for and Energy Efficient Economy.

Property Council New Zealand, 2008. *2008 operating expenses benchmark.* Auckland, New Zealand: Property Council New Zealand Incorporated.

Property Council of New Zealand, 2000. *Office building energy consumption - An analysis of the energy expenses incurred by New Zealand CBD office buildings,* Auckland, New Zealand: Property Council of New Zealand (PCNZ).

Raftery, P., Keane, M. & Costa, A., 2009. *Calibration of a detailed simulation model to energy monitoring system data: A methodology and case study.* Glasgow, Scotland, The International Building Performance Simulation Association, pp. pp.1199-1206.

Reinhart, C. & LoVerso, V., 2010. A rules of thumb-based design sequence for diffuse daylight. *Lighting Research and Technology,* 42(1), pp. 7-31.

Rhaman, M. M., 2009. *Building energy conservation and indoor air quality assessment in a subtropical climate,* Queensland, Australia: Central Queensland University.

Ries, C., Jenkins, J. & Wise, O., 2009. *Improving the energy performance of buildings: Learning from the European Union and Australia,* California: Rand Corporation.

Roberti, J., 2014. *Building Energy End-use Study (BEES) Year 5 Interim Report: Auckland's Water Use. BRANZ Study Report 277/8,* Judgeford: BRANZ Ltd.

Rosall, E., Peeters, E. & Creamer, M., 2009. *Business briefing: European landlord and tenant survey,* London: Cushman and Wakefield Research.

Rossouw, P., 2003. *A mathematical and computational framework for dynamic energy efficiency resource assessment in the EERA 8.2 model and database: CRL Energy Ltd., Report EERA 8/1,* Judgeford, New Zealand: BRANZ Ltd..

Rossouw, P., 2008. *End-use energy demand in New Zealand's non-residential buildings: Data requirements of the EERA Model: CRL Energy Report number 08/11039,* Judgeford, New Zealand: BRANZ Ltd..

Rossouw, P., 2009a. *Minimum data requirements to model New Zealand's non-residential buildings with EERA: CRL Energy Report number 09/11057,* Wellington, New Zealand: BRANZ Ltd..

Rossouw, P., 2009b. *Estimation and projection of non-residential floor areas in the EERA and EnergyScape models: CRL Energy Report number 09/110303,* Judgeford, New Zealand: BRANZ Ltd..

Saville-Smith, K., 2005. *National home maintenance survey 2004: The telephone interview data,* Wellington, New Zealand: Centre for Research, Evaluation and Social Assessment.

Saville-Smith, K. & Amey, B., 1999. *National home maintenance survey 1998: The telephone interview data,* Wellington, New Zealand: Centre for Research, Evaluation and Social Assessment.

Saville-Smith, K. & Fraser, R., 2012. *Building Energy End-use Study (BEES) Year 5 Interim Report: Buildings - Size, Management and Use. BRANZ Study Report 277/1,* Judgeford, New Zealand: BRANZ, Ltd.

Saville-Smith, K. & Warren, J., 2010. *Energy optimisation in non-residential buildings: Approaches internationally and New Zealand,* Wellington, New Zealand: Centre for Research, Evaluation and Social Assessment.

Sayce, S., Sundberg, A., Parnell, P. & Cowling, E., 2009. Green leases: Do tenants in the United Kingdom want green leases. *Journal of Retail and Leisure Property,* July, 8(4), pp. 273-284.

Schell, M. & Int-Hout, D., 2001. Demand control ventilation using CO2. *ASHRAE,* February.pp. 1-6.

Scott, D. L., 2003. *Wall street words: An A to Z guide to investment terms for today's investor.* Third ed. Boston, U.S.: Houghton Mifflin Harcourt.

Spence, W., 1998. *Construction: Materials, methods and technologies,* New York, U.S.: Delmar Publishers.

Staheli, J., 2008. *Green leases: Considerations for landlords and tenants,* London: Nabarro International Law Office.

Standards New Zealand, 1982. *NZS 4220:1982 - Code of practice for energy conservation in non-residential buildings.* Wellington, New Zealand: Standards New Zealand.

Standards New Zealand, 1990. *NZS 4303:1990 - Ventilation for acceptable indoor air quality.* Wellington, New Zealand: Standards New Zealand.

Standards New Zealand, 1992. *NZS 4222:1992 - Specification for materials for the thermal insulation of buildings.* Wellington, New Zealand: Standards New Zealand.

Standards New Zealand, 2002. *NZS 4214:2002 - Methods of determining the total thermal resistance of parts of buildings.* Wellington, New Zealand: Standards New Zealand.

Standards New Zealand, 2006. *AS/NZS 1680.1:2006 - Interior and workplace lighting - Part 1: General principles and recommendations.* Wellington, New Zealand: Standards New Zealand.

Standards New Zealand, 2007a. *AS/NZS 3000:2007 - Electrical installations (known as the Australian/New Zealand Wiring Rules).* Wellington, New Zealand: Standards New Zealand.

Standards New Zealand, 2007b. *NZS 4243.1:2007 - Energy efficiency - Large buildings - Part 1: Building thermal envelope.* Wellington, New Zealand: Standards New Zealand.

Standards New Zealand, 2007. *NZS 4243.2:2007 - Energy efficiency - Large Buildings - Part 2: Lighting.* Wellington, New Zealand: Standards New Zealand.

Standards New Zealand, 2009. *AS/NZS 1680.0:2009 - Interior lighting - Part 0: Safe movement.* Wellington, New Zealand: Standards New Zealand.

Statistics New Zealand, 1996. *Australian and New Zealand Standard industrial classification - Version 4.1,* Wellington, New Zealand: Statistics New Zealand.

Steadman, P., Bruhns, H., Holtier, S. & Gakovic, B., 2000. A classification of built forms. *Environment and planning B: Planning and design,* 27(1), pp. 73-91.

Tablada, A. et al., 2005. *Geometry of building's courtyards to favour natural ventilation: Comparison between wind tunnel experiment and numerical simulation,* Rotterdam, Netherlands: In-house Publishing.

Telaire, 2000. *Application note: Telaire's ABClogic Self Calibration Feature.* [Online] Available at: http://www.telaire.com/refernce/appnotes/abclogic.htm

Tonkin & Taylor Ltd., 2011. *Christchurch Central City geological interpretative report,* Christchurch: Tonkin & Taylor Ltd..

Torcellini, P. A. & Crawley, D. B., 2006. Understanding zero-energy buildings. *ASHRAE Journal,* 48(9).

Torcellini, P. A., Deru, M., Griffith, B. & Benne, K., 2008. *DOE commercial building benchmark models,* California, U.S.: U.S. Department of Energy.

Torgerson, C., 2003. *Systematic reviews,* London, U.K.: Continuum.

Tufte, E. R., 2006. *Visual display of quantitative information.* Second ed. Cheshire, Connecticut: Graphic Press.

U.S. Department of Energy - EnergyPlus, 2012. *Input output reference: The encyclopaedic reference to EnergyPlus input and output.* [Online] Available at: http://apps1.eere.energy.gov/buildings/energyplus/pdfs/inputoutputreference.pdf [Accessed 10 March 2012].

U.S. Department of Energy, 2005. *Buildings energy data book,* Washington, U.S.: Department of Energy (DOE).

U.S. Department of Energy, 2008. *Energy efficiency trends in residential and commercial buildings.* [Online] Available at: http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/bt_stateindustry.pdf

U.S. Eenergy Information Administration, 2005. *Commercial building energy consumption survey (CBECS).* [Online] Available at: www.eia.gov/emeu/cbecs/cbecs2003/introduction.html

Usable Buildings Trust, 2006. *BUS methodology.* [Online] Available at: http://www.busmethodology.org.uk/

van Esch, M. et al., 2012. The effects of urban and building design parameters on solar access to the urban canyon and the potential for direct passive solar heating strategies. *Energy and Buildings,* April, Volume 47, pp. 189-200.

Wade, J., Pette, J. & Ramsay, L., 2003. *Energy efficiency in offices: Assessing the situation,* London: Association for the Conservation of Energy.

Wei, G., Liu, M. & Claridge, D. E., 1998. *Signatures of heating and cooling energy consumption for typical AHUs.* Fort Worth, Texas, Proceedings of the Eleventh Symposium on Improving Building Systems in Hot and Humid Climates, pp. pp. 387-402.

World Business Council for Sustainable Development, 2007. *Facts and trends: Energy efficiency in buildings summary report,* Geneva: World Business Council for Sustainable Development.

World Business Council for Sustainable Development, 2008. *Facts and trends: Energy efficiency in buildings full report,* Geneva: World Business Council for Sustainable Development.

Young, K., Ashby, D., Boozy, A. & Grayson, L., 2002. Social science and the evidence-based policy movement. *Social Policy and Society,* 1(3), pp. 215-224.

Publications List

BRANZ Study Reports

Years 1 & 2

Isaacs, N. (ed.), Saville-Smith, K., Bishop, R., Camilleri, M., Jowett, J., Hills, A., Moore, D., Babylon, W.M., Donn, M., Heinrich, M., and Roberti J. (2009) **Building Energy End-use Study (BEES) Years 1 & 2.** (BRANZ Study Report SR 224) Judgeford: BRANZ Ltd.

Year 3

Isaacs, N. (ed.), Saville-Smith, K., Babylon, W.M., Bishop, R., Camilleri, M., Donn, M., Jowett, J., Moore, D., and Roberti, J. (2010) **Building Energy End-use Study (BEES) Year 3.** (BRANZ Study Report SR 236) Judgeford: BRANZ Ltd.

Year 4

Saville-Smith, K. (2011) **Building Energy End-use Study (BEES) Year 4: Insight into Barriers.** (BRANZ Study Report SR 260/1) Judgeford: BRANZ Ltd.

Camilleri, M. and Babylon, W.M. (2011) **Building Energy End-use Study (BEES) Year 4: Detailed Monitoring.** (BRANZ Study Report SR 260/2) Judgeford: BRANZ Ltd.

Bishop, R., Camilleri, M. and Isaacs, N. (2011) **Building Energy End-use Study (BEES) Year 4: Delivered Daylighting.** (BRANZ Study Report SR 260/3) Judgeford: BRANZ Ltd.

Bishop, R., Camilleri, M. and Isaacs, N. (2011) **Building Energy End-use Study (BEES) Year 4: Achieved Conditions.** (BRANZ Study Report SR 260/4) Judgeford: BRANZ Ltd.

Bishop, R., Camilleri, M. and Burrough, L. (2011) **Building Energy End-use Study (BEES) Year 4: Temperature Control.** (BRANZ Study Report SR 260/5) Judgeford: BRANZ Ltd.

Bishop, R. (2011) **Building Energy End-use Study (BEES) Year 4: Electrical Loads.** (BRANZ Study Report SR 260/6) Judgeford: BRANZ Ltd.

Isaacs, N. (2011) **Building Energy End-use Study (BEES) Year 4: From Warehouses to Shops - Changing Uses in the Non-Residential Buildings Sector.** (BRANZ Study Report SR 260/7) Judgeford: BRANZ Ltd.

Year 5

Saville-Smith, K. and Fraser, R. (2012) **Building Energy End-use Study (BEES) Year 5 Interim Report: Buildings – Size, Management and Use.** (BRANZ Study Report SR 277/1) Judgeford: BRANZ Ltd.

Saville-Smith, K. (2014) **Building Energy End-use Study (BEES) Year 5 Interim Report: Barriers to Resource Efficiency.** (BRANZ Study Report SR 277/2) Judgeford: BRANZ Ltd.

Bishop, R. and Isaacs, N. (2012) **Building Energy End-use Study (BEES) Year 5 Interim Report: Energy Use Outliers.** (BRANZ Study Report SR 277/3) Judgeford: BRANZ Ltd.

Bishop, R., Pollard, A. and Isaacs, N. (2012) **Building Energy End-use Study (BEES) Year 5 Interim Report: Estimating Whole Building Energy Usage.** (BRANZ Study Report SR 277/4) Judgeford: BRANZ Ltd.

Gates, A., Cory, S. and Donn, M. (2012) **Building Energy End-use Study (BEES) Year 5 Interim Report: Modelling Detail Analysis.** (BRANZ Study Report SR 277/5) Judgeford: BRANZ Ltd.

Cory, S., Munn. A., Gates, A. and Donn, M. (2012) **Building Energy End-use Study (BEES) Year 5 Interim Report: Building Design Optimisation.** (BRANZ Study Report 277/6) Judgeford: BRANZ Ltd.

Creswell-Wells, T., Donn, M. and Cory, S. (2012) **Building Energy End-use Study (BEES) Year 5 Interim Report: Christchurch Urban Form and Energy.** (BRANZ Study Report SR 277/7) Judgeford: BRANZ Ltd.

Roberti, J. (2014). **Building Energy End-Use Study (BEES) Year 5 Interim Report: Auckland's Water Use.** (BRANZ Study Report 277/8) Judgeford: BRANZ Ltd.

Publications, Journal Articles and Presentations

Student Research Papers and Theses

Au, P.P.Y. (2013) **HDR luminance measurement: Comparing real and simulated data.** (Thesis submitted for the degree of Master of Building Science) Wellington: Victoria University of Wellington.

Berg, B. (2012) **Modelling operative and embodied energy/CO_2.** (Report submitted for the degree of Master of Building Science, Part One) Wellington: Victoria University of Wellington.

Bint, L. (2012) **Water Performance Benchmarks for New Zealand: Understanding Water Consumption in Commercial Office Buildings.** (Thesis submitted for the degree of Doctor of Philosophy in Architecture (Building Science)) Wellington: Victoria University of Wellington.

Cory, S. (2009. **BBSc 432 – Buildings and Energy. Assignment 2 – EECA energy audit database assessment**. (Report submitted for the degree of Bachelor of Building Science with Honours). Wellington: Victoria University of Wellington.

Creswell-Wells, T. (2012) **Christchurch: The Effect of Central City Plan Proposed Urban Design Features on Energy Consumption in Buildings.** (Report submitted for the degree of Master of Building Science, Part One) Wellington: Victoria University of Wellington.

Dykes C. (2012) **User perception benchmarks for commercial and institutional buildings in New Zealand.** (Thesis submitted for the degree of Master of Building Science) Wellington: Victoria University of Wellington.

Gates, A. (2013) **Determining the modelling input parameters for heating, ventilation, and air-conditioning systems in New Zealand commercial buildings.** (Thesis submitted for the degree of Master of Building Science) Wellington: Victoria University of Wellington.

Heap, Q. (2011). **Opportunities in Otaki for improved energy efficiency in retail lighting and its offsetting through renewable resources.** (Thesis submitted for the degree of Master of Building Science) Wellington: Victoria University of Wellington.

Heap, Q. (2009) **Energy audit interventions: The Energy Efficiency and Conservation Authority audit database.** (Report submitted for the degree of Bachelor of Building Science with Honours). Wellington: Victoria University of Wellington.

Hsu, C.Y. (2011) **Commercial building façade design: Improving the consistency of early design tool predictions and detailed design tool calculations.** (Thesis submitted for the degree of Master of Building Science) Wellington: Victoria University of Wellington.

Hsu, C.Y. (2009) **Commercial building façade design: the relationship between early design lessons and detailed design lessons.** (Report submitted for the degree of Bachelor of Building Science with Honours). Wellington: Victoria University of Wellington.

Koerbin, H. (2011) **Energy efficient commercial building façades.** (Report submitted for the degree of Master of Building Science, Part One) Wellington: Victoria University of Wellington.

Thompson, J. (2013) **Are automated daylight control systems working as they should?** (Thesis submitted for the degree of Master of Building Science) Wellington: Victoria University of Wellington.

Magazine Articles

(2009) **BEES Overview.** (Victorious Magazine, February, VUW news magazine).

Bint, L., Vale, R. and Isaacs N. (2010) **Foundation of Demand Management – Understanding Water Use.** (Water 164 pp. 48-51).

Isaacs, N. (2009) **BEES – Studying Energy Use in Non-Residential Buildings.** (EMANZ e-zine June, Issue 62 pp. 5-6).

BUILD Articles

Amitrano, L. (2011) **Information flows from BEES.** (BUILD 125, August/September, pp. 52).

Bint, L. (2011) **Benchmarking water use in office buildings.** (BUILD 125, August/September, pp. 58-59).

Bint, L. (2010) **Benchmarking water use in office buildings.** (BUILD 118, June/July, pp. 58-59).

Bishop, R. (2013) **Behind the energy-use figures.** (BUILD 135, April/May, pp. 48-49).

Bishop, R. and Climo, D. (2012) **BEES achieved plenty.** (BUILD 131, August/September, pp. 70).

Cory, S. (2011) **Retrofit net zero-energy commercial buildings.** (BUILD 125, August/September, pp. 56-57).

Creswell-Wells, T., Donn, M. and Cory, S. (2013) **Let the sun shine on Christchurch.** (BUILD 134, February/March, pp. 68-69).

Isaacs, N. (2010) **BEES busy filling the hive.** (BUILD 120, October/November, pp. 82-83).

Isaacs, N. (2010) **BEES buzzing system.** (BUILD 116, February/March, pp. 70-71).

Isaacs, N. (2009) **BEES investigates commercial building energy and water use.** (BUILD 112, June/July, pp. 40-41).

Isaacs, N. (2008) **Energy use research turns non-residential (BEES).** (BUILD 104, February/March, pp. 44-45).

Pollard, A. and Babylon, M. (2013) **Computer secrets.** (BUILD 135, April/May, pp. 51).

Saville-Smith, K. (2013) **Who cares about water and energy?** (BUILD 135, April/May, pp. 53-54).

Saville-Smith, K. and Fraser, R. (2013) **Commercial building use.** (BUILD 134, February/March, pp. 82).

Saville-Smith, K. (2011) **Drivers for resource efficiency.** (BUILD 125, August/September, pp. 54-55).

Workshops and Presentations

Amitrano, L., Pollard, A. & Bint, L. (2014) **BEES seminar presentations: final results** – Dunedin 22 September 2014, Christchurch 23 September 2014, Hamilton 24 September 2014, Auckland 25 September 2014 and Wellington 30 September 2014.

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.

Isaacs, N. (2008) **Where does all the energy go – The HEEP and BEES studies in New Zealand.** (Seminar, Institute for Building Physics) Stuttgart: Fraunhofer Institute, 2 September.

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.