STUDY REPORT

SR 224 (2009)

Building Energy End-Use Study (BEES) Years 1 & 2

Nigel Isaacs (ed.), Kay Saville-Smith, Rob Bishop, Michael Camilleri, John Jowett, Alexandra Hills, Duncan Moore, Michael Babylon, Michael Donn, Matthias Heinrich, Hans Roberti

The work reported here was jointly funded by BRANZ from the Building Research Levy, the Foundation for Research, Science and Technology (FRST) from the Public Good Science Fund, the Department of Building and Housing (DBH) and the Energy Efficiency and Conservation Authority (EECA)

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Preface

This is the first of a series of reports to be prepared during research into the energy and water use of non-residential New Zealand buildings. It reports on the activities of the first two years of the Building Energy End-use Study (BEES). Activities included: setting up the project; selecting and purchasing monitoring equipment; developing suitable monitoring and analysis protocols; developing a sample framework from which to select buildings for data collection; undertaking technology transfer; and supporting the development of new researchers.

Acknowledgments

The work reported here was jointly funded by BRANZ from the Building Research Levy, the Foundation for Research, Science and Technology (FRST) from the Public Good Science Fund, the Department of Building and Housing (DBH) and the Energy Efficiency and Conservation Authority (EECA).

Note

This report is intended for researchers interested in understand the use of water and energy in the New Zealand non-residential building sector.

Later reports will provide analysis and results from the research. These will be of interest to architects, designers, engineers, manufacturers and product suppliers.

Title of Study Report

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BRANZ Study Report SR 224

Nigel Isaacs (ed.), Kay Saville-Smith, Rob Bishop, Michael Camilleri, John Jowett, Alexandra Hills, Duncan Moore, Michael Babylon, Michael Donn, Matthias Heinrich, Hans Roberti

Abstract

This report provides an overview of the starting two years of the Building Energy End-use Study (BEES). The overall goal is to understand patterns of use in order to identify opportunities for improved productivity, by investigating water and energy use in a random sample of New Zealand office and retail buildings.

There is no comprehensive N.Z. list of commercial buildings, so it has been necessary to develop one from property valuations. Ensuring this list is accurate has required extensive checking, including the use of web-based searching, but it will provide new knowledge about the non-residential building stock, including size distribution. This has been used to prepare a random, stratified sample for surveying.

An Aggregate, phone survey will be used to collect data from several hundred buildings, their occupants and use patterns. Energy and water data will be obtained with occupant permission.

In a smaller number of buildings, Targeted surveys will obtain monitored time-of-use information on energy and water and the services they provide. Suitable equipment has been selected, purchased and piloted in a small number of buildings to monitor energy (electricity and gas), air temperature, relative humidity, light level and carbon dioxide (CO_2).

Case studies will be used to obtain more detailed information on selected services. Results from pilot studies are reported.

Thermal simulation models will be used to enable the results from specific buildings to be used to explore consequences of changes to the entire building stock. The basis for the modelling process has been documented and pilot study undertaken to explore its use.

CRESA Centre for Research, Evaluation and Social Assessment

BRANZ

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA UNIVERSITY OF WELLINGTON

energy solutions

Executive Summary

Building Energy End-Use Study (BEES) Years 1 & 2

Authors

Nigel Isaacs (ed.), Kay Saville-Smith, Rob Bishop, Michael Camilleri, John Jowett, Alexandra Hills, Duncan Moore, Michael Babylon, Michael Donn, Matthias Heinrich, Hans Roberti

Introduction

This Executive Summary provides an overview of the report, which can be downloaded from www.branz.co.nz or purchased from the BRANZ Bookshop.

The BEES programme will provide a greater understanding of the how, why, where and when of energy and water use in New Zealand's non-residential buildings. Through actual measurement and analysis of energy use in buildings, BEES will identify opportunities for increased operational energy and water efficiency. The programme has eight key objectives:

- Quantify and characterise the energy use in N.Z. non-residential buildings
- Understand how energy is used in today's non-residential buildings
- Improve the basis for Government policy development and implementation
- Improve models of non-residential building energy use
- Provide guidance to create more productive work environments
- Support the reduction of GHG emissions and adaptation to climate change
- Provide design and operation guidance to reduce energy consumption and GHG emissions
- Improve the basis for development of the N.Z. Building Code (NZBC), Standards and energy rating tools such as GreenStar.

The first two years have been spent developing the research methodology and trialling data collection and analysis methodology. The result is that the research is now well able to obtain high quality data to support the analysis required to help understand the energy and water use in this sector. The work has also included extensive reviews of New Zealand and international literature, and contacts with related researchers throughout the world.

Research Questions & Methodology

Eight key research questions have been identified for this research on energy and water use in the non-residential buildings sector:

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

In order to provide suitable answers, BEES has been structured into five strands or components. Each is designed to align with one or more key research questions:

A. Aggregate Resource Use Patterns (Energy and Water)
B. Determinants of Resource Use (Energy and Water)
C. Building Dynamics
D. Interventions
E. Forecasting.

Table i sets out the components of the BEES programme in relation to key research questions and the studies which will be undertaken for each programme component.

Research Component	Method	Key Questions
A. Aggregate Resource Use Patterns (Energy and Water)	National survey Up to 1000 buildings	1-3
B. Determinants of Resource Use (Energy and Water)	Targeted survey and coarse monitoring Up to 1000 buildings	4-6
C. Building Dynamics	Case studies 10-20 buildings per annum	1-7
D. Interventions	Systematic review of international literature	7
	Education and Health Building Energy Use Review	7
E. Forecasting	Modelling and simulation	8

Table i: Research components, method and key research question alignment

Most of the programme components can be progressed simultaneously in relation to instrumentation development, procedural development and piloting. It is intended that the aggregate survey (Component A) and the interventions component of the programme (Component D) will deliver findings first. Component B (the targeted survey with direct monitoring) and Component C (the case studies) will be informed by both the aggregate survey and the systematic review components. Elements of all those components will contribute to the proposed forecasting work.

Building Use Coverage

BEES is studying non-residential buildings where the building can impact on the energy and/or water use. In broad terms, these uses are office and retail uses.

It was decided to use the NZ Building Code definitions, as these are consistent and uniformly used. Based on NZBC definitions, BEES will investigate **Commercial** buildings and **Communal Non-residential Assembly-Care** buildings, but will exclude **Industrial,** all **Ancillary, Outbuildings** and **Communal Non-residential Assembly-service** buildings. This is illustrated in Figure i.

There is no simple 'list' of all the non-residential buildings in New Zealand. The best available is the PropertyIQ Valuation Roll which is principally used for the purposes of local government rating. Selected 'valuation records' were obtained, but it must be recognised that each valuation record refers to a 'rating unit', and a rating unit may, or may not, be a single building. For example in a multi-storey building each floor can be strata-titled, and hence is a 'rating unit'. As BEES is concerned with physical buildings and not legal descriptions, it was necessary to first combine the 'valuation records' into 'Building Records'. Once inspection has been completed on a Building Record it can be determined whether, or not, this is a 'building'.

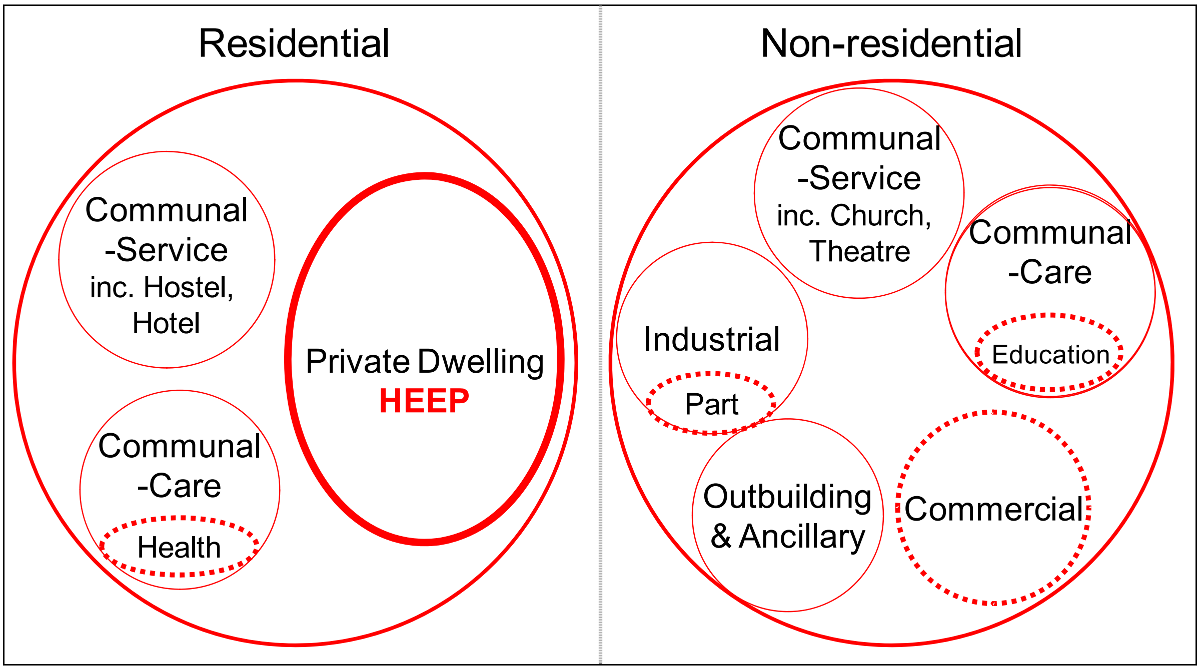

Figure i: Residential and Non-Residential Building Types Based on NZBC

The sample frame has been divided into 50 strata based on PropertyIQ categories:

- **5 size groups (quintiles)**, based on estimated total floor area by Building Record
- **5 use groups**, 'office', 'retail', 'mixed', 'IS' and IW, based on the use category of the PropertyIQ parent record
- **2 geographic groups** ('Auckland' and 'rest of New Zealand') – the Auckland group is defined by the area covered by the Auckland Regional Council.

The stratification by floor area is necessary to vary the sampling rates from size group to size group. The grouping has been done to give approximately equal total floor areas for all five groups. This stratification increases the statistical precision of the survey.

In particular, the 'Industrial Service' and 'Industrial Warehouse' categories (as defined by PropertyIQ) are expected to contain relatively few buildings with office or retail uses, the 'Office' and 'Retail' categories to contain few buildings without such uses, with the 'Mixed' being somewhere in between.

The two geographic groups were defined to help deal with what is expected to be a relatively low response rate in Auckland. It is desirable to replace non-responding Auckland buildings by Auckland buildings. The same consideration also applies to the other grouping variables.

Table ii summarises the floor area groups. Tables for use and geographic groups are provided in the full report.

As there is no list of suitable buildings, it is necessary to develop a comprehensive list that ensures all energy and water data is obtained from all business activities in the selected buildings. An innovative approach based on the use of internet searching, coupled with the use of Google Earth and StreetView, was found to provide a reasonable coverage. Further investigations are being undertaken in the 2009/10 year.

Floor Area Group	1	2	3	4	5	Total
Minimum Floor Area	5 m^2	650 m^2	1,500 m^2	3,500 m^2	9,000 m^2	
Approx. No. of 'Buildings'	33,781	10,081	4,288	1,825	564	**50,539**
% of Buildings	67%	20%	8%	4%	1%	**100%**
Total Floor Area (million m^2)	9.9	9.6	9.5	9.6	9.8	**48.3**
% floor	20%	20%	20%	20%	20%	**100%**

Table ii: Non-residential size strata

A pilot of the 'Aggregate Survey' based on telephone contact found that a reasonable response rate was obtained. Discussions with energy and water suppliers were used to develop a suitable permissions system to allow the researchers access to revenue meter data, which should provide high quality historic data for analysis. Further work on this is also being undertaken in the 2009/10 year.

Data Collection

Data logging requirements were established, suitable equipment was identified and adequate quantities purchased for the main monitoring work to commence in the 2009/10 year. Methodologies to support the installation, data collection and equipment removal were developed and initial documentation was prepared. Suitable calibration systems were also developed and used to ensure the monitoring equipment is fit for the expected end-uses of the results. The following monitoring will be undertaken:

- Temperature
- Humidity
- Light level
- CO_2 levels
- Fuels (primarily electricity & natural gas, but all fuels will be monitored)

Equipment obtained includes: Energy Logger Pro H22-01; Hobo Watt Node, Current Transformers & Environmental Loggers; Plogg electricity loggers; Xemtec Gas meter reader; Multivoies Logger & Rogowsky coils; Telaire 7001 CO_2 Sensor. Suitable testing and calibration procedures have also been developed. Pilot studies explored the use of the equipment, and developed on-site procedures for both the targeted and case study investigations.

The full report provides case study pilot reports on energy and water use in a selected building.

Modelling

BEES activities include the use of simulation modelling (notably thermal) in order to:

1. Generalise from the particular lessons of the survey data to scenarios of potential future energy use in the non-residential sector (sectoral energy efficiency opportunities).

2. Address the lack of reliable information about the patterns of energy determining behaviours so that future computer models for simulation in design can be improved (realistic modelling parameters; develop and test calibrated models).

Data collected from the detailed monitoring will be used in conjunction with simulation modelling to improve the quality of simulation models and develop models to investigate 'what if' scenarios. This work also contributes to International Energy Agency (IEA) Solar Heating and Cooling Agreement (SHC) Task 40 'Towards Net Zero Energy Solar Buildings' (see www.iea-shc.org/task40/index.html).

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1. INTRODUCTION

This Study Report provides information on the activities of Years 1 and 2 of the Building Energy End-Use Study (BEES).

The first two years have been spent developing the research methodology and trialling data collection and analysis methodology. The result is that the research is now well able to obtain high quality data to support the analysis required to help understand the energy and water use in this sector. The work has also included extensive reviews of New Zealand and international literature, and contacts with related researchers throughout the world.

1.1 Overview

(This section has been extracted from the BEES annual report to FRST.)

The commercial buildings sector spends over $NZ900 million/yr on energy, accounting in 2008 for 11% of New Zealand's energy[1].

According to official data, the commercial buildings sector was directly responsible directly for 3% of energy Greenhouse Gas (GHG) emissions in 2008[2].

In 2008 the sector consumed 22% of total national electricity use, making it indirectly responsible for just over 5% of energy GHG emissions.

Thus the sector is directly and indirectly responsible for 8% of national energy GHG emissions, which makes it vulnerable to any future carbon costs which may result from New Zealand not achieving its Kyoto targets. It is important for both macro-economic and environmental management to know where the cost-effective opportunities to reduce GHG emissions exist, and whether they are greater in this sector than others.

Eight key research questions have been identified for this research on the non-residential buildings sector:

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

Figure 1 provides an overview of the interactions between the different BEES activities,

[1] Ministry of Economic Development **Energy Data File 2009** (Table A.5b & Table B6)
[2] Ministry of Economic Development **Energy Greenhouse Gas Emissions 2009** (Table 2.7a,)

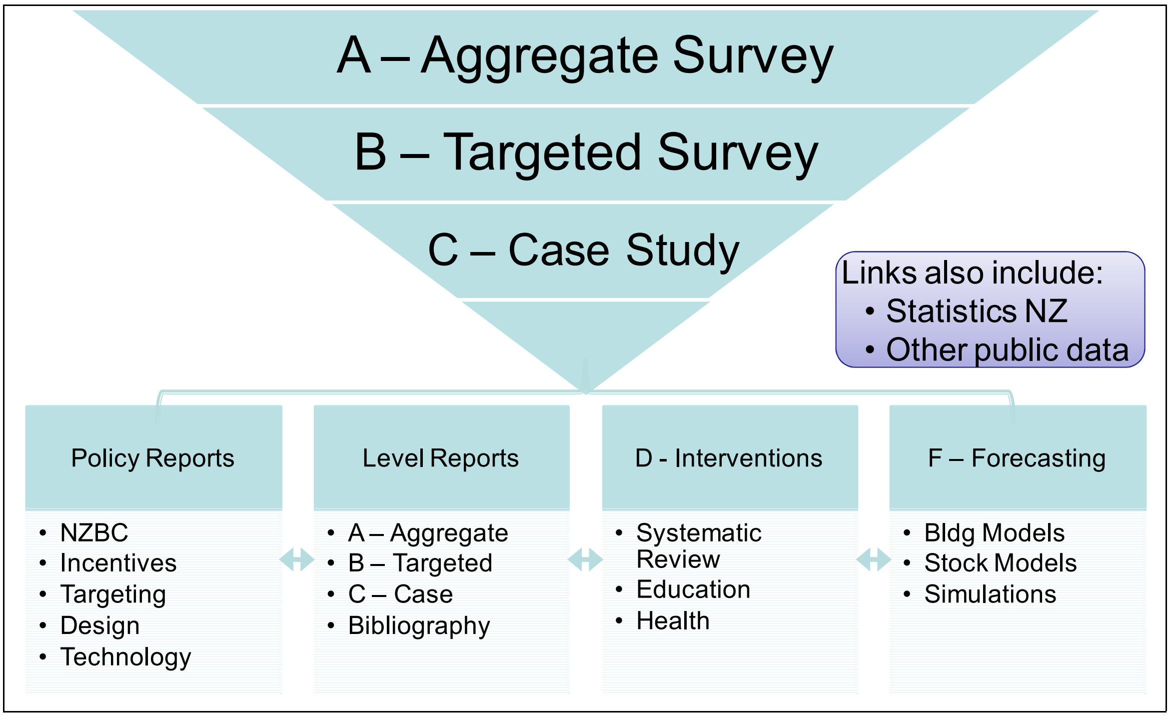

Figure 1: BEES Tasks Overview

Opportunities to learn from previous New Zealand and international experience have been maximised through the preparation of an annotated bibliography of New Zealand and international literature prepared by the Centre for Building Performance Research (CBPR), VUW. This compilation of over 600 papers and articles provided support for the monitoring methodology and was the basis for implementing a systematic review method.

CRESA has developed instrumentation for a systematic review. The first step of the review was to assess the research robustness of material-related interventions in non-residential building efficiency. Two findings emerged from that process. First, that this sector has a very small number of robust evaluations. Secondly, that the assessment reports prepared by the Inter-Governmental Panel on Climate Change (IPCC) (www.ipcc.ch) provide a systematic review of those few evaluations. Instead of replicating that process, the systematic review component has built on these reviews and is analysing the implications of those findings for improved resource efficiency in New Zealand's non-residential buildings.

Co-funded work by BRANZ, CRESA, CBPR and Energy Solutions Ltd during the past year has focused on developing the sampling and data collection methodologies, supported by pilot studies. Unlike housing, there is no information on the number and distribution of non-residential buildings. It has been necessary to first define the non-residential building occupancies of interest (primarily office and retail), then analyse the PropertyIQ (formerly known as 'Quotable Value New Zealand') national valuation database by combining information for individual legal titles into representing physical buildings. The research estimates that there are approximately 50,540 non-residential buildings of 48.3 million m² total floor area.

Five floor area groups have been identified, each with approximately the same total floor area: under 650 m²; under 1,500 m²; under 3,500 m²; under 9,000 m²; and 9,000 m² and over. By count, 87% of non-residential buildings are under 1,500 m² in floor area, but the remaining 13% by count represent 60% of the floor area. Random samples of buildings have been selected in each floor area range, and publicly available data has been collected on them.

Figure 2 provides an overview of the BEES activities. Central to these activities are the three data collection methods which have been developed and trialled in pilot studies:

- Aggregate survey – This is telephone-based survey of business owners and collects occupant, construction, location, energy and water data from a target 500 buildings. The pilot tested a process by which owners consent to provision of reticulated electricity and gas use to be sought directly from suppliers. The pilot is complete and the national survey will be conducted in the 2009/10 year.
- Targeted survey – Monitoring equipment and data transfer of monitored data is being tested. The selection of appropriate monitoring equipment was subject to considerable attention and testing in 2008/9. Data specification for both monitored and other data has been developed. Access and consent procedures are being refined.
- Case studies – in order to explore specific issues, about five different cases studies will be undertaken each year in buildings selected from the targeted survey. This co-funded work will commence in the 2010/11 year.

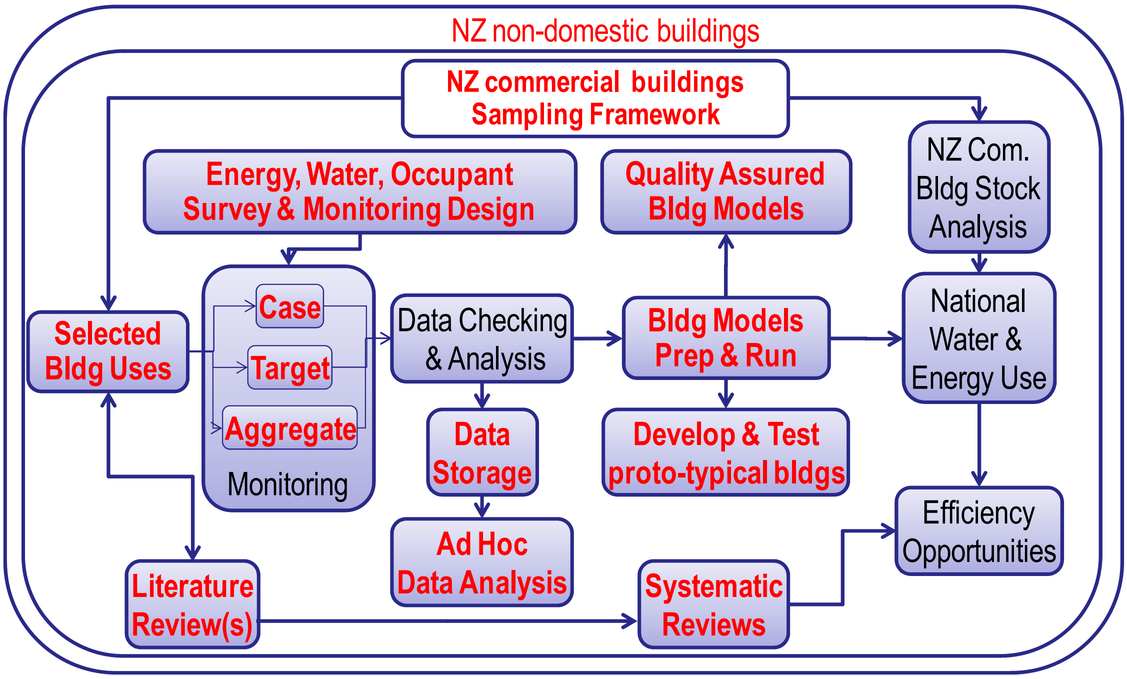

Figure 2: BEES Activities Flow Chart

Modelling activities have included the preparation of a library of representative New Zealand materials to facilitate the construction of simulation models of the surveyed buildings, the development of generic models of various building forms, and the creation of thermal simulation models of two real buildings.

In the future the results from the data collection will be used in comparison with computer simulation models developed by the Centre for Building Performance Research (CBPR) and tested against those developed by researchers in other countries. This was made possible by this project's participation in the development of the International Energy Agency (IEA) Solar Heating and Cooling Agreement (SHC) Task 40 and Energy Conservation in Buildings and Community Systems Programme

(ECBCS) Annex 52 'Towards Net Zero Energy Solar Buildings'. This Task will operate from 1 October 2008 to 30 September 2013.[3] This research will play a key role in Subtask C: 'Advanced Building Design, Technologies and Engineering' which will be co-lead by Dr Michael Donn, CBPR, VUW.

The results will also feed into the Energy Efficiency Resource Assessment (EERA) model developed by Dr Pieter Rossouw of CRL Ltd.

Scholarships have been provided to undertake research relevant to the project to three Bachelor of Building Science (Hons) students and one Master of Building Science student.

The Steering Group has met twice in the past year and provides valuable guidance and advice in the development of the research.

A formal research agreement has been put in place between BRANZ, VUW and The Bartlett School of Architecture, University College, London.

1.2 BEES people

BEES is supported by a multi-disciplinary team from the six organisations listed below, with the team leader followed by the other team members in alphabetical order:

BRANZ Ltd – Nigel Isaacs, Dr Michael Babylon, Dr Michael Camilleri, Duncan Moore, Johannes Roberti

CRESA Ltd – Kay Saville-Smith, Ruth Fraser

Energy Solutions Ltd – Rob Bishop

Centre for Building Performance Research, VUW – Dr Michael Donn, Alex Hills

John Jowett, Consulting Statistician

CRL Energy Ltd – Dr Pieter Rossouw, Dr Tony Clemens.

The overall BEES project is financially supported by:

Building Research Association of NZ (BRANZ) Inc

Department of Building and Housing (DBH)

Energy Efficiency and Conservation Authority (EECA)

Foundation for Research Science and Technology (FRST).

Members, and their substitutes, of the Governance Group appointed under the BEES Research Programme Agreement between BRANZ, DBH and EECA:

- **DBH** – David Kelly, Adrian Bennett, Louise Slocombe, Nick Lock
- **EECA** – Robert Tromop, Xanthe Howes
- **Building Research** – Wayne Sharman
- **BRANZ observer** – Lynda Amitrano
- **FRST observer** – Joseph Stuart
- **Statistics NZ observers** – Stephen Oakley, Martin Brown-Santirso
- **Ministry of Economic Development observer** – Simon Lawrence
- **Ministry for the Environment observer** – Chris Woods,
- **Electricity Commission observer** – Jenny Walton

Members of the Steering Group appointed under the FRST contract (BRAX0703) to provide input from key stakeholders into project design and operation:

- **Jason Happy** – Kiwi Income Property Trust

[3] For further information see www.iea-shc.org/task40/index.html

- **Professor George Baird,** School of Architecture, VUW
- **Associate Professor Deborah Levy**, Department of Property, University of Auckland
- **Norman Smith**, Rocky Mountain Institute (NZ)
- **Kees Brinkman**, Enercom.

It has been our practice to hold the full meetings of the Governance Group and the Steering Group at the same time.

1.3 Further information

Further information on the BEES research is available from the BRANZ website www.branz.co.nz under 'Current Research'.

2. UNDERSTANDING NON-RESIDENTIAL BUILDINGS

Although the team's earlier Household Energy End-Use Project (HEEP)[4] research has resulted in energy use in New Zealand residential buildings being well understood, there is no similar research available for non-residential buildings. This section examines the differences and sets out the methodology used to develop an understanding of the population of non-residential buildings in New Zealand.

2.1 Key research questions

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

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

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

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

BEES also requires a research approach that generates usable findings as early as possible and then regularly over the timeframe of the programme.

It is recognised that one of the difficulties for stakeholders in relation to HEEP was the considerable elapsed time before robust data could be released. This was in part caused by HEEP's reliance on a single surveying and monitoring approach in which the sample was accumulated over a number of years.

2.1.1 BEES programme components

To meet the challenges of the diversity of the non-residential stock, to maximise the robustness of data generated by BEES, and to ensure that BEES is enabled to address stakeholder informational needs, the BEES programme has been structured into five strands or components. Each of those components is designed to align with one or more key research questions. The methods associated with each component are specific to that component, but the components as a whole are designed to interface with each other to ensure that the overall goals of the BEES programme are met.

The five programme components are:

A. Aggregate Resource Use Patterns (Energy and Water)
B. Determinants of Resource Use (Energy and Water)
C. Building Dynamics
D. Interventions
E. Forecasting.

The eight key research questions identified as critical to achieving the BEES goals and objectives and their alignment with improving policy setting, building performance and building management are set out in Table 1.

[4] Further information on HEEP is available from the BRANZ website www.branz.co.nz

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

Table 1: Alignment of BEES objectives and contributions

Table 2 sets out the components of the BEES programme in relation to key research questions and the studies which will be undertaken for each programme component.

Research Component	Method	Key Questions
A. Aggregate Resource Use Patterns (Energy and Water)	National survey Up to 500 buildings	1-3
B. Determinants of Resource Use (Energy and Water)	Targeted survey and coarse monitoring Up to 50 buildings per year	4-6
C. Building Dynamics	Case studies Up to 5 per year	1-7
D. Interventions	Systematic review of international literature	7
	Education and Health Building Energy Use Review	7
E. Forecasting	Modelling and simulation	8

Table 2: Research components, method and key research question alignment

Most of the programme components can be progressed simultaneously in relation to instrumentation development, procedural development and piloting. It is intended that the aggregate survey (Component A) and the interventions component of the programme (Component D) will deliver findings first. Component B (the targeted survey with direct monitoring) and Component C (the case studies) will be informed by both the aggregate survey and the systematic review components. Elements of all those components will contribute to the proposed forecasting work.

2.2 What are 'Non-residential' uses

This section sets out the selected boundary for the BEES research and provides an overview of the components of the research programmes that have been developed to meet the programmes goals and objectives. Both the boundary and the research components have been developed to ensure that the BEES programme effectively meets the research objectives, ensuring value for money.

In setting the boundary of the building stock, BEES has used the statute-based classification systems of the Census and the NZBC (see Table 3) to distinguish between non-residential and residential buildings.

2.2.1 The BEES boundary

The BEES programme will provide a greater understanding of the how, why, where and when of energy and water use in New Zealand's non-residential buildings. Through actual measurement and analysis of energy use in buildings, BEES will identify opportunities for increased operational energy and water efficiency. The programme has eight key objectives:

- Quantify and characterise the energy use in New Zealand non-residential buildings
- Understand how energy is used in today's non-residential buildings
- Improve the basis for Government policy development and implementation
- Improve models of non-residential building energy use
- Provide guidance to create more productive work environments
- Support the reduction of GHG emissions and adaptation to climate change
- Provide design and operation guidance to reduce energy consumption and GHG emissions
- Improve the basis for development of the New Zealand Building Code (NZBC), Standards and energy rating tools such as GreenStar.

In order to optimise the programme and meet the goals and objectives, BEES must focus on the following key priorities:

- Understanding energy and water use in a set of buildings that can be robustly studied
- Providing stakeholders with new knowledge as to the greatest opportunities to improve resource use efficiency
- Ensuring the study complements, rather than duplicates, other relevant research activities, and
- Ensuring that data collection and analytic activities are cost-effective and 'right-for-use'.

A robust and transparent definition of the boundaries of the set of buildings included in the programme is therefore critical to optimising its informational and knowledge contribution. Setting those boundaries is not a trivial task, and therefore a stepwise consideration and specification of the following three issues has been undertaken:

i. Determining which building types constitute the non-residential and residential building stocks
ii. Clearly defining the part(s) of the non-residential building stock that is of most concern to BEES and its stakeholders

iii. Establishing the measures and methods appropriate to gathering and analysing data.

To complete the data collection and subsequent analysis the boundary from which the sample is taken needs to be defined. To clarify the study boundary and generate a robustly articulated focus for BEES, the BEES team has referred to the three classificatory systems used to categorise buildings in New Zealand:

- The Census classification
- NZBC Clause A1 Classified Uses
- PropertyIQ.

In order to understand these definitions it is easiest to look at residential buildings first. The Census and the NZBC together provide a consistent definition of the boundary between residential buildings and non-residential buildings.

In the Census, residential buildings are divided into two categories. The first category is private dwellings in which households reside, including detached, semi-detached or multi-units. The other category is non-private dwellings. Non-private dwellings include: hotels, motels, guest houses, boarding houses, rest homes, hostels, motor camps, prisons and hospitals.

The NZBC Classified Use also defines hotels, motels, rest homes, hostels and hospitals as 'Residential'.

PropertyIQ takes a different approach and classifies uses such as hospitals, motels and hotels as either 'Commercial' or 'Other' rather than 'Residential'.

BEES will use the Census and NZBC approach to defining the division between residential and non-residential buildings for a number of reasons. Most importantly:

- The Census and Building Code Classified Use are associated with statute and are well defined and specified while PropertyIQ classifications are not.
- PropertyIQ categories tend to become catch-alls for a diverse set of buildings and uses, often without national consistency. In particular, the PropertyIQ categories fail to distinguish adequately between buildings with substantial residential components of use and non-residential components.
- PropertyIQ classifications are embedded in planning and zoning considerations rather than building performance.
- Both the Census and the NZBC classifications provide standard definitions used nationally. PropertyIQ classifications are used by most, but not all, local authorities but are subject to local and regional variations.

2.2.2 Building uses are in the non-residential stock?

The next issue is whether all the buildings in the non-residential building stock should be the focus of BEES, and prioritisation of the remaining stock, to ensure the study provides the best information possible for the size and structure of the programme and meeting its goals and objectives.

The NZBC identifies five non-residential building stock categories (see Table 3):

- Communal non-residential buildings
- Commercial buildings
- Industrial buildings
- Outbuildings, and

- Ancillary buildings.

4.0 COMMUNAL NON-RESIDENTIAL **4.0.1** Applies to a building or use being a meeting place for people where care and service is provided by people other than the principal users. There are two types: **4.0.2 Assembly Service** Applies to a building or use where limited care and service is provided. Examples: a church, cinema, clubroom, hall, museum, public swimming pool, stadium, theatre, or whare runanga (assembly house). **4.0.3 Assembly Care** Applies to a building or use where a large degree of care and service is provided. Examples: an early childhood centre, college, day care institution, centre for handicapped persons, kindergarten, school, or university.
5.0 COMMERCIAL **5.0.1** Applies to a building or use in which any natural resources, goods, services or money are either developed, sold, exchanged or stored. Examples: an amusement park, auction room, bank, car-park, catering facility, coffee bar, computer centre, fire station, funeral parlour, hairdresser, library, office (commercial or government), police station, post office, public laundry, radio station, restaurant, service station, shop, showroom, storage facility, television station or transport terminal.
6.0 INDUSTRIAL **6.0.1** Applies to a building or use where people use material and physical effort to: (a) extract or convert natural resources, (b) produce goods or energy from natural or converted resources, (c) repair goods, or (d) store goods (ensuing from the industrial process). Examples: an agricultural building, agricultural processing facility, aircraft hanger, factory, power station, sewage treatment works, warehouse or utility.
7.0 OUTBUILDINGS **7.0.1** Applies to a building or use which may be included within each classified use but are not intended for human habitation, and are accessory to the principal use of associated buildings. Examples: a carport, farm buildings, garage, greenhouse, machine room, private swimming pool, public toilet, or shed.
8.0 ANCILLARY **8.0.1** Applies to a building of use not nor human habitation and which may be exempted from some amenity provisions, but which are required to comply with structural and safety related aspects of the building code. Examples: a bridge, derrick, fence, free standing outdoor fireplace, jetty, mast, path, platform, pylon, retaining wall, tank, tunnel or dam.

Table 3: Building Code classified uses – non-residential

Source: *New Zealand Building Code Handbook* (3rd Edition)

The original BEES proposal and subsequent discussions with stakeholders have reaffirmed that BEES should focus on the occupation, use and performance of non-residential buildings. This focus is consistent with BEES generating data that will assist Government and organisations that use buildings to prompt the market to provide more energy and water-efficient buildings and promote more resource efficient building use. Therefore BEES is a study about building energy and water use, not a study about the energy and water used in manufacturing, service or industrial processes.

Industrial: Buildings in which processes dominate the overall consumption of energy and water (for example foundries and smelters) are of less concern to BEES than buildings whose operations constitute a considerable proportion of the overall water and energy consumption.

With this approach, both ‘**Outbuildings**’ and ‘**Ancillary**’ buildings have less importance to the focus of BEES and so too do most of the Industrial buildings as defined by the NZBC.

Warehouses: There was one sub-category within the PropertyIQ Industrial classification that the BEES team initially considered should be included in the study, namely, IW – industrial warehouses. At the start of the building selection process, it was believed that unlike other industrial buildings, the overall resource consumption of warehouses was likely to be associated more with the building itself and its management than the processes that go on within it. The initial validation of the PropertyIQ categories also found that many buildings built as warehouses had been converted to commercial uses.

However, as analysis of the PropertyIQ data proceeded it was found that the Industrial Warehouse category was far more complex than initially expected. This complexity would limit the value of including this entire category in Component A (Aggregate Survey). It was decided not to include the IW category unless the building was being used for office or retail purposes. Should resources be available in a later year, some specific work could be undertaken on energy and water use in warehouse buildings.

Communal Non-residential: There must also be a question about the inclusion of the whole of the NZBC Communal Non-residential building category. In that category, 'assembly-service' buildings have characteristics that suggest that their exclusion may be desirable:

- First, many of the buildings are only occasionally operated.
- Secondly, the activities and patterns of operation can be expected to show considerable diversity.

Both those characteristics present significant analytic difficulties which would require considerable sampling and monitoring to resolve. That monitoring is likely to be out of proportion compared with other building types and with the potential energy or water savings associated with those buildings.

In addition, some of the buildings in the Communal Non-residential sub-category are likely to have their resource consumption strongly associated with delivery of the services within them, rather than the performance of the buildings that shelter them. Stadiums, theatres and cinemas are, in this sense, rather akin to industrial buildings. Just as, for instance, the energy consumption in a building housing a metal smelter is dominated by the manufacturing process, so in a cinema or stadium, energy consumption is likely to be dominated by session frequency and audience management. The similarity of these buildings to industrial buildings is reinforced by the fact that Communal Non-residential assembly-service buildings have no requirements currently placed on them for space conditioning under NZBC Clause H1 Energy Efficiency regulations. In this regard, they are treated the same as ancillary buildings, outbuildings and industrial buildings.

In contrast, the Communal Non-residential 'Assembly-care' buildings are characterised by features much more akin to commercial buildings. Indeed, it is expected that many, although by no means all, of these buildings will have been built to similar designs and requirements as commercial buildings.

Like Commercial buildings, Communal Non-residential 'Assembly-care' buildings are subject to the functional requirements of Clause H1 Energy Efficiency in relation to space condition, hot water and lighting. In addition, 'Assembly-care' buildings tend to be persistently and regularly occupied. As a consequence, the performance of the buildings and the way in which they are managed can be expected to have a profound effect on overall operating costs for occupant businesses.

For those reasons, the inclusion of this set of buildings appears consistent with the overall focus and intent of the BEES research programme. However, it must also be acknowledged that some of these buildings will have distinct design, building and occupation characteristics. This is particularly the case for purpose-built educational buildings, such as schools and universities.

2.2.3 Hospitals and educational uses

Hospitals and educational buildings are building types that are of specific interest to the BEES programme and its stakeholders.

The boundary definition as structured means that hospitals are not within the boundary limits for the BEES programme because they are classified as 'Communal Residential'. They provide temporary housing and their energy load is dominated by process not by use.

If we look more closely at hospitals, the PropertyIQ data for the health/medical category covers everything from small community Plunket rooms up to very large regional hospitals. This category has a total of approximately 2.6 million m^2 of floor area compared to approximately 30 million m^2 in the office and retail category. Due to the large variation in building type and use within the category and the small category size, to get meaningful energy and water use estimates would require a significant oversampling. This would compromise the data collection and information that can be gathered in other buildings categories. Therefore, it is proposed that hospitals should not be sampled as for other building uses.

However, to ensure their inclusion in the overall BEES programme, a separate preliminary examination of energy end-uses in hospitals is being conducted. BEES has undertaken to review current research on energy and water use (and expenditure) to find out what data is being collected and compiled at a regional or national level. This work includes reviewing the 15 audits of hospitals in the EECA Energy Audit database, and the documentation for about 75 hospital-based Crown Loans for energy-efficient capital developments.

Educational buildings are included within the proposed boundary limits as they are classified as 'Communal Non-Residential'. However, due to their purpose-built nature they present some methodological challenges for the sampling framework.

The education sector is largely funded through central government, and hence cost reductions may permit the redirection of funding from the operational costs to investing in teaching outcomes. The Ministry of Education has already collected a large amount of data on educational building energy use. Initial contact suggests this data can be accessed centrally by BEES, and hence it offers an opportunity to attempt to identify the patterns of resource use in schools and the value case for improved energy and water performance.

BEES will separate purpose-designed school and university buildings from the buildings already part of Components A and B. This will increase the robustness of analysis of those non-residential buildings while, at the same time, ensuring that the school and university sectors are included in the overall BEES work. Education building sizes are further discussed in Section 4.6.

2.3 BEES Selected Use Categories

Overall, then, the boundary for the BEES research programme has the following parameters (see Figure 3):

- It will address energy and water use in the non-residential building stock.
- Based on NZBC definitions, **Commercial** buildings and **Communal Non-residential Assembly-Care** buildings will fall within the ambit of the programme.

- Based on NZBC definitions, stock defined as **Industrial** will be excluded from the study.
- Based on NZBC definitions, all **Ancillary** and **Outbuildings** will be excluded, along with **Communal Non-residential 'Assembly-service'** buildings.
- Given the confusion within the PropertyIQ category of 'Industrial Warehouses', this category will be included in the sampling framework, but due to the complexity of this building type, the phone survey will only collect data from those with retail or office uses.

Although PropertyIQ classifications do not map precisely to the NZBC Classified Use categories, mapping is possible. From this we estimate that using the boundaries we propose will include around 55,000 buildings.

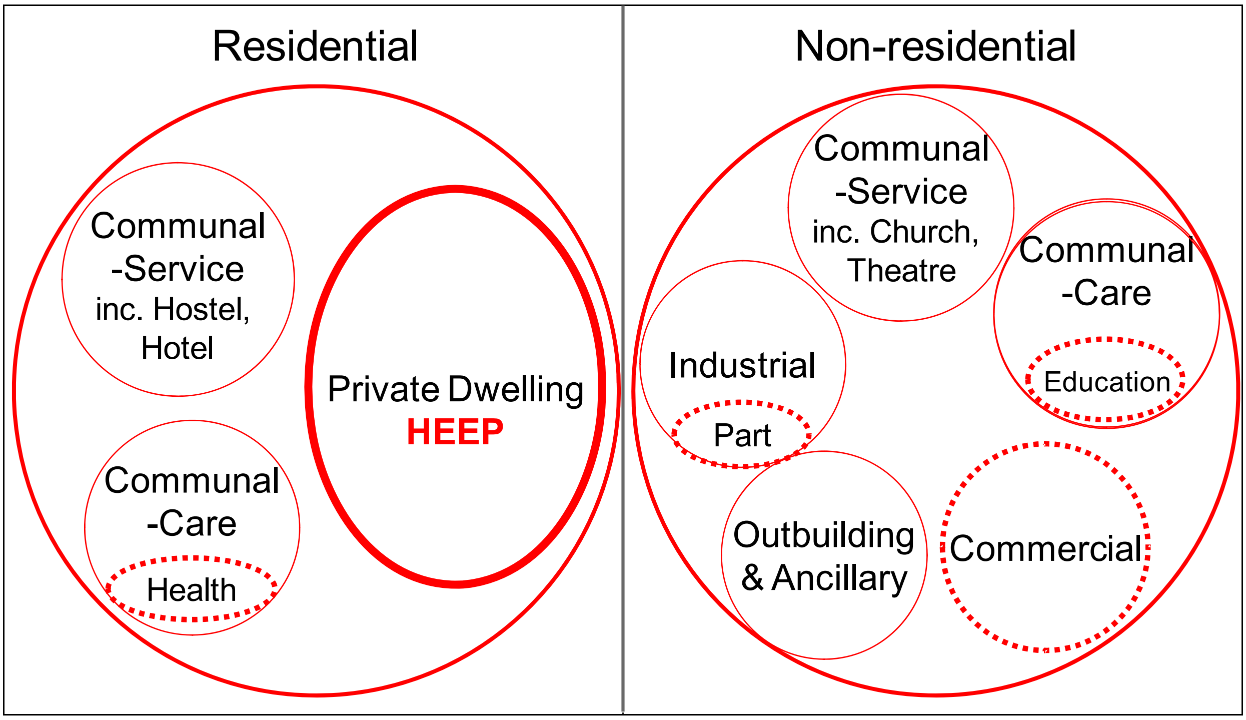

Figure 3: Residential and Non-Residential Building Types Based on NZBC

2.4 What is a 'building'?

What is a 'building'? There is no simple 'list' of all the non-residential buildings in New Zealand. The best available is the PropertyIQ Valuation Roll which is principally used for the purposes of local government rating. Selected 'valuation records' were obtained from PropertyIQ. However, each valuation record refers to the value placed on a rating unit, and a rating unit may, or may not, be a single building. For example in a multi-storey building each floor can be strata-titled, and hence it is called a 'rating unit'. As BEES is concerned with physical buildings and not legal descriptions, it was necessary to first combine the 'valuation records' into 'Building Records'. Once inspection has been completed on a Building Record it can be determined whether, or not, this is a 'building'. See Appendix C for further discussion and the 'record' definitions used in the BEES work.

The criteria for determining whether a structure is one or more buildings also needs to be clear. This is not necessarily simple, as often a range of factors may need to be considered in defining the boundary. These will be more formally established as the project develops:

- **Architectural boundary:** It is usually fairly obvious from the street that adjacent buildings are different, with different materials, styles and form, even though they may have a common wall or adjacent walls.
- **Services boundary:** Services are not usually shared between buildings.
- **Ownership boundary:** The valuation often relates to the ownership, and separate ownership often indicates a separate building.

The BEES study requires a definition and a process for deciding what constitutes a building. The definitions used by other non-residential building studies are reviewed, and definitions suggested for the BEES project.

Definitions of relevance to BEES are found in: the Statistics NZ Business Frame; the Building Act 2004; the USA 'Commercial Buildings Energy Consumption Survey' (CBECS); the USA 'California Commercial End-Use Survey' (CEUS); the Canadian 'Commercial and Institutional Building Energy Use Survey' (CIBEUS); the British 'Non-domestic Building Stock' (NDBS); the British 'Carbon Reduction in Buildings' (CaRB)'; and in a current British research project 'Non-domestic Energy Efficiency Data Framework' (NEED).

2.4.1 Statistics NZ Business Frame definitions

Statistics NZ collects information on business activity using the Business Frame. Definitions used for the Business Frame are:

Enterprise: A business entity operating in New Zealand either as a legally constituted body such as a company, partnership, trust, local or central government trading organisation, incorporated society, or as a self-employed individual.

Kind of Activity Unit (KAU): A subdivision of an enterprise consisting of a set of one or more activity units for which a single set of accounting records are available.

Geographic Unit: A separate operating unit engaged in New Zealand in one, or predominately one, kind of economic activity from a single physical location or base.

The hierarchy is Geographic Unit is a sub-set of KAU which is a sub-set of Enterprise.

2.4.2 Building Act 2004 definition

The NZBC refers to Sections 8 and 9 of the Building Act 2004 to define a 'building' (see Appendix B: NZBC Definitions) It defines a building very broadly as 'a temporary or permanent movable or immovable structure', and has a long list of exclusions.

Section 8, Part (c) includes any two or more buildings that, on completion of building work, are intended to be managed as one building with a common use and a common set of ownership arrangements.

2.4.3 CBECS definition

The Commercial Buildings Energy Consumption Survey (CBECS) definition for a building is:[5]

Criterion 1 – Building Definition: The definition of a building was the same one used in the past: a structure totally enclosed by walls that extend from the foundation to the roof that is intended for human access. Therefore, structures such as water, radio and television towers were excluded from the survey. Also excluded

[5] From http://www.eia.doe.gov/emeu/cbecs/2003howconducted.html

were: partially open structures, such as lumber yards; enclosed structures that people usually do not enter or are not buildings, such as pumping stations, cooling towers, oil tanks, statues or monuments; dilapidated or incomplete buildings missing a roof or a wall; and, beginning with the 1995 CBECS, stand-alone parking garages. There is one exception to the building definition criterion – structures built on pillars so that the first fully enclosed level is elevated are included. These types of buildings are included because such buildings fall short of meeting the definition due only to the technical shortcoming of being raised from the foundation. They are totally enclosed, are used for common commercial purposes, and use energy in much the same way as buildings that sit directly on a foundation.

2.4.4 CEUS definition

The California Commercial End-Use Survey (CEUS) primary sampling unit was the premise, defined as:

Premise: a single commercial enterprise operating at a contiguous location.[6]

Note that the word 'premise' is not a proper English word for a building or property, but is a term in formal logic. The correct word is 'premises'.

2.4.5 CIBEUS definition

The CIBEUS definition of a building appears to be derived from the CBECS definition.

Building: A structure totally enclosed by walls extending from the foundation to the roof. Only buildings containing over 93 m^2 (1,000 sq ft) of floor space and intended for human occupancy are considered. Structures included in the survey as a specific exception are those that are erected on pillars to elevate the first fully enclosed level but leave the sides at ground level open. The following structures are excluded from the survey as non-buildings: structures that are not totally enclosed by walls and a roof (such as oil refineries, steel mills and water towers); street lights, pumps, billboards, bridges, swimming pools, oil storage tanks and construction sites; and mobile homes and trailers not attached to permanent foundations, even if they house commercial activity. Military bases and embassies are also excluded.

2.4.6 NDBS definitions

The Non-domestic Building Stock (NDBS) database for England and Wales defines a building as follows.[7]

> What, for these purposes, is to constitute a 'building'; and what is to count as 'nondomestic'? **We specify that a 'building' encloses space which is accessible and usable for some human activity.**
>
> Thus a monument like the Cenotaph would not qualify as a building, nor would a tank for storing liquids or gases. A building we assume is reasonably permanent and fixed in place: thus we exclude caravans and tents (but include some moveable structures such as 'portakabins'). A building must be covered by a roof, although it need not have walls. Thus an electricity sub-station in which the transformers are enclosed just by a wall would not count; but a barn with a roof on columns would be included.

[6] CALIFORNIA COMMERCIAL END-USE SURVEY. March 2006. Itron. Report No. CEC-400-2006-005.

[7] H Bruhns, P Steadman, H Herring, S Moss & P Rickaby. 2000. 'Types, Numbers, and Floor Areas of Non-domestic Premises in England and Wales, Classified by Activity'. *Environment and Planning B: Planning and Design* 2000 (27): 641-665.

> Finally we put a (rather approximate) lower limit on size, so that, for example, telephone boxes and potting sheds are excluded.

They go on to define a 'premise' as their unit of analysis, not 'building', as the relationship between premise and activity is much easier to deal with than the relationship between building and activity, and 'premise' is closely related to 'hereditament' which is the valuation unit:

> By 'premise' then we mean an area of floor space (perhaps in part of a structure, the whole of a structure, or many adjacent structures) *occupied by a single organisation or enterprise, on a single site.* For the present purposes the Valuation Office hereditament is taken as equivalent to a 'premise'. Should one organisation be split between many sites (as, for example, a university with separate departmental buildings, halls of residence, sports facilities etc all on different sites) then this would constitute as many premises as there are sites.

CaRB uses the NDBS classification and definitions.[8]

2.4.7 Non-domestic Energy Efficiency Data Framework (NEED)

NEED is the most recent piece of research that has evolved from CaRB and NDBS. The following is an extract from an unpublished paper, provided by Harry Bruhns.

Collections of buildings: Common examples of collections of buildings are a hospital, university or business park, with commonality of activity or ownership. Their heating and cooling may be provided by a single set of HVAC services.

Buildings: Physically, the non-domestic stock is comprised of buildings and the thermal properties (fabric and glazing u-values, solar gains etc) of these buildings are generally the major determinant of energy consumption. Buildings tend to have a central system of building services (heating, cooling etc) and metering. Many carbon reduction measures will target buildings as a whole via either retrofitted construction or their centralised building services.

Premises: The facility under the management and control of a single occupant. The premises may comprise a portion of a building, a whole building, a collection of buildings, or arbitrary grouping of all of these.

Hereditaments: Hereditaments are the property units liable for business rates and for which rateable value is assessed. Defined essentially by occupancy, they may be part of a building, a whole building or several buildings.

2.4.8 Overview of definitions used in non-residential building research

The CEUS and CIBEUS studies use the 'building' in the architectural sense as their sample unit.

The CEUS uses 'premise' and the CaRB/NDBS studies use 'premises' as their sampling unit, which are conceptually similar.

The Statistics NZ 'Geographic Unit' appears to be very similar to the CaRB/NDBS 'premise'.

The BEES sample unit is a 'valuation', which will be sampled at a 'building', 'premises' or 'part-premises' level, with the intention of reporting at the level of 'valuation', 'building' and 'premises'.

Overall the approach used in NEED is the most comprehensive and best developed, and offers a model for BEES.

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[8] www.carb.org.uk

2.5 BEES terminology:

The suggested terminology broadly follows

the NEED (Section 2.4.7) approach and takes account of Statistics NZ definitions. Further details are provided in Appendix C: Record Definitions.

- **Building**: An enclosed physical structure intended for human occupation.
- **Premises:** A single physical location occupied by a single geographic business unit. This may be a single building, more than one building, or parts of one of more buildings.
- **Floor:** A floor in a multi-storey building.

Terminology for dealing with groups of buildings:

- **Campus:** A collection of buildings on a single piece of land occupied by a single business e.g. a school, university or hospital.
- **Facility:** One or more buildings used for a common purpose.
- **Outdoor mall:** A large building or buildings containing a large number of diverse businesses (mainly shops) with large common outdoor pedestrian areas.
- **Shopping mall:** A large building or buildings containing a large number of diverse businesses (mainly shops) with large common indoor pedestrian areas.

3. ANNOTATED BIBLIOGRAPHY

An annotated bibliography was prepared by CBPR based on an extensive international and national literature review. Following use by team members, the full document will be prepared for publication by February 2009. Extracts from the seven sections are provided below.

3.1.1 Equivalent studies – methodology

This explores other equivalent studies that are being undertaken currently or that have been completed in the past. The other major international studies are:

- United Kingdom – Non-Domestic Building Stock (NDBS) and Carbon Reduction in Buildings (CaRB)
- Canada – Commercial and Institutional Building Energy Use Survey (CIBEUS)
- United States of America – California Commercial End-Use Survey (CEUS) and Commercial Buildings Energy Consumption Survey (CBECS).

The methodologies of other studies that include aspects relevant to BEES have also been included. This section is drawn from the approximately 257 identified items and covers the topic under the headings:

- Equivalent Studies
- Non-Domestic Building Stock (NDBS)
- Carbon Reduction in Buildings (CaRB)
- Commercial and Institutional Building Energy Use Survey (CIBEUS)
- California Commercial End-Use Survey (CEUS)
- Commercial Buildings Energy Consumption Survey (CBECS)
- Methodology to Energy Studies
- Guidelines to Energy Studies.

3.1.2 Monitoring + equipment

This examines the science of monitoring and currently available equipment. Monitoring of energy consumption and energy end-uses within non-residential buildings will be a large part for the BEES project. This section reviews monitoring methods, data collection instruments, surveys, energy audits and energy analysis.

This section is drawn from the 94 items identified under the criteria and covers the topic under the headings:

- Monitoring Methods
- Data Collection Equipment/Instruments
- Conclusions.

3.1.3 Social ramifications

This section provides support for the systematic review. It explores publications relating to the determinants of or patterns related to social impacts towards buildings and energy use. This paper is drawn from items identified under the policy criteria and covers the topic under the headings:

- Energy consumption determinants related to activities within buildings
- Energy consumption determinants associated with the ownership, management and/or occupation of a building
- Energy consumption determinants related to spatial position within settlement systems

- Energy consumption determinates related to actual behaviour, perceptions and/or comfort of people using buildings.

3.1.4 Interventions – energy efficiency + policy

This section provides support for the systematic review. It explores publications relating to the range of intervention programmes and regulatory requirements for building stock efficiency improvements. The interventions can affect energy sources, energy generation, building design, energy management and energy-efficiency measures. The paper draws from the 141 items identified under Interventions, Energy Efficiency or Policy and covers the topic under the headings:

- Interventions through Energy Efficiency
- Interventions through Energy Policy
- Conclusion.

3.1.5 Geographic Information Systems, modelling and simulation

This section supports the work on modelling of buildings to study the energy trends and patterns. This section reviews modelling methods and computer tools that have been used around the world for use in the area of energy consumption. This section is drawn from the 78 items identified under Modelling, Simulation and GIS and covers the topic under the headings:

- Modelling Methods
- Modelling Computer Tools.

3.1.6 Factors that affect energy use in buildings

This section supports the work reviewing the factors that influence energy use in buildings. It ties in with the section concerning current research on energy/water use and expenditure. The section also examines publications dealing with energy indicators. These indicators describe the links between energy use and human activity in a disaggregated framework. Advantages of knowing about energy indicators are that they can help in understanding driving forces behind growth in energy demand and being able to separate factors related to energy efficiency from those that are not. Energy indicators describe the links between energy use and human activity in a disaggregated framework. This section is drawn from the 68 items identified under Energy Efficiency, Energy Indicators and Energy End-use and covers the topic under the headings:

- Factors Specific to Energy End-uses
- Factors Specific to Building Design and/or Component
- Factors related to Human or Building Activities
- Energy Indicators
- Factors that Affect the Efficient Use of Energy.

3.1.7 Water use in buildings

Water use in buildings has does not appear to have been monitored or studied in-depth in the past. Due to this, all the publications found regarding major sub-category areas have all been included in this section, starting from Water Supply, Water Efficiency through to Water Monitoring Equipment. This section is drawn from the 59 items identified under Water Monitoring and Equipment, Water Audits, Water Use, Water End-use and Supply, Water conservation, Alternatives and Efficiency, Water Management and Water Benchmarks and covers the topic under the headings:

- Water Monitoring Equipment
- Water Monitoring Methods & Audits

- Water Use, End-use and Supply
- Water Conservation, Alternatives and Efficiency
- Water Management
- Water Benchmarks.

4. SELECTING NON-RESIDENTIAL BUILDINGS

Unlike housing, there is no regular census of non-residential buildings. No one agency has a specific interest in the performance of non-residential buildings, and hence the only data that is available is in a structure or form that suits the specific needs of the specialist users.

The nearest to a comprehensive database is the valuation records maintained by PropertyIQ. These records have been used for previous studies for example: Baird & Newsam. 1986. *Estimation of Energy Consumption in the NZ Commercial Building Sector*[9]; and Isaacs, Lee & Donn. 1995. *Energy Efficiency in the NZ Building Code – A New Structure*[10].

It was therefore decided to arrange to purchase from PropertyIQ and Auckland City Council (who have their own Valuation Department) selected valuation records.

4.1 PropertyIQ Database

The goals of the valuation data analysis for the BEES project were to understand the valuation data so that the target population and sampling strategy could be developed to achieve the most accurate results possible with the minimum number of buildings, and to aid in the development of survey and monitoring methodologies.

There are some problems with the valuation data that may cause difficulties for the BEES sampling frame. These include missing and incorrect floor areas, incorrect categorisation and out-of-date records. Strategies for dealing with these problems are being developed as part of the survey design, and some valuation records are being validated in the field to minimise the number of incorrect records.

The analysis of the valuation data shows that the buildings are highly heterogeneous, being unevenly distributed throughout the country (~2/3 of the floor area is Auckland, Hamilton, Wellington and Christchurch) and with widely varying floor area (from <10 to over 100,000 m²). Overall about 50% of the total floor area is in the largest 5% of valuations, clearly showing that large buildings (although very low in number) dominate the floor area. These characteristics also differ widely by category of building, with a disproportionate number of very large floor areas for hospitals and educational facilities, and large office and retail valuations unlikely to be outside the major cities. These factors combined present considerable difficulties for designing an efficient and valid sampling strategy, and a thorough understanding of the data was required to devise appropriate strategies.

The total floor area for Commercial, Industrial Service and Warehouse, and Other categories is approximately 75 million m² in 75,400 valuations. The Commercial category is the largest with 36 million m² in 40,000 valuations. The three largest Commercial sub-categories are Commercial-Retail, Commercial-Multiple/Other and Commercial-Office, and their combined floor area is 27 million m², which is 75% of the total Commercial floor area. In the Other category the Educational sub-category has 45% of the total floor area, far larger than any other sub-category.

[9] Baird G & Newsam G. 1986. *Estimation of Energy Consumption in the NZ Commercial Building Sector.* NZERDC Report P103.

[10] Isaacs N, Lee J & Donn M. 1995. *Energy Efficiency in the NZ Building Code – A New Structure.* Wellington: CBPR for BIA/EECA (replaces Draft July 1994), pp. 100.

4.2 BEES sampling frame: brief description

The following describes the sampling frame for the BEES surveys, and the procedure used to sample it for the aggregate survey. It is a record of what has been done, rather than why it was done. Discussion of the rationale and various investigations that were made before the frame and sampling procedure were set up are recorded in two internal reports: *BEES Survey Design* and *BEES Valuation Data Analysis.*

However, a brief description of the parent/child structure of the valuation records from which the frame was constructed is given below, as it is necessary for understanding the remainder of the document

4.2.1 Parent and child records

The sampling frame for the BEES project consists of a set of records from the PropertyIQ valuation roll for all New Zealand.

The valuation roll contains a separate valuation record for each Certificate of Title (CoT) which is valued separately. In many cases a single 'building' will contain more than one CoT, and for these buildings Property IQ constructs a single 'parent' record relating to the building as a whole. This contains pointers to all the 'child' records relating to the component CoT. Each valuation record, parent or child, contains various information describing the size, type and use of the entity concerned: for the parent valuation record this relates to a whole building or group of buildings; for a child valuation record it relates to its specific part of the building.

4.2.2 Data from which the frame was constructed

The set of data originally supplied consisted of the following:

Mode 1: All valuation records with no children for with uses given in Table 4 or Table 5. Such valuation records are considered as parents, each of which has exactly one child – itself.

Mode 2: All parent valuation records with children, for which the parent use category was Commercial (Table 4), together with all the associated children, irrespective of the use code of these children.

Mode 3: All parent valuation records with at least one child with major use code from Table 4 or Table 5, whatever the use code of the parent, together with all associated child records with use codes in these tables.

The term 'mode' may be confusing – it refers to the type of database query used by Property IQ to generate the associated set of records. We may think of the modes as describing three different sets of valuation records.

The number of records originally provided was very large and contained many irrelevant records relating to dams, hospitals, golf courses and so on, particularly in Mode 3. The scope of the survey was confined to parent valuation records that included some office and retail uses. The selected category use codes are given in **bold.**

Use	Description
CC	Cinema, theatre and public hall-type complexes
CE	Rest homes for elderly
CL	Liquor outlets including taverns etc
CM	Motor vehicle sales, service etc
CO	Office-type use
CP	Parking buildings etc
CR	Retailing use
CS	Service stations
CT	Tourist-type attractions as well as other amenities with a emphasis on leisure activities of a non-sporting type
CV	Vacant land which when developed will have a commercial use
CX	Numerous commercial uses on one site or where the use is not previously specified

Table 4: Property categories with primary code 'Commercial'

Use	Description
IS	Service industrial usually has an interface with the general public as direct clients
IW	Warehousing with or without associated retailing
IX	Industrial-Other/Mixed
OA	Other-Assembly (halls etc)
OE	Other-Educational
OH	Other-Health/Medical
OM	Other-Maori Sites
OP	Other-Passive Reserve
OR	Other-Religious
OS	Other-Sporting
OU	Other-Utilities
OV	Other-Vacant
OX	Other-Multiple/Other

Table 5: Other property categories for which records were obtained

4.2.3 The sample frame

The sampling frame consists of those parent records from Modes 1 and 2 with property category codes CL, CM, CO, CR, CS, CT, CV, CX, IS or IW (see Table 4 and Table 5 above).

The pointers to associated child valuation records are of course maintained. In principle, these child valuation records should cover the entire building or set of buildings covered by the parent valuation record. However, inaccuracy or datedness of the relevant valuation records may need to be taken into account.

The sampling frame as finally defined consisted a sub-set of these Building Records that was estimated to contain at least 95% of office and retail use, both by number of Building Records and by total floor area.

The sampling frame, particularly for the IS and IW use codes, may include a significant number of valuation records that do not in fact contain office or retail use. The estimation of the number and floor area of buildings in the sampling frame that do in fact contain such uses, and the floor area associated with these uses, is an important part of the aggregate survey.

4.2.4 Stratification of the frame

The frame has been divided into 50 strata, formed by all combinations of the following:

5 size groups (quintiles), based on estimated total floor area by Building Record, as listed in Table 6 below:

Size Group	1	2	3	4	5
Minimum Floor Area (m^2)	0	650	1500	3500	9000
Frame Total (million m^2)	9.9	9.6	9.5	9.6	9.8

Table 6: Floor area size groups

5 use groups, 'office', 'retail', 'mixed', 'IS' and IW, based on the use category of the parent record, as listed in Table 7 below:

Use Group	Office	Retail	Mixed	Industrial Service	Industrial Warehouse
Categories	CO	CL,CM,CR,CS,CT,CV	CX	IS	IW

Table 7: Use groups

.

2 geographic groups 'Auckland' and 'rest of New Zealand') – the Auckland group is defined by the area covered by the Auckland Regional Council.

The distribution of Building Records among the 50 strata is given in Table 8, with associated floor areas in Table 9.

		Size Quintile (Count)					
Use Group	Region	1	2	3	4	5	Total
Office	Auckland	905	402	256	170	58	1,791
	Rest of NZ	3,310	794	378	190	73	4,745
Office Total		4,215	1,196	634	360	131	6,536
Retail	Auckland	2,912	545	217	76	39	3,789
	Rest of NZ	13,433	2,524	738	247	74	17,016
Retail Total		16,345	3,069	955	323	113	20,805
Mixed	Auckland	1,398	505	267	126	31	2,327
	Rest of NZ	2,910	1,117	444	239	95	4,805
Mixed Total		4,308	1,622	711	365	126	7,132
IS	Auckland	520	484	262	104	18	1,388
	Rest of NZ	5,672	1,786	547	184	48	8,237
IS Total		6,192	2,270	809	288	66	9,625
IW	Auckland	491	644	550	264	73	2,022
	Rest of NZ	2,230	1,280	629	225	55	4,419
IW 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 8: Sampling frame: distribution of Building Records by stratum

Use Group	Region	Size Quintile ('000 m^2) 1	2	3	4	5	Total
Office	Auckland	240	401	598	918	937	3,093
	Rest of NZ	909	754	844	1,005	1,041	4,552
Office Total		1,149	1,154	1,442	1,922	1,978	7,646
Retail	Auckland	777	516	488	398	792	2,971
	Rest of NZ	3,640	2,352	1,616	1,271	1,293	10,171
Retail Total		4,417	2,869	2,103	1,669	2,085	13,143
Mixed	Auckland	436	496	585	640	926	3,083
	Rest of NZ	899	1,065	980	1,293	1,585	5,822
Mixed Total		1,335	1,561	1,565	1,932	2,511	8,905
IS	Auckland	204	476	586	517	346	2,130
	Rest of NZ	1,850	1,690	1,175	981	696	6,392
IS Total		2,054	2,166	1,761	1,498	1,042	8,522
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
IW 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

Table 9: Sampling frame: distribution of floor area by Building Record stratum

The stratification by floor area is necessary to vary the sampling rates from size group to size group. The grouping has been done to give approximately equal total floor areas for all five groups.

The stratification by use groups is to increase the statistical precision of the survey. In particular, the IS and IW groups are expected to contain relatively few buildings with office or retail uses, the 'office' and 'retail' groups to contain few buildings without such uses, with the 'mixed' being somewhere in between.

The two geographic groups were defined to help deal with what is expected to be a relatively low response rate in Auckland. It is desirable to replace non-responding Auckland buildings by Auckland buildings. The same consideration also applies to the other grouping variables.

4.2.5 Sampling of the frame

Equal sample sizes will be selected for each of the five size groups. Within each size group the sample will be distributed among the 10 strata making up that size group in proportion to the number of Building Records in the frame (i.e. each Building Record within a given size group has the same probability of selection.)

The sampling is carried out by selecting 'slices' as required. Conceptually this amounts to ordering the frame in such a way that any substantial consecutive group of Building Records yields a sample that is properly distributed among the 50 strata.

Five slices were drawn (at 15 July 2009) as listed below:

1. 62 Building Records for pilot testing of aggregate survey.
2. 1,240 Building Records for aggregate survey.
3. A further 196 Building Records for aggregate survey.
4. 1,545 additional Building Records for the web-based survey, also to be used as replacements in the aggregate survey.
5. 480 Building Records for use in piloting the targeted survey.

It should be noted that during Slice 4, the available Building Records for size group 5 were exhausted. Thus any further slices can contain no further Building Records from this size group.

4.3 Correspondence between frame records and buildings

This section deals with cases where a Building Record does not cover the whole of exactly one building, but one or more whole or part buildings.

The requirement is that every building of which a part is covered by one or more Building Records in the frame should be 'pointed at' by exactly one of those records. Conflicts are resolved by comparing the floor areas (as given in the sampling frame) for the Building Records, with the phone interview or site inspection then selecting the building of greater floor area.

In the case of exact ties (e.g. two buildings of the same floor area in one Building Record) the priority must be resolved using some other method. The order of occurrence in the randomly ordered frame used to define the slices is not suitable. The 'ID' field (column F) in the randomly ordered frame should be used, with the Building Record of lower ID having priority.

A building is 'pointed at' by a Building Record in the frame if, and only if, a part of that building is covered by that Building Record, and the same or another part of the same building is not covered by a Building Record in the frame of higher priority.

Examples:

IF Building Record A covers the whole of buildings 1 and 2 and a small part of building 3. Building Record B covers the rest of building 3. The floor area given in Building Record A (presumably covering buildings 1 and 2 and part of 3) exceeds that given in Building Record B.

Then Building Record A points at buildings 1, 2 and 3 and Building Record B points at no building.

IF Building Record A covers the whole of buildings 1 and 2 and a small part of building 3. Building Record B covers the rest of building 3. The floor area given in Building Record B exceeds that given in Building Record A.

Then Building Record A points at buildings 1 and 2 and Building Record B points at building 3.

4.3.1 Sampled records

When a Building Record is drawn in the sample, it is necessary to determine which of the buildings it refers to it actually points at. Those buildings, and only those buildings, are considered to have been selected for the survey. In principle this involves a search of the whole frame to ensure that no other Building Record of higher priority refers to any of the buildings concerned, but in practice this may rarely be necessary (see Section 4.3.2 below.

The fact that a sampled Building Record points at no building is valid and important data in respect of that Building Record, and must be recorded. Such a Building Record need not be replaced. If it is replaced to keep the number of sampled buildings up, it should be by the next Building Record in the randomly ordered frame. Such replacements, used in order, will in effect extend the current 'slice', although they could be distinguished by a different slice identifier.

4.3.2 Resolving the position in practice

It is the intention of PropertyIQ that different valuation records relating to the same building should be grouped together under the same parent. These parents form the Building Records of the frame. It is probably reasonable to assume that in the majority of cases PropertyIQ has got it right, although:

1) The frame may now be somewhat out-of-date; and
2) PropertyIQ may not mean the same thing as BEES does for by a ‘building’
3) There could presumably be situations where single valuations overlap (e.g. Valuation Record A is for building 1 and part of building 2, Valuation Record B is for building 3 and part of building 2).

Consequently:

1) It the area of a Building Record is a fairly close match to the apparent area of the buildings it covers, it seems fairly safe to assume that that Building Record points at those buildings.
2) If a Building Record covers only one building and has significantly over half the apparent area of that building, it MAY be reasonable to assume that any other Building Record covering that building will be of smaller area, and that therefore the original Building Record points at that building. The MAY is because of the possibility of overlapping valuations: the smaller part (or some of it) may in fact be a part of a larger valuation which includes other buildings.
3) In cases where more than half of the floor area of any building may not be covered by the Building Record, further investigation will be required to determine whether the remaining area is covered by some other Building Record of higher priority in the frame (whether or not that Building Record has been drawn in the sample.)

4.4 Building Eligibility & Sampling

Figure 42 (Appendix D) provides the BEES building eligibility flow chart and rules for the selection of buildings to be included in the study. The flow chart has been designed to be worked through on site (or on the phone before the visit) to determine whether it is worth investing BEES time in monitoring the building.

Steps 1 & 2: If the building is totally office or retail activities then it is included in the first step, while if there is no office or shop in the building then it is excluded at the second step.

There will always be buildings with mixtures of activities, and the next 3 steps are designed to deal with these in a consistent way:

Step 3: If the office or retail type activity (e.g. factory office) only supports the other activities carried out in the building (e.g. industrial factory), then the data will be of limited use to BEES, and the building will not be monitored; OR

Step 4: If the office or retail activity (e.g. staff cafeteria) is only open to staff in the building, then it will not be monitored; OR

Step 5: If the office or cafeteria (etc) is open to the public, but if this is only a tiny portion of the whole building (less than 5% of the floor area) then the building will not be monitored.

The BEES survey sampling strategy has been designed to give the best precision possible, whilst avoiding bias caused by the huge diversity of building types and sizes, and minimising the effect of other sampling issues. The sampling strategy finally decided on is to select a random sample of non-residential buildings stratified into five groups by floor area. Each size group represents a similar total floor area, and the number of buildings to be sampled from each group is the same. This is provisionally estimated to give a precision of 4% for total energy consumption on a sample of 1,000 buildings. The sample is to be for all of New Zealand, without any geographic clustering. The possibility of geographic clustering, i.e. of selecting a relatively small number of geographic units from which the sample is drawn, has been examined carefully and rejected as leading to considerable difficulties in the design, carrying out and analysis of the survey, without any clear benefit in terms of precision compared to the alternative of surveying a smaller number of buildings for the same cost.

Within the five main floor area strata, further strata may by defined geographically or by use type to minimise bias due to non-response.

A number of potentially serious issues have been identified, for example, missing floor area or incorrect categories in the valuations roll. Strategies have been developed to handle these in a way that does not introduce bias into the survey estimates.

4.5 Web search

Extensive use has been made of the internet to obtain information on the Building Records and the occupants. The results of the pilot study to identify premises are discussed in Section 6.3.

Appendix F Web Search Data provides an example of the type of information available from a web-based search. In this case set out on a sheet designed to be used by the team involved in undertaking a targeted survey on this building. The information collected from the web is presented along with spaces for correction. Any corrections will be recorded in the Building Record on the main database upon return from the survey.

4.6 Education buildings

There are a variety of issues that would have to be managed if BEES were to include educational buildings:

- Floor area is more skewed than the 'Non-residential' sector so probably will need different size strata (see tables below)
- StreetView will NOT in general give useful images, so need different survey and data gathering methods for the aggregate survey
- Most schools and tertiary facilities are campuses with multiple buildings, with huge diversity
- Would estimates be required for each facility (analogous to the 'each building' estimates) or would averages per facility be adequate?
- Energy use could be expected to vary hugely between term-time (large numbers of students and staff) and semester breaks (mainly staff). We may not be able to use two-week monitoring, and hence would require additional investment in monitoring equipment

The total floor area of Educational buildings in the valuation data is approximately 8.3 million m², which is about the same as each of Office, Retail, and Multiple/Other – and hence would require similar numbers to be investigated, similar levels of resource but additional equipment, as noted above. If we assumed the total number of buildings would remain the same, in simple terms we would go from 3 to 4 building types. Including educational buildings would require the 'Office, Retail, and Multiple/Other' sample to drop from 1,000 buildings to 750, with a sample of 250 for Educational (in simple terms). In practice, the likely greater resource needed for the more complex educational buildings will further reduce the sample size, either of the sample as a whole, or for the educational buildings strata.

It is not clear that the Valuation roll will form a suitable sampling framework for educational buildings, as it is likely that most are campuses with multiple buildings. This will greatly increase the difficulty of sub-sampling. The PropertyIQ data gives no useful data on the number of buildings in each Educational valuation record. An alternative sampling framework may need to be developed, for example, carving up campuses using Google Earth, or using Ministry of Education information on buildings.

The following tables show the valuation count and floor area for all buildings (Table 10) and Educational buildings according to the size strata used for the Non-residential building sample (Table 11), and for size strata based on the Educational buildings alone (Table 12).

Table 11 shows that using the existing Non-residential building sample size strata gives a very unbalanced sample for Educational valuations, and is likely not an efficient sample. Table 12 uses size strata based on quintiles of floor area for Educational valuations alone. Strata 5 is valuations over 18,000 m² (of which there are 42) and clearly shows how skewed the distribution of floor area is for Educational valuations. Assuming that the planned sample size is 250 Educational valuations, there would be 50 valuations in Strata 5, which is greater than the 42 valuations that exist. Clearly, this sampling strategy will not work either. Overall, it would appear that the discussion and approach in Section 2.2.3 is the correct on to follow.

Floor Area Group	**1**	**2**	**3**	**4**	**5**	**Total**
Minimum Floor Area	5 m^2	650 m^2	1,500 m^2	3,500 m^2	9,000 m^2	
Approx. No. of ‘Buildings’	33,781	10,081	4,288	1,825	564	**50,539**
% of Buildings	67%	20%	8%	4%	1%	**100%**
Total Floor Area (million m²)	9.9	9.6	9.5	9.6	9.8	**48.3**
% floor	20%	20%	20%	20%	20%	**100%**

Table 10: Non-residential size strata

Floor Area Group	**1**	**2**	**3**	**4**	**5**	**Total**
Minimum Floor Area	5 m^2	650 m^2	1,500 m^2	3,500 m^2	9,000 m^2	
Approx. No. of ‘Valuations’	2,270	588	860	344	168	**4,230**
% of Buildings	54%	14%	20%	8%	4%	**100%**
Total Floor Area (million m²)	0.55	0.6	2.0	1.9	3.3	**8.3**
% floor	6%	7%	24%	22%	39%	**100%**

Table 11: Education size strata using the same as the non-residential sample

Floor Area Group	**1**	**2**	**3**	**4**	**5**	**Total**
Minimum Floor Area	5 m^2	2000 m^2	3,600 m^2	8,600 m^2	18,000 m^2	
Approx. No. of ‘Valuations’	3,144	595	309	140	42	**4,230**
% of Buildings	54%	14%	20%	8%	4%	**100%**
Total Floor Area (million m²)	1.6	1.66	1.7	1.6	1.7	**8.3**
% floor	20%	19%	20%	20%	21%	**100%**

Table 12: Education size strata using approximate quintiles of floor area

4.7 Unique identifiers

The BEES naming conventions set out how Building Records, buildings and premises are labelled when names are required for files or similar purposes. The use of an alpha character at the start of the identifier both provides a key for use by the BEES team and ensure that the analysis software recognises it as a unique text identifier.

4.7.1 Identifier rules

There are three components that contribute to the unique identifier:

1. Building Record

A Building Record corresponds to a unique record in the BEES sampling frame. They are labelled as with a five character string, starting with the letter 'R', where Building Record 1 corresponds to R0001, Building Record 2 to R0002 etc:

R0001, R0002 etc

This allows for up to 9,999 Building Records. It is expected that up to 3,000 Building Records will be required to obtain the BEES sample.

2. Premises

A Premises corresponds to a specific business, occupying any amount of floor area, located within a Building Record. They are labelled with a two alpha characters:

AA, AB, AC, AD …, AZ, BA, … and so on to ZZ

This allows for 676 premises in a given Building Record. It is expected there could be up to 100 premises in a very large floor area Building Record.

3. Building

A Building corresponds to a physical building within a Building Record. In most cases there is only one building per Building Record, but while there can be more than one this is unlikely to be found until the completion of the aggregate survey and possibly not until the targeted survey. A single alphanumeric character codes the building number within the specific Building Record:

1, 2, 3, 4, 5, 6, 7, 8, 9, A, B etc

'0' (zero) is reserved for cases where there is the possibility of multiple buildings and a particular premise cannot yet be allocated to a specific building. This will be manually changed when the premises is allocated to a building, with the reason recorded in an event log.

This gives the possibility of up to 35 buildings in any given Building Record. It is expected that there could be up to 20 buildings within a large land area Building Record.

Resulting unique code:

The final unique code combines these three identifiers:

e.g. a Premises in a specific Building Record located in the first Building will be coded:

R0001AA1

As each Building Record, Building or Premises is brought into the BEES survey it will be allocated a unique identifier which will not change during the BEES project. If for some reason, e.g. what was thought to be a single premises is actually two premises, a new identifier will be assigned to the new premises with the reason recorded in an event log.

5. DATA COLLECTION

This year the data logging requirements were established, suitable equipment was identified and adequate quantities purchased for the main monitoring work to commence in the 2009/10 year. Methodologies to support the installation, data collection and equipment removal were developed and initial documentation was prepared. Suitable calibration systems were also developed and used to ensure the monitoring equipment is fit for the expected end-uses of the results.

5.1 Monitoring equipment

The monitoring needed to record on a suitable frequency (one reading every 10 minutes was used as a minimum):

- Temperature loggers
- Humidity loggers
- Light loggers
- CO_2 loggers
- AC current transformers and loggers.

Each piece of equipment was required to be accompanied by suitable:

- Instruction manuals
- Software
- Calibration certificates
- Spare parts.

Table 13 sets out specifications for the different environment (temperature, relative humidity and light) logging equipment. Table 14 lists the websites for the different equipment manufacturers. All of the possible equipment was readily available from reliable manufacturers, and had acceptable accuracy, precision, downloading and processing systems available.

Type	Parameters	Temp	RH	Light	Days @ 10 min	Battery type and life		PC Connection
NVSI Enviropoint	T, RH, L, + Ext	+/- 0.3°C	+/- 2%	-	N/A	AA	back up	w-less
HOBO U12 -012	T, RH, L, + Ext	+/- 0.35°C	+/- 2.5%	+/- 2.5%	99	3V,CR-2032	1 year	USB
Testo 175-H1	T, RH	+/- 0.5°C	+/-3%	-	55	1/2 AA Li	2.5 years	dock(USB, Serial)
TiniTag TGP-4500	T, RH	/- 0.5°C	+/- 3%	-	111	1/2AA,3.6V	1 year	serial/USB
BRANZ	T, RH	+/- 0.4°C	-	-	900	9 V	3 months	special
HOBO U12 - 011	T, RH	+/- 0.35°C	+/- 2.5%	-	298	3V,CR-2032	1 year	USB
PointSix	T, RH	+/- 0.5°C	+/- 5%	-	N/A	3.6V lithium	2+ years	serial/w-less
iButton DS1923	T, RH	+/- 0.4°C	+/- 4.5%	-	28	button internal	2 years	dock
Testo 174 - mini	T	+/- 0.44°C	-	-	27	3V, CR 2032	18 months	dock(USB, Serial)
TiniTag TGP-4017	T	/- 0.5°C	-	-	111	1/2AA,3.6V	1 year	serial
HOBO U12 - 001	T	+/- 0.35°C	-	-	594	3V,CR-2032	1 year	USB
HOBO U10-001	T	+/- 0.4°C	-	-	361	3V,CR-2032	1 year	USB
Point Six	T	+/- 0.5°C	-	-	N/A	3V,CR-2032	2+ years	serial/w-less
HOBO UA002-64K	T, L	+/- 0.47°C	-	-	97	3V, CR2032	1 year	USB
Odyssey -Odyphoto	L		-	-	113	7.2V Lithium	-	serial
HOBO U9-002	Light on/off	-	-	-	298	3V, CR-2032	1 year	USB
Telaire 7001	CO_2	NA	-	-	-	AA	3 days	HOBO U12
Multivoies System	Electric current	-	-	-	5 mon	NA	NA	Palm PDA
Plogg	13 parameters	-	-	-	8.6 – 56	NA	NA	ZiggBee (USB)

Table 13: Comparison of specifications

Parameters: T - temperature, RH - relative humidity, L - light, + Ext at least one external measurement

Equipment	Web Reference
Enviropoint NVSI	http://www.nvsi.com.au/products.htm
Hobo U12 - 012	http://www.onsetcomp.com/data-logger
Testo 175-H1	http://www.microdaq.com/temperature_humidity/
Tiny Tag TGP-4500	http://www.geminidataloggers.com/data-loggers
Branz (Modified)	N/A (designed and built by BRANZ)
Hobo U12 - 011	http://www.onsetcomp.com/data-logger
Point Six	http://www.pointsix.com/home.html
iButton DS1923	http://www.maxim-ic.com/quick_view2.cfm/qv_pk/4379
Testo 174 - mini	http://www.microdaq.com/temperature_humidity/
Tiny Tag TGP-4017	http://www.geminidataloggers.com/data-loggers
Hobo U12 - 001	http://www.onsetcomp.com/data-logger
Hobo U10 - 01	http://www.onsetcomp.com/data-logger
Point Six	http://www.pointsix.com/home.html
Hobo UA 002 - 64k	http://www.onsetcomp.com/data-logger
Odyssey - Odyphoto	http://www.odysseydatarecording.com
Hobo U-9 - 002	http://www.onsetcomp.com/data-logger
Telaire CO_2	http://www.microdaq.com/telaire/i
Multivoies System	www.omegawatt.fr
Plogg	www.plogg.co.uk

Table 14: Monitoring equipment web links

The selection process put particular emphasis on the following objectives:

- Parameters that each unit or system can measure and store
- Quality (accuracy of reading and recording)
- Practicability for the project
  a. Memory size
  b. Dimensions and design
  c. System and way of programming the unit and setting up the system
  d. The system and time required for the data upload
- Durability
- Maintenance cost (calibration frequency and cost, battery type, price and availability)
- Handling and general maintenance
- Price relevant to the other above listed requirements.

An important part of the equipment selection methodology was obtaining sample units for the examination and testing according to all the required circumstances and conditions relevant to the project.

At the completion of this process the following equipment was selected:

- Energy Logger Pro H22-01 + interface modules (Figure 4)
- Hobo Watt Node (Figure 5)
- Hobo Current Transformers (Figure 6)
- Hobo Environmental Loggers (Figure 7)
- Plogg electricity logger (Figure 8)
- Xemtec Gas meter reader and logger (Figure 9)
- Multivoies Logger (Figure 10)
- Multivoies flexible Rogowsky coil (current transducer) (Figure 11)
- Telaire 7001 CO_2 Sensor (Figure 12)

Figure 4: Energy Logger Pro H22-01 + interface Modules

Figure 5: Hobo Watt Node

Figure 6: Hobo Current Transformers

Figure 7: Hobo Environmental Loggers

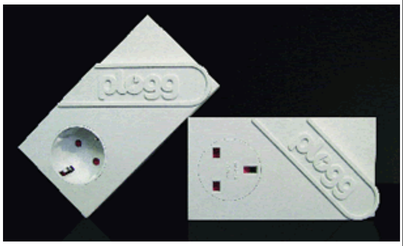


Figure 8: Plogg electricity Logger

Figure 9: Xemtec Gas Meter Reader and Logger

Figure 10: Multivoies Logger

Figure 11: Multivoies R Current Transformer

Figure 12: Telaire 7001 CO_2 Sensor

A summer student project explored the automated reading of gas and water meters. This found considerable difficulties in establishing a camera-based system which would reliably record the meter readings for later transfer through to OCR to analysis. A range of different cameras and meters were trialled, but it was found that it was not possible to develop a simple system with the available timeframe.

Market research found the Xemtec's Comet Meter Reader which is based around their proprietary universal 'optical' interface.[11] A sample has been obtained and is under test in the 2009/10 year.

[11] http://www.xemtec.com/.

5.2 Monitoring strategy

Monitoring strategies were developed for each of the five floor area size quintiles (see Table 6):

Floor Area Size Groups 1-3 buildings: Assume buildings up to 3,500 m^2 can be monitored from at most two distribution boards. Metering requirements are likely to depend more on the equipment installed, presence of three-phase electricity, and building layout rather than the floor area

Floor Area Size Group 4 buildings: Buildings up to 9,000 m^2 may require additional logging equipment as have three-phase electricity, multiple distribution boards, multiple buildings/floors etc. They may also require additional temperature sensors as larger area with multiple zones or floors. Higher capacity electric circuits may require additional, larger CTs.

Floor Area Size Group 5 buildings: Buildings over 9,000 m^2 require additional logging equipment as they will have three-phase electricity, multiple distribution boards, multiple floors etc. If BEES is to monitor more than one floor, each floor will need to be treated as one 'building'. These large buildings may also require additional temperature sensors as larger area with multiple zones. Higher capacity electric circuits will require additional, larger CTs.

Table 15 lists the selected equipment, the numbers required to create a set of equipment for each floor area size group and the approximate cost.

Floor Area Size Groups 1- 3 Equipment	**Count**	**Cost**
Energy Logger Pro	2	
Watt Node	2	
CURRENT TRANSFORMERS (CT)s	24	
Environmental Loggers	3	
Plogg	3	
Gas logger	1	
Multivoies system	1	
CO_2 logger	1	
Total per set for Floor Area Size Groups 1-3		**$15,000**
Floor Area Size Group 4 Equipment		
Energy Logger Pro	3	
Watt Node	3	
CURRENT TRANSFORMERS (CT)s	40	
Environmental Loggers	6	
Plogg	6	
Gas logger	1	
Multivoies system	2	
CO_2 logger	1	
Total per set for Floor Area Size Group 4		**$30,000**
Strata 5 Equipment		
Energy Logger Pro	6	
Watt Node	6	
CURRENT TRANSFORMERS (CT)s	60	
Environmental Loggers	12	
Plogg	12	
Gas logger	2	
Multivoies system	3	
CO_2 logger	1	
Total per set for Floor Area Size Group 5		**$43,500**
Number of sets of equipment and estimated cost (Feb 2009)	**20**	**$330,000**

Table 15: Equipment numbers and approximate costs

The final estimated preliminary expenditure on monitoring equipment is based on having 20 sets of equipment able to be used across all five floor area size groups. This assumes that one set of equipment will not be required to monitor buildings across all the groups at one time.

In addition, ancillary equipment to support the monitoring programme was selected and obtained:

- Laptop
- A circuit tracer device
- PDA Palm units
- Digital cameras
- Miscellaneous.

5.3 Equipment management

The ordered equipment, including spare parts, was initially checked upon delivery and then entered into a preliminary inventory list including assigning inventory ID numbers. During the course of this phase of the project, appropriate inventory system was developed and implemented. However this may need further improvements.

During the next phase, all equipment was tested for conformance and performance according to their specifications and requirements of the project. This work was performed in the BRANZ laboratory, IRL Measurement Standards Laboratory,[12] and in the field.

All computers were configured according to the requirements. Software packages for equipment configuration, data upload and primary data processing have been installed and made operational.

Appropriate calibration methodologies have been proposed and explored. Suitable calibration techniques have been developed and are being implemented in the 2009/10 year.

Instruction and process manuals have been prepared and documented for the majority of the equipment.

[12] http://www.irl.cri.nz/scienceandtechnology/technology-platforms/Measurement-for-Industry.aspx

6. AGGREGATE SURVEY

Three of the research components are concerned with obtaining data and processing it into a useful form as set out in Table 1 and Table 2.

- Component A: Aggregate Resource Use Patterns (Energy and Water)
- Component B: Determinants of Resource Use (Energy and Water)
- Component C: Building Dynamics.

The following three sections are concerned with the data collection aspects of these research components.

The aggregate survey (Component A) was piloted in April 2009. While not all interfaces and processes were tested, the piloting of sampling frames and various data collection techniques provides a sound basis for:

- Estimating data capture rates per building
- Identifying risks around sample bias, its quantification and management
- Replacement requirements.

Many of the findings from the aggregate survey pilot, especially around the adequacy of the building and business information for accessing sampled buildings, response rates and replacement requirements, affect both Component A and B. They are also critical to the ability of BEES to deliver a dataset sizeable enough to describe patterns at the aggregate as well as the determinants of energy consumption and end-use patterns.

The aggregate survey has two objectives. The first is to effectively address three questions. The second is to contribute to the robust development of other components within the BEES research programme.

The three questions are:

- What is the aggregate energy/water consumption of non-residential sector buildings?
- What is the average kWh/m2/annum energy use and L/m^2/annum water use?
- What categories of non-residential buildings appear to contribute most to the aggregate energy/water consumption of the non-residential building sector?

The aggregate survey is intended to contribute to the other components of the BEES research programme by:

- Implementing a data collection strategy that generates empirical data required in the analysis of one or more of the other components of the BEES research programme
- Providing a robust descriptive analysis that may assist other components to better specify key elements of methodology such as sampling or case frames, or better interpret the robustness and meaning of data generated by other components of the research programme.

The successful implementation of the aggregate survey requires three sets of data, which are:

- Data that allow a robust method to be developed and implemented, which is data that:
    - allows for a robust sample of buildings to be drawn;
    - provides a unique point around which substantive data such as building and business profiles can be matched from different sources
    - provides the opportunity to contact key respondents that can provide substantive data unavailable from other sources.

- Data that provides empirical measures of aggregate resource use and its distribution over the stock. Component A was developed to ensure some very basic information requirements of the funders would be met relatively quickly and cost-effectively. Addressing the key research questions of Component A can be achieved by analysis of:
    - aggregate energy consumption by building
    - total building size
    - building type using the NZBC classification.
- Data that provide empirical data useful to the analysis of determinants, building dynamics and forecasting through modelling and simulation. That data includes some end-use data, characteristics around building materials, design amenities, as well as ownership and occupancy characteristics.

6.1 Data sources and data collection

The BEES programme gathers data from four data sources:

- Administrative data sources, in particular:
    - Valuation data (PropertyIQ)
    - Energy supply data (retail energy companies)
- Existing non-administrative data, in particular:
    - Business directory data (APN Ltd)
    - Google StreetView
- Reported data from occupants/managers/owners of selected buildings
- Observed data through:
    - Direct monitoring of resource use
    - Direct on-site observational.

Some of this data can be directly accessed without dealing with building occupants, owners or managers. Others require direct contact or permissions by those parties. Table 16 sets out the relationship between these datasets and their acquisition pathways. Those bolded are relevant to Component A. Those in italics are relevant to Component B, albeit some of that data is likely to be collected by way of Component A and transferred to Component B.

Dataset Type	**Acquisition Pathway**	
	Building/Business Pathway	***Direct Source Pathway***
Administrative Data	Resource Supplier Data	Valuation Data
Other Existing Data		Business Directory Data StreetView and Satellite Data
Reported Occupant/Owner Data	Interview-based Data	
Observed Data	Direct Monitoring Detailed On-site Observation	Limited On-site Observation

Table 16: Datasets and acquisition pathways

The most obvious implication from Table 16 is that the critical data related to resource use must be acquired through directly engaging with businesses and building occupants. This is unavoidable and is a necessary part of Component A and Component B. Indeed, it is not an overstatement to suggest that the BEES programme as a whole is dependent on optimising access to building occupants/owners.

Nevertheless, a considerable proportion of BEES desired dataset can be collected through alternative sources. In Component A, pilot collection of data from alternative sources has involved:

- Valuation data extraction
- Building/business matching, and
- StreetView and web-based searching.[13]

The collection of data from businesses in buildings is being piloted through telephone interviewing using a closed-ended schedule which also activates the permissions to seek data from energy and water suppliers.

Table 17 summarises the data domains that the pilot is capturing through each method.

Information Domain	Information	Source
Building	Age	QV
	Number of floors	StreetView/Google/On-site
	Size of floor plate	StreetView/Google/On-site
	Total building m²	StreetView/Google/On-site and QV
	Building materials	StreetView/Google/On-site
	Building characteristics	StreetView/Google/On-site
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/On-site
Occupation	Total number of businesses	Business Directory/Survey
	Businesses per floor	Survey
	Employees per business	Survey
	Hours of use per business	Survey
Building Ownership/Management	Owner	QV
	Contact address for owner	Possibly QV
	Owner occupied	Business Directory/Survey
	Tenanted	Business Directory/Survey
	Tenancy agreement	Survey
	Building manager	Survey
	Cleaning	Survey
	Operation of heating and cooling	Survey
Resource Types	Water	Supplier and Survey
	Electricity	Supplier and Survey
	Gas	Supplier and Survey
	Other	Supplier and Survey
Suppliers and Billing	Water	Supplier and Survey
	Electricity	Supplier and Survey
	Gas	Supplier and Survey
	Other	Supplier and Survey

Table 17: Information domains and primary sources

[13] Supplemented by ancillary activities undertaken by the VUW School of Architecture.

There are three interfaces and processes that are critical to Component A delivering on its research objectives:

i. Data transfer, consolidation and management
ii. Acquiring permission from users to access data related to their energy and/or water use from suppliers
iii. Receipt of energy use and water use data from suppliers.

6.2 Pilot objective

The objective of the pilot is to identify the optimal method for collecting aggregate energy/water resource use data across the non-residential building sector. That is, data collection methods that:

- generate a consistent set of data across buildings within the sample
- generate data necessary to:
  - calculate average kWh/m^2/pa across the sector
  - identify key variables driving energy/water use patterns
- maximise data collected for minimised costs
- minimise occupant contact
- minimise sample bias.

The pilot has involved:

- selecting of a sample from the existing sample frame
- testing the coverage of desired data by different data collection methods
- testing instruments and developing process forms and protocols
- evaluating the efficacy of the data acquisition strategy and its costs.

6.3 Pilot findings

The following section presents the results from the pilot study.

6.3.1 Valuation and business data

Data from valuation and business directories has been extracted for two reasons. First, that data provides empirical information about the buildings and the businesses that occupy those buildings. Second, that data is crucial to implementing the sample frame and recruiting participants into the study.

With regard to the former, Alex Hills and Michael Camilleri have undertaken processes to verify the empirical accuracy of valuation data. In essence this work concludes that missing or incorrect data is evident for a minority of cases – 25% or less depending on the variable and building rank.

In contrast, the business/building matching process shows less certainty around the data. Some of that uncertainty is quantifiable and some is more difficult to quantify. The first issue is that of coverage.

Sixty-two buildings were drawn from the valuation database and sent for matching by the Business Directory provider, DataMarket. Of those, business matches were found for 37 buildings (59.7%). Even among those buildings that were matched, the pilot surveying has found that of the 100 businesses that were identified as occupying the 37 buildings from the sample, 12 businesses proved to have incorrect contact details and/or had moved buildings entirely. In addition, it must be recognised that a building/business matched cannot be interpreted as generating the complete set of businesses for that building.

Among the 25 buildings without any sort of business match, size stratum 5 shows some over-representation and size stratum 3 shows some under-representation. As Table 18 shows, most of the buildings that were unmatched were in Rank 1, although

Rank 1 is somewhat under-represented compared to the pilot sample as a whole, while Rank 2 is over-represented.

Building Size Strata		Building Rank		
Strata	*% of Unmatched Buildings*	*Rank*	*% of Unmatched Buildings*	*% of All Pilot Sample Buildings*
1	20	**1**	60	68
2	20	**2**	28	24
3	16	**3**	4	3
4	20	**4**	4	2
5	24	**5**	4	2

Table 18: Size strata and rank of the 25 unmatched buildings in the pilot sample

Two alternatives were considered to locate businesses attached to buildings not matched through the Business Directory matching process:

- First, the possibility of using geocodes to undertake building/business matching was considered.
- Secondly, the effectiveness and costs of undertaking further searching.

DataMarket has advised that using geocodes will require a costly conversion process for each geocode before matching can be undertaken. That is approximately $36 per geocode. There is no guarantee that any matches will emerge from such a process.

An alternative search process was implemented involving direct enquiry and/or on-site visiting of the 25 buildings not matched through the Business Directory process. This consisted of enquiries by telephone to local authorities, Citizens' Advice Bureaus, neighbouring buildings and businesses, as well as site visiting. That process allowed businesses to be located in 20 of the 25 buildings not previously matched.

It is notable that the building/business matching process generated 100 businesses across 37 buildings, an average of 2.7 businesses per building. The 20 buildings found by the supplementary search process generated 115 businesses, an average of 5.8 businesses per building. This is in part because two of the buildings in the non-matched set were shopping malls. However, it does raise some issues about the completeness of the business/building match from the Business Directory process, even for those buildings in which a match has been found.

The cost of achieving business addresses for 90% of the pilot sample buildings is estimated to be $0.85 per supplied business match with a building unit for the directory match process and an additional $20 per unit for remaining non-matched buildings.

There has already been a sunk cost of $797.50 for IT programming, which is a one-off payment if the current programming and reporting is replicated for additional matching. There is no apparent reason why that reporting structure should be changed.

6.3.2 Street View, Google Earth and websites

The results of the use of Street View, Google Earth and other website sources has been piloted on two sets of valuation data selected through the current sample frame.

This approach provides rich data necessary to undertake analysis of the determinants of resource consumption patterns and as an input into Component E of BEES. It does not collect empirical data on energy or water resource consumption. The cost of collecting data per unit is calculated on the timing of separate milestones and is estimated to be around $25 per record.

6.3.3 Business surveying

Surveying of businesses occupying sampled buildings is required to elicit information regarding their resource use and/or provision of permission to seek use data from energy and/or water suppliers. A limited set of questions was also included in the piloted questionnaire (see Appendix 1). The questionnaire was pre-tested prior to piloting on the 100 businesses derived from the Datamarket matching process. The pilot process was undertaken over a two-week period to:

- Establish the likely response rates
- Identify any resistance to providing particular sets of information and data reliability
- Test interview times
- Establish other processes and times related to call-backs and acquiring permission forms.

Response rates

Response rates are important for two reasons:

- First, any analytic work dealing with multiple variables, associations and determinants requires a reasonable number of cases for statistical relationship to be explored.
- Second, low response rates may impact negatively on the representativeness of the achieved sample. If low response rates lead to sample bias then the generalisability of the data that emerges is limited. How material those limitations are depends on the nature of the sample bias itself.

There are a number of techniques to deal with the problem of sample size and of sample bias.

To maintain adequate numbers of cases requires either a very large initial sample set to account for low response rates and/or a significant number of replacements. Replacement for non-eligible cases is a universal response to needing certain sample sizes. It is neutral in relation to sample bias if replacement is a response to problems of case eligibility and is undertaken using the rules as in the original case selection.

However, it is common for surveyors to maintain achieved sample sizes by replacing cases unable to be contacted and where there have been refusals. This may lead to sample bias. That bias may be mitigated by using the same rules for selecting replacements as for selecting the original cases. By definition, however, the act of refusing or agreeing to participate may generate sample bias.

Two approaches are used in an attempt to manage sample bias. The first is to optimise response rates. The second is to develop robust assessment of the nature of any possible bias and attempt to account for that in subsequent analysis.

Internationally the main ways of optimising response rates are:

i. Making participation part of a regulatory compliance regime
ii. Surveying only on topics that have high public or target population profile
iii. Avoiding surveys that require ongoing commitment
iv. Ensuring that survey instruments are:
    - short
    - allow easy responses
    - avoid asking for commercial or other sensitive information

v. Implementing surveys using:
   - telephone interviewing
   - repeated attempts to make initial contact
   - repeated follow-up.

Even so, there are a wide range of response rates to surveys. Those rates may vary regionally or in relation to the targeted respondents. Individuals are, for instance, easier to attract into participation than businesses. Similarly in New Zealand, Pakeha and older people are more likely to participate than younger people or members of ethnic minorities. Participation rates for individuals are known to fall markedly in the Auckland region relative to other parts of the country. There is a general tendency for participation rates to improve when moving North to South.

There has been for some time indications that response rates are falling. Both experience and conversation with telephone survey companies suggest that response rates are being found to be lower than 20% when involving some respondent groups or in some areas. The result of this is that sample sizes are being maintained by replacement.

In developing the survey instrument it was recognised that this survey had none of the characteristics of i-iii above. Consequently the questionnaire was designed to be short, limited responses to relatively straightforward aspects of business life within buildings. By definition, however, asking what might be considered sensitive information about resource use which is associated with business cost and pricing structures could not be avoided.

Nor, because of the detail required around energy use, could we avoid asking respondents for further commitment. Respondents effectively are given a choice between a low time commitment at the time of surveying to agree to permitting access to energy supplier records, or a longer time commitment in the interview reporting on energy.

The questionnaire is implemented by telephone and this appears to be the most acceptable way of initially approaching potential respondents. It has the advantage, compared to self-complete surveying, of providing an immediate picture of response rates and progress towards desired sample sizes. Three attempts were made in the two-week period of piloting to make contact with selected buildings and their associated businesses. Table 19 sets out the categories of response at the end of the two-week period.

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

Table 19: Response categories after two weeks' telephone contacting (n=100)

The response categories on a building basis are set out in Table 20 which shows that 43% of all buildings had either some businesses agreeing or complete refusal. Twenty-seven percent of buildings had all or Some Businesses in the building agreeing to participate. Two buildings who had apparently matched businesses could not be recruited because the businesses associated with them were Not Eligible or appeared to be non-existent. Those buildings could be pursued through additional searches for business matches as previously described in Section 4.

Response Category	Buildings	% of Pilot Sample Buildings
Agreed – Some Businesses	6	16
Agreed – All Businesses	4	11
Refused – Some Businesses	10	27
Refused – All Businesses	6	16
No Engagement – Some Businesses	3	8
No Engagement – All Businesses	0	0
Call Back – Some Businesses	8	22
Call Back – All Businesses	11	30
Not Eligible/Not Contactable – Some Businesses	6	16
Not Eligible/Not Contactable – All Businesses	2	5

Table 20: Response categories after two weeks' telephone contacting (n=37)*

*Multiple Response Table

If it is assumed that only buildings with agreements from All Businesses is required, and the patterns currently evident prevail, then the best possible response rate is 18.9%. If it is assumed that buildings with Some Businesses agreeing will become cases in the survey, the current ratios of Agreed to All Refused suggests that if similar patterns were sustained for the remaining building, the best possible building response is 48.6% of sampled buildings.

As previously noted, response rates have impacts on both the effort required to generate a certain sample size and on problems of sample bias. With regard to the generation of a sample of a certain size (for instance 1,000 buildings), this would require a pool of buildings for the worst case scenario of 5,000 buildings and for the best case scenario of around 2,000 buildings. There may be issues with the current random sample within strata whether there will be enough buildings in particular stratum to provide replacement.

It appears that buildings in size stratum 3 are most clearly over-represented among the refusals and size strata 2 and 3 are most under-represented among the agrees. Retail complexes in mall configurations appear the most difficult to engage and get high percentages of agreement or, indeed, refusal. The availability of building managers in those complexes suggest that promoting participation through them may be more likely to optimise participation. Notwithstanding, there are signs that some sample bias from self-selection is likely to arise.

Sample bias can be extremely difficult to prevent. The target population for BEES generates considerable response rate problems, as does the nature of the information sought. If sample bias is likely because of low response rates which are not amenable to significant improvement, and if recruitment of a population is required, the only alternative is to consider the extent of sample bias in the course of data analysis, interpretation and reporting. In this regard, BEES has considerable advantages. There are a wide range of building characteristics, business sector and locational data, that the Component A pilot has shown to be relatively comprehensive in coverage and robust with regards to accuracy. That data will allow BEES to make reasonable assessment of sample bias in relation to key variables.

Information provision

The major information provision resistance relates to participation agreements. Two interviewees have agreed to participate and subsequently refused or been unable to provide the complete information set, or not agreed to permit access to supplier data. One individual completed all questions, but did not want to disclose any energy use data, nor would the respondent give permission to have that data sourced from suppliers. One individual completed all questions except those relating to operational catchment, date of operation from the building and energy data. We were referred to head office to get energy and water use information.

Twelve of the 14 participants that agreed to interviews asked that energy data be sought from the energy supplier. One of the remaining interviews has undertaken to self-complete the interview and another has referred us on to national office to get relevant energy data. The piloting will continue to test elapsed time patterns and coverage of the permissions acquired from those participants who agreed to provide them. Ensuring compliance is likely to require repeat calls.

Responses to all questions appear to be internally consistent. There are no indications of problems with reliability.

Interview duration

Interview times with participants is around 10 minutes where interviewees agree to BEES seeking supplier energy and/or water data.

Processing and other times

The major processing times in addition to interviewing are:

- Call-up
- Call-back
- Supplier permission send out
- Supplier permission follow-up
- Supplier request transfer
- Supplier data receipt
- Sample replacement.

The latter three of those process have not been time-tested. Table 21 sets out estimated times for each process.

Process	Average Actions	Unit Time (minutes)	Total Time/Case
Call-up	1	3	3
Call-back	3	3	9
Supplier permission send out	1	2	2
Supplier permission follow-up	4	5	20
Request to supplier	1	2	2
Supplier follow-up and receipt	3	5	15

Table 21: Estimated processing times

It is estimated that each business surveyed may require about one hour of processing time in addition to interviewing time.

Costs

It is assumed business surveying will involve around 3,000 businesses if a target of 1,000 buildings is pursued. If it is also assumed that if an achieved sample of 800 buildings is acceptable, surveying costs (including replacements) are likely to be in the region of $160,000 for telephone surveying and $96,000 for processing. That cost excludes analytic and reporting costs.

6.3.4 Processing and forms

Agreements have been reached that energy suppliers will release energy data on permission from customers. Initial forms have been developed to get participant business permission. These used CRESA's free-phone and fax numbers for the pilot. Those numbers will have to be changed if surveying is implemented to align with the agreed data transfer and database system. As energy data is likely to be analysed by BRANZ in the first instance, it is preferable that BRANZ is the point of phone contact. No personal telephone numbers are to be included on the form. It should be noted that suppliers have been consulted regarding the form. They appear ready to undertake supply data provision on the basis of customer/ICP number.

6.4 Some summary comments

The piloting of Component A has highlighted the richness and comprehensive coverage of data that can be generated from accessing directly existing datasets including web-based information and administrative data such as valuation data. At the same time, it reinforces that the key consumption data is only accessible through some form of engagement with businesses in the buildings selected in the sample frame. This raises real issues for both Component A and Component B because the piloting has revealed that sample sizes are likely to be low because of response rates that can be expected to range between 20% and 50%.

The nature of the study means that it is unlikely to prompt high participation rates. Optimising response rates requires stringent control of the questionnaire length, assiduous call back, and robust replacement strategies. It must also be recognised that inherent problems of recruitment are exacerbated by considerable uncertainty around the building/business coverage provided by the matching process. Coverage must be increased by independent search processes especially those described in Section 4. It seems unlikely that geocodes are a useful option.

It is unlikely that the usual range of techniques to optimise response rates will raise them to the point that sample bias can be ignored. Careful analysis of bias will need to be undertaken if any surveying is undertaken in either Component A or Component B. The real issue that BEES most address is the value of random surveying at all, the issue of sample size and the issue of resource allocation.

It can be broadly estimated that the direct costs for Component A for an achieved sample of 800 buildings will be in the region of $360,000 excluding data analysis and reporting. Some of that cost at least should be seen as contributory to other components and reducing the costs of collecting data necessary to those components.

7. TARGETED SURVEY

This section describes the BEES targeted survey (Component B) pilot. In this pilot the planned data collection, monitoring and logistical processes to be used in the targeted survey were developed, tested and refined in a variety of buildings. Critical factors were:

1) Practicality of field data collection
2) Time and cost
3) Reliability and traceability
4) Disruption to occupants
5) Health and safety
6) Learning of potential problems and mitigating them.

7.1 Targeted pilot survey instruments

The main survey instruments[14] in the targeted survey are:

1) Monitored energy and environmental data
2) Appliance audit
3) Lighting audit
4) Building audit
5) Hot water audit
6) Water audit
7) Equipment audit (e.g. HVAC, lifts etc)
8) Occupant questionnaire.

These survey instruments were first developed based on the planned data collection, tested separately on a limited scale, then deployed as part of pilot installations with the full set of survey instruments.

7.2 Pilot installations

The pilot installations were carried out in a variety of buildings, starting with BRANZ buildings and two buildings where easy repeated access had been negotiated, then moving onto buildings that were part of the aggregate survey pilot and, when those were exhausted, buildings selected at random from the BEES sample frame.

The earliest installations tested early versions of the instruments, and the easy access process gave a good testing ground for learning. The survey instruments tested in the aggregate pilot buildings and later were refined versions, which were close to the final versions.

There was a delay in delivery of the Multivoires electrical equipment caused by a breakdown in the manufacturing plant. Due to this delay some of the installations were delayed this has reduced the number of installation that could be done. Some installations took a long time to arrange appointments with the occupants (as long as six weeks from first contact). One business pulled out after more than a month of negotiation.

A total of 11 sites were used in the pilot study activities, covering 14 buildings. To maintain confidentiality, neither the building names or locations are provided in this report.

The process has been one of continual learning and refinement. After each pilot test or installation the survey process and results were evaluated and improvements made. This recognises that the desired output for the targeted pilot is not a collection of data,

[14] 'Survey instrument' in this context means a method for collecting information or data.

but a set of survey instruments that work, along with robust processes and procedures for field implementation.

7.2.1 Contacting and recruiting

The buildings that already participated in the aggregate survey were used for the first targeted survey pilots. There were only three in the Wellington region, so buildings that were not part of the aggregate pilot were also required.

The aggregate survey had contact details so initial contact did not require any additional searching for contacts. The initial contact for the three aggregate survey participants took between two and four calls to enter a conversation about the BEES project. A script based on the aggregate survey script was used to start the conversation and try to secure a 'yes' as quickly as possible. For the aggregate survey participants one gave a quick yes. Another gave a provisional yes, awaiting confirmation from business partners, and another was interested but wanted further information.

Additional information is in the form of the BEES participants' agreement, BEES data access policy, and BEES energy company permission form. This information was emailed or mailed to the occupants after the initial yes or provisional yes.

Securing a site visit appointment proved more difficult. One of the aggregate survey participants quickly agreed to a date over the phone. One was still under negotiation six weeks later as they are busy and hard to contact (although they have signed the participants agree), and another has been dropped as no progress was being made. So in principle there is a 2/3 success rate out of the aggregate survey.

Once these were exhausted then recruits were needed from buildings that had not been part of the aggregate survey. A new sample slice was taken, and contact details obtained using Google, StreetView and Datamatch.

Initial contact was more difficult as there was usually no named contact, and they had no prior knowledge of the BEES study. It usually took two or three calls to find someone who had the authority to agree (at least in principle) to participate, and if a yes was not obtained at that point, another one to three calls to get a yes and make an appointment for the site visit.

7.3 Monitored data

7.3.1 Energy

The two types of circuit energy monitoring equipment used in the BEES project are:

1) Multivoires
2) Energy Logger Pro.

The targeted survey will mainly use the Multivoires system for a variety of reasons discussed in previous reports including:

1) Easier and safer installation process
2) Large number of available channels
3) Small size is easier to fit, and less likely to cause electrical problems
4) Greater accuracy.

Early piloting focused on learning how the equipment operated and developing protocols for installation, set-up and downloading. At this stage mistakes were made, and sometimes the data collection failed or was incomplete due to installation errors or operation errors. Procedures were developed to check for an mitigate these types of errors. Later pilots focused on properly identifying circuits so that all end-uses of interest were reliably captured, and refining the protocols.

Plug-in electrical appliance monitoring has been tested using two types of devices: the Plogg and the Enerplug. The Plogg have worked reliable, however one Enerplug failed due to an electrical problem (see related document on testing of this equipment). A final decision on which type of equipment to use has not yet been made – they are functionally equivalent so cost and reliability are the deciding factors.

Forms have been developed and tested to record the equipment and what was monitored so that the data can be correctly identified in processing, and so that there is traceability.

One lesson learned from the pilot installations is that more Multivoires equipment may be needed for small buildings that have more than one distribution board, and for distribution boards with a large number of circuits. This will be evaluated, and either the existing equipment re-distributed to handle these contingencies or additional equipment purchased.

7.3.2 Environmental data

The environmental data to be monitored is:

1) Temperature
2) Humidity
3) Lux level
4) CO_2 concentration.

The equipment selected for temperature, humidity and lux level is the Hobo U12 Logger. These are small, battery-powered loggers that are easy to conceal.

In the targeted pilot 4-10 U12 temperature/humidity/lux loggers were installed in the buildings. Most were installed in the main areas of the buildings (e.g. office, retail floor) and one or more in secondary areas (e.g. kitchen, back room). They were installed away from heat sources, draughts and direct sunlight at heights that people are typically at (e.g. 0.4 to 2 m).

The CO_2 concentration is measure by a Telaire meter, connected to a Hobo Logger. It measures CO_2 concentrations up to 2,500 ppm (which is very high and unlikely to exceeded often). Only one CO_2 meter is available for each set of installation equipment, so only one location can be monitored in each building. This is selected to be a typical space in the main area (e.g. office, retail floor).

Forms have been developed and tested to record the equipment and what was monitored so that the data can be correctly identified in processing, and so that there is traceability to the equipment inventory and calibration.

7.4 Energy audits

7.4.1 Appliance audit

The reason for doing an appliance audit is so that stock levels of appliances can be determined. This is essential information for energy/stock models and for energy simulation models, and relates directly to one or more of the BEES research outputs.

Initial piloting of the appliance audit was based on the HEEP appliance audit, where a lot of information on each appliance was collected. This included type, make, model, serial, spot power measurements and photographs (prioritised for different appliance types).

Such a detailed appliance audit was discovered to be impractical in the early testing on BRANZ buildings for the following reasons:

1) Takes too much time
2) Causes too much disruption to the occupants' normal work (e.g. turn off computer and restart twice)
3) Difficulty in accessing power outlets
4) Potential to disrupt critical equipment (e.g. networks, tills)
5) Difficulty in accessing model/serial number information.

Experience from HEEP suggested that the make/model/serial number information was only useful for a limited range of appliance types, and that it is too difficult to track down model/serial number information for most appliance types (e.g. TV, computer etc) as the stock changes rapidly and there is a large diversity of local and international suppliers.

The decision was made not to 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 will be obtained directly from monitoring appliances, and a larger amount of monitoring equipment will be dedicated to this task (anticipated 5-10 plug monitors per installation), along with detailed information on the appliances monitored.

The appliance audit trialled in the later buildings was a simple tally count by appliance type. Subsequent pilots were used to refine the types and categories, and there are now 10 categories, with a total of 73 different appliances. Care has been taken to separate appliances by size or type where appropriate, for example, small printers (desktop), medium (floor) and large (production), and separating domestic size whiteware (refrigeration, washing machine, dryer, dishwasher) from commercial sizes.

The appliance tally is a fast process that can be done with a single walk-through of the building, with little or no disruption to the occupants. The appliance tally is subsequently used to randomly select which appliances to monitor.

7.4.2 Lighting audit

Lighting has been identified as one of the major energy end-uses in non-residential buildings, and considerable effort is being put into the monitoring and audit to measure and characterise lighting.

The lighting audit evolved rapidly from the typical process used in an energy audit to one suited to the purposes of the BEES study.

Lights are identified to a location in the building (matching the building audit) and to a switch control. Data is collected on each type of lamp in each light fitting with the wattage and total number recorded. The lamp type is selected from the list below, as is the control type. The wattage is either read off the lamp (if readable) or estimated.

To assist in the identification of lighting circuits the lights are switched on and off when the monitoring equipment is in place, and the lighting audit plan is matched to the circuit monitoring as closely as possible.

7.4.3 Building audit

The purpose of the building audit is to collect information on the physical layout and structure of the building so that energy simulation models can be constructed, and so that characteristics of the buildings are known.

The first stage of the building audit is to copy or draw and annotate a floor plan, identifying activity areas, room height, floor coverings, glazing, doors etc (see for example Figure 44). This is a time-consuming process, however with experience a floor plan of 1,000 m² with approximately 10 rooms can be measured and drawn up and annotated in about 30 minutes. The time taken depends more on the number of rooms than on the floor area.

Data on each elevation is matched to the floor plan.

Early versions of the building audit collected detailed information on the elevations. However, as most of that information is collected visually the photographs of each elevation are now used to collect the information (such as window areas, shading etc), for later coding and integration in the simulation models. This saves time in the field.

Some information that was desired has often turned out to be practically impossible to collect, for example floor insulation for slab-on-ground floors. Some questions were dropped or simplified to reflect the quality of information that could be obtained.

There appears to be no other viable way to collect and annotate this type of information. If floor plans are available ahead of time then this could save time in measuring and drawing the plan. Attempts have been made to obtain floor plans from council building consent records. However, this takes a lot of time and effort, and with BEES going to most district councils the effort may not be worthwhile. Efforts are now focused on the major metropolitan city councils where a large proportion of the BEES buildings are located.

7.4.4 Hot water audit

In the HEEP project hot water was a major use of energy, and a lot of effort was put into collecting information on hot water heating equipment and water use.

For non-residential buildings hot water use is expected to be less important, and perhaps less effort is warranted.

The initial hot water audit quickly ran into difficulties, paramount being finding the hot water system. Unlike houses, hot water systems in non-residential buildings are often in out-of-the-way places, and access is often difficult or impossible. There are also a large variety of types, from small kitchen bench models to domestic size and large, and a variety of circulating hot water systems running off boilers of HVAC systems.

Where a hot water cylinder can be found information on size, make, model and grade will be collected. At the minimum, a hot water temperature will be measured. For circulating systems in larger buildings information will be collected under the Equipment Audit.

7.4.5 Equipment audit

The equipment audit covers large equipment used for central services (such as HVAC systems and components, lifts, boilers etc) as there is such a large diversity in the type of equipment and the services provided.

7.4.6 Water audit

The water audit collects basic information about water use in the building, including the number of water using fixtures. The water meter is located (if it exists) and trials of water meter monitors are underway, although these will only be used in a limited number of buildings.

7.5 On-site activities

Appendix E Target Survey Forms provides selected extracts from the targeted survey forms.

7.5.1 Occupant questionnaire

The occupant questionnaire was the last survey instrument to be trialled. Most of the information that was planned to be collected has ended up being collected in other survey instruments, leaving a relatively small residual of questions that require a response from the occupant.

The occupant questionnaire is planned to be conducted as a short telephone interview, not done at the same time as the installation. This reduces the time spent in the field, and allows the occupant to choose a convenient time.

7.5.2 Photographs

Photographs are taken of the following:

1) All exterior elevations
2) Surrounding buildings and terrain from all exterior elevations
3) Adjacent buildings
4) General photographs of the interior
5) All distribution boards where equipment is installed
6) Environmental logger locations
7) All major equipment (e.g. hot water systems, HVAC, chillers)

The photographs serve several purposes. Some are a record of the installation to assist in recall and identifying any problems later. Some are to record information that will be extracted and coded later (e.g. exterior elevations to identify glazing area, site shading etc). Using photographs, particularly for the exterior elevations, greatly reduces the amount of time required on-site.

7.5.3 Paper or plastic?

A limited trial of electronic data collection for the audit data was conducted. Due to the complexity of the data collection, hand-held electronic devices are slower than paper records. Tablet PCs might be comparable in speed, however the cost and time to set-up the systems are prohibitive. One option still under investigation is digital pen and paper, which records information on coded paper sheets using a digital pen which writes in ink and also stores the writing digitally. This is then downloaded to the form that was being written on, and can be immediately imported into GIS or CAD formats, or be imported into EXCEL with OCR.

7.5.4 Logistics

The pilot has been conducted using a team consisting of an electrician, and two or three other people. Part of the pilot has been to work out how many people are needed for the various audits, and how they interrelated during the installation. A team of three is required for a typical installation.

The roles identified are:

1) BEES team leader. Install electrical monitoring equipment with electrician. Install all data loggers. Supervise installation.
2) BEES auditor. Conduct all the audits, with assistance from BEES team leader as required.

On-site, the time required for each of these tasks has been roughly the same. In some cases the BEES team leader has finished before the auditor and can assist the auditor.

Some audit tasks need to be done in a specified order so that information can be transferred to the team leader to assist with the monitoring equipment installation.

In order:

1) Floor plan for building audit
2) Lighting audit
3) Appliance audit
4) Other audit tasks in no particular order.

The floor plan needs to be done before the lighting plan so that rooms or locations can be allocated to lighting circuits. The floor plan and lighting plan assist in identifying and tracing circuits. The appliance audit is needed before the appliance for monitoring can be selected.

The time taken varies depending on the size and complexity of the installation. A small shop or office (50-150 m²) takes about 1½ hours with three people. A large shop or office (~1,000 m²) takes about three hours with three people. The time taken does not scale in proportion to the floor area, but to the complexity of the installation in terms of number of circuits, distribution boards, rooms and equipment.

7.5.5 Equipment removal

The equipment removal was done by the electrician. This will save a lot of time and money for BRANZ staff, especially for locations outside Wellington.

During the installation the electrician was shown where all the equipment has been installed. The electrician was sent a list of all installed equipment and locations, which is compiled from the monitoring installation forms, and a copy of the floor plan with the locations of all equipment marked. This should be sufficient to locate equipment. If there are any problems the electrician can call back to BRANZ for assistance. If equipment has been moved than the occupants are asked for assistance. All the equipment has BRANZ ID tags with contact details to assist in locating equipment should the electrician not be able to retrieve it.

The removal process is fast – typically taking less than 30 minutes to remove the electrical equipment from the distribution boards, and 5-10 minutes to retrieve the environmental loggers and appliance loggers.

The equipment is taken by the electrician and stored in the provided equipment cases. It is either held by the electrician for the next installation, or returned to BRANZ by courier.

7.5.6 Downloading monitored data

Equipment that is returned to BRANZ is downloaded by BRANZ. The monitoring installation forms allow the data to be correctly identified.

Equipment that is held by the electrician is either downloaded on-site before being installed in the next building, or is swapped for fresh equipment and taken back to BRANZ for downloading.

7.6 Calibration

Calibration processes are being developed for all the measurement equipment used in the targeted survey. These include:

1) Temperature
2) Humidity
3) Lux

4) Temperature probes
5) Electrical power.

So far, the temperature and humidity loggers have been calibrated, and the remainder of the equipment will be calibrated before the main survey starts.

7.7 Conclusion

The targeted survey has been piloted on a variety of building types and a robust set of survey instruments, forms, equipment, procedures and processes has been developed. The scale of the task has been determined and appropriate resources (personnel and equipment) allocated.

With some minor refinements the targeted survey will be ready to commission at full-scale as soon as buildings are available from the aggregate telephone survey.

Work is underway to develop the processes and procedures for handling, processing and analysing the data from the targeted survey.

8. CASE STUDIES

This section provides an overview of the development of the case studies (Component C). It reviews the energy monitoring and analysis technology planned to be used including:

- the set of metrics describing buildings and end-uses
- the data required to give those metrics
- the recommended methods of analysis of those data
- the recommended methods of presenting that analysis
- equipment trialled with results and recommendations.

The ***aggregate survey*** is where the building's historical metered energy consumption will be recorded and analysed. Thus, this should be accomplished before the measurements required for the ***targeted survey*** are carried out on-site. If a ***case study*** is to follow, it should contain some supplemental measurements and analysis beyond that of 'normal' ***targeted surveys.***

Buildings tend to use energy in repetitive patterns. Two of these energy use patterns generally characterise the energy performance of buildings:

The **annual pattern** shows the month-to-month (or day-to-day) variation of electricity (and gas and other fuel) purchases. This indicates how much seasonal heating and cooling the building requires above its (normal, base load) energy purchases, and allows the temperature dependence of energy use to be evaluated.

The **diurnal pattern** shows the 24 hour pattern of energy purchases. This is most commonly available for TOU electricity purchases, but in the BEES project should be available for gas as well. These patterns determine the 'load factor' of the building, and its peak loads, as well as showing the occupancy.

There are two main results planned from the ***targeted survey*** monitoring:

The first is a statistical sampling of energy end-uses, in kWh/d per m^2, in a wide variety of building types and sizes. This is expected to be independent of the type and size of building, and would be used to determine averages for the end-uses.

The second is the value of each energy end-use within a given building, comprising the same range of building sizes and types as above. This would be used to understand the usage of energy within a building, and the interactions between end-uses.

Ideally, all the end-uses within a building would be directly monitored for an entire year. This would give relative certainty to the two results listed above. However, budgetary limitations and the requirements to monitor a statistically significant number of buildings preclude this approach, so short-term monitoring and extrapolation (both over time, to extrapolate to a whole year, and over space, to extrapolate to a whole building) will be required. The methods recommended to achieve this are discussed in the **Analysis** section of this report.

Seven buildings were monitored, but to maintain confidentiality neither their names nor locations are given.

8.1 Reporting

The building metrics to be reported follow from the definitive NREL Report #TP-550-38601 (‘Procedure for Measuring and Reporting Commercial Building Energy Performance’ by Barley, Daru, Pless and Torcellini), which was for US monitoring of single buildings (not populations) with self-generation and thermal storage, and few monitoring budget restrictions. Their list of metrics was adapted to the requirements and conditions of the BEES.

8.1.1 Aggregate survey metrics

The main metric to report will be the ‘Energy Use Index’ (EUI) in kWh/m^2/yr for the building, broken down by energy source (electricity, gas etc). Water use data can be reported the same way, as cubic metres/m^2/yr.

Since only monthly energy data is expected in most circumstances, the month-to-month consumption patterns are the main secondary metric. If possible, where TOU electricity data is available, each building’s annual peak electrical load (in kVA or kW) and peak power density (in W/m^2 or VA/m^2) will also be reported.

The buildings will be segregated into type (retail, office, other) and size (by the five strata). They can also be sorted by the many other data that are recorded for each building.

8.1.2 Targeted monitoring metrics

The main metric to report will be the EUI for each energy end-use, again in kWh/m^2/yr for the building. The secondary metrics will be:

- peak power density for each energy end-use, in W/m^2
- delivered energy service, as space temperature, illuminance (lux) and air quality (CO_2 concentration) during occupied hours
- temperature dependence of heating and cooling loads, as kWh/d per °C (normally expressed as a linear slope and y-intercept).

In addition to the primary and secondary metrics described above, tertiary building metrics are recommended in the NREL report, only if the building has significant on-site electrical generation or thermal energy storage. In this case, it is recommended to report the amount of generation, and the net effect of the building on the grid, or the annual amount of thermal energy stored and released.

A complete list of the metrics listed in the NREL report, and compared to those suggested for this project are given in Appendix G: Comparison of NREL and BEES Metrics.

8.1.3 List of end-uses

The list of individually reported end-use areas suggested for the BEES is given in the following list. Definitions of these end-uses are given in the NREL report.

- **Building Lighting Energy** Use – totalled, and divided into:
  - Installed Lighting Energy Use
  - Plug-in Lighting Energy Use (possibly based on lamp count)
  - Facade Lighting Energy Use
- **HVAC Energy** Use – totalled, and divided into:
  - Heating Energy Use
  - Cooling Energy Use

    - Air Distribution Energy Use
    - Other HVAC Energy Use
- **DHW Energy** Use
- **Outdoor Energy** Use
- **People-Mover Energy** Use
- **Data Centre Energy** Use – totalled, and divided into:
    - Computer Server Energy Use
    - Process Cooling Energy Use
- **Plug Loads Energy** Use
- **Process Energy** Use
- **Other Building Energy** Use.

Some of these end-uses are different from those used during the pilot stages of BEES monitoring, including the segregation of lighting into installed (i.e. hardwired) vs. plug-in. Likewise there is a separate category for 'Process Energy Use', like cooking in a restaurant, or a pottery kiln.

Beyond those recommended by the NREL report a new category of end-uses, 'Data Centre Energy Use', is recommended for BEES, as this appears to be a major and misunderstood load in New Zealand office buildings in particular.

This list excludes end-uses regarding cogeneration, self-generation and thermal storage, which are quite rare in New Zealand buildings. In any buildings where these do appear, the NREL recommended metrics should be used.

This list has eliminated the metric of DHW efficiency, which requires the hot water flow rate and temperature increase to be continuously monitored, which is not practical where monitoring equipment is planned to be moved often.

This list also includes the explicit temperature dependence of the daily heating and cooling energy use. Ideally these would be separately recorded for the heating and cooling end-uses but, alternatively, these can be inferred from the whole-building energy purchase vs. temperature relationship. The slope of these parameters is effectively the building's heat loss coefficient (divided by the delivery efficiency), and the day-to-day variability indicates how well controlled the heating and cooling are.

The consumption of each of these end-uses is recommended in the NREL report to be reported as:

- Monthly total (kWh)
- (Monthly) daily average (kWh/d)
- Annual total (kWh/y)
- Load profile during peak day during each billing period.

These are relevant for a building with all energy end-uses directly measured for a full year, but the BEES will mostly be monitoring for short (fortnightly) periods, so the primary data should be reported as daily average consumption (kWh/d) separately for weekdays and weekend/holidays.

We also should report the peak demand, and ideally the installed load should also be reported for each of these end-uses.

Finally they should be reported on an area basis, as kWh/m^2/yr and W/m^2, so they can be extrapolated to whole buildings and groups of buildings.

8.2 Primary data

BEES data will be used to describe the distributions of energy use by individual end-uses, on an area basis, for the entire population of buildings studied, and to extrapolate this for policy advice. This will be done on a statistical basis, in addition to descriptions of energy used by individual buildings.

Because quantifying the energy performance of buildings (as a whole) is an important part of this study, this aspect is expanded upon here.

8.2.1 Aggregate report data

The aggregate report will use published data from the PropertyIQ and equivalent databases and Google Earth to give floor area data for the buildings selected. As there are several different methods of calculating building floor area, each of which can give different results, using the PropertyIQ database gives a traceable and (hopefully) consistent source for this crucial element.

Annual energy purchase records will be sourced from the energy supply companies servicing each host site, normally as monthly or bi-monthly energy meter readings. These can be combined into annual totals for each energy source.

Where possible, half-hourly electricity purchase records will be sought, as these can give the daily usage, whose variation and temperature dependence reveal useful information about the building.

8.2.2 Building description

The building will be described according to the list of typologies in Table 22 thought to influence energy use in non-residential buildings.

The typologies in Table 22 were modified in the pilot reports (as seen in Section 8.9), so we have not yet developed a consistent, finalised list of categories by which we will describe a building.

ACTIVITY:	Retail Office Restaurant/cafe Nightclub/bar etc
MORPHOLOGY:	Big box Two-storey max row Converted/adapted house Medium rise block 10+-storey tower
LOCALE:	CBD adjacent sites Office park Suburban sprawl
CONSTRUCTION:	Old – pre-1950s New – post-1950s Modern – last 10 years 'High performance'
THERMAL TYPOLOGY:	High insulation + small windows + compact form High insulation + large high performance windows +compact form Permeable form (daylight and natural ventilation) + shallow plan Poor insulation + large windows
SERVICES TYPOLOGY:	Natural ventilation + central heat Mixed mode – no central cool Central heat and/or cool
CENTRAL SERVICES TYPOLOGY:	Local (in building) and water distribution Local plus air distribution Shared between buildings and water distribution locally Shared between buildings and air distribution locally Decentralised (e.g. distributed array of heat pumps; electric heaters)
CONTROL TYPOLOGY:	Fully automated time/temperature or light level based Fully manual Automated but with intelligence e.g. overrides Automated HVAC not lights or blinds Automated HVAC and lights and blinds

Table 22: Examples of key typologies relevant to building energy use

8.2.3 Targeted monitoring

The targeted monitoring will supplement the aggregate report data with on-site measurements and observations of the building and its energy use. These will include:

- Equipment counts
- Estimation of areas devoted to each activity in the building
- Logging of some electrical end-uses
- Logging of some delivered space conditions.

Equipment counts will total the number of each type of energy using equipment in the building (or the spaces in the building that are monitored). Tally sheets have been developed to allow accurate counting of lights by type, office equipment and other equipment. Lighting counts will count the number of lights by activity area (based on switching), luminaire power, lamp type and control type.

In the HEEP study, detailed information was obtained on each piece of equipment observed in a building. This included the type of equipment, manufacturer, model number, nameplate power rating, and usually a measure of the power consumption during operation. This level of detail is not considered necessary in the BEES, especially considering the extra time and disruption to the occupants this causes.

Lighting and equipment counts will be used to extrapolate or check end-use monitoring results. The NREL study grouped all 'plug loads' together, outside of plug-in lighting. The initial plan for BEES is to separate the plug loads into the different types of equipment, though this may change.

The different groupings of equipment follow the list of end-uses:

- Lighting:
  - Installed lighting
  - Facade lighting
  - Plug-in lighting
- Outdoor energy using equipment (beyond façade lighting, including security lighting)
- Office equipment:
  - Personal office equipment (PCs, small printers etc) plug loads
  - Larger office equipment (photocopiers, shredders etc) plug loads
- Cooking equipment
  - dishwashers, plug-in refrigerators etc
  - plug loads
- Refrigeration equipment
  - hardwired, not a plug load
  - plug loads
- HVAC
  - Heating equipment
  - Cooling equipment
  - Air distribution equipment
  - Other HVAC equipment
- DHW
- Computer server equipment
- Process cooling equipment
- People-mover equipment
- Special process equipment (kilns, pizza ovens)
- Other building energy using equipment.

For each of the separate categories above, the number of each type of equipment in the space should be observed and recorded, with the estimated power requirement of each in operation. These will be combined to yield a total estimated power and load profile for each equipment grouping.

As different types of activities are believed to affect the energy use of those spaces where they are carried out, the different activity areas within each building will be observed and recorded, initially on a scaled plan of the building. This will inform the modelling of the building in ways to be seen.

The different activity areas to be recorded in BEES are listed below:

- Office (which could be separated into private and open-plan offices)
- Retail / display
- Meeting / assembly rooms (classrooms, auditoriums etc)
- Computer server rooms
- Kitchen (cooking areas, even if only small)
- Toilets / bathrooms
- Reception areas / entryways
- Parking garages
- Process areas (e.g. workshops or plant rooms in office buildings)
- Storage, refrigerated

- Storage, conditioned
- Storage, unconditioned
- Exhibition / museum (which could be combined with retail / display)
- Vertical transport (stairwells, lifts, escalators) (added during the writing of this report).

Where there are **residential spaces** within a building, they **will be recorded if possible**, even though it is expected that there will be no logging of end-uses nor space conditions (including light levels, temperature etc) , as this is outside the 'sample frame'. This is essential to ensure that all energy uses in the building are recorded.

As many as possible of electrical end-uses should be logged via the Multivoies data logger. When there are more circuits than there are monitoring points available on the Multivoies, then the entire switchboard should be checked by moving Multivoies sensors from one circuit to the next to see which ones draw the most load, or are otherwise the most important. There is a check sheet to record the resulting one-time-measurements of circuit power, power factor and waveform.

When the circuits to be monitored have been chosen, the Multivoies is installed to log their power at one minute intervals for two weeks. Previous studies have stored power data at much longer intervals (often half-hourly, to match energy purchase records), but the value of the high-time-resolution data in understanding space loads is so great that this interval is highly recommended.

Ideally, the actual equipment hooked to each circuit (distinguished by an individual fuse or breaker) should be recorded using a circuit tracer. (This is described in Appendix 3.) In many cases, though, the total load of each end-use in the whole space will be by far the most important thing to measure.

Measuring the actual power consumed by each light switch circuit is recommended immediately after the Multivoies is installed because of the large difference between nominal and observed lamp power. (This is described in more detail in Appendix 3).

Some typical *individual appliance* electrical loads will be measured via the Plogg plug-in loggers. These will supplement the Multivoies measurements of *circuits*, and allow reconciliation of actual vs. assumed power usage.

In larger buildings, with centralised HVAC systems, the electrical use of the separate components (pumps, fans, chillers etc) will be measured if necessary using an older generation of electrical data loggers, called Energy Logger Pros, which use current transformers (CTs) as their transducers. Most of this equipment is three-phase, and monitoring any single phase will characterise its power use, so only one-third as many transducers are required as for whole-board end-use monitoring. This will be a useful application for this hardware that will not be used for general monitoring, as it has been superseded by the Multivoies.

Ideally, the end-uses for each activity area will be logged separately. However, the intermingling of electrical distribution and activity areas means this will usually be difficult.

8.2.4 Logging of whole-building energy and water use

For many of the smaller buildings, there will be no whole-building TOU electrical purchase data. In this case, each electrical incomer into the building should be monitored, to give the total usage of the building. This will also provide a base to compare the total of end-uses to. This would normally be done on the same one minute interval as the electrical end-uses.

In some cases, as for case studies, longer-term logging will be done, using longer time intervals, to extend the length of the dataset that can be held in the logger's storage.

Whole-building gas and water usage should also be logged where this is possible, so we have information on the patterns of gas and water use beyond annual or monthly totals. This technology has not been developed for field deployment yet, but is expected to be in the next year, with the recent availability of the Xemtec Comet clip-on optical meters,[15] which should give detailed TOU measurements of these quantities.

8.2.5 Logging of some delivered space conditions

Space conditions (temperature, lux and humidity) will be measured via the Onset U12 loggers. These values do not change very quickly, so 10 minute storage intervals are sufficient.

Based on previous experience, it is recommend that about one U12 logger would be deployed per 50 m^2 of the space, covering all the main activity areas, with at least one logger in an unshaded location within about 3 m from a window on each facade to check the daylighting potential. In the pilot monitoring, one logger typically was used per 100 m^2 or more, and this did not seem dense enough, in that there were usually significant spaces that were not logged.

Air quality, as measured by CO_2 concentration, will be logged in one location in each space. This has the limitation of relatively high power consumption, resulting in a relatively short battery life in the meter (about five days using four AA alkaline cells), but if they are plugged into a mains power point they can record effectively indefinitely. If a CO_2 logger is plugged into a power point, a two-way plug should be provided so that the point can be used for other loads during the CO_2 logging, to not overly inconvenience the space occupants.

Ideally, occupant surveys would be performed on the occupants nearest each condition logger, so the variation in measured conditions could be correlated directly with the responses of the people affected.

8.3 Analysis of data

The consumption of each of the end-uses is recommended in the NREL report to be reported as:

- Monthly total (kWh/mo)
- (Monthly) daily average (kWh/d)
- Annual total (kWh/y)
- Load profile during peak day during each billing period.

Because of the short-term monitoring we will be doing, reporting the results in the recommended formats above will require some extrapolation. This section describes the recommended methods.

There are two basic principles underlying this analysis. The first basic principle is that some end-uses are temperature-dependent (heating and cooling), and others (office lighting, computers) are temperature-independent.

The end-uses expected to be strongly temperature-dependent are:

- Heating Energy Use
- Cooling Energy Use.

The end-uses expected to be weakly temperature-dependent are:

[15] http://www.xemtec.com/

- Plug-in Lighting Energy Use
- DHW Energy Use
- Process Cooling Energy Use
- Air Distribution Energy Use
- Other HVAC Energy Use.

The end-uses expected to be effectively temperature-*independent* are:

- Installed Lighting Energy Use
- Facade Lighting Energy Use
- Outdoor Energy Use
- People-Mover Energy Use
- Computer Server Energy Use
- Plug Loads Energy Use
- Process Energy Use
- Other Building Energy Use.

The second basic principle is that the total of the observed energy end-uses should be reconciled with the total energy purchases for the same space over the same timeframe. The technique for doing this is often referred to as creating an 'energy balance', and is recommended to be done on an hourly basis for winter, summer and swing season months, for both weekday and weekend days.

8.3.1 Temperature-independent end-uses

The data on whole-building and individual end-uses are analysed in several different manners to produce the information required.

The most useful metrics are the **energy use per m^2 per year**, for both total energy and end-uses. This can be used to extrapolate to whole-building information, where we do not have data from all the occupants of a building.

This should be straightforward to calculate, for the temperature-independent uses. We will for the time being assume that the measured data are representative of annual average operation.

Then the energy use should initially be calculated as daily kWh/d, then separated into weekday and weekend/holiday usage. The annual usage can then be calculated by multiplying the daily weekday use by the number of weekdays per year, multiplying the weekend/holiday use by the number of weekend/holidays per year, and summing the two.

8.3.2 Temperature-dependent end-uses

Ideally, the building's heating and cooling loads would be estimated by taking them as proportional (linearly) to daily average temperature. This will probably require more than two weeks of monitored heating and cooling loads, but for buildings with automatic temperature control, the technique appears to be quite accurate.

It is often assumed that space heating in perimeter zones of buildings only occurs when outdoor temperatures are cool, and that space cooling generally only occurs when outdoor temperatures are warm. But this does not account for the design of many modern HVAC systems, where heating and cooling are available continuously when the building is occupied, and control valves do not seal completely, thus letting heating and cooling mix in various proportions all year round. There is also a need for interior zones of deep-plan buildings to be continuously cooled.

Both of these issues are reasons why there may be simultaneous heating and cooling in buildings, so the temperature dependence of heating and cooling loads should be calculated separately.

For the temperature-dependent uses we need to perform a curve fit (regression) analysis. It is expected that, in most cases, even two weeks of data will not provide enough temperature variation that the temperature dependence will be shown. Analyses of two to four weeks of whole-building data for the BRANZ Administration (Admin) building and an office building at Victoria University showed that the reasonably large scatter and small variation in ambient temperature did not allow a reasonable assessment of temperature effects from this quantity of data.

8.4 Extrapolating data

As it is not possible to monitor each building for a long period of time, it will be necessary to extrapolate the collected data to cover different time periods. Appendix H: End-use Profiles from Short-Term Monitoring provides a preliminary analysis based on data from the HEEP study. This suggests that short-term monitoring should be capable of providing the necessary data.

8.4.1 Annual energy performance from two weeks' monitoring

To characterise a building's energy performance, the annual pattern is required. In the context of the BEES programme, this requires estimating the annual energy end-uses, including heating and cooling, which are seasonal and may not occur during the monitoring period.

As the programme progresses, more information will become available about the patterns of end-uses over time and these estimates will become more accurate. For the time being the recommended procedure involves developing average daily load profiles for each end-use, and the entire building, and matching them. This is often called 'energy balancing' – matching the observed end-uses to the recorded purchases to account for all the energy used in the building.

First, calculate the average daily electrical load profile for the building for the month (or other time period) when the end-use monitoring occurs. Separate the patterns of usage between weekday and weekend/holiday, as these are usually quite different. An example is shown in Figure 13 below for a medium-sized academic office building.

The graph on the left is the time series of the measured electrical power at half-hour intervals. The graph on the right is the same data expressed as a daily load profile.

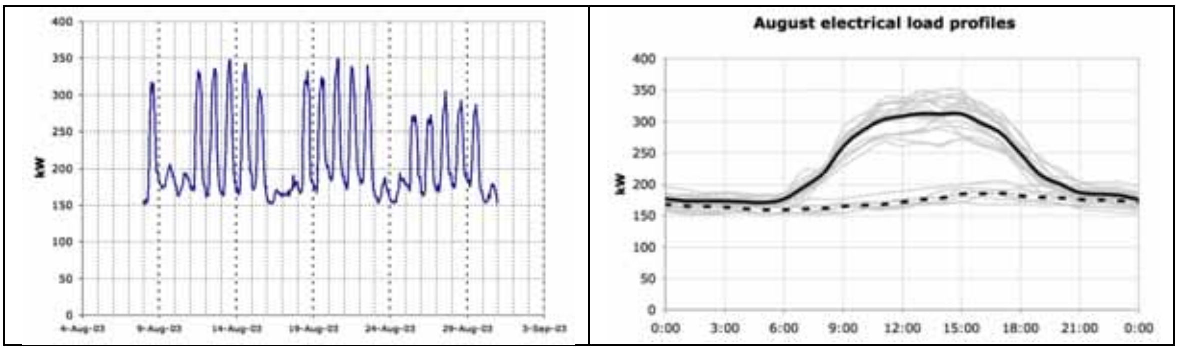


Figure 13: Daily load profiles

The variability in the daily load profile can be expressed as a statistical comparison of either daily energy use (kWh/d) or daily peak demand (kW or kVA). Much of the day-to-day variation is expected to be caused by the temperature-dependent end-uses responding to different outdoor temperatures.

Second, compare the highest recorded demand of the monitored end-use load profiles with the total installed load for each end-use monitored. This is to indicate what fraction of the total end-use power is being monitored. (In some cases, all of an end-use will be monitored. This is the best case, but will not occur everywhere.)

Third, scale the monitored end-use daily load profile to the total installed load. The result of this is an energy end-use load profile that is expected to represent the total load of that end-use within the building. Again, the usage pattern will probably be different on the weekends than on weekdays, so two load profiles are required.

Fourth, repeat the process for all the monitored end-uses. Sum the loads at each hour of the day, and if all of each load has been monitored, and scaled correctly, they should match the average daily load profile of the energy purchases for the same time period. If not, note the difference, either positive or negative.

Examples of weekday and weekend load profiles for the same building are shown below in Figure 14. Note that as the example is for a commercial energy audit, the difference was manually adjusted to zero.

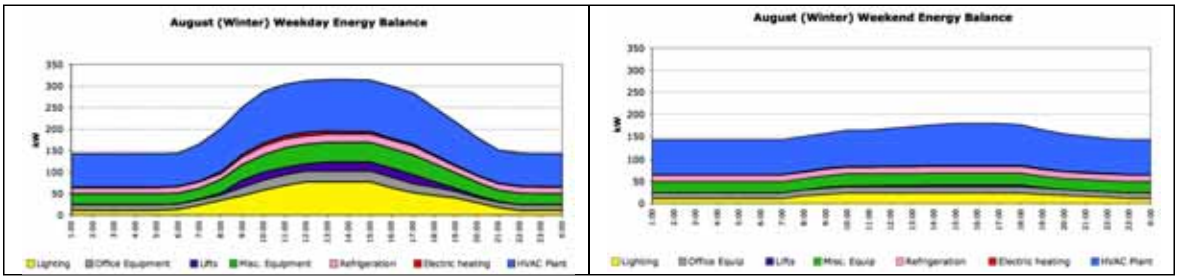


Figure 14: Weekday and weekend winter energy profiles

Fifth, repeat this process for typical winter, summer and swing season months. If no directly monitored end-use data is available, then assume that the quantity and pattern of usage for the end-uses expected to be temperature-independent are consistent, and the same for each month.

The other necessary assumption at this stage is that heating and cooling cause the difference in loads from month-to-month.

An example of the assumed end-use distribution for a summer month is shown below in Figure 15 for weekdays and weekends.

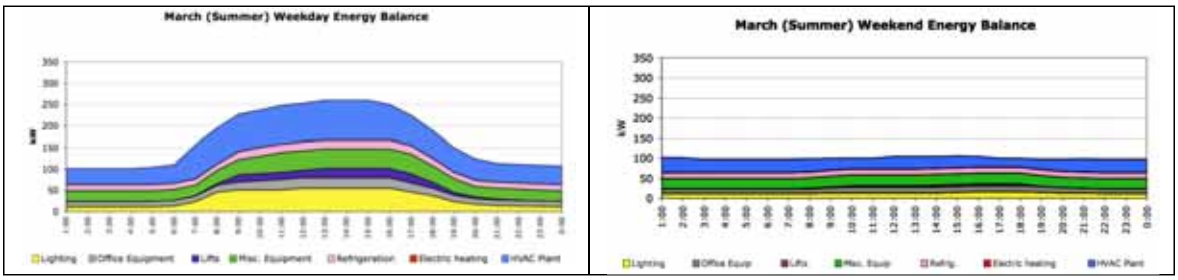


Figure 15: Weekday and weekend summer energy profiles

There is no electric heating this month, so the red band is negligible.

Sixth, use the load profiles for each month, and the number of weekdays and weekend days, to calculate the monthly average kWh/d for each end-use. These should match the total purchased kWh/d for the same month (including the effect of the ‘differences’ described above).

Then interpolate the values of lighting and any other energy end-uses (other than heating and cooling) that vary from winter to summer between the two extremes linearly (until more information is known).

Finally, for this step fill in the difference between the sum of the measured end-uses (in kWh/d) and the total recorded purchases (again in kWh/d) with heating in the winter, or cooling in the summer. The result is shown in Figure 16.

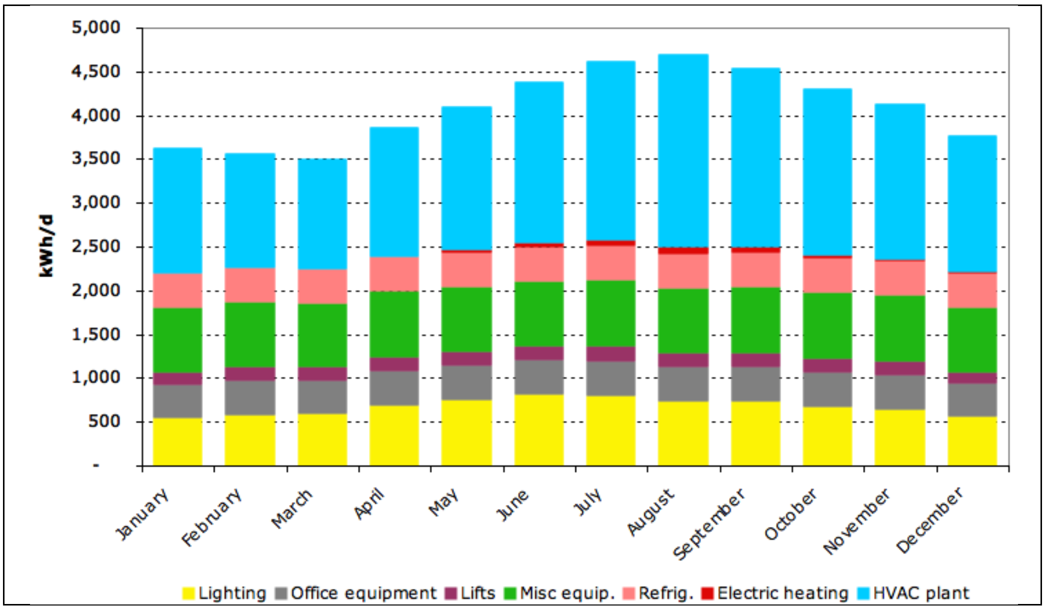


Figure 16: Monthly energy use by end-uses

8.4.2 Total annual energy use from part of the building

There are two types of extrapolations that this covers:

1 A building, with several office / retail tenants, some of who have chosen not to participate

2 A multi-use building, where some of the uses are outside our sample frame.

In both cases, the extrapolation will be done on a per m^2 basis.

In the first case, if we have data from a sub-set of tenants we have two choices, to assume that the non-participants have (1) the same EUI (kWh/m²/yr) as the participants, or (2) the average EUI of all similar participants in our recorded sample.

Probably the best solution is to report both results, to cover the expected range of results.

In the second case, where some uses are outside our sample frame, we should estimate the areas for all activities, and the EUIs for the areas in these outside-sample-frame uses, and use them to report the estimated total annual energy use for the building. (Of course, if we have total purchased energy records for the outside-sample-frame portions of the building, then the total building energy use can be reported accurately.)

8.4.3 Total annual energy use for one of a group of buildings

If a building is part of a group that is jointly metered, and there are no records for the individual building, again as a first approximation estimate the usage of such a building to be in proportion to the fraction of its floor area to the total of the group of buildings for which energy is metered.

Also, the individual building should be monitored for total electricity use over a longer period using Energy Logger Pros.

When more information is available about the different usage patterns in buildings by activity, more sophisticated estimates may be possible.

8.5 Presentation of data

The targeted monitoring sites for 2008-09 had a two-page summary prepared for each building, showing the results in terms of energy uses and benchmarks. An example is included as Appendix 1. The following parts were used in these reports:

Descriptive graphics:
- Air photograph of building on-site elevation photographs
- Location reference and built area in m^2 from PropertyIQ
- Occupancy in number of people, from site visit count
- Geometric form
- Activities pie chart, in terms of estimated space usage
- Electricity purchase graphs (e.g. daily for 1 yr, monthly average for 10 yr)

Descriptive table: listing the 'typologies' representing the building:
- Construction material
- Construction era (decade)
- Building fabric (envelope) insulation, material and form
- Lighting/shading: brief description of windows and lights
- Central controls: description
- Building services: brief description of HVAC, including natural ventilation
- General equipment: brief description of other energy end-uses
- HVAC equipment (seems like a duplication)
- Fuels used: list
- Indoor air quality.

Energy use report:
- Pie chart of kWh/yr by end-use
- EUI
- Table of end-uses in kW, kWh/yr, W/m2, kWh/m2yr and h/yr.

Other results that 'should' be included (but were not last year):
- Graphs of daily (hourly) and annual (monthly) energy end-use distributions, showing their proportions of the whole-building load (i.e. the energy balance as described on the previous pages).
- Gas (and water and other fuel) use patterns (daily and/or annual)
- Graphs of conditions monitoring: internal temperature histograms, comments on lux levels
- Graphs of energy use as a function of temperature: whole-building electricity, heating energy, cooling energy.

If the report were to be given to the building manager, owner or operator, then an indication of how the overall EUI for this building compares with the sample of buildings measured would be a useful addition.

The information gained about each building's energy use patterns (both for the whole-building and individual end-uses) can be made most understandable by expressing it visually as load profiles and histograms (as described below). Energy data can also be shown as time series, but this is much less informative than load profiles, and is probably best reserved for confirming data completeness.

Other useful graphic forms include load duration charts and x-y charts, for showing the relationship of one not time-dependent parameter to another (as for correlations of energy use with outdoor air temperature).

Uncommon data visualisation forms for expressing energy use patterns include ‘carpet plots’ which represent load profiles in two dimensions, with one axis representing the hour of the day, and the other the day of the year, with data intensity represented as a colour, and multi-dimensional scatter plots showing x-y correlations between many (10 or more) variables.

8.6 Load profiles

Load profiles will probably be the most useful method of illustrating the patterns of end-uses, as well as delivered services (temperature, CO_2 and lux).

8.6.1 Whole-building load profiles

Building energy use patterns are recognisable as following certain recurring patterns. The two recurring cycles are the annual cycle and the daily cycle. Load profiles are visual representations of the patterns, showing how variable yet repeatable these patterns are over the course of one or more cycles.

For every monitored building, an **annual load profile** should be able to be generated, as billing data at monthly intervals should be available for electricity and gas (and water and other fuels) as well, even if the data will not span 10 years. The monthly interval is somewhat artificial (one-twelfth of an annual cycle, with an inconsistent ratio of weekend days to weekdays), but in most cases will be the only historical record of energy purchases available.

The graph on the left of Figure 17 below shows the month-to-month electricity consumption of a site from 1998 through 2008. Energy use is shown in consistent units (kWh/d), and consumption is much higher in winter than summer. (If energy use were expressed as kWh/month, then the variation in days per month as well as meter reading dates would affect this pattern.) For the months when data was unavailable, the consumption was shown as zero on this graph.

The graph on the right of Figure 17 shows the daily electric energy consumption of the same site from September 2007 through August 2008. This is the same information as in the group of points to the right on the previous graph, but disaggregated from months into days. This clearly shows the difference between weekdays and weekend days, as well as the day-to-day variation that is concealed by monthly averages.

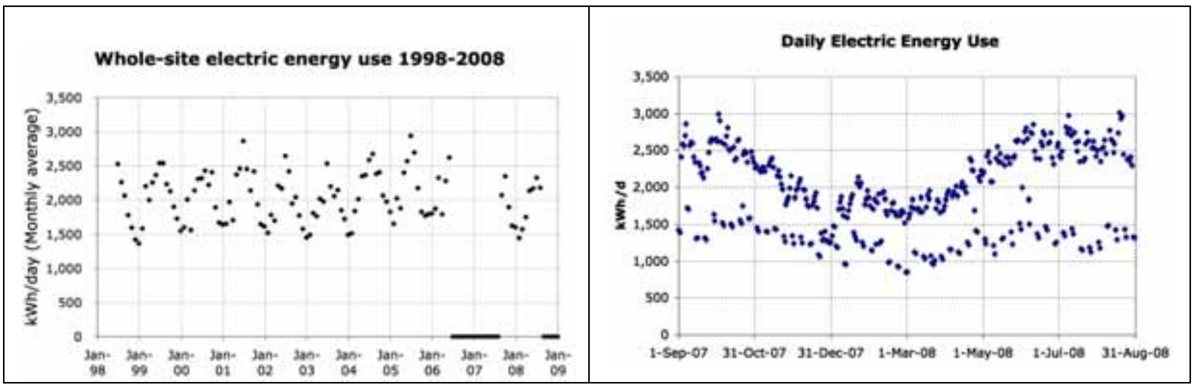


Figure 17: Daily electricity use – monthly and daily averages 1998 to 2008

For example, the left (monthly) graph shows that the highest usage was about 2,300 kWh/d (averaged over a month), and the lowest about 1,450 kWh/d. This graph of daily use showed the highest day used over 3,000 kWh/d and the lowest under 1,000. The range of variability is likely to be of great interest to our funders and stakeholders and the future users of our research results.

Organisations working on the energy supply side will be interested because they need to plan for extreme events and loads. Organisations working on the demand side will be interested because they need baselines to compare with the performance of current and future buildings. Researchers will be interested in the variability because it can inform estimates of the accuracy and applicability of the measurements of end-uses.

Figure 18 provides two graphs of **daily load profiles** showing the measured electric consumption of a large building over the course of a winter and a summer month. In these graphs, the light grey lines show the electric consumption for each individual day, and the dark lines show the average consumption for a weekday (solid line) and weekend (dashed line).

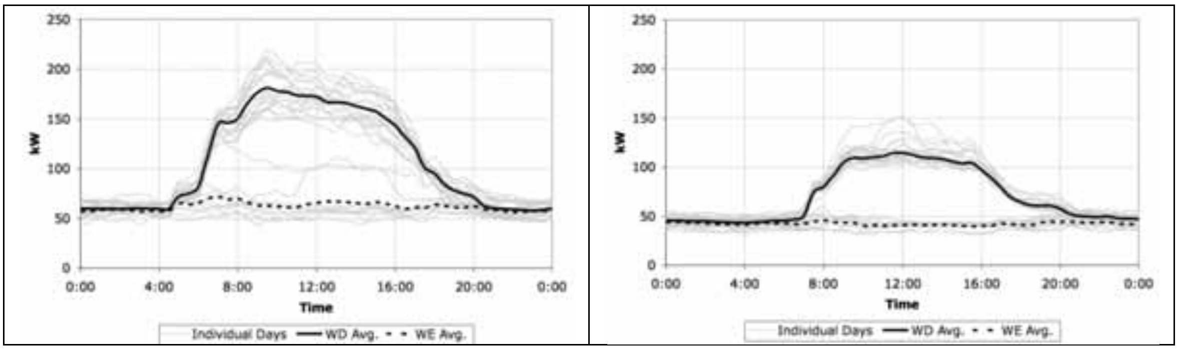


Figure 18: Load profile June and March 2008

These daily load profiles show the hour-to-hour usage for the same building as above. They also show the variation and timing of peak loads, which will be of major interest to some of our stakeholders.

8.6.2 End-use daily load profiles

End-use energy daily load profiles will be the most commonly provided form of results from the end-use monitoring. Ideally, these will be segregated into weekday / weekend profiles, and will show both the average load at any time of day and the range of variability. The variability could be shown either as the standard deviation at any time of day or as the range of measured results.

As a method of normalising load profile data, the loads can be normalised as a fraction of average (or peak) loading. This allows profiles with different amplitudes to be compared quantitatively.

The following two sets of graphs illustrate this. The graph on the left in Figure 19 shows the measured electric power of an area in one monitored building, in kVA, as a load profile over two weeks. Figure 19 on the right shows the same data, but expressed as a fraction of the average power over the same period. The central line in the right-hand plot is the mean power at any time during the monitoring, and the higher and lower lines are the mean ± the standard deviation of the measurements.

This allows different amplitude load shapes to be compared directly.

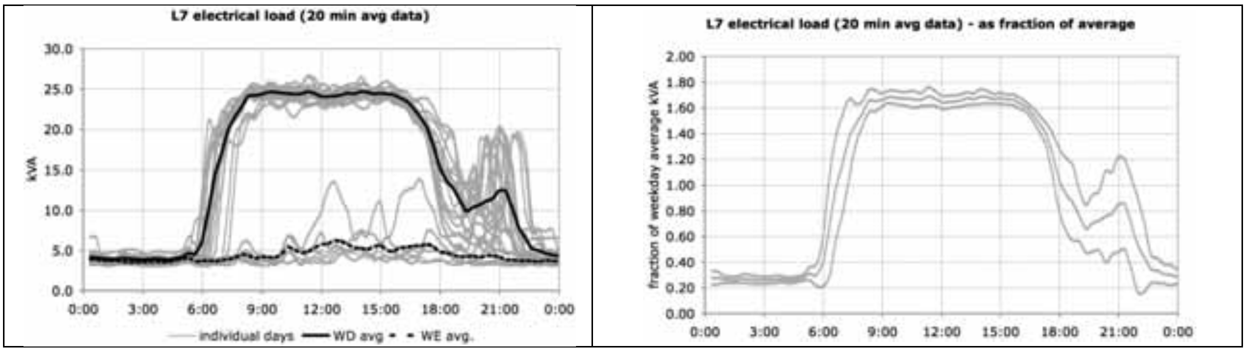


Figure 19: Electrical load – absolute and fraction (Area 1)

For comparison, the same information for another area is shown in Figure 20.

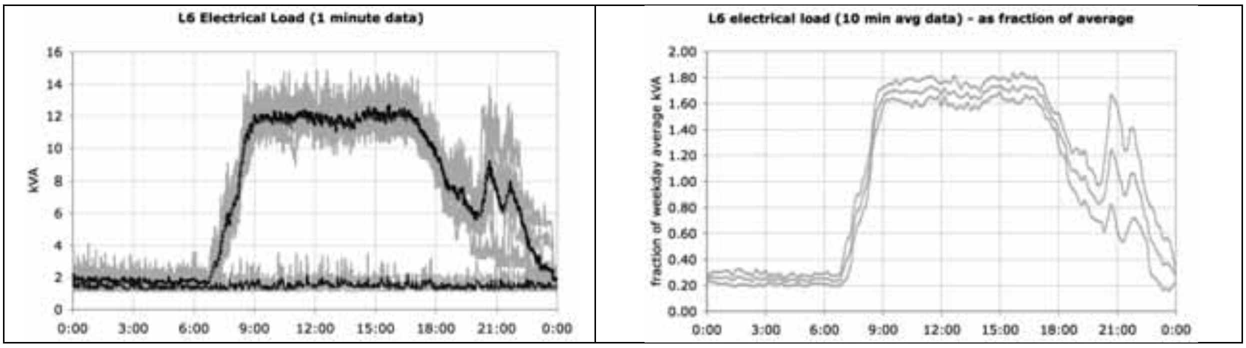


Figure 20: Electrical load – absolute and fraction (Area 2)

This normalisation method allows a quantitative comparison between the two load shapes. Thus, it can be used to extrapolate the results of measurements to spaces with different areas or installed power densities. This will be useful for electric supply load research or modelling of building energy performance.

8.7 Histograms of conditions data

In this context 'Conditions' means the delivered energy services, specifically temperature, illuminance (lux) and air quality (CO_2 concentration). Humidity is also being recorded and should be reported as dew point, as this shows the moisture content of air and relates it to the possibility of condensation on cold surfaces.

The results of the conditions monitoring should be reported as load profiles, as these clearly show the daily patterns, but additionally as **histograms** of conditions achieved in each space, preferably separated into occupied and unoccupied times. Examples of these are shown in Figure 21 below (for the same room).

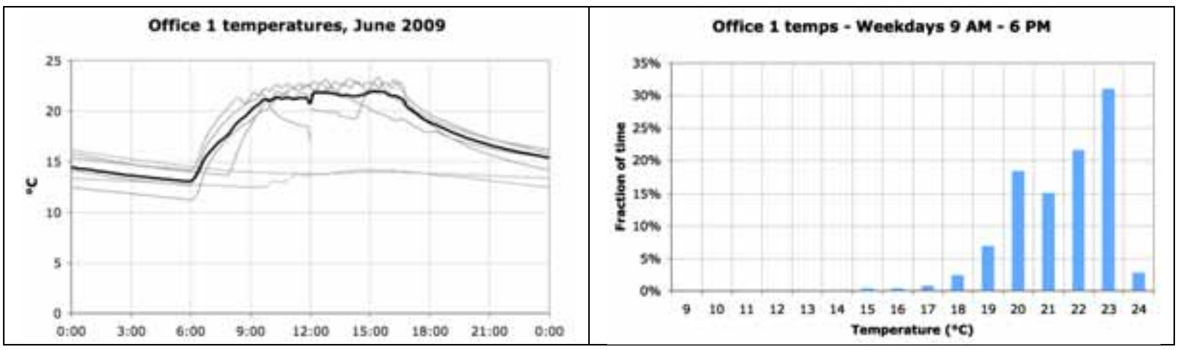


Figure 21: Office 1 temperatures – profile and histogram

At another site, it was apparent that some spaces were only used during hours that we would normally consider ‘unoccupied’. For example one office was heated only from Friday at noon until Sunday evening, and hardly at all during the week, while we have considered ‘normal’ occupied hours to be weekdays between 9 am and 6 pm.

Also, note that the scale on the histogram had to be expanded on the bottom end to accept the very low temperatures (under 10°C). These are lower than expected, but will probably occur again in other buildings.

Set the chart templates to cover the range of temperatures expected in all buildings, so that the load profile graphs can be directly visually compared. This will require a temperature range of about 10°C to 30°C, even if this compresses the results in many cases to a small region of the graph.

8.8 Other graphic formats

Time series, as shown in the previous section, are the direct results of plotting the recorded data. They are most useful as checks on data reliability and reasonableness, rather than for turning data into information.

The **load duration chart** is a useful illustration of the duration of peaks for a building or end-use. In Figure 22 the chart on the left below shows the duration of the peak electrical demands for a building. As can be seen, the highest 15% of the peaks (over 200 kW) occurred less than 1% of the time. The chart on the right of Figure 22 shows the duration of temperatures in an air-conditioned room in the building.

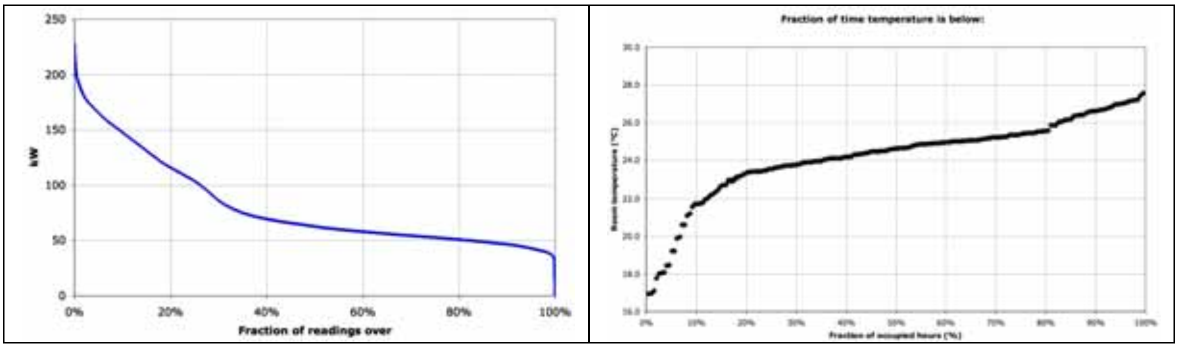


Figure 22: Load duration chart – peak electrical and temperatures

A very useful index of a whole-building’s or a temperature-dependent energy use is an x-y plot of **energy use vs. outdoor air temperature**. This can be for the heating and/or cooling energy or whole-building energy. It is best done on a daily basis, comparing whole-building (or heating/cooling system) kWh/d with outdoor air (dry bulb) temperature. Theoretically it could use on-site measured temperatures, but weather station data would be preferred for extrapolation allowing use of the long-term records.

This is highly recommended as a method of estimating the heating and cooling energy use for months when monitored data is not available.

Figure 23 shows a plot of weekday (left) and weekend (right) electricity consumption for a building, as a function of 24-hour average daily dry bulb air temperature, as recorded at the nearest Met Office location.

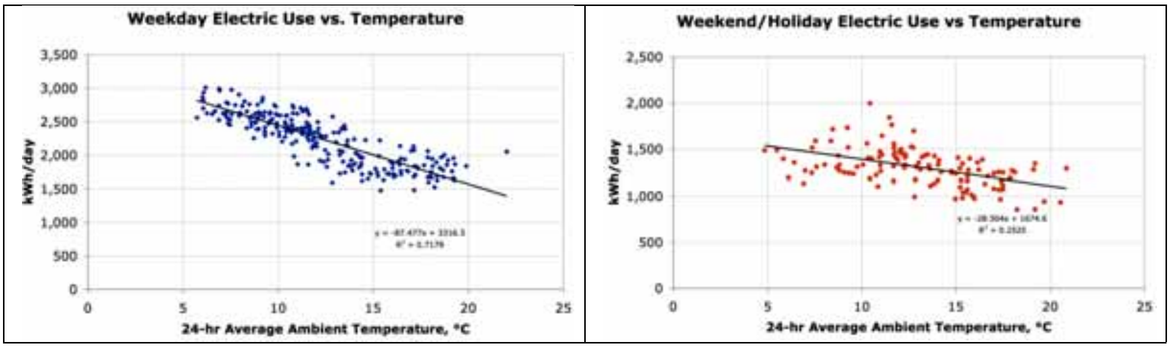


Figure 23: Daily use of electricity vs. temperature – heating and cooling

The temperature effect is clear, with more electricity consumed on cooler days, primarily from extra space heating required, then on both weekday and weekend days. This shows that the building is electrically heated on weekdays, and to a lesser extent on weekends, when the building is nominally unoccupied.

By comparison, Figure 24 plots electricity use versus temperature for an electrically cooled but not electrically heated building.

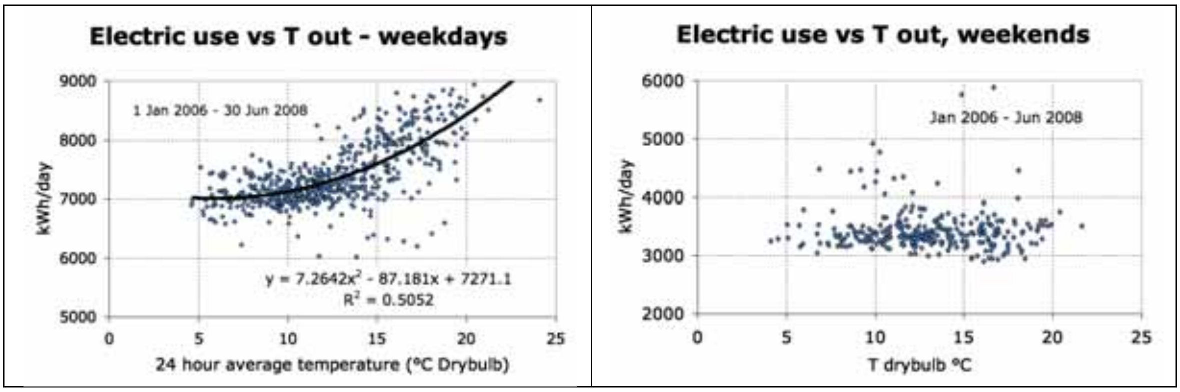


Figure 24: Daily use of electricity vs. temperature – cooling only

As can be seen, this building shows a definite rise in energy use at increased temperatures. The polynomial curve is the best-fit regression for these data. The weekend electric use appears to be independent of temperature. This is because the HVAC system is scheduled off for the weekends.

Often **x-y plots** can be used to show relationships between two variables. An example is Figure 25 which plots the measured power factor for a large building as a function of the half-hourly electrical load in kVA.

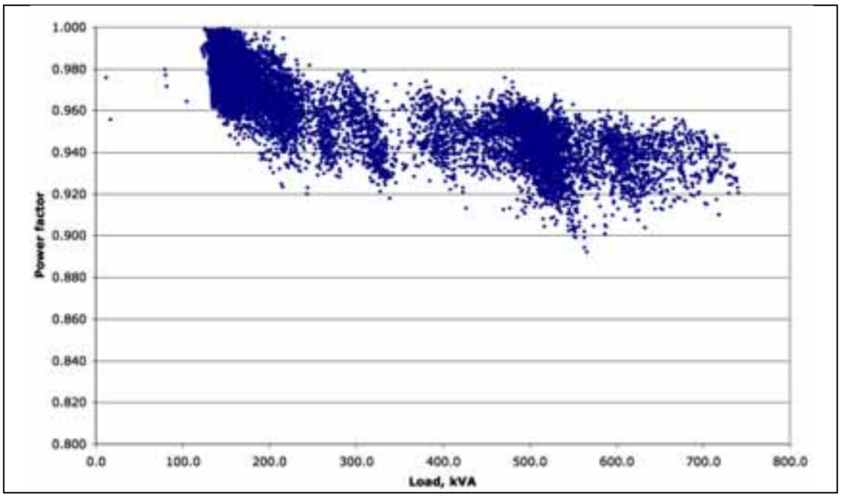


Figure 25: Power factor vs. electrical load

Figure 25 shows that the power factor is good and high at low loads, but during peak demand periods it dips, dropping to about 0.92 at the highest peak. This shows that this power factor correction unit is either undersized or malfunctioning, causing higher peak demand charges than necessary and possibly even a safety hazard due to overheating.

Other more complex graphic representations are also available. These two examples are taken from a report issued through the International Energy Agency's (IEA) Energy Conservation in Building and Community Systems (ECBCS) Annex 40 'HVAC Commissioning', and were prepared using the commercial software 'Matlab'.

Figure 26 is a **multi-dimensional scatter plot** showing the response of a heating hot water system in a building which uses a 'compensator' for load modulation. The three colours show whether there was a heating load (red points), a cooling load (green points) or an intermediate load (blue points). The supply hot water temperature is called T_{SW}, the return hot water temperature is T_{RW}, and the temperature difference is $\Delta\ T_{SW\text{-}RW}$. The position of the mixing valve, which mixes return water with supply water, is also shown.

Figure 27 is a **carpet plot** of the same variables. In this case, the vertical axis of each stripe represents the hour of the day, and the horizontal axis represents the day of the year. The colour of each point shows the value of each variable at that time.

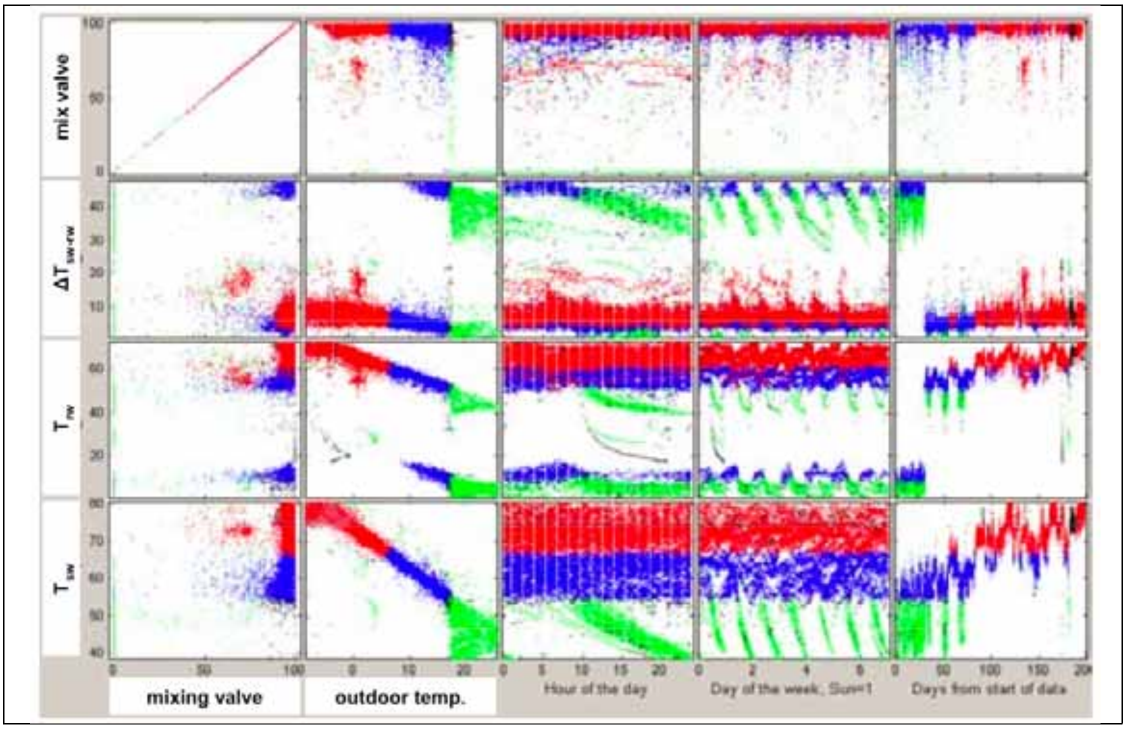


Figure 26: Hot water system performance – multi-dimensional scatter plot

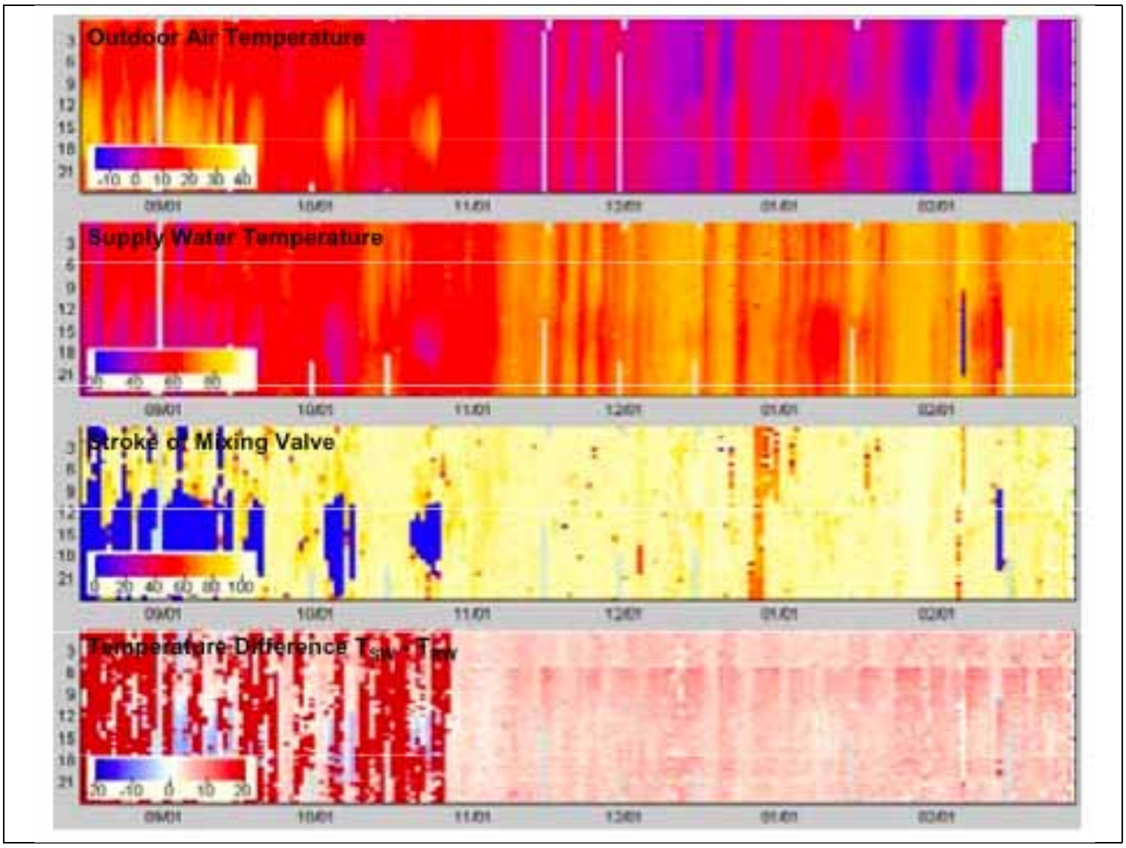


Figure 27: Hot water system performance – carpet plot

In terms of showing the range of conditions in a space, perhaps one of the best ways of illustrating this is by superimposing one of the chart types shown above onto a plan of the space, as illustrated in Figure 28, showing the range of temperature histograms measured in a building in March 2009.

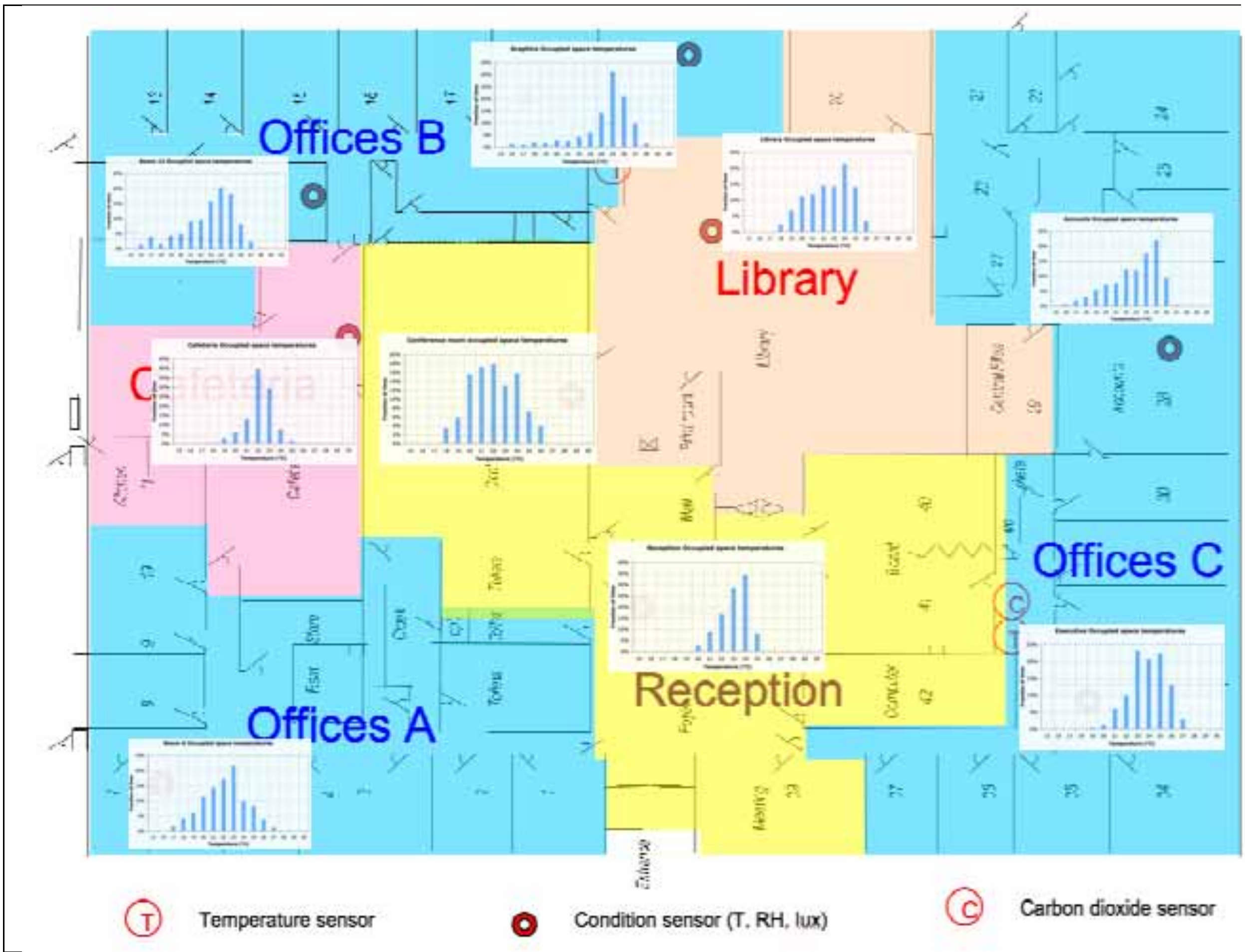


Figure 28: Occupied space temperature distribution by location in building

The histograms in Figure 28 are for ‘occupied hours’ (9 am to 6 pm weekdays), and have a range of 15°C to 30°C, which means that only their middle thirds (20°C to 25°C) are comfortable.

8.9 Sample report

The following is an example of the type of report that was created during 2008-09 to summarise the performance of a monitored building. This was created by Alex Hills, using the data from the BRANZ Admin building case study.

QV: BRANZ, MOONSHINE RD, JUDGEFORD WELLINGTON

N/A

BUILD M²

1,700

LAND M²

N/A

FLOORS

1

OCCUP

50

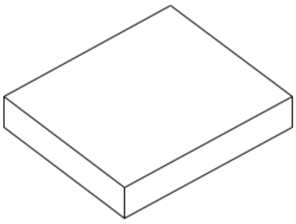
DATE OCCUP

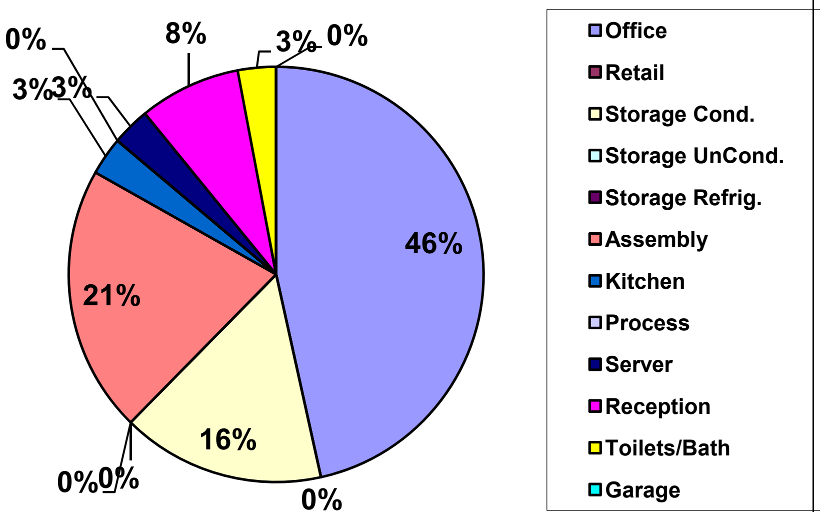
Mar '09 (typical)

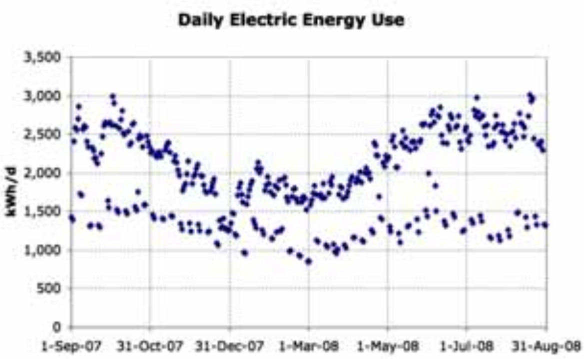
M² /PERSON AERIAL PHOTO: KEY ELEVATION:

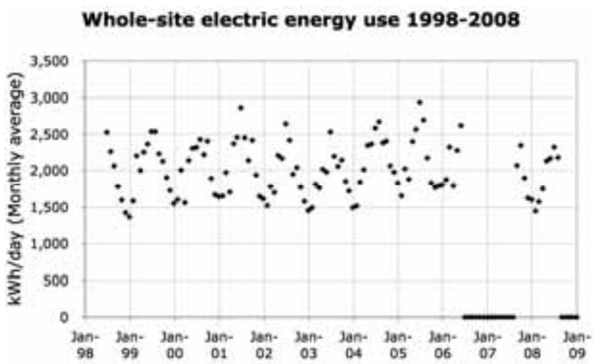
34

FORM: [CDO-CS5.jpg] ACTIVITIES: (double-click chart to modify)









CONSTRUCTION:	1970s	Concrete
BUILDING FABRIC:	Some insulation. Compact form.	Single glazing / large low performance windows.
LIGHTING / SHADING:	Blinds to control glare. Mostly 1500 mm T8 fluorescents delivering 550 lux average, no significant glare.	Horizontal shading, perimeter daylighting possible (not implemented).
CENTRAL / CONTROLS:	24-hour timer switches on electric resistance heating.	Otherwise manual control of heating and lighting.
BUILDING SERVICES:	Openable windows for natural ventilation.	Mechanical ventilation to conference room only
GENERAL EQUIPMENT:		Most rooms not air-conditioned.
HVAC EQUIPMENT:	Electric resistance (panel) heaters in most rooms. Lockout timers (24 hr) on most electrical panels.	Some rooms have reverse-cycle heat pumps.
FUEL:	Office equipment and misc. gains 27 W/m^2. EUI (all-electric)= 159 kWh/m2 yr	
INDOOR AIR QUALITY	CO2 600-1500 ppm; variable ventilation	

	kW inst.	kWh/yr	W/m2	kWh/m2/y	FLH/y	Certainty
Lights						
Interior	21	47,340	13.2	31	2,356	A-
Exterior	1	4,015	0.6	3	4,317	A+
Office equipment						
Plug loads	3	7,800	2.0	5	2,557	B
Kitchen						
Refrigeration	0.8	3,075	0.5	2	3,727	B+
Cooking	8	1,300	5.3	1	163	D
Services						
DHW	4	15,140	2.7	10	3,693	A-
Space Heating	15	68,954	10.2	45	4,441	B
Heat Pumps	22	35,365	14.4	23	1,613	B+
Other	12		6			
Total		**182,989**		**120**		
Measured		**176,645**		**117**		

Table 23. Estimated energy end uses.

The total of the estimated loads equals the estimated annual purchases, within 3%.

These are (except for cooking) all based on measurements, with extrapolations as discussed after each end-use in the preceding section. The best estimate of certainty is given in the final column.

The security light is rated “A+” certainty. Its load is very regular and predictable. This is almost certainly all of the exterior security lighting in this building.

The hot water and interior lighting loads are both rated “A-“. This almost certainly covers all of these loads in this building, but it is not certain that they are operated consistently with average annual pattern.

The refrigeration and heat pump loads are both rated “B+” certainty. Most of the loads have been monitored, and their operation seems consistent, but it is not certain that they are operated consistently with average annual pattern.

The space heating and plug (office powerpoint) loads are both rated “B” certainty. Some of the loads have been monitored, but it is not certain that they are operated consistently with average annual pattern.

The cooking load has been rated “D”. The equipment has been observed, but its power demand and operation not monitored. The value is only a reasonable-seeming assumption about the load. The following graphic shows the layout of spaces in the building, for the lighting, equipment and occupancy counts, and placement of the condition loggers.

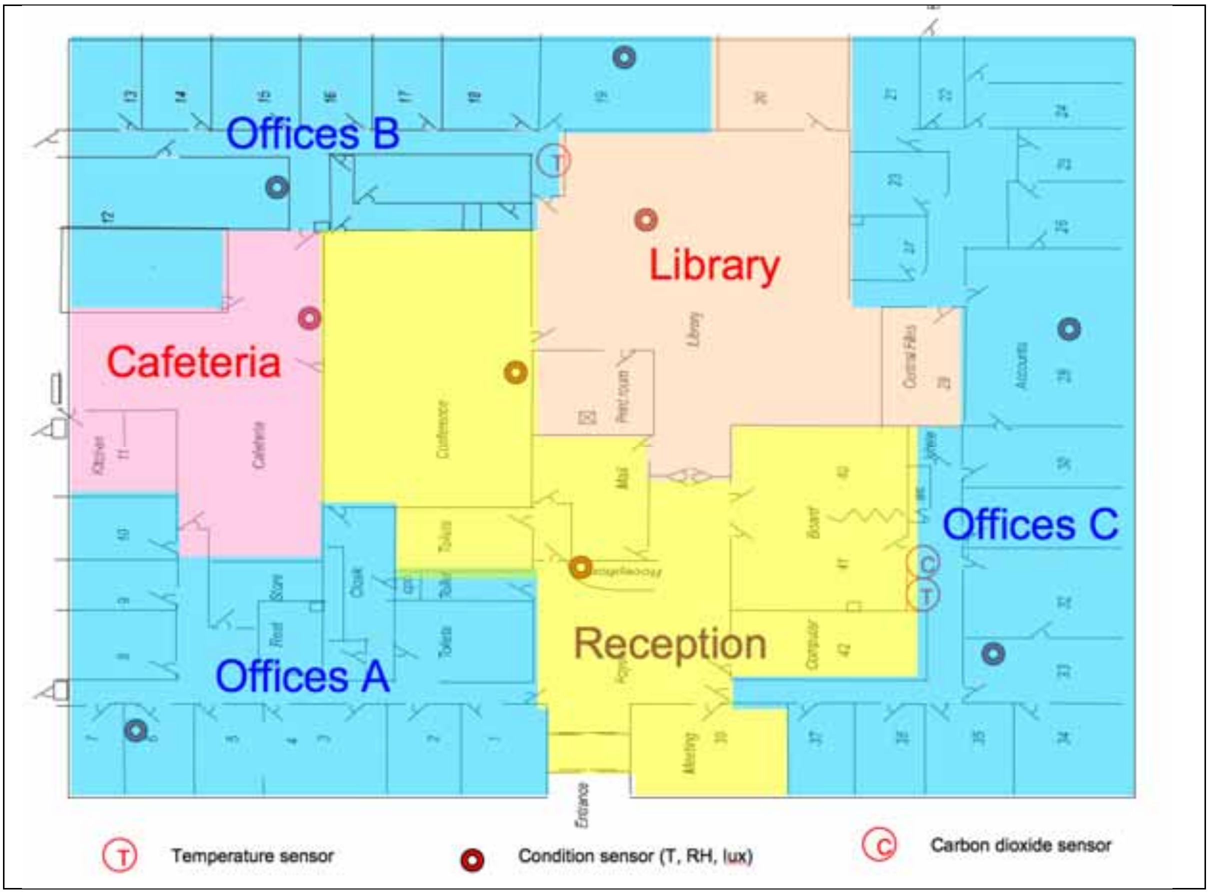


Figure 29: Building floor plan showing sensor locations

9. WATER USE

To explore potential monitoring methods, three separate buildings on the BRANZ site in Judgeford were equipped with high resolution water meters and data loggers to see where the water is used. Spot measurements have also been conducted, to look at the water use of individual units of equipment.

9.1 The site

The Wellington water main runs along SH 58, from which the BRANZ water supply branches off. This water gets fed into two 25,000 L storage tanks on a hilltop (reservoir), from which it is gravity fed to the individual buildings. Some laboratories have booster pumps to increase the pressure, as the reservoir provides just over 20 m of head.

Two neighbouring farms branch off from the BRANZ water supply on the hill and are metered from this point. A manual reading is taken once a month by the caretaker. Another neighbouring property branches off before the reservoir, and a yearly reading is made.

From the hill top tanks, a 150 mm galvanised steel pipe feeds the ring main which feeds each of the individual buildings on the site.

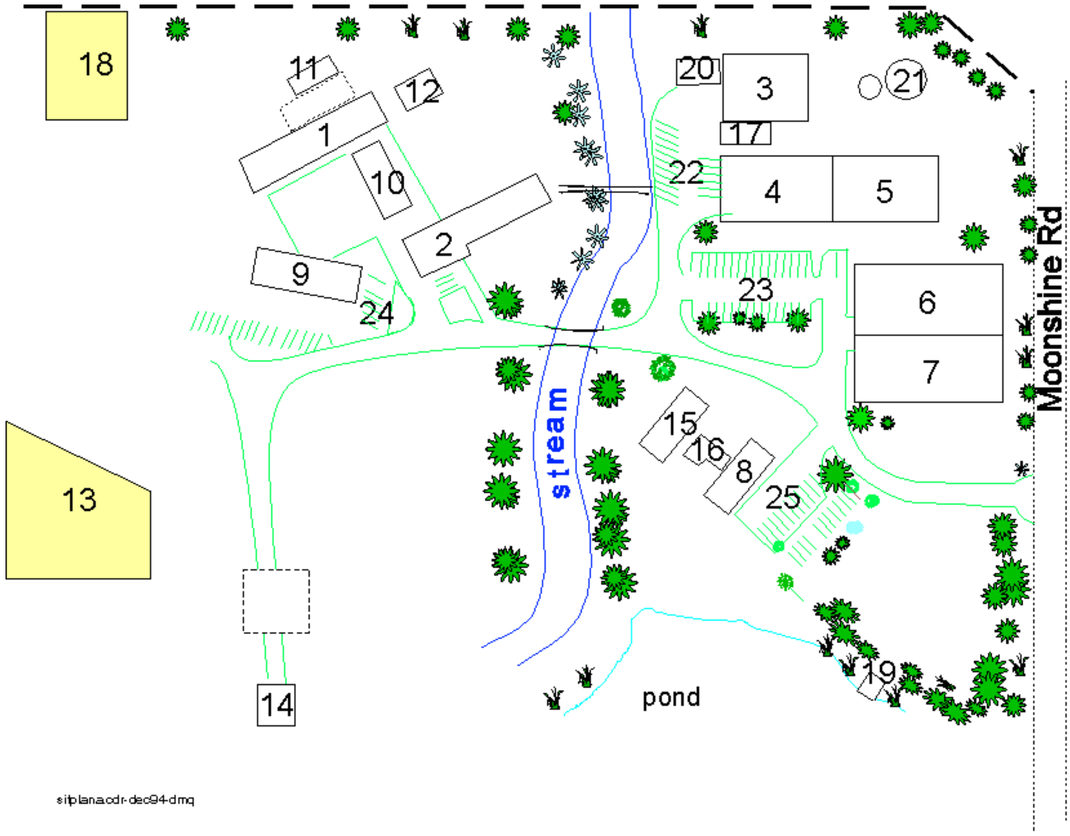


Figure 30: BRANZ site plan

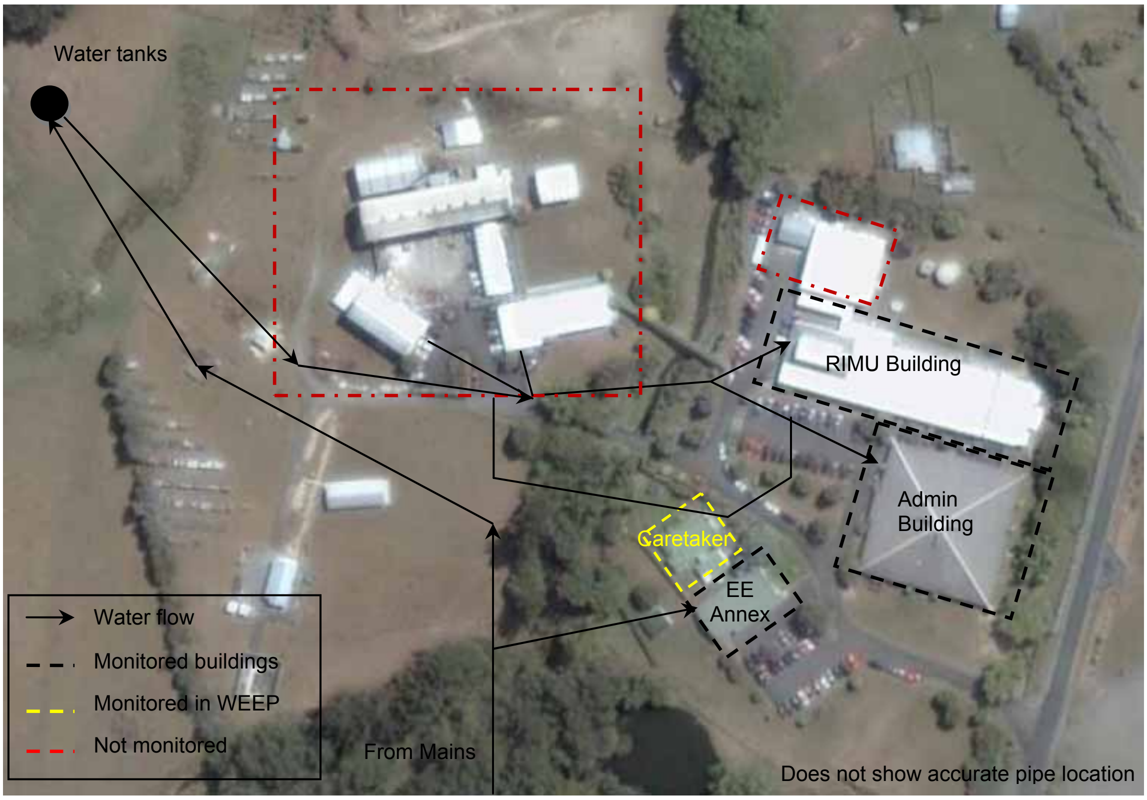


Figure 31: Aerial photograph – water flow distribution of BRANZ site

9.2 Building information

This section gives a brief description of the buildings monitored. More detailed information on the appliance and water usage types can be found in section 9.4.

The **Admin building** has a total floor area of 1,514 m^2, of which 623 m^2 is for office use. This is the most used building, as it contains common facilities such as cafeteria, kitchen, showers, conference rooms, library and other services.

This was the least complicated meter installation, as the pipe feeding the building was only 30 cm below ground and its location was known.

The **Rimu building** is a mixed use building, containing offices on one side and laboratories on the other. Many labs use water regularly and some equipment uses water continuously.

The **Energy Efficiency Annex's** (EEA) main use is for offices and storage. Water-efficient toilets are installed within the building.

9.3 Data collection

As outlined in Figure 32, data was collected in various ways and levels of detail. A first step was to look at historical water records for the site. The next step was to conduct an in-depth water audit of each building on the site (see section 9.5).

It was decided to monitor three separate buildings in detail: the Admin building, the Rimu building, and the Energy Efficiency Annex (EEA) building.

High resolution water meters, like the ones used in the Water End-use and Efficiency Project (WEEP) were installed under the EEA and the Admin building as both had 20-25 mm Ø pipe sizes (residential size). The Rimu building had a 40 mm Ø pipe, and hence a larger and more costly meter was required. Due to the larger size of the meter, Initially the western side of the stream (Kauri building and laboratories) were to be monitored, but when excavating the pipe it was found that this was too expensive due to the pipe diameter and the layout of the pipes. This could potentially be carried out in the future by using the water meter currently installed on the Rimu building.

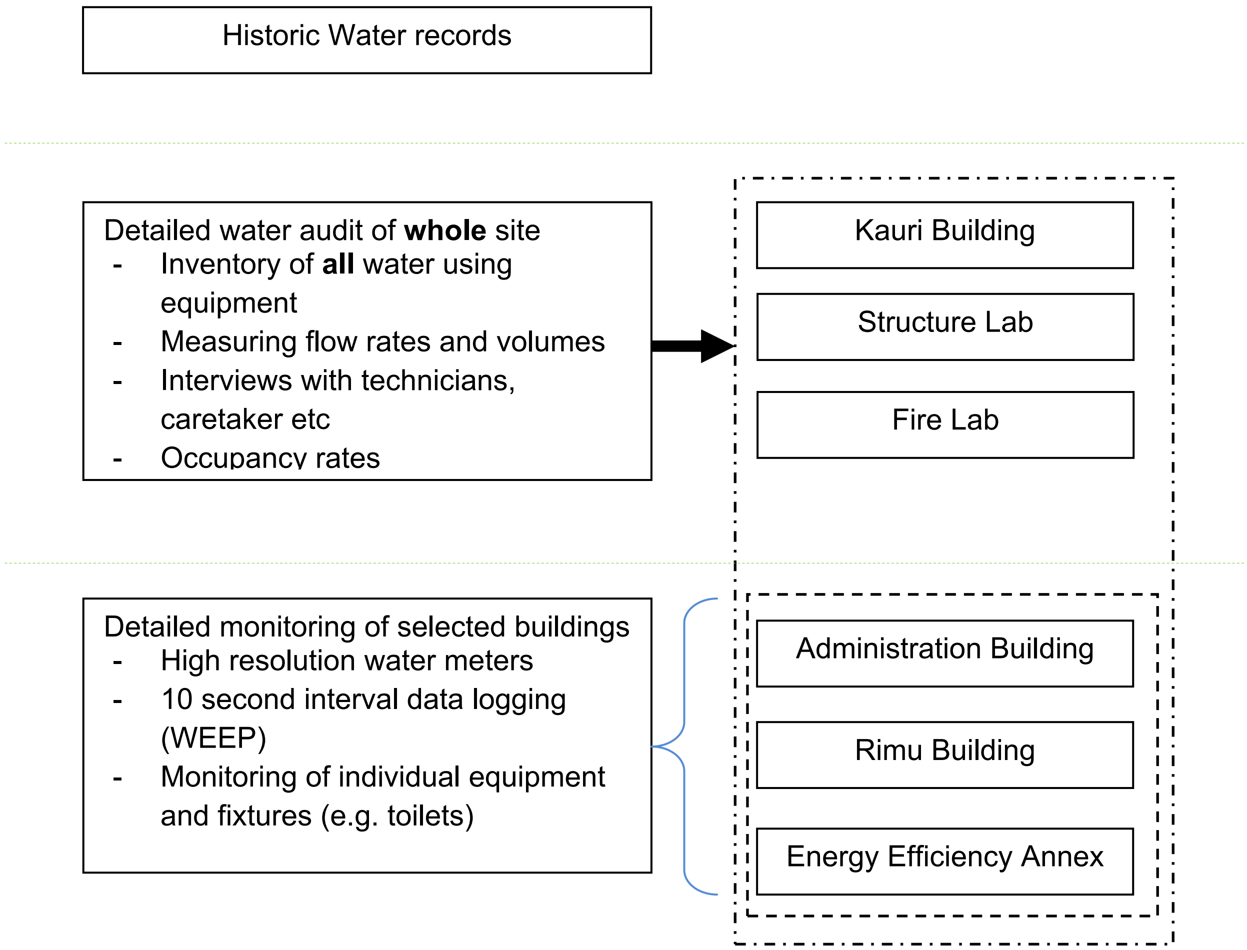


Figure 32: Data collection flow chart

9.3.1 Monitoring equipment

Data collection methodologies successfully trialled in WEEP and follow-up studies have been used. This is not discussed in detail. For further information see BRANZ *Study Report 159* (Heinrich 2007).

High resolution **nutating disk meters** (Neptune) were used on the three buildings. These were similar to the ones used in WEEP, with the exception of the 40 mm Ø pipe, which was being tried out for the first time.

Table 24: Water meter types and pipe sizes

Building	Pipe Ø (mm)	Meter Type	Pulse Rate
RIMU	40	MES 40	7.2
ADMIN	20	MES 25	34.2
EEA	20	MES 25	34.2

Ideally, a water meter should have been installed after the pipe-joint coming from the reservoir tanks, to measure only BRANZ consumption. This was not feasible, as the 150 mm Ø PVC pipe joined a galvanised pipe which could not be cut and there was no space to install a meter without major excavation. Other alternative locations were explored, but not feasible, so separate buildings were monitored instead. An ultrasonic flow meter, which does not require the pipe to be cut, could have been installed instead.

An **ultrasonic flow meter** (non-intrusive Doppler flow meters) is a volumetric flow meter which requires particulates or bubbles in the flow. Current technology requires that the liquid contains at least 100 parts per million (ppm) of 100 micron or larger suspended particles or bubbles. Installation costs are generally low, as the pipe does not require to be cut. However, these meters require large upfront costs ($10,000+). This instrument can be rented for $180 to $300 per day, which would allow for a trial period first. Another use for this meter is that it can be used in sub-metering quite easily, or for monitoring wastewater flows out of the building. It needs to be established and tested whether this type of meter is suitable for monitoring of mains water supply due to the low ratio of suspended solids. Manufacturers include:

- http://www.flexim.com/
- http://www.omega.com/prodinfo/ultrasonicflowmeters.html
- http://www.sierrainstruments.com/products/innosonic.html?gclid=CJCuuIT-IZYCFSBciAod8E6jEg

BRANZ P84 series USB **data loggers**, which were used for the Auckland Water Use Study (Heinrich 2008), have been used to capture flow information at a 10 second interval.

9.4 Historical records

Historical water use information was available from quarterly billing records which went back to 1994. Due to the water distribution network of the site, this data had its pitfalls. Three other surrounding properties are connected to the BRANZ water supply and are sub-metered. One property only supplies its water reading at the end of the financial year and the others are read monthly by the caretaker.

Occupancy rates: both historical and present building occupation was collected through the payroll manager. Site information such as floor information was collected from building plans. The total floor area was 5,160 m^2, which included the laboratories and all other buildings. However when looking at the water consumption benchmarks expressed on the floor area, currently BRANZ is using water at a rate of 1.13 m^3/m^2/yr. It is hard to compare this figure to other buildings, as the BRANZ site does not really fit into a specific benchmark category since it is mixed use. Also the population density of the site is lower than the majority of other buildings, and there are large laboratory floor spaces. This makes a much lower impression on the water use, as the floor area is so high.

The average yearly metered usage at BRANZ was over 9,000 m^3 (9 million L). There is a large variation in usage over the years. The last water bill (June 2008) that was received showed a remarkable water drop to historical volumes. This drop could not be explained; a possible cause could be the fixing of a long-term leak. Hence historical information cannot always be trusted completely, and can give a false impression about water use, especially if the site is large with extensive pipe work.

9.5 Audit information

The audit information was collected by walking through each building and laboratories. It was helpful to talk to the caretaker, site manager, plumber and laboratory technician to see where the water was used. Immediately leaks and ways to improve efficiency have been found, but first we needed a benchmark to collect information on the current situation. This section focuses on the three buildings monitored, but water audit information was collected for the whole site. These areas were not metered, but immediately efficiency improvements were found.

Standard audit tools have been used, such as the stopwatch, bucket (for measuring volumes), forms etc. This basically consisted of a walk-through survey, noting down the type of appliances, usage patterns etc. In other words, everything that was related to water use was noted down to find out as much as possible about the site. Standard templates could be set up to ease the task, but each building has different appliances, so it was easiest to start with a blank piece of paper.

The **Admin building** has a total floor area of 1,514 m^2, of which 623 m^2 is for office use. This is the most used building, as it contains common facilities such as cafeteria, kitchen, showers, conference rooms, library and other services.

The labs in the **Rimu building** were identified as the highest water user in the building.

The EEA building had minimal water use, due to low occupancy and low volume toilets.

9.6 Monitoring results

This section analyses the monitored results from each of the separate buildings and provides an overall analyses. The section is structured according to building names, and the entities measured within each building are discussed in the relevant sub-section.

Only full days of data have been used in the analysis, and the monitoring dates (water meter) are shown in Table 25. Data is still being collected at the time of writing.

Table 25: Monitoring dates

Building	Start	End	# of Days
Rimu	6/08/2008	08/10/2008	63
Admin	6/08/2008	08/10/2008	63
EEA	18/07/2008	08/10/2008	82

9.7 Site water use

Table 26 provides the NABERS benchmarks for Office Buildings (DEH 2006) for comparison.

Table 26: NABERS benchmarks for office buildings in kL/m^2/yr

	Sydney	Melbourne	Canberra	Adelaide	Brisbane	Perth
1 star	1.73	1.03	0.99	1.08	2.53	1.41
2 stars	1.39	0.86	0.83	0.9	1.99	1.14
2.5 stars	1.21	0.77	0.75	0.8	1.72	1.01
3 stars	1.04	0.69	0.67	0.71	1.44	0.88
3.5 stars	0.87	0.6	0.59	0.62	1.17	0.75
4 stars	0.7	0.53	0.51	0.53	0.9	0.61
4.5 stars	0.52	0.43	0.43	0.44	0.62	0.48
5 stars	0.35	0.35	0.35	0.35	0.35	0.35

Whole site

Water information for the **whole site** was obtained from historical quarterly billing records. As explained before it was not feasible to install a single water meter which just monitored site usage, as the existing plumbing was not set up for this task, and major works or high costs would have been required to complete this. Hence it was decided to monitor individual buildings instead.

Admin building

The Admin building has a total floor area of 1,514 m^2, of which 623 m^2 is for office use. This is the most used building (35 permanent residents and many other users), as it contains common facilities such as cafeteria, reception, kitchen, showers, conference rooms, library and other services. A 25 mm Ø water meter was installed to the pipe feeding the building.

Water use in the Admin building was around 2,093 L/d over all monitoring days (2,710 L/d during working days and 551 L/d on the weekend). Continuous usage was found throughout the monitoring period. Every three to five minutes around 3 L (5 L per minute (Lpm) flow rate) of water was consumed somewhere in the building. This was further explored by interviews and auditing the building. It was first assumed that this use was due to air-conditioning or computer cooling, but this was not the case. Another assumption was that this use was due to urinal flushing (timer), but this was refuted, since the urinals were turned off overnight and the flow pattern (Figure 33) still continued to show the same continuous use (process of elimination). It is highly unlikely that this pattern is due to a leak, since a leak would have a more continuous flow rate instead of peaks every three to five minutes. At the time of writing the cause of this is still being further explored.

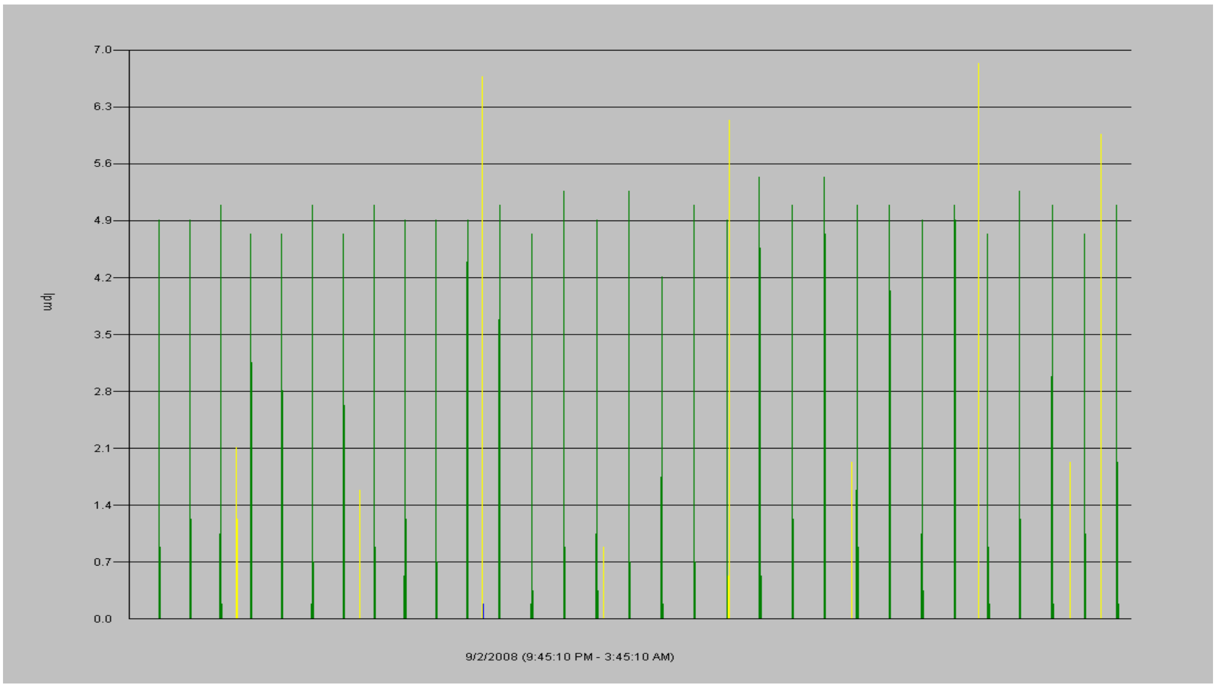


Figure 33: Six hour overnight flow profile Admin building

The Admin building was fairly complicated to disaggregate into end-use components using flow trace analysis, as many uses occurred simultaneously. Twenty-two percent of end-uses could not be identified.

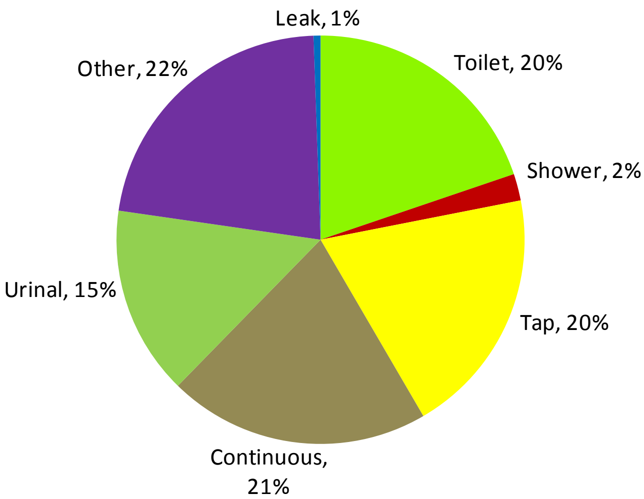


Figure 34: Admin building end-uses

The 'Other' category contains dishwasher use as well. This could not accurately be separated out, due to the complexity of the flow patterns. However the cafeteria contractor was asked to note down when the dishwasher was used for a few days. It is possible to monitor the dishwasher separately by installing a water meter to its feed line. This is something that could be explored further, but has not been done to date.

Toilets

The two male toilets in the Rimu building were separately monitored for just under 100 days by installing a reed switch, which is an electrical switch operated by a magnetic field, to the toilet's flush mechanism. A BRANZ pulse logger recording at a six minute interval was attached to the reed switch recording the number of times the toilet was flushed. The reed switch is fixed in a stationary position, and every time the flush button is activated, the magnet passes over the switch and records the flush. There are many different flush mechanisms, so each installation might be slightly different. Figure 35 show the set-up of two different installations using two different types of reed switches.

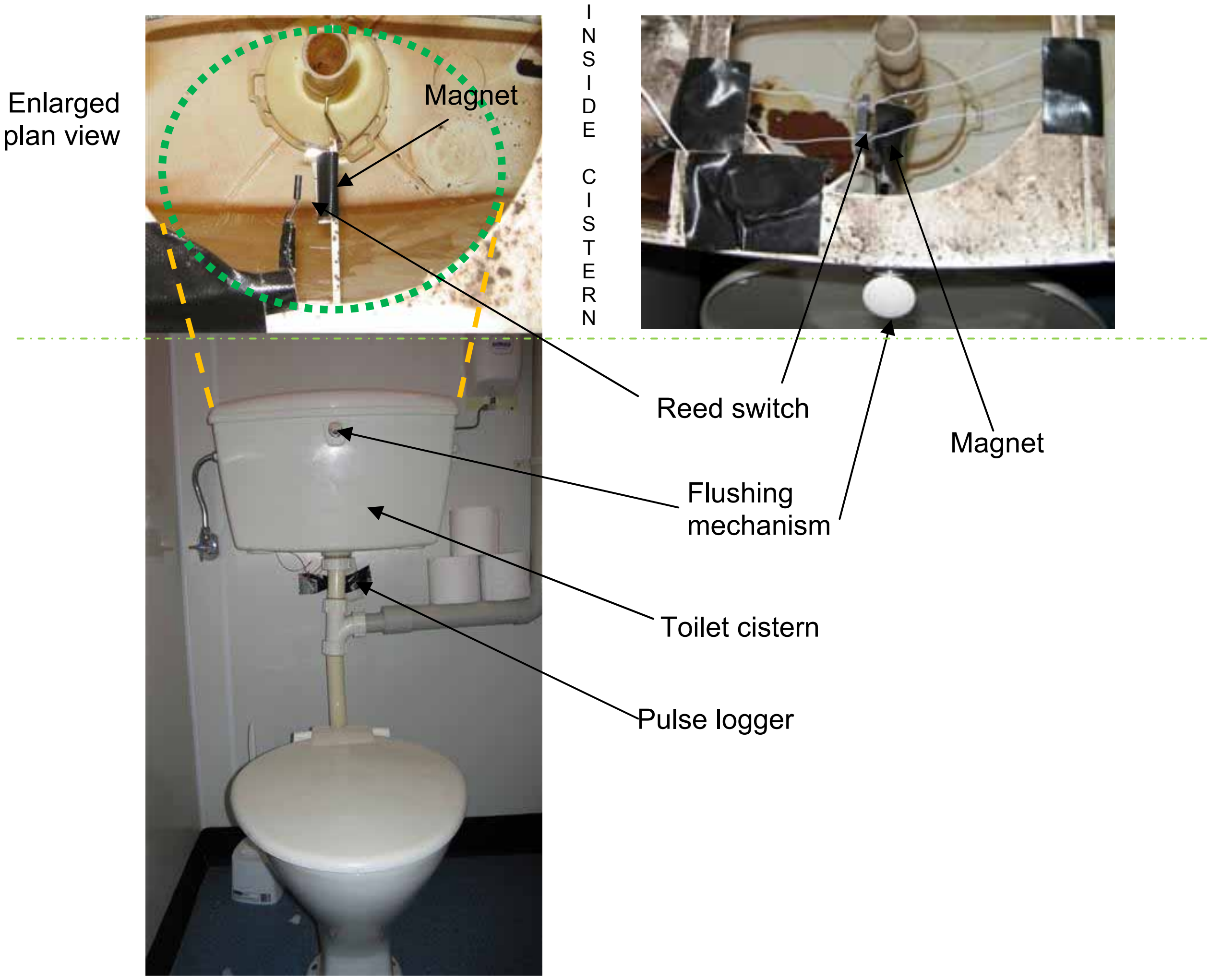


Figure 35: Toilet monitoring system and set-up

On average both toilets (male bathroom) were flushed a total of 16.9 times a day (12.2 flushes/d including weekends; equates to ≈4400 flushes/yr), using about 8 L/flush (from monitoring data). This is around 135 L/working day or 35 kL/yr. The female toilets have not been monitored, but they are a small use, as only three females are located within the building. Toilet flushes are also fairly easily detected by the Trace Wizard disaggregation program.

This low tech and low cost method was an effective way of monitoring the number of toilet flushes. However each installation will be slightly different and innovation is required for placing the reed switches. It was not an issue to keep data loggers in the toilets at BRANZ, but in other applications this might prove more difficult. The logger could potentially be hidden in the toilet cistern itself if weathertightness issues are being addressed (e.g. sealed boxes used in WEEP). This was not trialled, as the logger was just taped to the side of the cistern.

9.8 Disaggregate from revenue meter

Trace Wizard (Aquacraft) only allows naming two events at the same time i.e. base event and super event. This is adequate for residential homes. Non-residential buildings tend to have higher water use and more events occurring simultaneously. It is not always possible to disaggregate because flow traces resemble blocks (**Error! Reference source not found.**).

Due to the continuous flows the limit of the program is sometimes reached, which can crash the program. The Rimu building was complex to disaggregate, but it was still possible, especially when it was documented when certain water using machines were switched on or off. Toilet flushes and urinal filling were easily identified. However 18% of the total uses could not be placed into any category with certainty.

The Admin building was more complex to disaggregate, as there are many simultaneous uses such as kitchen, showers, toilets and others. Twenty percent of uses could not be accurately defined.

Using disaggregation software, without knowing how water is used in the building beforehand, can prove to be a very tricky process. It was an advantage, to be on-site and know the responsible people who could assist in identifying water use. This is not going to be the case in every installation, making disaggregation even trickier. The water use disaggregation of the Admin building has shown the limit to this method unless sub-metering of smaller sections (e.g. separate kitchen etc) is undertaken. This was not possible due to the existing plumbing and the complications/costs. A benefit however of this method is the possibility to separate out continuous usage such as

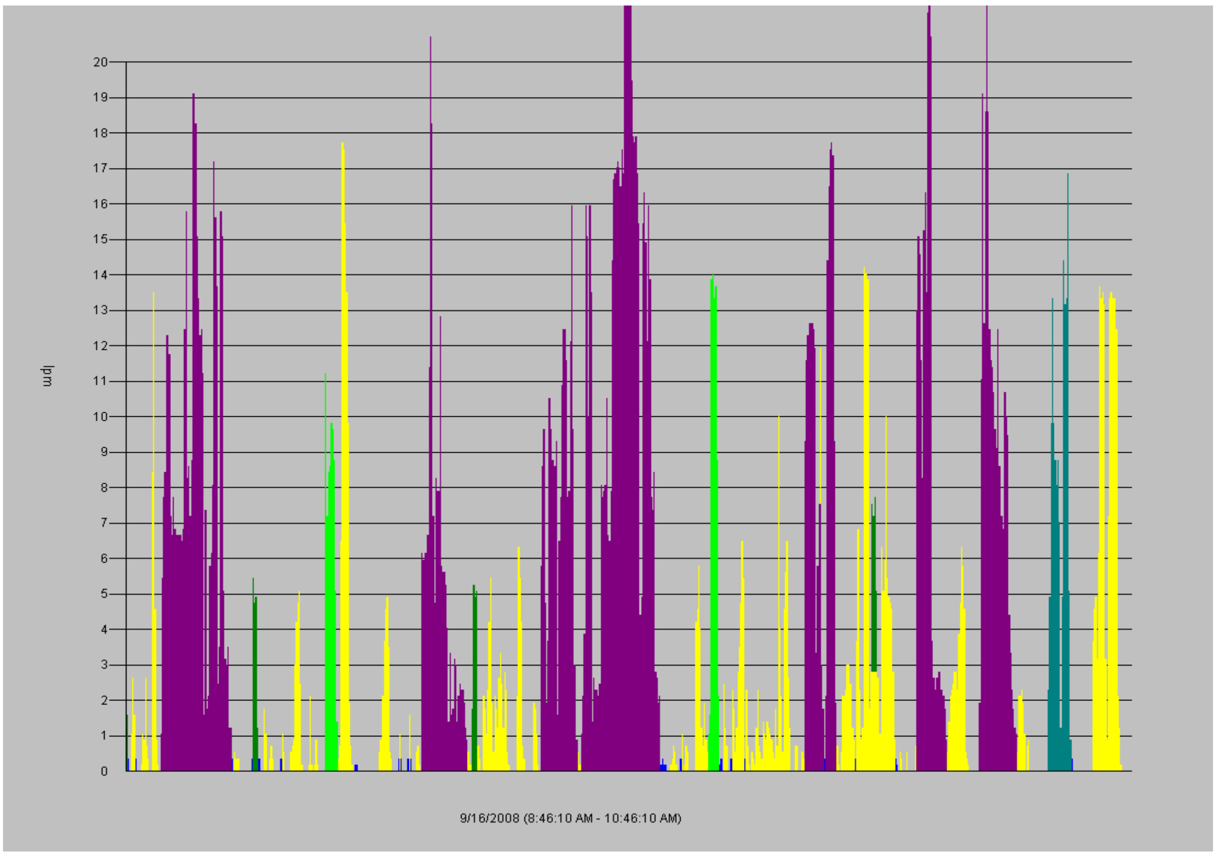


Figure 36: Sample TraceWizard© output of Admin building 25 mm Ø water meter

leaks, cooling towers or water using machinery. The process of elimination, i.e. shutting off urinals overnight, helped further to identify or rule out certain appliances. Figure 36 shows the sample flow trace from the Admin building, which is at a higher resolution (more pulses per/L) than from the Rimu building.

Before trying to use flow trace analysis on large non-residential buildings, the different types of water uses need to be identified; the more different uses and the higher the overall water use, the harder it becomes to get a detailed picture. Even though the Rimu building used more water and had a lower resolution meter, disaggregation was much easier than from the higher resolution meter of the Admin building.

9.9 Conclusion and recommendations

Savings potential

Over the last few years there has been a substantial decrease in water usage at BRANZ, which has resulted from long-term leaks being repaired, as well as a number of water efficiency measures being implemented within the laboratories. These have included the installation of water recycling processes / procedures for test facilities and equipment that use high volumes of water during their operation. Additional water efficiency measures will be implemented over the next few years, as part of the BRANZ site redevelopment.

The Kauri building (not monitored, but audited) still has 20 Lpm shower heads, which for today's standard are regarded as wasteful. Installing low flow shower heads not only reduce water consumption, but also energy usage. This is a very low investment with a high payback, which is essential to be addressed (see Appendix C).

Disaggregation potential

Using the flow trace analysis process has proven both tricky, but achievable, in the three buildings monitored (see section 9.8 for further detail).

Historical records

Historical records cannot always be trusted, especially if other properties are being supplied from different points in the distribution network (this can be seen in section 9.4). In the BRANZ case there needs to be a single meter which looks at BRANZ-only consumption.

Audit information

Developing audit templates was feasible for residential application, but non-residential uses vary widely from building to building and it is recommend to start off with an empty piece of paper, noting down the following:

- Appliance types (including count, volumes, usage behaviour etc)
- Water meter types, location, pipe diameters etc
- Is there sub-metering?
- Other.

The more that can be figured out about how a building uses water the better, and the easier it becomes later to construct a water use model for this building. Communication can go a long way and save valuable time in the end. Caretakers, building managers and lab technicians can provide valuable insight into how a building is actually used.

REFERENCES

Aquacraft Inc. *TraceWizard© Water Use Analysis Software* (www.aquacraft.com/ accessed 10/10/2008).

Camilleri M. 2000. 'Implications of Climate Change for the Construction Sector'. BRANZ *Study Report 94.* BRANZ Ltd, Judgeford, New Zealand.

Heinrich M. 2007. 'Water End-use and Efficiency Project (WEEP) – Monitoring Report'. BRANZ *Study Report 159.* BRANZ Ltd, Judgeford, New Zealand.

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10. MODELLING

There are two basic purposes for including modelling in the BEES programme:

1) To generalise from the particular lessons of the survey data to scenarios of potential future energy use in the non-residential sector (sectoral energy efficiency opportunities).
2) To address the lack of reliable information about the patterns of energy determining behaviours so that future computer models for simulation in design can be improved (realistic modelling parameters; develop and test calibrated models).

10.1 Research method

The following discussion leads from an examination of the two basic purposes to an examination of the implications for survey design.

HYPOTHESIS I: ***That the input data currently used by designers as input to their simulation models represents the real world.***

Building scientists, engineers and architects currently use computer programs such as Energy+, ESP-r and SUNREL to model the potential energy use of buildings. This energy use modelling can be modified by the outputs from daylight simulation programmes. Until approximately five years ago, daylight availability was based upon some estimates of performance calculated at three times of the day on 'typical' clear and cloudy days. Now, annual simulations of useful daylight indexes and glare are possible, although not yet in widespread use.

What is crucially missing from the input data to these models is anything but the most crude estimates of:

1. **Behaviour of people:** as represented by time of day, week and month schedules of appliance, lighting and HVAC system switching.
2. **Loads:** as represented by time of day, week and month schedules of appliance face-plate, in-use and stand-by energy consumption.
3. **Building performance:** the difference between the design and the performance in reality due to differences in construction, maintenance, refurbishment and use (e.g. designed for 24 hour operation but only used 9 am to 5 pm).

The modeller ideally would have available statistically-based data on the likely values for the heat gain in an office from, say, people, fax, copier or computer. These likely values would be associated with diversity factors:

a) Given name-plate energy use of x, what is the likely performance-in-use in a shop or office of machine y?
b) What are 95% upper and lower bounds? (To examine risk, for example, of overheating because all the machines are contributing at the high end of the range found in the BEES study.)
c) What is the likely breakdown amongst, say, 100 computers and their screens in a building amongst those running at full energy load, those where the computer is up but the screen is in energy saver mode, and those where the whole machine is in energy saver/standby mode?
d) And similarly, what is the likely breakdown amongst 100 people in a building where: everyone will be at their desks; a significant proportion will be out of the office; a significant proportion will be collected in one room for a meeting.

BEES should be able to provide the energy modelling and energy audit professions with survey-based energy use 'norms', which in turn can provide appropriate median, mean and daily patterns of the end-uses. This data will support more realistic breakdowns of energy end-uses from an overall energy bill.

HYPOTHESIS II: ***That, in descending order of importance, the following factors influence energy use in buildings:***

1. **Behaviour of people:** as represented by time of day, week and month schedules of appliance, lighting and HVAC system switching.
2. **Maintenance:** as represented by the performance of the HVAC, lighting and other systems to specification.
3. **Loads:** as represented by time of day, week and month schedules of appliance face-plate, in-use and stand-by energy consumption.
4. **Building construction:** as represented by R-values, heat capacity, air flows, heat transmission through windows and similar physically measurable parameters.
5. **Building form:** design as represented by window-to-wall ratio, compactness, orientation to the sun, self shadowing, external shading etc.

The random sampling within each size range can answer the research questions about the overall uses to which energy is put in the sector. It can provide answers about the level of service delivery in those same buildings.

What it cannot do is provide answers on the relationship between energy use and equipment in the building or between energy use and design of the building. How does the design and energy use combine to provide a satisfactory level of service in terms of temperature, lighting and air quality?

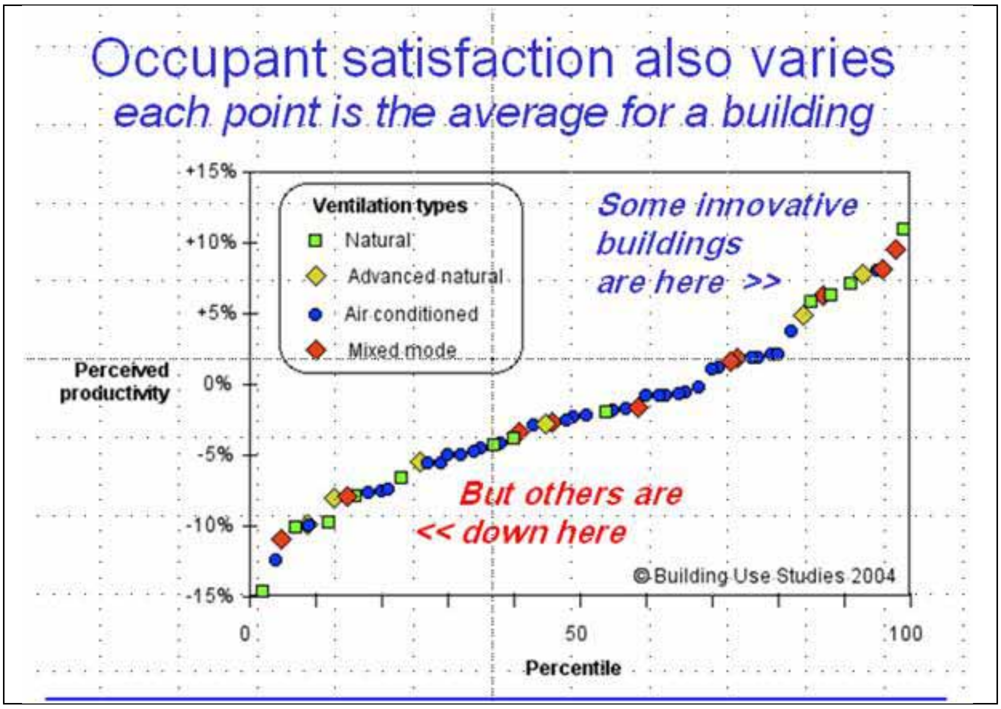


Figure 37: From Bill Bordass' presentation on 10 June 2008, LBNL

Figure 37 provides an analysis of ‘service delivery’ based on Business Use Studies (BUS) research – this survey will be applied to the BEES buildings. Figure 37 illustrates that none of the four very different modes of HVAC design (natural ventilation, advanced natural ventilation, air-conditioned and mixed mode) are a simple way to achieve occupant satisfaction.

These will be explored through the use of standardised typologies relating to the building use activity, morphology, locale, construction, thermal typology, services typology, central services typology and control typology, as set out for initial consideration in Table 22.

After a detailed review of the various thermal simulation programmes available internationally, it was decided to use EnergyPlus.

10.2 Modelling process

The following is an outline of the steps to follow in the creation of EnergyPlus computer models of the BEES monitored and audited buildings:

STEP 1: Weather data must be available at sub-hourly levels for the monitored buildings including at a minimum: air temperature, humidity, direct normal and global horizontal solar radiation and wind speed (but also preferably direct normal and global horizontal illuminance).

STEP 2: For the targeted and case study buildings, the same annual weather data parameters should be collected for the time period for which energy records are collected. Note: this dataset is for the calibration processes, as the EECA standard weather data files will be used to establish ‘typical’ year datasets.

STEP 3: Use Google Earth, Maps and Street View to capture a plan site view of the building to be monitored/audited; import this geo-referenced into SketchUp.

STEP 4: Extrude this plan view vertically by the estimated height of the building(s) on the site from the valuation database; print this data as axonometric views, plus a series of outline plan views – one for each floor in the building.

STEP 5: ‘In the field’ use these printed SketchUp views as forms onto which to confirm dimensions and provide annotations as to materials; take photographs of as many exposed walls as possible.

STEP 6: ‘Back at base’ take the annotated field data forms and photographs and accurately dimension the building, internal partitions, window sizes, number of floors, wall finishes etc.

STEP 7: ‘Back at base’ take the field data on the window transmissivity; colour of the outside walls; likely wall roof and floor construction for each level of the building and build into the SketchUp model – drawing from a library of standard wall, roof, floor, window components.

STEP 8: ‘Back at base’ use the online link from OpenStudio to the NREL website to create an EnergyPlus input file, including the appropriate outline HVAC services description for the building. Read this new file back into SketchUp.

STEP 9: Select appropriate zones from the whole-building model that are being studied in detail and copy them individually into a new SketchUp file. Ensure that the openings to the outside world are modelled with accurate thickness and overhangs. Export these individual room models to Radiance.

STEP 10: Run the EnergyPlus simulation and the Daysim/Radiance simulation directly from inside SketchUp.

STEP 11: Investigate setting up these Energy+ and Radiance files in a spreadsheet for multiple re-design studies.

This multi-step process will be explored in the coming year.

The initial goal of the modelling work will be to produce:

1. A set of calibrated models of 'representative' New Zealand buildings which can be shown to model energy use and daylight accurately in these existing monitored buildings.
2. A set of variants to these models that explore the HVAC, Façade and Alternative Energy Generation (solar panels etc) options to make this design a Net Zero Energy Building.
3. An online database of these models that are trusted as part of a Quality Assurance process for thermal and lighting simulation in design.

This work will link in with the IEA 'Towards Net Zero Energy Solar Buildings' research tasks.[16]

10.3 Prototypical models

There are a limited number of built forms used in non-residential buildings. For example, the USA 1992 Commercial Building Energy Consumption Survey[17] categorised commercial building footprints into five groups, as summarised in Table 27

Building Footprint	Count	%
Square	280	6
Rectangle	3,659	76
Rectangle or square with courtyard	47	1
Right angle	333	7
Other	485	10
TOTAL	4,804	100

Table 27: CBECS building footprints

UK research has developed a classification of built forms[18]. This work has been reviewed and applied to the non-residential buildings found in the BEES work thusfar.

Table 28 lists the built forms used to categorise the BEES buildings, while Figure 38 provides illustrations for two selected building forms. The left-hand sketch is taken from *A Classification of Built Forms* (2000), while the right-hand computer images are their representation created using the SketchUp add-in for Energy Plus. The advantage of this add-in is that it permits the models to be modified (stretched/pulled) to match the dimensions of the individual building. Once the basic shape has been allocated for a given building, further details can be readily added, such as the construction materials, glazing type and HVAC plant.

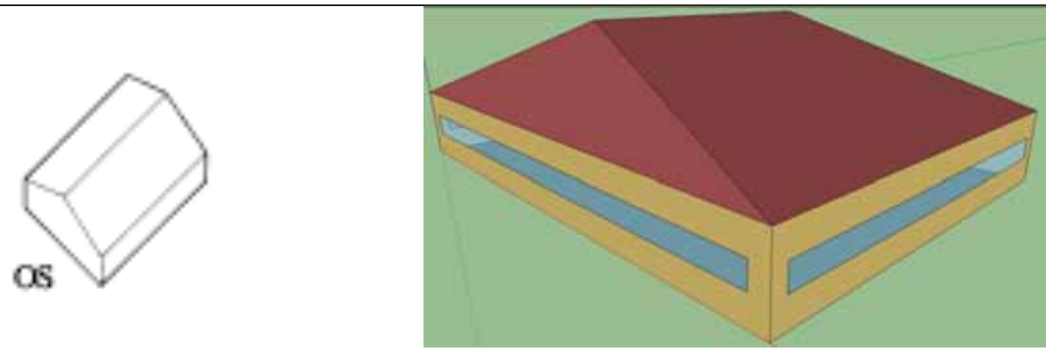
This approach follows that used by NREL to develop a series of Non-residential Buildings EnergyPlus Benchmark models[19]

Figure 43 provides an example of how this is being used in the BEES work.

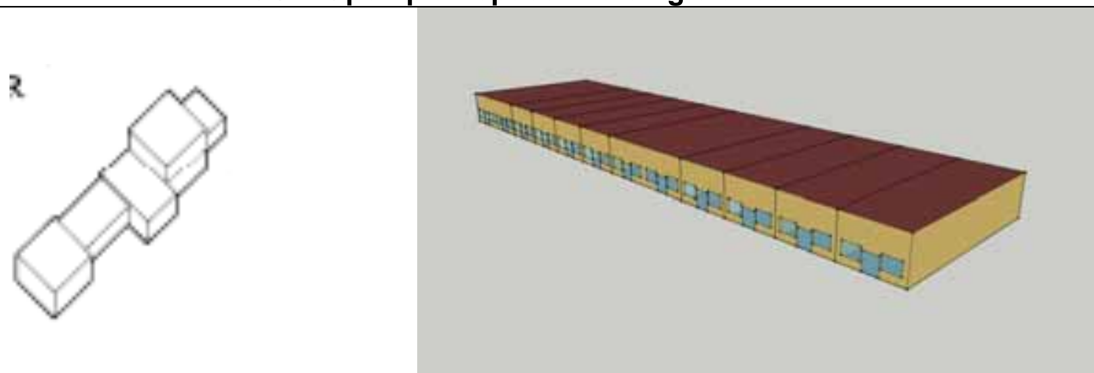
[16] For further information see www.iea-shc.org/task40/index.html
[17] (EIA 1993 ??)
[18] *A Classification of Built Forms* (2000 p. 87)
[19] NREL Benchmark models report

Code	Form Description
CS4	Daylit (sidelit) cellular strip, 1 to 4 storeys
CS5	Daylit (sidelit) cellular strip, 5 storeys or more
OD4	Daylit (sidelit) open-plan strip, 1 to 4 storeys
OD5	Daylit (sidelit) open-plan strip, 5 storeys or more
CT1	Toplit cellular, single-storey
HD	Daylit hall, either sidelit or toplit (or both)
HA	Artificially lit hall
OS	Open-plan space in a single shed
OC1	Open-plan continuous single-storey space
OG	Open-plan car parking or trucking deck
OA	Artificially lit open-plan multi-storey space
SR	Single-room form
SSR	String of single-room forms
CDO4	Daylit (sidelit) cellular strip with open plan space, 1-4 storeys
CDO5	Daylit (side) cellular strip with open plan space, 5 storeys or more

Table 28: Built forms used to categorise BEES buildings



OS – Open plan space in a single shed



SSR – String of single room forms

Figure 38: Examples of built forms

10.4 Thermal simulation models

It is possible to take a photograph of a selected building and convert it into a visual model, which in turn can be used for input into a thermal simulation programme.

Figure 39 gives a photograph of 18 Viaduct Harbour, Auckland taken from Google Street View. Figure 40 provides a computer rendering of the same building modelled in SketchUp, based on photographs of all sides of the building.

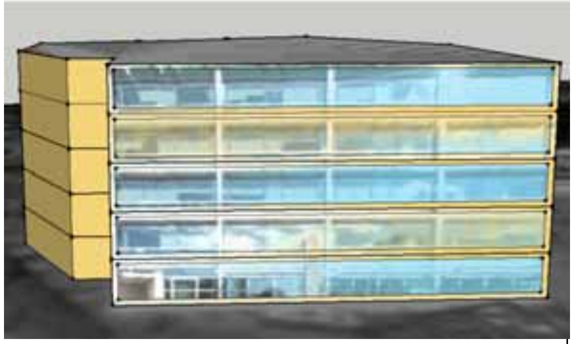


Figure 39: Photograph Figure 40: SketchUp model

Although the details are limited, the SketchUp model can be imported directly into EnergyPlus and its performance explored through thermal simulation. Simple visual and thermal simulation models can be quickly prepared for a large number of buildings, which can then be explored for their energy performance.

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11. WHAT NEXT?

BEES commenced in 2007 and is due to be completed by 30 September 2013.

11.1 Year 3 Activities

Figure 41 illustrates the relationship between Study Components A and B, and help provide a conceptual base for the coming years activities.

Study Component A -- Aggregate Resource Use Patterns – will be a one-off national survey of buildings in our valuation-record sample frame, using four main sources of information as follows:

- business directories;
- publically available internet data;
- a phone survey; and
- energy and water use revenue meter data.

This is planned to be completed in the 2009-10 year. Component A is designed to produce a national estimate of water & energy consumption in the non-residential building sector; an estimate of the average kWh/m^2/annum of the sector; and a clear description of the buildings in this sector (e.g. floor areas, number of buildings, number of businesses, types of occupants, etc).

Study Component B – Determinants of Resource Use – will randomly select and recruit 50 buildings in this 2009-10 year for which on-site measurements will be made of indoor environments and energy use. (By 2013, it is planned that a total of 300 buildings will be measured.) The sample size is smaller than for Component A because on-site measuring is many times more costly per building (see diagram below). As many as possible of the buildings for on-site monitoring will be recruited from the buildings which participated in the Component A phone survey.

By the end of the BEES Study, Component B is designed to find

- average kWh/m^2/annum for various categorisations of non-residential buildings;
- breakdowns of total energy and water use by the various end-uses (e.g. lighting versus HVAC versus other uses);
- what drives variations between different buildings' energy- and water-use patterns (e.g. building materials, building structure and form; function; operating behaviours, etc.).

Study Component C – Building Dynamics – will not commence until 2010/11, when focused Case Studies will be developed based on the Component A & B results from the 2009/10 year.

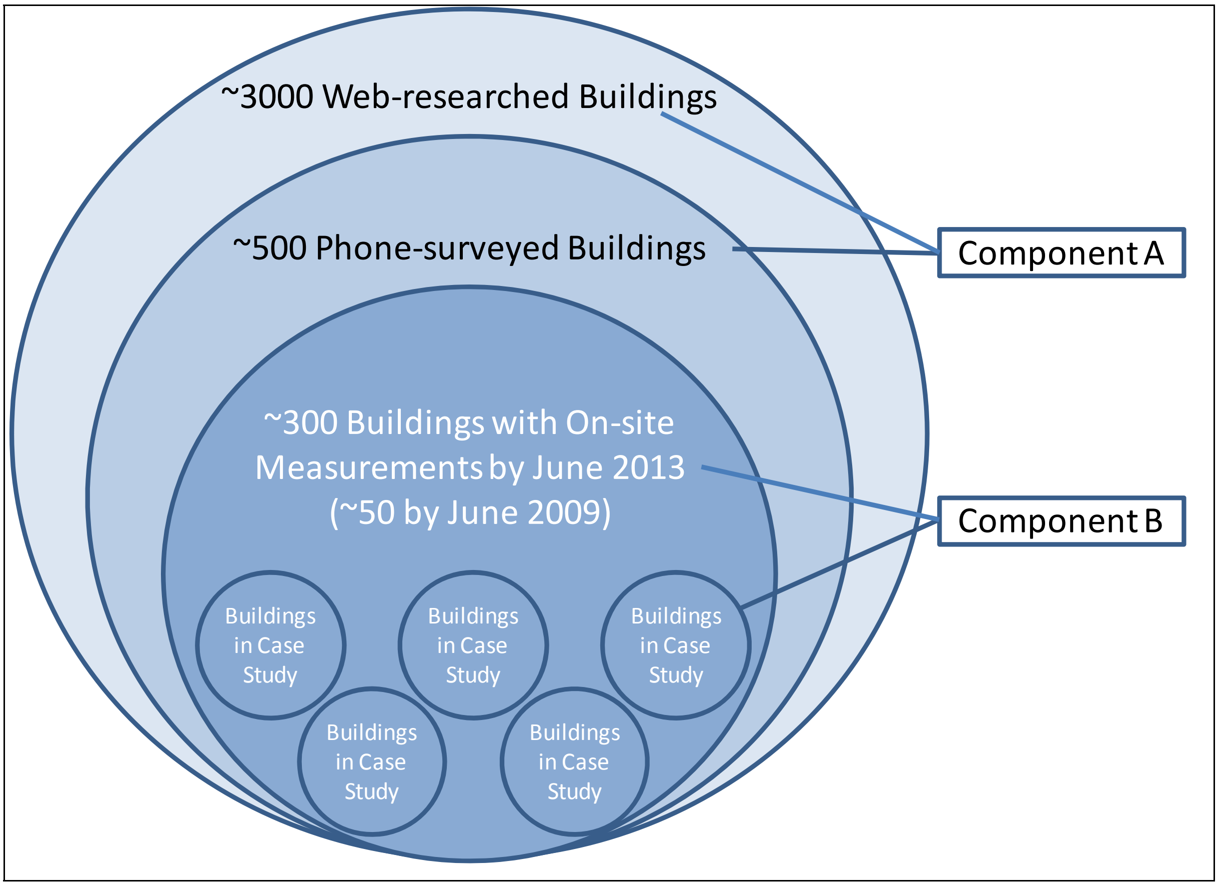


Figure 41: Conceptual Diagram of Components A & B

Study Component D – Facilitating Improved Resource Management (FRST funded) – is designed to allow the BEES data to be used and/or applied successfully. It will review a set of attempts to influence resource use in non-residential buildings. Its method is termed a "systematic review" (after the fashion of the Cochrane Collaboration). Component D will also use data from existing sources to produce an analysis of energy and water consumption and expenditure in New Zealand's public education and public health sectors.

Component E – Modelling – will constitute two sub-projects. First, the BEES data will be used to develop and update EERA (Energy Efficiency Resource Assessment), which is a computer based tool for modelling scenarios of aggregate energy demand, e.g. in response to changes in the numbers or types of non-residential buildings, or changes in the NZBC Clause H1. Secondly, BEES data will be used to create thermal simulation models of the buildings documented in Components A, B and C. These models will use the computer programmes Google Earth, SketchUp, OpenDesign, Radiance, su2rad and EnergyPlus. We will explore generating these building models in a standardised and quasi-automated manner. This will both improve the empirical basis of the models themselves, thus improving their accuracy at the individual building level, and (unlike EERA) generate scenarios that show the *distribution* of responses to a change (e.g. a single change in NZBC H1 might improve thermal performance of one part of the non-residential stock but decrease performance in another).

In addition to the specific, focused component activities, **Cross-Component** activities are tasks focused on project management, international cooperation (especially through IEA Task 40), and technology transfer (including presentations, stakeholder consultations, and supervising FRST-funded honours, Masters and PhD students).

APPENDIX A PUBLICATIONS

A.1 Internal reports

A.2 Publications, journal articles and presentations

Introduction for **Electricity Commission** BEES (March 2008)
Overview for **EMA Newsletter** (June 2009)
Overview for **BUILD Magazine** (May 2009)
Overview for **Victorious Magazine** (Feb 2009)
Overview **Presentation to FRST Steering Group** (November 2008)
Overview **Presentation to FRST Steering Group** (April 2009)

A.2.1 Articles

Isaacs NP. 2009. *BEES – Studying Energy Use in Non-Residential Buildings.* EMANZ e-zine June 2009, Issue 62, pp. 5-6.

Isaacs NP. 2009. *BEES Investigates Commercial Building Energy and Water Use.* BUILD 112, pp. 40-1 (Jun/Jul 09).

A.2.2 Workshops

Isaacs N. **Where Does All The Energy Go – The HEEP and BEES Studies in New Zealand.** Seminar, Institute for Building Physics, Fraunhofer Institute, Stuttgart, 2 September 2008.

Isaacs N. **Where Does All The Energy Go – The HEEP and BEES Studies in New Zealand.** Seminar, Environmental Energy Technologies Division, LBL, Berkeley, California, 5 September 2008.

Michael Donn. 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.

A.2.3 Peer reviewed conference paper

Michael Donn, Steve Selkowitz & Bill Bordass. 2009. 'Simulation in the Service of Design – Asking the Right Questions'. International Building Performance Simulation Association Biennial Conference, Glasgow (presented Session: APP4: Simulation and the User, 29 July 2009).

A.3 International agreements

Two international agreements were developed during the first two years. Both will be formally signed during the 2009/10 year:

International Energy Agency (IEA) Solar Heating and Cooling Agreement (SHC) Task 40 and Energy Conservation in Buildings and Community Systems Programme (ECBCS) Annex 52 'Towards Net Zero Energy Solar Buildings'. This Task will operate from 1 October 2008 to 30 September 2013 (http://www.iea-shc.org/task40/index.html). BEES is a major contributor to Subtask C: Advanced Building Design, Technologies and Engineering. VUW, New Zealand represented by Michael Donn, who is Subtask C Leader, with a Co-Leader from Université de la Réunion, France represented by François Garde.

The Bartlett School of Architecture, University College London – a formal agreement between BRANZ, VUW and The Bartlett to co-operate with related research.

APPENDIX B NZBC DEFINITIONS

The Building Act 2004 No 72 (as at 01 August 2009), includes in 'Part 1 Preliminary provisions, Subpart 2—Interpretation' the following (source www.legislation.govt.nz):

Clause 7 Interpretation
In this Act, unless the context otherwise requires,—
…
NUO system means a system owned or controlled by a network utility operator

other property—

(a) means any land or buildings, or part of any land or buildings, that are—

(i) not held under the same allotment; or

(ii) not held under the same ownership; and

(b) includes a road

owner, in relation to land and any buildings on the land,—

(a) means the person who—

(i) is entitled to the rack rent from the land; or

(ii) would be so entitled if the land were let to a tenant at a rack rent; and

(b) includes—

(i) the owner of the fee simple of the land; and

(ii) for the purposes of sections 32, 44, 92, 96, and 97, any person who has agreed in writing, whether conditionally or unconditionally, to purchase the land or any leasehold estate or interest in the land, or to take a lease of the land, and who is bound by the agreement because the agreement is still in force

Clause 8 Building: what it means and includes

(1) In this Act, unless the context otherwise requires, building—

(a) means a temporary or permanent movable or immovable structure (including a structure intended for occupation by people, animals, machinery, or chattels); and

(b) includes—

(i) a mechanical, electrical, or other system; and

(ii) a fence as defined in section 2 of the Fencing of Swimming Pools Act 1987; and

(iii) a vehicle or motor vehicle (including a vehicle or motor vehicle as defined in section 2(1) of the Land Transport Act 1998) that is immovable and is occupied by people on a permanent or long-term basis; and

(iv) a mast pole or a telecommunication aerial that is on, or forms part of, a building and that is more than 7 m in height above the point of its attachment or base support (except a dish aerial that is less than 2 m wide); and

(c) includes any 2 or more buildings that, on completion of building work, are intended to be managed as one building with a common use and a common set of ownership arrangements; and

(d) includes the non-moving parts of a cable car attached to or servicing a building; and

(e) after 30 March 2008, includes the moving parts of a cable car attached to or servicing a building.

(2) Subsection (1)(b)(i) only applies if—

(a) the mechanical, electrical, or other system is attached to the structure referred to in subsection (1)(a); and

(b) the system—

(i) is required by the building code; or

(ii) if installed, is required to comply with the building code.

(3) Subsection (1)(c) only applies in relation to—

(a) subpart 2 of Part 2; and

(b) a building consent; and

(c) a code compliance certificate; and

(d) a compliance schedule.

(4) This section is subject to section 9

Clause 9 Building: what it does not include

In this Act, building does not include—

(a) a NUO system, or part of a NUO system, that—

(i) is external to the building; and

(ii) is connected to, or is intended to be connected to, the building to provide for the successful functioning of the NUO system in accordance with the system's intended design and purpose; and

(iii) is not a mast pole or a telecommunication aerial that is on, or forms part of, a building; or

(a) a pylon, free-standing communication tower, power pole, or telephone pole that is a NUO system or part of a NUO system; or

(b) cranes (including any cranes as defined in regulations made under the Health and Safety in Employment Act 1992); or

(c) any of the following, whether or not incorporated within another structure:

(i) ski tows:

(ii) other similar stand-alone machinery systems; or

(d) any description of vessel, boat, ferry, or craft used in navigation—

(i) whether or not it has a means of propulsion; and

(ii) regardless of what that means of propulsion is; or

(e) aircraft (including any machine that can derive support in the atmosphere from the reactions of the air otherwise than by the reactions of the air against the surface of the earth); or

(f) any offshore installation (as defined in section 222 of the Maritime Transport Act 1994) to be used for petroleum mining; or

(g) containers as defined in section 2(1) of the Hazardous Substances and New Organisms Act 1996; or

(h) magazines as defined in section 222 of the Hazardous Substances and New Organisms Act 1996; or

(i) scaffolding used in the course of the construction process; or

(j) falsework

APPENDIX C RECORD DEFINITIONS

In order to ensure consistent communication, the following definitions are used by BEES. The word '*record*' **is never** used alone – it is always accompanied by a modifier that makes clear exactly what type of record is being considered. Table 29 provides a summary of definitions from a range of references.

'Valuation Record' – The '**Valuation Record**' has been obtained from PropertyIQ (or Quotable Value NZ) for the selected property categories.

The Valuation Record is used for the purposes of local government rating. Under the Rating Valuations Act 1998, a value is placed on each '*rating unit*', which is generally represented by a '*Certificate of Title*'. This can be for an '*estate in fee simple*' (e.g. a piece of land) or for a '*stratum estate*' (e.g. part of a piece of land or building). The valuation record is based on the '*land'* and the '*improvements*'. In general, the largest part of the '*improvements*' is one or more buildings.

Each **Valuation Record** is allocated to a *Property Category* at some point in the valuation cycle. This allocation is based on the rules provided by LINZ, but their application may (or may not) be uniform across all valuers across time or at any given time. Where there is more than one property use, the 'mixed' category is used. It is not known from the PropertyIQ **Valuation Record** when this *Property Category* was allocated, nor whether it is current.

Where the '*improvements*' are clearly a building, then PropertyIQ allocates a code to each **Valuation Record** to indicate whether the record is a 'parent' (i.e. the overall building) or a 'child' (i.e. part of a building). Where the child is the same as the parent, then the whole building is covered by one '*Certificate of Title*'. This may (or may not) be uniformly applied by all valuers across time or at any given time

In summary, each '**Valuation Record**' represents a whole or part of a piece of land. As far as can be determined, those selected by BEES represent whole or part of an actual building.

'**Building Record**' – The 'Building Record' represents the best estimate of a building from the sampling frame ('Frame Record') developed for the BEES sampling.

The **Building Record** was created by BEES by using the parent and child relationships in the PropertyIQ '*Valuation Records*'. The **Building Record** may include none (if no building has yet been built), one or more real buildings Until the BEES field work is completed, we do not know whether this **Building Record**:

- is one (or more) existing buildings;
- is occupied by activities which are of interest to BEES
- has not been demolished.

'**Building**' – A BEES **Building** (i.e. the word alone with no modifiers) is a **Building Record** that has been subjected to the BEES aggregate survey (initial field survey, phone call etc), has been found to include **BEES uses** and appropriate details are known about the physical building, its occupants and use(s).

Where there is more than one **Building** in a **Building Record,** then an appropriate selection method will be used to select which one of the buildings will be included in the BEES research. It is also possible that there is no **Building** in a specific **Building Record**, in which case the record will not be used, but the reason will be recorded e.g. no physical building, no BEES uses in a physical building etc.

A **Building** may have one or more uses, which may (or may not) be the same as the '*Property Category*' identified by PropertyIQ.

'**BEES uses'** – **BEES uses** are spaces within buildings that are used for office and publically accessible retail ventures. Spaces used for office or retail activities that primarily support the operation of the building for a non-**BEES use** do not qualify the building to be included in the study (e.g. warehouse storeman's office or a staff cafeteria in a factory).

A **Building** which has no **BEES uses** is not to be included in the study.

A **Building** which has the majority of the floor area (over 75%) occupied by non-**BEES uses** is not to be included in the study e.g. a **Building** that is largely or totally used for car parking, residential, warehouse, industrial or ancillary purposes is not included in the study (see Figure 42: BEES building eligibility flow chart and rules).

Term and Source	Definition
principal building (Rating Valuations Rules 2008.)	a significant building on a property, as determined by the property category (LINZS30300 Rating Valuations Rules 2008. Effective date: 31 March 2009www.linz.govt.nz)
property category (Rating Valuations Rules 2008.)	the category code used to identify the highest and best use of each property. The required data fields are set out in Appendix F. (LINZS30300 Rating Valuations Rules 2008. Effective date: 31 March 2009www.linz.govt.nz)
Improvements (Rating Valuations Act 1998)	in relation to any land, means all work done or material used at any time on or for the benefit of the land by the expenditure of capital or labour so far as the effect of the work done or material used is to increase the value of the land and its benefit is not exhausted at the time of valuation; but does not include— (a) Work done or material used in— (i) The provision of roads or streets, or in the provision of water, drainage or other amenities in connection with the subdivision of the land for building purposes: (ii) The draining, excavation, filling, or reclamation of the land, or the making of retaining walls or other related works: (iii) The grading or levelling of the land or the removal of rocks, stone, sand, or soil: (iv) The removal or destruction of vegetation, or the effecting of any change in the nature or character of the vegetation: (v) The alteration of soil fertility or of the structure of the soil: (vi) The arresting or elimination of erosion or flooding: (b) Except in the case of land owned or occupied by the Crown or by a statutory public body, work done or material used on or for the benefit of the land by the Crown or any statutory body except to the extent that it has been paid for by way of direct contribution (Source: www.legislation.govt.nz/act/public/1998/0069/latest/whole.html#dlm427488)
Land (Rating Valuations Act 1998)	means all land, tenements, and hereditaments, whether corporeal or incorporeal, in New Zealand, and all chattel or other interests in the land, and all trees growing or standing on the land (www.legislation.govt.nz/act/public/1998/0069/latest/whole.html#dlm427488)
Meaning of certificate of title (Rating Valuations Act 1998)	Clause 5A: In sections 5B and 5C, certificate of title means a certificate of title— (a) issued under the Land Transfer Act 1952 for an estate in fee simple; or (b) issued under the Unit Titles Act 1972 for a stratum estate; or (c) issued under the Land Transfer Act 1952 for both— (i) an undivided share in an estate in fee simple; and (ii) an estate in leasehold of a building or part of a building on, or to be erected on, land comprised in the estate in fee simple under subparagraph (i) (www.legislation.govt.nz/act/public/1998/0069/latest/whole.html#dlm427488)
Certificate of Title (Consumer Build)	A Certificate of Title (CT) is a record of who owns or has an interest in land in New Zealand. (www.consumerbuild.org.nz/publish/legal/legal-other-pimsland.php)
rating unit (Rating Valuations Act 1998)	has the meaning given to it under sections 5B and 5C Clause: 5B What constitutes rating unit if there is certificate of title (1) For land for which there is a certificate of title, the land comprised in the certificate of title constitutes a rating unit.
Fee simple (Consumer Build)	The maximum interest a person can have in a piece of real estate. It entitles the owner to unrestricted enjoyment of the property (subject to any relevant laws) including the right to dispose property in any manner they see fit. Also known as fee simple absolute. (www.consumerbuild.org.nz/publish/legal/legal-other-pimsland.php)
Stratum estate (Consumer Build)	A title that records ownership of a 'unit' of a larger property, and an undivided share in the ownership of the common property. The owner becomes a shareholder in the company that manages the common areas, such as a garden, garage, pool, parking space, lifts and laundries. The unit can be bought and sold, or leased or mortgaged. Other names for stratum estate are unit title or strata title' (www.consumerbuild.org.nz/publish/legal/legal-other-pimsland.php)

Table 29: Selected Terms & Definitions (with sources)

APPENDIX D BEES ELIGIBILITY CHART

See Section 4.4 Building Eligibility for a discussion of this chart.

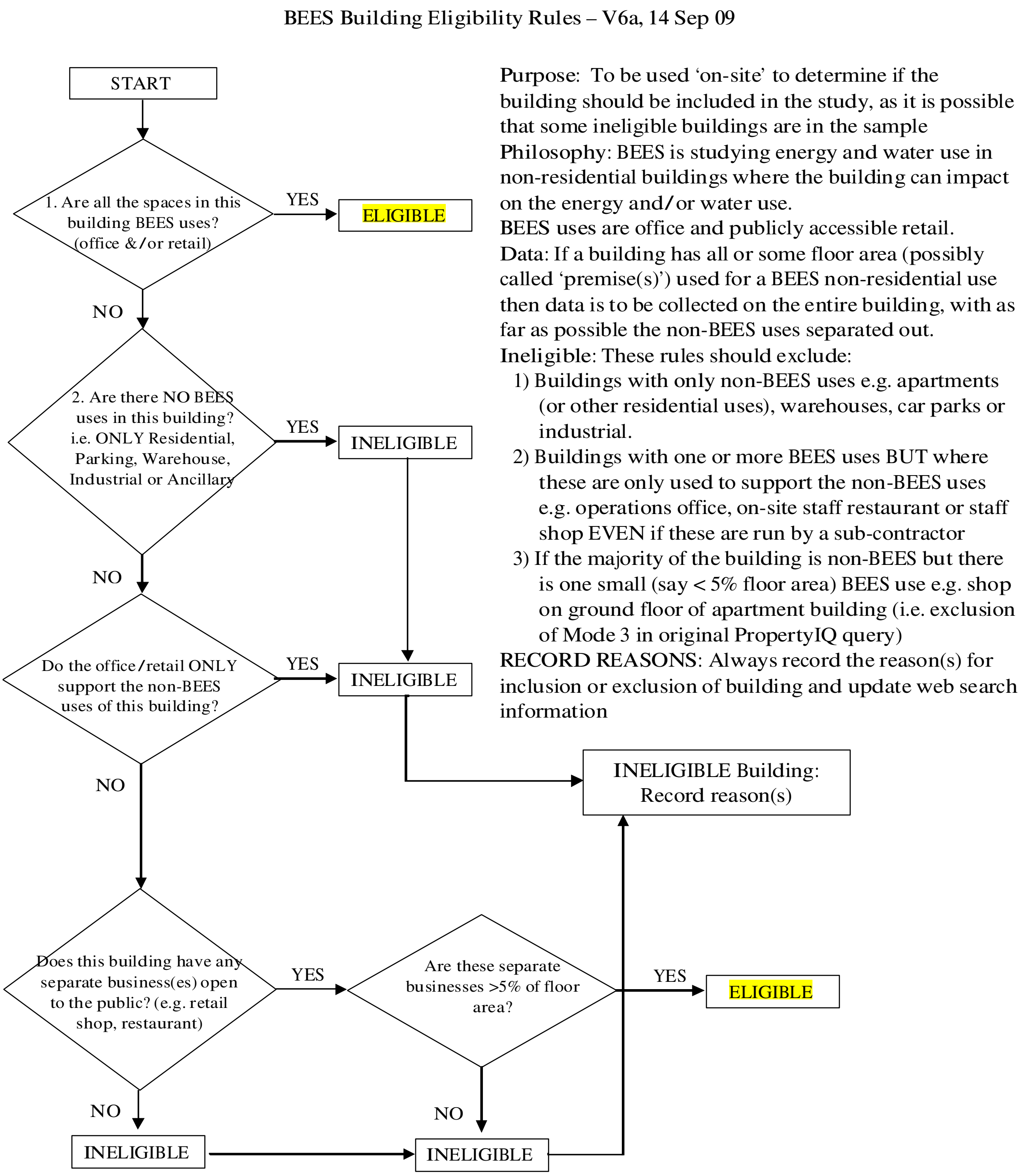


Figure 42: BEES building eligibility flow chart and rules

APPENDIX E TARGET SURVEY FORMS

This provides selected extracts from some of the targeted survey forms which are presented in the following figures: Figure 43: Building audit – example of questionnaire; Figure 44: Building audit – example of floor plan; Figure 45: Appliance audit form; and Figure 46: Lighting audit form.

E PHYSICAL CHARACTERISTICS OF BUILDING

Version 3 June 16th 2009

BEES BUILDING ID:	B001

Type in ID, and it will be printed on all forms

E.1 BUILDING FORM

1. What is the actual year of construction (if known)? Year: ___________
2. Has the building had major renovations (Y/N)
   - ☐1 Yes
   - ☐2 No
   - ☐9 Don't know
3. Decade major renovations done (e.g. 1920) Decade: ___________
4. Was the building built from 2001 onwards?
   - ☐1 Yes 2001 onwards
   - ☐2 No 2000 or before
5. Does the building have carparking in the building (e.g. basement)
   - ☐1 Yes
   - ☐2 No
6. Estimated building floor area (from plans)

   Entire building Floor area: ___________ m²

   Premises Floor area: ___________ m²
7. Number of storeys (count half storeys)
   Number: ___________
8. Number of units
   Number: ___________
9. Number of vacant storeys (count half storeys)
   Number vacant: ___________
10. Number of vacant units
    Number vacant: ___________

1. Building Form (see diagrams below)
   Select Primary and Secondary
   - ☐0 ☐0 CS4 Daylit (sidelit) cellular strip, 1 to 4 storeys
   - ☐1 ☐1 CS5 Daylit (sidelit) cellular strip, 5 storeys or more
   - ☐2 ☐2 OD4 Daylit (sidelit) open-plan strip, 1 to 4 storeys
   - ☐3 ☐3 OD5 Daylit (sidelit) open-plan strip, 5 storeys or more
   - ☐4 ☐4 CT1 Toplit cellular, single-storey
   - ☐5 ☐5 HD Daylit hall, either sidelit or toplit (or both)
   - ☐6 ☐6 HA Artificially lit hall
   - ☐7 ☐7 OS Open-plan space in a single shed
   - ☐8 ☐8 OC1 Open-plan continuous single-storey space
   - ☐9 ☐9 OG Open-plan car parking or trucking deck
   - ☐10 ☐10 OA Artificially lit open-plan multistorey space
   - ☐11 ☐11 SR Single-room form
   - ☐12 ☐12 SSR String of single-room forms
   - ☐13 ☐13 CDO Daylit (sidelit) cellular strip around some or all edges of artificially lit or toplit open-plan space
   - ☐14 ☐14 CDH Daylit (sidelit) cellular strip around some or all edges of artificially lit or toplit hall
   - ☐15 ☐15 CDS Open-plan shed with daylit cellular strip or strips inside, along one or more edges

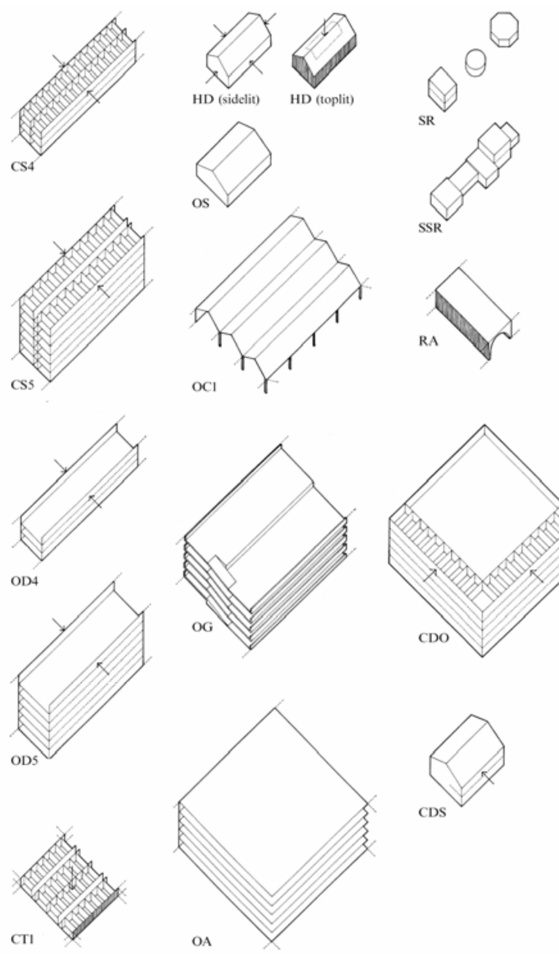


Figure 43: Building audit – example of questionnaire

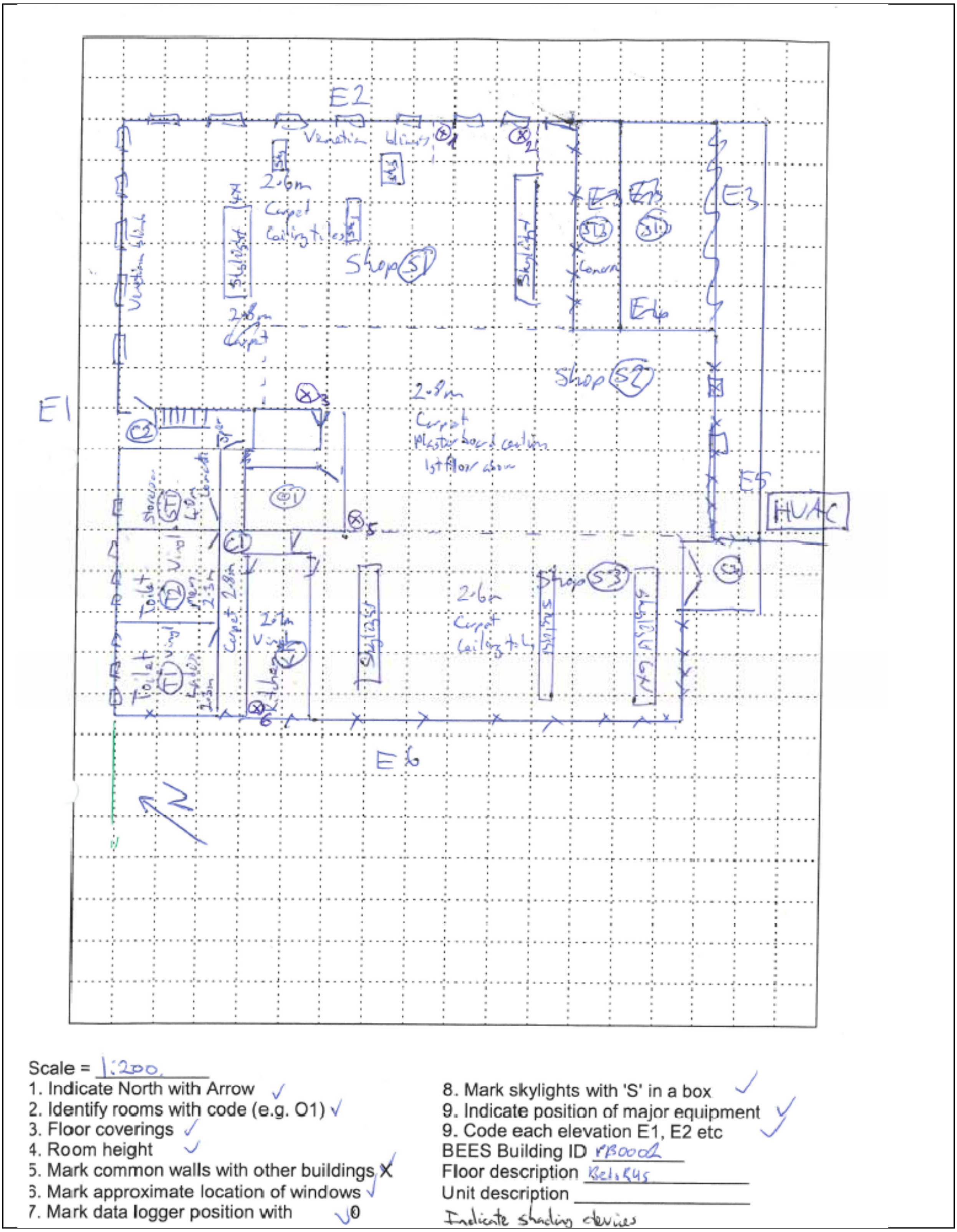


Figure 44: Building audit – example of floor plan

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

Figure 45: Appliance audit form

LIGHTING INFORMATION

Location e.g. Kitchen	Switch/ Circuit	Lamp Type	No. Lumaires	Lamps/ lumaire	Lamp W	Total W	Control type	Room W subtotal

Lamp Types

H = Halogen
IP = Incandescent PAR
IR = Incandescent Reflector
I = Incandescent
CFL = Compact fluorescent
CFLR=CFL reflector
F = Fluorescent
LED = LED
EX = Exit sign
O = Other (please specify)

Control types

N = None (no switch)
S = On/Off
T = Time clock
P = Photocell
D = Dimmer

Figure 46: Lighting audit form

APPENDIX F WEB SEARCH DATA

This is an example of the type of material available from a search of the web.

Existing QV Data: **Additions / Corrections:**

QV Address:	*7 Forgotten Lane, Tinsel Town*	
Floor Area Total:	*630*	
Floor Plate Area (where avail.):	*510*	
Category Code:	*IW*	
Building Age:	*1990*	
Building Fabric:	*Mix.Material*	
Roof Construction:	*Steel/G-Iron*	

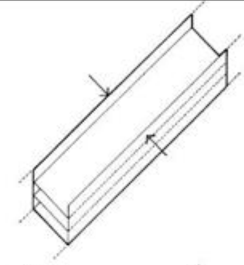
Data Market Info "1": **Additions / Corrections:**

Business Name:	*XY Jones Ltd*	
"Finda" Category:	*Manufacture*	
No. Employees:	*6*	

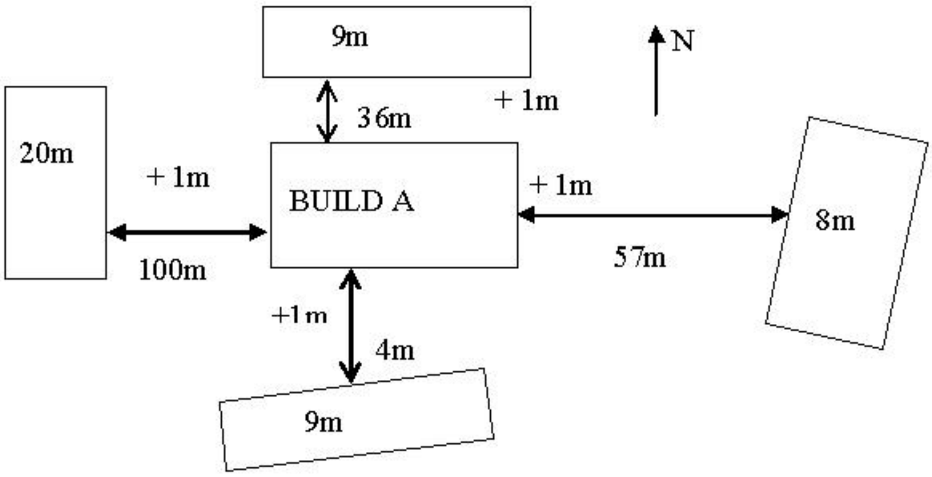
Web Search Info Building "A": **Additions / Corrections:**

Building ID:	*A*	
Floor Plate Area:	*526*	
# Storeys:	*2*	
Average Building Height (m)	*9*	

Floor Area Calc:	*1052*	
Floor Area Est.:	*526*	
Category:	CR	
Business Names:	XY Jones and Friends	
Glazing% - North	90%	
Elevation - North	965866A-NE.jpg	
Glazing% - East	20%	
Elevation – East	965866-SE.jpg	
Glazing% - South	10%	
Elevation – South	965866A-S.jpg	
Glazing% - West	-	
Elevation – West	-	
Building Fabric:	*Concrete*	
Building Fabric Secondary:	-	
Roof Construction:	*Flat Roof (trafficable)*	
Roof Construction Secondary:	-	
Glazing Type:	*Aluminium Framed Single Glazing*	
Glazing Type Secondary:	*Curtain Wall - Single Glazed*	

Built Form:	*OD4 - Daylit (sidelit) open-plan strip, 1 to 4 storeys*	 OD4
Built Form Secondary:	*HA - Artificially lit hall*	 HA (artif. lit)
Notes:	*Google Street View is not available to show the front of the building. Surrounding hill noted as building for overshadowing 100m W 20m high.*	
Extra Elevations:		
	-	
	-	
	-	
	-	

Surrounding Building + Ground Heights (illustration only not to scale)



APPENDIX G COMPARISON OF NREL AND BEES METRICS

The following table lists the recommendations for building metrics resulting from monitoring, from NREL Report #TP-550-38601 ('Procedure for Measuring and Reporting Commercial Building Energy Performance' by Barley, Daru, Pless and Torcellini), and those recommended to be included in the BEES targeted monitoring.

The two lists differ slightly, as the NREL metrics are for comprehensive monitoring of a single building, often with significant self-generation or thermal energy storage, while the BEES metrics are for a sample of typical buildings, with the data to be used to extrapolate to a larger population of buildings.

Metrics recommended for the BEES (but not by NREL) are bolded, italicised and shown in red in the table for ease of scrutiny. Brief comments are given in this table for these, and for metrics recommended by NREL, but not recommended for the BEES.

Some of the monitoring recommended by NREL could be useful and interesting, but is believed to be beyond the cost-effective scope of the BEES project. For example, the Sample Project defined in Appendix A of that report is for a building of 127 m^2 of conditioned floor area (including photovoltaics, solar heating and heat recovery ventilation), which is to be monitored in detail for a year.

The cost of this monitoring is estimated as US$27,000, plus 150 hours of NREL staff time. At reasonable staff charge rates and currency exchange rates, this equates to about $500/$m^2$ for monitoring this building. This is approximately 1,000 times more than typical commercial energy audits are costed in New Zealand.

Metric from NREL	Recommended by NREL?	Included in Targeted	Comments
Air Distribution Energy Use – kWh/month, kWh/yr	Yes	Yes	
Air Distribution Energy Use – kWh/m^2 y		Yes	Area-normalise
Building Peak Electrical Demand – kVA or kW	Yes	Yes	
Building Electrical Demand Intensity – W/m^2	Yes	Yes	
Building Energy Use – kWh/month, kWh/yr	Yes	Yes	
Building Energy Use Intensity – kWh/m^2 y	Yes	Yes	
Building Energy Use vs. Temperature – monthly or daily		Yes	
Building Lighting Energy Use – kWh/month, kWh/yr	Yes	Yes	
Building Lighting Energy Intensity – kWh/m^2/yr		Yes	Area-normalise
Building Purchased Energy Cost – $/yr	Yes		Interested in energy, not costs
Building Purchased Energy Cost Intensity – $/$m^2$/yr	Yes		Interested in energy, not costs
Cogeneration Electrical Energy Output – kWh/month, kWh/yr	Yes		Cogeneration rare and difficult to monitor – case studies only
Cogeneration Fuel Use – kWh/month, kWh/yr	Yes		Ditto
Cogeneration Losses – kWh/month, kWh/yr	Yes		Ditto
Cogeneration Thermal Energy Output – kWh/month, kWh/yr	Yes		Ditto
Cold Storage Transfer – kWh/month, kWh/yr	Yes		Thermal storage rare – case studies only
Computer Server and Process Cooler Energy Use – kWh/month, kWh/yr		Yes	Apparently a large commercial end-use in NZ
Cooling Energy Use – kWh/month, kWh/yr	Yes	Yes	
Cooling Energy Intensity – kWh/m^2/yr		Yes	Area-normalise
Cooling Energy Use vs. Temperature - Monthly or daily		Yes	
DHW Energy Use – kWh/month, kWh/yr	Yes	Yes	
DHW Energy Intensity – kWh/m^2/yr		Yes	Area-normalise
DHW System Efficiency – %	Yes		Need to measure load

Metric from NREL	Recommended by NREL?	Included in Targeted	Comments
DHW Load – kWh/month, kWh/yr	Yes		Difficult to measure HW flow rate and ΔT
Electrical Generation System Losses – kWh/month, kWh/yr	Yes		Internal generation unusual in NZ
Facade Lighting Energy Use – kWh/month, kWh/yr	Yes	Yes	
Facade Lighting Energy Use Intensity – kWh/m^2/yr		Yes	Area-normalise
Facility Energy Production – kWh/month, kWh/yr	Yes	Yes	Internal generation unusual in NZ; thermal difficult to monitor
Functional Area – m^2	Yes	Yes	
Gross Interior Floor Area – m^2	Yes	Yes	
Heating Energy Use – kWh/month, kWh/yr	Yes	Yes	
Heating Energy Use Intensity – kWh/m^2/yr		Yes	Area-normalise
Heating Energy Use vs. Temperature – monthly or daily		Yes	
HVAC Energy Use – kWh/month, kWh/yr	Yes	Yes	
HVAC Energy Use Intensity – kWh/m^2/yr		Yes	Area-normalise
Indoor Zone Temperature – °C	Yes	Yes	
Installed Lighting Energy Use – kWh/month, kWh/yr	Yes	Yes	
Installed Lighting Energy Use Intensity – kWh/m^2/yr		Yes	Area-normalise
Installed Lighting Power Density – W/m^2		Yes	Area-normalise
Net Facility Electrical Demand – kVA or kW	Yes	Yes	Only if self-generation
Net Facility Energy Use – kWh/month, kWh/yr	Yes	Yes	Only if self-generation
Net Facility Load Factor – %	Yes	Yes	
Net Facility Purchased Energy Cost – $/yr	Yes		Interested in energy, not costs
Other Building Energy Use – kWh/m^2 y	Yes	Yes	
Other Facility Electrical Energy Production – kWh/month, kWh/yr	Yes	Yes	Only if self-generation
Other HVAC Energy Use – kWh/month, kWh/yr	Yes	Yes	
Outdoor Ambient Temperature – °C	Yes	Yes	
Outdoor Energy Use – kWh/month, kWh/yr	Yes	Yes	
People-Mover Energy Use – kWh/month, kWh/yr	Yes	Yes	
People-Mover Energy Intensity – kWh/m^2/yr		Yes	We want to area-normalise
Plug-in Lighting Energy Use – kWh/month, kWh/yr	Yes		Part of hard-wired lighting
Plug Loads Energy Use – kWh/month, kWh/yr	Yes	Yes	
Plug Loads Energy Intensity – kWh/m^2/yr		Yes	We want to area-normalise.
Process Energy Use – kWh/month, kWh/yr	Yes	Yes	(Cooking, refrigeration etc)
Process Energy Use Intensity – kWh/m^2/yr		Yes	We want to area-normalise.
Produced Energy Storage Transfer – kWh/month, kWh/yr	Yes		
PV Energy Production – kWh/month, kWh/yr	Yes		On-site PV is unusual in NZ – for case studies only
Thermal Energy Production – kWh/month, kWh/yr	Yes		On-site production is unusual in NZ – case studies only
Total Facility Electrical Demand – kVA or kW	Yes	Yes	
Total Facility Energy Us – kWh/month, kWh/yr	Yes	Yes	
Wind Energy Production – kWh/month, kWh/yr	Yes		On-site production unusual in NZ – case studies only

APPENDIX H END-USE PROFILES FROM SHORT-TERM MONITORING

The BEES targeting survey monitoring was proposed to be for only a short period of time in each building – perhaps as short as two to four weeks. HEEP data is used here to test how short monitoring periods affect the estimation of annual average profiles of total energy consumption.

A variety of monitoring periods were tested, each with a different number of buildings, to represent different utilisation of a set of monitoring equipment, as shown in Table 30. For the 14, 28 and 60 day periods, the number of buildings has been reduced to reflect the time that would be lost in moving equipment from one building to another.

Figure	Monitoring Period Length (days)	Number of Buildings Per Year
Figure 47	14	200
Figure 48	28	130
Figure 49	60	65
Figure 50	90	45
Figure 51	180	22
Figure 52	360	10

Table 30: Monitoring period vs. number of buildings monitored each year

Total energy consumption for one random building was selected with a random period from within the year, and an average profile was then calculated. This was repeated for the number of randomly selected buildings per year to be simulated, and an average of all the profiles taken. This process was repeated 20 times for each monitoring period length to estimate how much variability there is.

The results are displayed in Figure 47 to Figure 52, one for each monitoring period length. The thick red line is the average profile of total energy consumption for all 400 HEEP buildings for the full monitoring period. The remaining lines are for the 20 simulation runs for each monitoring period length.

The shorter monitoring periods have less variability and are closer to the average of all data than the longer periods. It does appear that short-term monitoring with limited equipment spread across a number of buildings will give good estimates of the actual profile. Inter-building variation is a major source of variation in profiles, and spreading the equipment across a larger number of buildings appears to be more important than having a longer monitoring period in fewer buildings.

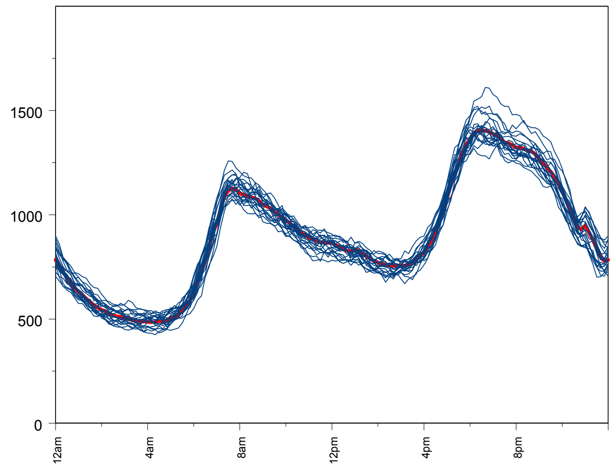


Figure 47: 14 day monitoring period

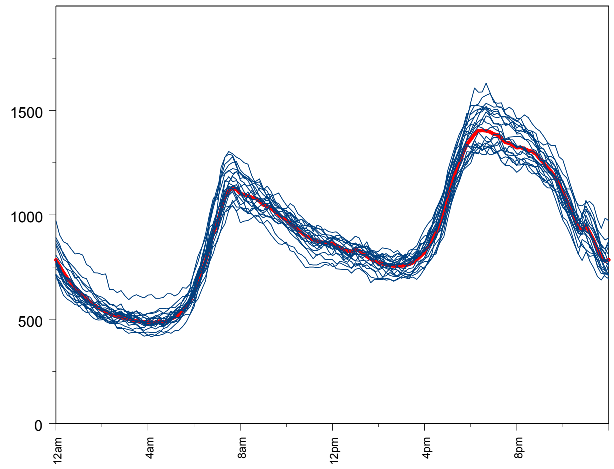


Figure 48: 28 day monitoring period

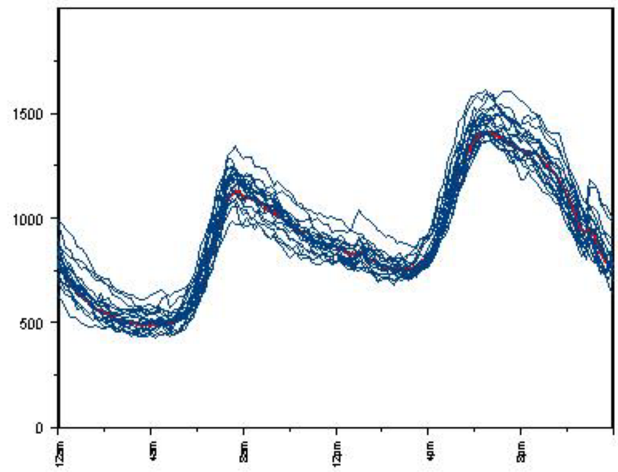


Figure 49: 60 day monitoring period

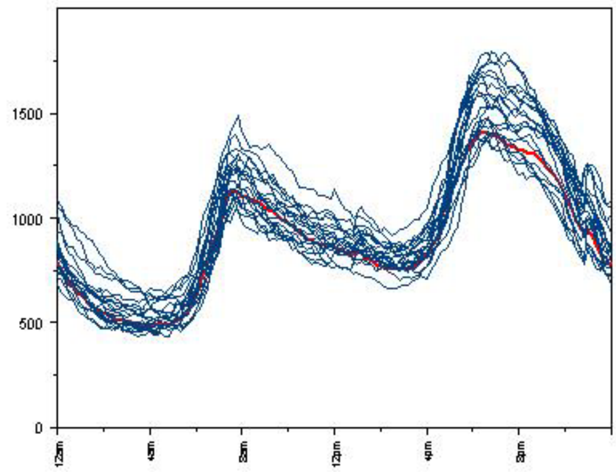


Figure 50: 90 day monitoring period

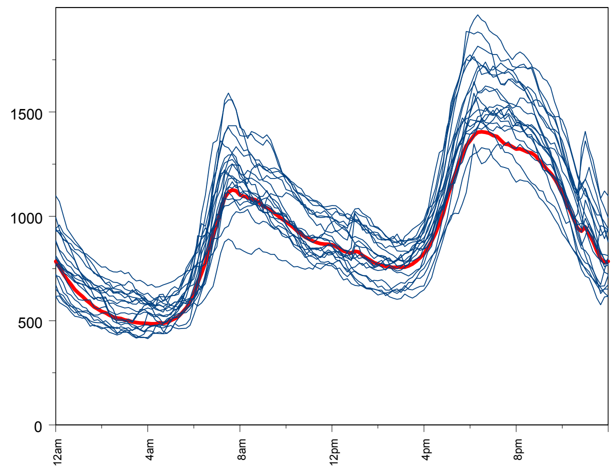


Figure 51: 180 day monitoring period

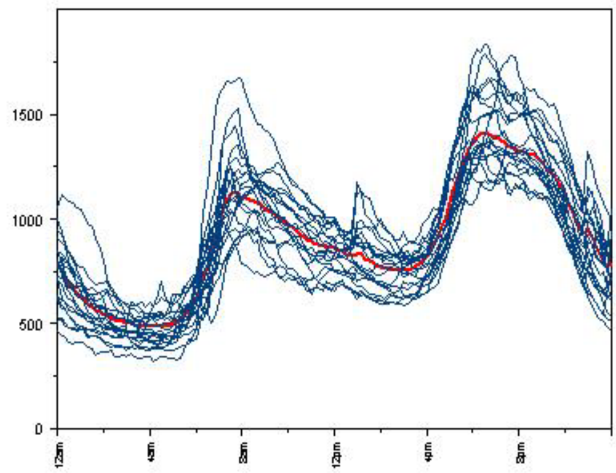


Figure 52: 360 day monitoring period